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Integration Of Action-Oriented Environmental Sustainability, Climate And Forest Cover Change Education Into The Secondary School Geography Curriculum: Evidence From Metekel Zone, Northwest Ethiopia

Tamiru, Toga

BAHIR DAR UNIVERSITY

COLLEGE OF EDUCATION

DEPARTMENT OF SOCIAL SCIENCE

SCHOOL OF TEACHER EDUCATION

INTEGRATION OF ACTION-ORIENTED ENVIRONMENTAL SUSTAINABILITY, CLIMATE AND FOREST COVER CHANGE EDUCATION INTO THE SECONDARY SCHOOL GEOGRAPHY CURRICULUM: EVIDENCE FROM METEKEL ZONE, NORTHWEST ETHIOPIA

D. ED. DISSERTATION

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TAMIRU TOGA WAHELO

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DE.D. DISSERTATION

BY

TAMIRU TOGA WAHELO

ADVISORY BOARD MEMBERS:

DR. DANIEL AYALEW, PH.D. (PRINCIPAL ADVISOR)

PROFESSOR TADESSE MELESSE, PH.D. (CO-ADVISOR)

APRIL, 2026

BAHIR DAR, ETHIOPIA

DECLARATON

I, the undersigned, certify that the research work titled "**Integration of action-oriented environmental sustainability, climate and forest cover change education into the secondary school geography curriculum: Evidence from Metekel Zone, Northwest Ethiopia"** submitted in partial fulfillment of the requirements for the award of the degree of Doctor of Education in "**Geography and Environmental Education**" to the Graduate Program of College of Education, School of Teacher Education, Bahir Dar University, is my original work. The work has not been presented elsewhere for assessment of a graduate degree. Where material has been used from other sources, it has been properly acknowledged.

D. ED candidate: Tamiru Toga Wahelo	_______________	15/04/2026
Name	Signature	Date

BAHIR DAR UNIVERSITY

College of Education

School of Teacher Education

Department of Social Science

Approval of Dissertation for Defense

I hereby certify that I have supervised, read, and evaluated this dissertation titled "**Integration of action-oriented environmental sustainability, climate and forest cover change education into the secondary school geography curriculum: Evidence from Metekel Zone, Northwest Ethiopia"** by Mr. Tamiru Toga Wahelo, prepared under my guidance. I recommend that the dissertation be submitted for oral defense.

Name of the Advisory Board Members:

Major Advisor: Dr. Daniel Ayalew Signature__________ Date:________________

Co-advisor: Professor. Tadesse Melesse Signature _________ Date: ________

BAHIR DAR UNIVERSITY

College of Education

School of Teacher Education

Department of Social Science

Approval of Dissertation for Defense Result

As a member of the Board of Examiners, we examined this dissertation entitled " **Integration of action-oriented environmental sustainability, climate and forest cover change education into the secondary school geography curriculum: Evidence from Metekel Zone, Northwest Ethiopia"** by **Mr. Tamiru Toga Wahelo.** We hereby certify that the dissertation is accepted for fulfilling the requirements for the award of the degree of Doctor of Education in Geography and Environmental Education**.**

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Dedication

This dissertation is dedicated with deep love and gratitude to my beloved elder sister, Tagesech Toga, whose sudden passing on September 10, 1994, left an enduring void in my heart. Though you are no longer with us, your memory continues to inspire my perseverance and commitment. I also lovingly dedicate this work to my brother, Tesfaye Toga, whose unwavering love, guidance, and selfless sacrifices have shaped the person I am today. From my earliest childhood, you stood beside me as a guardian, mentor, and source of strength, nurturing my dreams and enabling me to reach this stage of my life and academic journey. Your faith in me has been my greatest motivation, and this achievement is as much yours as it is mine.

List of published papers

This dissertation is composed of four original papers which are published in reputable journals (1-4) and one (5) currently under review derived from the study's objectives.

1. Wahelo, T. T., Mengistu, D. A., & Merawi, T. M. (2025). Curbing environmental problems related to deforestation and climate change: The level of secondary school students' knowledge, attitudes and determinants in Metekel Zone, Northwest Ethiopia. *Geo: Geography and Environment*, *12*(1), e70004.
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2. Wahelo, T.T., Mengistu, D.A. & Merawi, T.M. Spatiotemporal trends and drivers of forest cover change in Metekel Zone forest areas, Northwest Ethiopia. Environ Monit Assess 196, 1170 (2024). **https://doi.org/10.1007/s10661-024-13294-7**
3. Wahelo, T. T., Mengistu, D. A., & Merawi, T. M. (2025). Geography teachers' implementation of problem-based learning for deforestation and climate change education in Metekel Zone Secondary Schools, Northwest, Ethiopia. *International Journal of Educational Development*, *117*, 103314. **https://doi.org/10.1016/j.ijedudev.2025.103314**
4. Wahelo, T. T., Mengistu, D. A., & Merawi, T. M. (2025). Spatiotemporal Climate Variability and Its Impact on Local Community Livelihoods: A Focus on Crop Production in Metekel Zone, Northwest Ethiopia. *Journal of Agriculture and Food Research*, 102159. **https://doi.org/10.1016/j.jafr.2025.102159**
5. Integrating Deforestation and Climate Change themes in the Ethiopian Secondary School Geography Curriculum: Toward Action-Oriented Environmental Education and Sustainability.

List of Abbreviations and Acronyms

Abbreviation	Full Form
AOESE	Action-oriented environmental sustainability education
ARDL	Autoregressive Distributed Lag
API	Application Programming Interface
CRGE	Climate-Resilient Green Economy
CV	Coefficient of Variation
DPSIR	Drivers–Pressures–State–Impact–Response
EECS	Environmental Education and Communication Strategy
ESD	Education for Sustainable Development
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GEE	Google Earth Engine
GIS	Geographic Information System
IDW	Inverse Distance Weighting
KAP	Knowledge, Attitude, and Practice
KII	Key Informant Interview
LAI	Leaf Area Index
MLC	Minimum Learning Competency
MK	Mann–Kendall (Trend Test)
MoA	Ministry of Agriculture
MoE	Ministry of Education
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NIR	Near Infrared
OA	Overall Accuracy
PBL	Problem-Based Learning
RF	Random Forest
ROI	Region of Interest
SAVI	Soil Adjusted Vegetation Index

SDG	Sustainable Development Goal
SPI	Standardized Precipitation Index
STI	Standardized Temperature Index
SVM	Support Vector Machine
TPB	Theory of Planned Behavior
UA	User Accuracy
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNEP	United Nations Environment Programme
USGS	United States Geological Survey

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General Abstract

Ethiopia's rapid deforestation and climate variability threaten ecosystems and livelihoods, especially in the ecologically vital Metekel Zone. Despite increasing forest loss and climate instability, understanding their dynamics, causes, and mitigation from environmental and educational perspectives remains limited. This study aimed to integrate spatiotemporal analyses of deforestation and climate change with environmental sustainability education. It also sought to propose action-oriented content and pedagogical strategies for the secondary school geography curriculum in the Metekel Zone. A pragmatist mixed-methods design, integrating a longitudinal biophysical assessment with cross-sectional and convergent embedded surveys were employed to explore the educational facets. A multistage sampling technique combining purposive, simple random, and quota sampling was used to identify survey sites and subjects. Land use and land cover data were derived from Landsat imagery, climate data from the National Meteorological Agency, and crop yields from the Central Statistical Agency. In addition, both primary and secondary data were gathered through standardized tests, surveys, key informant interviews (KIIs), focus group discussions (FGDs), curriculum content analysis, and field and classroom observations. Land use land cover changes were assessed using Landsat images of 1986, 2002 and 2019 using Random Forest and Support Vector Machine classifiers, along with vegetation indices such as the normalized difference vegetation index (NDVI), soil-adjusted vegetation index (SAVI), normalized difference water index (NDWI), and leaf area index (LAI). Climate variability was analyzed using the Coefficient of Variation, Mann–Kendall trend test, Standardized Precipitation Index, and ARDL model to assess rainfall, temperature, and crop yield relationships. Educational data were analyzed with descriptive statistics, chi-square tests, t-tests, correlations, and binary logistic regression to identify factors influncing environmental knowledge, attitudes, and teachers' implementation of Problem Based Learning (PBL). Qualitative data from KII, FGDs, curriculum reviews, and observations were thematically analyzed to contextualize and enrich the quantitative results. Findings revealed a significant forest cover decline from 51.37% in 1986 to 17.20% in 2019, propelled by agricultural expansion, resettlement, charcoal/fuelwood extraction, and weak institutional enforcement. Climate analysis showed significant warming trends, with annual maximum and minimum temperatures rising by 0.33 °C and 0.31 °C per decade, respectively, with a rainfall decline of 5.32 mm per decade. Rising temperatures have severely affected temperature-sensitive crops in Dangur and Bullen districts, whereas fluctuations in rainfall patterns have diminished agricultural yields in Dibate and Wombera districts. Curriculum review indicated moderate climate change coverage (17.8% of minimum learning competencies in upper secondary grades) but negligible deforestation integration (3.85%), prioritizing cognitive domains (60.8%) over affective (27.5%) and psychomotor (12.5%) outcomes. Students exhibited low environmental knowledge (52.2%) and unfavorable attitudes (52.7%) toward environmental protection; determinants included age ($p = 0.007$), gender ($p = 0.003$), residence ($p = 0.003$), parental education ($p = 0.018$), family income ($p = 0.002$), access to environmental information (p =

0.000), grade level (p = 0.000), and participation in environmental clubs (p = 0.010) significantly influenced awareness and attitudes. In contrast, social pressure, limited contextual learning, curriculum challenges, resource gaps, and restricted personal agency negatively influenced awareness and engagement. Investigation of teachers' practices showed that geography teachers in Metekel Zone demonstrate moderately positive beliefs in the value of problem based learning (M = 2.56, t = −3.884, p < .001), though beliefs in heuristic approaches (M = 2.49, t = −4.341, p < .001) and contextualizing lessons to students' real-life experiences (M = 2.47, t = −4.590, p < .001) remain low. Only 24–29% of teachers applied inquiry-based, real-world, and independent problem-solving strategies, while 58–61% expressed negative views toward heuristic methods. Teachers' beliefs strongly correlated with their classroom practices (r = 0.726, p < 0.01). Binary logistic regression revealed that teachers' adaptation of PBL (p = .006), emotional intelligence (p = .003), teachers' perception of students' environmental identity (p = .002), teacher's perception of student motivation and engagement (p = .005), and teacher's content experience (p = .008), significantly enhanced PBL implementation, whereas large class sizes (p = .038), reliance on traditional methods (p = .024), and time-intensive nature of PBL (p = .044) constrained it. Despite teachers' conceptual support, structural and pedagogical barriers including traditional assessment systems, inadequate logistics, and extensive curriculum content limit effective PBL adoption. This study integrates spatiotemporal environmental evidence with curriculum and pedagogy to illuminate the profound effects of deforestation and climate change on livelihoods and agricultural productivity in Ethiopia. It reveals critical gaps in contextual, action-oriented learning while showing that incorporating real-world ecological data significantly enhances student engagement. By connecting biophysical data with curriculum-pedagogy gaps, this study underscores deforestation/climate impacts on livelihoods and advocates embedding real-world data to boost engagement. It calls for collaborative reforms among educators, curriculum developers, policymakers, and communities to advance sustainable environmental education in Ethiopia.

Keywords: Deforestation; Climate variability; Spatio-temporal analysis; Action-oriented environmental and sustainability education; Geography curriculum; Problem based learning; Environmental knowledge and attitudes; Metekel zone

CHAPTER ONE

1. INTRODUCTION

1.1.Background of the Study

Environmental sustainability has become one of the crucial problems of the 21st century, as societies grapple with accelerating deforestation, climate change, and the degradation of natural resources. As a result of these growing challenges, environmental problems now constitute some of the most severe threats facing humanity, endangering the survival and well-being of the global community (Nahar et al., 2021; UNEP, 2021; UNESCO, 2014). As a resut, addressing these threats requires a strong commitment to environmental sustainability. This involves balancing ecological integrity, economic growth, and social well-being to support present and future generations (Dong & Hauschild, 2017; Hecht & Fiksel, 2015).However, this goal is increasingly undermined by a combination of interrelated factors. These include rapid population growth, unsustainable agricultural expansion, and large-scale deforestation, overexploitation of natural resources, unplanned urbanization, industrial pollution, and reliance on fossil fuels that accelerate climate change (FAO, 2020; IPCC, 2023; Pranadji & Wahida, 2021; Samways, 2022; Teo et al., 2019; UNEP, 2021). Moreover, weak institutional frameworks and inadequate integration of sustainability principles into education, policy, and community practices have further constrained progress toward sustainable development (Gusmão et al., 2018; Hariram et al., 2023; Sachs et al., 2019; UNESCO, 2019). Equally important is the irresponsible environmental behavior that intensifies these pressures, often reinforced by gaps in knowledge, weak environmental attitudes and values, and limited levels of commitment and skills necessary for safeguarding ecosystems (Ahmad et al., 2015; Lange & Dewitte, 2019).

Given these global challenges, forests occupy a central position in sustaining environmental balance and human welfare, covering about 30% of the Earth's land surface and providing vital ecosystem services (FAO, 2020; Jenkins & Schaap, 2018; Miura et al., 2015; Pugh et al., 2019). They regulate climate, support biodiversity, and act as major carbon sinks, storing more carbon per unit area than any other terrestrial ecosystem (Brockerhoff et al., 2017; Díaz et al., 2009; Pugh et al., 2019). However, escalating land use and land cover changes from natural and anthropogenic drivers have triggered rapid global deforestation contributing about 10–15% of

CO_2 emissions annually (FAO, 2020; Roy et al., 2022), releasing stored carbon, disrupting the carbon cycle, and amplifying climate variability (Bala et al., 2007; Cramer et al., 2004; Savita, 2025). This creates a vicious feedback loop: deforestation intensifies climate extremes, which in turn accelerate land degradation and biodiversity loss, imperiling agricultural productivity and livelihoods (IPCC, 2023; Nguyen et al., 2023; Webb et al., 2017). Breaking this cycle requires integrated ecological interventions. In addition, action-oriented environmental sustainability education (AOESE) is essential to equip present and future generations, especially youth, with the knowledge, skills, and values needed for proactive stewardship (Ardoin et al., 2018; Byerlee et al., 2014; UNESCO, 2019).

Evolving from traditional knowledge-focused paradigms, AOESE now prioritizes participatory, competence-driven approaches that bridge behavioral and skill deficits (Annelise & William, 2010; N. Evans & Acton, 2022). Here, "action" denotes purposeful, reflective behaviors fostering environmental improvement, grounded in action competence, the capacity and motivation for informed, effective interventions (Jensen & Schnack, 1997; Van Poeck et al., 2024). AOESE thus empowers learners to transcend awareness, cultivating the practical abilities, self-efficacy, and commitment essential for sustained environmental engagement.

The imperative for action-oriented environmental education has been enshrined in landmark global declarations since the 1972 Stockholm Conference (Handl, 2012), advancing through the Belgrade Charter (UNESCO-UNEP, 1975), Tbilisi Declaration (1977), Rio Earth Summit UNESCO-UNEP (1975), and the 2030 Agenda for Sustainable Development. These milestones underscore education, awareness, and training as essential for cultivating sustainability literacy, climate resilience, and responsible behaviors.

In the developing world, however, constrained environmental awareness, explosive population growth, and fragile governance exacerbate resource overexploitation, hastening deforestation and amplifying climate vulnerabilities (Ali & Rahman, 2024; Bremner et al., 2010; Goswami, 2024; Jha & Bawa, 2006; Nguyen et al., 2023; Younis, 2015). Similarly, Africa confronts acute environmental crises such as soil erosion, deforestation, desertification, and climate intensification that stifle sustainable development (Eze, 2020; Mesele et al., 2025; Ogwu, 2019; UNEP, 2021). Compounding these are profound knowledge deficits among communities, educators, students, policy makers alongside scant localized environmental data, which hinder effective responses (Abernethy et al., 2016; Adenle et al., 2015; Breidlid, 2009; David, 2024; Owuor, 2007). Addressing these challenges requires a combination of strategies among others community-driven solutions, sustainable farming practices, and education programs that build environmental awareness and action (Adom et al., 2024; Al Blooshi et al., 2020; Arora, 2019; Seddon et al., 2021). Equally important are site-specific rigorous scientific investigations, including spatiotemporal analyses of deforestation, land degradation, and climate shifts (Asimakopoulou et al., 2021; Masolele et al., 2021; Ngoma et al., 2021; Reddy, 2021; Sorelle et al., 2024; Sun et al., 2016). Such research must synergize with action-oriented environmental education, leveraging empirical insights to deepen public comprehension, revitalize curricula, and mobilize communities for stewardship (Kruger, 2020; Lotz-Sisitka, 2004; Parayiwa & Shabalala, 2025; Van Poeck et al., 2024). Ultimately, intertwined scientific and pedagogical efforts offer a potent antidote to Africa's environmental perils, fostering informed, collective action for enduring sustainability.

In response, several vulnerable African nations including Kenya, Nigeria, Uganda, and South Africa have pioneered action-oriented environmental sustainability education initiatives to combat climate change and deforestation, embedding spatiotemporal tools such as satellite forest assessments, GIS land-use mapping, and community climate monitoring into curricula and awareness campaigns to foster data-driven, community-led solutions (Duguma, 2023; Dziob et al., 2020; Huho, 2015; Tlhabanelo, 2020). These efforts extend to curriculum reforms, public campaigns, environmental clubs, reforestation linked to mapping, teacher training, and multi-stakeholder partnerships, converting scientific insights into practical action (Coleen, 2015; Mugwedi et al., 2017; Panek & Vlok, 2013; Wanjiru, 2011).

Ethiopia also grapples with similar crises, marked by rapid land-use shifts from population pressures, resource dependency, agriculture, resettlement, and investments, fueling deforestation that has raised average temperatures by 0.37°C over four decades and rendered rainfall erratic, undermining agriculture and livelihoods (Bahiru et al., 2023; Baumgartner et al., 2015; Bedane et al., 2022; Bezu, 2020; Daley, 2016; Gebrechorkos et al., 2019; Gezie, 2019; Muluneh et al., 2017; Wassie et al., 2023). Similarly, othr Ethiopian scholarly works have emphasized that environmental degradation in the country is closely linked with population pressure, land-use change, and weak environmental awareness, which together accelerate forest loss and ecosystem decline (Sisay et al., 2020; Tilahun et al., 2022; Wassie, 2020a). Studies examining environmental education in Ethiopian secondary schools further reveal that although environmental themes are included in the curriculum, they are often treated superficially and lack sufficient practical engagement that would enable students to develop action-oriented competencies (Balcha et al., 2025; Gebrekidan, 2024).

Compounding these pressures is a widespread lack of environmental awareness among the general community and students in particular, which limits public engagement, weakens proactive conservation behaviors, and hinders informed decision-making (Zewdie, 2022; Dalelo, 2012; MoE, 2023). National assessments also indicate that environmental education is commonly delivered through a cross-curricular approach in subjects such as geography and biology, yet its implementation remains fragmented and insufficiently supported by resources and teacher training (Gebrekidan, 2024). Furthermore, studies conducted in Ethiopian secondary schools have shown that classroom practices frequently emphasize theoretical knowledge about the environment while providing limited opportunities for practical engagement or community-based environmental action (Balcha et al., 2025; Berku, 2007).

Despite growing attention, persistent data gaps on local environmental issues make spatiotemporal analyses essential, as limited reliable information combined with low awareness obscures the scale and drivers of deforestation and climate impacts, worsening Ethiopia's environmental challenges (Yeshalem, 2013). This demanded urgency of action-oriented environmental education to address low levels of awareness. Furthermore, it helps compensate for the scarcity of site-specific spatiotemporal data by equipping learners with context-specific knowledge. In the same veine, it strengthens pro-environmental attitudes and develops the skills needed to understand local environmental changes and sustainability challenges (Yeshalem, 2013; Hassen & Assen, 2018; Mohamed et al., 2020; Mudau & Hebe, 2025).

In light of this, scholars advocate for action-oriented environmental education's pivotal role in ecological restoration, transcending knowledge dissemination to nurture pro-sustainability values, attitudes, and competencies while dismantling behavioral obstacles (Bamberg, 2003; Dalelo, 2012; Frisk & Larson, 2011; Kollmuss & Agyeman, 2002; Wiek et al., 2011). This demands active civic engagement, ethical decision-making skills, and blended theoretical-practical pedagogies tailored to contexts like Ethiopia (Mohamed et al., 2020; Mudau & Hebe, 2025; Kayombo et al., 2025). Thus, fusing spatiotemporal evidence with action-oriented teaching holds transformative potential, evolving environmental education into experiential, locally anchored practice. Similarly, recent studies (Kayombo et al., 2025; Shabalala, 2025) reaffirm that environmental education must integrate both theoretical and practical dimensions to ensure that learners engage in problem-solving, policy understanding, and context-specific sustainability practices. In this regard, integrating appropriate environmental education contents and findings from spatiotemporal analysis with action-oriented pedagogy emerges as a key strategy for transforming environmental education from abstract theory into experiential, locally grounded practice in Ethiopia (Awayehu, 2023, 2025; Dalelo, 2012; MoE, 1994, 2023).

Aligned with these educational imperatives, Ethiopia has launched a range of initiatives to combat environmental degradation via action-oriented environmental education. One of the initial measures involved embedding context-specific environmental education drawing on local, national, and global environmental data into various subjects, most notably geography and biology. One of the overarching objectives of the national education policy is to cultivate citizens who can manage and utilize natural resources responsibly, while also being equipped with practical skills that enhance both individual and societal well-being (MoE, 1994, 2023). Complementing this, the government established the Ethiopian Environmental Protection Authority (EEPA) with the mandate of tackling environmental problems through education, awareness creation, and policy interventions (Ababa, 2004). In addition, environmental protection has been enshrined in the national constitution, where Article 92/4 clearly stipulates that both the government and citizens have a duty to safeguard the environment (FDRE, 1995). Despite these efforts, persistent environmental degradation reveals a gap between policy commitments and classroom realities. Topics related to deforestation and climate change exist in the curriculum, but their implementation often lacks adequate content and pedagogical integration, local contextualization and active, problem-based approaches that foster action-oriented learning (Belay, 2010; Dalelo, 2012; Hassen & Assen, 2018; Tombe, 2016). This shortfall is further widened by the limited availability of localized scientific studies including spatiotemporal assessments that teachers and students can use to meaningfully contextualize environmental problems within their immediate surroundings (Yeshalem, 2013).

Within this broader national and educational context, the Metekel Zone of the Benishangul–Gumuz Regional State emerges as a critical case. Situated in the Tana–Beles Basin, the zone supports both the Abay River system and the Grand Ethiopian Renaissance Dam (GERD). Within this context, the landscape is characterized by extensive woodlands, dry forests, riverine ecosystems, and diverse agro-ecological conditions that sustain local livelihoods such as smallholder farming, shifting cultivation, gum collection, and livestock rearing (Anbessa et al., 2024; Bessie et al., 2016; Degu et al., 2020). In recent years, observations indicate growing pressures on these natural systems, including rapid land-use changes and increasing climate variability. Field observations and local authority reports show that cultivation-driven forest clearing, settlement expansion, infrastructure development, and large-scale agricultural investments have transformed the landscape, leading to forest fragmentation, encroachment into intact areas, and heightened climate-related risks despite limited scientific evidence.

Despite these observable pressures, comprehensive site-specific evidence on the dynamics and determinants of deforestation and climate variability in Metekel is still scarce. This scarcity limits the capacity of teachers, students, local institutions, and other key stakeholders, including community leaders, policy makers, and development actors, to translate environmental realities into informed and practical action. School observations indicate that the effectiveness of environmental education in the Metekel Zone depends on the combined roles of geography teachers, students' understanding, and the national curriculum. However, the dominance of teacher-centred methods, limited practical activities, a centralized curriculum, and insufficient local adaptation often result in superficial engagement and constrained pro-environmental action. Within this context, the depth of secondary school students' understanding and their capacity to respond to environmental challenges are pivotal for promoting meaningful environmental engagement. Students exposed to active, locally relevant, and data-driven lessons tend to exhibit stronger pro-environmental dispositions and are more likely to engage in actual sustainability behaviors (Carcellar-Abrencia, 2025; Deborah et al., 2024; Nkongho et al., 2025). Equally important, the effectiveness of teachers and the national curriculum in facilitating the teaching–learning process plays a central role (MoE, 2018, 2023). The curriculum provides the structural blueprint by embedding environmental topics that enables students to analyze global, national and local scale deforestation, climate variability, and their consequences. Through active and student-centered teaching methods coupled with learning activities and embedded questions, students are encouraged to link theoretical concepts with real-world environmental issues (Hannafin et al., 2014; Juvova et al., 2015; Krahenbuhl, 2016; Yli-Panula et al., 2020). When such themes are systematically integrated into carrier subjects like geography and reinforced through a progressive approach across grade levels, learners can progressively move from conceptual understanding to inquiry and practical action (Ardoin et al., 2020; Granados-Sánchez, 2022; MoE, 2023; UNESCO, 2019).

Against this backdrop, the present study seeks to explore how environmental sustainability education can be strengthened through the integration of spatiotemporal analysis of deforestation and climate change with action-oriented content and pedagogy in secondary school geography. It examines the interplay among scientific evidence, curriculum content, teacher practice, and student learning outcomes to promote meaningful educational responses to environmental challenges in Ethiopia in general and in the Metekel Zone in particular.

1.2.Statement of the problem

Ethiopia is experiencing one of the most alarming rates of environmental degradation in Sub-Saharan Africa, where deforestation and climate change threaten ecosystems, agricultural productivity, and rural livelihoods. Historical records show that Ethiopia’s forest area has undergone a significant reduction, declining from 35% at the beginning of the twentieth century to only 11.4% by 2015 (FAO, 2016). Recent satellite-based analyses and field studies confirm this trend, revealing a continued net loss of forest cover due to agricultural expansion, fuelwood extraction, and settlement growth (Hansen & Loveland, 2012; Young et al., 2020). Compared with the sub-Saharan African average, where forests cover around 20–21% of total land area, Ethiopia’s remaining forest cover is considerably lower, reflecting the country’s prolonged deforestation and intense anthropogenic pressure on forest resources (FAO, 2016). Such an accelerating trend has triggered a chain of environmental consequences, including altered rainfall patterns, intense temperature, severe soil erosion, depletion of water resources, loss of biodiversity, increased crop pests, reduced agricultural productivity, and heightened livestock diseases (Moisa et al., 2022; Muluneh et al., 2017; Nega, 2025; Roth et al., 2018; Zegeye, 2017).

Within this national crisis, the Metekel Zone of Northwest Ethiopia stands out as a hotspot of vulnerability. As part of the Tana–Beles sub basin and home to the GERD, the zone harbors strategic forests and woodlands. Yet, observation shows that deforestation is driven by agricultural expansion, resettlement, demographic pressures, forest fires, charcoal production, and infrastructure growth, compounded by weak institutional enforcement and limited community awareness. Local experiences indicate increasingly irregular rainfall, recurrent droughts, and rising temperatures undermining agricultural production and livelihood. Farmers report difficulties in predicting seasonal rains and coping with prolonged dry spells, heightening risks to food security and livelihoods.

These challenges are consistent with broader empirical evidence. Land use and land cover studies across Ethiopia document extensive forest decline and reveal the limited effectiveness of participatory forest management initiatives (Belay & Mengistu, 2019; Betru et al., 2019; Feyissa & Gebremariam, 2018; Masha et al., 2024; Negese, 2021; Regasa et al., 2021; Tolessa et al., 2017). However, most of these studies focus on broader basin or regional contexts, providing limited insight into the specific conditions of the Metekel Zone. As a result, the precise extent, spatiotemporal patterns, and localized drivers of environmental change in Metekel remain insufficiently documented, leaving the dynamics of forest loss and its implications for local communities largely unexamined. Such gaps obscure how deforestation evolves over time and space and how these patterns intersect with local socio-economic and climatic realities. Furthermore, the absence of locally derived empirical data constrains the capacity of key stakeholders, including local administrators, policymakers, community-based organizations, as well as curriculum developers, teachers, and education planners, to effectively integrate context-specific environmental issues into school programs and community initiatives. Generating such spatially grounded evidence is therefore crucial for strengthening environmental education, enriching the geography curriculum, and fostering informed awareness and positive attitude change among students and the broader community.

In parallel, national and regional research highlights the adverse effects of climate variability on agriculture and rural livelihoods (Demem, 2023; Deressa et al., 2011; Etana et al., 2021; Hadgu et al., 2015; A. Kassaye, Shao, Wang, Shifaw, et al., 2021). Yet, despite this broader evidence, localized studies remain scarce, particularly in Metekel Zone, where detailed analysis of how spatial and temporal shifts in rainfall and temperature directly influence crop production and livelihoods is still lacking. This lack of temporal and spatial understanding limits the ability of communities, educators, and policymakers to interpret environmental transformations within their local contexts (Cox et al., 2014; Kunkyebe, 2015; Mochizuki & Vickers, 2024; Tidball & Krasny, 2011; Xiang & Liu, 2017). More importantly, spatiotemporal evidence of climate change, when integrated into education, can serve as a vital pedagogical tool, enabling students, teachers, and local institutions to visualize environmental changes, understand cause–effect relationships, and develop context-based solutions (Masolele et al., 2021; Mudau & Hebe, 2025; Shepardson et al., 2012). In this sense, education informed by spatiotemporal analysis transforms abstract environmental knowledge into tangible, place-based learning experiences, empowering learners to connect scientific data with lived realities and community action.

Building on this recognition, it becomes clear that bridging the gap between scientific evidence and school-based action demands an educational response. Spatiotemporal understanding alone cannot drive sustainable change unless it is translated into knowledge, skills, and values that shape responsible behavior. Therefore, education serves not merely as a medium for information transfer but as a transformative force linking empirical research with community-based environmental action (Frisk & Larson, 2011; Timperley & Parr, 2007; Wilson et al., 2010).

Addressing such complex challenges therefore, requires not only community-driven and ecological interventions but also educational strategies that prepare citizens to act. Action-oriented environmental sustainability education is particularly vital: by equipping learners with knowledge, values, and skills, it empowers them to critically engage with ecological realities and contribute to sustainable solutions (Saleem & Dare, 2023; Thor & Karlsudd, 2020; Van Poeck et al., 2024). Within this context, the secondary school geography curriculum, together with students and teachers, is strategically positioned to foster environmental awareness. Curriculum can translate global challenges such as deforestation and climate change into locally relevant learning; students, as active learners, can develop critical thinking and action competence; and teachers, as curriculum mediators, determine whether environmental education remains abstract or becomes transformative through participatory pedagogies (Enke & Budke, 2023; Firth & Winter, 2007; Granados-Sánchez, 2022; Perkins et al., 2018; Rushton, 2021). Thus, the alignment of curriculum content, student engagement, and teacher practice coupled with spatiotemporal evidence is essential for building environmentally literate citizens capable of addressing deforestation and climate change in Metekel zone and beyond.

To date, three major strands of research have addressed these issues, yet their findings remain fragmented. The first strand focuses on studies linking environmental education (EE) with environmental problems (Aliman et al., 2019; Boo & Park, 2013; Liefländer et al., 2013; Otto & Pensini, 2017; Saito, 2013; van de Wetering et al., 2022; Wals et al., 2014; Zsóka et al., 2013) which demonstrate that learner-centered and action-oriented approaches can effectively enhance students' environmental knowledge, attitudes, and skills. These studies emphasize the potential of EE to foster sustained environmental action when programs address the knowledge–action gap, incorporate practical and experiential learning, and are closely aligned with local environmental contexts. However, most of these studies are situated in international contexts and do not address Ethiopia's unique socio-ecological and educational challenges, nor do they integrate localized evidence such as spatiotemporal forest loss and climate variability into teaching and learning. As a result, the connection between lived ecological crises and student action competence remains underdeveloped in Ethiopia in general and in the study region in particular.

Second, studies on curriculum, pedagogy, and student learning in Ethiopia reveal that geography education continues to rely heavily on rote memorization, with insufficient integration of environmental themes such as deforestation and climate change and limited use of participatory, inquiry-based pedagogies like problem-based learning and the various factors affecting its implementation (Berku, 2007; Dalelo, 2011; Hassen & Assen, 2018; Mohamed et al., 2020; Waktola, 2009; Yeshalem, 2013). While these studies illuminate broad instructional weaknesses, they often conceptualize curriculum and pedagogy in isolation and assess them largely in abstraction, detached from local environmental issues such as deforestation and climate change. Consequently, they provide little insight into how classroom practices connect with the lived ecological realities that shape students' experiences and worldviews. Moreover, although national-level investigations (Bekalo & Bangay, 2002; Emiru & Waktola, 2018; Esa, 2010; Getachew et al., 2021; Paulos, 2017; Zikargae et al., 2022) offer valuable perspectives on environmental education, they stop short of examining secondary school students' levels of environmental knowledge, attitudes, and the demographic, socio-economic, behavioural, environmental and educational factors influencing their engagement in addressing deforestation and climate change. Equally, there has been no systematic analysis of the newly revised geography curriculum to determine how effectively it embeds these issues in ways that promote critical thinking, attitudinal transformation, and environmentally responsible action. This absence of context-specific, empirically grounded research underscores a significant gap in understanding how recent curricular reforms and pedagogical practices can cultivate action-oriented environmental learning aligned with Ethiopia's sustainability priorities.

Third, empirical studies on land use/land cover change and climate variability in Ethiopia (Abeje et al., 2019; Berihun et al., 2023; Bewket & Abebe, 2013; Bogale & Erena, 2022; Esayas et al., 2019; Hessebo et al., 2021; Kindu et al., 2013; Kuma et al., 2021; Weldearegay & Tedla, 2018) provide strong evidence of deforestation, changing rainfall, and rising temperatures. Some have even examined these patterns within the Tana–Beles basin, of which Metekel is a part (Gelete et al., 2020; Mengistu et al., 2021). Yet, they rarely extend their findings to education and fail to analyze spatiotemporal dynamics specific to Metekel zone. In doing so, they miss the opportunity to connect biophysical evidence with educational processes that could translate knowledge into joint action.

Collectively, these strands underscore a persistent and multidimensional research gap. Environmental education related to deforestation and climate change in Ethiopia remains inadequately integrated into the geography curriculum and potentially insufficiently linked to local ecological contexts. At the same time, environmental studies conducted at the local level tend to operate in isolation from curriculum development and classroom pedagogy, limiting their educational impact. As a result, the degree to which recent curriculum reforms and instructional practices meaningfully address these interrelated challenges remains uncertain and empirically underexplored. Bridging this divide is therefore crucial: without doing so, the education system risks producing students who are theoretically informed yet lack the competence and agency to act, while locally generated environmental data continues to inform research but not classroom practice.

This study therefore seeks to integrate both biophysical and educational dimensions. Specifically, it will generate spatiotemporal evidence on deforestation and climate variability in the Metekel Zone, assess their impacts on agriculture and livelihoods, and examine how these issues are represented in the secondary school geography curriculum and support the globalcontexts. In addition, it will evaluate students' environmental knowledge, attitudes, and behaviors, as well as teachers' use of problem-based learning. By linking ecological realities with pedagogical practice, the study aims to provide a holistic foundation for action-oriented sustainability education in Ethiopia.

1.3.Objectives of the Study

1.3.1. General objective

The general objective of this study is to integrate environmental and sustainability education within the secondary school geography curriculum through spatiotemporal analysis of deforestation and climate change in the Metekel Zone, in order to develop action-oriented content and pedagogical strategies that enhance students' sustainability-oriented knowledge, attitudes, and action competence.

1.3.2. Specific Objectives

In line with the general objective, the study was attempted to achieve the following specific objectives. It is to:

1. Analyze the spatiotemporal trends and drivers of forest cover change in the Metekel Zone of Northwest Ethiopia (1986–2019) using Google earth engine plat form.
2. Examine spatiotemporal patterns of climate variability and assess its impacts on crop production and rural livelihoods in the study region.
3. Evaluate the extent to which deforestation and climate change themes are integrated into the Ethiopian secondary school geography curriculum.
4. Examine secondary school students' level of environmental knowledge, attitudes and the determinants related to deforestation and climate change in the Metekel Zone,
5. Investigate geography teachers' implementation of PBL for deforestation and climate change education in the study region.

1.4.Basic Research Questions

1. What are the spatiotemporal trends and drivers of forest cover change in the Metekel Zone over the last three decades?

2. How do spatiotemporal patterns of climate variability affect crop production and rural livelihoods in the study region?
3. To what extent are deforestation and climate change themes integrated into the Ethiopian secondary school geography curriculum?
4. What is the level of knowledge, attitudes, and behavioral determinants of secondary school students regarding deforestation and climate change?
5. How effectively do geography teachers implement problem-based learning to teach deforestation and climate change themes?

1.5. Significance of the Study

Ethiopia is facing serious environmental challenges, particularly rapid deforestation and increasing climate variability, which threaten livelihoods and sustainable development. The Metekel Zone, as one of the most affected regions, experiences accelerated forest loss and climate stress but remains under-researched and insufficiently addressed in education and policy. Hence, understanding the dual challenges of deforestation and climate variability in the Metekel Zone is not only a scientific concern but also an educational imperative. The persistent forest loss and shifting climate patterns directly affect local livelihoods, ecosystems, and development pathways. Yet, the integration of these realities into the secondary school geography curriculum remains limited, constraining the potential of education to foster environmental awareness and action competence among students. This study is therefore significant as it bridges the gap between empirical evidence on environmental change and pedagogical practice, offering a pathway to strengthen action-oriented environmental sustainability education in Ethiopia.

At the scientific level, the research addresses the scarcity of localized evidence on forest cover change and climate variability in the Metekel Zone. It also generates reliable data on the dynamics of deforestation and climate change in a region that has received limited scholarly attention. These findings not only fill a critical knowledge gap but also provide a solid foundation for sustainable natural resource management and climate adaptation strategies, which in turn can inform the policy dimensions of the study.

Building on this scientific evidence, the study contributes to the educational domain by linking empirical data with curriculum content, student learning, and teacher practices. Integrating biophysical realities into classroom instruction enables students to acquire knowledge, develop positive environmental attitudes, and participate responsibly in managing environmental quality from local to global levels. In this way, the research aligns with the United Nations Sustainable Development Goal 4 (Assembly, 2015), which underscores the importance of equipping learners with the knowledge and skills necessary to advance sustainable development, particularly through education that fosters sustainable lifestyles.

Extending beyond the classroom, the study also holds policy and practical significance. By generating context-specific recommendations, it offers guidance for curriculum developers, teacher training programs, and education policymakers on embedding sustainability issues into teaching and learning. In this way, the research bridges biophysical realities with pedagogical practice, equipping learners with the skills and critical awareness necessary to respond effectively to environmental challenges.

Finally, at the societal level, the study contributes to empowering local communities through students and schools to better understand and address deforestation and climate change. This not only enhances environmental stewardship and supports sustainable livelihoods but also advances Ethiopia's commitments to the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 15 (Life on Land).

1.6.Scope of the Study

Geographically this study is delimited to the Metekel Zone of Northwest Ethiopia, a region located within the Tana–Beles basin that is ecologically significant yet under-researched. The zone has been selected because of its accelerated deforestation, climate variability, and the rsulting livelihood pressures, as well as its strategic importance due to major development projects such as the GERD. Within this context, the study integrates spatiotemporal analysis of forest cover change and climate variability with an educational inquiry into how these issues are addressed in the secondary school geography curriculum.

Thematically, the research addresses two interrelated dimensions: the biophysical and the educational. On the biophysical side, the scope encompasses spatiotemporal analysis of forest cover dynamics from 1986 to 2019 and climate variability from 1981 to 2019. This analysis not only identifies long-term trends but also examines the drivers and livelihood impacts of deforestation and climate variability, with particular attention to their implications for agricultural productivity and community resilience.

On the educational side, the study directs its attention to the secondary school geography curriculum, with a particular emphasis on how deforestation and climate change are represented, taught, and understood within the classroom context. This dimension is structured around three interrelated areas of inquiry. First, it assesses whether the curriculum content is analyzed to determine the extent to which themes of deforestation and climate change are integrated into the national geography curriculum, and whether this content is sufficiently localized, action-oriented, and aligned with broader sustainability education frameworks. Second, the study examines the student dimension by assessing learners' levels of environmental knowledge, their attitudes toward ecological stewardship, and their behavioral orientations in relation to deforestation and climate change, while also identifying the key determinants that shape these knowledge levels and attitudes. Third, attention is given to the teacher dimension, focusing on the pedagogical strategies employed by geography teachers. In this regard, the study investigates the extent to which teachers utilize PBL for deforestation and climate change education to move beyond theoretical instruction and foster critical thinking, problem-solving, and action competence among students.

Institutionally, the study involves all districts and secondary schools in the Metekel Zone, targeting geography teachers and students as the main educational actors, while also generating insights relevant for curriculum developers, educational planners, and policymakers. To ensure comprehensive and reliable data, the study incorporated all secondary schools within the zone for the teacher-focused component, specifically concentrating on those offering grades 9–12 across all *kebeles.* For the student-focused component, out of the 14 secondary schools in the zone, seven were selected and used in the study.

Conceptually, the scope is limited to integrating spatiotemporal biophysical evidence on deforestation and climate change with pedagogical evaluation to enhance environmental sustainability education. Broader ecological and social issues beyond deforestation and climate variability—such as water resource management, population growth, or detailed policy impact analysis—are acknowledged but remain outside the direct focus of this study.

Temporally, the study covers forest cover change from 1986 to 2019 and climate variability from 1981 to 2019, offering a long-term view of environmental trends in Metekel. The educational component uses contemporary data to examine the current curriculum, teaching practices, and student learning, allowing the study to assess how present instruction reflects and responds to these long-term patterns of deforestation and climate change.

Methodologically, this study is confined to an integrated geospatial, climatic, and socio-ecological analysis of deforestation and climate variability in the Metekel Zone. It encompasses the use of multi-temporal satellite imagery to assess long-term land use and land cover change, and the analysis of historical rainfall and temperature records to characterize climate variability and trends. The scope extends to modeling the influence of climate variability on crop yields and livelihoods, and to interpreting environmental change through the driverse, pressures, state, impact, response (DPSIR) analytical framework. In addition, the study includes qualitative inquiry based on purposively selected key informants and focus group participants to contextualize drivers, pressures, and local perceptions. Beyond th components, the methodological scope does not include experimental designs, household surveys, or biophysical field measurements.

The methodological scope of the educational component is limited to examining how secondary school geography instruction addresses deforestation and climate change through curriculum analysis, student learning assessments, and teacher practice evaluations. It covers the systematic review of the revised geography curriculum, the assessment of students' environmental knowledge, attitudes, and practices using structured surveys, and the investigation of teachers' beliefs and instructional behaviors through questionnaires, interviews, and classroom observations. The scope further includes the application of descriptive and inferential statistics to identify determinants of student outcomes and to analyze the consistency between teachers' beliefs and their classroom practices, particularly regarding the implementation of problem-based learning. Beyond these areas, the study does not extend to longitudinal tracking of student performance or experimental interventions in teaching practices.

Timing and weighting: following (Creswell, 2014) both quantitative and qualitative data were collected concurrently and integrated during the analysis stage. However, priority was given to the quantitative component, as most objectives required remote sensing, GIS, statistical modeling, and survey data to generate reliable generalizations. The qualitative component played a supportive role, enriching and validating the quantitative findings.

1.7.Limitations of the Study

This dissertation, while providing significant contributions to understanding the intersections of deforestation, climate change, and environmental sustainability education, is not without limitations. First, some FGD and KII participants were unable to attend their initial appointments to complete the interview and discussion. This posed a potential risk of non-response bias and delays in data collection. To alleviate the problem, trained enumerators made follow-up visits to participants' households, schools, offices, and workplaces, ensuring that all intended respondents eventually completed the questionnaires through face-to-face interviews. While this approach minimized missing data, the rescheduling process still has influenced the timing and flow of data collection. Second, the climate change–livelihood analysis emphasized rainfall and temperature variability, yet other important factors such as soil quality, pest outbreaks, and socio-economic conditions were not incorporated. A more integrated approach would have yielded a fuller picture of the drivers of agricultural productivity and vulnerability. Third, the absence of longitudinal and cross-regional comparative data limited deeper insights into how student learning and teacher pedagogical practices such as problem-based learning evolve and adapt across different school settings. Fourth, budget and time constraints posed a limitation to this study, as they restricted both the geographical coverage and the thematic depth that could reasonably be pursued. Although the research was designed to address multiple objectives across spatiotemporal, curricular, and pedagogical dimensions, financial and temporal limitations required prioritization of specific regions and themes. This inevitably has excluded additional perspectives or variables that could have enriched the findings.

Finally, political unrest in the study region, which occurred during the research period, created significant challenges for data collection and coordination. Travel restrictions, safety concerns, and disruptions to institutional operations limited the researcher's ability to access certain areas or respondents in a timely manner. This not only delayed some phases of fieldwork but also risked reducing the representativeness of the data, as certain participants and locations could not be engaged as initially planned. To minimize these impacts, data collection was rescheduled in more stable periods, and additional follow-up sessions were arranged to capture missing perspectives. These adjustments ensured that core research objectives were met, although the process extended the study timeline and required greater flexibility in field management.

1.8.Theoretical Framework of the study

This dissertation adopts an integrated theoretical approach to capture the interlinked dynamics of deforestation and climate change, livelihoods and environmental education in the Metekel Zone. Because environmental sustainability is both an ecological and a social challenge, the study integrates theories from environmental psychology, education, socio-ecological systems, and population–environment linkages. Together, these perspectives provide a robust foundation for analyzing spatiotemporal trends of deforestation and climate variability while also guiding the development of action-oriented educational strategies for secondary school geography education. Although each strand emphasizes different dimensions, they collectively reinforce the central argument that environmental sustainability education in the Metekel zone requires both ecological analysis and educational transformation (Figure 1.1).

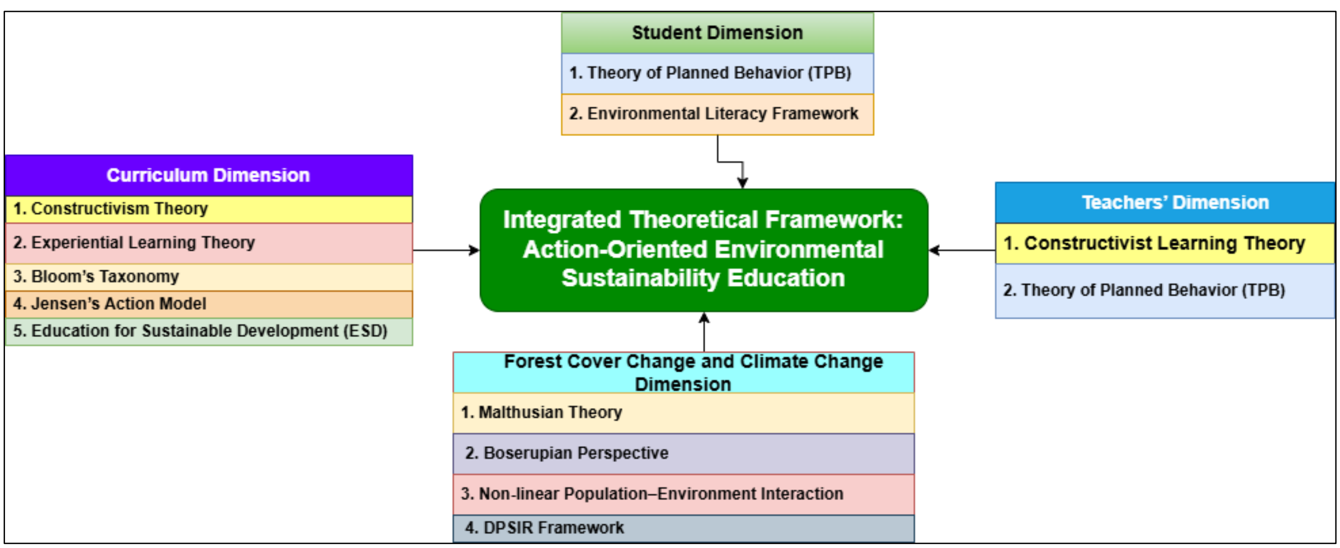


Figure 1.1: Theoretical framework of the study developed by the author based on a review of the related literature

1.9.Conceptual Framework of the Study

The conceptual framework of this study is grounded in the intersection between ecological realities and educational processes, with the predominant aim of strengthening Environmental Sustainability Education (ESE) in Ethiopian secondary school geography education in general and in the study region in particular (Figure 1.2). The dependent variable is defined as the level and quality of action-oriented environmental sustainability education integration in the secondary school geography curriculum, operationalized through curriculum content, teaching practices, and student outcomes. This is influenced by a set of interrelated independent variables that span ecological, curricular, student-related, and pedagogical domains. The framework, therefore, seeks to bridge empirical environmental evidence with pedagogical and curricular reform, ultimately fostering action-oriented environmental competence among learners (Jensen, 2002; Sterling, 2010). The detailed description and operationalization of each component of the conceptual framework are presented and discussed comprehensively in the subsequent chapters of this dissertation.

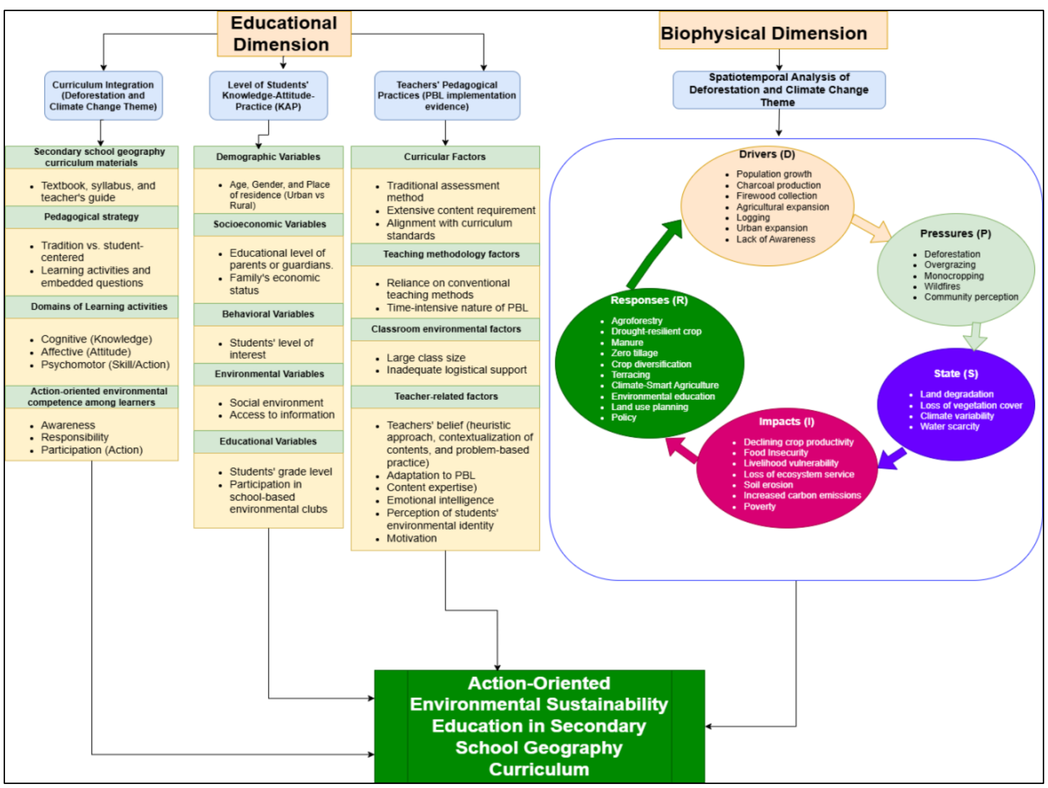


Figure 1.2: Conceptual framework of the study developed by the author based on a review of the related literature

1.10. Organization of the Dissertation

This dissertation examines the interconnected environmental and educational dimensions of deforestation and climate change in the Metekel Zone, Northwest Ethiopia. It integrates biophysical analyses of forest cover and climate variability with curriculum evaluation and pedagogical investigations that seek to promote environmental sustainability through secondary school education.

The first chapter provides a comprehensive overview of the study, presenting the background, statement of the problem, objectives, research questions, significance, scope, limitations, and the theoretical and conceptual frameworks guiding the research, while also outlining the expected contributions to environmental management, geography education, and policy development.

The second chapter outlines the research methodology, describing the study area and the mixed-methods approach employed. It details the data collection procedures, including remote sensing and climatic analyses, curriculum content evaluation, and educational surveys, along with the sampling techniques, analytical methods, and ethical considerations that ensured the reliability and validity of the findings.

The third chapter reports the spatiotemporal trends and drivers of forest cover change in the Metekel Zone forest areas. Using remote sensing and GIS tools, it quantifies the extent and rate of forest cover loss between 1986 and 2019 and identifies the proximate and underlying drivers such as agricultural expansion, settlement growth, and institutional factors contributing to deforestation.

The fourth chapter focuses on climate variability and its impact on local community livelihoods, particularly on crop production. It analyzes long-term temperature and rainfall patterns and applies econometric analyses to assess the relationships between climatic variables and agricultural productivity, thereby revealing the implications of climate variability for rural livelihoods and adaptation strategies.

The fifth chapter turns to the educational dimension of the study by analyzing the Ethiopian secondary school geography curriculum. It examines the extent to which deforestation and climate change themes are integrated into the curriculum and evaluate their alignment with action-oriented environmental education principles, highlighting gaps and opportunities for promoting sustainability learning.

The sixth chapter presents findings on secondary school students' knowledge and attitudes toward deforestation and climate change and identifies the major determinants influencing these variables. It reveals the level of environmental awareness among students and their readiness to engage in practical actions that address environmental challenges.

The seventh chapter explores geography teachers' implementation of PBL in teaching deforestation and climate change topics. It investigates teachers' beliefs, practices, and challenges in adopting the PBL approach and discusses how institutional support, curriculum design, and teacher motivation shape effective PBL implementation.

The eighth chapter provides a synthesis of the findings from both the biophysical and educational components of the study. It integrates evidence from forest cover change, climate variability, curriculum analysis, student knowledge and attitudes, and teacher practices to offer a holistic understanding of how environmental and educational systems interact in promoting sustainable development in the Metekel Zone.

Finally, the ninth chapter presents the overall conclusions and recommendations, synthesizing the major findings, outlining policy and educational implications, and proposing future research avenues to enhance the link between environmental conservation and education for sustainable development in Ethiopia.

CHAPTER TWO

2. GENERAl RESEARCH METHODOLOGY

2.1.Biophysical characteristics of the study area

2.1.1. Geographical location

The study was carried out in the Metekel Zone, situated in the north-western part of Ethiopia. It was the largest zone within the Benishangul-Gumuz Regional State. Geographically, the zone extended between 10°15′N and 11°45′N latitude and 34°45′E and 36°45′E longitude (Figure 3-1). It was bordered to the south and southwest by Kamashi, to the west by Sudan, and to the north and east by the Amhara Region. The Abay River marked the boundary with Kamashi, while the Dinder River defined part of the border with Amhara. Administratively, the zone was divided into seven districts: Bullen, Dibate, Dangur, Guba, Mandura, Pawe, and Wembera. It contained 170 *kebeles* (village clusters) and covered an estimated total area of 22,028 km². Its administrative center, Gilgel Beles, was located 575 km by road from Addis Ababa (the national capital) and 365 km from Assosa (the regional capital). The area was primarily accessed through the Addis Ababa–Guba and Chagini–Wombera all-weather roads. Within the existing administrative structure, the Gumuz people predominantly inhabited the Metekel Zone north of the Abay/Nile River and the Kamashi Zone to its south.

2.1.2. Topography

The topography of the Metekel Zone, as illustrated in the elevation map, is characterized by considerable variation in elevation ranging from low-lying areas at **500** meters in Guba to highlands in Dangur, Belaya reaching up to approximately 2,731 meters above sea level. The southern and central parts of the zone are dominated by rugged highlands and mountainous terrain, indicated by the red and orange shades, suggesting steep slopes and elevated landscapes. In contrast, the northern and western portions are predominantly lowland areas, represented by blue tones, which indicate gentle slopes and flatter terrain. The variation in elevation reflects the diverse physical landscape of Metekel Zone, influencing local climate, vegetation cover, and land use patterns. The elevated areas likely serve as sources of streams and rivers flowing towards the lower plains, contributing to the hydrological and ecological diversity of the region (Wagino & Amanuel, 2021).

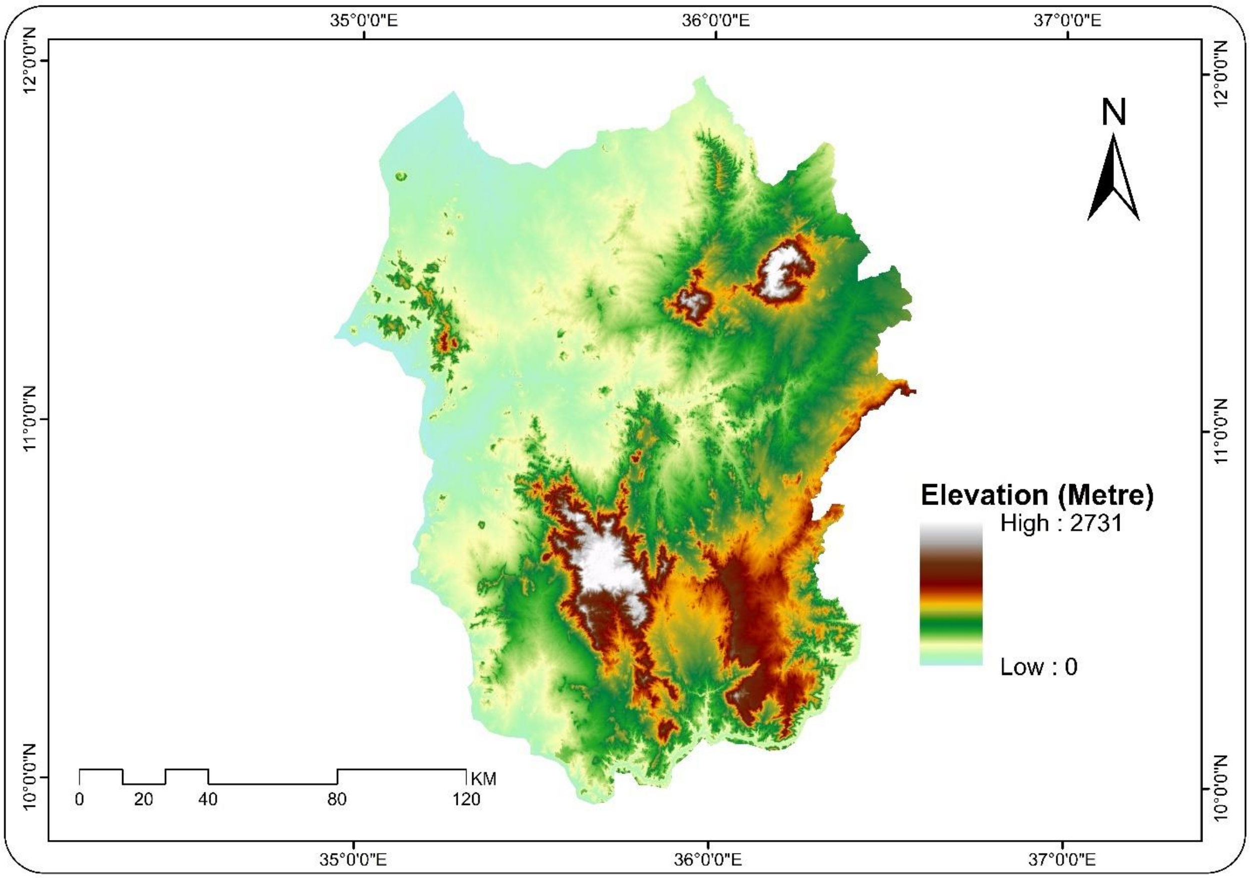


Figure 2.1: Topography of Metekel Zone derived from USGS

2.1.3. Soil

The soils of the Metekel Zone are diverse and influenced by variations in topography, parent material, and climatic conditions. The major soil types identified in the area include dystric nitisols, dystric cambisols, eutric cambisols, chromic vertisols, and eutric vertisols, which together form the dominant soil cover across the landscape. Nitisols and Cambisols are widespread in the central and western parts of the zone, where the terrain is moderately elevated and well-drained. These soils are generally deep, well-structured, and moderately fertile, making them suitable for both crop cultivation and grazing. According to the FAO (2006) soil classification, Nitisols are typically developed from basaltic parent material and are known for their strong aggregation, good drainage, and moderate to high fertility, while Cambisols are younger soils with weak horizon development but good potential for agriculture under proper management.

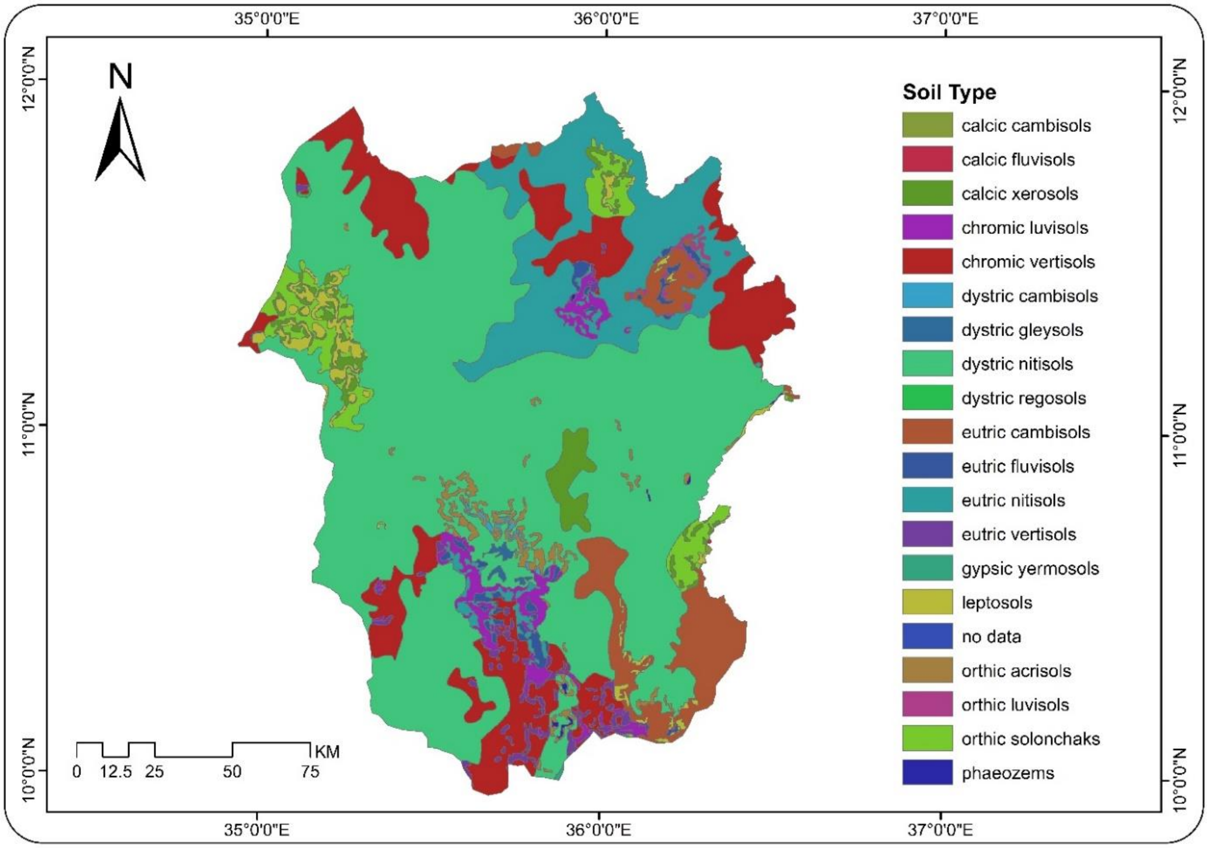


Figure 2.2: Soil classes in Metekel Zone generated from FAO

In the southern and southwestern parts of Metekel, Vertisols—particularly Chromic Vertisols and Eutric Vertisols—are common. These soils are characterized by their high clay content and strong shrink–swell properties, which lead to deep cracks during dry periods and sticky conditions when wet. In the eastern and low-lying parts of the zone, Fluvisols and Luvisols are prevalent, especially along river valleys and floodplains. Fluvisols are young alluvial soils formed from recent sediment deposits, making them fertile and suitable for irrigated agriculture. Luvisols, on the other hand, exhibit clay accumulation in their subsoil and moderate fertility, supporting a variety of crops and vegetation types (FAO, 2006). Additionally, small patches of Leptosols and Gypsic Yermosols occur in the more rugged and arid areas, where shallow soil depth and limited organic matter restrict vegetation growth and agricultural potential.

2.1.4. Drainage

The drainage system of the zone is primarily characterized by the Abay, Beles, and Ayima river systems, which constitute the major waterways discharging across several districts within the study area. Complementing these are other significant rivers, including Burgy, Aykota, Shar, and Bar, which further contribute to the hydrological network of the zone. Beyond their ecological role, some of these rivers also provide vital socio-economic benefits, particularly through their use in small- and large-scale irrigation practices (MZARDD, 2021).

2.1.5. Temperature

The Metekel Zone experiences a generally warm climate throughout the year. The long-term temperature record (1981–2024) shows that the maximum temperature ranges between 28°C and 33°C, while the minimum temperature varies from 12°C to 15°C. The area exhibits a slight increasing trend in both maximum and minimum temperatures over the past four decades, indicating a gradual warming pattern. According to the Ministry of Agriculture (MoA, 2023) and the Ethiopian Agricultural Transformation Agency, the Metekel Zone exhibits a unimodal rainfall pattern, with a distinct wet season extending from May to October. The annual precipitation of the Metekel Zone during 1981–2024 is characterized by periods of relatively low rainfall in the earlier years of the record and consistently higher rainfall in the recent years, with the highest values occurring after 2015, as shown in Figure 2-4.

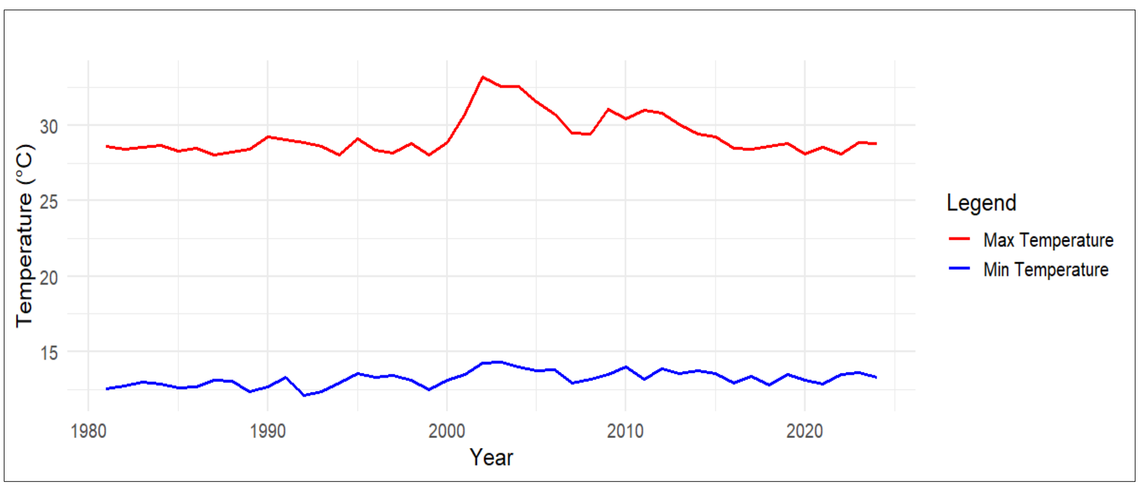


Figure 2.3: Temperature distributions of Metekel zone (1991-2024) sourced from EMA

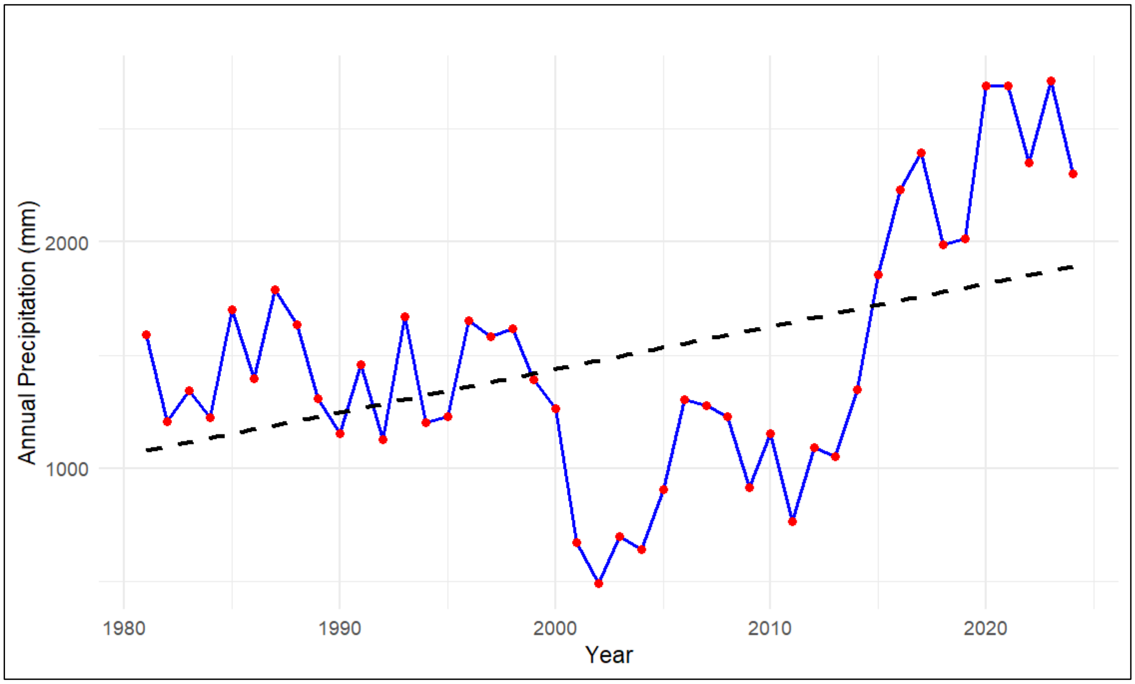


Figure 2.4: Monthly rainfall distribution for Metekel Zone sourced from EMA

2.1.6. Vegetation Distribution

A significant portion of the total land area of the Zone is covered with diverse vegetation and forest resources. The major forest types include bamboo (Oxytenanthera abyssinica), incense tree (Boswellia papyrifera), gum Arabic tree (Acacia Senegal), eucalyptus (Eucalyptus globulus), wanze (Cordia africana), zigba (Podocarpus falcatus), tid (Juniperus procera), tikur enchet (Dalbergia melanoxylon), koso (Hagenia abyssinica), and girar (Acacia abyssinica). These forests play an essential role in providing construction materials, fuelwood, and food, particularly for indigenous communities (Anbessa et al., 2024; Bessie et al., 2016; Birhanu, 2023). The original vegetation cover of the Metekel Zone was characterized by dense hyparrhenia grass, extensive bamboo thickets, scattered trees, and a combination of arboreal species and thick shrubs that typically flourished along waterways (Wagino & Amanuel, 2021). This rich plant cover once sustained both ecological balance and local livelihoods.

2.2. Socio-economic Situation of the Study Area

2.2.1. Population

According to the Ethiopian Central Statistics Authority (CSA, 2024), Metekel Zone has a total population of 534,305, comprising 268,288 males and 266,017 females. A considerable proportion of this population resides in rural areas, as 71.3% (380,786 individuals) live in the countryside, whereas only 28.7% (153,519 individuals) reside in urban centers. Consequently, this distribution highlights the predominance of rural livelihoods and the continued dependence of the zone on agriculture and related activities.

In light of this demographic setting, both rural and urban areas of the Metekel Zone are served by government secondary schools, which play a crucial role in educating young people. Based on the 2023/24 (2025 E.C.) annual report from the Benishangul Gumuz Education Bureau, the zone has a total of 38 government secondary schools. Among them, 24 schools offer education only for grades 9–10, while the remaining 14 are full-cycle schools that include grades 9–12. The full-cycle schools collectively serve 11,652 secondary school students. Moreover, the zone has 134 geography teachers who employ different teaching approaches, although their classroom practices are largely dependent on the official curricular materials such as the student textbook, teacher's guide, and syllabus prepared by the Ministry of Education (MoE, 1994, 2023).

2.2.2. Economic condition

The livelihood system of the study region is dominantly agricultural (mixed farming) which is practiced as the primary source of income for the population of the zone. Agricultural activities in the zone dominated by mixed crop-livestock production, which accounts 96.2% of the farmers and the rest 3.8%, were involved only in livestock production. Its diverse agro-ecology provides the potential for the cultivation of different crops (Altaye et al., 2014). The dominant crops cultivated in the Zone in terms of areal coverage are cereals—maize (Zea mays), sorghum (Sorghum bicolor), and finger millet (Eleusine coracana)—and oilseeds such as soybean (Glycine max), sesame (Sesamum indicum), and groundnut (Arachis hypogaea). Haricot bean (Phaseolus vulgaris) is also widely grown by smallholder farmers. Around homesteads, farmers cultivate and intercrop mango (Mangifera indica), papaya (Carica papaya), cabbage (Brassica oleracea), banana (Musa paradisiaca), lemon (Citrus limon), potato (Solanum tuberosum), pepper (Capsicum annuum), pumpkin (Cucurbita pepo), onion (Allium cepa), and climbing beans (Phaseolus vulgaris). Small-scale traditional irrigation practices are also used in some districts of the Zone to support crop production (Degu et al., 2020).

2.3. Research Methodology

2.3.1. Philosophical Assumption of the Study

Philosophical assumptions form the foundation of research design, guiding how reality (ontology), knowledge (epistemology), values (axiology), and methods (methodology) are understood (Creswell, 2014). In educational research, key paradigms include positivism, post-positivism, constructivism, transformative, and pragmatism.

Positivism views reality as objective and measurable, emphasizing neutrality and quantitative methods (Creswell, 2014; Emon, 2024). Post-positivism, while still realist, recognizes the limits of objectivity and uses strategies like triangulation to reduce bias (Musa & Aldiabat, 2024). Constructivism, by contrast, sees reality as socially constructed and explored through qualitative inquiry (Willig, 2016), while transformative paradigms link research to social justice and empowerment (Mertens, 2010).

Each paradigm offers valuable insights but also limitations: positivism and post-positivism often neglect subjective meaning, whereas constructivist and transformative approaches may limit generalizability. Pragmatism, therefore, provides a balanced alternative embracing pluralism, flexibility, and practicality (Morgan, 2007). It values both objective and subjective realities, prioritizing methods that best address the research questions (Creswell, 2014).

This study adopts a pragmatic stance to integrate quantitative and qualitative methods, surveys, standardized tests, interviews, focus groups, and observations to examine both measurable trends in deforestation and climate change and the perceptions of students and teachers. Pragmatism enables the combination of empirical rigor with contextual understanding; ensuring findings are both academically sound and practically relevant for enhancing environmental sustainability education in the Metekel Zone.

2.3.2. Field Work for the Study

Fieldwork was conducted from April to May 2023 to collect primary data, validate secondary sources, and capture the views of communities, students, and key stakeholders. It involved several stages, including reconnaissance surveys, stakeholder consultations, classroom observations, and student engagement, providing a comprehensive understanding of deforestation, climate change, and environmental education in the Metekel Zone.

The reconnaissance survey across selected districts helped the researcher become familiar with local physical and socio-economic conditions and identify priority sites for detailed inquiry. It revealed major drivers of deforestation such as agricultural expansion, charcoal production, firewood collection, and unsustainable land-use practices. This stage also helped refine research tools and build connections with communities and key informants.

Subsequent consultations with agricultural and forestry experts, education officials, kebele administrators, teachers, and community leaders provided valuable insights into institutional challenges and local efforts related to forest conservation, environmental management, and climate change adaptation.

A major part of the fieldwork focused on secondary school students to examine their awareness, attitudes, and participation in activities like afforestation, waste management, and the use of renewable energy. This highlighted their role as both learners and active participants in promoting environmental sustainability.

Finally, classroom observations were carried out to assess how teachers incorporated topics on deforestation, climate change, and sustainability into geography lessons, the teaching strategies applied, and the level of student engagement. These observations were essential for evaluating how well the curriculum addressed current environmental challenges.

2.3.3. Research Approach

The study employed a mixed research approach, which is an approach to inquiry involving the collection of both quantitative and qualitative data, the integration of the two forms of data, and the use of distinct designs that may involve philosophical assumptions and theoretical frameworks (Johnson et al., 2022). The core assumption of this form of inquiry was that the combination of qualitative and quantitative approaches provided a more complete understanding of a research problem than either approach alone.

Creswell (2014) emphasized that the procedures for both qualitative and quantitative data collection and analysis need to be conducted rigorously, including adequate sampling, appropriate sources of information, and clear data analysis steps. In line with this, the two forms of data were integrated in the design and analysis through merging, connecting or embedding the data. In this study, the mixed research approach was applied mainly because the research addressed two separate but interrelated issues within a single investigation, which required both qualitative and quantitative data collection and analysis (Mulisa, 2022).

2.3.4. Research Design

This study employed a mixed-methods research design to capture the complex interplay between biophysical change and environmental sustainability education (ESE) related to deforestation and climate change in Ethiopian secondary school geography curriculum. Within the mixed-methods design, the study adopted multiple, complementary designs to address the varied thematic areas. For the biophysical dimension, a longitudinal research design was applied. As Plano et al. (2015) emphasize, longitudinal designs are particularly suited for exploring dynamic processes that unfold over time. In this study, the design guided the spatiotemporal analysis of deforestation from 1986 to 2019 and climate variability from 1981 to 2019. This approach enabled the various periods' observations of forest cover change and climate variability, thereby allowing for the assessment of long-term patterns and their implications for rural livelihoods and crop production in the Metekel Zone.

In the educational domain, different but complementary designs were employed. First, a cross-sectional survey design was used to assess the status of environmental awareness, knowledge, and attitudes among secondary school students in the study area. This design allowed the researcher to capture a snapshot of students' level of knowledge and attitude and behavioral determinants regarding deforestation and climate change (Olsen & Marie, 2004).

Second, the cross-sectional survey design guided the study by enabling the collection of data from a large and diverse group of secondary school students at a single point in time, providing a clear snapshot of their environmental knowledge, attitudes, and related determinants. This design allowed for systematic comparison across demographic, socio-economic, behavioural, and educational variables, making it possible to identify patterns, variations, and associations relevant to deforestation and climate change education. Moreover, the design supported the integration of both quantitative and qualitative data, strengthening the analysis and ensuring that the findings reflected the real-time conditions and contextual challenges within the Metekel Zone.

Third, a convergent embedded mixed-methods design was adopted to take advantage of the complementary strengths of a QUAN + qual convergent approach. This design allowed for the systematic collection, organization, and analysis of data on the state of content and pedagogical integration in the secondary school geography curriculum. In addition, it provided a comprehensive examination of teachers' beliefs and practices, as well as the structural and systemic factors that influence their performance in implementing PBL for deforestation and climate change lessons. In this design, quantitative and qualitative data were collected simultaneously, with the quantitative strand serving as the dominant component to assess geography teachers' implementation of problem-based learning, while the qualitative strand offered contextual explanations and deeper insights (Creswell, 2007; Younas et al., 2023). In addition, qualitative content analysis of curriculum documents and textbooks assessed the depth and quality of topic coverage. The integration of survey, interview, and content analysis data enabled identification of strengths and gaps in environmental teaching and learning outcomes.

2.3.5. General methodological flow chart

The methodology integrates educational and biophysical dimensions to support action-oriented environmental sustainability education. Educational data from surveys, interviews, focus groups, observations, and document reviews are pretested, cleaned, and analyzed using quantitative and qualitative methods to assess environmental knowledge, attitudes, teaching practices, and curriculum integration. Concurrently, Landsat imagery, climate variables, and crop yield data are preprocessed and analyzed using spectral indices, machine learning classification, trend tests, and spatial techniques to evaluate land use/cover change, deforestation, and climate variability impacts (Figure 2.5). Findings from both dimensions are triangulated to inform evidence-based sustainability education strategies.

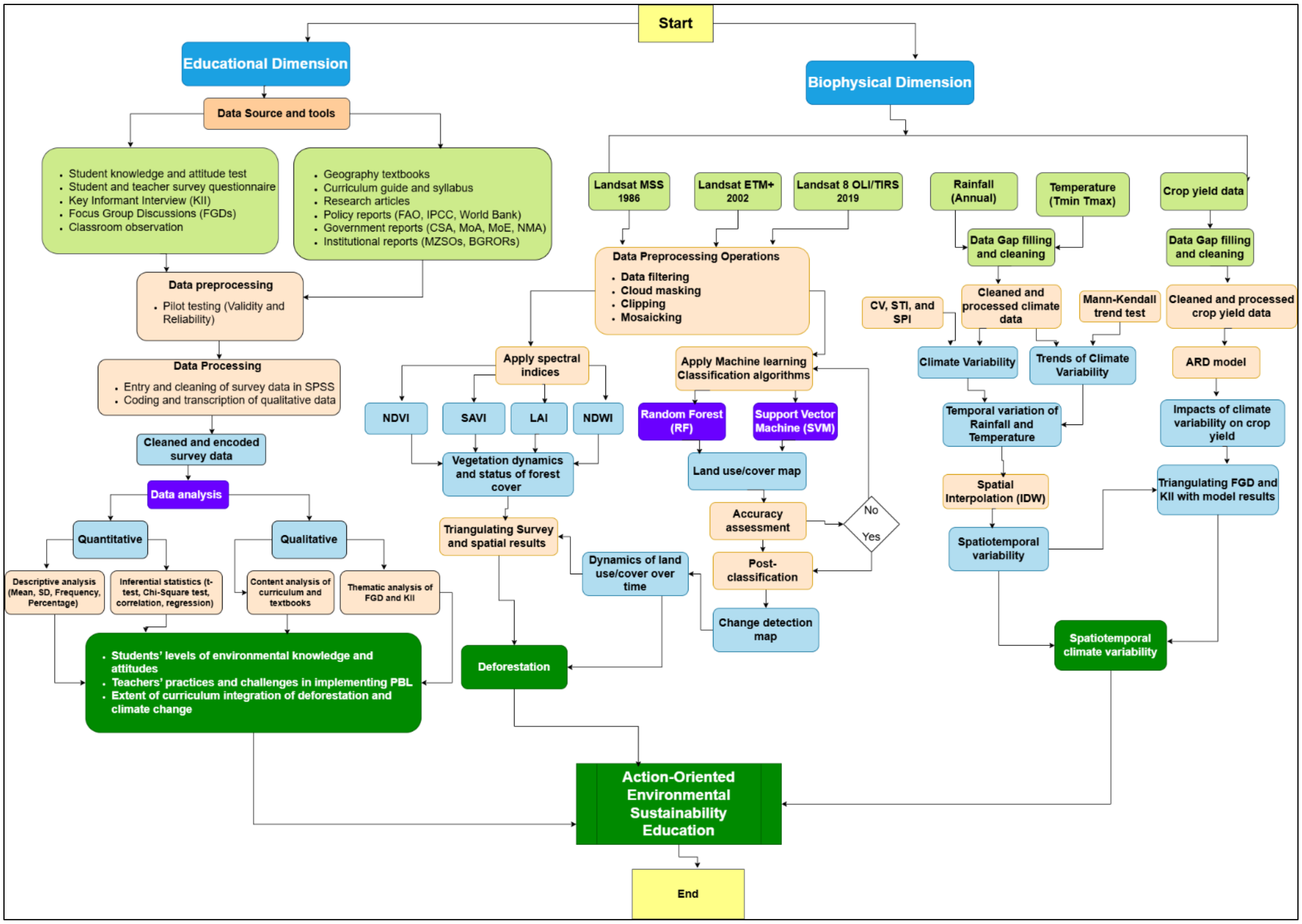


Figure 2.5: Methodological flow chart developed by the author based on a review of related literature

CHAPTER THREE

3. Spatiotemporal trends and drivers of forest cover change in Metekel Zone forest areas, Northwest Ethiopia

Abstract

The spatiotemporal dynamics of forest cover are essential for understanding the patterns and processes of forest change over time and space. This research focused on the spatiotemporal trends and drivers of forest cover change in the Metekel Zone of Northwest Ethiopia. Landsat-5, Landsat-7, and Landsat-8 imagery, covering the period from 1986-2019, were used to classify land use/cover using the Google Earth Engine (GEE) platform. Land use/cover classification was performed via random forest (RF) and support vector machine (SVM) algorithms, with training samples obtained through visual image interpretation. The accuracy of these classifications was evaluated via validation points from ground control points and Google Earth imagery. Spectral indices, such as the normalized difference vegetation index, soil-adjusted vegetation index, leaf area index, and normalized difference water index, were analyzed to examine forest cover dynamics over time. In addition, key informant interviews (KIIs) and focus group discussions (FGDs) were conducted and analyzed thematically. Findings revealed that forest cover decreased significantly from 51.37% in 1986 to 17.20% in 2019, driven largely by human activities such as agricultural expansion, increased demand for firewood, and urban expansion. Spectral indices derived from the near-infrared, shortwave infrared, and red bands further corroborated the finding that forest cover in the study region (mainly in the southwestern part) substantially decreased from 1986-2019. With respect to forest depletion, the lack of local community awareness has become a key challenge. This problem is attributed to communities prioritizing immediate needs such as fuel and land for agriculture over long-term forest conservation. When the performance of the classification algorithms was compared, the SVM demonstrated strong performance, with an overall accuracy of 0.88 for the Landsat-5 and Landsat-7 sensor data. However, the RF model performed better with the Landsat-8 data, with an overall accuracy of 0.85. To combat ongoing deforestation, the Metekel Zone Administration, in collaboration with the land administration office and other stakeholders, revisited and strengthened existing forest policies and control systems. It is also suggested that community awareness, chiefly among youth, should be enhanced through the strategic expansion of formal and nonformal educational initiatives, which empower the youth as agents of change and promote the dissemination of knowledge throughout the community.

***Keywords**:* Machine learning algorithms, vegetation dynamics, deforestation, Google Earth Engine

3.1.Introduction

Recent empirical research at a global scale, coupled with reports from international organizations, has yielded crucial evidence on the trends of forest cover change worldwide. Using satellite imagery, Song et al. (2018) analyzed global land change from 1982-2016, revealing significant forest cover loss in tropical regions. Their study revealed that the Amazon and Congo basins continue to experience high deforestation rates. Additionally, UN (2021) reported that the year 2020 experienced a significant increase in deforestation, with primary forest loss in the tropics increasing by 12% compared with that in the previous year. The United Nations Food and Agricultural Organization (FAO) also reported that the global forested area suffered a net decline of 178 million hectares between 1990 and 2020, caused primarily by deforestation and forest degradation. However, the rate of forest loss has notably slowed, which is attributed to reduced deforestation in certain countries and increased afforestation efforts and natural forest regrowth in others (FAO, 2020; Keenan et al., 2015; Rotich & Ojwang, 2021). Another report (FAO, 2015) pointed to this positive trend, showing that the global annual rate of net forest loss has significantly decreased, dropping from 7.3 million hectares per year in the 1990s to approximately 3.3 million hectares per year by 2015.

In Africa, deforestation constitutes a profound environmental challenge, with the continent experiencing some of the fastest rates of forest loss globally (UN, 2021; UNDP, 2023), posing severe threats to biodiversity, climate stability, and human well-being (Wassie, 2020b). This issue is particularly acute in East Africa, where recent studies have documented alarming rates of deforestation. Ojoatre et al. (2023) reported that between 1986 and 2017, Mau Forest experienced an annual deforestation rate of -0.82%, whereas Mount Elgon Forest experienced an even higher rate of -1.03%. Aleman et al. (2018) further emphasized the severity of the situation, reporting that East African forests have experienced an almost complete decline, with as much as 93% of forest cover being lost since 2010. Similarly, Ethiopia's forest area has undergone a significant reduction, declining from 35% at the beginning of the 20th century to only 11.4% by 2015 (FAO, 2015). Numerous studies corroborate this trend, indicating a consistent decrease in forest cover across various regions of the country over time (Deribew, 2020; Gebrehiwot, 2013; Negassa et al., 2020).

The growing trend of deforestation is driven by a complex array of factors influencing forest cover change, encompassing both direct and indirect impacts. These drivers are often a blend of anthropogenic factors spanning social, political, economic, demographic, and cultural dimensions and biophysical elements, each contributing to these impacts in various ways (Kogo et al., 2019; Messier et al., 2019). Agricultural expansion, a leading driver of deforestation, primarily impacts tropical regions, with significant forest loss observed in countries such as Brazil and Indonesia (Laurance et al., 2014; Pendrill et al., 2019). This phenomenon is driven by a combination of anthropogenic factors, including economic and political factors, as evidenced by the privatization of forestlands and their conversion to agricultural land, which has intensified deforestation through logging (Alix-Garcia et al., 2016). Curtis et al. (2018) conducted a comprehensive assessment of global forest loss from 2001-2015, identifying agricultural activities, particularly commercial agriculture in tropical regions, as the primary driver of deforestation. This finding highlights the significant role of economic factors, specifically agricultural expansion, in contributing to forest cover change. Chen et al. (2019) investigated the impact of climate variability, a key biophysical factor, on global forest dynamics and reported that climate-induced disturbances, such as droughts and fires, have led to substantial forest cover loss in recent years.

In Ethiopia, the drivers of deforestation are similarly multifaceted and region-specific. In highland areas, anthropogenic factors such as smallholder agriculture and fuel wood collection are predominant, whereas in lowland regions, a combination of economic factors such as large-scale commercial agriculture and infrastructure expansion plays a significant role (Assefa & Bork, 2014). Further compounding these issues, studies in Southwest and northern Ethiopia have identified a mix of anthropogenic and biophysical drivers, including agricultural expansion, excessive grazing, logging, fuel wood collection, and population growth, which are often exacerbated by climate-induced disturbances such as droughts and fires (Gebeyehu et al., 2023; Solomon et al., 2018). In regions where forest resources are crucial to local livelihoods, economic activities such as charcoal production, firewood collection, and farmland expansion further drive forest loss (Belayneh et al., 2020; Betru et al., 2019; Debebe et al., 2023; Yahya et al., 2020). While these drivers all show similar patterns across different regions, their impact vary depending on local livelihood practices.

Widespread deforestation in Ethiopia results in severe ecological consequences, including biodiversity loss, soil erosion, and increased carbon emissions, emphasizing the urgent need for region-specific, sustainable land management strategies to address these complex and diverse challenges (Bessie et al., 2016; Cusack et al., 2016; García-Ruiz, 2010; Hughes, 2017; McNicol et al., 2018; Mengist et al., 2022). The loss of biodiversity, for example, threatens the extinction of various endemic species, which play vital roles in maintaining ecosystem stability and resilience (Madalcho et al., 2022; Schmitt et al., 2009). Soil erosion, exacerbated by deforestation, has not only degraded the land but also contributed to the siltation of rivers and reservoirs, which in turn affects water availability for agriculture and hydroelectric power generation (An et al., 2008; Restrepo et al., 2015; van de Schootbrugge et al., 2020). The increase in carbon emissions due to forest loss further intensifies global climate change, undermining efforts to mitigate its impacts (Lambin et al., 2018). Moreover, the intricate connection between deforestation and land degradation in Ethiopia has profound implications for food security, as the loss of fertile soil diminishes agricultural productivity, leading to food shortages and heightened vulnerability among rural communities (Kassie et al., 2010). The socioeconomic consequences are equally severe, as deforestation disrupts livelihoods dependent on forest resources, exacerbating poverty and driving further environmental degradation in a vicious cycle (Kassa et al., 2017).

As a human-induced factor, rapid deforestation is also attributed to the perception of the community toward the value of forests. Community perceptions of deforestation are influenced by a complex interplay of socioeconomic and cultural factors (Meijaard et al., 2013; Twongyirwe et al., 2018). In Latin America, rural communities often view deforestation as a necessary means for economic development, driven by limited economic opportunities and dependence on forest resources (Adhikari et al., 2004; Moraes et al., 2021). This perception reflects a broader trend where immediate livelihood needs often take precedence over long-term environmental considerations. However, there is a growing shift in perception among younger generations, driven by increased environmental awareness and education, which witnesses the long-term impacts of deforestation on biodiversity and climate (Rousell & Cutter-Mackenzie-Knowles, 2020; Wolf & Moser, 2011). Similar patterns are observed in Africa, where local communities recognize the detrimental effects of deforestation on ecosystems but are frequently compelled by immediate needs such as agriculture and fuel wood collection (Codjoe & Owusu, 2011; Egoh et al., 2012). In East Africa, community perceptions of deforestation are often linked to external pressures, such as logging operations and urban expansion, which overshadow local environmental concerns (Maes & Verbist, 2012). In Ethiopia, these issues are intensified by deep-rooted socioeconomic difficulties, where poverty and restricted access to alternative livelihoods lead many to view forests as immediate sources of income through activities such as logging, charcoal production, and agricultural expansion (Tadesse et al., 2018; Tadesse & Teketay, 2017). Additionally, a lack of trust in collective management and limited perceived benefits from conservation efforts further contribute to the negative attitudes of local communities toward forest management and conservation. The situation is compounded by inadequate environmental education and a lack of visible benefits from conservation, leading many to regard forests as expendable resources rather than crucial ecological assets, which emphasize the need for more inclusive strategies (Gezahegn et al., 2024; Tadesse et al., 2018; Tesfaye et al., 2012).

Like many other parts of Ethiopia, the Metekel Zone has experienced significant changes in land use and cover, with dramatic declines in forest cover largely attributed to a combination of natural and anthropogenic factors. The community in the area relies heavily on forest resources for their livelihoods, engaging in activities such as agricultural expansion, firewood collection, and charcoal production. These activities are shaped by a complex mix of socioeconomic and cultural factors that influence local perceptions of deforestation. The situation is further exacerbated by other anthropogenic drivers, including large-scale farm investments, demographic expansion, and both formal and informal settlements, all of which have contributed to substantial changes in forest cover. The geographical position of the Metekel Zone within the Tana Beles basin, which accounts for 60% of the flow to the Abay River (Abtew & Dessu, 2019), adds another layer of complexity. The region is home to significant infrastructure projects, including the Great Ethiopian Renaissance Dam (GERD), which, while vital to national development, has unintentionally increased pressure on forest resources. Additionally, forest degradation, exacerbated by climate change, has increased the sediment load in the river basin, further stressing the ecosystem and diminishing the broader ecosystem services in the region. Together, these factors illustrate how the challenges faced in the Metekel Zone mirror those at the national level while also witnessing the unique pressures specific to this area.

Despite these clear environmental impacts, there is a significant research gap regarding the spatiotemporal dynamics of land use/cover changes in the Metekel Zone, as well as their broader consequences. Additionally, although national efforts have been made to engage local communities in collaborative forest management initiatives, there remains a notable lack of data concerning local community awareness of the underlying causes and potential solutions for forest degradation in the area. This emphasizes the need for a multidisciplinary approach that combines the Google Earth Engine (GEE) method with participatory and community engagement approaches to develop effective management and mitigation strategies (Amani et al., 2020; Becker et al., 2021; Defries et al., 2010; Hansen & Loveland, 2012; Yang et al., 2022).

The use of the GEE, a scalable, cloud-based platform that enables efficient processing of large satellite datasets, is a promising approach for accurately quantifying and analyzing forest cover changes over time. GEE offers integrated tools for preprocessing tasks, such as cloud masking and image compositing, although it requires familiarity with programming and has limited customization options (Gorelick et al., 2017). When combined with machine learning algorithms such as random forest (RF) and support vector machine (SVM), GEE demonstrates superior accuracy in forest classification compared with traditional maximum likelihood methods (Noi Phan et al., 2020). RF is particularly robust in handling noisy data and providing feature importance, although it can be computationally intensive and less interpretable (Breiman, 2001). SVMs, on the other hand, are highly effective in high-dimensional spaces and excel at handling both linear and nonlinear problems through kernel functions, despite requiring careful parameter tuning and facing challenges with very large datasets (Cortes et al., 1995).

Globally, the combination of machine learning and GEE has been recognized for its effectiveness in forest cover mapping over time (Chowdhury, 2024; Dagne et al., 2023). However, studies leveraging GEE for forest cover assessment in Ethiopia, particularly in the Metekel Zone, are scarce. Previous studies in Ethiopia, such as those by Sisay et al. (2020) in Yabello Forest, Mengist et al. (2022) in Kaffa, and Babiso et al. (2020) in Duguna Fango, southern Ethiopia, utilized conventional maximum likelihood classification methods to reveal significant forest cover changes attributed to recurrent droughts, fuel wood extraction, and population growth. These studies highlight the need for more advanced tools such as GEE to enhance forest cover analysis.

To address these gaps, the present study utilized the GEE cloud computing platform in conjunction with RF and SVM machine learning algorithms to analyze forest cover changes in the Metekel Zone over a 33-year period from 1986-2019. This study focused on investigating spatiotemporal changes in forest cover, assessing the effectiveness of the RF and SVM algorithms on the GEE platform for land use/cover classification, and identifying the drivers and impacts of forest cover changes in the zone. Additionally, it explored the local community's perspectives on these changes, examining their causes, effects, and potential solutions for addressing forest cover degradation.

This research significantly contributes to the development of targeted conservation strategies by identifying key drivers of forest cover change. It also provides essential insights for designing interventions that are associated with local needs, ensuring more effective and participatory conservation efforts. Moreover, the findings offer valuable support for policy development, clarifying the primary drivers of forest loss and their impacts, thereby guiding policymakers in creating evidence-based strategies for sustainable land use and forest management.

3.2.Methodology

3.2.1. Study area

The investigation was conducted in the Metekel Zone of the Benishangul Gumuz Regional State in Northwest Ethiopia. Geographically, the Zone is located between 9^{0} 55' and 12^{0} $0^{'}$ North latitude and 34^{0} $55^{'}$ and 36^{0} $55^{'}$ East longitude (Figure 3.1). The study area covers an estimated area of 22,028 square kilometers. Gumuz, the predominant ethnic group, inhabits the lowlands, while higher escarpments are home to various ethnic groups. The soil types include chromic Vertisols and Eutric Nitosols, with vertisols accounting for 33% and nitosols accounting for 47% of the total area (Tamene & Haile, 2021). The climate ranges from hot to warm moist lowlands, characterized by an unimodal rainfall pattern from March to September, with a peak in July and August (Wagino & Amanuel, 2021).

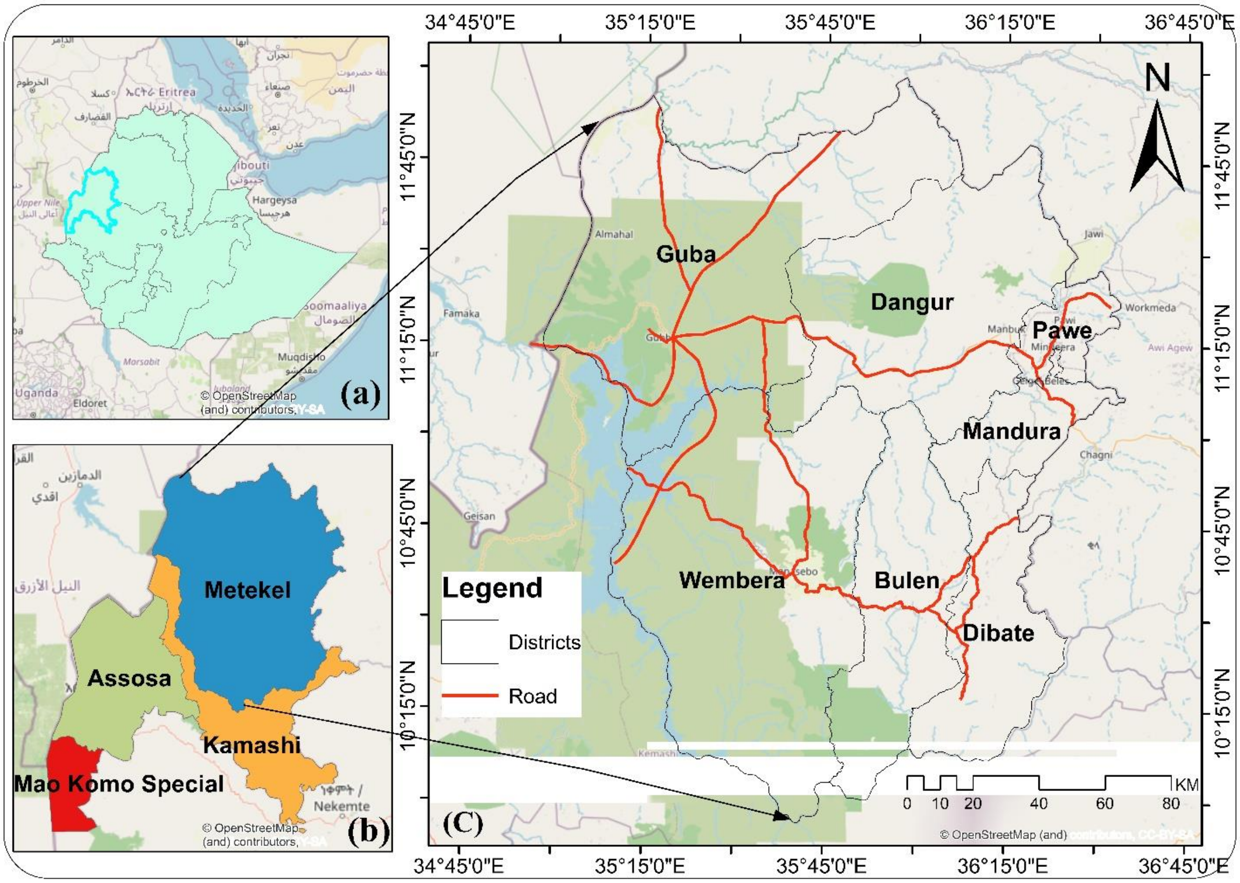


Figure 3.1: Location map of the study area developed from (CSA, 2024) using ArcMap

3.3.Data source

3.3.1. Remote sensing data

To investigate alterations in land use/cover within the Metekel zone, three multispectral satellite images were obtained for 1986, 2002, and 2019, as outlined in Table 3.1. The year 1986 is chosen as the initial year (baseline) for land use/cover change analysis because severe drought and famine affected Ethiopia from 1984 to 1985. Additionally, it was the time when the government planned the largest resettlement program, and those victims were moved into the Metekel zone, where vacant areas and scarce settlements with fertile soil and ample water resources exist. On the other hand, large farm investments coupled with additional spontaneous settlements, charcoal production, firewood collection, and forest fires took place from the middle of 2002 onward. Due to these realities on the ground, 2002 was taken as a benchmark. The year 2019 was considered the final year of analysis and represents the most recent period for which satellite imagery and verified land use/land cover data were available for the Metekel Zone.

Therefore, the analysis of forest cover change in this study is limited to the 1989–2019 period, and conclusions are drawn strictly based on data within this timeframe.

Table 3.1: Satellite data sources of the study area used to analyze land use/cover changes

Sensor	Landsat	Spatial Resolution	Spectral Resolution	Year	Source
Landsat MSS[1]	Landsat 5	30 m	7 bands	1986	www.glovis.usgs.gov
Landsat ETM+[2]	Landsat 7	30 m	7 bands	2002	www.glovis.usgs.gov
Landsat OLI[3]	Landsat 8	30 m	11 bands	2019	www.glovis.usgs.gov

3.3.2. Focus Group Discussion (FGD)

FGDs were included in the data collection process to supplement and verify information gathered from satellite data. The study area encompasses seven districts: Bullen, Dibate, Dangur, Guba, Mandura, Pawe, and Wembera. A purposive sampling method was used to select three FGDs from four districts on the basis of consultation with the Metekel Zone Administration and experts from the agricultural, rural development, and forest and land resource departments. The districts of Guba, Dangur, Pawe, and Mandura were chosen because they are presumed to have higher levels of human interference affecting land use and forest cover than other areas in the zone. The selection of FGDs for this study was conducted via purposive sampling, in alignment with established literature on optimal participant numbers for effective discussions. According to Fern (1982), an ideal range of six to eight participants is often sufficient to facilitate meaningful dialog. In our study, each of the Pawe and Mandura districts hosted one FGD, each with six participants. Additionally, Guba and Dangur districts conducted a joint FGD, featuring three participants from each district, resulting in a total of six participants for that session. This structure allowed for a cumulative total of 18 participants across three focus group discussions. This diverse representation facilitates a rich array of insights; however, it is acknowledged that a single session may not thoroughly cover all the complexities of multifaceted topics (Scheelbeek

[1] MSS: Multispectral Scanning System
[2] ETM+: Enhanced Thematic Mapper
[3] OLI: Operational Land Imager

et al., 2020). The participants in the FGDs were carefully selected and included *kebele*[4] leaders, experts from natural resources and agriculture offices, heads of household, land administration specialists at the zonal and district levels, development agents, and representatives from nongovernmental organizations. The discussion points for qualitative data collection are presented in Table 3.2.

3.3.3. Key Informant Interview (KII)

The researchers conducted in-depth interviews with nine purposively selected key informants. The selection was strategically designed to capture a wide array of perspectives and expertise relevant to the research topic based on the discussion points (Appendix 1). Two *kebele*[4] leaders were included for their critical insights into community dynamics, governance, and resource allocation, serving as vital links between the community and higher levels of government. Additionally, two experts from the district's Natural Resources and Agricultural Office were selected to provide specialized knowledge on agricultural practices and natural resource management, which is essential for understanding the technical aspects affecting local livelihoods and environmental sustainability. The inclusion of two heads of household allows for direct insights into the lived experiences and challenges faced by community members impacted by policies and practices, whereas a development agent contributes real-time information on the effectiveness of agricultural programs and community engagement initiatives. Individual elders were chosen to provide a historical and cultural context, shedding light on traditional practices and the impacts of change over time, thereby enriching the study's understanding of community resilience. Finally, a worker from a nongovernmental organization offers valuable perspectives on external interventions, partnerships, and collaborative dynamics in improving community welfare.

Table 3.2: Themes of discussion points for qualitative data collection

Theme/Discussion Point	Main Issues Explored	Description
Causes of Deforestation	Agricultural expansion, illegal logging, charcoal production, population growth	Examines the drivers behind deforestation, focusing on human activities and socioeconomic factors

[4] *Kebele* is the smallest administrative unit in Ethiopia.

Consequences of Deforestation	Soil degradation, loss of biodiversity, changes in microclimate, water scarcity	Focuses on the impact of deforestation on the environment and community livelihoods
Mitigation Measures	Reforestation efforts, community-based forest management, policy enforcement	Identifies existing and potential strategies for addressing deforestation and promoting conservation
Community Perception of Forest Change	Participants' understanding and observations of changes in forest cover over time Awareness, attitudes, and beliefs about forest conservation and sustainability	Explores the community's understanding of forest cover change and their role in conservation efforts
Historical and Cultural Context	Traditional practices, changes over time, intergenerational knowledge	Provides a historical perspective on how forest management practices and perceptions have evolved
Challenges in Forest Conservation	Obstacles faced by the community in forest conservation efforts	Identify obstacles faced by the community in forest conservation efforts
Recommendations for Forest Management	Suggestions from participants on improving forest management and conservation efforts	provides suggestions from participants on improving forest management and conservation efforts

3.3.4. Validation points

Validation points were collected from the Google Earth platform via the time slider feature for the years 1986, 2002, and 2019, with 153, 159, and 300 ground control points (GCPs) collected, respectively (Table 3.3). These GCPs were categorized into six land use types: settlements, forests, shrublands, grasslands, agricultural areas, and water bodies. The settlement GCPs were gathered from built-up areas and road networks within various towns, whereas the forest GCPs were gathered from densely vegetated areas. Shrubland GCPs were obtained from areas characterized by short trees in mountainous regions, and grassland GCPs were sampled from grassy areas within both shrubland and forest zones. Agricultural GCPs were collected from individual farmlands and large investment farms, and waterbody GCPs were referenced to the Blue Nile River.

3.3.5. Training points

In this research, training points, or regions of interest (ROIs), were collected for three different years to classify Landsat images into various land use/cover classes. For the year 1986, a total of 395 ROI points were collected and distributed as follows: 50 for settlements, 75 for forests, 80 for shrublands, 90 for grasslands, 40 for water bodies, and 60 for agriculture. In 2002, a total of 343 ROI points were gathered: 65 for settlements, 78 for forests, 56 for shrublands, 46 for grasslands, 55 for water bodies, and 43 for agriculture. By 2019, the number of ROI points had increased to 600, with 80 for settlements, 120 for forests, 70 for shrublands, 100 for grasslands, 80 for water bodies, and 150 for agriculture. These ROIs were essential for training the classification models, with their numbers varying on the basis of the discernibility of land cover classes in the images.

Table 3.3: Description of the spatial sampling framework

S. N	Land use/cover	1986 Region of interest	Ground control points	2002 Region of interest	Ground control points	2019 Region of interest	Ground control points	Class Description
1	Settlement	50	25	65	27	80	45	Urban zones are characterized by compact human-built structures and road networks.
2	Forest	75	22	78	20	120	61	Thickly forested areas exhibit a dense concentration of trees.
3	Shrubland	80	34	56	35	70	43	Regions are predominated by shrub area and low-height trees on the fringes of urban areas.
4	Grassland	90	32	46	36	100	47	Open spaces are predominantly covered with grass vegetation.
5	Waterbody	40	20	55	19	80	42	Water bodies, such as reservoirs, lakes, and rivers.
6	Agriculture	60	20	43	22	150	62	Cultivation land and large investment areas
Total		395	153	343	159	600	300	

3.4.Methods of data processing and analysis

3.4.1. Data Preprocessing

Landsat datasets obtained from the USGS through the GEE application programming interface (API) were used in this study. Using the JavaScript API, all the Landsat images were collected, analyzed, and mosaicked (Figure 3.2). Initially, sample datasets for training and validation, along with the boundary of the Metekel Zone, were uploaded to the GEE platform. Essential preprocessing steps were carried out, including cloud masking to obtain cloud-free images, data filtering by specifying dates, mosaicking to combine images from different path/row acquisitions, and clipping to the extent of the study area. For effective land cover mapping with Landsat data, imagery with less than 10% cloud cover is recommended (Sano et al., 2007). In this research, the GEE cloud masking tool was employed to ensure that only Landsat images with less than 10% cloud cover were used.

3.4.1. Feature selection

For land use/cover classification, specific spectral bands were selected from each Landsat dataset (Landsat-5, Landsat-7, and Landsat-8). For the 1986 and 2002 data from Landsat 5 and Landsat 7, bands 4, 3, and 2 (red, green, and blue) were chosen because of their relevance for land use/cover classification. For the 2019 data from Landsat 8, the near-infrared (NIR) band replaced the red band, resulting in the selection of bands 5, 4, and 3 (NIR, red, and blue). These selected bands were composited to create a false-color combination of the Landsat data. Training points for classification were then extracted from the composited images.

3.4.1. Land use/cover classification

After preprocessing and feature selection, land use/cover classification was carried out to categorize the satellite images into distinct classes. Machine learning algorithms, specifically RF and SVM, were employed on the GEE platform to perform this classification. These algorithms were chosen for their robustness and accuracy in handling large datasets and complex classification tasks (Breiman, 2001; Cutler, 2012; Goldstein et al., 2010). The process involved training the models with the collected ROI and applying the trained models to classify the images into various land use/cover classes.

3.4.1. Spectral indices derivation

After preprocessing the Landsat imagery, spectral indices were derived in GEE platform. GEE enables the generation of key spectral indices such as the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Normalized Difference Water Index (NDWI), and Leaf Area Index (LAI) through Python scripts. These indices were computed for the years 1986, 2002, and 2016 within the GEE and subsequently mapped via ArcGIS 10.7.1. For the years 1986 and 2002, bands 5, 4, and 3 were used as the SWIR, NIR, and Red bands, respectively. In contrast, for 2019, bands 7, 5, and 4 were utilized as the SWIR, NIR, and Red bands, respectively, to account for the different sensor configurations between Landsat 7 and Landsat 8.

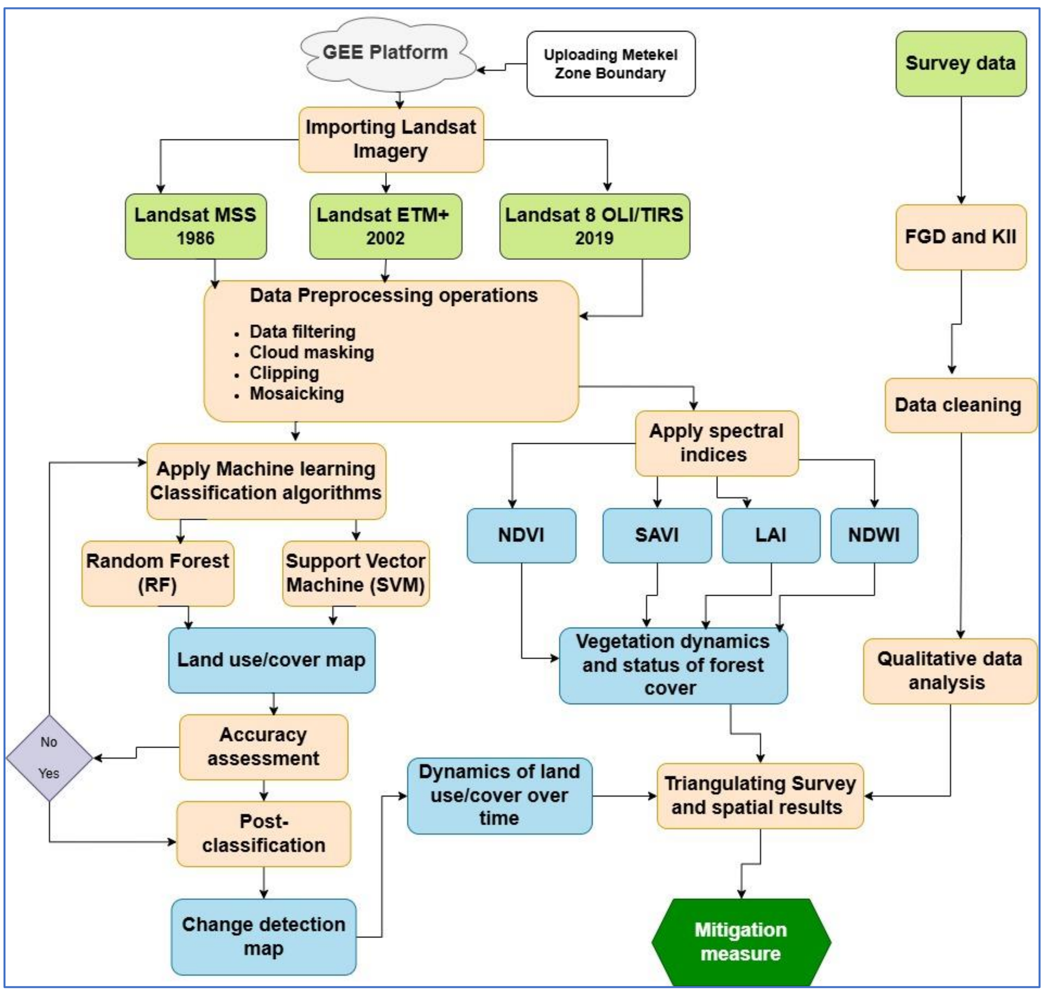


Figure 3.2: Methodological flowchart that depicts the analysis of land use/cover on the Google Earth Engine platform and survey data from focus group discussions and key informant interviews.

3.4.2. Change detection

Following the independent classification of the entire Metekel zone for the years 1986, 2002, and 2019, the subsequent step involved conducting a land use/cover change detection analysis. This was achieved through post-classification processes, overlaying the classified satellite imagery, and utilizing the image differencing technique available on the GEE platform. Change detection analysis was conducted at 16 and 17-year intervals. The first post-classification analysis compared the classified image from 1986 with that from 2002, whereas the second analysis focused on comparing the classified image from 2002 with that from 2019. The last post-classification analysis involved differencing the classified image of 1986 from that of 2019. Ultimately, aesthetic land use/cover maps were created via plausible standards on the GEE mapping platform and ArcGIS 10.7.1.

3.4.3. Qualitative data analysis

The qualitative data gathered from KII with purposively selected key informants were analyzed thematically. In this study, thematic analysis was employed to extract insights from KII and FGD regarding the drivers, consequences, and mitigation measures associated with deforestation in the Metekel Zone. Through thematic analysis, we systematically examined the qualitative data to identify recurring patterns, concepts, and ideas related to deforestation, enabling us to develop a thorough comprehension of the qualitative aspects pertaining to the phenomenon within the study area. Additionally, the thematic content analysis of FGDs complemented and validated information obtained from the classification results, providing a more holistic view of deforestation dynamics in the region.

3.4.4. Classification algorithms

The RF technique, renowned for its exceptional classification outcomes, involves generating random features, constructing numerous regression trees, and classifying data by utilizing the predictive power of each regression tree (Breiman, 2001). RF classifiers are widely recognized for their robustness, scalability, and capacity to manage high-dimensional data with intricate interrelationships (Cutler, 2012). The SVM classifier is also utilized in land use/cover classification because of its ability to assess the proportional significance of each target feature class (Cortes et al., 1995). SVM classifiers excel in handling nonlinear data and have a solid theoretical foundation, making them suitable for various classification tasks (D.-X. Zhou & Jetter, 2006). The decision to utilize the RF and SVM classifiers in this study is justified by their demonstrated effectiveness in handling complex datasets, measuring class relevance, and producing accurate classification results. While other classification algorithms exist, RFs and SVMs offer distinct advantages in terms of performance, scalability, and theoretical underpinnings, making them suitable choices for land use/cover classification tasks (Breiman, 2001; Cortes et al., 1995).

Random Forest (RF)

The RF encoder operates by constructing a combination of regression trees during training (Sahin, 2020). This ensemble approach enhances robustness and accuracy by combining the predictions of multiple individual decision trees (Shelestov et al., 2017). The training process begins by randomly selecting bootstrap samples from the dataset, allowing for variations in the training sets. For each bootstrap sample, a decision tree is grown using a random subset of features out of the total number of features available. These trees are constructed through recursive binary splitting of the data on the basis of feature thresholds that optimize impurity reduction, typically measured via metrics such as Gini impurity or entropy (Cutler, 2012; Goldstein et al., 2010). This process is repeated to grow a forest of decision trees. To classify a new sample, it is passed through all decision trees, and for classification tasks, the mode (most frequent class) of the predictions across the ensemble is considered the final prediction, as indicated in Eq. 3-1. The formulation for the RF encapsulates these principles, contributing to its effectiveness in various machine learning applications.

$$y_{RF}(x) = Mode(y^1_{tree}(x), y^2_{tree}(x), \ldots\ldots y^n_{tree}(x)) \qquad \text{Equation 3.1}$$

where $y_{RF}(x)$ is the random forest prediction for sample x and where $y^i_{tree}(x)$ is the prediction of the i th decision tree for sample x.

Support Vector Machine (SVM)

The SVM is an overwhelming algorithm used for classification tasks in remote sensing and other fields (Maulik & Chakraborty, 2017). SVM operates by finding the optimal surface that best distinguishes between subclasses. It aims to maximize the difference between the nearest data points of different features, thereby promoting robustness and generalization to unseen data (Muñoz-Marí et al., 2010). Assume initial data {(x1, y1), (x2, y2) ..., (xn, yn)}, with xi denoting attribute vectors and yi indicating class names (either -1 or 1 for binary classification). For linearly separable datasets (Eq. 3-2 and Eq. 3-3):

$$Minimize \frac{1}{2}\|w\|^2 \qquad \text{Equation 3.2}$$

subject to:

$$y_i(w * x_i + b) \geq 1 \ \ for\ all\ i \qquad \text{Equation 3.3}$$

The SVM employs the kernel trick to transform nonlinearly separable datasets into a higher-dimensional space that allows for linear separation (Eq. 3-4 and Eq. 3-5). The optimization problem becomes:

$$Minimize \frac{1}{2}\|w\|^2 + C\sum_{i}^{n} \xi_i \qquad \text{Equation 3.4}$$

subject to:

$$y_i(w * \phi(x_i) + b) \geq 1 - \xi_i \qquad \text{Equation 3.5}$$

The value of the regularization parameter is C, and the kernel algorithm is represented by (ξ_i), and the slack factor is (- ξ_i) allows for misclassification. Assuming that the ideal hyperplane constants w and b are identified, the decision criterion for categorizing a fresh sample x is as follows (Eq. 3-6):

$$f(x) = sign(w * \ \phi(x) + b) \qquad \text{Equation 3.6}$$

SVMs are famous for their ability to handle multidimensional data and intricate connections, making them appropriate for diverse classification problems, including land cover classification in remote sensing fields.

3.4.5. Accuracy assessments

Overall accuracy (OA): OA is an evaluation of the number of properly identified samples across the whole dataset (Pal et al., 2013). It provides an overall assessment of the classification performance (Eq. 3-7). In the GEE, computing the OA involves the use of the ‘error matrix’ object, which is obtained from the confusion matrix. By summing the diagonal elements of this matrix, we extracted the aggregate amount of correctly classified samples for all features. Segmenting this total by the overall number of samples in the dataset provides the proportion of correctly classified samples, which represents the OA.

$$OA = \frac{Sum\ of\ correctly\ classified\ pixel\ in\ the\ diagonal}{Total\ number\ of\ pixel} * 100 \quad \text{Equation 3.7}$$

Producer's accuracy (PA): In the GEE, computing the PA involves the use of the 'error matrix' object obtained from the confusion matrix, which contains information about correctly classified and misclassified objects for each class (Becker et al., 2021). To calculate the PA, the number of correctly classified pixels is divided by the sum of the row totals and multiplied by 100 (Eq. 3-8).

$$PA = \frac{Correctly\ classified\ pixel}{Row\ total} * 100 \quad \text{Equation 3.8}$$

User accuracy (UA): The UA is another crucial evaluation metric used in the verification of classification tasks. It determines the proportion of correctly categorized samples for a certain class among all samples classified as that class by the classifier. To calculate the UA for a specific class, the number of successfully categorized pixels in each column (true positives) and the total number of pixels in a column corresponding to that class from the confusion matrix are multiplied by 100 (Eq. 3-9).

$$UA = \frac{Correctly\ classified\ pixel}{Column\ total} * 100 \quad \text{Equation 3.9}$$

F score: The F score is a comprehensive measure that integrates both recall and accuracy, making it especially useful when dealing with imbalanced datasets in image classification tasks (Solórzano et al., 2021). By taking the harmonic range of accuracy as well as recall, the F score accurately categorizes positive instances (precision) and its ability to capture all positive instances from the dataset. This balanced approach ensures that the F score remains robust in scenarios where classes are unevenly distributed or where certain classes are of particular interest (Eq. 3-10).

$$Fscore = \frac{2(Precision * Recall)}{Precision + Recall} \quad \text{Equation 3.10}$$

Kappa Coefficient (K): The kappa statistic is an arithmetical evaluation of interrater consensus that takes into account chance. It compares the observed classification accuracy with the accuracy that is expected by chance alone. The formula for the kappa coefficient (κ) is given in Eq. 3-11:

$$K = \frac{OA - EA}{1 - EX} \qquad \text{Equation 3.11}$$

where OA is the proportion of appropriately identified samples across our entire dataset, and the expected accuracy (EA) is the expected proportion of agreement by chance. In GEE, we compute the kappa coefficient by first calculating the OA and then determining the EA on the basis of the minimal likelihood of the confusion array.

3.4.6. Spectral indices algorithms

Normalized difference vegetation index (NDVI)

The NDVI is widely recognized for monitoring vegetation health and cover. It measures the difference between the near-infrared (NIR) and red (R) bands, which are sensitive to the chlorophyll content in plants. The NDVI is highly effective in distinguishing between vegetated and non-vegetated areas, making it a robust tool for monitoring forest cover changes (Pettorelli et al., 2005). It provides critical information about vegetation health, vigor, and biomass, which are essential for assessing forest degradation (Ferreira et al., 2010). The NDVI was selected for this research because of its proven effectiveness in detecting changes in vegetation health and forest cover over time, which is particularly useful for large-scale assessments and long-term monitoring (Eq. 3-12).

$$NDVI = \frac{NIR - R}{NIR + R} \qquad \text{Equation 3.12}$$

where NIR is the near-infrared band and R is the red band.

Soil-Adjusted Vegetation Index (SAVI)

The SAVI is an adjusted form of the NDVI designed to reduce the influence of soil brightness on the vegetation signal, making it more reliable in areas with sparse vegetation. The SAVI minimizes the impact of soil reflectance, thereby offering more accurate vegetation detection in regions with low plant density (Huete, 1988). It is particularly useful in arid and semiarid areas where the soil background significantly influences the vegetation signal (Qi et al., 1994). The SAVI was chosen for its ability to provide more accurate vegetation information in areas with sparse or patchy forest cover, which is relevant for regions experiencing deforestation or forest degradation (Eq. 3-13).

$$SAVI = \frac{NIR - R}{NIR + R + L} * (1 + L) \qquad \text{Equation 3.13}$$

where L is a soil adjustment factor (L = 0.5).

Leaf area index (LAI)

The LAI measures the total leaf area per unit ground area, indicating canopy density and forest structure. LAI provides vital information about the vertical structure of forests, including canopy cover and leaf density, which are important for understanding forest health and productivity (Asner et al., 2003). It is also useful in estimating biomass and carbon storage, key factors in forest management, and conservation efforts (Myneni et al., 2002). The LAI was included in this research to assess the structural characteristics of forests, particularly canopy density and leaf biomass, which are crucial for understanding the impacts of land use changes on forest ecosystems. The equation to drive the LAI for this research work is adapted from (Myneni et al., 2002; Turner et al., 1989). The LAI is calculated using Eq. 3-14.

$$LAI = \frac{-\ln\left(\frac{NDVI_{max} - NDVI}{NDVI_{max} - NDVI_{min}}\right)}{K} \qquad \text{Equation 3.14}$$

where NDVImax is the maximum NDVI value, NDVImin is the minimum NDVI value and K is the extinction coefficient, an empirical parameter that depends on the vegetation type.

Normalized difference water index (NDWI)

The NDWI is designed to detect the water content of vegetation, which is a critical factor in assessing forest health and the impacts of drought or other stress factors. The NDWI is effective in monitoring vegetation water content, making it useful for detecting forest stress and degradation, particularly in areas affected by drought (Gao, 1996). Additionally, it helps identify water bodies and wetland areas within forested regions, which are crucial for ecosystem functioning (McFeeters, 1996). The NDWI was selected for its ability to provide insights into the water content of vegetation, which is essential for monitoring forest health and is calculated using Eq. 3-15.

$$NDWI = \frac{NIR - SWIR}{NIR - SWIR} \quad \text{Equation 3.15}$$

Where SWIR is short-wave infrared

3.5.Results

3.5.1. Spatiotemporal dynamics of land use/cover change

The land use/cover maps in the study were generated using SVM and RF classification algorithms, each of which was chosen for its specific strengths with different types of satellite data. The maps shown in Figure 3-3a and Figure 3-3b were created using the SVM classification method. This approach was selected because SVM demonstrated superior classification performance against ground observations, particularly when working with MSS and ETM+ data, as highlighted in Table 3-5. Owing to its higher classification accuracy, the SVM-generated land cover maps were used for the years 1986 and 2002, ensuring more reliable results for those periods. For the final year of analysis, 2019, a land use/cover map was generated using an RF algorithm (Figure 3.3c). This choice was made because RF showed higher accuracy in classifying OLI data, as detailed in Table 3-6. Given its better performance with the data available for 2019, the RF-generated map was selected for that year.

A significant trend was the dramatic decline in forest cover. In 1986, forests constituted a substantial 51.37% of the total land area. However, by 2019, this figure had plummeted to 17.20% (Table 3-4). Initially, concentrated in the southern, northwestern, and northeastern regions in 1986, forest cover underwent substantial changes. The northwestern area experienced severe degradation by 2002, while the southern and northeastern portions retained more forest cover but also exhibited a decline (Figure 3-3). This trend continued, with a further reduction and heightened degradation in the remaining forest areas of the southern and northeastern parts by 2019. Concurrently, agricultural land experienced significant expansion, increasing from 22.34% in 1986 to 48.12% in 2019 (Table 3-4). Spatially, this growth was initially modest in the eastern part of the study area in 1986. However, by 2002, agriculture had expanded considerably into the northeastern, northern, and eastern regions. This trend persisted, culminating in extensive agricultural land, particularly in the eastern part of the study region, by 2019, which was largely driven by large-scale investment farms (Figure 3.3).

During the FGD, the participants experienced a substantial loss in forest cover in the research area over the past 33 years. They revealed that the reduction in forested areas is attributed to several factors, including the expansion of arable land, increased demand for firewood, the rising population, charcoal production activities, and the proliferation of wetlands, all of which contribute to significant environmental challenges. The KII participants also supported this response. A 63-year-old individual contended that Pawe (one of the study region's districts), the following.

> *At the beginning of the resettlement program (1986), the area was entirely covered with dense bamboo and various trees, such as acacia and other broad-leaved varieties. During that period, the prevalence of thick forests acted as a protective barrier against floods and erosion, contributing to fertile soil. The abundant vegetation allowed substantial crop yields from even small plots of land, and the flourishing ecosystem facilitated animal breeding. Consequently, an abundance of livestock provided a regular supply of milk, meat, and honey, ensuring that hunger was not a prevalent concern. However, the present scenario paints a stark contrast, as the insufficient means of livelihood have compelled the community to rely on the forest not only for sustenance but also as a source of income and daily survival.*

According to KII, Dangur, and Guba, *woreda*[5] investment is a significant indicator of tangible evidence of forest loss in the Metekel Zone. This degradation is notably attributed to the activities of large investors over the past three decades who have acquired substantial land holdings. These investors have converted once-forested areas into agricultural land, contributing to diminishing forest cover. Furthermore, the situation is exacerbated by an influx of settlers from neighboring areas who arrive in search of available agricultural lands. This influx intensifies the pressure on forests as more land is cleared for settlement and farming activities.

One of the key challenges in addressing and mitigating the decline in forest cover is the lack of awareness within the local community regarding the severity of forest depletion. The absence of knowledge or understanding about the ecological consequences of deforestation makes it difficult to mobilize community efforts toward sustainable land use practices. Raising awareness about the importance of forest conservation, the impacts of deforestation on the environment, and potential solutions becomes crucial in fostering a collective commitment to retain and oversee the remaining forest resources in an environmentally friendly way. This lack of

[5] *Woreda* is an administrative division in Ethiopia, equivalent to a district.

awareness compounds the challenges faced by authorities and environmental advocates in their efforts to curb and reverse forest cover loss.

Shrubland and grassland cover also underwent notable changes within the Metekel Zone. Shrubland expanded from 24.70% in 1986 to 27.18% in 2019. The shrubland initially concentrated in the northwestern region and interspersed with forest significantly increased in this area by 2002 following forest degradation. This trend continued, with shrubland spreading to the central and northern parts of the study area by 2019. Concurrently, the grassland area increased from 1.40% to 2.82% between 1986 and 2019. Initially, in the southern part adjacent to mountainous forest areas, grassland expanded southward and followed the receding forest boundary by 2002. This expansion persisted, with grasslands becoming more prevalent in the central region by 2019.

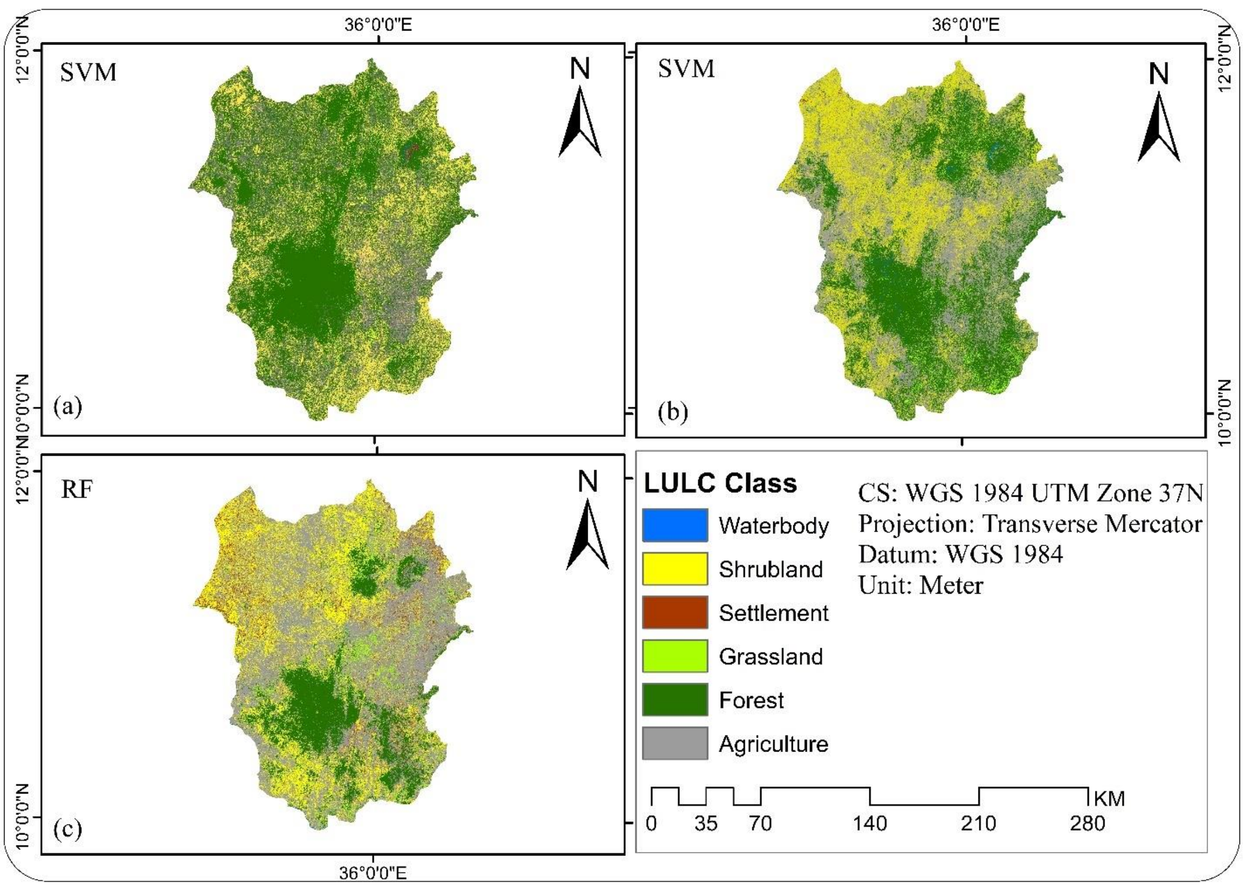


Fig. 3.3: Land use/cover over the past 33 years; support vector machine classification in 1986 (a) and 2002 (b), random forest classification in 2019 (c).

Unusually, the waterbody percentage experienced a notable surge, rising from 0.07% in 1986 to 0.28% in 2019. This unusual increase can be attributed to specific changes in the landscape, particularly concerning the Beles and Blue Nile Rivers. In 1986 and 2002, these rivers were concealed by dense forest cover, rendering their spectral signatures undetectable. However, by 2019, there was a discernible shift in the environment as the forest surrounding the rivers had significantly diminished (Table 3.4). Consequently, the spectral signature of the waterbody became fully evident, leading to a substantial increase in the waterbody percentage compared with that in previous years.

According to the KII, more than 80% of the region is characterized by extensive forests and grasslands. Approximately 33 years ago, the area was rich in wild food, featuring a diverse range of plant species. However, the current scenario reveals a significant decline in the natural habitat. Many once-prevalent and valuable plant species are now endangered or have become extinct due to rampant deforestation. The transformation of forests, woodlands, and grasslands into human-made areas has been a prominent trend, contributing to the loss of biodiversity.

The KII emphasizes the critical threat posed to the survival of notable species of plants and animals due to overexploitation. The overexploitation of natural resources, driven by human activities such as deforestation, poses a serious challenge to maintaining the ecological balance in the region. The conversion of natural habitats into man-made landscapes not only diminishes the diversity of plant species but also impacts the entire ecosystem, potentially leading to the decline or extinction of various animal species dependent on these habitats. This highlights the urgent need for conservation efforts, environmentally friendly land utilization strategies, and increased awareness to resolve the consequences of deforestation and overexploitation, ensuring the preservation of valuable plant and animal species in the area.

The findings from the spatial analysis confirmed the alarming trends of progressive deforestation and forest degradation throughout the study region from 1986-2019. In 1986, the analysis revealed extensive pristine forests in the southeastern, northern, and central areas, whereas signs of agricultural expansion were noticeable along the eastern edge (Figure 3.3). By 2002, there was a noticeable increase in agricultural activities expanding in all directions, leading to the large-scale conversion of forests, even in areas that were previously untouched. This trend persisted through 2019, illustrating a significant loss of forest cover accompanied by the continual expansion of settlements and farmland.

Table 3.4: Percentage and area share of each land use/cover type in the Metekel Zone (1986--2019)

	1986		2002		2019		1986-2019	
Class	Ha	%	Ha	%	Ha	%	Ha	%
Forest	1323980	51.37	885065.4	34.34	443267.8	17.2	-880712	-34.17
Agriculture	575840	22.34	913617.5	35.45	1240346	48.12	664506.1	25.78
Settlement	3187.71	0.12	3969.09	0.15	113368.9	4.4	110181.2	4.27
Shrubland	636534.6	24.7	696112.8	27.01	700539.7	27.18	64005.03	2.48
Grassland	36128.16	1.4	64136.79	2.49	72614.43	2.82	36486.27	1.42
Waterbody	1767.42	0.07	14535.81	0.56	7300.62	0.28	5533.2	0.21
Total	2577437	100	2577437	100	2577437	100		

Table 3.5: Land use/cover change detection matrix between 1986 and 2019 in Hectare

		LULC in 2019						
		Agriculture	Forest	Grassland	Settlement	Shrubland	Waterbody	Grand Total
LULC in 1986	Agriculture	1026109.43	2.79	1956.25	1645.58	28139.25	0.00	1057853.30
	Forest	296770.83	188249.51	3124.37	1921.12	39134.49	89.60	529289.93
	Grassland	996.59	8.88	22244.12	1334.09	166662.15	0.00	191245.83
	Settlement	0.00	0.00	0.00	2.80	0.00	0.00	2.80
	Shrubland	186681.49	72.07	2803.33	3101.19	606303.57	0.00	798961.66
	Waterbody	0.75	0.93	0.01	0.16	0.34	81.77	83.95
	Grand Total	1510559.09	188334.19	30128.08	8004.94	840239.79	171.37	2577437.46

The spatial analysis aligns with the observations made during the KII, which reported a decline in forest cover over the past 33 years. The KIIs highlighted various factors contributing to this decline, including large-scale investments, agricultural expansion, the rise in population, and a dearth of consciousness within the local community. The spatial analysis not only confirms but also visually illustrates the transformation of the landscape over the years, establishing a thorough understanding of the extent of deforestation and degradation observed in the study region. This alignment between spatial analysis and on-the-ground interviews underscores the urgency for conservation efforts and sustainable land management practices to lessen the adverse effects of these trends on the local ecosystem and communities.

3.5.2. LULC transformations

A confusion matrix was used to assess the transformation of land use/cover in the study region from 1986--2019. A significant trend observed over the last three decades has been the substantial conversion of forestland into agricultural areas, amounting to 296,770.83 hectares. This shift underscores the role of agricultural expansion as a primary factor contributing to the degradation of forest areas. Additionally, the forested areas underwent conversion into grasslands, settlements, shrublands, and water bodies, comprising 3,124.37, 1,921.12, 39,124.49, and 89.60 hectares, respectively. Conversely, a noteworthy transformation involved the conversion of 186,681.49 hectares of shrubland into agricultural land. Furthermore, substantial portions of shrubland and grassland were transformed into settlement areas, accounting for 1,334.09 and 3,101.19 hectares, respectively (Table 3.5). This transformation suggests that urban expansion in the study region has occurred at the cost of forested, shrubland, and grassland areas over the past 33 years.

3.5.3. Spatiotemporal pattern of forest cover – insights from spectral indices

To support land use/cover analysis aimed at detecting deforestation over time, spectral indices such as the SAVI, NDWI, NDVI, and LAI were investigated for the years 1986, 2002, and 2019. The findings reveal significant spatiotemporal changes in forest cover across the Metekel Zone. In 1986, the SAVI values ranged from -0.46 to 1.039, with the highest values concentrated in the southern part of the study area (Figure 3.4a). By 2002, the SAVI values had shifted, ranging from -0.73-0.85. The areas with the highest SAVI values, now peaking at 0.85, expanded to cover both the southern and northeastern parts of the region (Figure 3.5a). However, this peak value was lower than the 1986 maximum of 1.039, indicating a reduction in vegetation vigor. By 2019, the SAVI values had significantly decreased, ranging from -0.16-0.79, with the highest values now limited to a small area near the central part of the study region (Figure 3.6a).

The NDWI, which ranged from -0.61 to 0.34 in 1986, revealed that the southern and northwestern edges of the study area presented the highest water content in terms of vegetation (Figure 3-4b). The central part of the study area presented the lowest NDWI values. In 2002, the peak NDWI value increased from 0.34 to 0.52 but was confined to a smaller area, particularly in the northeastern part of the study region. Compared with that in 1986, the spatial extent of high NDWI values significantly decreased by 2002 (Figure 3.5b). By 2019, the NDWI values had further declined, ranging from -0.52-0.11, with the highest values now concentrated in the northwestern part of the study area (Figure 3.6b).

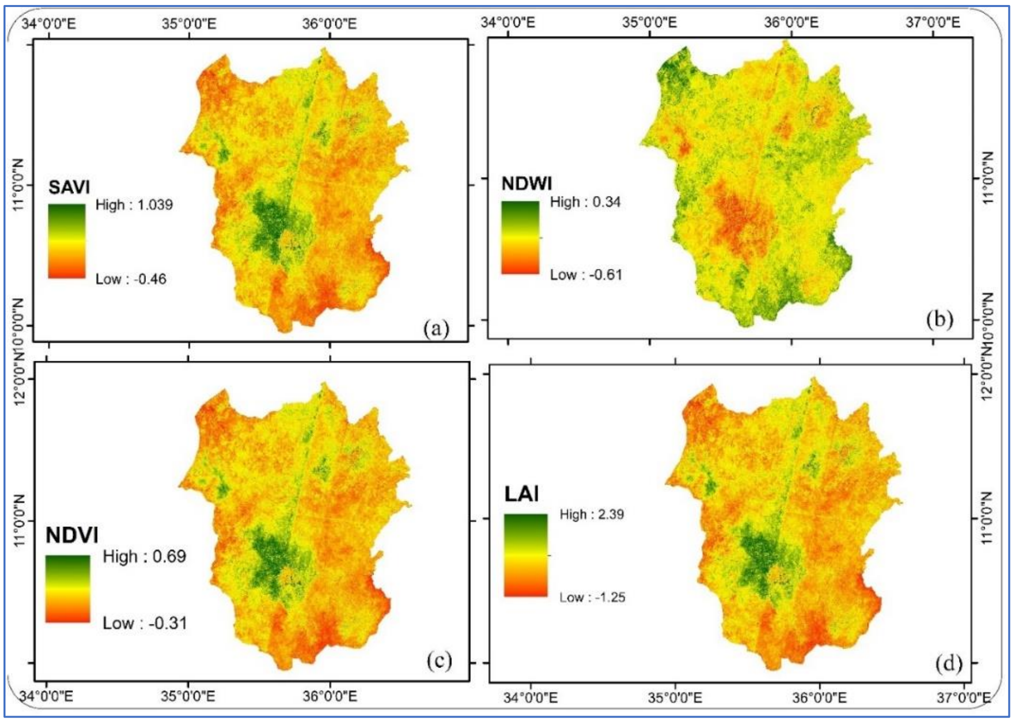


Figure 3.4: Spectral indices of forest cover in 1986: (a) SAVI, (b) NDWI, (c) NDVI, and (d) LAI

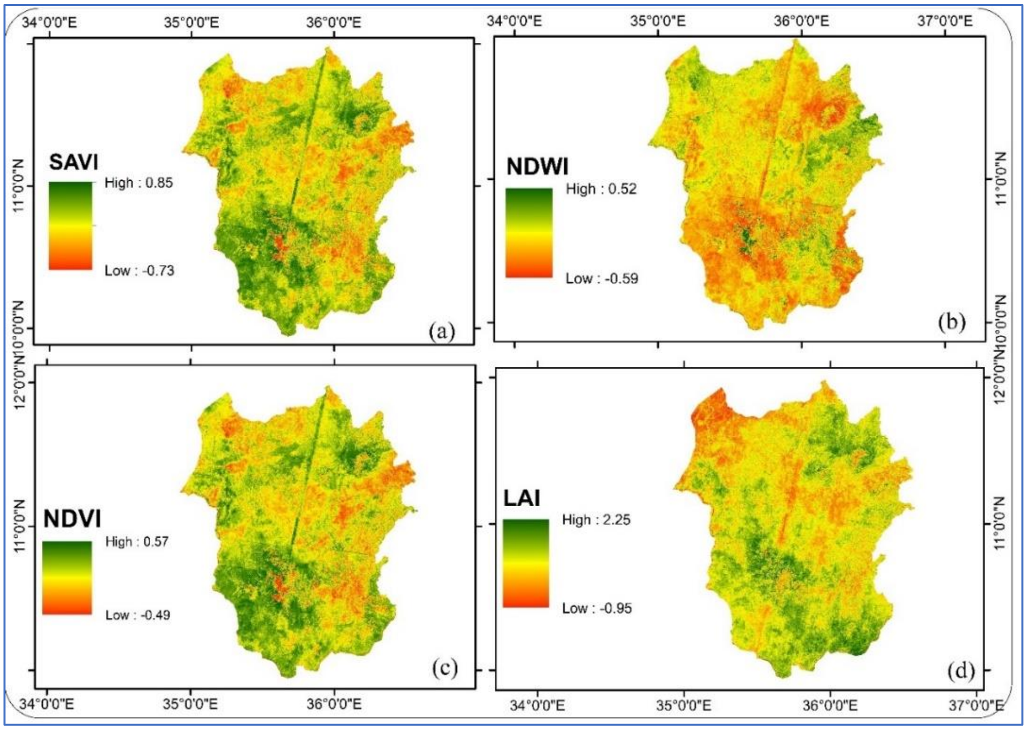


Figure 3.5: Spectral indices of forest cover in 2002: (a) SAVI, (b) NDWI, (c) NDVI, and (d) LAI

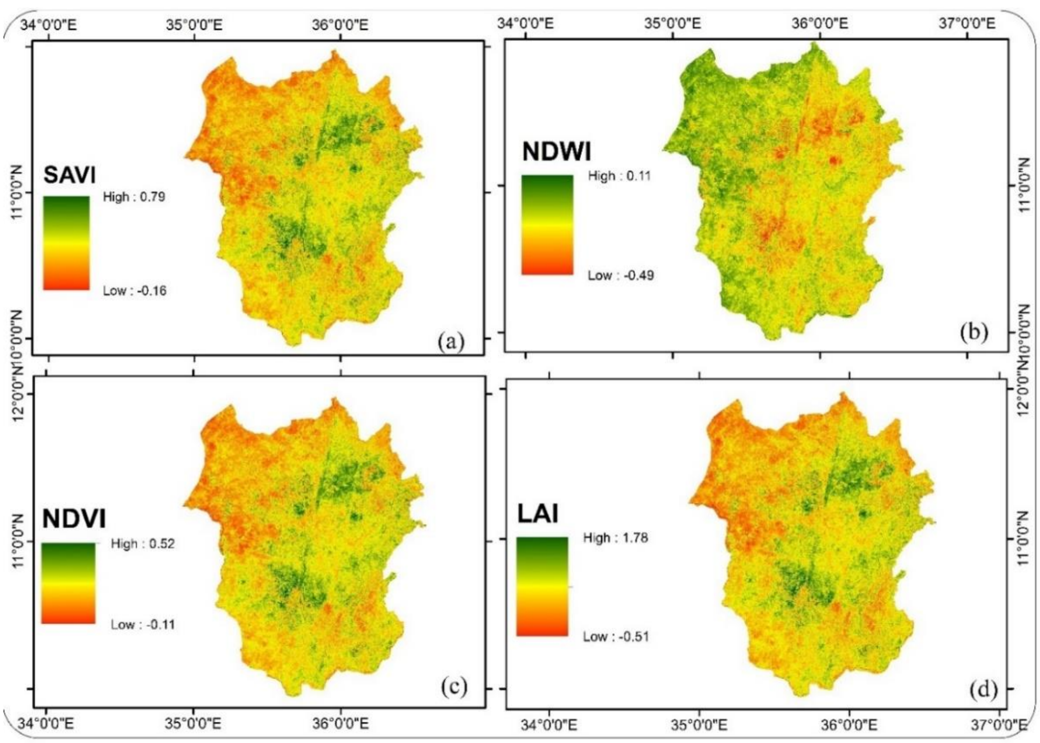


Figure 3.6: Spectral indices of forest cover in 2019: (a) SAVI, (b) NDWI, (c) NDVI, and (d) LAI

The NDVI, another crucial indicator of forest trends, also showed notable changes. In 1986, the NDVI values ranged from -0.31 to 0.69 (Figure 4c), with the highest values concentrated in the southern part of the study area, albeit over a small portion. By 2002, the peak NDVI value had decreased from 0.69 to 0.57, but the distribution of high NDVI values had expanded to cover both the southern and northeastern parts of the region (Figure 3.5c). The eastern part of the study area, however, experienced significant degradation, with lower NDVI values than those in 1986. By 2019, the NDVI values and spatial distributions of high-NDVI areas had further deteriorated. The peak NDVI value decreased from 0.69 in 1986 to 0.52 in 2019, with the highest values now concentrated near the central and northeastern edges of the study area (Figure 3.6c). The eastern region continued to experience low NDVI values, reflecting ongoing deforestation and land degradation.

The LAI, which reflects forest canopy density, also exhibited significant changes over time. In 1986, the LAI values ranged from -1.25-2.39, with the highest values concentrated in the central part of the study area (Figure 3.4d). By 2002, the peak LAI value had slightly decreased from 2.39 to 2.25, but the distribution of high LAI values had expanded to the southern and northeastern parts of the study region (Figure 3.5d). However, by 2019, the LAI values had significantly decreased, ranging from -0.52-1.78, with a notable decline in spatial distribution across the entire study area (Figure 3.6d). The highest LAI values were now limited to the central and northeastern parts of the region. The northeastern part of the study area experienced low LAI values, whereas the eastern region, characterized by extensive agricultural expansion, presented medium LAI values.

3.5.4. Capability of SVM and RF for identification of Landsat MSS and ETM+ on the GEE platform

The effectiveness inspection of the SVM and RF algorithms in detecting Landsat MSS and ETM+ data on the GEE platform demonstrated significant improvements in classification accuracy. The SVM performed especially well at classifying wooded areas, with a PA of approximately 88%, a UA of approximately 82%, and a remarkable F score of approximately 93%. These metrics highlight the SVM's ability to distinguish and accurately label forestland cover, which is crucial for effectively mapping forest cover across the study region. The SVM displayed exceptional accuracy in the water body class, attaining a PA of approximately 93%, a

UA of approximately 87%, and an F score of approximately 90% (Table 3.6). This underscores the robust ability of the SVM to identify water bodies accurately.

Table 3.6: Efficiency of SVM and RF in discriminating Landsat MSS and ETM+

	SVM			RF		
Land cover type	Producer	User	F score	Producer	User	F score
Forest	88%	82%	93%	84%	70%	91%
Settlement	91%	68%	77%	68%	83%	75%
Agriculture	89%	72%	85%	65%	64%	69%
Shrubland	89%	82%	87%	73%	71%	85%
Grassland	67%	69%	76%	84%	74%	67%
Waterbody	93%	87%	90%	80%	82%	79%
	OA=88%	Kappa:86%		OA=79%	Kappa: 67%	

The OA of the SVM was notably high at 88%, accompanied by a kappa coefficient of 86%, indicating a high level of consistency between the actual and anticipated categories. This comprehensive measure of accuracy further reinforces the effectiveness of the SVM in providing accurate and reliable land use/cover classifications for Landsat MSS and ETM+ sensor data. The justification for SVM's high performance lies in its inherent ability to handle complex, nonlinear relationships within the data. SVM is adept at defining optimal hyperplanes in high-dimensional spaces, enabling it to effectively discriminate between different land cover types in Landsat MSS and ETM+ sensor data.

3.5.5. Performance of SVM and RF in classifying Landsat 8 OLI data on the GEE platform

In the classification of high-accuracy land cover classes, both the SVM and RF algorithms demonstrated notable proficiency in discerning specific categories within Landsat 8 OLI data. Notably, in the classification of water bodies, the SVM yielded a PA of 83%, indicating an impressive 83% accuracy in correctly identifying such areas. This was accompanied by a high UA of approximately 66% and an F score of approximately 81%, demonstrating the algorithm's ability to reliably characterize water features. Similarly, RF excelled in waterbody classification, with an OA of approximately 85% and a kappa coefficient of approximately 82% (Table 3.7), reinforcing its ability to precisely delineate this crucial land use/cover type.

Moreover, in the classification of settlement areas, RF achieves strong accuracy metrics, with a PA of approximately 81% and a UA of approximately 81%. These values highlight the algorithm's effectiveness in accurately identifying urban and built-up regions. The F score of 65% further emphasizes the balanced performance of RF in settlement classification. While SVM exhibited a slightly lower PA of 81% and a UA of 65% in settlements, its competitive performance is evident in the nuanced balance reflected by an F score of 67%.

The superiority of the RF over the SVM in classifying Landsat 8 OLI sensor data can be attributed to the characteristics of the Landsat sensor and the inherent strengths of the RF algorithm. Landsat sensors capture multispectral data with a range of spectral bands, providing rich information about the Earth's surface. RF is well suited for handling such complex, high-dimensional data because of its ability to process and interpret diverse spectral signatures effectively.

Landsat sensors typically produce datasets with a considerable number of spectral bands, and RF excels in leveraging this information to discern intricate patterns within the data. The algorithm's capacity to create diverse decision trees and aggregate their outputs through majority voting enhances its adaptability to the multispectral nature of Landsat imagery. In contrast, SVMs, while powerful, face challenges in fully exploiting the rich spectral information provided by Landsat sensors, potentially leading to suboptimal performance in certain land use/cover classifications.

Table 3.7: Efficacy of SVM and RF in categorizing Landsat 8 OLI data

	SVM			RF		
Land cover type	Producer	User	F score	Producer	User	F score
Forest	78%	72%	83%	74%	69%	68%
Settlement	81%	65%	67%	61%	81%	65%
Agriculture	79%	69%	75%	62%	62%	66%
Shrubland	69%	72%	65%	71%	68%	75%

Grassland	66%	64%	72%	82%	71%	68%
Waterbody	83%	66%	81%	78%	64%	81%
	OA=78%	Kappa:66%		OA=85%	Kappa: 82%	

3.5.6. Environmental consequences of deforestation

According to the FGD report, the most prominent repercussion of deforestation is the eminent threat to biodiversity, as forests stand as pivotal hubs of diverse ecosystems. These ecosystems provide habitats for a wide array of species, including mammals, birds, and insects. Unfortunately, the study area is experiencing the adverse impact of deforestation, leading to the disappearance of both animal and plant species due to habitat loss. Additionally, a decline in forest area has led to a decline in water retention, resulting in soil desiccation and decreased agricultural productivity. The study area's dependence on forests for livelihoods is further exacerbated by the expansion of exposed lands, which contributes to the vulnerability of native communities. Furthermore, the clearing of large forested areas releases substantial amounts of greenhouse gases, exacerbating alterations in climatic conditions in the region.

The environmental consequences of deforestation can be categorized into two distinct timelines. Long-term effects include an enduring reduction in the population of trees and diverse plant species, including bamboo, which contributes to climate change, desertification, and an increase in greenhouse gases in the atmosphere. On the other hand, short-term consequences include immediate impacts such as soil erosion, biodiversity loss, water scarcity, diminished crop yields, and an elevated risk of flooding. The persistent removal of trees and vegetation not only poses imminent threats to soil stability, biodiversity, and water availability but also has extensive ramifications for the global climate and ecosystem health in the long run. Addressing both short-term and long-term consequences is vital for implementing effective strategies to combat deforestation and its multifaceted environmental impacts.

3.5.7. Mitigation measures

As per the FGD report, the Green Legacy Initiative was initiated in the study area as a proactive measure for forest conservation. Noteworthy conservation efforts include the construction of terraces, guided by agricultural experts, to prevent soil compaction. Health extension workers are actively promoting the adoption of fuel-efficient stoves among women, contributing to both environmental sustainability and improved health. Furthermore, women engaged in forest extraction activities, such as selling firewood and charcoal, are being organized into associations to increase their economic capacity. A significant aspect of the initiative involves large-scale recultivation of depleted forests through the planting of seedlings, including bamboo and mango species, which are subsequently distributed within the community. These multifaceted initiatives underscore a comprehensive approach toward the sustainable management of forests and community participation in the research area.

3.6.Discussion

Numerous studies conducted in various regions of Ethiopia have highlighted the consistent trend of forest degradation over several decades. Shiferaw and Suryabhagavan (2019) focused on Harena Buluk Forest in the Bale Zone and noted a continuous decline in forest cover alongside an increase in settlement and agricultural activities. Getahun et al. (2013) explored the factors influencing deforestation patterns in southwest Ethiopia's lush, evergreen Afromontane woodlands and revealed that subsistence farming played a substantial role in the loss of forest cover in the studied region. These collective findings underscore a consistent theme of declining forest cover across Ethiopia due to various human-induced factors. The Metekel zone aligns with this trend, experiencing a substantial 22.7% decline in forest cover over the past 33 years (1986-2019). Despite the global trend of declining forest cover, significant efforts toward forest restoration are being made around the world. Various empirical studies have examined the effectiveness, challenges, and outcomes of these restoration initiatives. In Latin America, Brazil’s restoration efforts in the Atlantic Forest have notably accelerated the recovery of native flora and fauna while also increasing carbon storage (Shimamoto et al., 2018). Similarly, Costa Rica’s Payment for Ecosystem Services (PES) program has successfully restored degraded lands by providing economic incentives to landowners, fostering widespread reforestation efforts (Powers et al., 2009). Moreover, China’s Grain for Green Program has significantly increased forest cover and improved ecosystem services, although success has varied across regions (Guo, 2014). In Africa, Ethiopia’s Green Legacy Initiative has contributed to increased forest cover in certain regions, although challenges related to species selection and ongoing maintenance remain. In the Metekel Zone, initial reforestation efforts have been initiated through Ethiopia’s Green Legacy

Program, yet significant gaps in forest restoration remain, highlighting the need for continued and enhanced efforts.

Our research findings indicate that agricultural expansion, firewood collection, and charcoal production are the primary drivers of land use/cover changes, leading to significant forest resource degradation. Agricultural expansion involves clearing forests to create farmland, which reduces forest cover and disrupts forest ecosystems. Firewood collection, which is crucial for domestic energy in many rural areas, leads to the overharvesting of forest resources and diminishes tree density. Similarly, charcoal production, a major fuel source in many regions, involves cutting down trees and burning them in low-oxygen conditions, resulting in deforestation. These findings are supported by various empirical studies that explore the impacts of these activities on forest ecosystems. Agricultural expansion is well documented as a major driver of deforestation. Defries et al. (2010) reported that large areas of tropical forests were cleared for agriculture, significantly impacting biodiversity and contributing to greenhouse gas emissions. Similarly, Margono et al. (2014) reported extensive deforestation in Indonesia due to the expansion of oil palm plantations, which led to the loss of critical habitats and alterations in local climate patterns. A study by Acheampong et al. (2019) in the developing world highlighted that reliance on firewood for energy leads to the overharvesting of forest resources, which diminishes tree density and affects soil stability. Similarly, Sassen & Sheil, (2013) reported that firewood collection was a significant factor in deforestation, leading to reduced forest cover. Charcoal production is another critical factor in forest degradation. A study by Sedano et al. (2016) revealed that the process of cutting and burning trees for charcoal results in the loss of forest cover. These findings align with our research, which indicates that agricultural expansion, firewood collection, and charcoal production contribute to forest resource degradation by depleting tree density and impacting environmental stability.

Empirical studies across different regions of the world have extensively compared the performance of SVMs and RFs in land use/land cover and forest cover mapping via Landsat data. RF has been widely adopted for forest cover mapping because of its ability to handle complex and heterogeneous forest types across different ecological regions. Rodriguez-Galiano et al. (2012) demonstrated that the RF outperforms the SVM in classifying forest cover, where mixed forests dominate the landscape. This study highlighted RF’s ability to manage the high variability and mixed pixels associated with Landsat data, resulting in higher overall accuracy. However, where landscapes are often more arid and less vegetatively complex, the SVM performed comparably to the RF. Huang et al. (2002) reported that SVMs provide better delineation of sparse vegetation and urban areas, which are prevalent in the region, because of their ability to model complex class boundaries effectively. A study by Gislason et al. (2006) in Bavaria revealed that RF was superior in classifying diverse agricultural fields, which are characterized by varying crop types and phenological stages. RF's feature selection ability proved crucial in identifying the most relevant spectral bands for distinguishing between different crop types, leading to higher classification accuracy. A study by Liu et al. (2010) revealed that the RF outperforms the SVM in classifying urban expansion areas via Landsat data. This study attributed RF's superior performance to its robustness in handling mixed land use/cover types and high-dimensional data characteristics of urban–rural transitions. In contrast, the SVM performed better in differentiating between various forest types, including dense evergreen forests and mixed deciduous forests. A study by Fei et al. (2022) revealed that SVM's precision in modeling nonlinear class boundaries contributed to its higher accuracy in this region's complex forest landscapes. Our research revealed that the SVM classification algorithm is well suited for MSS and ETM+ sensor data, whereas the RF classification algorithm excelled in handling OLI sensor data. The superior performance of the SVM with MSS and ETM+ data from 1986 and 2002 can be attributed to the lower spectral resolution of these sensors, which provided less detailed spectral information. The strength of SVM lies in its ability to classify data effectively with fewer features and less complexity by modeling complex class boundaries, making it well suited for these earlier, less detailed datasets. In contrast, the higher spectral resolution of Landsat 8 in 2019 provided richer and more detailed information across multiple spectral bands. This allowed the random forest algorithm to better exploit the increased data complexity and dimensionality, leading to improved classification accuracy in 2019.

Several scientific papers have articulated diverse mitigation measures for forest conservation. Porter-Bolland et al. (2012) highlighted the crucial role of well-managed protected areas and active community participation in preserving biodiversity. Bowler et al. (2012) demonstrated that community-based forest management can effectively reduce deforestation and enhance forest health when local communities are engaged and supported. The findings of Araya and Hofstad, (2016) highlighted the potential effectiveness of monetary incentives, particularly within the framework of Reducing Emissions from Deforestation and Degradation (REDD+), in mitigating deforestation. The research suggests that providing financial rewards for avoiding deforestation in montane forests could be a feasible strategy under the REDD+ scheme. This emphasizes the importance of incorporating economic incentives into forest management and conservation strategies to encourage sustainable practices. In parallel, the Green Legacy Initiative in the Metekel zone, as indicated by the KII report, presents cases of a community-centric and holistic approach to forest conservation. The initiative integrates various measures, such as terrace construction to prevent soil compaction and the promotion of fuel-efficient stoves through health extension workers. Additionally, the organization of women involved in forest extraction activities into associations enhances their economic capacity, contributing to both livelihood improvement and forest conservation. The large-scale recultivation of depleted forests through tree planting initiatives, including bamboo and mango species, further demonstrates a commitment to long-term restoration efforts. Additionally, alternative energy sources, such as biofuels (biogas), hydropower, solar energy, and wind energy, which can be used to minimize pressure on forests, should be given special attention. Together, these findings underscore the importance of adopting diverse and integrated mitigation measures for effective forest management and restoration. While monetary incentives present a valuable tool at a broader policy level, community-driven initiatives, as exemplified by the Green Legacy Initiative, play a crucial role in implementing on-the-ground conservation practices and fostering sustainable relationships between communities and their forested environments. Integrating both approaches can contribute to comprehensive and impactful strategies for addressing deforestation and promoting sustainable forest management.

3.7.Conclusions

Over the past 33 years (1986–2019), land use/cover has undergone significant changes, with a marked decline in forest cover and substantial increases in agricultural and urban areas. Our analysis, supported by findings from FGD and KII, reveals a consistent trend of deforestation and forest degradation driven by agricultural expansion, firewood collection, and charcoal production. This period (1986-2019) experienced intensified pressure on forest resources, leading to substantial changes in land cover dynamics. In addition, the spatiotemporal pattern of forest cover from 1986-2019 was examined via various spectral indices, such as the NDVI, SAVI, NDWI, and LAI. These indices indicate a decline in forest cover in the study area subjected to intensive human activities, effectively highlighting areas of significant forest loss and degradation. The combined results of the land use/land cover and spectral indices revealed that the forest cover over the southern region has declined and that agricultural expansion has intensified over the eastern part of the study area. Our evaluation of the SVM and RF algorithms for land use/cover identification via Landsat MSS and ETM+ data from the GEE platform revealed that the SVM performed well for the 1986 and 2002 classifications and adequately handled the limited spectral resolution and simpler class boundaries of the MSS and ETM+ imagery. However, for the Landsat 8 OLI data, RF demonstrated superior performance in classifying the 2019 dataset. The enhanced spectral resolution and additional bands in Landsat 8 enabled the RF to leverage its ensemble learning capabilities, achieving higher classification accuracy. This study underscores the urgent need for comprehensive awareness campaigns and sustainable land management strategies to address the complex interplay of factors contributing to deforestation in the Metekel Zone. Conservation efforts, coupled with effective policy interventions and community engagement, are essential to mitigate the adverse environmental consequences of forest loss and ensure the long-term ecological sustainability of a region.

3.8.Limitations

The primary limitation of this study arises from the use of Landsat data for land use/cover classification. Landsat MSS, ETM+, and Landsat 8 OLI imagery, with a spatial resolution of 30 m, offers lower precision than higher-resolution Sentinel-2 imagery, which has a spatial resolution of 10 m. This reduced spatial resolution can affect the accuracy of land cover identification, particularly at a regional scale over time. Despite this limitation, Landsat data were chosen for this research because of their extensive temporal coverage, which provides long-term data for land cover change analysis.

3.9.Future research

Future research should address the limitations of this research by incorporating higher-resolution imagery, such as Sentinel-2, which offers a 10-meter spatial resolution. Integrating high-resolution data with Landsat imagery and employing advanced data fusion techniques can increase spatial accuracy and provide a more detailed analysis of land cover changes. Additionally, the use of multisource data along with machine learning algorithms can improve classification precision and yield better results in both long-term and short-term land cover dynamics.

CHAPTER FOUR

4. Spatiotemporal Climate Variability and Its Impact on Local Community Livelihoods: A Focus on Crop Production in Metekel Zone, Northwest Ethiopia

Abstract

Climate variability poses a critical challenge to agriculture and livelihoods in vulnerable regions. This study investigates the spatiotemporal climate variability and its impacts on crop production and livelihoods in the Metekel Zone, Northwest Ethiopia. Data from meteorological stations (1981–2019), crop yield records from central statistics agency, and qualitative data from focus group discussions (FGDs) and key informant interviews (KIIs) were collected. The study used purposive sampling to select nine key informants and conducted three FGDs with 18 participants across four districts. Temporal variability was assessed using the Coefficient of Variation, Standardized Precipitation and Temperature Indices, and Mann-Kendall trend tests. Spatial variability was analyzed through Inverse Distance Weighting, and the Autoregressive Distributed Lag model was used to quantify the effects of climate variables on crop yields. The DPSIR framework was applied to explore socio-economic and environmental drivers of change. Findings reveal significant warming trends, with annual maximum and minimum temperatures increasing by 0.33°C and 0.31°C per decade, and a decline in rainfall by 5.32 mm per decade. Temperature-sensitive crops in Dangur District and Bullen districts are most affected, while rainfall variability impacts yields in Dibate District and Wombera districts. Thematic analysis highlighted concerns over reduced crop productivity, deforestation, and soil degradation, intensified by population growth and agricultural expansion. To address these challenges, the study recommends adopting climate-resilient crop varieties (millet, and sorghum), sustainable agricultural practices (crop diversification), and enhanced climate awareness (adaptation) through education. Policymaking should focus on promoting environmental sustainability to safeguard local livelihoods and ensure agricultural resilience amidst climate variability.

Keywords: Climate change, Crop productivity, Livelihoods, Metekel Zone, ARDL model

4.1.Introduction

Climate change and variability, marked by changes in temperature, precipitation patterns, and extreme weather events (Singh, 2024), represent some of the most pressing global environmental challenges, with significant consequences for agriculture, food security, and livelihoods (Praveen & Sharma, 2019; Thornton et al., 2014). These shifts, driven by both natural and anthropogenic factors, have led to major disruptions in global weather systems (du Plessis, 2019). Since the pre-industrial era, the global average temperature has risen by about 1.1°C, intensifying occurrences such as extreme rainfall, rising sea levels, and disturbances to ecosystems (IPCC, 2023). This warming trend is mainly attributed to increased concentrations of greenhouse gases (GHGs) in the atmosphere, including carbon dioxide (Neupane et al., 2018; Reshmidevi et al., 2018), methane (Zhang et al., 2017), and nitrous oxide (Liu et al., 2023). As GHG emissions continue to alter atmospheric dynamics, extreme weather events, such as heat waves, floods, and droughts, are becoming severe (Calvin et al., 2023). These climatic disruptions jeopardize not only natural ecosystems but also human systems, particularly agricultural productivity, which is highly sensitive to climate variability (Gomez-Zavaglia et al., 2020; Wu & Etienne, 2021; Yadav et al., 2021). This poses a significant challenge to achieving SDG 2 (Zero Hunger), which seeks to eliminate hunger and improve food security through sustainable agricultural practices.

Sub-Saharan Africa's agricultural and forest-based livelihoods are highly vulnerable to climate change and variability, as they depend on climate-sensitive ecosystems (Chisale et al., 2021; L. Zhou et al., 2022). Rain-fed agriculture, which supports the majority of the population (Streimikis & Baležentis, 2020), is severely impacted by erratic rainfall, prolonged droughts, and rising temperatures, leading to declining crop yields and heightened food insecurity (Gebrechorkos et al., 2019; Sultan & Gaetani, 2016). Smallholder farmers face compounding challenges, including soil degradation and pest outbreaks aggravated by changing climatic conditions (Mubiru et al., 2018; Touch et al., 2024). Similarly, forest-based livelihoods, which provide income through timber, non-timber products, and ecosystem services (Assaye et al., 2024; Mukul et al., 2016), are at risk from deforestation and climate-driven changes in biodiversity and ecosystem health (Kapuka & Hlásny, 2021; Seo, 2014). Diminished forest resources threaten the livelihoods of rural communities that depend on them for subsistence and income (Angelsen et al., 2014; Wunder et al., 2014).

Ethiopia, situated in the Horn of Africa, exemplifies the vulnerabilities faced by agrarian nations that are heavily reliant on natural resources. With over 80% of the population depending on agriculture for subsistence and income, the sector serves as a cornerstone of the country's economy (Worldbank, 2019). However, the agricultural sector is highly sensitive to climate variability, with significant increases in temperature and erratic rainfall patterns over the past four decades, according to data from Ethiopia's National Meteorological Agency (NMA, 2023). Consequently, these climatic changes have caused substantial disruptions in agricultural production, as droughts and unpredictable rainfall patterns directly impact crop yields and livestock production (Deressa et al., 2011; Gebrehiwot, 2013). Furthermore, rising temperatures, irregular rainfall, and extreme weather events (Singh, 2024; Streimikis & Baležentis, 2020) worsen the disruption to agricultural productivity, leading to reduced crop yields and heightened food insecurity affecting community's livelihood (Cooper et al., 2008). (Hadgu et al., 2015) found that increasing temperatures and fluctuating rainfall patterns notably reduced maize and sorghum yields in northern Ethiopia. Rural Ethiopian communities are particularly vulnerable to these challenges, as prolonged droughts result in water scarcity and significant livestock losses (Bogale & Erena, 2022; Tofu et al., 2022, 2023). Additionally, marginalized groups, such as women, children, and other vulnerable populations, are disproportionately affected by climate change, as their livelihoods depend on natural resources that are highly sensitive to climate fluctuations (Ngcamu, 2023; Ngcamu & Chari, 2020).

Considering these vulnerabilities, a crucial tactic to lessen the effects of climate change on agricultural communities is adaptation. Ethiopian and global farmers have adopted a number of adaptation techniques to deal with climate change. To lessen reliance on rain-fed agriculture, they include crop diversification, the adoption of drought-resistant crop types, enhanced soil conservation methods, and irrigation systems (Teshome et al., 2016). Government programs like the Productive Safety Net Program (PSNP) and the Climate Resilient Green Economy (CRGE) give farmers financial support, technical aid, and training to help them adjust to changing climate conditions (MOFEC, 2018). The CRGE strategy is particularly significant as it integrates climate resilience into Ethiopia's national development goals, aiming to reduce emissions and promote sustainable land management practices (Makondo & Thomas, 2018). For a climate change adaptation, providing both formal and non-formal education to students and the community is a key element. Formal education integrates climate literacy into school curricula, equipping future generations with the knowledge to address environmental challenges (Akinsemolu & Onyeaka, 2025; Okada & Gray, 2023). Meanwhile non-formal education provides immediate solutions through community training, awareness campaigns, and capacity-building programs (Rogers, 2019; Romi & Schmida, 2009). These dual approaches offer a comprehensive strategy for climate resilience, supported by global and national practices and empirical evidence.

In this regard, although Ethiopia has made progress by introducing environmental science and climate change topics in schools and implementing non-formal programs on sustainable land use, afforestation, and water resource management, however, challenges such as limited resources, uneven access, and cultural barriers hinder their full potential. Due to this, climate change impacts across the country are worsening. For example, the Metekel Zone in Northwest Ethiopia, situated close to the Grand Ethiopian Renaissance Dam, is experiencing significant climate change impacts, particularly on its agriculture, which relies on mixed crop-livestock systems and pastoralism. Irregular rainfall and extended droughts have reduced water availability, reduced crop yields, and increased food insecurity, especially for temperature-sensitive crops like maize and sorghum. Additionally, rapid population growth and deforestation have led to a decline in forest cover, from 51.37% in 1986 to 17.20% in 2019 (Wahelo et al., 2024). This further intensifies the challenges by disrupting rainfall patterns and increasing temperatures. Limited community awareness of climate adaptation strategies worsens the region's vulnerability, threatening both agriculture and livelihoods.

Even though the amount of study on climate variability and how it affects livelihoods is growing, little is known about how climate change affects crop yields in the Metekel Zone over time. The effects of climate change on agriculture have been examined in more general research (Blanc, 2012; Ziervogel & Ericksen, 2010) and the specific effects on crop yields (Asfawa et al., 2016; Deressa et al., 2011), there is a lack of localized research that considers the variations in climate patterns over time and space, and their direct impact on specific crops within this study region. Most existing literature focuses on national or regional trends, overlooking the detailed local variations in temperature and precipitation that significantly impact agricultural productivity and livelihoods. For instance, while recent studies have explored how climate variability influences rainfall distribution and temperature patterns, the spatiotemporal aspects of these changes and their effects on crop production remain underexplored (Gizaw & Gan, 2017)

Similarly, while national or regional studies (Eshetu et al., 2020; Hadgu et al., 2015; Kassaye et al., 2021) provide evidence on the aspects of climate variability, they often overlook the localized manifestations of climate change, such as those experienced in the Metekel Zone, where its impacts are more pronounced. As a result, there is a clear knowledge gap in understanding the spatiotemporal effects of climate change on crop yields in Metekel Zone, particularly how localized shifts in temperature and precipitation influence crop production and the livelihoods of the local community. Therefore, this study seeks to address this gap by: (i) investigating the spatiotemporal climate variability and change over time in the study area, and (ii) assessing the impacts of climate change and variability on the community's livelihood, with a special focus on agricultural crop production.

The research is significant as it directly supports Ethiopia's commitment to the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger). The study provides empirical evidence to inform national policy frameworks, including the Climate Resilient Green Economy (CRGE) strategy and Ethiopia's National Adaptation Plan (NAP). It emphasizes the need for context-specific adaptation strategies tailored to the vulnerabilities of smallholder farmers in the Metekel Zone. Specifically, the research outlined sustainable agricultural practices such as crop diversification, the adoption of drought-tolerant and early-maturing crop varieties (e.g., sorghum, teff, and millet), conservation agriculture techniques like zero-tillage and mulching, terracing to prevent soil erosion, and agroforestry to enhance soil fertility and microclimatic conditions.

4.2.Conceptual framework

The conceptual framework for this study integrates multiple theoretical perspectives to explain how spatiotemporal climate variability impacts crop production in the Metekel Zone of Northwest Ethiopia. Rooted in Malthusian theory, the framework highlights the pressures arising from rapid population growth, agricultural expansion, and charcoal production, which intensify deforestation, overgrazing, and monocropping. These activities accelerate climate variability, manifested in increased temperatures and erratic rainfall, ultimately diminishing agricultural productivity and exacerbating food insecurity (Thomas, 1998). While Malthus viewed such crises as inevitable outcomes of unchecked population growth outpacing food supply, modern frameworks offer more nuanced interpretations. The Sustainable Livelihood Framework (SLF) emphasizes how households mobilize diverse assets such as human, natural, physical, financial, and social capital to adapt and sustain their livelihoods under environmental stress (Natarajan et al., 2022). In the Metekel Zone, strategies such as drought-resilient crops, crop diversification, agroforestry, and zero-tillage reflect adaptive responses that strengthen resilience and counter the deterministic predictions of Malthusian Theory (Pretty, 2011).

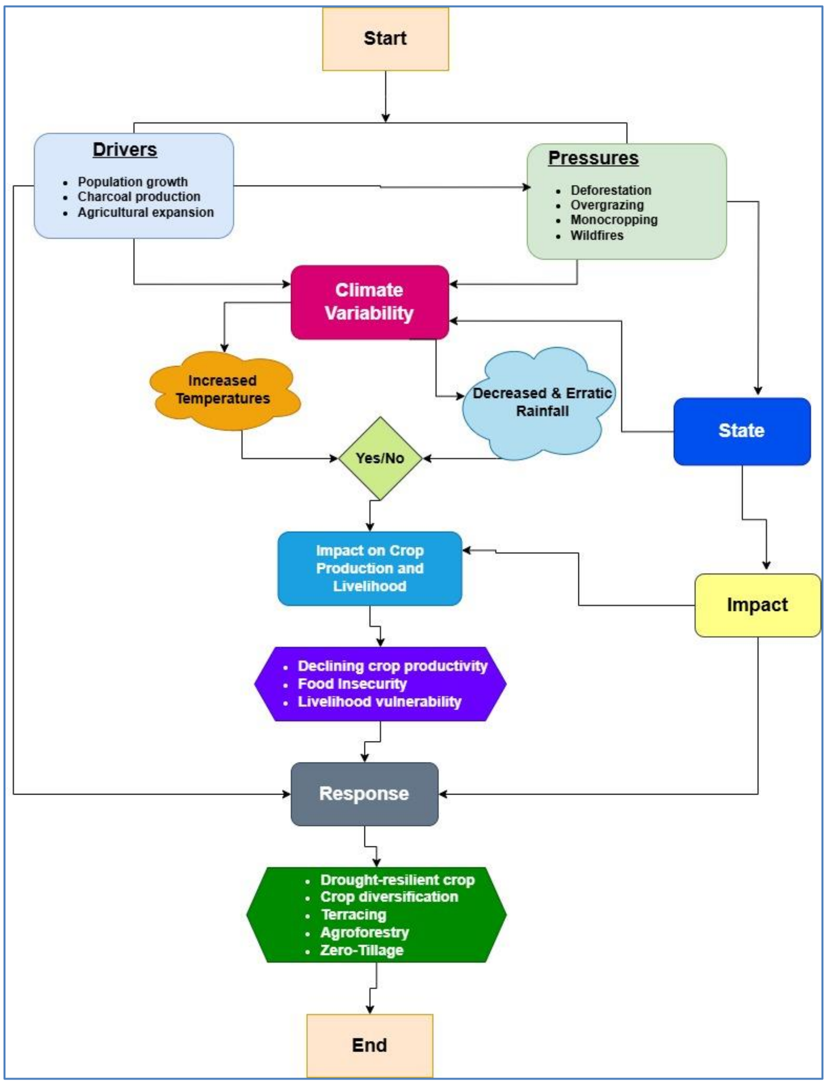


Figure 4.1: Conceptual framework of the study developed by the author based on the literature review

Complementing the SLF, the IPCC Framework for Vulnerability and Risk Assessment conceptualize risk as a function of hazards, exposure, and vulnerability, emphasizing the role of socio-economic factors in shaping communities' responses to climate variability (IPCC, 2014). In this context, the DPSIR Framework (Drivers–Pressures–State–Impact–Response) structures the relationship between human actions and environmental outcomes, illustrating how drivers like population growth lead to pressures on ecosystems, resulting in climate variability and subsequent impacts on livelihoods (Kristensen, 2003). Together, the SLF, IPCC, and DPSIR frameworks advocate for adaptive management and policy interventions that enhance resilience and sustainable development, offering a dynamic, solution-oriented counterpoint to Malthusian pessimism (Figure 4.1).

Although these theories and frameworks vary in emphasis, they offer complementary insights into the relationship between spatiotemporal climate variability and rural livelihoods. Malthusian Theory provides a foundational understanding of the pressures resulting from population growth and limited resource availability but often presents a deterministic and linear view of the problem. In contrast, both the SLF and IPCC Framework focus on adaptive capacity and risk management, offering more dynamic and solution-oriented approaches. The DPSIR Framework serves as an overarching structure that integrates these perspectives, enabling a systematic assessment of the causes, consequences, and responses to climate variability.

4.3. Method

4.3.1. Study area

The investigation was conducted in the Metekel Zone of the Benishangul Gumuz Regional State in Northwest Ethiopia. Geographically, the Metekel Zone is located between 10^{0} 15' $8^{''}$ to 12^{0} $15^{'}$ $5^{''}$ North latitude and 35^{0} $10^{'}$ $5^{''}$ to 36^{0} $15^{'}$ $10^{''}$ East longitude (Figure 4-2). The zone is administratively divided into seven districts and comprises 170 Kebeles. Metekel Zone, located in the northwestern lowlands of Ethiopia, lies within an altitude range of 500 to 2,731 meters above sea level, comprising predominantly lowland areas (82%), with midland (10%) and highland (8%) zones. The zone features diverse soils, dominated by Vertisols (33%) and Nitosols (47%), supporting mixed crop-livestock farming (Tamene & Haile, 2021). The region slopes westward toward the Sudanese border and is traversed by major rivers such as the Abay (Blue Nile), Beles, and Ayima, which play a vital role in irrigation and hydropower generation, including the ongoing GERD project. The climate is characterized by hot to warm sub-humid and humid tropical conditions, with annual rainfall averaging 1,607.8 mm and temperatures ranging from 16.2°C to 32.5°C. Rainfall follows a unimodal pattern, peaking from July to August. Vegetation includes bamboo forests, incense trees, and eucalyptus, although deforestation and land degradation are increasing due to agricultural expansion and settlement programs (Wagino & Amanuel, 2021). Agriculture in Metekel Zone is predominantly rain-fed, based on a mixed crop-livestock system. Major crops include cereals like maize, sorghum, and teff, alongside oilseeds such as sesame and soybean, with horticultural crops intercropped around homesteads.

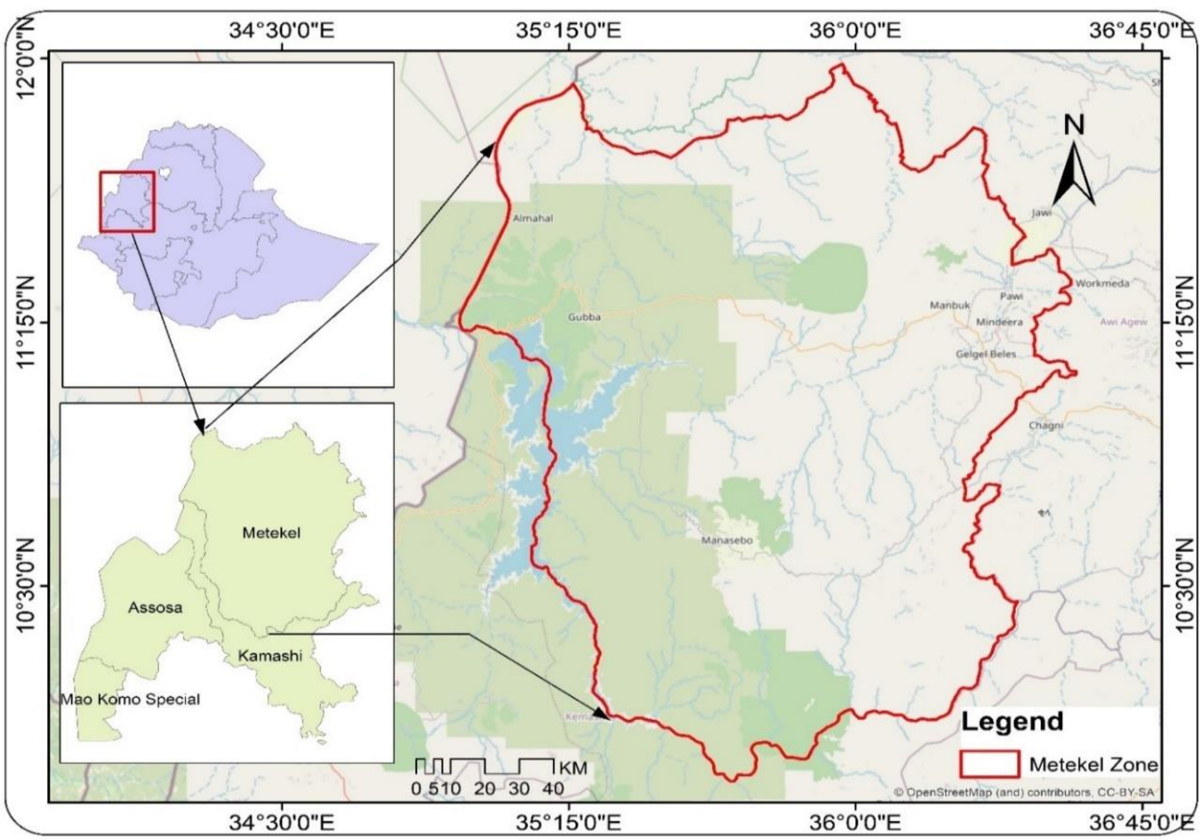


Figure 4.2: Location map of the study area developed from (CSA, 2024) using ArcMap

4.3.2. Research Approach

This study examines the effects of spatiotemporal climate variability on agricultural livelihoods, namely crop production, using a mixed research strategy that integrates quantitative and qualitative methodologies. In order to provide objective measurements of climatic variability and its effects, quantitative approaches were employed to examine historical climate data, crop production patterns, and vulnerability indicators. The quantitative results are further enhanced by qualitative techniques such as FGDs and KIIs, which examine incidental aspects of climate change, the effects of climate variability on livelihood, and adaptive measures (Plano, 2017).

4.3.3. Research design

This study employs a longitudinal research design, which, as (Plano et al., 2015) highlighted is particularly well-suited for investigating phenomena that evolve. The longitudinal approach allows for the integration of both qualitative and quantitative methods, providing a comprehensive framework for analyzing dynamic processes. (Wang et al., 2017) further emphasized that longitudinal studies involve repeated observations of the same subjects over an extended period, enabling the assessment of temporal changes in substantive variables. Guided by this design, the present study investigates the long-term spatiotemporal climate variability and its impacts on the local community's livelihood, with a particular focus on crop production in Metekel Zone, Northwest Ethiopia.

4.4.Data sources

4.4.1. Primary data collection procedure

Key Informant Interview (KII)

This study employs KII to gather in-depth qualitative insights into the impact of spatiotemporal climate variability on agricultural crop production and, by extension, the livelihoods of local communities in the study region. Nine participants, purposefully selected for their specific roles and expertise, offer a multifaceted understanding of this impact. The chosen number is supported by the literature, which suggests that smaller, purposively selected groups of informants can provide detailed and crucial information regarding the impact of climate variability on agricultural crop production and the livelihoods of local communities (Creswell, 2003; Guest et al., 2006).These participants include two *kebele*[6] leaders, who contribute insights on community-level climate impacts, local resilience, and the implementation of adaptive strategies; two district-level agricultural and natural resource experts, who provide technical knowledge on policy-driven responses and the broader challenges climate variability poses to sustainable farming practices; two development agents, who add valuable perspectives from their frontline experience in supporting farmers’ adaptive practices and resource management efforts; one

[6] *Kebele is the smallest administrative unit in Ethiopia*

representative from a non-governmental organization (NGO), expert on external support mechanisms, training programs, and community outreach activities; and two household heads, who represent the direct experiences of climate-affected farmers, sharing firsthand accounts of crop yield fluctuations, income stability, and food security challenges. The purposive selection of these key informants was essential to ensure that the study captures expert perspectives, institutional knowledge, and firsthand experiences critical for understanding climate change impacts and adaptation strategies. By selecting individuals with specialized knowledge, the study integrates both policy-level insights and on-the-ground realities, strengthening the depth and applicability of the findings. The theme that details the main issues and topics for KII is attached in Appendix.

Focus Group Discussion (FGD)

To supplement and validate findings from, meteorological data, crop data and in-depth interviews with key informants, this study employed FGD to gain in-depth insights into the causes, consequences, mitigation, and adaptation strategies for climate change and variability within the Metekel Zone (Appendix 2). From the seven districts in the study area Wembera, Guba, Dibate, Dangur, Mandura, Pawe, and Bullen four districts (Mandura, Dangur, Pawe, and Guba) were purposively selected based on their pronounced vulnerability to climate variability, which disrupts local livelihoods and agricultural activities by affecting crop yields, water resources, soil quality, and income stability. With guidance from experts in the Metekel Zone administration, agricultural and rural development offices, and forest and land resources departments, FGDs were structured with representation from key stakeholders, including *kebele* leaders, natural resources and agricultural office experts, household heads, land administration experts, development agents, and NGO workers. For this study, FGDs were selected using purposive sampling, in line with the recommendations of Nyumba et al. (2018), who argue that FGDs are meant to capture insights from a deliberately chosen group, rather than a statistically representative sample of the larger population. (Guest et al., 2017) provide empirical evidence supporting an ideal FGD participant range of 6-8, analyzing how this group size influences data saturation and the depth of insights obtained. The selection of FGD participants was deliberately structured to ensure a diverse range of perspectives, particularly from key stakeholders directly impacted by climate variability. By including farmers, women, and youth, the study accounts for varying experiences and adaptive responses, as different groups face distinct challenges and employ unique coping strategies. This approach enhances the comprehensiveness of the findings, capturing the broader socio-economic and gendered dimensions of climate adaptation at the community level. In the context of this study, one FGD was held in each of the Pawe and Mandura districts, with six participants per group. Additionally, a combined FGD was organized for the Guba and Dangur districts, with three participants from each district, resulting in a group of six individuals. Overall, three FGDs were conducted, involving a total of 18 participants across the selected districts, with each group consisting of six members. Each focus group discussion lasted 90 minutes, aligning with findings by (Nyumba et al., 2018), who indicated that 90 minutes (median) is a suitable duration for exploring participants' views on environmental conservation.

Validity of qualitative data

This study acknowledges the potential limitations of relying on self-reported data, which can introduce biases related to subjective perceptions, memory recall, and social desirability. Farmers' recollections of climate variability and adaptation strategies may not always align with objective meteorological data, leading to inaccuracies in assessing long-term trends and responses. To address these concerns, self-reported data were cross-referenced with meteorological records and expert insights to validate the findings. Additionally, anonymity was ensured to encourage honest and unbiased responses from participants, minimizing the risk of social desirability bias.

4.4.2. Secondary data collection procedure

Meteorological data

This study utilized temperature and rainfall data from seven meteorological stations spanning the years 1981 to 2019. The data, sourced from the Ethiopian National Meteorological Agency (NMA), covered the stations at Mandura, Pawe, Manbuk, Mankush, Bullen, Wombera, and Dibati. For temperature variability analysis, minimum, maximum, and annual temperature data were collected from these stations. To analyze rainfall variability, seasonal and annual rainfall data were obtained from the same stations.

Crop data

To analyze the impacts of climate variability and trends on agricultural crop yields, data was obtained from the Ethiopian Central Statistical Agency (CSA) at both the zonal and District levels. For the Metekel Zone, zonal-level data is available from 1995 to the present and was collected directly from the CSA head office in Addis Ababa. District-level data, available from 2000 onwards, was gathered from the respective District agricultural offices. The analysis focuses on key crop types, including Teff, Millet, Sorghum, Maize, Sesame, and Niger seed (Nueg).

Agroecological classification

According to MoA (2023), the Metekel Zone encompasses four distinct agroecological zones (Table 4.1): Tepid Moist Mid Highlands (TMMH), characterized by a growing period of 180-270 days, annual rainfall of 800-1200 mm, temperatures ranging from 15-20°C, and mixed crop-livestock farming; Tepid Sub-humid Mid Highlands (TSHMH), with a growing period of 120-180 days, rainfall of 600-800 mm, similar thermal conditions, and a focus on crop farming with supplementary livestock; Warm Moist Lowlands (WML), which has a growing period of 180-270 days, rainfall of 900-1500 mm, temperatures exceeding 20°C, supporting agropastoral and irrigated farming; and Warm Sub-humid Lowlands (WSHL), featuring a growing period of 120-180 days, rainfall of 600-900 mm, warmer temperatures, and predominantly pastoral farming.

Table 4.1: Agroecological classification of Metekel Zone

Letter Code	Type of Agroecology	Length of Growing Period (days)	Annual Rainfall (mm)	Thermal Zone (°C)	Elevation (m)	Farming System
TMMH	Tepid Moist Mid Highlands	180-270	800-1200	15-20	1500-2300	Mixed crop-livestock farming
TSHMH	Tepid Sub-humid Mid Highlands	120-180	600-800	15-20	1500-2300	Crop farming with supplementary livestock
WML	Warm Moist Lowlands	180-270	900-1500	>20	500-1500	Agro-pastoral and irrigated farming
WSHL	Warm Sub-humid Lowlands	120-180	600-900	>20	500-1500	Predominantly pastoral farming

Source: (MoA, 2023)

4.5.Data analysis method

4.5.1. Auto Regressive Distributed Lag (ARDL) model

The ARDL model is particularly suitable for this research on the impact of climate change on crop yield because it effectively captures both short-term and long-term relationships between the dependent and independent variables, allowing for the inclusion of lagged effects (Attiaoui & Boufateh, 2019; Waris et al., 2023). Unlike other regression models that require all variables to be stationary, the ARDL approach can accommodate a mixture of stationary and non-stationary time series data, making it flexible for empirical analysis in agricultural studies. Furthermore, it allows for the estimation of dynamic interactions between climate variables, such as rainfall and temperature, and their cumulative effects on crop yield over time (Waris et al., 2023). This is crucial for understanding the complex relationships inherent in climate impacts on agriculture. The ARDL model can be expressed mathematically in Eq. 4.1:

$$Y_t = \alpha \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{J=0}^{q} \delta_j X_{t-j} + \varepsilon_t \qquad \textit{Equation 4.1}$$

where:

- Y_t is the dependent variable (crop yield) at time t,
- X_{t-j} represents the independent variables (rainfall and temperature) with lagged values,
- α is the constant term,
- β_i and δ_j are the coefficients of the lagged terms,
- $p \text{ and } q$ are the maximum lag orders for Y and X, respectively,
- ε_t is the error term at time t.

To express the ARDL model with both short-term and long-term components, the model is typically reformulated in the Error Correction Model (ECM) format, which isolates short-term dynamics from the long-term equilibrium relationship. When re-parameterized as an ECM, the ARDL model separates the short-term adjustments from the long-term equilibrium relationship (Eq.4-2).

$$\Delta Y_t = \gamma_0 + \sum_{i=1}^{p-1} \gamma_i \, \Delta Y_{t-1} + \sum_{j=0}^{q-1} \lambda_j \, \Delta X_{t-j} + \phi(Y_{t-1} - \theta X_{t-1} + \eta_t \qquad \textit{Equation 4.2}$$

where:

- $\Delta \boldsymbol{Y_t}$ and $\boldsymbol{\Delta X_{t-j}}$ represent the short-term changes (first differences) in Y and X, capturing short-term effects.
- $\boldsymbol{\gamma_0}$ is the constant term.
- $\boldsymbol{\gamma_i}$ and $\boldsymbol{\lambda_j}$ represent short-term coefficients of Y and X, respectively.
- $\boldsymbol{\phi}$ is the coefficient of the error correction term, indicating the speed of adjustment back to the long-term equilibrium.
- $\boldsymbol{Y_{t-1} - \theta X_{t-1}}$ represents the long-term relationship between Y and X, where $\boldsymbol{\theta}$ is the long-term coefficient.
- $\boldsymbol{\eta_t}$ is the error term in the ECM.

4.5.2. Climate variability

To analyze climate variability, the Coefficient of Variation (CV), Standardized Precipitation Index (SPI), and Standardized Temperature Index (STI) were employed. For trend analysis, the Mann-Kendall test (MK) was utilized for both rainfall and temperature data.

4.5.2.1. Coefficient of Variation (CV)

The Coefficient of Variation (CV) is a metric that quantifies the extent of variability in a probability or frequency distribution, expressed relative to its mean (Pang et al., 2005). Represented as a percentage, CV is particularly useful for comparing the level of dispersion between different data sets, even when their means differ significantly (Castagliola et al., 2013). It is calculated using a standardized formula, as shown in Eq. 4.3.

$$CV = \frac{\delta}{\mu} * 100 \qquad \textit{Equation 4.3}$$

Where; δ is the standard deviation and μ is the mean of the observation

4.5.2.2. Standardize Precipitation Index (SPI)

The Standard Precipitation Index (SPI) is a commonly used method for analyzing and tracking precipitation variations over different time periods. It plays a vital role in detecting drought conditions and periods of excessive rainfall (Tirivarombo et al., 2018). By standardizing precipitation data, the SPI facilitates consistent and meaningful comparisons across various climatic regions and geographic areas (Raziei, 2021). The SPI is calculated using the formula shown in Eq. 4.4:

$$Z = \frac{Xi - \overline{X\iota}}{S} \qquad \textit{Equation 4.4}$$

Here, Z represents the SPI, which quantifies the deviation of a specific year's precipitation (Xi) from the historical average ($\overline{X\iota}$), normalized by the standard deviation (S) of the annual precipitation. This approach ensures a standardized evaluation of precipitation anomalies over time and across locations.

4.5.2.3.Standardize Temperature Index (STI)

The Standardized Temperature Index (STI) is a statistical tool designed to evaluate temperature anomalies over a defined period (Li et al., 2021). It is particularly effective for identifying and analyzing periods of significantly high or low temperatures, making it valuable for understanding climate variability and long-term trends (Alexander et al., 2006). The STI operates similarly to the Standardized Precipitation Index (SPI), which is used to assess drought conditions based on precipitation data. The STI is calculated using the formula provided in Eq. 4.5

$$\text{STI} = \frac{Ti - \mu}{\sigma} \qquad \textit{Equation 4.5}$$

In this equation:

- Ti represents the temperature for a specific time period, such as a season.
- μ denotes the mean temperature over a reference period.

σ is the standard deviation of the temperature during the same reference period.

4.5.3. Trends of climate variability

4.5.3.1.Mann-Kendall Trend Test

The Mann-Kendall Trend Test, also known as the M-K test, examines time-series data for consistent upward or downward trends (monotonic) in Y values (Mallick et al., 2021; Rahman et al., 2017). For this study, we employed the Mann-Kendall test to determine statistically significant trends in temperature and precipitation from 1981 to 2019. For a time series X1, X2, X3…. Xn, where n is greater than 10, we calculate the MK test statistic (S), the variance of the MK test statistic V(S), and the related standard normal test statistic (Z) using the approach described in Eq. 4.6-4.9.

$$Z = \begin{bmatrix} \frac{S-1}{\sqrt{V(S)}}, for\ S > 0 \\ 0 \quad for\ s = 0 \\ \frac{S+1}{\sqrt{V(S)}}, for\ S < 0 \end{bmatrix}$$

Equation 4.6

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(X_j - X_i)$$

Equation 4.7

$$sign = \begin{bmatrix} 1\ for\ (X_j - X_i) > 0 \\ 0\ for\ (X_j - X_i) = 0 \\ -1\ for\ (X_j - X_i) < 0 \end{bmatrix}$$

Equation 4.8

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right]$$

Equation 4.9

4.6.Spatiotemporal variations

To analyze the spatiotemporal variations in rainfall and temperature, this research applied a combination of temporal and spatial analysis techniques. First, the Mann-Kendall trend test was used to assess the temporal trends at each station, providing insights into changes over time at specific points. However, because these data are collected at individual stations, they represent isolated points and lack spatial continuity across the entire study area. To address this, spatial interpolation was necessary to estimate trends across the larger area. points (F. Huang et al., 2011). This method estimates values for unsampled locations by assigning higher weights to nearby points, thus capturing spatial trends based on Inverse Distance Weighting (IDW) interpolation was selected for its simplicity and effectiveness in creating spatially continuous surfaces from discrete proximity. The IDW interpolation equation, detailed in Eq. 3.10, illustrates how point-based trend values are spatially distributed across the region. Finally, contour lines were generated to map these trends visually, allowing the magnitude and direction of rainfall and temperature trends to be observed spatially.

$$Z(x) = \frac{\sum_{i=1}^{n} \frac{Z_i}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}} \qquad \textit{Equation 4.10}$$

where:

- $Z(x)$ is the estimated value at the target location x,
- Z_i is the value at the known point i,
- d_i is the distance between the target location x and each known point i,
- p is a power parameter that controls the weight of the distance,
- n is the total number of known points used in the interpolation.

4.7. Data analysis procedure

The data analysis process begins with data collection and preparation, where various datasets, including rainfall, temperature, crop yield data, and qualitative inputs from FGDs and KIIs, are gathered. Afterward, the data undergo essential preprocessing steps, such as filling in missing data points and cleaning, to improve the quality and consistency of the dataset. The next step is climate variability analysis. This involves analyzing cleaned rainfall and temperature data using key indicators like the Coefficient of Variation (CV), Standardized Temperature Index (STI), and Standardized Precipitation Index (SPI). Following this, the study conducts temporal trend analysis to identify significant long-term trends in climate data. The Mann-Kendall trend test is applied to the rainfall and temperature data, examining whether there are statistically significant trends over time. The process then moves to spatiotemporal analysis, where spatial interpolation techniques are used to generalize point-specific data across the study area. Given that climate data is typically collected at individual stations, creating a spatially continuous surface is necessary to understand regional trends. Inverse Distance Weighting (IDW) interpolation is employed to extend point data across the area, enabling the visualization of spatial patterns. The temporal variability and ARDL modeling phase integrate climate and crop yield data to explore their relationship. The Autoregressive Distributed Lag (ARDL) model is applied to examine the short-term and long-term impacts of climate variability on crop yields. Additionally, qualitative data analysis of FGDs and KIIs supplements the quantitative findings. Finally, the study undertakes result triangulation and synthesis, where findings from both quantitative and qualitative analyses are combined (Figue 4.3). This triangulation ensures consistency across different data sources, enhancing the reliability of the results.

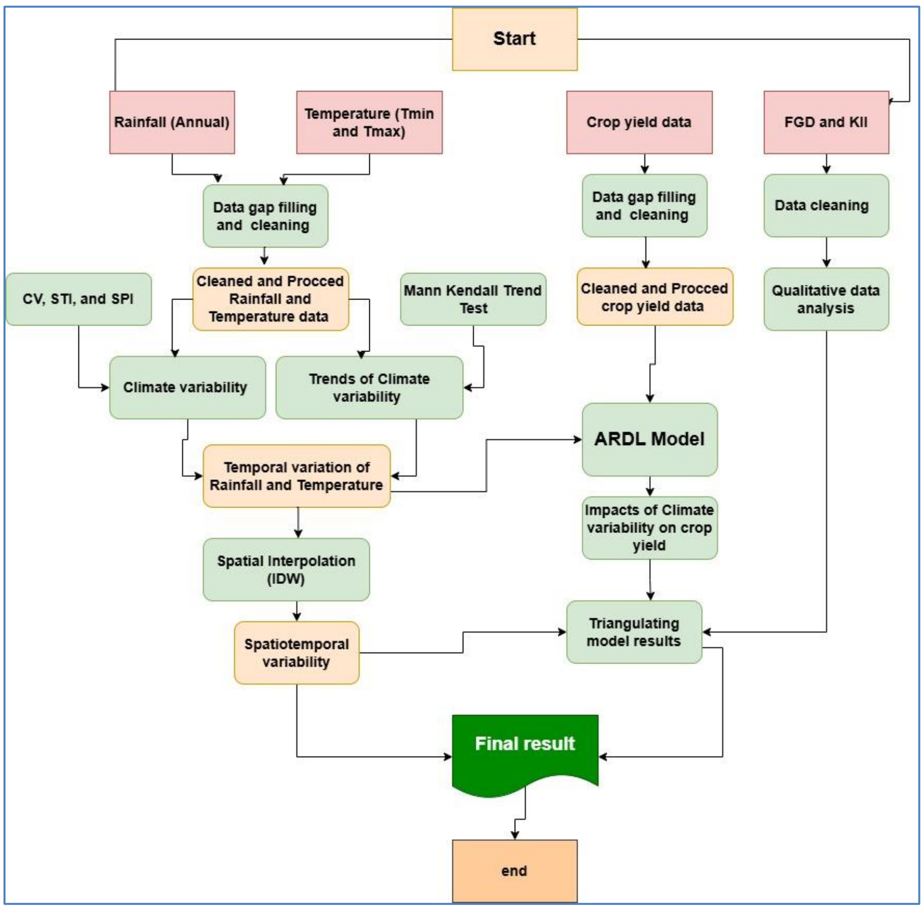


Figure 4.3: Methodological flowchart developed by the author based on literature review

4.8.Results

4.8.1. Variability and trend in maximum and minimum temperatures

Maximum temperature variability and trends

The analysis of mean maximum temperature variations over the Metekel Zone from 1981 to 2019 reveals significant warming trends across multiple seasons and on an annual basis. Table

4.2 shows that Winter and Spring exhibit the most pronounced increases, with trends of 0.33°C and 0.24°C per decade, respectively, both highly significant ($p = 0.005$ and $p = 0.001$). Autumn also shows a significant warming trend of 0.31°C per decade ($p = 0.031$), while summer exhibits only a slight increase of 0.04°C per decade, which is not statistically significant ($p = 0.735$). On an annual basis, the mean maximum temperature has increased by 0.33°C per decade ($p = 0.001$), reflecting an overall steady rise in maximum daytime temperatures over the 38-year period (Table 4.3).

These results align with broader trends observed at both the national and regional levels. (Deressa et al., 2009) highlighted a significant increase in mean maximum temperatures across Ethiopia, with rates of 0.25°C to 0.35°C per decade from the 1980s onward. These findings are comparable to the warming trends in Metekel, particularly during Winter and Autumn, where temperatures have increased by 0.33°C and 0.31°C per decade, respectively. The study emphasized that this rise in temperatures has had severe impacts on agriculture, especially in drought-prone areas, leading to reduced crop yields and water scarcity. Further support for these findings comes from (Berihun et al., 2023), who examined temperature trends across Ethiopia. Their research showed that mean maximum temperatures in the region have been increasing by 0.3°C to 0.4°C per decade over the past four decades. This rate of warming is consistent with the trends observed in the Metekel Zone, particularly on an annual scale, where the temperature has risen by 0.33°C per decade. The study linked these rising temperatures to reduced agricultural productivity, particularly in areas reliant on rain-fed agriculture, and highlighted the need for improved climate adaptation strategies. Another relevant study by (Setegn et al., 2011) focused on the impacts of climate change in Western Ethiopia, where temperature increases of 0.28°C to 0.34°C per decade were observed in different parts of the region (Figure 4.4). These findings closely align with the trends seen in Metekel, especially during Spring and Winter.

Table 4.2: Mean Maximum temperature variation over time

Season	Kendall's tau	p-value	Sen's slope/Year	Sen's slope/Decade
Winter	0.312	**0.005**	0.033	0.33
Autumn	0.242	**0.031**	0.031	0.31
Summer	0.039	0.735	0.004	0.04
Spring	0.366	**0.001**	0.024	0.24
Annual	0.358	**0.001**	0.033	0.33

Figure 4.4: Temporal variation of mean maximum temperature over the past decades (1981-2019) in Metekel Zone

Minimum temperature variability and trends

The analysis of mean minimum temperature variations over the Metekel Zone from 1981 to 2019 reveals significant warming trends on both seasonal and annual scales (Figure 4.5 and Table 4.3). On a seasonal basis, Autumn and Spring exhibited the most notable increases in mean minimum temperatures, with trends of 0.27°C and 0.19°C per decade, respectively, both significant at $p < 0.05$. These findings suggest that these two seasons are experiencing substantial warming in nighttime temperatures. On an annual scale, the mean minimum temperature showed a significant increase of 0.31°C per decade, indicating a steady warming trend throughout the entire period. Breaking down the seasonal trends further, Winter and Summer exhibited relatively lower trends in mean minimum temperatures, with Winter showing a non-significant increase of 0.06°C per decade (p = 0.498) and Summer an increase of 0.08°C per decade (p = 0.161). While these trends are not statistically significant, they still point to a general pattern of rising minimum temperatures across all seasons, with Autumn and Spring experiencing the most pronounced warming. These results align with national reports and scientific research findings. The Ethiopian National Meteorological Agency has reported rising temperatures across Ethiopia at rates of 0.2 to 0.3°C per decade over the past five decades. This is consistent with the warming rates observed in the Metekel Zone, particularly in Autumn and Spring, where minimum temperatures increased by 0.27°C and 0.19°C per decade. Moreover, scientific studies support these findings. Research by Alemayehu et al. (2022) identified significant increases in minimum temperatures in Northern Ethiopia, with trends of 0.25°C to 0.35°C per decade from the 1980s to 2015. Similarly, (Gebrechorkos et al., 2019) found that mean minimum temperatures across East Africa have been rising by 0.3°C to 0.4°C per decade, which aligns with the trends observed in Metekel.

The spatial variations of mean minimum temperature across the Metekel Zone reveal significant seasonal and annual trends, with clear warming in the northern and central regions, contrasted by cooling in the southern parts (Figure 4.6). During Winter (Figure 4.6a), the northern and western regions exhibit substantial warming, with temperature increases ranging from 0.6°C to 1.6°C per decade. This significant temperature rise is consistent with findings from (Worku et al., 2019), who identified warming trends in Ethiopia's northern highlands during dry seasons, attributed to changing global climate patterns. However, the southern part of Metekel shows a cooling trend, with significant temperature decreases of around -1.2°C per decade. This cooling, while less common, is also reported in specific localized studies, such as (Abdel-Hameed & El-Sayed El-Mahdy, 2021), who observed that certain regions experience microclimatic variations due to topography, land cover, and hydrological factors.

Table 4.3: Mean Minimum temperature variation

Season	Kendall's tau	p-value	Sen's slope/Year	Sen's slope/Decade
Winter	0.077	0.498	0.006	0.06
Autumn	0.300	**0.008**	0.027	0.27
Summer	0.158	0.161	0.008	0.08
Spring	0.330	**0.003**	0.019	0.19
Annual	0.038	**0.0074**	0.031	0.31

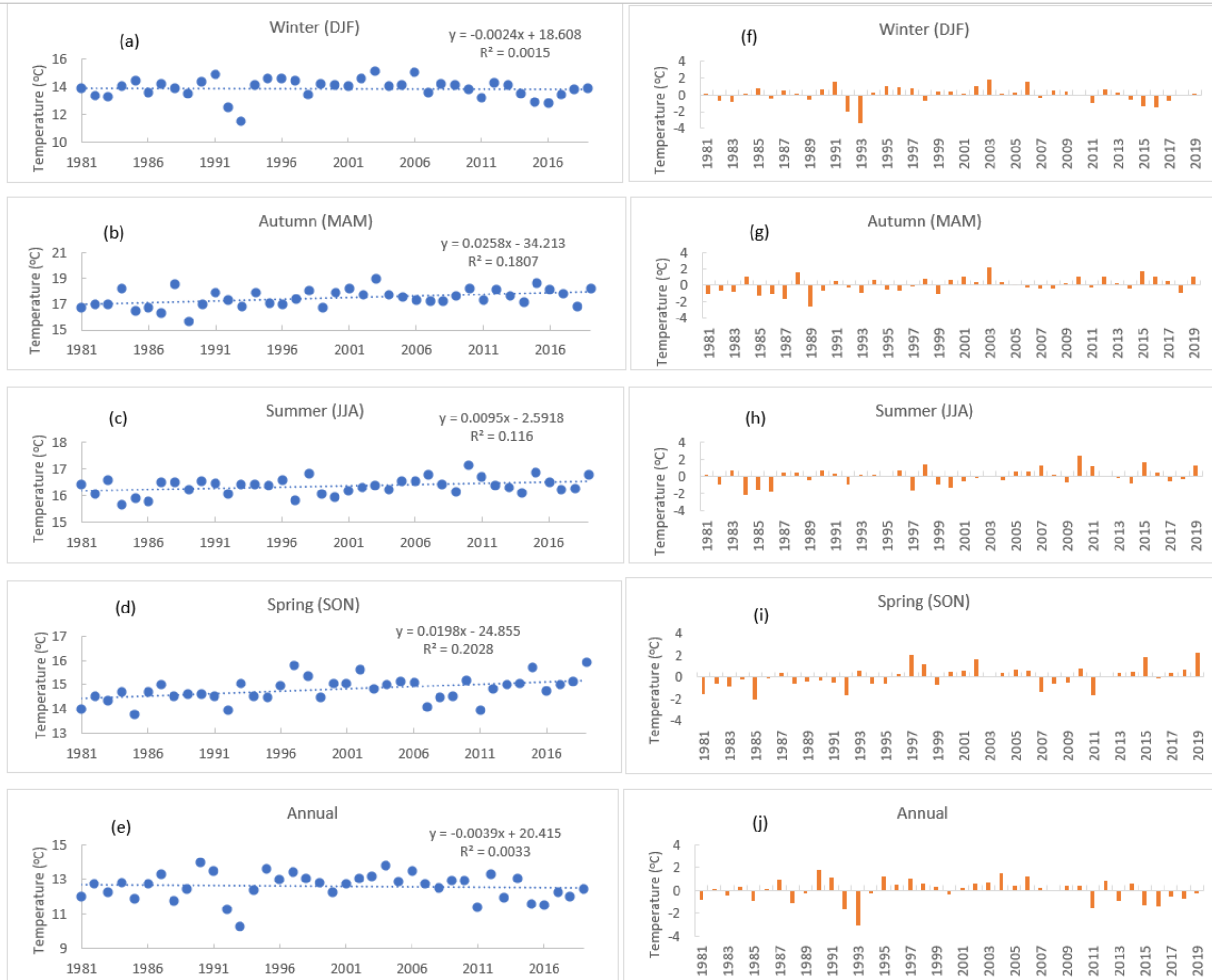


Figure 4.5: Temporal variation of mean minimum temperature over the past decades (1981-2019) in Metekel Zone

In Autumn (Figure 4-6b), the warming trend continues in the northern regions, where temperatures increase up to 1.8°C per decade, aligning with national reports of rising temperatures during the post-rainy season across Ethiopia. Studies such as (Kourouma et al., 2022) document similar trends in northern Ethiopia, where the post-rainy season has experienced consistent warming over the past few decades. Conversely, the southern regions continue to show cooling, with decreases of -1.2°C per decade. During Summer (Figure 4.6c), mean minimum temperatures are relatively stable across the Metekel Zone, with only modest warming trends of 0.4°C per decade in the northern parts. The absence of significant warming during the summer season contrasts with broader findings from (Asfaw & Neka, 2017), which identified rising summer temperatures in other parts of Ethiopia, particularly in lowland areas.

In Spring (Figure 4.6d), significant warming is observed again in the northern and central parts of the zone, with temperature increases between 1.4°C and 1.8°C per decade. Similar patterns of warming have been reported in the Ethiopian highlands by (Amare & Simane, 2017), who attributed these trends to both global climate change and deforestation. However, the southern parts of Metekel show strong cooling, with a marked decrease of -1.7°C per decade. On an annual basis (Figure 4.6e), the mean minimum temperature shows a consistent warming trend in the northern and central regions of Metekel, with increases of up to 2.3°C per decade. These findings are in line with (IPCC, 2023) reports on the general warming of East Africa, where minimum temperatures are rising more rapidly than maximum temperatures, particularly in higher altitudes. The southern parts of the Metekel Zone, however, continue to exhibit significant cooling, with annual temperature decreases of -1.6°C to -1.7°C per decade.

The spatiotemporal trends in mean maximum temperature across the Metekel Zone, as depicted in Figure 4.7, illustrate varying warming patterns with distinct regional and seasonal variations. In Winter (Figure 4.7a), the warming trend is particularly pronounced in the northern and central parts of the Metekel Zone, with increases in mean maximum temperature reaching up to 1.5°C per decade. The southern regions exhibit a cooling trend of up to -0.8°C per decade. During Autumn (Figure 4.7b), the northern and central parts continue to show substantial warming, with increases of up to 1.7°C per decade. This pattern is supported by (B. Getachew et al., 2021), who observed that the warming trend during the transitional seasons is consistent with broader climate change projections for East Africa. The southern regions, however, experience a cooling trend of -1.1°C per decade.

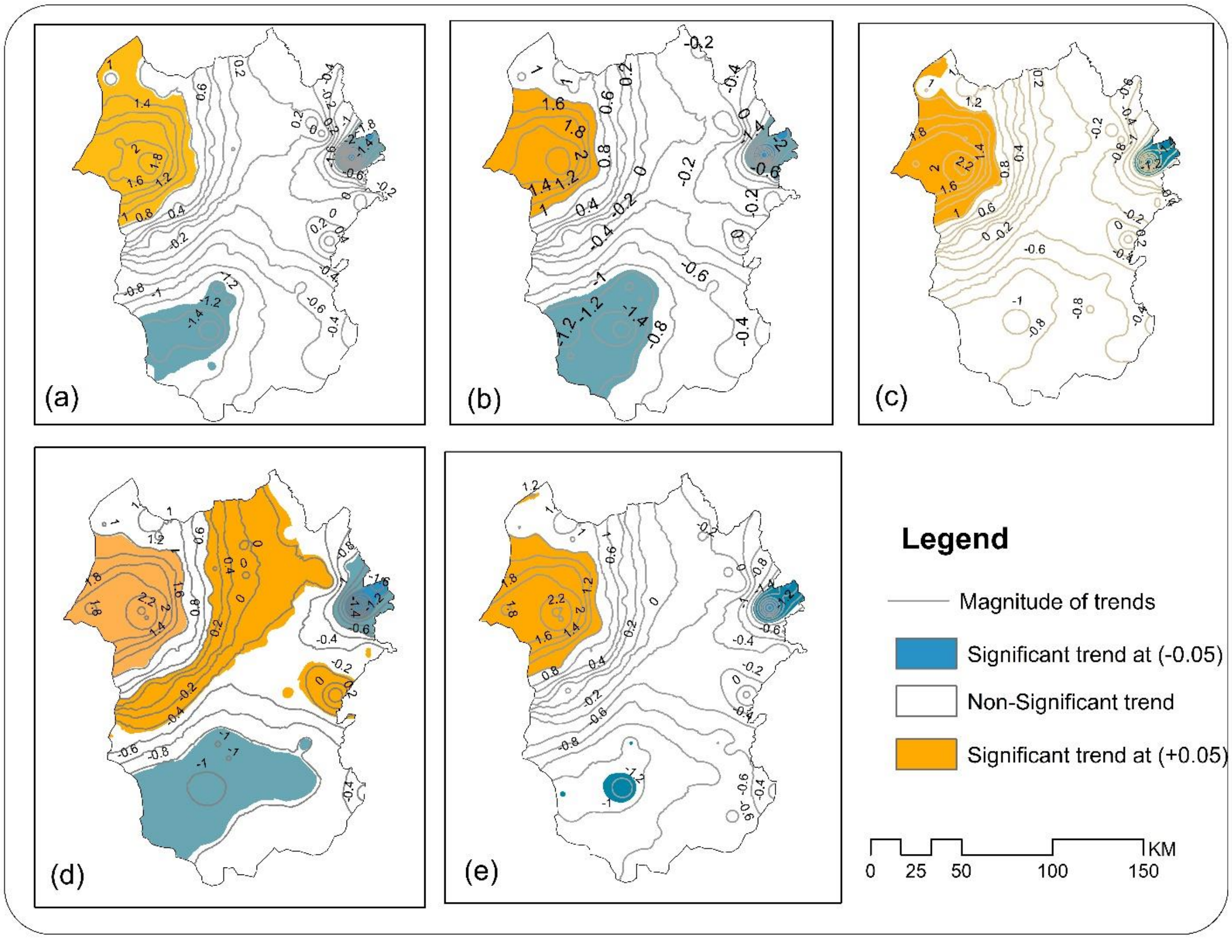


Figure 4.6: Spatiotemporal trends in mean minimum temperature (a) Winter (DJF); (b) Autumn (MAM); (c) Summer (JJA); (d) Spring (SON); (e) Annual

In Summer (Figure 4.7c), the temperature trends are less pronounced, with the northern and central regions showing moderate increases of 0.9°C per decade. This stability is consistent with (Fazzini et al., 2015), who noted that summer temperatures in Ethiopia have shown less variability compared to other seasons. In Spring (Figure 4.7d), significant warming is observed in the northern and central parts, with temperature increases reaching 1.8°C per decade. The southern part of the zone shows cooling of -1.3°C per decade. On an annual scale (Figure 4.7e), the warming trend is evident across the northern and central regions, with increases of up to 1.8°C per decade. This broad warming aligns with the (Sharma & Ravindranath, 2019) assessment, which identifies significant warming trends in East Africa. The southern regions exhibit a cooling trend of -1.0°C per decade. Studies by (Bezu, 2020) have highlighted similar regional cooling trends in parts of Ethiopia due to localized environmental changes.

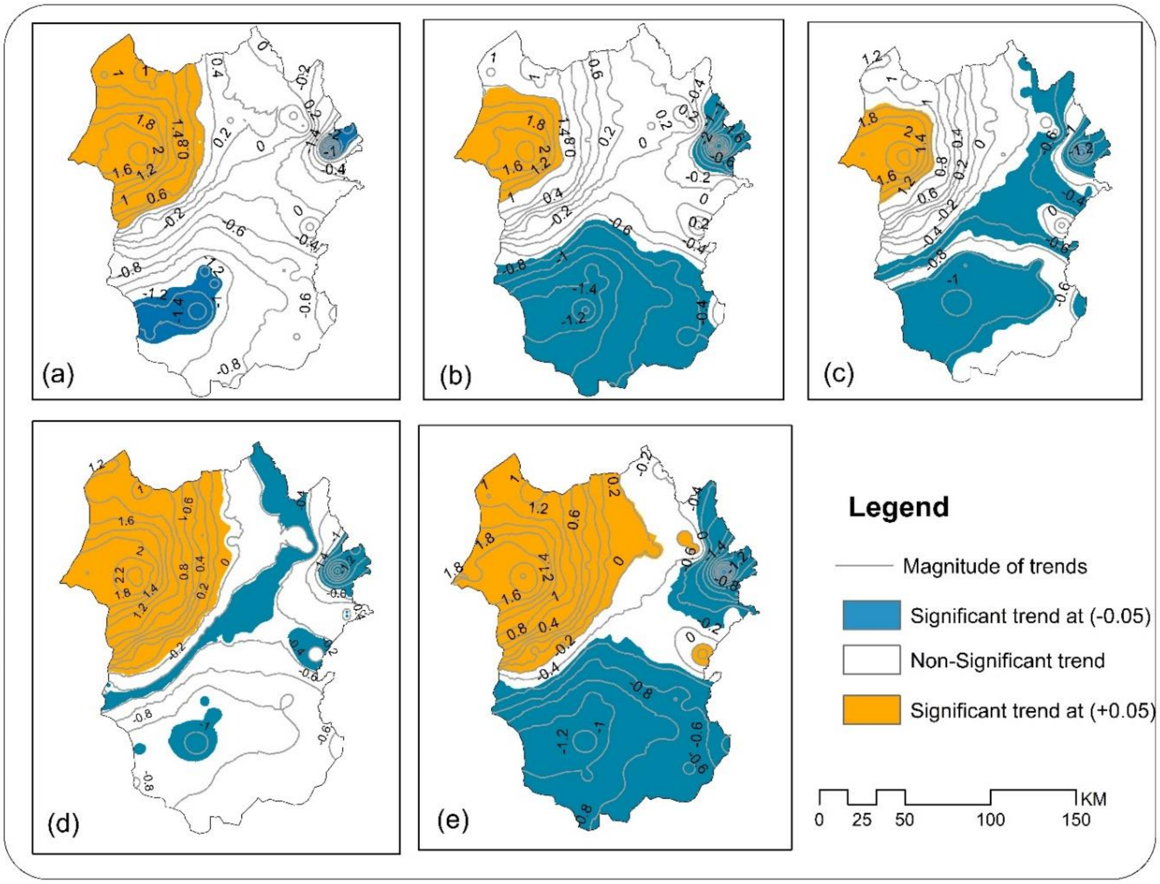


Figure 4.7: Spatiotemporal trends in mean maximum temperature (a) Winter (DJF); (b) Autumn (MAM); (c) Summer (JJA); (d) Spring (SON); (e) Annual

4.8.2. Agroecological based analysis

The spatiotemporal variation of minimum and maximum temperatures over different agro-ecological zones in the Metekel Zone, as presented in Table 4.4, reveals distinct patterns of warming, particularly in maximum temperatures. The results indicate that while minimum temperatures show weak and statistically insignificant trends, maximum temperatures exhibit stronger, significant warming trends across all agro-ecological zones (Figure 4.8). The minimum temperature trend in this zone shows a Kendall's tau of 0.066, with a p-value of 0.561, indicating no significant change in the minimum temperature over time (Figure 4.9). The Sen's slope value of 0.07 suggests a very slight upward trend, but this is not statistically meaningful. However, the maximum temperature shows a significant increasing trend, with a Kendall’s tau of 0.382 and a p-value of 0.001, reflecting a clear warming pattern. The Sen’s slope of 0.34°C per decade indicates a notable increase in maximum temperatures. This warming is consistent with the findings of (Gebrechorkos et al., 2019), who observed significant increases in maximum temperatures in Ethiopia's highlands due to global warming and reduced cloud cover during the dry season, which increases surface heating.

Similarly, in the Tepid Sub-humid Mid Highlands, minimum temperature trends are weak (Kendall's tau of 0.070 and p-value of 0.537), with an insignificant Sen's slope of 0.09°C per decade. The maximum temperature, however, shows a significant positive trend (Kendall's tau of 0.326 and p-value of 0.004), with a Sen's slope of 0.34°C per decade. This result suggests that maximum temperatures in the mid-highlands are rising at a substantial rate, which is in line with (Brown et al., 2017), who reported a similar increase in maximum temperatures in Ethiopia's highland regions, attributing this trend to increased greenhouse gas emissions and changes in local radiative properties.

In the Warm Moist Lowlands, the minimum temperature trend is even weaker, with a Kendall's tau of 0.030 and a p-value of 0.799, indicating no significant change in minimum temperatures. The Sen's slope of 0.05°C per decade further confirms the lack of substantial warming in minimum temperatures. Conversely, the maximum temperature trend is significant, with a Kendall's tau of 0.293 and a p-value of 0.009, and a Sen's slope of 0.31°C per decade. This suggests that the maximum temperatures in the lowlands are increasing, consistent with findings by (Segele et al., 2015), who documented rising maximum temperatures in lowland regions of Ethiopia, increased by the reduced cooling effects of vegetation and increased solar radiation.

In the Warm Sub-humid Lowlands, the minimum temperature trend is similarly insignificant (Kendall's tau of 0.026 and p-value of 0.828), with a very small Sen's slope of 0.03°C per decade. In contrast, the maximum temperature trend is statistically significant, with a Kendall's tau of 0.302, a p-value of 0.007, and a Sen's slope of 0.30°C per decade. This increase in maximum temperatures reflects the warming patterns reported by (Nicholson, 2017), who found that lowland regions in Ethiopia are experiencing more rapid increases in maximum temperatures due to the effects of global climate change, including shifts in atmospheric circulation and increased land surface heating.

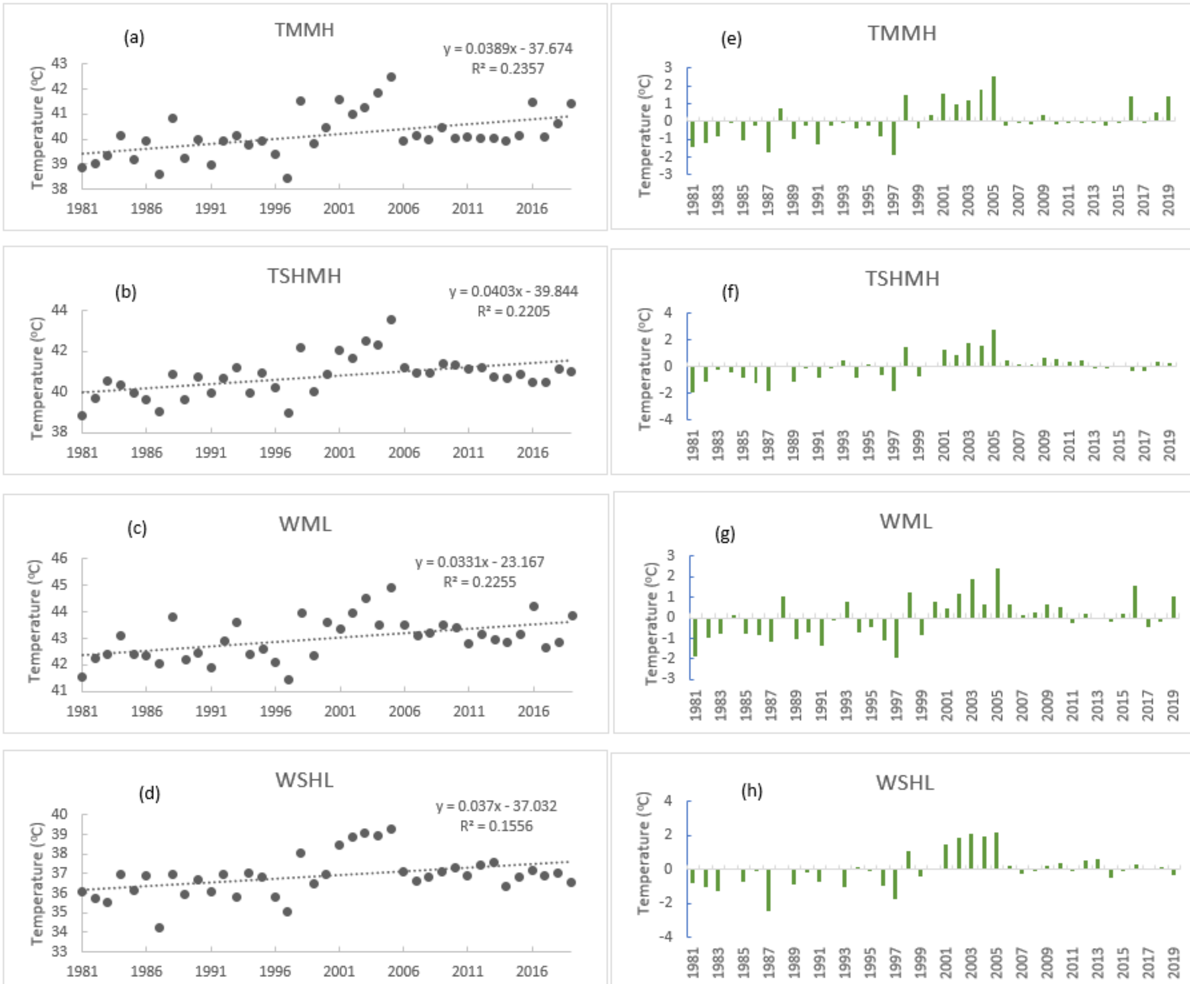


Figure 4.8: Spatial variation of maximum temperature across each agroecology zone

Table 4.4: Spatiotemporal variation of minimum and maximum temperature over each agro-ecological zone

Agroecology	Min/max	Kendall's tau	p-value	Sen's slope
Tepid Moist Mid Highlands	Min	0.066	0.561	0.07
	Max	0.382	**0.001**	0.34
Tepid Sub-humid Mid Highlands	Min	0.070	0.537	0.09
	Max	0.326	**0.004**	0.34
Warm Moist Lowlands	Min	0.030	0.799	0.05
	Max	0.293	**0.009**	0.31
Warm Sub-humid Lowlands	Min	0.026	0.828	0.03
	Max	0.302	**0.007**	0.30

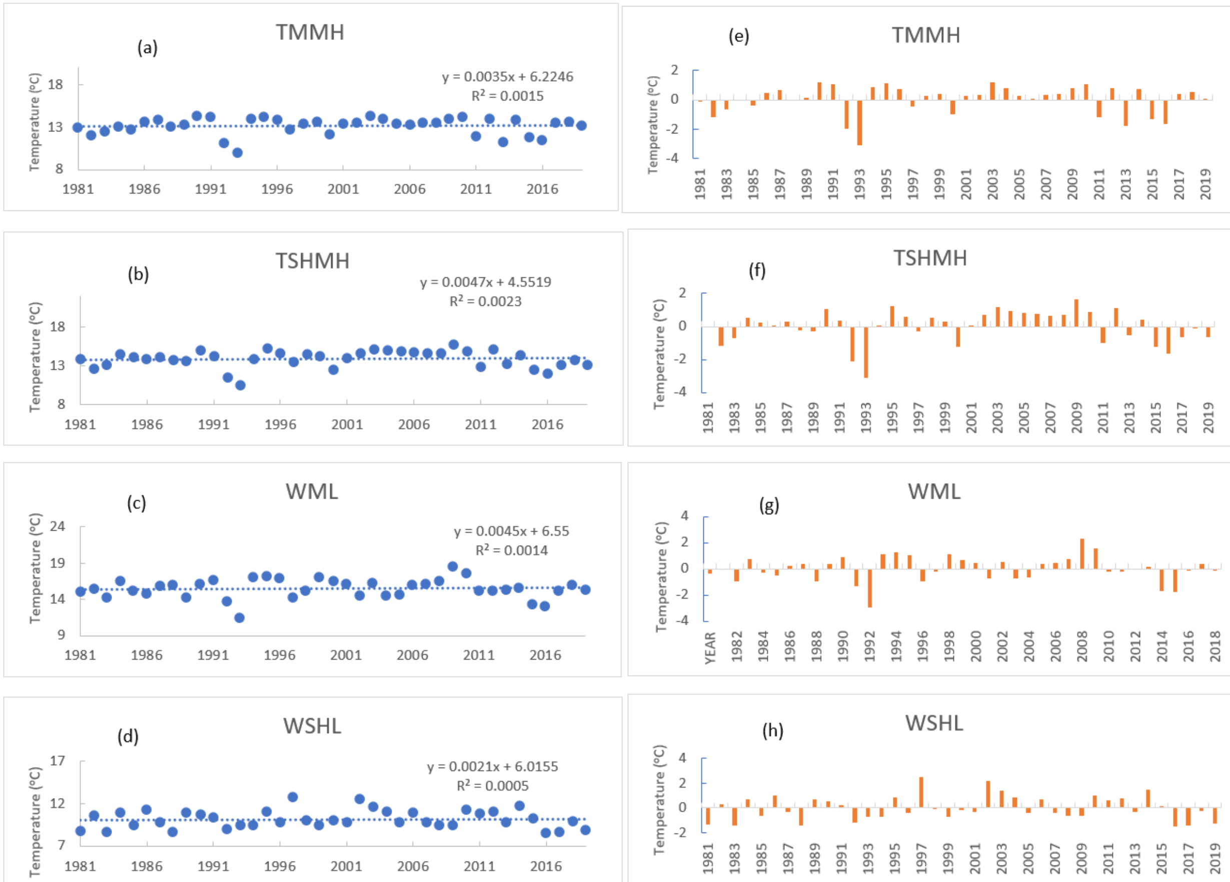


Figure 4.9: Spatial variation of Minimum temperature across each agro-ecological zone

4.8.3. Rainfall variability and trends

The spatiotemporal variation of seasonal and annual rainfall in the Metekel Zone is detailed in Table 4.5 and Figure 4.10. Winter rainfall in the Metekel Zone shows no significant trend over time, with a Kendall's tau of 0.003, a p-value of 0.990, and a Sen's slope of 0.01 mm per decade. This lack of trend indicates that winter precipitation has remained relatively stable. This stability is consistent with findings from (Segele et al., 2015), who reported that winter rainfall in Ethiopia often exhibits minimal variability.

Autumn rainfall demonstrates a significant decline, with Kendall's tau of -0.245, a p-value of 0.029, and a Sen's slope of -3.295 mm per decade. This trend indicates a substantial decrease in precipitation during the autumn months (March-May). The observed decline aligns with broader trends reported by (Meskelu et al., 2024), who noted that rainfall during the Belg season has been decreasing due to shifts in atmospheric circulation and changing climatic conditions.

Summer rainfall also shows a declining trend, with a Kendall's tau of -0.215 and a Sen's slope of -6.922 mm per decade. Although the p-value of 0.056 suggests that this trend is not statistically significant at the conventional 0.05 level, the negative trend still highlights a concerning reduction in summer precipitation. Summer, which includes the Kiremt rainy season (June-August), is critical for agriculture in Ethiopia. Spring rainfall shows a weak and statistically insignificant decreasing trend, with a Kendall's tau of -0.078 and a p-value of 0.498. The Sen's slope of -0.633 mm per decade indicates a very modest reduction in precipitation during the spring months (September-November). On an annual basis, rainfall in the Metekel Zone exhibits a significant decreasing trend, with a Kendall's tau of -0.341 and a p-value of 0.002. The Sen's slope of -5.321 mm per decade reflects a substantial reduction in total annual precipitation.

Table 4.5: Spatiotemporal variation of seasonal and annual rainfall over the study area

Seasonal	Kendall's tau	p-value	Sen's slope/Decade
Winter	0.003	0.990	0.01
Autumn	-0.245	**0.029**	-3.295
Summer	-0.215	0.056	-6.922
Spring	-0.078	0.498	-0.633
Annual	-0.341	**0.002**	-5.321

The analysis of spatiotemporal trends in mean annual rainfall in the Metekel Zone reveals significant seasonal and regional variations. The maps show the rainfall trends for winter, autumn, summer, spring, and annual rainfall patterns (Figure 4.11). These trends indicate marked changes in the spatial distribution of rainfall across different parts of the zone. In the winter season, a significant decreasing trend is observed in the western part of Metekel, while the eastern regions show an increasing trend. This suggests that certain areas are becoming drier, particularly in the west, while others, such as the eastern part, are receiving more rainfall. In autumn, the pattern remains similar, with decreasing trends in the west and increasing trends in the northeast.

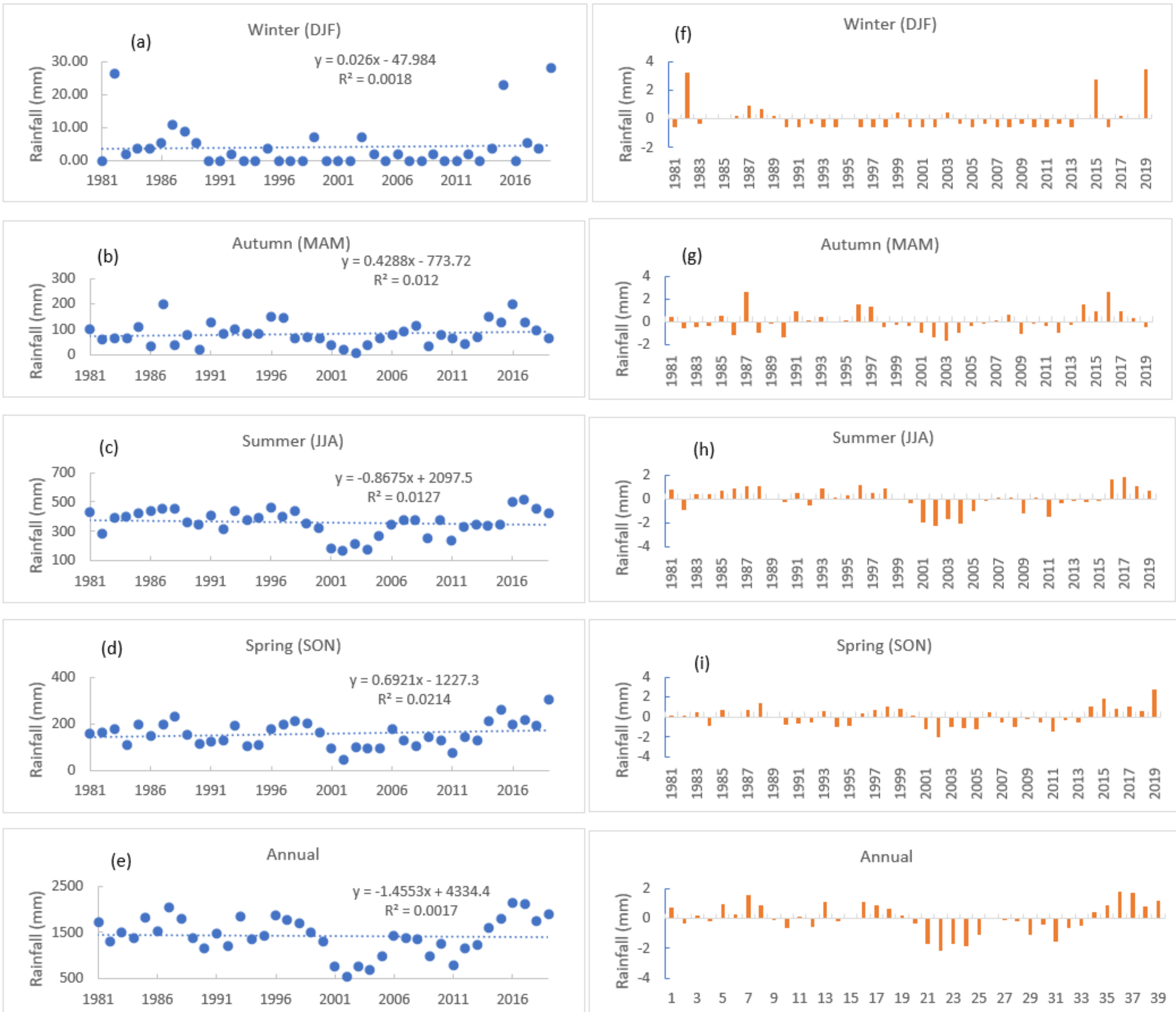


Figure 4.10: Temporal variation in mean annual rainfall in the study area

During the summer season, the central and eastern parts of the zone show significant positive trends, while the west experiences a decline. Summer rainfall, being part of the Kiremt rains, is vital for agricultural productivity in Ethiopia, making these trends important for local farmers. The spring season follows the same pattern, with reductions in the west and increases in the east. The annual trends reveal a significant overall decrease in rainfall in the west and an increase in the east, pointing to a redistribution of rainfall across the study area, where certain areas are receiving less precipitation while others are becoming wetter. The rainfall trends in study area align with broader patterns observed across Ethiopia and the Horn of Africa. The decreasing winter rainfall in the western part of the study area corresponds with findings by (Mekonen & Berlie, 2020), who reported similar reductions in dry-season rainfall across the western highlands of Ethiopia. This is often linked to changes in the Intertropical Convergence Zone (ITCZ) and the weakening of the East African Monsoon.

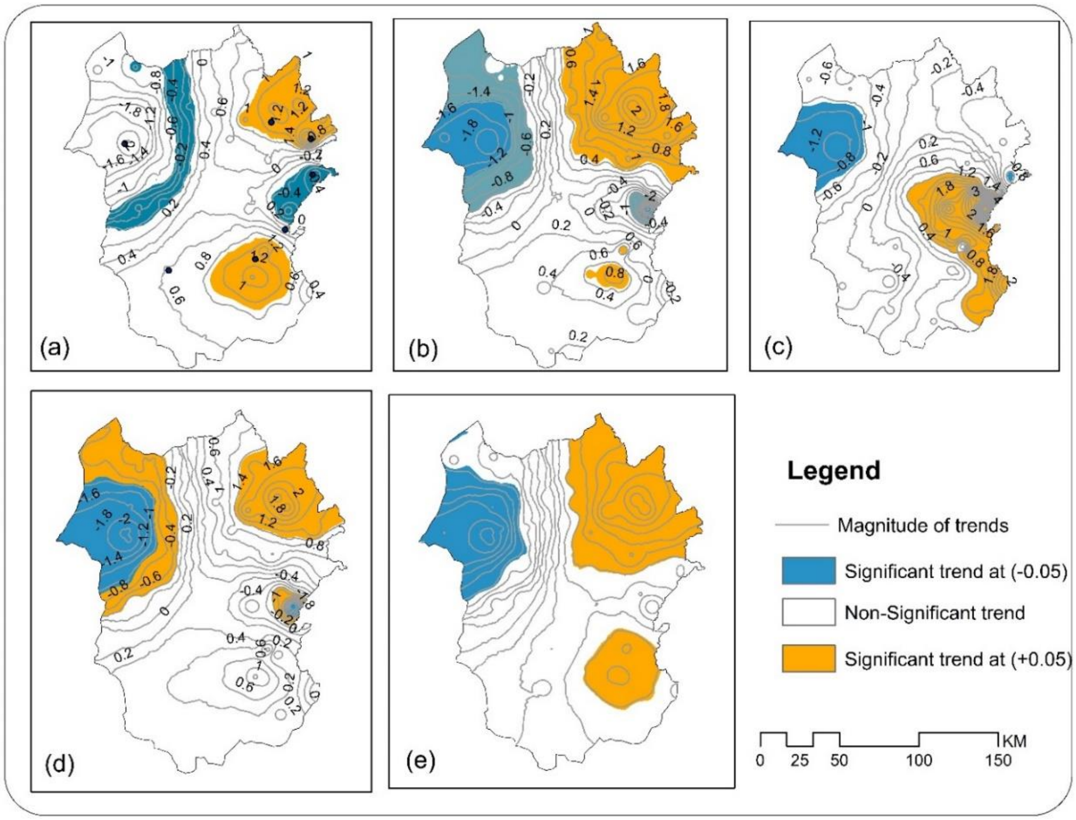


Figure 4.11: Spatiotemporal trends in mean annual rainfall (a) Winter (DJF); (b) Autumn (MAM); (c) Summer (JJA); (d) Spring (SON); (e) Annual

4.8.4. Impacts of climate change on major agricultural crop yield

Descriptive statistics

Table 4.6 summarizes the major crop production in selected districts of the Metekel Zone, focusing on teff, sorghum, and maize. Teff production varies significantly, with Dangur having the highest mean production (59,694.05), while Pawe reports the lowest (107.86). Sorghum production also shows variability, with Dangur producing the highest mean (383,896.57) and Guba the lowest (106,087.73). Maize production is consistently high across the districts, with Dangur leading at 723,127.33 and Guba showing the lowest value (4,187.55).

Table 4.6: Summary of major crop production in Metekel zone of selected districts

	Teff (Quintals)		Sorghum (Quintals)		Maize (Quintals)	
Districts	Mean	STD	Mean	STD	Mean	STD
Dangur	59694.05	8934.01	383896.57	153700.30	723127.33	184315.95
Bullen	44240.28	16822.82	285690.34	80599.24	780338.77	124570.45
Dibate	45477.18	5195.88	475569.32	177034.08	824014.80	124570.45
Mandura	3232.92	1095.97	438132.69	128599.61	765941.83	190926.49
Pawe	107.86	48.58	46545.48	12019.60	710847.43	180699.80
Guba	160.61	66.43	106087.73	9444.35	4187.55	3184.25
Wombera	93708.58	5232.62	132538.00	3079.18	122753.03	55914.36

Test for unit roots trends

The results from the Augmented Dickey-Fuller (ADF) unit root test for the climate variables (T-Min, T-Max, and Rainfall) are presented in Table 4.7. For T-Min (minimum temperature), the test results show that in most of the selected districts, the variable exhibits stationarity at the I (0) level, such as in Dangur, where the T-statistic of -5.05 with a p-value of 0.031 suggests that the minimum temperature is stationary and does not require differencing. This implies that the minimum temperature in Dangur follows a predictable pattern and could have a direct, long-term effect on crop yields. Minimum temperature is particularly crucial for crops like Teff and Maize, where low temperatures can lead to stunted growth or delayed flowering, reducing yields. The significance of minimum temperature on crop yield trends aligns with the findings of (Gray & Brady, 2016), who noted that minimum temperatures have a direct impact on plant development, especially for crops sensitive to temperature fluctuations.

On the other hand, T-Max (maximum temperature) shows a more varied pattern across districts. In Guba, the T-statistic of 0.85 with a p-value of 0.051 suggests that T-Max is not stationary at the I (0) level and requires differencing, indicating that this variable exhibits trends over time. This could reflect temperature extremes, which are increasingly associated with climate change and can significantly affect crop productivity. High maximum temperatures during the growing season can cause heat stress, leading to reduced yields for crops like maize and sorghum.

Rowhani et al. (2011) found that extreme high temperatures during the reproductive stages of crop development often result in severe yield losses, particularly for heat-sensitive crops like maize.

Table 4.7: Trends of Augmented Dicky-Fuller (ADF) unit root test

		Unit root at *I (0)*		Unit root at *I (1)*	
District	Variables	T Stat	P-value	T Stat	P-value
Dangur	Teff	-2.51	0.075	-3.71	0.001
	Maize	-3.17	0.001	-3.61	0.006
	Sorghum	-2.17	0.061	-2.62	0.021
	T-Min	-5.05	0.031	-2.14	0.068
	T-Max	-4.41	0.081	-3.42	0.078
	Rainfall	-2.01	0.002	-2.86	0.099
Bullen	Teff	-2.17	0.003	-2.91	0.372
	Maize	-2.85	0.007	-5.57	0.008
	Sorghum	-2.84	0.341	-2.78	0.035
	T-Min	-2.48	0.005	-5.05	0.007
	T-Max	-3.24	0.653	-5.08	0.004
	Rainfall	-2.63	0.082	-2.75	0.448
Dibate	Teff	-3.21	0.061	-2.54	0.749
	Maize	-2.17	0.431	-2.83	0.075
	Sorghum	-2.69	0.801	-2.37	0.059
	T-Min	-2.84	0.171	-3.49	0.002
	T-Max	-2.24	0.541	-3.25	0.009
	Rainfall	-2.95	0.911	-3.71	0.002
Mandura	Teff	-2.76	0.731	-3.19	0.061
	Maize	-1.93	0.531	-2.76	0.079
	Sorghum	-3.13	0.331	-4.04	0.004
	T-Min	-0.56	0.131	-3.41	0.005
	T-Max	-0.56	0.069	-4.07	0.001
	Rainfall	-0.69	0.269	-3.06	0.003
Pawe	Teff	-0.51	0.085	-2.95	0.035
	Maize	-2.39	0.326	-4.23	0.005
	Sorghum	-5.43	0.001	-8.66	0.003
	T-Min	0.44	0.316	-4.87	0.006
	T-Max	1.95	0.274	-3.74	0.213
	Rainfall	-0.87	0.312	-2.89	0.987
Guba	Teff	-4.64	0.003	-2.69	0.874
	Maize	-2.28	0.001	-2.76	0.657
	Sorghum	-2.72	0.641	-2.97	0.165
	T-Min	-0.06	0.732	0.52	0.318
	T-Max	0.85	0.051	-3.62	0.005
	Rainfall	1.49	0.337	-0.52	0.184
Wombera	Teff	-3.01	0.005	-4.32	0.001

Maize	-2.03	0.571	-3.11	0.006
Sorghum	1.73	0.064	-3.69	0.063
T-Min	-1.49	0.272	-3.35	0.651
T-Max	-1.49	0.301	-2.62	0.001
Rainfall	-1.49	0.331	-3.47	0.003

Finally, Rainfall shows mixed stationarity results across the districts. In Dangur, the rainfall data is stationary at I (1) (T-statistic of -2.01 with a p-value of 0.002), suggesting that the rainfall variable requires differencing to account for long-term trends. This could indicate that rainfall patterns are subject to variability and shifts over time, which can profoundly impact crop yields. Erratic rainfall, especially in the form of delayed or excessive precipitation, can cause soil erosion, nutrient leaching, and flooding, all of which negatively affect crop production (Rao et al., 2015). Conversely, insufficient rainfall can lead to drought stress, limiting water availability for crops. Studies like (Farooq et al., 2011) emphasize the importance of stable rainfall patterns for maintaining crop yields, particularly in regions dependent on rainfed agriculture like the Metekel zone.

ARDL long-run bounds test

The results of the ARDL (Autoregressive Distributed Lag) long-run bounds test presented in Table 4.8. The F-statistics are a key indicator in the bounds test, assessing whether a long-run relationship exists between the variables. In Mandura, the highest F-statistic of 6.182 (with R^2 of 0.8504 and adjusted R^2 of 0.8360) indicates a strong and statistically significant long-run relationship between the variables, suggesting that the climate variables have a substantial long-term impact on crop yields in this district. On the other hand, in Wombera, the lowest F-statistic of 3.321 (with R^2 of 0.6330 and adjusted R^2 of 0.6121) points to a weaker, but still statistically significant, long-run relationship between the variables. The relatively lower R^2 and adjusted R^2 values in Wombera suggest that other factors, potentially socio-economic, influence crop yields, in addition to the climate variables considered in this study.

Districts such as Bullen ($R^2 = 0.8122$) and Mandura ($R^2 = 0.8504$) have high explanatory power, implying that the model captures most of the variability in crop yields through the climate variables. These districts experience significant and consistent changes in temperature or rainfall, which are reflected in the crop yield patterns over time. In contrast, districts like Dibate ($R^2 = 0.6901$) and Wombera ($R^2 = 0.6330$) show relatively lower R^2 values, suggesting that the model is less effective in explaining yield variations in these areas, possibly due to more complex or variable climate conditions, or the influence of other unaccounted factors (Sharma et al., 2023).

Table 4.8: ARDL long-run bounds test

District	F-Statistics	R^2	Adj R^2
Dangur	5.6233	0.7561	0.7420
Bullen	4.4532	0.8122	0.7981
Dibate	3.7910	0.6901	0.6732
Mandura	6.1821	0.8504	0.8360
Pawe	5.0025	0.7103	0.6925
Guba	4.9344	0.7202	0.7012
Wombera	3.3213	0.6330	0.6121

4.8.4.1.Short-term and long-term relationships between climate factors and crop yield

Table 4.9 presents long-term and short-term effects of climate factors on crop yield for each district. For the long-term effects (lagged variables), it is evident that temperature, particularly minimum temperature (T-min), plays a significant role in influencing crop yield. For instance, in Dangur, T-min (t-1) shows a positive relationship with the yield of Teff (coefficient: 1.6542, t-statistic: 6.3421) and Sorghum (coefficient: 0.9845, t-statistic: 6.0122), indicating that higher minimum temperatures in the past year correlate with increased crop yields. This is in line with research by (Hatfield & Prueger, 2015; Luo, 2011), which suggests that moderate increases in minimum temperatures can have positive effects on crops by extending the growing season and increased crop yield. However, the results also highlight negative effects for other crops like Maize in Dangur (coefficient: -3.8935, t-statistic: -5.7891), where high temperatures appear to hinder yield, which aligns with findings from (Rowhani et al., 2011), showing that extreme heat reduces maize yields.

Rainfall also shows long-term negative effects across most regions. For example, in Dangur, Rainfall (t-1) has a strong negative effect on the yields of Teff, Maize, and Sorghum, with coefficients of -1.6017, -1.0237, and -0.8433, respectively. These findings reflect the sensitivity of these crops to erratic rainfall patterns, corroborating findings from (Sahoo & Moharaj, 2024), who emphasize how unpredictable rainfall can significantly reduce agricultural productivity, especially for rain-fed crops.

When looking at the short-term effects (the first differences of the variables), temperature and rainfall continue to exert significant influence on crop yields. For instance, T-min in Dangur has a positive effect on Teff and Sorghum yields (coefficient: 0.5879, t-statistic: 2.4513 and coefficient: 0.7148, t-statistic: 4.9031, respectively), suggesting that increases in minimum temperature in the short term can positively influence these crops. The positive short-term relationship between T-max and Maize in Dibate (coefficient: 1.4722, t-statistic: 2.5722) is particularly interesting, as it indicates that a short-term increase in maximum temperatures may benefit maize yields. This finding aligns with the work of (Zhao et al., 2017), which highlights that temperature fluctuations can have short-term impacts on yield by accelerating crop growth.

Rainfall in the short term also shows a generally negative effect on most crops, as seen in Dangur and Dibate where ΔlnRainfall has significant negative coefficients, particularly for Teff and Maize. This negative impact of short-term rainfall is consistent with (Lobell & Field, 2007), who discuss how extreme rainfall events, including both droughts and floods, can lead to crop stress, particularly in regions where irrigation is not available, and where crops are dependent on seasonal rainfall.

Table 4.9: Trends to estimate long-term and short-term effects

Variable	Coefficient	t-statistic	Variable	Coefficient	t-statistic
Dangur					
Teff (t−1)	-0.5123	-9.1450 (0.00)	ΔlnTeff	-0.3024	-3.29804 (0.015)
Sorghum (t−1)	0.9845	6.0122 (0.000)	ΔlnSorghum	0.7148	4.9031 (0.000)
Maize (t−1)	-3.8935	-5.7891 (0.000)	ΔlnMaize	-1.0237	-4.7622 (0.019)
T-min (t−1)	1.6542	6.3421 (0.000)	ΔlnT-min	0.5879	2.4513 (0.028)
T-max (t−1)	0.1235	0.2973 (0.762)	ΔlnT-max	1.2032	2.4014 (0.034)
Rainfall (t−1)	-1.6017	-5.6821 (0.000)	ΔlnRainfall	-0.8433	-4.5215 (0.001)
Bullen					
Teff (t−1)	-1.2101	-10.7111 (0.000)	ΔlnTeff	-1.3121	-9.8011 (0.011)
Sorghum (t−1)	-1.6310	-2.6312 (0.015)	ΔlnSorghum	-0.8112	-2.3623 (0.045)
Maize (t−1)	3.9822	0.8313 (0.461)	ΔlnMaize	12.1233	5.0214 (0.000)
T-min (t−1)	0.7123	2.3212 (0.040)	ΔlnT-min	1.3121	3.1621 (0.038)
T-max (t−1)	0.7721	1.0160(0.389)	ΔlnT-max	0.7325	0.9013 (0.485)
Rainfall (t−1)	-0.6321	-2.5812 (0.012)	ΔlnRainfall	-0.7810	-2.6314

					(0.001)
Dibate					
Teff (t−1)	-0.8740	-8.4111 (0.000)	ΔlnTeff	-0.4020	-4.1121 (0.018)
Sorghum (t−1)	1.1224	4.8712 (0.000)	ΔlnSorghum	0.9213	5.3410 (0.000)
Maize (t−1)	-2.6514	-6.1025 (0.000)	ΔlnMaize	-1.2140	-3.9821 (0.021)
T-min (t−1)	1.4722	6.0091 (0.000)	ΔlnT-min	0.6636	2.5016 (0.024)
T-max (t−1)	0.1875	0.4022 (0.712)	ΔlnT-max	1.4722	2.5722 (0.030)
Rainfall (t−1)	-1.2336	-5.3221 (0.000)	ΔlnRainfall	-0.8924	-4.7121 (0.002)
Mandura					
Teff (t−1)	-0.9110	-9.4321 (0.000)	ΔlnTeff	-0.5121	-3.8323 (0.023)
Sorghum (t−1)	1.2013	6.1030 (0.000)	ΔlnSorghum	0.8320	5.2014 (0.000)
Maize (t−1)	-4.0151	-5.1322 (0.000)	ΔlnMaize	-1.5427	-4.2015 (0.015)
T-min (t−1)	1.6828	5.9821 (0.000)	ΔlnT-min	0.5736	2.7217 (0.027)
T-max (t−1)	0.1120	0.2672 (0.798)	ΔlnT-max	1.3028	2.4022 (0.033)
Rainfall (t−1)	-1.4929	-5.3824 (0.000)	ΔlnRainfall	-0.9321	-4.5324 (0.000)
Pawe					
Teff (t−1)	-1.1211	-10.6124 (0.000)	ΔlnTeff	-1.1420	-9.5320 (0.011)
Sorghum (t−1)	-1.4319	-2.6125 (0.013)	ΔlnSorghum	-0.9120	-2.1923 (0.037)
Maize (t−1)	2.7216	0.7313 (0.482)	ΔlnMaize	11.7214	4.8122 (0.000)
T-min (t−1)	0.8324	2.4211 (0.036)	ΔlnT-min	1.2323	2.9221 (0.041)
T-max (t−1)	0.8913	0.9116 (0.372)	ΔlnT-max	0.8722	0.9413 (0.464)
Rainfall (t−1)	-0.6523	-2.6017 (0.010)	ΔlnRainfall	-0.6827	-2.6924 (0.001)
Guba					
Teff (t−1)	-0.8502	-8.9203 (0.000)	ΔlnTeff	-1.0132	-7.9511 (0.001)
Sorghum (t−1)	1.1501	5.3804 (0.000)	ΔlnSorghum	-0.7486	-2.5031 (0.023)
Maize (t−1)	-3.211	-5.4601 (0.000)	ΔlnMaize	9.5801	6.4570 (0.000)
T-min (t−1)	1.2513	5.2201 (0.000)	ΔlnT-min	1.4708	4.8122 (0.000)
T-max (t−1)	0.4453	0.9400 (0.460)	ΔlnT-max	0.9518	2.3611 (0.028)
Rainfall (t−1)	-1.3521	-6.3207 (0.000)	ΔlnRainfall	-0.9512	-5.0211 (0.000)
Wombera					
Teff (t−1)	-1.1001	-9.5201 (0.011)	ΔlnTeff	-0.9504	-8.7324 (0.000)
Sorghum (t−1)	1.2503	5.5102 (0.000)	ΔlnSorghum	-0.8206	-3.1423

					(0.007)
Maize (t−1)	-2.8506	-6.1121 (0.000)	ΔlnMaize	7.3282	5.9412 (0.000)
T-min (t−1)	1.3521	5.4801 (0.000)	ΔlnT-min	1.0225	3.5122 (0.004)
T-max (t−1)	0.4575	1.0102 (0.459)	ΔlnT-max	0.7111	1.8832 (0.062)
Rainfall (t−1)	-1.4531	-6.5123 (0.000)	ΔlnRainfall	-0.7452	-4.0710 (0.000)

4.8.5. Integrated DPSIR framework for a cause-effect relationship

The FGDs and KIIs identified causal factors, drivers, and their associated impact of climate change on the livelihood of the local community, which can be systematically analyzed using the DPSIR (Drivers, Pressures, State, Impact, and Response) framework (Figure 4.12). This framework is particularly relevant in studying climate change, as it systematically identifies the root causes of environmental changes (drivers and pressures), evaluates their current conditions (state), assesses their impacts, and proposes actionable strategies for mitigation and adaptation (responses) (Martins et al., 2012).

Drivers (D)

The Drivers (D) in the DPSIR framework refer to the socio-economic and demographic factors that cause climate changes. In the Metekel Zone, these drivers are primarily linked to human activities that shape land use and resource exploitation. Based on the findings from the FGDs and KIIs, the primary drivers of environmental degradation in the region include population growth, charcoal production, firewood collection, and policy-driven agricultural expansion.

Increasing population growth and spontaneous resettlements are significant drivers of environmental change in the study area. As the population grows, the demand for agricultural land and fuel wood intensifies, resulting in widespread deforestation and land-use changes. One FGD participant observed, *"The growing population means more land is needed for farming and fuel wood, leading to cutting down forests."* Harte (2007) argued that increasing population density often leads to more intensive agricultural practices and deforestation, which in turn leads to environmental degradation. In addition, (Maja & Ayano, 2021) emphasizes that population growth, especially in rural areas, accelerates resource extraction activities, such as logging and agriculture, which amplify land degradation and increase vulnerability to climate change.

Charcoal production and firewood collection are essential livelihood activities and are significant drivers of environmental degradation. The demand for fuel wood and charcoal has led to extensive deforestation, particularly in districts like Dangure and Guba. Charcoal production, in particular, strips the land of vegetation, reduces forest cover, and worsen soil erosion. This reliance on biomass for energy contributes to the loss of forest resources, which in turn alters the region's microclimate and increases vulnerability to climate change. (Zulu & Richardson, 2013) indicated that charcoal production is a leading cause of deforestation in sub-Saharan Africa, where demand for fuelwood and charcoal is high. Chidumayo & Gumbo, (2013) also noted that the unsustainable harvesting of firewood and charcoal contributes significantly to forest degradation and climate change in many developing countries.

Government policies promoting agricultural expansion are a significant driver of deforestation and land-use change in the study area. Large-scale farming investments have been encouraged to meet the growing demand for food and agricultural products. However, these policies have often overlooked the environmental impacts of forest clearance and land degradation. The expansion of agriculture, particularly commercial farming, has led to large-scale land conversions, further exacerbating deforestation, soil erosion, and the loss of biodiversity. (Lencucha et al., 2020) confirmed that agricultural policies promoting cash crop production and large-scale farming contribute significantly to deforestation and land degradation in tropical regions.

Pressures (P)

In the DPSIR framework, Pressures (P) refer to the direct effects of socio-economic drivers that stress the environment. These pressures are the result of human activities such as deforestation, overgrazing, unsustainable agricultural practices, and resource extraction. In the case of the Metekel Zone, several significant pressures were identified through FGDs and KIIs. These include deforestation for agriculture, overgrazing, monocropping, chemical use, and wildfires.

Deforestation, primarily driven by agricultural expansion, stands out as one of the most critical environmental challenges in the study area. Participants in the FGDs and KIIs highlighted that the conversion of forests into agricultural land has significantly disrupted ecosystems and heightened the region's susceptibility to climate change and variability. This process has led to a decline in biodiversity, soil nutrient depletion, and alterations in local weather patterns. Wahelo et al. (2025) corroborates these findings, emphasizing that deforestation in the Metekel Zone is a prominent issue, further intensified by agricultural expansion and charcoal production.

Overgrazing by livestock is another critical pressure in the study area. The FGDs revealed that excessive grazing has led to soil compaction, reduced vegetation cover, and increased erosion Overgrazing reduces the ability of the land to recover and supports a vicious cycle of land degradation. Kairis et al. (2015) found that overgrazing accelerates soil degradation by reducing vegetation cover and increasing the vulnerability of soil to erosion. The reduction in soil fertility and increased erosion caused by overgrazing make it difficult for the land to recover and continue supporting productive agriculture (Pimentel & Burgess, 2013).

Monocropping, particularly the repeated cultivation of maize, and intensive tillage are significant pressures in the study area. Participants in the FGDs highlighted that planting the same crop year after year depletes soil nutrients, while deep plowing worsen soil erosion. This practice forces farmers to rely on chemical fertilizers to maintain yields, which further degrades soil quality. Monocropping and intensive tillage have long been recognized as pressures in the study area particularly in Pawe district that degrade soil health. Jacques & Jacques (2012) explains that monocropping depletes soil organic matter, making the land more vulnerable to erosion and less productive in the long run. Additionally, intensive tillage disrupts soil structure, reducing its capacity to retain water and organic matter, further accelerating soil degradation (Lal, 2015).

The use of chemical fertilizers and pesticides in farming practices was significant pressure in the study area. FGDs revealed that the unregulated use of these chemicals leads to soil degradation and water pollution. One participant explained, *"Runoff from fertilizers pollutes our rivers, killing fish and affecting aquatic life."* The excessive application of chemical fertilizers reduces soil biodiversity and the ability of the soil to retain nutrients, while pesticides harm beneficial organisms, such as pollinators. Rashmi et al. (2020) found that the excessive use of fertilizers leads to water pollution, eutrophication, and a decline in soil quality. Weldeslassie et al. (2017) also highlights that the overuse of chemical inputs reduces soil biodiversity and disrupts ecosystems, making it harder for the land to support healthy crops.

Wildfires, often intensified by land degradation and climate variability, are another growing pressure in the study area. Participants in the FGDs reported that uncontrolled fires destroy natural vegetation and contribute to carbon emissions, which further intensify climate change and variability. One KII respondent noted, *"The frequent fires and deforestation have created an atmosphere where temperatures are rising."* Wildfires destroy soil structure, reduce vegetation cover, and release carbon dioxide into the atmosphere. According to Chidumayo & Gumbo (2013), wildfires release greenhouse gases and contribute to deforestation, while also exacerbating land degradation. Wildfires also reduce soil fertility by destroying organic matter, making it difficult for land to support crops in the future (Datta, 2021).

State (S)

In the DPSIR framework, the State (S) refers to the current condition of the environment resulting from the cumulative pressures exerted by human activities. In the Metekel Zone, the State is characterized by significant environmental degradation, including land degradation, loss of vegetation cover, climate variability, and water scarcity. The findings from FGDs and KIIs reveal how these environmental conditions are directly impacting local livelihoods, agriculture, and community resilience.

Land degradation, marked by soil fertility decline, compaction, and erosion, is a major environmental challenge in the study area. Participants in the FGDs described the soil as becoming increasingly "hard and unproductive," with even rainfall failing to support crop growth. As one FGD participant noted, *"When we look at the overall impact of these unsustainable practices, it is clear that our soil is losing its richness."* This is a direct consequence of pressures such as overgrazing, monocropping, and deforestation in the Pawe, Mandura, and Dangure districts. Angon et al. (2023) argues that intensive agricultural practices, such as monocropping and excessive tilling, lead to the depletion of soil organic matter, which reduces soil fertility and increases the vulnerability of land to erosion. Similarly, overgrazing contributes to soil compaction and erosion, making it difficult for the land to regenerate (Centeri, 2022).

The loss of vegetation cover, particularly forests, is another prominent feature of the State in the Metekel Zone. The FGDs and KIIs revealed that large-scale deforestation, driven by agricultural expansion and charcoal production, has significantly reduced forest cover. The destruction of forests has significant ecological consequences in the study area. Sheil (2018) highlighted that forests are crucial in regulating local and global climates, maintaining biodiversity, and stabilizing the water cycle. Moreover, Nguyen-Le (2022) indicated that deforestation has contributed to climate instability and disrupted the natural balance of ecosystems, further exacerbating environmental challenges.

Climate variability in the Metekel Zone is characterized by rising temperatures, erratic rainfall, and prolonged droughts. As noted in the FGDs, local communities have observed significant changes in weather patterns, with rainfall becoming increasingly unpredictable. One participant shared, *"We are seeing a shift in seasonal rainfall, which directly affects crop yields and makes it difficult for farmers to plan their planting and harvesting schedules."* This variability poses significant challenges to agriculture, which is the backbone of the local economy. Leng & Hall (2019) found that changing rainfall patterns and rising temperatures are key drivers of reduced agricultural productivity and increased vulnerability to droughts. In the Metekel Zone, these climate changes have made agriculture less predictable and have intensified food insecurity.

Impact (I)

In the DPSIR framework, Impact (I) refers to the effects of environmental degradation on ecosystems, human health, and livelihoods. In the Metekel Zone, the state of environmental decline driven by pressures such as deforestation, overgrazing, and monocropping has resulted in several significant impacts on local communities. These include declining agricultural productivity and livelihood vulnerability.

One of the most immediate and visible impacts of environmental degradation in the Metekel Zone is the decline in agricultural productivity. Participants in the FGDs and KIIs observed that crop yields, particularly maize, have decreased due to poor soil quality, erosion, and unpredictable weather patterns. The combined effects of soil erosion, nutrient depletion, and erratic rainfall have made farming increasingly difficult and less reliable. Gomiero (2016) argued that soil degradation, driven by monocropping and intensive farming, directly impacts crop yields. Additionally, (Hossain et al., 2020) pointed out that reduced soil fertility and soil erosion undermine long-term agricultural productivity, contributing to food insecurity and economic instability in rural areas.

The environmental changes in the study area have increased the vulnerability of local livelihoods. Farmers, facing declining yields and eroding soil quality, are increasingly turning to unsustainable practices, such as expanding farmland into forested areas. This reliance on unsustainable farming methods contributes to a downward spiral of environmental degradation, which, in turn, reduces agricultural productivity. The increasing vulnerability of agricultural livelihoods due to environmental degradation is a common theme in global studies. Byerlee et al.

(2014) found that the intensification of land use, driven by economic necessity, often leads to deforestation and further environmental degradation. These practices create a cycle where land degradation reduces long-term agricultural potential, undermining livelihoods (Wehkamp et al., 2015).

Responses (R)

In the DPSIR framework, Response (R) represents the actions and strategies implemented to mitigate environmental impacts, reduce pressures, and adapt to the changing climate. In the Metekel Zone, various adaptation strategies have been adopted by local communities to cope with the challenges posed by climate change. These strategies, deeply rooted in traditional knowledge and supported by modern agricultural techniques, aim to improve soil health, enhance crop resilience, conserve water, and promote sustainable farming practices.

Traditional practices, including animal manure application, terracing, and zero tillage, are fundamental responses in the districts of Pawe, Guba, and Dangur. These practices address soil degradation, improve fertility, and enhance water retention. Animal manure enriches the soil with essential nutrients like nitrogen and potassium while improving its structure and water-holding capacity, particularly in semi-arid areas prone to drought. Diacono & Montemurro (2011) emphasizes that organic inputs such as manure enhance soil fertility and support long-term productivity. Terracing, widely practiced in the highlands of Guba and Dangur, prevents soil erosion by creating flat levels on slopes, reducing water runoff, and conserving moisture. Chen et al. (2017) found that terracing significantly improves soil and water conservation in sloped agricultural areas. Similarly, zero tillage, adopted in Mandura and Dangur, minimizes soil disturbance, preserves organic matter, and reduces erosion, making it a vital adaptation technique in semi-arid regions (Lahmar et al., 2012).

Farmers across Pawe, Guba, and Mandura have embraced drought-resistant and early-maturing crop varieties to adapt to shorter growing seasons and irregular rainfall. Millet, teff, and sorghum are particularly effective, as they require less water and withstand higher temperatures. Research institutions like the Pawe Agricultural Research Centre have introduced improved varieties of rice, soybean, and mung bean, which are pest-resistant and yield more than traditional crops. Srinivasa Rao et al. (2016) underline that adopting climate-resilient crops enhances food security by stabilizing yields under adverse conditions. These new varieties have reduced vulnerability to environmental changes, ensuring consistent agricultural output and supporting household income.

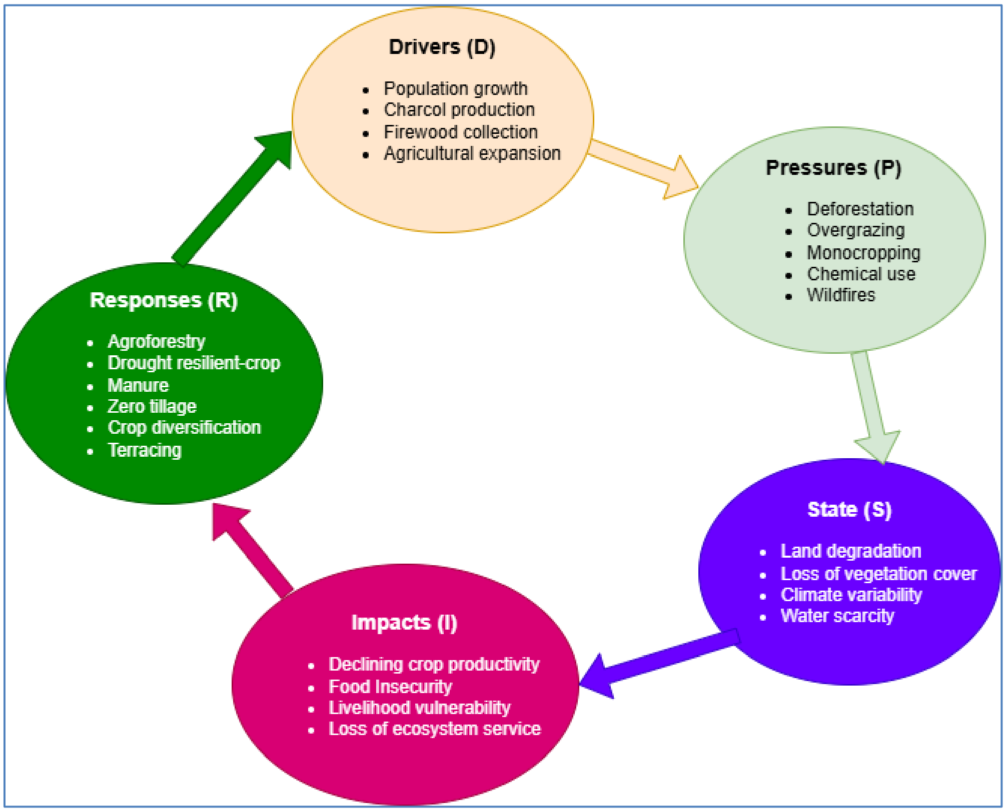


Figure 4.12: DPSIR framework of the study that correlates cause-and-effect relationship developed by the author based on literature review

In districts like Pawe, Guba, and Dangur, crop diversification has emerged as a key strategy for risk mitigation. By planting a variety of crops such as rice, millet, sorghum, groundnut, and papaya, farmers distribute the risks posed by climate variability. This strategy ensures that at least some crops thrive even during unfavorable weather conditions. Agroforestry and mixed farming systems are widely practiced in Guba, Pawe, and Dangur, combining crops, trees, and livestock into integrated systems. Agroforestry enhances soil fertility, reduces erosion, and stabilizes local microclimates by providing shade and retaining moisture. Mbow et al. (2014) highlights the role of agroforestry in mitigating climate impacts by improving ecosystem services and supporting sustainable agriculture. Mixed farming systems complement agroforestry by creating a symbiotic relationship between crops and livestock. Livestock manure serves as an organic fertilizer, enriching soil fertility, while crop residues provide feed for animals.

Communities in the Metekel Zone have identified several future strategies, including reforestation, wildfire prevention, and controlled grazing, to further enhance resilience. Reforestation aims to restore degraded lands, stabilize the climate, and improve water retention, while wildfire prevention protects natural vegetation and agricultural lands. Controlled grazing involves managing livestock densities to allow vegetation recovery and prevent overgrazing. Policy reforms are also critical to supporting these responses. Policies promoting sustainable agricultural practices, regulating resource use, and encouraging reforestation will play a crucial role in scaling up adaptation efforts across the Metekel Zone.

4.8.6. Discussion

Our research findings revealed significant warming trends in both maximum and minimum temperatures, especially in Winter and Autumn, from 1981 to 2019. This observation aligns with numerous studies on climate change in Ethiopia, where rising temperatures have been observed in many regions, particularly in the highlands. For instance, (Berihun et al., 2023; Deressa et al., 2009) report warming trends across Ethiopia, with a rise of approximately 0.25°C to 0.35°C per decade since the 1980s. These findings are in agreement with our research findings, which show a consistent increase in maximum and minimum temperatures in Metekel, particularly during critical growing seasons like Winter and Autumn. However, there are some variations between regions. While our study shows the most pronounced warming in Winter and Autumn, Setegn et al. (2011) observed a more consistent warming trend across all seasons in Western Ethiopia, which could be due to differences in geographical and climatic conditions. This discrepancy highlights that while broader regional trends are evident, local variations in temperature patterns can exist, influenced by topography, land cover, and elevation (Pepin et al., 2022). The increase in temperatures observed in Metekel also resonates with global findings on climate change. Rowhani et al. (2011) argue that rising temperatures lead to increased heat stress, particularly for crops like maize and sorghum. Our results indicate a general warming of both Minimum and maximum temperatures, which are consistent with studies that find minimum temperatures, in particular, are crucial for crop development.

Our analysis of rainfall variability indicates a significant reduction in rainfall, particularly in the Autumn and Summer seasons. This finding aligns with broader trends documented by (Funk et al., 2015), who observed a decline in rainfall, particularly during the Kiremt (Summer) and Belg

(Spring) seasons. These reductions are attributed to shifts in atmospheric circulation patterns, such as the weakening of the Intertropical Convergence Zone (ITCZ) and changes in the East African Monsoon. Our study contributes to this body of literature by confirming the observed decreases in rainfall during these critical seasons in Metekel Zone. Interestingly, while our findings report a regional decrease in rainfall, particularly in the western parts of Metekel zone, (Kiros et al., 2016) documented more complex rainfall shifts across Ethiopia, with some areas experiencing localized increases. Mekonen & Berlie (2020) also reported that parts of North Eastern Ethiopia have experienced increases in rainfall during the Kiremt season. This contrast with our findings reflects regional microclimatic effects or local climatic anomalies, which can create varying rainfall patterns even within the same region. This contrast also by (Vinayak et al., 2022) who argues the regional microclimate has an impact on local climate and resulting in rainfall variability.

The impacts of temperature and rainfall trends on crop production are a central focus of our research. We found significant variability in crop yields, especially for teff, sorghum, and maize, across districts in Metekel zone. This variability is linked to the observed climatic changes, with reduced rainfall and rising temperatures leading to water stress and heat stress for crops. Rosenzweig et al. (2014) documented similar trends, emphasizing how erratic rainfall and extreme temperatures significantly reduce yields, particularly for rain-fed crops like maize and sorghum. Our findings, showing that areas like Dangur report the highest crop yields, contrast with areas like Guba, where yields are much lower. This pattern aligns with studies such as (Rowhani et al., 2011), who suggest that areas with better access to water resources (through rainfall) are likely to show better crop productivity. However, our results also reveal that even in regions like Dangur, where yields are higher, temperature and rainfall variability can still pose a risk to long-term agricultural sustainability, as seen in the correlation between crop yield variability and climatic trends. (Hatfield & Prueger, 2015; Linderholm, 2006) found that moderate increases in minimum temperatures can enhance crop growth and yield, which aligns with the principle that warmer minimum temperatures can extend the growing season and improve photosynthetic efficiency. However, our research suggests that this is not always the case, as extreme heat during the reproductive phase of crops, such as maize, can result in yield reductions. This finding is in agreement with (LI et al., 2022; Waqas et al., 2021), who highlighted the negative impact of heat stress during critical crop stages, especially for heat-sensitive crops like maize.

The DPSIR framework analysis of the Metekel Zone highlights drivers such as population growth, resettlements, and policy-driven agricultural expansion, consistent with findings from (Lambin & Meyfroidt, 2011), which emphasize deforestation and land-use change due to economic pressures. However, the Metekel Zone uniquely identifies subsistence activities like charcoal production and firewood collection as critical drivers, diverging from industrial logging-dominated studies in other regions (Chidumayo & Gumbo, 2013). Pressures such as deforestation, overgrazing, and monocropping align with (P. Smith et al., 2016) findings on soil degradation but reveal localized challenges, including the adverse effects of unmanaged chemical fertilizer use, contrasting with (Tao et al., 2015), who advocates for its combined use with organic inputs. The degraded state of land in the zone, marked by reduced soil fertility and water scarcity, parallels global findings on deforestation's impact on hydrological cycles (Bonan, 2008), but the region's semi-arid conditions worsen these issues. The impacts on livelihoods, particularly declining crop yields and food insecurity, align with (Connolly-Boutin & Smit, 2016) but differ from regions with better irrigation infrastructure, as highlighted by (Gleick et al., 2011). Responses such as agroforestry, crop diversification, and water conservation mirror global strategies (Gaffney et al., 2019) but reflect a reliance on traditional practices like zero tillage and extended fallowing, less common in regions with high agricultural intensification (Baudron et al., 2012). These findings underscore the universal relevance of sustainable practices while emphasizing the need for localized, community-driven approaches to address resource and climatic constraints.

Our study findings align with international concerns raised by major organizations like the United Nations Framework Convention on Climate Change (UNFCCC), and the Intergovernmental Panel on Climate Change (IPCC). These organizations have long highlighted the importance of addressing the adverse impacts of climate change on agriculture. The UNFCCC and its Paris Agreement stress the need for nations to enhance their climate resilience, with a focus on adaptation to climate impacts, especially in agriculture. Our findings, particularly the increase in temperatures and the decline in rainfall, reflect the very challenges identified by the UNFCCC. The National Adaptation Plans (NAPs) emphasized in the Paris Agreement call for integrating climate change impacts into national development and agricultural planning, which is central to our research. Similarly, the IPCC's (2019) report directly connects climate variability to agriculture, noting how rising temperatures and shifting rainfall patterns threaten crop yields, particularly in rain-fed systems like those in Ethiopia. Our findings on temperature increases, especially in Winter and Autumn, and decreasing rainfall are consistent with the IPCC's projections, which highlight how such trends are likely to aggravate food insecurity (IPCC, 2019). The reduction in rainfall during the critical growing seasons of Autumn and Summer, as identified in our research, mirrors global concerns about the increasing frequency and intensity of droughts. In response to these challenges in Metekel Zone, it is crucial for the local government to strengthen environmental regulations. Enforcing sustainable land-use policies that promote soil conservation and prevent deforestation would mitigate water scarcity and soil degradation, which are exacerbated by the changing climate. Additionally, promoting climate-resilient agricultural practices such as crop diversification and the use of drought-tolerant crops can enhance food security and improve farmers' adaptive capacity.

As a limitation, our study focuses primarily on climatic factors such as temperature and rainfall, but other factors like soil health, pest invasions, and socio-economic variables also play crucial roles in agricultural productivity. Literatures emphasized the need for a more integrated approach that considers not only climate but also other environmental and socio-economic factors. Including such variables would provide a more comprehensive assessment of the risks to agriculture and guide more holistic adaptation strategies. Future research can expand in the exploration of climate-resilient agricultural practices. This could include investigating the effectiveness of drought-tolerant crops, the potential for irrigation systems, and the role of agroforestry in improving water retention in the soil.

4.8.7. Conclusion

The study highlights significant temporal and spatial patterns of climate variability across the Metekel Zone, with notable impacts on agricultural productivity and livelihood of the local community. Findings reveal that both minimum and maximum temperatures have increased over the past 38-years, with winter and spring showing the highest warming rates. This trend is consistent across the northern and central regions experience more pronounced temperature rises than southern areas. In terms of rainfall, the study region exhibits a marked decline in precipitation, particularly during key rainy seasons essential for agriculture. This reduction is most evident in the western part of the study area, where rainfall has become less predictable, while certain eastern areas have experienced slight increases. The spatial analysis shows a clear warming trend in the northern and central parts of the study area, where both minimum and maximum temperatures are rising consistently, while some cooling trends are observed in isolated southern areas. Rainfall patterns also vary spatially, with the western regions seeing a reduction in annual rainfall, while the eastern parts experience relatively stable or increasing rainfall levels. These changing rainfall dynamics have led to increased unpredictability in agricultural planning, affecting crop rotation cycles and water resource management. Temperature increases, especially during the growing season, have been linked to declining soil moisture levels, increased evapotranspiration, and altered phenological cycles of key crops, reducing yields for temperature-sensitive crops like maize, teff and sorghum. The Autoregressive Distributed Lag (ARDL) model affirms the significant long-term relationship between these climate factors and crop yields, emphasizing the critical need for adaptive measures to maintain agricultural productivity. This highlights the necessity for location-specific climate adaptation strategies that consider varying temperature and precipitation trends across the region. The DPSIR framework analysis reveals a complex interplay between socio-economic drivers, such as population growth and agricultural expansion, and environmental pressures like deforestation, overgrazing, and monocropping. These pressures have degraded soil fertility, reduced vegetation cover, and intensified climate variability, leading to significant impacts on agricultural productivity, food security, and livelihoods. Additionally, continued environmental degradation exacerbates feedback loops, where declining soil fertility further compels unsustainable farming practices, perpetuating a cycle of land degradation and reduced productivity. Adaptive responses, including agroforestry, crop diversification, and water conservation, demonstrate the community's resilience and commitment to sustainable practices. However, many of these adaptive responses remain limited in scale due to insufficient institutional support, inadequate access to climate information, and financial constraints faced by local farmers.

To address the significant climate variability observed in the study area, it is crucial develop policies that balance agricultural expansion with environmental conservation. This includes promoting sustainable practices such as controlled grazing, reforestation, and soil conservation techniques. Integrating these policies into national and regional development agendas, alongside ensuring farmer participation in policy formulation, can enhance the effectiveness and local acceptance of adaptation strategies. Strengthening agricultural research and providing the necessary infrastructure will support these efforts, enhancing the resilience of local communities and ensuring long-term environmental and economic sustainability. Future research should focus on evaluating the long-term effectiveness of implemented adaptation measures and exploring innovative climate-smart agricultural techniques tailored to the region's unique climatic and socio-economic conditions.

The findings of this study contribute to the broader literature on climate variability, agricultural sustainability, and socio-environmental interactions in climate-sensitive regions. The observed temperature and rainfall trends align with global climate change projections, reinforcing existing research on the disproportionate impacts of climate variability on developing regions. Furthermore, the study supports previous findings that link climate change to declining crop yields, emphasizing the need for region-specific adaptation measures. The integration of the DPSIR framework provides a valuable methodological approach for analyzing the complex relationships between socio-economic drivers and environmental outcomes, making this study a useful reference for future research on human-environment interactions. Additionally, this study underscores the importance of policies that bridge the gap between scientific research and practical adaptation strategies, offering insights that can inform climate resilience planning in other similar agro-ecological contexts.

CHAPTER FIVE

5. Integrating Deforestation and Climate Change Themes in the Ethiopian Secondary School Geography Curriculum: Toward Action-Orientated Environmental and Sustainability Education

Abstract

The 21st century faces severe environmental challenges such as deforestation and climate change, disproportionately affecting developing countries like Ethiopia. Addressing these complex issues requires transformative education. Geography, as a discipline that explores human–environment relationships, is vital for equipping students with the knowledge, values, and skills for sustainable action. This study examined how Ethiopia's revised secondary school geography curriculum and textbooks integrate deforestation and climate change themes. Guided by Jensen's action-oriented learning framework and the principles of education for sustainable development (ESD), and in alignment with the Ethiopian Ministry of Education's curriculum standards, the study employed a concurrent embedded design, incorporating interviews with teachers, students, and education experts from Metekel Zone, alongside content analysis of curriculum guides and minimum learning competencies (MLCs) for grades 9–12. Findings revealed that climate change receives moderate attention, particularly in upper grades, while deforestation is minimally integrated. Quantitative analysis showed that climate change appears in an average of 8 MLCs (17.8%) and 8 topics (18.6%) out of 45 MLCs and 48 topics, representing a moderate level of inclusion. In contrast, deforestation appears in only 2 MLCs (3.85%) and 2 topics (3.2%), showing weak representation. The MLCs emphasize cognitive outcomes (60.8%) over affective (27.5%) and psychomotor (12.5%) domains, highlighting a focus on knowledge rather than environmental values or practical engagement. The curriculum also lacks contextual relevance and coherence in teaching methods, learning activities and embedded questions. The study concludes that Ethiopia's current geography curriculum does not adequately promote pro-environmental attitudes or practical competencies. It recommends reorienting geography education toward integrated, action-oriented content and pedagogies supported by interdisciplinary methods, locally relevant examples, and experiential learning. Such reforms would empower students to engage meaningfully in sustainable practices and strengthen geography's role in advancing environmental education and sustainability goals in the Global South.

Keywords: Deforestation, Climate Change, Geography Curriculum, Environmental Education, Action-Orientated Learning, Sustainability, textbooks

5.1. Introduction

Throughout human history, the interaction between human activity and the environment has caused significant and long-lasting ecological changes. Nowadays, however, this connection has gotten worse, with climate change and deforestation becoming major environmental issues on a global scale (Dearing et al., 2006; Scharlemann et al., 2020; Wolff & Wiechmann, 2018; Wolff et al., 2018; Zhou & Gu, 2024). Forests are essential for regulating the climate because they store carbon, protect biodiversity, and sustain livelihoods, particularly in developing nations (Bherwani et al., 2024; Cherinet & Lemi, 2023). However, the Food and Agriculture Organisation (FAO, 2020) estimates that logging, infrastructure development, and agricultural growth are the main causes of the world's ongoing annual forest loss of about 10 million hectares. Deforestation is estimated by the Intergovernmental Panel on Climate Change (IPCC, 2023) to account for almost 10% of global carbon emissions, which exacerbates climate change and jeopardizes international efforts to keep temperature increases to 1.5°C over pre-industrial levels.

While these global environmental challenges are well documented, a critical concern lies in how such interconnected issues are conceptually framed and pedagogically integrated within formal education systems, particularly within subject-specific curricula such as secondary school geography. In the Ethiopian context, scholars have emphasized that the education sector plays a critical role in shaping environmental awareness and responsible citizenship, particularly in addressing national environmental challenges such as land degradation, deforestation, and climate variability (Awayehu, 2025; Dalelo, 2012; Wolde, 2008).

Global frameworks that acknowledge these risks include the Paris Agreement (Delbeke et al., 2017), the Sustainable Development Goal (SDG) 15 (Opoku, 2015), and the United Nations Strategic Plan for Forests 2017–2030 (UN, 2017). These frameworks underlined the need to stop deforestation, mitigate climate change, restore degraded ecosystems, and promote sustainable land management. But even with these increasing international efforts, the rate of forest loss and the subsequent climate change is still concerning, especially in the Global South, where it exacerbates ecological vulnerabilities and socioeconomic disparities (FAO, 2020; IPCC, 2023). Researchers advocate strategies such as community-based conservation, afforestation, sustainable land-use practices, and improved policy implementation (Chazdon et al., 2017;

Muttaqin et al., 2019; Reyer et al., 2009; Zomer et al., 2008). Yet, comparatively less attention has been given to examining whether school curricula, particularly geography curricula, frame these strategies as actionable learning experiences or merely as descriptive environmental content. This gap reflects a broader disconnect between environmental policy ambitions and pedagogical practice. Ethiopian educational studies similarly note that although environmental themes appear in school curricula, their pedagogical implementation often remains largely theoretical and insufficiently connected to local environmental realities (Dalelo, 2012).

The cornerstone of these interferences is action-oriented environmental education, which helps to reduce environmental issues like deforestation and climate change by establishing knowledge, influencing attitudes, and encouraging responsible behavior. More precisely, it is becoming more widely acknowledged that incorporating action-oriented environmental education into school curricula is essential to equipping the next generation to effectively address these environmental issues (Ardoin et al., 2020; Byerlee et al., 2014; Dalelo, 2012; Mochizuki & Vickers, 2024; Monroe et al., 2019; Sinakou et al., 2022). This is particularly crucial in secondary education, where students can acquire the abilities, values, and agency necessary to promote long-lasting change in addition to theoretical knowledge (Aminrad et al., 2013). However, the effectiveness of such education depends not merely on the inclusion of environmental topics, but on how coherently they are integrated into curriculum objectives, content sequencing, competency frameworks, and assessment structures.

Africa, which experienced the greatest rate of forest loss worldwide between 2010 and 2020 with an average of 3.94 million hectares disappearing each year, has a particularly urgent need for this (FAO, 2020; UN, 2021; UNDP, 2023). Even though the continent contributes less than 4% of global greenhouse gas emissions, it is simultaneously facing some of the most severe effects of climate change, such as rising temperatures, protracted droughts, and extreme weather events (IPCC, 2023; UNEP, 2021). The impacts of deforestation and climate change have also affected Ethiopia, which is in the Horn of Africa. The amount of forest cover in the nation has drastically decreased, falling from 40% in the early 20th century to less than 15% today (FAO, 2020). Likewise, the effects of climate change are becoming more apparent, as rising temperatures, unpredictable rainfall patterns, protracted droughts, and frequent floods negatively impact agriculture, water availability, and livelihoods, particularly in rural areas that heavily rely on rain-fed farming (Worldbank, 2019). National assessments and environmental reports further indicate that land degradation and deforestation remain among the most serious environmental challenges affecting Ethiopia's economic development and ecosystem sustainability (Gebreselassie et al., 2015).

Numerous national programs have been started in response to repair damaged ecosystems and increase resilience. In order to restore degraded landscapes, the Green Legacy Program was started in 2019 and has since planted over 25 billion trees (Beyene & Shumetie, 2023). The REDD+ framework encourages carbon offsetting and sustainable forest management (Miah, 2021), and Participatory Forest Management (PFM) gives local communities the ability to preserve forest resources (Siraj et al., 2018). Furthermore, the Climate Resilient Green Economy (CRGE) Strategy (Paul & Weinthal, 2019) and Proclamation No. 1065/2018 have institutionalised sustainable development and forest protection at the policy level (FDRE, 2004, 2011). In addition, the Environmental Policy of Ethiopia and the Environment, Forest and Climate Change Commission's national environmental education and awareness strategies emphasize the importance of integrating environmental education into formal schooling and community engagement programs (EFCCC, 2018; EPA, 1997).

Despite these commendable efforts, the scale of forest degradation and the escalating impact of climate change in Ethiopia indicate the urgent need for a more integrated approach, particularly within the formal education system. Secondary school geography, a subject closely linked to these environmental themes, offers a strategic platform for embedding action-orientated learning. However, this potential remains underexplored in the newly revised secondary school geography curriculum of Ethiopia. While deforestation and climate change are included in the policy document and in the curriculum (MoE, 1994, 2023), there is little understanding of whether these topics are framed adequately and in ways that move beyond theoretical instruction to foster critical thinking, attitudinal change, and environmental action.

Additionally, effective action-oriented environmental education must encompass all three domains of learning: cognitive (knowledge acquisition), affective (attitude formation), and psychomotor (skills and action). It must also incorporate learner-centred pedagogies that enhance student participation and real-world application (Jensen, 2002; Jensen & Schnack, 1997).

However, empirical evidence is lacking on the extent to which these pedagogical strategies are integrated into the new Ethiopian secondary school geography curriculum. This gap presents a significant barrier to cultivating environmentally responsible citizens capable of confronting today's urgent ecological challenges.

In response, this study aims to critically analyse the extent to and ways in which deforestation and climate change, two of the contemporary issues and problems, have been actually integrated into the new curriculum guides for Ethiopian schools' geography at secondary levels. Specifically, it examines the degree to which the curriculum aligns with action-orientated learning principles, including the integration of MLCs linked to deforestation and climate change themes and ESD principles that promote action-orientated environmental knowledge and engagement in alignment with the Ethiopian Ministry of Education's curriculum standards. The study further assesses whether the curriculum addresses the three key domains of learning and whether it incorporates student-centred pedagogies suited for fostering environmental sustainability. More significantly, the following research questions were the focus of this study:

1. To what extent are deforestation and climate change issues integrated into the new Ethiopian secondary school geography curriculum?
2. How well do the MLCs developed for deforestation and climate change education in the curriculum reflect action-orientated environmental knowledge and sustainability goals?
3. To what extent does the curriculum emphasize the cognitive, affective, and psychomotor domains of learning in teaching deforestation and climate change?
4. To what extent are appropriate activities and pedagogical strategies for delivering deforestation and climate change lessons incorporated into the Ethiopian secondary school geography curriculum?

5.2.Theoretical Framework of the Study

This study is grounded in a convergence of theoretical models that collectively shape its pedagogical vision and analytical lens. It specifically incorporates concepts from Constructivist and Experiential Learning Theories, Bloom's Taxonomy of Learning Domains, Jensen's Action-Oriented Environmental Learning Model, and the principles of education for sustainable development (ESD). When combined, these frameworks provide a thorough framework for comprehending how deforestation and climate change can be successfully incorporated into geography lessons to encourage students' environmental literacy, values, and action. In line with the Ethiopian Ministry of Education’s curriculum standards (MoE, 2018, 2023), these frameworks also guide the alignment of learning objectives, content, and pedagogical approaches to national educational priorities.

At the core, Jensen (2002) action-oriented environmental education model emphasized on four essential elements that are required to build students' ability to engage meaningfully with the environment. Accordingly, the first dimension of the model is Dimension 1, which addresses the question “What kind of problem is it?” and is grounded in knowledge about effects as its core idea. This dimension focuses on understanding the nature of environmental problems by emphasizing knowledge of their existence, scale, and impacts. It involves recognizing the consequences of issues such as acid rain, declining air quality, workplace pollution, deforestation and its contribution to climate change, land degradation, and related challenges. By enhancing awareness of these effects, this dimension stimulates concern and attention, thereby laying a foundational basis for informed action and behavioral change.

Following the first dimension, Jensen’s action-oriented environmental education model introduces the second dimension, Dimension 2, which asks “Why do we have the problems we have?” and centers on knowledge about root causes. This dimension helps learners explore the deeper reasons behind environmental problems, looking at the social, cultural, and economic factors that influence human behavior and decision-making. By understanding these underlying causes, students can see environmental issues not just as physical events, but as outcomes shaped by the ways societies live, work, and interact with the environment.

Building on the second dimension, Jensen’s action-oriented environmental education model moves to the third dimension, Dimension 3, which asks “How do we change things?” and focuses on knowledge about strategies for change. Here, the focus shifts from understanding problems to finding practical ways to make a difference. It explores how individuals and communities can take action to improve both their own lives and the wider society. This includes mobilizing communities, forming partnerships, engaging in policy advocacy, and fostering cooperative efforts, while also understanding power dynamics, navigating institutions, and working together for collective impact. Drawing from psychological, political, and sociological perspectives, this dimension gives learners the knowledge, tools, and confidence to create and sustain real, positive change in their environment and beyond.

Building on the strategies for change in the third dimension, Jensen’s action-oriented environmental education model introduces the fourth and final dimension, Dimension 4, which asks “Where do we want to go?” and focuses on knowledge about alternatives and visions. This dimension emphasizes the importance of imagining and shaping alternative futures. Beyond understanding problems and solutions, it encourages individuals and communities to develop personal and collective aspirations for a sustainable world. By forming clear and realistic visions for the future, learners gain motivation and a stronger commitment to take meaningful environmental action.

By encouraging student empowerment via involvement, research, and well-informed action, this model goes beyond conventional transmission-based learning (Ardoin et al., 2020; Jensen, 2002)**.** By advocating for transformative education that gives students the competencies such as knowledge, skills, values, and attitudes—necessary to contribute to a sustainable future, ESD enhances this theoretical foundation even more (UNESCO, 2019). Because ESD emphasises interdisciplinary learning, participatory pedagogies, and real-world problem-solving, it is particularly applicable to teaching complex, systemic issues like climate change and deforestation. In order to connect students' learning to local environmental realities and global sustainability goals, ESD also emphasises the significance of contextual relevance (UNESCO, 2014, 2019, 2020, 2021).

Concurrently, Bloom's taxonomy provides a framework for assessing how well learning goals promote students' overall development. It organized cognitive learning objectives into six hierarchical levels such as knowledge, comprehension, application, analysis, synthesis, and evaluation—progressing from basic recall to higher-order judgment. This framework was later updated to align with contemporary educational priorities, renaming the levels as remembering, understanding, applying, analyzing, evaluating, and creating, with a focus on active engagement and the use of action-oriented verbs (Anderson and Krathwohl, 2016). The ability of students to learn and apply knowledge is addressed by the cognitive domain

(Virranmäki et al., 2021), attitudes and values are shaped by the affective domain (Alafnan, 2025), and skills and action are emphasised by the psychomotor domain (Simpson, 1996). Effective environmental education requires the integration of all three domains, enabling students to internalise environmental concern and acquire the practical skills necessary to take action in addition to intellectually understanding environmental issues.

Additionally, the study is influenced by experiential learning and constructivist theories, especially those of David Kolb and John Dewey. According to (Kolb, 1981), active participation and experience with real-world issues are the foundations of authentic learning. The aims of action-oriented environmental education, where students investigate and tackle environmental challenges within their communities, closely align with his belief that education should be grounded in real-life experiences. Building on this, the experiential learning theory developed by (Kolb, 1984) offers a methodical framework for creating educational opportunities that influence behaviour and cognition. A pedagogical guide for involving students in meaningful environmental learning is Kolb's experiential learning cycle, which consists of concrete experience, reflective observation, abstract conceptualisation, and active experimentation. Students engage with environmental realities in this model, think back on their experiences, develop conceptual understandings, and then apply what they have learnt in novel contexts. Students benefit from this iterative process as they progress from awareness to responsible action.

Combining these theoretical elements, the study uses a multi-theoretical framework that sees geography education as a means of promoting agency, critical thinking, and behavior that is focused on sustainability in addition to disseminating environmental knowledge. Through informed, thoughtful, and transformative engagement, learners will be empowered to address the urgent issues of deforestation and climate change. The framework supports an interdisciplinary, participatory, and contextually grounded educational approach that aligns with the Ethiopian Ministry of Education’s curriculum standards ensuring national relevance while fostering global sustainability competencies.

5.3.Conceptual Framework

The conceptual framework guiding this study integrates key constructs from prior research and environmental education theory (Figure 5.1). At the foundational level, the geography curriculum guide, textbooks, and teacher guide for grades 9–12 form the core instructional inputs. These materials determine how deforestation and climate change are represented, guiding what and how teachers teach and students learn. As (Butt, 2011; Dhakal, 2017) note, such curriculum resources shape lesson planning and influence students' ability to "think geographically," thereby enhancing their understanding of environmental issues. According to the authors, in geography education, these materials specifically syllabi, textbooks, and teacher guides play a pivotal role in shaping students' understanding of environmental systems and the interplay between human activity and natural processes. They function not only as carriers of content but also as vehicles for pedagogical guidance, helping educators determine what to teach and how to teach it. For this study, curricular materials are understood to encompass secondary school geography textbooks, teacher guides, and syllabi, particularly as they relate to teaching environmental issues such as deforestation and climate change.

The second construct focuses on content integration across the three learning domains: cognitive (concepts and knowledge), affective (values and attitudes), and psychomotor (skills and practices). This ensures that students not only understand deforestation and climate change but also develop ethical awareness and practical skills to address them (Ardoin et al., 2020).

The third construct emphasizes instructional methodology, contrasting traditional approaches with student-centered pedagogies like PBL, inquiry-based, and experiential learning (Juvova et al., 2015). These methods promote critical thinking, problem-solving, and active engagement with local environmental challenges.

Aligned with Jensen's four action-oriented learning dimensions, the framework examines how well curriculum objectives and MLCs enable students to understand issues, identify causes, explore solutions, and take action. Together, these interlinked components contribute to developing Action-oriented environmental competence, equipping learners to address deforestation and climate change through informed, values-driven, and community-based action.

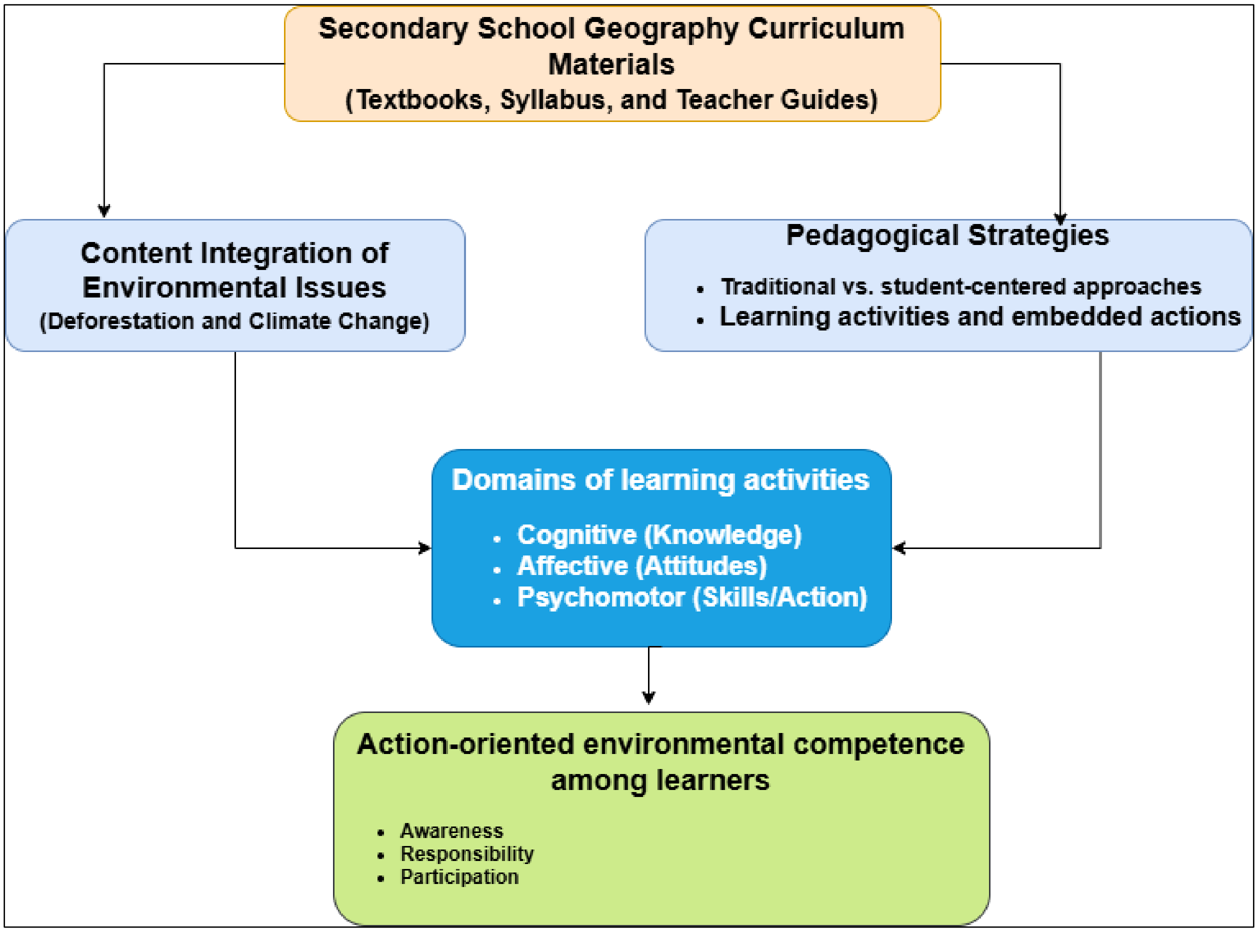


Figure 5.1: Conceptual framework of the study developed by author based on review of related literature

5.4.Research Methodology

5.4.1. Research Approach and Design

This study employed a mixed-methods research approach (Plano, 2017), which was considered the most suitable methodology for investigating the integration of deforestation and climate change within the Ethiopian secondary school geography curriculum guide and textbooks. The mixed methods approach was selected because it enables a more comprehensive and well-rounded exploration of the phenomenon by drawing on the strengths of both qualitative and quantitative data collection and analysis (Schoonenboom & Johnson, 2017). This combination facilitates deeper insight into not only the extent and nature of environmental content coverage related to deforestation and climate change but also the underlying pedagogical intentions and curriculum structure. The complexity of environmental education, particularly as it relates to deforestation and climate change, requires an approach that captures both measurable trends and interpretive meanings. Relying solely on quantitative or qualitative data could have limited the scope of understanding; thus, integrating both approaches helped to balance objectivity with contextual depth and provided a fuller picture of how these global environmental challenges are embedded in the curriculum materials.

Within this mixed methods framework, the study adopted a concurrent embedded research design (Aultman et al., 2018). This design was chosen to systematically gather, organize, and analyze data regarding the current state of content and pedagogical integration. Specifically, the concurrent embedded design facilitated an in-depth examination of how deforestation and climate change themes and the appropriate pedagogical approaches are presented in the curriculum guide and geography textbooks, including the clarity, accuracy, and alignment of MLCs, content depth, and the promotion of cognitive, affective, and action-orientated learning outcomes. By using this design, the study was able to assess not only the presence of environmental themes under investigation but also how well they are contextualized for students' understanding and engagement. Moreover, this design supported the identification of potential gaps or strengths in the curriculum's ability to foster environmental awareness, critical thinking, and problem-solving skills among secondary school students, which are key competencies in addressing climate and deforestation issues at both local and global levels.

5.4.2. Sample Size and Sampling Techniques

This study examined the content and pedagogical approaches of Ethiopia's secondary school geography curriculum guide and textbooks for grades 9–12, developed in 2022 and implemented in 2023. These materials were purposefully selected for their recent development, relevance, and alignment with national priorities addressing pressing environmental issues such as deforestation and climate change.

Four main reasons guided the selection of these instructional materials. First, the 2022/2023 curriculum guide and textbooks reflect updated pedagogical principles and contemporary environmental concerns. Second, geography materials present clearly defined objectives, MLCs, teaching methods, and learning activities, making them suitable for analyzing how deforestation and climate change are integrated. Third, the researcher's expertise in geography and environmental education provided deeper insight into curriculum interpretation and implementation. Lastly, geography's interdisciplinary nature makes it particularly suited to investigating environmental themes.

To complement the document analysis, qualitative data were collected through semi-structured interviews with 10 geography teachers, 8 students, and 4 education experts from the Metekel Zone (Table 5.1). Participants were drawn from seven districts such as Wombera, Dibati, Bullen, Dangur, Pawe, Mandura, and Guba using purposive and convenience sampling. Purposive sampling ensured inclusion of those directly involved in curriculum implementation, while convenience sampling considered proximity for logistical feasibility. Efforts were made to capture diversity in school's location, experience, and administrative level to ensure representativeness.

Ethical standards, including informed consent and confidentiality, were strictly maintained. Reliability and validity were enhanced through inter-coder reliability checks (Cohen's kappa = 0.82) and member validation, confirming coding accuracy and thematic consistency. This multi-source approach ensured robust triangulation between curriculum analysis and field-based insights, strengthening the study's overall credibility.

Table 5.1: Demographic Distribution of Key Informants in the Study

Participant Code	Position	Gender	Age	Education Level	Work Experience (Years)
Teacher 1	Geography Teacher	Male	35	B.Ed. in Geography	10
Teacher 2	Geography Teacher	Female	29	B.Ed. in Geography	18
Teacher 3	Geography Teacher	Male	41	B.Ed. in Geography	16
Teacher 4	Geography Teacher	Female	31	MA. in Geography and Environmental studies	8
Teacher 5	Geography Teacher	Female	29	B.Ed. in Geography	6
Teacher 6	Geography Teacher	Male	30	B.Ed. in Geography	6

Teacher 7	Geography Teacher	Malee	34	MA. in Geography and Environmental studies	8
Teacher 8	Geography Teacher	Female	42	B.Ed. in Geography	12
Teacher 9	Geography Teacher	Male	28	B.Ed. in Geography	5
Teacher 10	Geography Teacher	Male	41	B.Ed. in Geography	
Student 1	Secondary School Student	Female	19	Grade 12	-
Student 2	Secondary School Student	Male	18	Grade 11	-
Student 3	Secondary School Student	Male	16	Grade 9	-
Student 4	Secondary School Student	Male	17	Grade 10	-
Student 5	Secondary School Student	Male	17	Grade 10	-
Student 6	Secondary School Student	Male	18	Grade 11	-
Student 7	Secondary School Student	Female	20	Grade 12	-
Student 8	Secondary School Student	Female	19	Grade 12	-
Education expert 1	Education Expert (Zonal)	Male	39	MA in Curriculum studies	16
Education expert 2	Education Expert (Zonal)	Male	46	MA in Educational Planning	20
Education expert 3	Education Expert (District)	Female	38	MA in Geography Education	14
Education expert 4	Education Expert (District)	Male	33	B.Ed. in Geography	9

5.4.3. Data Collection: Document Review Process

In this study, document review was employed as the principal method of data collection to examine the integration of deforestation and climate change issues within the newly developed Ethiopian secondary school geography curricula. Document review is particularly well-suited for curriculum analysis, as it allows for the systematic evaluation of existing instructional materials, policy texts, and educational frameworks without influencing the phenomenon under investigation (Darling-Hammond et al., 2020). This approach aligns with the study's objective to critically assess the extent to which secondary school geography curricula reflect action-orientated environmental education and support transformative learning aligned with sustainable development goals.

The process of data collection in this study followed a multi-step procedure to ensure rigor, relevance, and analytical depth. The first step involved the identification and collection of relevant documents, including the official secondary school geography syllabi for grades 9 through 12, textbooks, teacher guides and policy documents that outline MLCs in relation to environmental issues linked to deforestation and climate change. These materials were obtained from the Ethiopian Ministry of Education, regional education bureaus, and secondary school archives to ensure authenticity and contemporaneity.

Once the documents were collected, the second step involved the development of an analytical framework grounded in international best practices and theoretical constructs of action-orientated environmental education. This framework was informed by (Jensen, 2002) model of action-orientated learning, which emphasizes the need for curricula to go beyond knowledge transmission and foster participatory, skill-based, and affective learning domains. Additionally, UNESCO's ESD indicators (UNESCO, 2019, 2020) and the principles of the 1977 Tbilisi Declaration served as benchmarks for evaluating the environmental content of the curriculum under investigation.

The third step entailed a systematic coding and categorization of the curriculum content using both deductive and inductive strategies. Based on the categories identified within the analytical framework, a coding sheet was developed to guide the analysis. The content was then examined across multiple levels of the textbook, including the entire textbook, individual chapters, sections, paragraphs, and sentences. Deductively, key constructs such as deforestation, climate change, environmental sustainability, action-oriented learning, and student engagement were employed as pre-defined categories. Complementing this, inductive analysis was conducted through iterative reading to identify emergent themes. This process focused on uncovering topics, content areas, problems, minimum learning competencies, objectives, activities, and teaching methods related to deforestation and climate change. This allowed for a comprehensive insight into how environmental issues under study are framed, the depth and breadth of content coverage, and the presence or absence of student-cantered pedagogical approaches.

The fourth phase entailed a systematic examination of textbook content through the application of established content analysis frameworks Guided by (Bryman, 2016; Elo & Kyngäs, 2008) three-phase model comprising the stages of preparation, organization, and reporting the analysis followed an inductive approach to identify and categorize emergent themes. Concurrently, Bryman (2016) methodological principles reinforced thematic coherence, reflexivity, and triangulation, thereby enhancing analytical credibility. Collectively, these frameworks provided a robust and contextually grounded basis for examining how deforestation and climate change are represented within the curriculum.

5.4.4. Data Analysis Procedures and Steps

The data analysis aimed to assess how deforestation and climate change are integrated into Ethiopia's newly revised secondary school geography curriculum. A mixed-method approach combining quantitative and qualitative content analysis was employed to examine the curriculum guides and textbooks for grades 9–12, with particular focus on the MLCs.

The analysis began with a detailed screening of official curriculum documents issued in 2022 and implemented in 2023 to identify content, competencies, activities, and teaching methods addressing environmental issues. Each element was reviewed across grade levels to capture progression and thematic depth. A coding framework, guided by Jensen (2002) action-oriented learning theory and (UNESCO, 2019, 2020), was then developed. Coding categories included: (1) representation of deforestation and climate change, (2) alignment with cognitive, affective, and psychomotor domains, (3) presence of action-oriented learning competencies, (4) nature of learning activities and embedded questions, and (5) use of student-centered strategies.

MLCs served as the primary unit of analysis since they define the essential knowledge, skills, and attitudes expected from students. Of the 181 MLCs identified across grades 9–12, 7 relate to deforestation and 33 to climate change. Coding and counting were jointly conducted by the principal investigator and four geography experts to ensure accuracy and consistency.

Quantitative analysis employed descriptive statistics (frequencies and percentages) to determine the extent and pattern of environmental integration. Ambiguities were resolved through triangulation with teacher guides and textbooks. Parallel to this, qualitative thematic analysis following (Braun & Clarke, 2006) six-phase model explored the depth and pedagogical framing of environmental themes. Finally, quantitative and qualitative findings were triangulated using a matrix that mapped alignments among curriculum content, interview insights, and policy documents—ensuring a comprehensive and validated interpretation of results.

5.4.5. Ethical Considerations

To ensure ethical integrity, this study was conducted in compliance with academic and institutional research standards. An official permission letter was obtained from Bahir Dar University, where the researcher is pursuing doctoral studies. This letter was subsequently submitted to the Ministry of Education (MoE), regional, zonal and district education offices, and the directors of selected secondary schools in Metekel Zone. Prior to data collection, the purpose and procedures of the study were clearly explained to all participants. Informed consent was secured from teachers, students, and education experts who participated in the key informant interviews. Participation was entirely voluntary, with the right to withdraw at any stage without consequence. Confidentiality and anonymity were strictly maintained throughout the research process. All personal identifiers were removed, and data were coded to ensure privacy. Interview responses and document analyses were handled with care to avoid any form of harm or misrepresentation.

5.5.RESULTS

5.5.1. Representation of deforestation and climate change in the secondary school geography curriculum

Integrating deforestation and climate change into secondary school geography curricula is vital for promoting environmental literacy and preparing students to address urgent environmental challenges. Both the curriculum guide and textbooks should balance cognitive, affective, and psychomotor learning domains to ensure these competencies are effectively reflected in teaching materials. This section analyzes how climate change and deforestation are incorporated into Ethiopia's secondary school geography curriculum (grades 9–12) and assesses the representation of the three learning domains. By examining the number of MLCs and related topics, it highlights the curriculum's emphasis on these key environmental issues.

As the grade-level analysis depicted in Table 5.2 shows, the grade 9 geography curriculum allots 79 periods per year and includes 47 MLCs covering 58 topics and subtopics (MOE, 2022c, 2022b, 2023c). Of these, 4 MLCs (8.5%) and 5 topics (8.6%) are directly related to climate change. Additionally, 5 MLCs (10.6%) and 5 topics (8.6%) pertain to deforestation-related issues. These figures indicate a relatively balanced yet inadequate integration of both themes in the curriculum. Likewise, with 78 periods allocated per year, the grade 10 curriculum includes 34 MLCs and 47 topics/subtopics. Climate change coverage increases slightly, with 5 MLCs (14.7%) and 5 topics (10.6%) addressing climate change. However, the focus on deforestation declines, with only 1 MLC (2.9%) and 1 topic (2.1%) covering this issue. This reduction in content related to deforestation suggests a potential gap in the curriculum's continuity regarding forest conservation education. The grade 11 curriculum, on the other hand, provides 115 instructional periods annually, containing 52 MLCs and 47 topics/subtopics. Climate change receives a more significant emphasis, with 11 MLCs (21.1%) and 11 topics (23.4%) related to the subject. Conversely, deforestation receives minimal attention, with just 1 MLC (1.9%) and 1 topic (2.1%) addressing it. This pattern highlights a growing emphasis on climate change, while deforestation-related education remains under-represented. Similarly, with 114 periods allocated per year, the grade 12 curriculum comprises 48 MLCs and 41 topics/subtopics. Climate change receives the highest level of attention, with 13 MLCs (27%) and 13 topics (31.7%) dedicated to the subject. In contrast, no MLCs or topics explicitly address deforestation-related issues, marking a complete omission of the topic at this stage. This suggests that while climate change education strengthens in the final year, deforestation, an equally critical environmental concern, is overlooked.

On average, Ethiopian secondary school geography curricula allocate 96.5 periods per year, covering 45.25 MLCs and 48.25 topics/subtopics. Climate change is incorporated into an average of 8.25 MLCs (17.8%) and 8.5 topics (18.6%), showing a consistent increase in focus across grade levels. In contrast, deforestation-related issues appear in only 1.75 MLCs (3.85%) and 1.75 topics (3.2%), reflecting a much weaker integration (Table 5.2). The analysis reveals a progressive enhancement of climate change education, particularly in grades 11 and 12 (MOE, 2023b, 2023d, 2023e, 2023a, 2023c). However, the diminishing and eventual absence of deforestation-related content by grade 12 raises concerns about the curriculum's comprehensiveness in addressing environmental challenges holistically.

This discrepancy was reflected in the views of multiple participants during the interviews. For instance, teacher 2 observed, *"Although climate change has been given some space in the upper secondary grades, deforestation, which is deeply intertwined with the daily lives and realities of our rural communities, is almost completely overlooked in the current curriculum. This creates a significant gap in our teaching. It limits our ability to contextualize lessons in a way that resonates with students' lived experiences. As a result, students struggle to make meaningful connections between what they learn in the classroom and the environmental issues they witness firsthand, such as illegal logging, charcoal production, firewood collection, overgrazing, land clearing, and the degradation of nearby forests for large farm investment."*

From the students' perspective, student 1 commented,

"We studied a lot about climate change in grades 11 and 12, but I don't remember learning much about how deforestation affects our region or how we can stop it. It feels like a missing part in the curriculum. Deforestation was mentioned briefly in earlier grades, but it was not explained in a way that made us think deeply about it or relate it to what we see happening around us. Even the climate change topics, although better covered, still don't go far enough. We mostly learnt about its elements, controls, classification, greenhouse gases, global warming, and international agreements, but we didn't discuss how these global issues are connected to our everyday lives—like the unpredictable rains, farming problems, or the forests that are disappearing near our villages. It would be better if the lessons connected more with what's happening here and showed us how we can actually help."

Moreover, education experts highlighted the concern that the curriculum demonstrates uneven and incomplete integration of environmental education across grade levels, particularly in balancing global and local environmental issues. Education Expert 1 stated,

"The curriculum has attempted to align with global trends, especially on climate change. However, there is a gap in addressing local environmental issues like deforestation adequately, which are equally pressing. This undermines the curriculum's responsiveness to national and community-based environmental education needs."

A closer look at the curriculum confirms addtional concern, particularly in terms of how environmental topics are distributed across grade levels. The education expert 2 pointed out that while climate change is increasingly addressed in the upper grades, especially Grades 11 and 12, the coverage is not consistently framed throughout the curriculum. In contrast, deforestation-related content appears sporadically and lacks a structured presence, particularly in the higher grades where students are expected to develop more advanced and applied understandings. As the expert noted, deforestation is introduced briefly in lower grades but is not revisited or expanded upon in later years, leading to missed opportunities for deeper learning and critical engagement with the issue. This uneven integration, according to the expert, highlights the need for a more balanced curricular design that gives equal attention to both climate change and deforestation throughout the secondary school experience.

Table 5.2: Deforestation and climate change related issues in the secondary school geography textbooks

Grades	Periods allotted/year	No. of MLCs	No. of topics/sub topics	MLCs related to CC		Topics related to CC		MLCs related to Deforestation related issues		Topics related to Deforestation related issues	
				No.	%	No.	%	No.	%	No.	%
9	79	47	58	4	8.5	5	8.6	5	10.6	5	8.6
10	78	34	47	5	14.7	5	10.6	1	2.9	1	2.1
11	115	52	47	11	21.1	11	23.4	1	1.9	1	2.1
12	114	48	41	13	27	13	31.7	0	0	0	0
Average	96.5	45.25	48.25	8.25	17.8	8.5	18.6	1.75	3.85	1.75	3.2

Source: Source: Author’s content analysis based on the Ethiopian Secondary School Geography Curriculum Framework and Geography Textbooks for Grades 9–12 (MoE, 2023 editions).

An effort has also been made to examine whether the cognitive, affective, and psychomotor learning domains outlined in the policy document are effectively reflected in teaching materials (textbooks) to enhance students' awareness and engagement with environmental issues related to deforestation and climate change.

To this end, the study categorizes the MLCs into the three learning domains such as knowledge, attitude, and skill which collectively represent learning competencies. These domains encompass cognitive, affective, and psychomotor aspects of education, as defined in this study. As presented in Table 5.3, the distribution of climate change-related MLCs across grades 9 to 12 shows a predominant focus on the knowledge domain (60.8%), followed by attitude (27.5%), and skill (12.5%). Proportion of knowledge-based competencies is observed in grade 9 (75%), while the lowest is in grade 12 (53.8%). Notably, skill-based learning remains underrepresented, with its highest proportion in grade 11 (27%) and absent in grades 9 and 10. This suggests a gap in the curriculum in terms of providing students with appropriate practical learning experiences related to climate change adaptation and mitigation. In contrast, deforestation-related MLCs appear to be less consistently distributed across the grades. While grade 9 places a balanced emphasis on knowledge (60%) and attitude (60%), skill development is similarly addressed (60%), indicating a well-rounded approach at this level. However, in grade 10, deforestation is minimally covered, with only one skill-based competency, and knowledge and attitude components entirely absent. Grade 11, on the other hand, shows a complete shift towards attitudinal learning (100%) with no representation of knowledge or skill-based competencies. Interestingly, deforestation-related competencies are entirely absent from grade 12, highlighting a critical gap in the curriculum at the final stage of secondary school geography education.

On average, across all grades, climate change education within the curriculum leans heavily towards cognitive knowledge (60.8%), with attitude (27.5%) and skill (12.5%) receiving comparatively less emphasis. For deforestation, attitudinal learning (40%) and skill-based learning (40%) are emphasized more than knowledge (15%), though with notable inconsistencies across grade levels. This is supported by the participants of the KII who witnessed the gaps in the curriculum and emphasized the need for a more balanced and comprehensive approach to environmental education.

For example, Education Expert 1, with 16 years of professional experience, explained that *"the current curriculum places a strong emphasis on cognitive knowledge, particularly in the lower grades. However, it falls short in providing practical, skill-based learning opportunities, especially in relation to deforestation and climate change. The curriculum does not sufficiently equip students to engage with these issues through practical experiences. Students need more than theoretical knowledge they require practical activities that help them understand the real-world consequences of deforestation."*

Table 5.3: Numbers and percentages of deforestation and climate change related MLCs addressed in secondary school geography curricula in relation to the three domains of learning.

Grades	Climate change							Deforestation						
	Total MLCs	Knowledge		Attitude		Skill		Total MLCs	Knowledge		Attitude		Skill	
		No.	%	No.	%	No.	%		No.	%	No	%	No	%
9	4	3	75	1	25	0	0	5	3	60	3	60	3	60
10	5	3	60	2	40	0	0	1	0	0	0	0	1	100
11	11	6	54.5	2	18	3	27	1	0	0	1	100	0	0
12	13	7	53.8	3	27	3	23	0	0	0	0	0	0	0
Average	8.25	4.75	60.8	2	27.5	1.5	12.5	1.75	0.75	15	1	40	1	40

Source: Author's content analysis of the Ethiopian Secondary School Geography Curriculum Framework and officially approved Geography textbooks for Grades 9–12, MoE, 2023, with domain classification guided by Bloom's taxonomy.

Teacher 3, who has 16 years of experience, emphasized:

"The curriculum's focus is too much on cognitive knowledge in the earlier grades, and although climate change is adequately covered, there is little in terms of skills that students can use in practical scenarios. For deforestation, the curriculum barely scratches the surface, especially in higher grades where the focus shifts to attitude without providing students with the skills needed to address the issue practically."

Student 1, a grade 12 learner, reflected on the curriculum's imbalance by stating:

"Most of what we learn about climate change is focused on theory—like facts, causes, and global effects which makes sense because knowledge seems to be the main focus in our lessons. But I feel like there's less attention given to shaping our attitudes or helping us build practical skills. For example, we don't often discuss how we personally can help prevent deforestation or take part in restoring forests in our area. I think what's missing is more hands-on learning and *lessons that encourage us to act.*

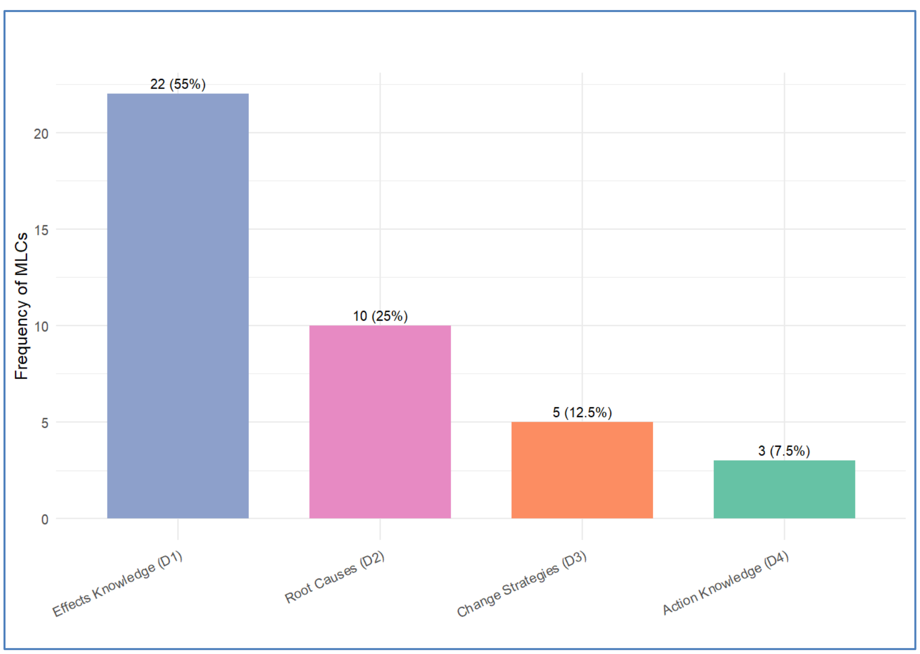
5.5.2. Content Analysis of Minimum Learning Competencies on Deforestation and Climate Change Through the Lens of Action-Orientated Dimensions in the secondary school geography curricula

As pointed out earlier, the Ethiopian secondary school geography curriculum incorporates a range of MLCs designed to equip students with the knowledge and skills necessary to understand environmental challenges, particularly deforestation and climate change. To assess the extent to which these competencies promote action-orientated environmental education, this study categorizes them according to Jensen's (2002) four aspects of action-orientated knowledge: knowledge about effects (knowledge about the existence and spread of environmental problems), knowledge about root causes ('causal' dimension of environmental problems), knowledge about change strategies (How do we change things), and knowledge about alternatives and visions (where do we want to go). A quantitative and qualitative content analysis of the curriculum guides for grades 9–12 reveals both strengths and gaps in fostering students' capacity for informed environmental action.

As depicted in Figure 5.2, a total of 40 MLCs relevant to deforestation and climate change were analyzed. The findings indicate that knowledge about effects (Dimension 1) dominates the curriculum, accounting for 55% of all MLCs. This strong emphasis is essential for understanding the consequences of environmental degradation. Topics such as climate classification, the impact of seasonal variations, and deforestation's role in poverty fall under this dimension, providing students with foundational knowledge (refer to Appendix 3). Thus, while students develop an understanding of environmental impacts, they lack the necessary skills to actively address these challenges.

Following Dimension 1, knowledge about root causes (Dimension 2) is the second most represented category, comprising 25% of the MLCs. This dimension enables students to critically assess the underlying factors contributing to environmental problems related to deforestation and climate change. Key competencies in this category include analyzing factors controlling climate distribution, understanding the role of human activities in climate change, and examining the connection between population growth and resource degradation, with a specific focus on deforestation (Appendix 3). The inclusion of such topics is crucial in fostering analytical skills, as it allows students to move beyond surface-level understanding. However, this category remains underdeveloped, particularly regarding the socio-economic and political drivers of deforestation and climate change.

Figure 5.2: Distribution of Minimum Learning Competencies across Jensen's Knowledge Dimensions



Source: Author's content analysis of the Ethiopian Secondary School Geography Curriculum and textbooks for Grades 9–12 (MoE, 023), classified using Jensen's (2002) action-oriented framework.

In contrast, knowledge about change strategies (Dimension 3) is only moderately represented, accounting for 12.5% of the MLCs (Figure 5.3). Competencies in this category include proposing climate solutions, assessing Ethiopia's climate-resilient green economy, and understanding indigenous conservation practices (Appendix 3). While these topics encourage students to think critically about environmental solutions, their overall representation remains relatively low compared to the dominance of effects knowledge.

The least represented category is action knowledge (Dimension 4), making up only 7.5% of the curriculum. This dimension includes competencies such as participating in climate change mitigation activities and evaluating international environmental agreements. While these topics offer opportunities for active engagement, their low frequency suggests that students are not sufficiently encouraged to take an active role in environmental problem-solving.

Additionally, figure 5.3 provides a grade-wise analysis of MLCs based on Jensen's Knowledge Dimensions. At the lower grade levels, grade 9 accounts for the largest proportion of MLCs (35% of the total), focusing primarily on fundamental topics such as climate classification, population growth, and its effects on resource depletion, including deforestation. However, the majority of these competencies fall under Effects Knowledge (Dimension 1), which emphasizes understanding environmental changes rather than identifying their root causes or exploring potential solutions.

Grade 10 follows, contributing 20% of the total MLCs, with a primary focus on the distribution of vegetation and climate across Africa, further reinforcing Effects Knowledge. At this level, students are introduced to global and African climate patterns and their broader implications, enhancing their comprehension of environmental issues. While discussions on climate types, regions, and their benefits help strengthen students' understanding of environmental effects, limited attention is given to the root causes of climate change and deforestation. Similar to grade 9, there is no coverage of change strategies (Dimension 3) or action knowledge (Dimension4), indicating that students at this stage are not yet exposed to solutions or active environmental participation.

In grade 11, which comprises 22.5% of the total MLCs, a shift towards more analytical learning is evident. Students begin to explore climate classification methods and the threats posed by deforestation, leading to a greater focus on root causes (Dimension 2). This stage includes discussions on climate classification, extreme weather conditions, and their socio-economic impacts, particularly in relation to deforestation. Additionally, the introduction of change strategies (Dimension 3) suggests that students start engaging with approaches to address environmental issues. However, action knowledge (Dimension 4) remains unaddressed, meaning students are still not actively involved in climate change mitigation or adaptation efforts.

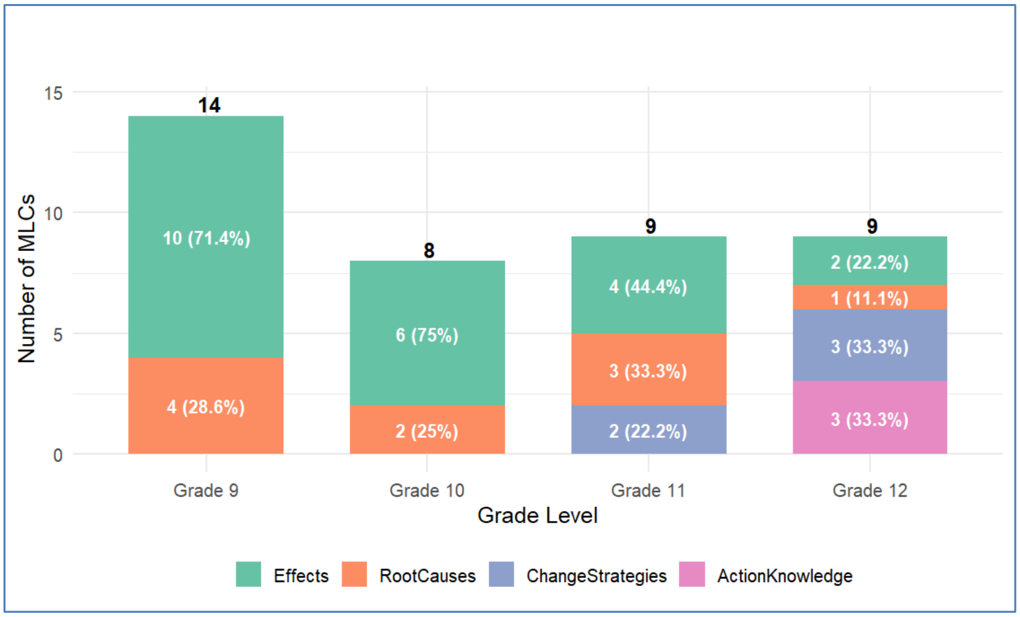
Finally, grade 12 also accounts for 22.5% of the total MLCs but places a stronger emphasis on climate change mitigation strategies and global environmental policies. At this stage, there is a noticeable increase in the inclusion of change strategies (33.3%) and action knowledge (33.3%), indicating a transition toward solution-oriented learning. Students are introduced to climate change adaptation and mitigation strategies, national policy frameworks, and international environmental agreements. Moreover, they are encouraged to participate in practical climate-related initiatives, fostering environmental responsibility and advocacy.

Overall, the progression of MLCs across grade levels reveals a gradual shift from foundational knowledge in the early years toward a more solution-focused approach in later grades. However, the distribution remains heavily skewed towards effects knowledge, with limited emphasis on root causes, change strategies, and action knowledge. Strengthening the integration of problem-solving and active participation elements across all grade levels could better equip students to address real-world environmental challenges.

These quantitative findings were further substantiated by insights drawn from KIIs, which reinforced the uneven distribution of action-orientated dimensions within the secondary school geography curriculum. Teachers and education experts expressed concern that the curriculum overemphasizes descriptive knowledge at the expense of actionable competencies. As Teacher 3, a seasoned educator with 16 years of experience, noted, *"The curriculum provides detailed descriptions of environmental effects, but there is very little room for students to explore what they can do to solve these problems. It's more about understanding than acting."* This sentiment was echoed by Education Expert 1, who emphasized that while knowledge about effects is essential, *"students often leave school with limited capacity to translate that knowledge into real-life problem-solving or activism."*

Teacher 2, a female teacher with a bachelor's degree, added that although the curriculum touches upon indigenous conservation methods and Ethiopia's climate strategies in grade 12, *"these components are introduced too late and are not adequately reinforced in the earlier grades."* The limited representation of change strategies and action knowledge was also evident to Student 1, who remarked, *"We talk about climate change and slightly deforestation in class, but rarely do we engage in any activities that involve us in environmental solutions."* Furthermore, Education Expert 3 from the district level expressed that *"the curriculum misses the opportunity to link learning with local environmental actions or student-led projects, which would make the knowledge more practical and transformative."* Collectively, these perspectives illustrate a clear disconnect between environmental awareness and environmental agency within the curriculum. The findings suggest an urgent need to rebalance the MLCs by embedding change-orientated and action-based competencies throughout all grade levels, rather than reserving them for the final year of study.

Figure 5.3: Grade-Level Distribution of Minimum Learning Competencies by Jensen's Knowledge Dimensions



Source: Author's content analysis of the Ethiopian Secondary School Geography Curriculum and textbooks for Grades 9–12 (MoE, 2023), using Jensen's (2002) framework.

5.5.3. Learning activities and embedded questions integrated in the secondary school geography curriculum guide and textbooks related to deforestation and climate change

Learning activities and their embedded questions encourage students to analyze, evaluate, and apply concepts, enhancing problem-solving skills and real-world connections**.** Well-structured questions also serve as assessment tools, helping educators identify misconceptions and refine instruction. Additionally, collaborative tasks develop communication and teamwork, while reflective questions promote deeper understanding.

The analysis of documents as shown in table 5.4 in the present study indicates that secondary school geography textbooks (grades 9-12) include a range of such learning activities and questions designed to engage students (MOE, 2022a, 2022b, 2023a, 2023b). Each activity incorporates several questions aimed at guiding students through different tasks. However, a close examination of the textbooks reveals a significant disparity in the focus on deforestation and climate change when compared to the overall content. The total number of activities across the four grades stands at 287, with 672 questions. However, only 54 activities (18.8%) and 93 questions (13.8%) are directly related to deforestation and climate change. This indicates that less than one-fifth of the activities and questions in the curriculum engage students with these crucial environmental issues, reflecting a major gap in fostering environmental literacy and action-orientated learning.

Grade-specific comparisons further expose the inconsistency in integrating learning activities related to deforestation and climate change education. In grade 9, only 9 of the 56 activities (16%) and 27 of the 226 questions (11.9%) address these issues. Similarly, in grade 10, 9 out of 56 activities (16%) focus on deforestation and climate change, with only 10 questions (12.3%). The situation slightly improves in grades 11 and 12, where 20 of the 95 activities (21%) and 37 of the 225 questions (16.4%) in grade 11, as well as 16 of the 80 activities (20%) and 19 of the 140 questions (13.6%) in grade 12, relate to these environmental challenges. Despite this incremental increase, the overall proportion remains considerably low, given the pressing need for a well-balanced integration of effective learning activities and embedded questions that promote education on deforestation and climate awareness.

As shown in Figure 5.4, analyzing the distribution of questions across the cognitive, affective, and psychomotor domains reveals the curriculum's focus on action-oriented environmental education. Examination of geography textbooks for grades 9–12 shows a strong dominance of the cognitive domain, accounting for 65.6% of all questions, emphasizing factual recall and conceptual understanding of deforestation and climate change. The highest proportions appear in grade 12 (73.7%) and grade 9 (70.3%), while grades 10 (60%) and 11 (59.5%) show moderate emphasis.

Table 5.4: Activities and Questions Developed in the Secondary School Geography Textbooks (grades 9-12)

Grade	Total No. of activities developed	Total No. of questions in the activities	Total No. of activities developed for deforestation and climate change		Total No. of questions in the activities related to deforestation and climate change	
			No.	%	No.	%

9	56	226	9	16	27	11.9
10	56	81	9	16	10	12.3
11	95	225	20	21	37	16.4
12	80	140	16	20	19	13.6
Total	287	672	54	18.8	93	13.8

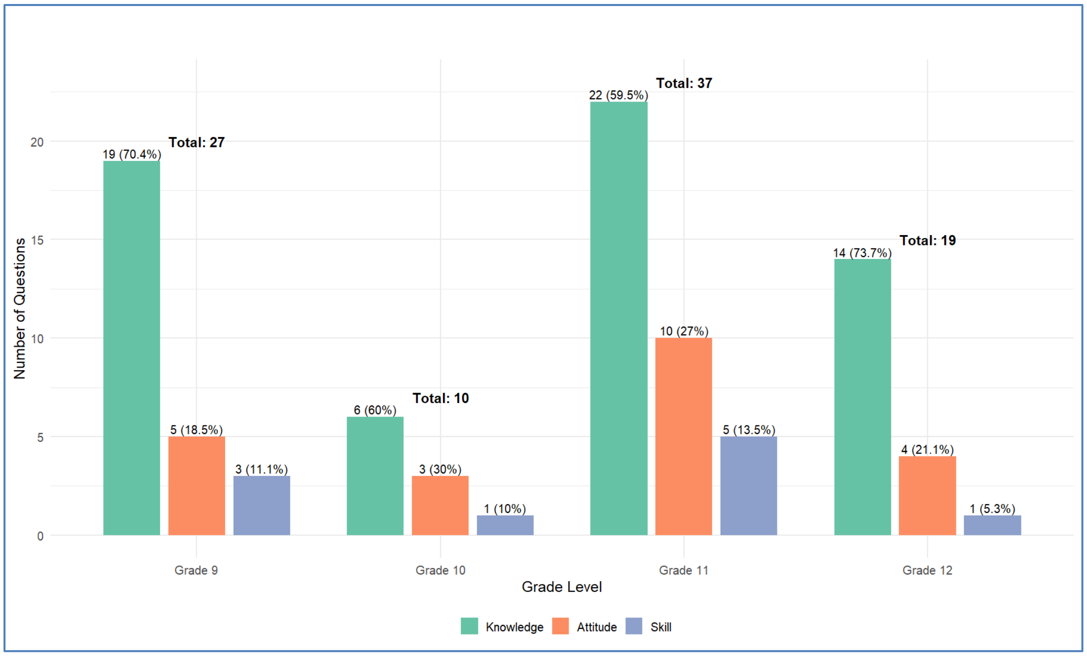
Source: Author's document analysis of Ethiopian secondary school geography textbooks (Grades 9–12), (MoE, 2023).

The affective domain, reflecting students' values and attitudes, represents 23.7% of total questions, peaking in grade 10 (30%) and grade 11 (27%). This indicates some effort to promote environmental concern, though inconsistently across grades. In contrast, the psychomotor domain—focused on practical skills—constitutes only 10.7%, with minimal emphasis in grades 10 (10%) and 12 (5.3%). This imbalance suggests that while the curriculum effectively builds knowledge, it provides limited opportunities for students to develop the hands-on skills needed to take concrete environmental action.

The KII responses robustly reinforce the quantitative findings, painting a consistent picture of a curriculum that is heavily weighted towards cognitive learning, with insufficient attention to skill development and attitudinal change. Students, educators and education experts agree that the current structure of questions and learning activities limits the transformative potential of environmental education. For instance, Teacher 3, with 16 years of experience, remarked:

"Most of the textbook activities and questions under these activities are centered on definitions and explanations. There are very few that encourage students to go outside the classroom or connect lessons to what is happening in their communities in terms of forest degradation or climate change impacts."

Figure 5.4: Distribution of questions on deforestation and climate change lessons across activities in relation to the three learning domains



Note. Data derived from the author's document analysis of Ethiopian secondary school geography textbooks (Grades 9–12). Questions were classified according to the cognitive, affective, and psychomotor domains of Bloom's learning taxonomy.

Teacher 1 similarly emphasized that while students are often able to recall definitions of climate change and deforestation, they struggle to relate these issues to real-world local scenarios due to the lack of action-orientated questions and activities in the curriculum.

The KIIs also illuminated a significant deficiency in activities and questions that foster attitudinal development. As one female teacher with six years of experience stated, while teachers make efforts to raise environmental awareness, the activities and questions in the curriculum are largely inadequate for shaping students' attitudes. The scarcity of skill-based questions and activities was also a concern repeatedly mentioned by students. *Student 6*, a grade 12 student, shared:

"We learn about deforestation, but we never go out to see what is happening in nearby forests or do projects that can help. It would be more interesting and useful if we could take action, not just learn theory."

5.5.4. Integration of Appropriate Teaching Methods for Deforestation and Climate Change Lessons in the Ethiopian Secondary School Geography Curriculum

This section assesses how effectively the Ethiopian secondary school geography curriculum integrates teaching methods for lessons on deforestation and climate change. Effective pedagogy is crucial not only for building knowledge but also for inspiring students to take meaningful environmental action. As indicated in Table 5.5, the findings from the analysis of curricular materials across grades 9 to 12 (MOE, 2022b, 2022c, 2022d, 2022a, 2023b, 2023d, 2023e, 2023a, 2023c) reveal a range of teaching methods, each with its own strengths and limitations. These methods reflect a complex interplay between traditional, teacher-centered approaches and more modern, student-centered strategies, with implications for the depth of student engagement and learning outcomes.

In grade 9, the curriculum shows a strong focus on interactive, student-centered methods. Brainstorming and group discussions (66.67% each) dominate instruction, promoting collaboration and critical thinking essential for understanding deforestation and climate change. Demonstrations (66.67%) further enhance engagement through visual and practical learning experiences. Additionally, PBL appears in 33.33% of lessons, marking a meaningful step toward real-world problem-solving and active inquiry, though its use remains limited.

In grade 10, the curriculum shifts toward more teacher-directed instruction, though group discussions and demonstrations remain dominant (100% each). While effective for delivering foundational knowledge, this approach limits opportunities for higher-order thinking and problem-solving. Notably, PBL increases to 66.67% which is the highest across all grades showing a strong effort to promote student-centered, real-world learning. Project-Based Learning (PJBL) also appears in 50% of lessons, encouraging inquiry and learner autonomy. However, other active methods such as systems thinking, scenario-based, action-oriented, and digital learning remain largely absent, indicating partial integration of innovative pedagogy.

In grade 11, the curriculum reverts to more traditional, teacher-centered methods, with questioning (41.67%) and demonstrations (16.67%) dominating instruction. While these reinforce key concepts, they offer limited opportunities for critical engagement with complex environmental issues. The use of PBL declines to 33.33%, reducing emphasis on problem-solving and interdisciplinary learning compared to grade 10. Although group discussions (58.33%) remain common, they do not fully counterbalance the passive nature of instruction, limiting students' critical thinking and collaborative problem-solving on deforestation and climate change.

By the time students reach grade 12, the curriculum is largely dominated by traditional methods such as explanation (46.15%) and questioning (53.85%), reinforcing a passive, lecture-based approach. While effective for information delivery, this limits the development of problem-solving and critical thinking skills vital for addressing environmental challenges. Experiential methods like field visits (23.08%) and case studies (0%) are rarely used. PBL appears in 38.46% of lessons slightly higher than in grade 11 but remains underutilized.

The curriculum across all grades relies heavily on traditional, teacher-centered methods such as demonstration, questioning, and explanation. These approaches convey foundational knowledge but do not sufficiently develop critical thinking, creativity, or problem-solving skills for addressing environmental issues like deforestation and climate change. Student-centered methods including project-based, inquiry-based, action-oriented, and experiential learning are largely absent. PBL appears inconsistently, from 33.33 percent in grades 9 and 11, to 66.67 percent in grade 10, and 38.46 percent in grade 12.

To substantiate and enrich the quantitative findings derived from the review of curriculum materials, qualitative data were collected through KII with a diverse group of stakeholders. A prevailing theme across the interviews is the acknowledgement of an imbalanced reliance on traditional, teacher-centered methods. Most geography teachers concurred that despite the inclusion of student-centered strategies in the curriculum, classroom implementation is largely dominated by explanation, questioning and answering, and lecture-based instruction. One teacher noted, *"While we understand to use participatory methods like* inquiry-based learning (IBL), scenario-based learning, action-orientated learning, digital and ICT-based learning, panel discussion and experiential learning, *the reality is that we often fall back on lectures due to time constraints and curriculum overload."*

On a more positive note, some teachers recognized the growing presence of PBL, particularly in grade 10. One teacher reflected, *"PBL has helped students engage more critically with environmental issues. When students engage with real-world issues like the effects of deforestation in their local area, their sense of interest and responsibility tends to grow. However, despite these benefits, PBL remains limitedly and inadequately integrated across other grade levels, constraining its broader and sustained impact."*

Student voices also shed light on the effectiveness of teaching strategies. While some students appreciated group discussions and project-based activities for their interactive nature, others criticised the overuse of lectures, which they found monotonous and disengaging. One Grade 11 student explained, "I learn more when we do group work or when the teacher shows us maps or pictures. But most of the time, we just listen and take notes." This insight underscores the curriculum's lack of emphasis on multimodal and participatory learning, as evidenced by the negligible inclusion of digital and visual tools.

Furthermore, the absence of systems thinking and action-orientated learning in the curriculum was seen as a missed opportunity by education experts. One remarked, *"Deforestation and climate change are complex and interrelated issues. Teaching them in isolation through linear methods doesn't prepare students for real-world problem-solving."* This highlights a critical curricular gap, consistent with the quantitative analysis that found no evidence of systems thinking approaches across any grade level.

Table 5.5: Distribution of Teaching Methods Used for Deforestation and Climate Change Lessons Across Grades 9–12 in the Ethiopian Secondary School Geography Curriculum

No	Types of Teaching Methods	Grade 9		Grade 10		Grade 11		Grade 12	
		No.	%	No.	%	No.	%	No.	%
1	PBL	3	33.33	4	66.67	4	33.33	5	38.46
2	Brainstorming	6	66.67	0	0	3	25	7	53.85
3	Experiential Learning	0	0	0	0	0	0	0	0
4	Demonstration	6	66.67	6	100	2	16.67	5	38.46

5	Inquiry-Based Learning (IBL)	0	0	0	0	0	0	0	0
6	Questioning and Answer	6	66.67	0	0	5	41.67	7	53.85
7	Case Study	6	66.67	1	16.67	3	25	0	0
8	Project-Based Learning (PJBL)	0	0	3	50	0	0	0	0
9	Group Discussion	6	66.67	6	100	7	58.33	7	53.85
10	Field Visit	4	44.44	2	33.33	2	16.67	3	23.08
11	Digital and ICT-Based Learning	0	0	0	0	0	0	0	0
12	Debating	0	0	1	16.67	2	16.67	2	15.38
13	Action-Oriented Learning	0	0	0	0	0	0	0	0
14	Panel Discussion	0	0	0	0	0	0	0	0
15	Systems Thinking and Scenario-Based Learning	0	0	0	0	0	0	0	0
16	Individual/Group Projects	1	11.11	0	0	2	16.67	0	0
17	Explanation	0	0	0	0	0	0	6	46.15
18	Jigsaw	0	0	1	16.67	0	0	0	0
19	Lecture Method	0	0	0	0	3	25	0	0
20	Memorization (Rote Learning)	0	0	0	0	0	0	0	0
Total MLCs	Total Number of MLCs	9	100	6	100	12	100	13	100

Source: Author's document analysis of Ethiopian secondary school geography curriculum guides and textbooks (Grades 9–12), (MoE, 2023).

5.6.Discussion

This section interprets the findings within broader theoretical, empirical, and policy contexts, linking them to existing scholarship on environmental and sustainability education. The discussion examines how the Ethiopian secondary school geography curriculum addresses deforestation and climate change, evaluates its alignment with national and international frameworks such as ESD and SDG 4.7, and situates the results in relation to prior empirical studies. Through this lens, the study provides critical insights into curricular balance, pedagogical orientation, and the integration of knowledge dimensions essential for fostering students' environmental competence and action readiness.

The analysis in the present study reveals a disproportionate representation of climate change and deforestation in Ethiopia's secondary school geography curriculum guide and text books. While climate change coverage progressively increases from grade 9 to 12, deforestation content declines sharply, culminating in complete omission in grade 12 both in curriculum guide and student textbooks. This imbalance contradicts both the (UNESCO, 2019) framework on ESD, which advocates for integrated environmental themes across curricula, and Ethiopia's Education Sector Development Program V (MoE, 2018), which emphasizes building environmental awareness at all educational levels. Empirical studies highlight the value of balanced environmental education, showing that comprehensive curricula focused on environmental issues improve students' systems thinking and action competence (Demissie, 2015). Similarly, (Wahelo et al., 2024) stresses that omitting key issues like deforestation and climate change limits learners' ability to grasp the interconnectedness of environmental problems.

The analysis shows a clear imbalance in the integration of cognitive, affective, and psychomotor domains within secondary school geography curricula on climate change and deforestation. Climate change content emphasizes knowledge (60.8%), while attitudes (27.5%) and skills (12.5%) are less represented. Deforestation topics give slightly more attention to attitudes and skills (40% each) but are inconsistently covered and nearly absent in upper grades. This misalignment contrasts with Ethiopia's Education and Training Policy and the Climate Resilient Green Economy Strategy, which stress practical, value-based education. Empirical studies (Brahma, 2015) support this, showing that knowledge alone is insufficient; effective environmental education must also cultivate critical thinking, ethical commitment, and proactive engagement. The curriculum's limited focus on skills reduces students' readiness to address deforestation and climate change in real contexts. To align with SDG 4.7 and ESD principles, curricula should integrate experiential, problem-based, and community-linked learning; ensuring students are informed, capable, and motivated to contribute to sustainable environmental solutions. Reform is essential to embed climate change and deforestation comprehensively.

This study also examined how the Ethiopian secondary school geography curriculum and textbooks support action-oriented environmental education by analyzing MLCs on deforestation and climate change using Jensen's four knowledge dimensions. Findings show a strong emphasis on Effects Knowledge (Dimension 1), comprising 55% of MLCs. While understanding environmental consequences is important, this imbalance limits students' readiness for proactive engagement. Previous research similarly highlights that content-heavy, cognitive-focused environmental education, without attention to affective and behavioral aspects, reduces learners' ability to engage meaningfully with environmental challenges (Mochizuki & Vickers, 2024).

The second most represented dimension was Knowledge about Root Causes (Dimension 2), accounting for 25% of MLCs. While these competencies encourage critical thinking about drivers like population growth and human activities, they give limited attention to complex systemic issues such as land tenure conflicts, political economy, and global carbon inequities. This narrow focus reflects critiques by (Alan, 2008) and others (Jimenez & Kabachnik, 2023; Mueller, 2009) emphasizing the need for curricula to address socio-political, cultural, and economic roots of environmental crises. In contrast, some national curricula, such as in Sweden and Brazil incorporate these critical perspectives (da Costa Ferreira & Barbi, 2016). Without such depth, students may develop fragmented understandings that hinder meaningful environmental action.

Strikingly, knowledge about Change Strategies (Dimension 3) and Action Knowledge (Dimension 4) are notably underrepresented, comprising only 12.5% and 7.5% of MLCs, respectively. This limited focus on solution-oriented and participatory knowledge hinders students' readiness to engage actively with environmental challenges. Tilbury, 2010 emphasizes that developing action competence is essential for Education for Sustainable Development, cautioning that curricula without it may create students who are environmentally knowledgeable yet inactive. In Ethiopia, grade 12 textbooks include some climate mitigation content, but earlier grades largely neglect these dimensions, delaying the development of student agency. Pedagogical models advocate early and continuous scaffolding of problem-solving and action-oriented skills (Mogensen & Schnack, 2010). Research shows that integrating systems thinking, future orientation, and action competence enhances environmental engagement and behavior (Rieckmann, 2012; Sinakou et al., 2022), though critics caution that overly prescriptive approaches may limit critical thinking (Jickling & Wals, 2008). Overall, the Ethiopian curriculum would benefit from consistently embedding change strategies and action knowledge to foster transformative environmental learning.

The findings of this study also resonate with global critiques of environmental education in developing countries, where curricula often mirror international discourse but fall short of contextualized, community-linked action (Reddy, 2021; Ritchie, 2013). This is strongly reinforced by qualitative data from key informant interviews, which emphasized that the absence of student-led projects or locally grounded sustainability initiatives reflects a significant missed opportunity to connect environmental knowledge with real-life experience. Incorporating locally relevant, participatory approaches would not only ground learning in students' realities but also empower them to become agents of change within their communities.

The integration of learning activities and their embedded questions plays a crucial role in fostering active engagement, critical thinking, and knowledge retention in the teaching-learning process (UNESCO, 2020). However, findings from this study reveal that Ethiopian secondary school geography textbooks offer limited engagement with these crucial issues. Of the 287 total learning activities and 672 questions analyzed, only 18.8% of activities and 13.8% of questions directly address deforestation and climate change. This inadequate integration undermines the goals of environmental education (EE) as outlined by international frameworks, including the Education for Sustainable Development Goals (UNESCO, 2019, 2020), which advocate for a balanced focus on knowledge, skills, and attitudes. These findings echo previous research in sub-Saharan Africa. For instance, (Boeve-de Pauw & Van Petegem, 2018; Fitzpatrick & Amenya, 2023) found that while cognitive content is often emphasized in EE materials, affective and action-based components are marginalized. Similarly, Ayalew (2015) reported that Ethiopian geography curricula tend to emphasize theoretical content, with minimal emphasis on field-based or community-orientated tasks.

The affective domain, which constitutes 23.7% of the questions, also falls short of encouraging sustained environmental attitudes and values. As Prati et al. (2017) and Tamar et al. (2021) argue, attitude formation is a vital predictor of pro-environmental behavior. Without deliberate affective engagement, students may gain awareness without developing the motivation or ethical responsibility to act.

Qualitative insights from teachers and students in this study support the quantitative trends. Participants repeatedly emphasized the over-reliance on definition-based activities and the lack of community-based or experiential learning. These concerns align with findings by (Jensen, 2002), who argue that EE must go beyond awareness to include participatory, skills-driven experiences. The absence of fieldwork or practical assignments in the curriculum, as noted by multiple key informants, confirms the curriculum's failure to meet the standards set by global EE policy recommendations.

Although a slight improvement in the representation of climate content activities and questions is noted in grades 11 and 12, the progression remains insufficient. This gradual shift is similar to findings by (Cebrián & Junyent, 2015), who noted a delayed and fragmented integration of sustainability education across school years, often missing continuity and coherence.

In conclusion, the current geography curriculum's limited incorporation of action-orientated and attitudinal learning undermines its transformative potential. Addressing this gap requires a reorientation of curriculum design toward more balanced inclusion of cognitive, affective, and psychomotor domains. Aligning with best practices from environmental education frameworks (UNEP, 2021; UNESCO, 2020) and embedding project-based, locally relevant, and field-driven pedagogies is essential to empower students as active environmental stewards.

The findings of this study also revealed a fragmented integration of appropriate teaching methods for delivering deforestation and climate change content in Ethiopia's secondary school geography curriculum. Although some student-centered strategies like PBL, group discussions, and demonstrations are present—particularly in grades 9 and 10—the curriculum remains predominantly traditional, especially in grades 11 and 12, where teacher-led explanations and questioning dominate. These findings mirror prior research in low-income countries, where traditional pedagogy often overshadows experiential and inquiry-based learning due to structural and systemic constraints (Lancaster, 2017; Sesen & Tarhan, 2011; UNESCO, 2020; Woods & Copur-Gencturk, 2024).

Empirical evidence consistently underscores the value of active and student-centered pedagogies for environmental education. For example, (Kricsfalusy et al., 2018) emphasizes that PBL enhances students' critical thinking and civic responsibility in addressing sustainability issues, including deforestation and climate change. Similarly, (Kricsfalusy et al., 2018) found that experiential learning, including field visits and project-based learning, significantly improves environmental awareness and action competency. Yet in this study, such methods—especially systems thinking, digital tools, and action-based learning—were rarely integrated or entirely absent.

This study contributes to environmental education, curriculum development, and sustainability by critically evaluating the Ethiopian secondary school geography curriculum and textbooks. Empirical findings reveal significant gaps, including under-representation of deforestation and climate change topics and limited use of action-oriented, student-centered pedagogies. The study provides valuable insights for stakeholders: teachers are encouraged to move beyond traditional methods toward experiential, community-linked learning guided by Jensen's knowledge dimensions, ESD principles, and MLCs; NGOs and local actors can support teacher training, environmental clubs, and school-community partnerships to enhance practical engagement; and policymakers are urged to better align national curricula with global sustainability commitments.

Hence, this study is critically positioned with both national and global educational frameworks aimed at advancing ESD. While it aligns with global commitments such as SDG 4.7 and UNESCO's ESD Roadmap, which emphasize transformative and action-orientated learning, it reveals a significant gap between policy aspirations and curricular realities in the Ethiopian context. At the national level, despite supportive policies like ESDP V and the Climate Resilient Green Economy Strategy, the geography curriculum lacks meaningful pedagogical integration of these goals.

This study highlights several directions for future research on curriculum and pedagogy in environmental education. Beyond content analysis, studies should examine how students and geography teachers interpret and enact topics like deforestation and climate change in classrooms. Context-specific research on students' knowledge, attitudes, and determinants, as well as teachers' capacity to implement participatory methods like PBL, is crucial, especially in resource-limited settings. Integrating indigenous knowledge and local practices, conducting comparative studies across regions or countries, and exploring teachers' professional development needs can further inform effective, culturally relevant curricula. Longitudinal research could track the long-term impact of curriculum and pedagogical reforms on students' environmental awareness and actions.

Despite its contributions, this study has limitations. It relied on a small sample of qualitative interviews, focused solely on geography, and was confined to secondary education, potentially overlooking interdisciplinary links and other educational levels. Future research should adopt broader, multi-level approaches, including classroom observations, student assessments, and cross-curricular analyses, to fully understand the effectiveness of environmental education in Ethiopia.

5.7.Conclusion

This study critically examined the content and pedagogical integration of deforestation and climate change within Ethiopia's secondary school geography curriculum guide and textbooks through a dual lens of content analysis and qualitative inquiry. Anchored in Jensen's (2002) action-orientated knowledge framework and aligned with national education policies and global agendas such as SDG 4.7 and the UNESCO ESD roadmap, the findings reveal significant curricular and pedagogical gaps that undermine the transformative potential of deforestation and climate change education in the Ethiopian context.

While both the curriculum guide and student textbooks demonstrate a progressive inclusion of climate change topics in upper secondary grades, deforestation, an issue of both national and global urgency, is inconsistently addressed. This imbalance reflects disconnect between curriculum content and both Ethiopia's national environmental priorities and international frameworks advocating for integrated and holistic environmental education. Furthermore, the curriculum is heavily skewed toward cognitive knowledge acquisition, with limited emphasis on affective and action-orientated learning domains. This narrow focus restricts the development of critical environmental competencies such as ethical awareness, civic engagement, and systems thinking.

The study also highlights a significant under-representation of change strategies and action knowledge across all grade levels, which inhibits students' preparedness to engage meaningfully with environmental issues related to deforestation and climate change. The limited presence of student-centered pedagogies such as PBL, inquiry-based learning (IBL), project-based learning, experiential learning, digital and ICT-based learning, action-orientated learning and community-linked activities further compounds this issue. Although teachers and stakeholders recognize the importance of these methods, their implementation is hampered by a lack of integration of the methods in the curricular materials, structural constraints, resource limitations, and a lack of professional development. As a result, the curriculum fails to scaffold student agency over time and remains slightly disconnected from real-life environmental challenges.

By exposing these structural and pedagogical deficiencies, the study makes an important contribution to the discourse on curriculum reform in Ethiopia's secondary school geography curriculum and other parts of the Global South. Furthermore, it emphasizes the need for a more coherent and context-responsive integration of deforestation and climate change concerns, which are critical and timely environmental themes, grounded in both local realities and international best practices. For teachers, curriculum developers, and policymakers, the findings call for a paradigm shift from awareness-based instruction to transformative learning that fosters action competence and civic responsibility. This includes embedding environmental education across subjects, strengthening Minimum Learning Competencies with a balance of cognitive, affective, and psychomotor goals, and institutionalizing professional support systems for teachers.

Although the study offers valuable insights, it also acknowledges its limitations. The research was confined to secondary school geography, relied on a limited number of key informant interviews, and did not account for interdisciplinary links or primary/tertiary education levels. Future research should expand on these dimensions by incorporating classroom observations, student performance data, and comparative analyses across regions and educational levels. Moreover, exploring the role of indigenous knowledge systems and community-based practices could enrich the cultural relevance and impact of environmental education in Ethiopia.

In sum, this study underscores an urgent need for curriculum reform that aligns educational practice with the goals of sustainable development. Only through an intentional and systemic integration of climate and deforestation content supported by active pedagogy, teacher empowerment, and locally rooted approaches can Ethiopian education related to these environmental concerns meaningfully contribute to the cultivation of environmentally literate, responsible, and empowered citizens.

CHAPTER SIX

6. Curbing environmental problems related to deforestation and climate change: The level of secondary school students' knowledge, attitudes, and determinants in Metekel Zone, Northwest Ethiopia

Abstract

Environmental problems, notably deforestation and climate change, pose significant threats to humanity and demand urgent intervention. In Ethiopia, where these challenges are pronounced, addressing these issues requires a solid foundation of knowledge and positive attitudes, especially among young people. This study examines secondary school students' level of environmental knowledge and attitudes and the determinants related to deforestation and climate change in the Metekel Zone, Ethiopia. A cross-sectional survey was used for the study, and a total of 372 secondary school students selected through a multistage sampling technique from seven government secondary schools in the Metekel Zone were participants. Data were collected via standardized tests, questionnaires interviews and focus group discussions and analyzed via descriptive statistics, chi-square tests, and binary logistic regression. The findings revealed that the knowledge levels and attitudes of secondary school students toward environmental issues related to deforestation and climate change were low. The results from the regression model revealed significant correlations between students' knowledge and attitudes, except for personal interest in environmental matters. A notable correlation comprises age, gender, residence, the educational level of the student parents, the family income level, and the social environment, access to information, the student's grade level, and the student's participation in school-based environmental clubs. The study also identifies key barriers to students' environmental knowledge and attitudes, including curriculum challenges, resource gaps, low awareness, emotional detachment, and limited personal agency. To inspire pro-environmental behaviours among students, enhancing environmental education in various disciplines to address gender, age, and grade level variations, along with proper content integration of deforestation and climate change issues, promoting problem-solving approaches, strengthening extracurricular activities such as environmental clubs, exposing students to media, fostering partnerships for place-based learning initiatives, organizing workshops, incorporating

localized and experiential learning and providing teachers with specialized training and resources are acclaimed.

Keywords: Environmental problems, level of students' knowledge and attitudes, deforestation, climate change

6.1.Introduction

Currently, environmental issues are becoming the gravest problems facing the globe and are a serious threat to human survival in both rural and urban areas (Nahar et al., 2021; Rakhimova, 2020). Human-induced factors, such as population pressure, urbanization, infrastructure development, intensive forest harvesting for fuel wood, and inadequate planning, have a noteworthy effect on human well-being and are the root cause of many contemporary environmental issues (Akhtar et al., 2021; da Costa Ferreira & Barbi, 2016; Teo et al., 2019). Consequently, the quantity and quality of life are changing dramatically as a result of these issues (Kharat et al., 2017), emphasizing the need for serious solutions before they reach the point of no return (Reddy et al., 2017).

Deforestation and anthropogenic climate change have emerged as principal components of these challenges, significantly affecting developing countries (Leon et al., 2022). Ethiopia, one of the countries in sub-Saharan Africa, suffers from these escalating problems, which have led to a decline in biodiversity, crop pest emergence and dissemination, animal illnesses, the frequency and distribution of unfavorable weather conditions (Oljirra, 2019), the deterioration of natural habitats, the depletion of water supplies, and the severity of soil erosion (Alemu et al., 2022; Muluneh et al., 2017).

Despite the growing difficulties, there is a notable lack of environmental awareness in Ethiopia, which has been linked to challenges in effectively implementing the goals of environmental education (Sulaiman et al., 2009; Yeshalem, 2013). Addressing environmental issues such as deforestation and climate change necessitates not only a solid foundation of knowledge and a positive attitude but also an understanding of the various factors that influence the translation of attitudes into pro-environmental behaviours (Akrofi et al., 2019). While education plays a crucial role in equipping the young generation with the awareness and skills needed for environmental sustainability, it is one component among many. Factors such as socio-cultural norms, personal motivations, structural barriers, and demographic factors, along with external influences (such as institutional, economic, social, and cultural aspects) and internal factors (including motivation, pro-environmental knowledge, awareness, values, attitudes, emotions, locus of control, responsibilities, and priorities), significantly influence behaviour (Chwialkowska et al., 2020; Kollmuss & Agyeman, 2002; P. Liu et al., 2020). Preparing the younger generation to be more environmentally conscious is essential, but it requires such a multifaceted approach that extends beyond educational institutions to include community engagement and policy support; ensuring the sustainability of our earth is a shared responsibility. Therefore, educational institutions must take and consider a multifaceted approach, fostering both awareness and the enabling conditions for students to adopt and sustain pro-environmental behaviours.

Various studies have examined the connections among knowledge, attitudes, and pro-environmental behaviour among students, though findings often vary by geographical context. For instance, Casaló et al. (2019) focused on European contexts, suggesting that knowledge has the strongest influence on environmental behaviour, likely reflecting the emphasis on environmental education within these regions. Similarly, Kaplowitz & Levine (2005), in their study of U.S. students, revealed that considerable environmental knowledge is often associated with positive attitudes, reflecting localized efforts in environmental education. However, in Ethiopia, (Paulos, 2017) found a positive correlation between environmental knowledge and attitudes among secondary school students but observed a weaker link between knowledge and environmental practices.

On the other hand, (Bamberg & Möser, 2007) and (Heimlich & Ardoin, 2008) demonstrated that differences in students' environmental knowledge, attitudes, and participatory behavior can be attributed to numerous factors. For instance, a Bamberg meta-analysis primarily focused on studies from North America and Europe, where cultural and educational systems emphasize individual agency in environmental actions. Similarly, Heimlich and Ardoin explored these differences within the context of North America environmental education programs, highlighting the role of localized teaching methods. Furthermore, Dijkstra & Goedhart (2012) study, conducted across five European nations, revealed a correlation between pro-environmental attitudes and understanding of climate change among secondary school students. This correlation was influenced by factors such as gender, age, and grade level.

Family socioeconomic status, particularly parents' occupation and education, plays a significant role in shaping student's pro-environmental behavior. Levinthal et al. (2021) found that parental engagement, influenced by their socioeconomic background, has a substantial impact on young people's environmental knowledge and attitudes in Finland and Portugal. In a similar vein, Stroetinga et al. (2019) emphasized the importance of parent-teacher collaboration in fostering environmental responsibility among students in Europe. Active involvement in school-based environmental clubs further nurtures pro-environmental attitudes. Smith (2019) explored the role of environmental clubs in Victoria, Australia, and discovered that these platforms promote ecocentrism and deepen students' connection to nature. Additionally, personal interest in environmental issues significantly influences students' pro-environmental behaviors. Otto & Pensini (2017), in their study conducted in Berlin, found that nature-based education not only enhances environmental knowledge but also fosters ecological responsibility. Geographical context also plays a crucial role in shaping students' environmental awareness and behaviors. The study by Berenguer et al. (2005), conducted in Spain, compared rural and urban populations, finding that while both groups exhibited high environmental concern, rural residents demonstrated stronger environmental responsibility and more consistent pro-environmental actions. Urban residents, on the other hand, showed more responsibility values but less alignment with their behaviors. In Mexico, Duron-Ramos et al. (2020) found that rural students, due to their closer connection to natural environments, were more actively engaged in pro-environmental actions compared to their urban peers.

In Ethiopia, these global perspectives align with efforts to integrate environmental education into the secondary school geography curriculum. This education addresses deforestation and both anthropogenic and natural causes of climate change, along with their consequences and mitigation strategies, aiming to equip students with knowledge that fosters positive attitudes and promotes pro-environmental behaviors and actions. As outlined in the policy documents of the country (MoE, 1994, 2023) and the Education Development Roadmap (MoE, 2018), efforts have been made to integrate environmental education into the curriculum since 1994, aiming to increase students' environmental knowledge and attitudes. In addition, the Ethiopian Environmental Protection Authority (EEPA) has been established to address the challenges of environmental problems through education and awareness (Ababa, 2004). Despite these initiatives, it appears that environmental challenges such as deforestation and anthropogenic climate change persist in different parts of the country, including the study region (Oljirra, 2019; Wagino & Amanuel, 2021).

Although several studies have focused on the issue at the national level (Birhanu, 2023; Paulos, 2017; Yeshalem, 2013), studies on the level of secondary school students' knowledge, attitudes, and factors affecting their action and participation in solving environmental problems related to deforestation and climate change have not yet been well studied and documented. To curb existing environmental problems and maintain the sustainable use of natural resources, understanding and analyzing the levels of students' environmental knowledge, attitudes and various determinants that affect their involvement in alleviating these problems play substantial roles. Hence, the present study aims to assess the level of secondary school students' knowledge and attitudes toward environmental problems related to deforestation and climate change and the determinants in the Metekel zone.

More specifically, this research aimed to answer the following basic questions: *i) What is the level of secondary school students' knowledge concerning environmental problems related to deforestation and climate change in the Metekel zone? ii) To what extent do secondary school students in the Metekel zone exhibit pro-environmental attitudes towards addressing problems related to deforestation and climate change? iii) What factors influence secondary school students' decisions to engage in pro-environmental actions addressing deforestation and climate change in the Metekel zone?*

6.2.Theoretical Framework

This study is grounded in the theory of planned behavior (TPB) (Ajzen, 1991), which serves as a robust theoretical foundation for examining how secondary school students' environmental knowledge, attitudes, and influencing factors shape their intentions and behaviors related to deforestation and climate change. Additionally, the framework is strengthened by integrating environmental literacy framework (McBride et al., 2013).

6.2.1. Combining the TPB and the Environmental Literacy Framework

To explore the level of knowledge and attitude and determinants of students' pro-environmental behaviors related to deforestation and climate change, this study integrates the TPB and the environmental literacy framework. Combining the TPB and the Environmental Literacy Framework allows for a more holistic understanding of how both individual psychological factors and broader environmental contexts influence students' pro-environmental behaviors, ensuring more effective strategies for fostering sustainable environmental actions. This integration also narrows the gap in the TPB by addressing its limitations in capturing emotional, social, and contextual influences on behavior.

The TPB, a widely applied psychological model, posits that individuals' behaviors are shaped by their intentions, which are in turn influenced by three key constructs: attitudes toward the behavior, subjective norms, and perceived behavioral control (Ajzen, 1991; Ateş, 2020; Yuriev et al., 2020) . In this context, Behavioral attitude, the first predictor of intentions, reflects an individual's positive or negative evaluation of a behavior. For secondary school students, attitudes toward mitigating deforestation and climate change involve emotional (affective), practical (instrumental), and knowledge-based (cognitive) aspects. Positive attitudes, shaped by education on conservation benefits and environmental risks, are essential for fostering pro-environmental intentions.

The second predictor, subjective norms, involves perceived social pressures to perform or not perform a behavior. This includes the influence of peers, family, teachers, and media on students' environmental behaviors. Subjective norms can be divided into injunctive norms, which indicate social approval, and descriptive norms, which reflect common behaviors within a social group. Understanding these differences is important for understanding how social influences affect behaviors and attitudes, particularly with respect to environmental issues. Environmental education programs can shape subjective norms by fostering a culture of environmental responsibility. When students perceive that significant others (e.g., peers, teachers, family) value and engage in pro-environmental behaviors, they are more likely to develop similar intentions.

The final predictor, Perceived behavioral control (PBC) refers to individuals' perceptions of their ability to perform a behavior, influencing their intentions and actions. For secondary school students, PBC impacts their engagement in combating deforestation and climate change. When students believe they have the necessary skills, resources, and support, they are more likely to take action. Educational programs should enhance confidence through hands-on activities and resource access, ultimately increasing participation in environmental behaviors. PBC also reflects students' beliefs in their capacity to address environmental issues effectively.

In general, the Theory of Planned Behavior provides a comprehensive framework for understanding how psychological factors and social influences interact to shape students' pro-environmental behaviors, offering valuable insights for designing effective educational interventions that promote sustainable environmental actions. However, while TPB provides valuable insights into understanding students' environmental behaviors, it has been widely criticized for several limitations that constrain its ability to fully explain environmental behaviors. First, it assumes a rational and linear relationship between attitudes, intentions, and actions. This oversimplification has been critiqued for neglecting the emotional, moral, and unconscious factors that often influence behavior (Armitage & Conner, 2001; Kollmuss & Agyeman, 2002). For example, while students may understand the need for environmental conservation, their emotional connection to the local environment could be a more significant driver of action, a dynamic not captured by the TPB. Second, TPB places limited emphasis on contextual and structural factors that significantly influence behavior, particularly in low-resource settings. As Barr & Gilg (2007) highlight, socio-economic conditions, cultural narratives, and logistical constraints often act as external barriers that hinder individuals from translating intentions into action. This is especially relevant in the Metekel Zone, where limited resources, socio-economic conditions and cultural practices might affect students' ability to participate in pro-environmental behaviors despite their intentions. Third, the TPB has been critiqued for its inability to address the intention-behavior gap, where individuals with strong pro-environmental intentions fail to act due to various barriers, such as insufficient resources, institutional limitations, or lack of practical skills (Beach, 2023; Hassan et al., 2016). This gap underscores the need for a more comprehensive framework that accounts for the factors mediating the transition from intention to action.

To address these critiques, this study incorporates the environmental literacy framework, which provides a multidimensional perspective on environmental behavior. This framework encompasses four key dimensions: knowledge, awareness, skills, and attitudes, all of which are critical for fostering pro-environmental actions (Evans et al., 2007; Kaya & Elster, 2019; Wong & Kerkez, 2016). By complementing the TPB's psychological constructs, the environmental literacy framework addresses the emotional, contextual, and dynamic aspects of environmental behavior. Knowledge, as a foundational dimension, equips students with an understanding of critical environmental issues such as deforestation and climate change, thereby enhancing their capacity to make informed decisions (Parrotta & Agnoletti, 2012; Turnhout et al., 2016). Awareness builds upon this by fostering emotional engagement and moral responsibility, encouraging students to recognize the urgency of addressing environmental challenges (Pawar & Rothkar, 2015). Skills, another critical component, empower students to analyze environmental problems and propose viable solutions, bridging the intention-behavior gap by enabling practical action (Turnhout et al., 2016). Finally, attitudes encompass both cognitive and affective elements, reflecting students' predispositions toward environmental conservation (Roczen et al., 2013).

The integration of the TPB with the environmental literacy framework offers a synergistic model that captures the complexity of environmental behavior formation. For example, the TPB's construct of perceived behavioral control aligns seamlessly with the framework's emphasis on skills, highlighting the importance of empowering students to act on their intentions. Similarly, the TPB's focus on subjective norms complements the framework's emphasis on socio-cultural awareness, acknowledging the role of peer and societal influences in shaping behavior. By combining these approaches, the study provides a more comprehensive understanding of the student's level of knowledge, attitude and the demographic, socioeconomic, psychological, and educational factors influencing their environmental actions. This combined framework is particularly relevant for addressing the unique challenges faced by students in the Metekel Zone. By bridging the psychological insights of the TPB with the multidimensional scope of the environmental literacy framework, this study captures the tones of students' environmental behaviors and provides actionable insights for fostering sustainable practices. Furthermore, this integration not only addresses the critiques of the TPB but also enhances its applicability to complex environmental contexts, making it a robust theoretical foundation for understanding and promoting pro-environmental behavior.

6.3.Materials and methods

To ascertain students' environmental knowledge and attitudes as well as the factors influencing their level of participation in addressing environmental issues such as deforestation and climate change, this study uses a mixed methods approach with a cross-sectional survey design.

6.3.1. Description of the study area and schools

The study was carried out in the Metekel Zone in Benishangul Gumuz Regional State, which is located in the northwestern part of Ethiopia. Geographically, the zone extends from 10°15′ N and 11°45′ N latitude and between 34°45′ E and 36°45′ E (Figure 6.1), covering an approximate area of 22,028 km^2. Its administrative center, Gilgel Beles, stands at a road distance of 575 km from Addis Ababa and 365 km from Assosa, the regional capital. The zone is further subdivided administratively into seven *woredas* (districts), namely, Bullen, Dibate, Dangur, Guba, Mandura, Pawe, and Wembera. Characterized by a subhumid and humid tropical climate, approximately 80% of the zone experiences an annual average temperature ranging from 16.2 °C to 32.5 °C, accompanied by an average yearly rainfall of 1,607.8 mm, which is concentrated between May and October (Wagino & Amanuel, 2021).

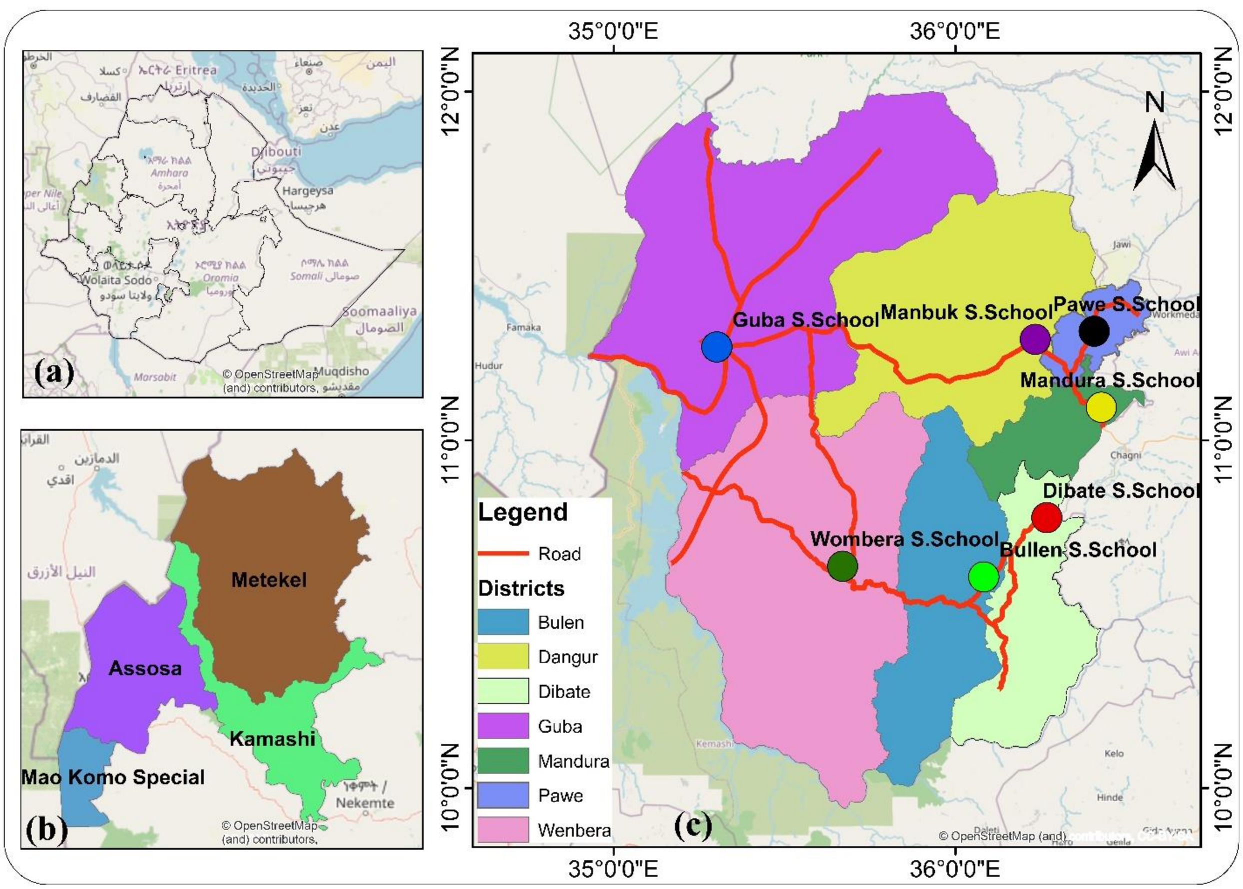


Figure 6.1: Location map of the study area developed from (CSA, 2024) using ArcMap: (a) Ethiopian regional state; (b) Zones of Benishangul Gumuz regional state; (c) Metekel Zone districts with sample secondary schools

The demographic composition of Metekel Zone, as reported by the Ethiopian Central Statistics Authority (CSA, 2024), indicates a total population of 534,305 individuals, consisting of 268,288 males and 266,017 females. A significant urban-rural divide characterizes the zone, with the rural population accounting for 71.3% (380,786 individuals) and the urban population comprising 28.7% (153,519 individuals). This distribution underscores the predominance of rural inhabitants in the region, reflecting the zone's continued reliance on rural livelihoods and settlements.

Amidst this demographic setting in the rural and urban areas of the Metekel zone, government secondary schools play a crucial role in educating young people. Consequently, as depicted in Figure 6.1, out of the 14 secondary schools in the zone, seven were selected using a simple random sampling technique. The selection criteria were guided by the curricular emphasis on deforestation and climate change in geography lessons across grades 9–12, the target educational levels for this study.

6.4.Subjects of the study and sampling procedure

Among the seven secondary schools included in this study, 5,324 students attended the 2023/24 school year. Thus, the sample frame comprises students from the seven sample secondary schools (grades 9-12), excluding Grade 11 and 12 natural science students since they did not learn geography. The sample size of students was calculated via Yamane (1967) sample size formula (Equation 6-1) because it accounts for population size, the desired confidence level, and accessibility for researchers with diverse statistical knowledge. The formula is represented as follows:

$$n = \frac{N}{1 + N(e)^2} \qquad \textit{Equation (6.1)}$$

where, *n = the sample size to be estimated, N= the number of students in the seven sample schools, and e= the margin of error, reflecting the level of precision (set at 0.05).*

Accordingly, the sample population was: n=5324/1+5324 (0.05)2 =372. Therefore, the samples of the study included 372 secondary school students. Since schools have different numbers of students in each grade with different gender compositions, a proportionate stratified random sampling technique was employed to take sample students from each grade level. Based on this procedure, students from each grade level were again selected through simple random sampling, as indicated in Table 6.1.

Table 6.1: Distribution of students sampled for the study on the basis of grade level and gender

Grade level	Number of students			Number of sampled students based on their proportion		
	M	F	Total	M	F	Total
Grade 9	948	1028	1976	67	73	140
Grade 10	966	1175	2141	67	83	150
Grade 11 (Social Science)	320	242	562	21	17	38
Grade 12 (Social Science)	331	314	645	23	21	44
Total	2565	2759	5324	178	194	372

Source: Metekel zone education department

6.5.Data collection instruments

To collect the data for the study, multiple data-gathering instruments, such as standardized knowledge and attitude tests, questionnaires, in-depth interviews, and focused group discussions, were employed.

Knowledge and attitude test: To investigate the level of students' knowledge of environmental problems with a particular emphasis on deforestation and climate change, 30 items were adapted from (de la Vega, 2006), which originally aimed to determine the environmental knowledge of different community groups, including secondary school students in Florida. However, adjustments were made to some questions, additional items were included, and the Likert-type items from the original document were changed to multiple-choice items on the basis of the contents of secondary school textbooks, local environmental challenges related to deforestation and climate change, and the characteristics of the respondents.

Similarly, to measure students' environmental attitudes toward environmental issues with a focus on deforestation and climate change, a standardized 30-point scale was adapted from Sarkar (2011), which was originally designed to measure the environmental attitudes of adolescents in Bangladesh. However, from the original 30-point scale, 1 represents strongly disagree to 5 strongly agree, three Likert scale items were cancelled, and some others were modified to align with the research objectives and the specific content of secondary school geography textbooks related to the topic under investigation. Finally, a Likert-type scale consisting of 27 items that measure students' attitudes toward the problem, cause, consequence and solution to deforestation and climate change is used. To determine the environmental attitudes of the respondents, the mean scores were categorized into three categories: those with mean scores greater than three indicated a favorable attitude category, those with mean scores of three indicated an undecided attitude, and those with mean scores less than three indicated an unfavorable attitude category.

Questionnaire: Similarly, the questionnaire included 21 items on factors influencing students' environmental knowledge and attitudes toward addressing deforestation and climate change. On the basis of the relevant literature, these items assess students' participatory behavior and ability to raise community awareness of local environmental issues.

In-depth interviews: This study used in-depth interviews to gather qualitative data on secondary school students' knowledge and pro-environmental attitudes toward deforestation and climate change, as well as factors influencing their engagement in mitigating these challenges. Nine Key participants were purposively selected for their diverse and relevant perspectives, following qualitative research principles emphasizing meaningful insights through focused sampling (Creswell, 2003; Guest et al., 2006). The participants included two geography teachers, two students, a parent-teacher association member, a geography department head, a school principal, and two district/zonal education experts. These stakeholders provided insights on curriculum integration, institutional support, and systemic influences shaping environmental education and engagement. The semi-structured interviews explored six key themes: students' knowledge of deforestation and climate change, pro-environmental attitudes, emotional and moral motivators, barriers to pro-environmental behaviors, school and community engagement, and broader factors shaping knowledge and attitudes. This method yielded rich data, illuminating challenges and opportunities in promoting environmental education and student participation.

Focus Group Discussions (FGDs): Three focus group discussions (FGDs) were conducted to complement quantitative data and in-depth interviews, gathering collective perspectives on secondary school students' knowledge, attitudes, and participation in addressing deforestation and climate change. The FGDs were held in three districts—Pawe, Dangur, and Mandura—chosen for their severe environmental challenges caused by resettlements, government farm investments, charcoal production, and firewood collection. Each FGD included six participants, aligning with the recommended group size for meaningful discussions (Nyumba et al., 2018; Rabiee, 2004). Participants included geography teachers, students, school principals, geography department heads, education experts, and parent-teacher association members, selected purposefully for their relevant insights. Each session lasted one hour, following best practices for effective FGDs, and was guided by open-ended prompts to explore students' engagement and the factors influencing their knowledge and attitudes. With the assistance of school directors and geography department heads, the FGDs revealed shared experiences and enhanced the quality of data by capturing a variety of perspectives. This approach provided a holistic view of environmental education challenges and opportunities in the Metekel Zone.

6.6. Validity and reliability of the instruments

For the face and content validity of the instruments, input from geography teachers and the research advisors was sought for the initial measurement instrument. On the basis of their feedback, item reconstruction was carried out for final utilization.

To determine the reliability of the knowledge items, a pilot test was conducted on 30 students at four secondary schools, and the reliability of the modified items was found to be 0.78. The test was subsequently piloted, the items were refined, and all 30 items were accepted by examining the relevance and reliability of each item to the research question. A correct response was assigned a score of one, and an incorrect response was assigned a score of zero. The lowest possible total score is zero, and the highest total score is 30 (30x 1), which is changed by 100% for comparison convenience. In addition, a cutoff point was set before the test was performed. Accordingly, on the basis of the national passing mark set by the Ethiopian Ministry of Education, scaling the test cutoff point was decided upon by the researchers. Thus, a cutoff point for a pass is a score of 50. Additionally, 50–70 and >70 are medium and high scores, respectively. On this basis, respondents are categorized into three knowledge levels: low, moderate, and high. Consequently, in this research, students who scored below 50 percent (who scored <15 points) were classified as having a "low" level of knowledge regarding deforestation and climate change as environmental issues explored in the study. Those who scored 50–70% (who scored 15–21 points) were considered to have a "moderate" level of knowledge, whereas those who scored 70% (who scored >21 points or more) were classified as having a "high" level of such knowledge.

Following the content and face validity, pilot testing was also carried out with 30 students from four secondary schools who did not take part in the sample groups to measure students' attitudes toward the problem, cause, consequence, and solution to deforestation and climate change. To identify the reliability of the attitude scale, Cronbach's alpha was used, and its result was calculated as 0.803, which is reliable. For the given five scales, a higher mean score closer to 5 reflects more favorable attitudes among students, whereas a lower mean score indicates less favorable attitudes.

6.7.Method of Data Analysis

The researchers employed a combination of qualitative and quantitative methodologies for data analysis.

6.7.1. Quantitative data analysis

Quantitative univariate, bivariate, and multivariate analyses were conducted on data obtained through standardized tests and structured questionnaires obtained through SPSS software version 27. Descriptive statistics, such as percentages, frequencies, and cross-tabulations, were utilized to examine students' levels of knowledge and attitudes, as well as the factors shaping their environmental knowledge and attitudes on addressing deforestation and climate change challenges. Additionally, the chi-square test was employed to examine the relationships between the dependent and independent variables, whereas binary logistic regression, as a component of the multivariate technique, was employed to establish relationships between these variables. Binary logistic regression was also used to identify and interpret the various explanatory variables affecting the level of students' environmental knowledge and attitudes toward alleviating deforestation and climate change. It was used when the dependent variable was dichotomous, i.e., variables that assume only a binary response. The model is specified as follows (Equation 6-2):

$$\ln\left[\frac{\mathrm{P}}{1-\mathrm{P}}\right] = \beta 0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \ldots + \beta_k X_k \qquad \textit{Equation (6.2)}$$

In this equation, the expression P/(1-P) represents the odds ratio, where P denotes the probability that a student develops a high level of environmental knowledge and positive attitude toward environmental issues related to deforestation and climate change, and 1−P denotes the probability of a low level of knowledge and an unfavourabl**e** attitude toward addressing the environmental issues under investigation. Additionally, β0 represents the intercept, while X1, X2, X3, ..., Xk represent the independent variables, and β1, β2, β3, ..., βk represent the regression coefficients. An odds ratio above 1 indicates a positive relationship between the independent variable and the dependent variable. A value of 1 suggests no relationship, whereas a value below 1 signifies a negative relationship between the dependent and independent variables (Tesfahunegn, 2019).

3.5.1.1. Variables used in the study

The study's outcome variable measures students' environmental knowledge and attitudes toward addressing deforestation and climate change on the basis of their formal education and extracurricular activities. It also assesses the changes in attitudes that motivate students to take action and inspire the public to prevent and mitigate these impacts. This variable was quantified via the median value derived from seven indicators: students’ involvement in planting trees (1 if yes, 0 otherwise); students’ commitment to refraining from engaging in charcoal production and fuel wood collection and selling; students’ dedication to their engagement and encouragement of the local community to adopt renewable energy sources; students’ participation and commitment in making awareness to the local community to perform climate change adaptation strategies; students' capacity to personally involve and inspire the community to advocate for the adoption of sustainable land management practices aimed at preventing soil erosion and conserving ecosystems; students’ ability to advocate for policies that promote forest conservation and climate action; and students’ capacity to guide the community in reducing population growth, all of which involve (1 if yes, 0 otherwise). The counted response for all these indicators ranges from 0 to 7.

Students' environmental knowledge and attitudes toward addressing deforestation and climate change were categorized on the basis of a total score, with a midpoint of four out of seven indicators. Students with a score of at least four were considered to have high environmental knowledge and a positive attitude, whereas those scoring below four were considered to have low knowledge and a negative attitude. This was measured as a dummy variable: 1 for high knowledge and positive attitudes and 0 for low knowledge and negative attitudes. The regression model's independent variables are hypothesized to influence students' environmental knowledge and attitudes toward addressing deforestation and climate change. Ten potential variables, categorized into demographic, socioeconomic, behavioural, environmental, and educational factors, were identified (Table 6.2). The former include age, gender, and residence (urban or rural areas). The socioeconomic variables include the educational level of the student's parents (determined by the highest level of schooling completed by the father, mother, or guardians who represent the household) and the family's economic status. On the other hand, the behavioural variable encompasses the student's interest. Environmental factors include the social environment and access to information. Finally, the educational variables include the student's grade level and participation in school-based environmental clubs.

Table 6.2: Descriptions of the independent variables and their associations with the dependent variable

Explanatory variables	Description and measurement	Variable type	Expected sign
Age of students	1=15–16; 2=17–18; 3=19 years and above	Continuous	+
Sex of students	1= if a student is male; 0, otherwise	Dummy	±
Educational status of student's families	1= Illiterate; 2=primary; 3= secondary and above	Categorical	+
Student's residence	1= If a student lives in urban residences = 0	Dummy	+
Family Income Level	1=Low-income level; 2=Middle income level;3= high income level	Continuous	+
Student's involvement in school-based environmental clubs	1= not involved; 0= involved	Dummy	+
Student's grade level	1= grade 9; 2= grade 10; 3= grade 11; 4=	Ordinal	+

	grade 12		
Student's interest	1= if students have a good personal interest in environmental matters; 0 otherwise	Dummy	+
Social environment	1=if norms, pressures, and traditions transmitted by the social environment to the student are good; 0 otherwise	Dummy	+
Access to information	1= if a student has access; 0, otherwise	Dummy	+

6.7.2. Qualitative Data Analysis

The qualitative data collected through KIIs and FGDs were analyzed using thematic analysis, grounded in established research methodologies. This approach allowed for the systematic identification and interpretation of recurring themes related to secondary school students' environmental knowledge, pro-environmental attitudes, and the factors influencing their engagement in environmental behaviors in the Metekel Zone. The analysis began with a familiarization phase, during which transcripts were thoroughly reviewed to capture contextual tones and variations in perspectives across districts and participant groups. Key segments of the text were coded based on meaningful ideas and recurring insights, which were then grouped into broader themes aligned with the study's objectives. Special attention was given to examining the relationship between students' environmental knowledge and their pro-environmental attitudes, particularly concerning deforestation and climate change. The analysis also explored demographic, socioeconomic, behavioral, environmental, and educational factors that shape students' knowledge, attitudes, and actions. Themes were refined iteratively to ensure coherence and relevance, with an emphasis on their alignment with the research questions. The relationships between themes and codes were critically assessed to provide a crucial understanding of how structural and contextual factors influence students’ environmental engagement. To ensure rigor, triangulation was employed by cross-verifying themes across KIIs, FGDs, and quantitative findings. Additionally, reflective practices, such as maintaining detailed notes on researcher decisions, enhanced the reliability of the analysis.

6.8.Results

6.8.1. Level of Students' Environmental Knowledge toward Deforestation and Climate Changes as Environmental Problems

Standardized items were used to assess level of secondary school students' knowledge of environmental issues, with an emphasis on deforestation and climate change. To simplify the analysis, we converted the test score and each student's test score to a percentage via the national scoring system (refer to the methodology subsection). Table 6.3 provides a full summary of the findings.

Table 6.3: Frequency of respondents' knowledge level on environmental issues, with a particular focus on deforestation and climate change (N = 372)

Level of category	Frequency of respondents	
	No.	Percent
High level of knowledge (>70%)	69	18.5
Medium level of knowledge (50-70 %)	109	29.3
Low level of knowledge (50 %)	194	52.2
Total	372	100

Source: Field survey, 2024

The students' knowledge test results (Table 6.3) show that while 29.3% of the respondents identified as having a medium level of knowledge on environmental issues, 18.5% of the respondents had a high level of knowledge, with an emphasis on deforestation and climate change. A total of 52.2% of the students, or over half, receive a score lower than 50%. From the results, it is possible to conclude that the level of students' knowledge about environmental problems related to deforestation and climate change in the study area is low. One can also infer that this may lead to unfavourable environmental behavior and negative attitudes. Qualitative data from FGDs and KIIs revealed that students struggle to understand deforestation and climate change due to lessons lacking local context and practical applications. Students reported limited awareness of how these issues affect their communities, citing insufficient resources, discussions, and awareness campaigns. Teachers and administrators reported systemic barriers, including inadequate curriculum time, resource shortages, and poor coverage of complex environmental topics. These challenges contribute to fragmented and superficial environmental knowledge among students.

6.8.2. Status of Students' Environmental Attitudes toward Deforestation and Climate Change as Environmental Problems

Changing mindsets and attitudes at the core of environmental problems cannot be achieved solely through the enactment of laws or regulations that forbid environmental destruction. This finding supports the objectives of environmental education, which include helping students develop positive attitudes toward solving environmental issues and becoming environmentally conscious citizens. Twenty-seven inventory items were surveyed and examined, and the results are shown in Table 6.4.

According to the survey analysis revealing students' attitudes toward the environment, with a particular focus on deforestation and climate change, 122 participants (32.8%) demonstrated positive attitudes, as indicated by mean scores higher than 3. A smaller percentage, comprising 54 respondents (14.5%), was unsure or maintained a neutral position, with mean scores of exactly 3. Additionally, 196 students (52.7%) recorded mean scores below 3, indicating a significant negative attitude. It is postulated that involvement in pro-environmental behavior is manifested by positive attitudes about environmental sustainability. Nonetheless, these findings suggest that the majority of students hold unfavorable attitudes, which hinder their willingness to engage in meaningful action to mitigate these issues. This validates a crucial need to address the major factors influencing students' attitudes to foster a more proactive approach to environmental challenges under investigation. Qualitative findings from FGDs and KIIs revealed that while some students expressed concern about deforestation and climate change, the majority lacked awareness, urgency, or engagement. Many perceived these issues as distant and unrelated to their lives, citing limited access to information, lack of guidance, and feelings of powerlessness. A teacher noted that students rarely understand the long-term consequences, while education experts observed that students often view environmental action as a government responsibility rather than a personal one.

Table 6.4: Environmental attitudes of the respondents toward alleviating environmental problems related to deforestation and climate change

Category	count	percent
Favorable attitude (mean scores >3)	122	32.8
Undecided (mean scores=3)	54	14.5
Unfavorable attitude (mean score <3)	196	52.7
Total	372	100

Source: field survey, 2024

Students' low engagement and negative attitudes were further reflected in their skepticism about individual efforts, with some questioning the relevance of environmental issues when basic needs remain unmet. This lack of emotional connection and belief in agency highlights the challenges in fostering pro-environmental attitudes and emphasizes the importance of making environmental issues personally relevant to students.

6.8.3. Determinants of the level of students' environmental knowledge and attitudes, with a particular focus on deforestation and climate change

Tables 6.5, 6.6, and 6.7 present findings from the chi-square test, which examines the relationships between the dependent and independent variables. Table 8 shows the results from the binary logistic regression model, identifying key determinants influencing students' knowledge and attitudes toward deforestation and climate change. As indicated in Table 8, nine of the ten variables studied significantly influence students' knowledge and attitudes toward environmental issues, especially deforestation and climate change. One factor had no statistically significant effect. Among the significant factors, three had a negative effect on students' attitudes and knowledge, whereas the remaining factors had a positive effect. The model summary revealed that the predictors explained 35.9% to 47.9% of the variation in students' environmental knowledge and attitudes, with 79.0% of the cases correctly classified. The chi-square test ($p < .000$) confirms strong predictive ability, with a value of 165.489. Multicollinearity analysis indicated no significant issues.

The binary logistic regression model (Table 6.8) and chi-square test (Table 6.5) confirm that demographic factors, such as sex, age, and residence, significantly impact students' environmental knowledge and attitudes. Notably, 32.5% of the students aged 15-16 years had high levels of environmental knowledge and positive attitudes, whereas 67.5% had low levels of knowledge and negative attitudes. In the 17–18 age range, 40.7% of the students had low knowledge and negative attitudes, which was lower than the previous levels, whereas 59.3% had high knowledge and positive attitudes. Among the students over 19 years of age, 53.9% exhibited high knowledge and positive attitudes, whereas 46.1% had low knowledge and negative attitudes. Table 6.5 reveals a significant correlation between students' age and their environmental knowledge and attitudes ($\chi 2 = 23.095$; $p = 0.000$). Table 6.8 further confirms that, holding other variables constant, each additional year of age increases environmental knowledge and positive attitudes by a factor of 1.720 ($p = 0.007$).

This study, examining the level of secondary school students' environmental knowledge and attitudes in relation to the national geography curriculum, supports the hypothesis that age correlates with increased maturity and greater environmental responsiveness. Findings from FGDs reveal that older students actively engage in conservation efforts, such as planting trees and avoiding harmful practices such as charcoal production. They also work to motivate their communities in sustainable land management, with a focus on preventing soil erosion and preserving ecosystems. The KII reports also suggest that older students are more environmentally conscious because they have better access to resources such as books, the internet, and extracurricular activities, particularly in urban schools. In contrast, younger students, with less exposure to environmental degradation and less influence from their peers, show lower environmental awareness and involvement. As students aged, they tend to develop more autonomy and a stronger personal interest in environmental issues, supported by their increased access to educational resources and experiences. This discrepancy verifies the importance of addressing environmental education tailored to different age groups and improving exposure to environmental issues for younger students.

Gender is the second important demographic factor affecting students’ knowledge and attitudes toward addressing deforestation and climate change as environmental problems. It is hypothesized that gender differences in environmental knowledge and attitudes stem from varying experiences, awareness, culture, and decision-making power. This study's data support this hypothesis. Among the male respondents, 39.3% had high levels of environmental knowledge and positive attitudes, whereas 60.7% had low levels of knowledge and negative attitudes. Conversely, 45.4% of females had low knowledge and positive attitudes, and 54.6% had high knowledge and positive attitudes. A chi-square test ($\chi 2 = 8.732$, $p = 0.003$) revealed a significant relationship between gender and environmental knowledge and attitudes, which was supported by the binary logistic regression model. Table 6.8 indicates that males are 0.095 times more likely to have high levels of environmental knowledge and positive attitudes than females are, with other variables held constant.

An in-depth interview with parent–teacher association member and education experts supported the study's findings. In districts such as Mandira, Dibati, Wombera, Bullen, and Dangur, in addition to attending school, female students manage household tasks such as food production, processing, cooking, fetching water, and collecting fuel wood. This daily interaction with their environment makes them more aware of environmental changes. The FGD participants also reported that female students' duties, combined with formal education and informal learning, enhance their engagement with the environment, leading to a positive response to environmental issues. They often cultivate home garden forests and use energy-efficient stoves and alternative energy sources such as biogas and solar energy. Conversely, male students, influenced by cultural norms and economic challenges, gather wild edible plants and sell wood products to meet their daily needs. The FGD participants also confirmed that economic dependency on forest products drives activities such as charcoal production and fuel wood collection, leading to forest degradation and climate change. The situation is more pronounced among teenage male students from the native Gumuz community, who are heavily involved in these activities. This finding supports the assumption that such activities attract primarily males.

Assessing the extent of students' environmental knowledge and attitudes, specifically focusing on deforestation and climate change in their residences, offers significant empathies into possible differences in environmental knowledge and attitudes depending on living conditions. Cross-tabulation revealed that 54.5% of the urban students had high levels of environmental knowledge and positive attitudes, whereas 39.1% of the rural students did. Conversely, 60.9% of the rural students had low knowledge and unfavorable attitudes, whereas 45.5% of the urban students did. The chi-square test ($x2 = 8.886$, p value = 0.003) and binary logistic regression model confirm a significant correlation between residence and environmental knowledge and attitudes. The odds ratio for rural students is 0.009 (p value = 0.000), indicating that they are less likely to have high levels of environmental knowledge and positive attitudes than urban students. Quantitative findings are supported by qualitative data from FGDs and KIIs, indicating key factors behind disparities in students' environmental knowledge and attitudes. FGDs revealed that urban students benefit from diverse information sources, such as the internet, media campaigns, and structured school programs, enhancing their awareness and proactive attitudes. In contrast, rural students face barriers like limited resources, infrequent awareness programs, and socio-economic challenges, leading to practical but localised knowledge that lacked broader contextual understanding. KIIs with geography teachers and principals confirmed these differences, with urban schools leveraging interactive methods and NGO support, while rural schools struggle with large class sizes, insufficient materials, and limited teacher training.

Table 6.5: Results of the chi-square test showing the relationship of demographic factors in 2024

		Level of students' environmental knowledge and attitude							
Variable		Low knowledge &negative attitude		High knowledge & positive attitude		Total			
		N	%	N	%	N	%	X2	P-value
Age	15-16	102	67.5	49	32.5	151	100	23.095	0
	17-18	59	40.7	86	59.3	145	100		
	>19	35	46.1	41	53.9	76	100		
Sex	Male	108	60.70%	70	39.3	178	100	8.732	0.003
	Female	88	45.40%	106	54.6	194	100		
Resi.	Urban	90	45.50%	108	54.50%	198	100	8.886	0.003
	Rural	106	60.90%	68	39.10%	174	100		

A student's environmental knowledge and attitude shifts can be influenced by socioeconomic and behavioral factors, such as parents' education level, family income, and interest. Table 6.6 details these characteristics and their relationships with students' environmental knowledge and attitudes toward deforestation and climate change, in line with the parameter coefficients in Table 6.8.

In terms of educational status, the data from the current study revealed that 41.2% of students whose parents are illiterate are likely to have high environmental knowledge and positive attitudes, whereas 58.8% have low knowledge and negative attitudes. For students whose parents completed primary school, 48.7% had high knowledge and positive attitudes, and 51.3% had low knowledge and negative attitudes. Among the students whose parents completed secondary education or higher, 56.8% presented high knowledge and positive attitudes, whereas 43.2% presented low knowledge and negative attitudes. Hence, a higher parental education level is correlated with better environmental attitudes in students. The chi-square test (x2 = 5.750, p = 0.018) and binary logistic regression (increase of 2.479 units, p = 0.018) support a significant association between parental education and students' environmental knowledge and attitudes.

Students' environmental knowledge and attitudes are also influenced by their family's income level. For this study, household income was measured as the total cash net income earned by each member for the previous calendar year. Income categories were determined through consultations with local stakeholders and classified as low (5,000-15,000 Ethiopian Birr annually), middle (16,000-30,000), or high (over 31,000). It is postulated that higher family income is associated with better environmental knowledge and positive attitudes toward deforestation and climate change. Table 6.6 shows that among students from low-income families, 52.6% have low knowledge and negative attitudes, whereas 47.4% have high knowledge and positive attitudes. Among middle-income families, 63.4% had low knowledge and negative attitudes, and 36.6% had high knowledge and positive attitudes. Among high-income families, only 33.9% have low knowledge and negative attitudes, whereas 66.1% have high knowledge and positive attitudes. As hypothesized, the data suggest that students from higher-income families are more likely to have favorable environmental attitudes and knowledge. The chi-square test of independence ($\chi^2 = 12.527$, $p = 0.002$) in table 6.6 reveals a significant link between family income levels and students' environmental knowledge and attitudes. Binary logistic regression supported this finding, indicating a statistically significant relationship. As shown in Table 6.9, when all the other variables are held constant, a 1-unit increase in family income corresponds to a 19.063-unit increase in students' environmental knowledge and attitudes toward deforestation and climate change (P = 0.000). Qualitative data from FGDs and KIIs highlight the impact of family income on students' environmental knowledge and attitudes. Students from higher-income households reported better access to resources, frequent discussions on deforestation and climate change, and active extracurricular participation, enhancing their knowledge and attitudes. In contrast, low-income students, especially in rural districts like Manura, Guba, Dangur, Pawe, and Dibati, faced resource shortages and financial constraints, prioritizing survival needs over environmental concerns. Limited access to materials like textbooks, digital resources, and transport hindered their exploration of environmental issues, despite firsthand knowledge of deforestation and climate change impacts.

Table 6.6: Results of the chi-square test showing the relationships of various socioeconomic and behavioural factors with students' levels of environmental knowledge and attitudes in 2024.

		Level of student's environmental knowledge and attitude							
Variable		Low level of knowledge and negative attitude		High level of knowledge and positive attitude		Total			
		N	%	N	%	N	%	X^2	P
Student's family education	Illiterate	97	58.8%	68	41.2%	165	100	5.750	0.018
	Primary	61	51.3%	58	48.7%	119	100		
	Secondary	38	43.2%	50	56.8%	88	100		
Income level of student's family	Low	113	52.6%	102	47.4%	215	100	12.527	0.002
	Middle	64	63.4%	37	36.6%	101	100		
	High	19	33.9%	37	66.1%	56	100		
Student's personal interest	Good interest	90	54.2%	76	45.8%	166	100	0.281	0.596
	No interest	106	51.5%	100	48.5%	206	100		

The nexus between students' interests and their environmental knowledge and attitudes has been widely studied. Interest in environmental issues drives cognitive engagement. However, there is limited knowledge about Ethiopian students' interest in environmental problems such as deforestation and climate change. To address this, we asked the students if they were motivated to address these challenges. The main premise is that motivated students will have greater environmental knowledge, confirming the influence of intrinsic motivation on environmental knowledge and attitudes. However, the current study did not find a relationship between students' interest in environmental issues and their knowledge or attitudes toward addressing deforestation and climate change. Table 6.6 shows no significant correlation between environmental knowledge, attitudes, and interest levels ($\chi^2 = 0.281$, $p = 0.596$). The binary logistic regression analysis also revealed an insignificant relationship ($p = 0.875$). Thus, students' interest in environmental matters did not influence their knowledge or attitudes in the research region.

Differences in students' environmental knowledge and attitudes are influenced by factors such as societal norms, traditions, access to information, educational aspects such as grade level, and involvement in school environmental clubs. Table 6.6 outlines these factors and their impacts on students' environmental knowledge and attitudes toward deforestation and climate change, in line with the parameter coefficients in table 6.8.

Table 6.7: Results of the chi-square test showing the relationships of various environmental and educational factors with students' environmental knowledge and attitudes in 2024.

		Level of students' environmental knowledge and attitude							
Variable		Low level of knowledge & negative attitude		High level of knowledge & positive attitude		Total			
		N	%	N	%	N	%	X^2	P
Access to information	Have access	94	42.9%	125	57.1%	219	100	20.372	0.000
	No access	102	66.7%	51	33.3%	153	100		

	Grade 9	92	67.6%	44	32.4%	136	100	30.536	0.000
Grade Level	Grade 10	42	51.9%	39	48.1%	81	100		
	Grade 11	31	31.3%	68	68.7%	99	100		
	Grade 12	31	55.4%	25	44.6%	56	100		
Club participation	Not participated	103	57.2%	77	42.8%	180	100	2.876	0.010
	Participated	93	48.4%	99	51.6%	192	100		

Pressures and traditions from the social environment (friends, family, culture, religion, media, and community) significantly influence environmental behavior. It is generally believed that positive social norms are correlated with high levels of environmental knowledge and attitudes. However, our study revealed the opposite results. Exposure to social pressures and traditions is associated with lower odds of having good environmental knowledge and attitudes toward deforestation and climate change. Specifically, each one-unit increase in these pressures decreases the odds by 0.260 (p value 0.017).

Addressing deforestation and climate change effectively involves engaging all society members, including secondary school students. Students should have access to diverse environmental information sources, such as school media clubs, academic lessons, social organizations, religious meetings, conferences, television, radio, newspapers, scientific journals, festivals, and the internet. This access is hypothesized to deepen their understanding of local environmental issues and empower them to contribute to climate change mitigation and forest conservation. Table 6.7 shows that among students with information access, 57.1% display high knowledge and positive attitudes, whereas only 33.3% do not.

Conversely, 42.9% with access exhibit low knowledge and negative attitudes, increasing to 66.7% without access. The chi-square test (X^2 = 20.372, p.000) and logistic regression (β = 3.632, p=0.021) confirm a significant positive correlation between information access and students' environmental knowledge and attitudes. This suggests that better access to environmental information can mitigate the environmental problems under investigation in the research region. This is highly supported by qualitative data collected from participants in FGD and KII. Students who engaged in FGD witnessed that they were more conscious of environmental issues both locally and globally, and they felt confident in their ability to support efforts to mitigate climate change and conserve forests when they get access to diverse information sources. In contrast, students without access to these information sources struggled to grasp complex environmental issues like deforestation and climate change, feeling less prepared to contribute to solutions. KIIs with geography teachers reinforced these findings, emphasising that students with access to multiple information platforms demonstrated higher engagement in school-based environmental activities, such as debates, projects, and community outreach. Geography department head identified media clubs and interactive lessons as valuable tools for improving environmental knowledge and developing pro-environmental attitudes.

Table 6.8: Parameter coefficients of determinants of the level of student knowledge and attitudes toward addressing environmental problems related to deforestation and climate change (N = 372) in 2024.

Variables in the model	B	S.E.	Wald	Sig.	Exp(B)	95% C.I. for Exp(B)	
						Lower	Upper
Age of students	0.542	0.202	7.225	0.007	1.720	1.158	2.554
Sex of students (1)	-2.350	0.637	13.615	0.000	.095	.027	.332
Family educational status			8.812	0.012			
Family educational status (1)	0.045	0.360	.015	0.901	1.046	0.516	2.119
Family educational status (2)	0.908	0.383	5.628	0.018	2.479	1.171	5.249
Students’ residence (1)	-4.714	0. 862	29.885	0.000	.009	0.002	.049
Income level of students’ family	2.948	0.515	32.710	0.000	19.063	6.942	52.347
Students’ participation in school based environmental clubs (1)	2.173	0.844	6.628	0.010	8.784	1.680	45.934
Student's current grade level			40.839	0.000			
Student's current grade level (1)	1.478	0.593	6.204	0.013	4.383	1.370	14.021

Student's current grade level (2)	2.453	0.610	16.156	0.000	11.625	3.515	38.452
Student's current grade level (3)	3.839	0.659	33.983	0.000	46.469	12.783	168.921
Students' interest in environmental matters (1)	0.072	0.458	.025	0.875	1.074	.438	2.636
Pressures and traditions transmitted by the social environment to the student (1)	-1.346	0.563	5.708	0.017	.260	0.086	.785
Access to information (1)	1.290	0.559	5.332	0.021	3.632	1.215	10.852
Constant	-5.954	1.264	22.193	0.000	.003		

A student's current grade level significantly influences their environmental knowledge and attitudes toward addressing deforestation and climate change. Higher grade levels correlate with better environmental knowledge and attitudes, as verified by the data in Table 6-8. Among grade 9 students, 67.6% presented low levels of knowledge and negative attitudes, whereas 32.4% presented high levels of knowledge and positive attitudes. For grade 10, 51.9% of the respondents reported low levels of knowledge and negative attitudes, whereas 48.1% reported high levels of knowledge and positive attitudes. Grade 11 students experienced a significant shift, with 31.3% having low knowledge and negative attitudes and 68.7% demonstrating high knowledge and positive attitudes. In Grade 12, 55.4% had low knowledge and negative attitudes, whereas 44.6% had high knowledge and positive attitudes. Bivariate ($x2 = 30.536$, $p = 0.000$) and multivariate analyses confirm that higher grade levels positively affect students' environmental knowledge and attitudes, with odds ratios ranging from 4.383-46.469 (all $p < 0.05$).

Active involvement in environmental clubs fosters responsibility toward the environment. There is a positive correlation between students' participation in school-based environmental clubs and their environmental knowledge and attitudes. Students in these clubs are 8.784 times more likely to have better environmental knowledge and attitudes toward deforestation and climate change ($p = 0.010$). Bivariate analysis ($x2 = 2.876$, $p = 2.10$) supported this finding. Among them, 57.2% had low knowledge and negative attitudes, whereas 42.8% had high knowledge and positive attitudes. For the participants, 48.4% had low knowledge and negative attitudes, and 51.6% had high knowledge and positive attitudes. FGDs revealed that the environment protection club is the primary environmental club in the sample schools, engaging in activities such as awareness campaigns, clean-up drives, tree planting, and educating communities on sustainable practices. However, some clubs face challenges such as a limited understanding of environmental education, logistical issues, and resource constraints, hindering their effectiveness.

6.9.Discussion

The findings of this study offer critical insights into the environmental knowledge and attitudes of secondary school students in the Metekel Zone, Ethiopia, and highlight the multifaceted determinants influencing their perspectives on deforestation and climate change. These results underscore the importance of addressing socio-economic, cultural, and educational barriers to foster a more informed and proactive younger generation in tackling critical environmental challenges related to deforestation and climate change.

6.9.1. Student’s environmental knowledge

Environmental education plays a critical role in shaping students’ understanding and attitudes toward environmental issues like deforestation and climate change. By integrating education about, for, and in the environment, students gain both the knowledge and skills necessary to engage in pro-environmental behaviors. Nonetheless, evidence from this study suggests that secondary school students in the Metekel Zone generally have a low level of environmental knowledge concerning deforestation and climate change. A thorough assessment of level of secondary school students' knowledge, related to the issue under investigation revealed that while 29.3% of the students had moderate knowledge and 18.5% had high knowledge, 52.2% scored below 50% on the knowledge test, indicating a generally low level of knowledge about deforestation and climate change in the study area. The implications of these results are substantial. Environmental education plays a critical role in fostering pro-environmental behaviors and attitudes. Without sufficient knowledge, students are less likely to engage with or address pressing environmental issues effectively. Furthermore, the observed gaps in knowledge could have long-term consequences, potentially limiting the capacity of these students to contribute to sustainable development efforts, both locally and globally. These results are consistent with those of Kollmuss & Agyeman (2002), who noted that limited environmental knowledge significantly inhibits efforts to increase environmental quality and alleviate deforestation and climate change.

6.9.2. Student's environmental attitude

Environmental attitudes serve as a foundation for shaping behaviour and fostering long-term environmental stewardship. Many researchers (Bamberg, 2003; Jackson & Pang, 2017; Marcinkowski & Reid, 2019; Mikołajczak et al., 2023; Nghiem et al., 2013) have emphasized the importance of shaping attitudes in environmental education in general and deforestation and climate change in particular. A similar study by (Uitto et al., 2011; Worsley & Skrzypiec, 1998) revealed the interconnectedness of attitudes and behavior. However, our findings diverge from these studies, revealing that 32.8% of the students had positive attitudes toward the environment, especially those addressing deforestation and climate change as critical environmental concerns; 14.5% were neutral, and 52.7% had negative attitudes. The negative attitudes observed among the majority of the students in the study area are attributed to their limited environmental knowledge, as shown by the knowledge assessment results. Additional factors, such as poor integration of environmental topics into the curriculum, limited access to environmental information, social and cultural influences, lack of role models, and inadequate promotion of environmental awareness, further contribute to these negative attitudes.

To promote such positive environmental attitudes that inspire actionable responses to environmental problems linked to deforestation and climate change, it is vital to explore the underlying factors that drive students to change their behavior. This can be facilitated through school-wide awareness campaigns such as Earth Day events, environmental fairs, and tree planting initiatives. However, the practical implementation of such campaigns must be evaluated, as their success can vary significantly across different school environments due to factors like available resources, student engagement, and local community support. For instance, organizing large-scale events in many of resource-limited Metekel zone secondary schools may require external partnerships, funding, or volunteer support, and the involvement of local environmental organizations or government agencies could help ensure the feasibility and sustainability of these events. Additionally, in-depth compulsory integration of environmental education into core subjects like geography—covering topics such as deforestation, climate change, biodiversity, and sustainability—can further enhance students' environmental awareness. Interactive methods, such as problem-based learning and simulations, make these topics more engaging. Additionally, experiential learning programs and observing role models can foster proactive attitudes and behaviors toward environmental issues.

6.9.3. Determinants of student’s level of knowledge and attitude

The development of secondary school students' knowledge and attitudes toward addressing global challenges such as deforestation and climate change is often hindered by various determinants, limiting their potential to engage meaningfully with environmental issues. In light of this, the present study highlights how demographic, socioeconomic, behavioural, environmental, and educational factors influence secondary school students' environmental knowledge and attitudes of these issues. The findings show that older students generally have greater environmental knowledge and more positive attitudes, aligning with studies by (Fransson & Gørling, 1999; Korfiatis et al., 2004; Mayer & Frantz, 2004), which suggest a correlation between age, maturity, and environmental responsiveness. Compared with male students, female students typically possess greater environmental knowledge and more positive attitudes, as supported by previous research (Franzen & Vogl, 2013; Korfiatis et al., 2004). Urban students have better access to resources and environmental education, which boosts their knowledge and attitudes. Conversely, rural students, despite high levels of environmental concern, often show lower pro-environmental behaviour due to limited resources and educational opportunities, which is in line with findings of (Berenguer et al., 2005). To overcome this problem, schools should improve their environmental education curricula with gender- and age-appropriate content and ensure equitable access to high-quality resources through digital platforms, particularly in rural regions. Engagement and experiential learning can be further encouraged through community-based awareness campaigns, after-school programs, and partnerships with environmental organizations, all of which are essential.

Our findings also show that students with more educated parents tend to have greater environmental knowledge and more positive attitudes toward deforestation and climate change. Higher parental education levels increase exposure to environmental values at home, fostering positive attitudes in students. (Evans et al., 2018; Müderrisoğlu & Altanlar, 2011), highlighting the significant role of parental education in shaping young people's environmental attitudes and behaviors. In addition, the study revealed a strong correlation between family income and students' environmental knowledge and attitudes. Students from higher-income families exhibit greater environmental knowledge and more positive attitudes toward conservation, aligning with previous research (Grønhøj & Thøgersen, 2009; Shen & Saijo, 2008), which links higher income to increased environmental awareness and pro-environmental *behaviours*. However, our survey revealed no significant link between students' interest in environmental issues and their knowledge or attitudes, indicating that intrinsic motivation alone may not suffice. Supporting studies suggest that both intrinsic and extrinsic factors, including socioeconomic influences, are crucial in shaping environmental attitudes and knowledge (Gifford & Nilsson, 2014; Kollmuss & Agyeman, 2002; Tian et al., 2017).

Access to information and progression through higher grade levels significantly enhance students' environmental knowledge and attitudes, highlighting the importance of structured learning opportunities which is in line with the findings of (Alp, 2005; Altin et al., 2014; Coi et al., 2016). These findings emphasize that comprehensive environmental education and progressive learning are crucial for fostering deeper environmental consciousness among students. Participation in environmental clubs positively influences students' attitudes toward the environment. This finding is similar to those of studies by (Ana et al., 2009; Beach, 2023; Roberts, 2009; Smith, 2019), who reported that these clubs improve environmental conservation and increase awareness. However, social pressures and traditions negatively impact their environmental knowledge and attitudes.

Additionally, the findings of this study is attributed to the abstract and generalised nature of lessons on deforestation and climate change which significantly limits students' ability to connect these global issues to their local context. This disconnect is further exacerbated by systemic curriculum shortcomings identified by teachers, including insufficient instructional time, inadequate resources, and a lack of locally relevant content. These issues highlight the need for contextualized and experiential learning approaches, which teachers view as essential for bridging these gaps. This perspective aligns with findings in recent literature, emphasizing the importance of localized, hands-on, and problem-based strategies to enhance students' understanding and involvement (Du et al., 2018; Kalafatis et al., 2019; Reddy, 2021). Moreover, socio-economic and cultural factors further impede students' ability to acquire knowledge and cultivate pro-environmental attitudes, which are essential for fostering pro-environmental behavior. Responsibilities like informal work, household duties, and caregiving not only restrict their time for education but also limit their ability to fully engage in environmental learning. These findings resonate with the work of (Gifford & Nilsson, 2014), who underscored the negative impact of socio-economic pressures on student's knowledge and pro environmental behaniour. To address these issues, educational reforms should focus on incorporating localized and experiential learning approaches that make global topics like deforestation and climate change relatable to students' immediate environments. Enhancing curriculum design by increasing instructional time, providing adequate resources, and including context-specific content can help bridge the gap.

By examining secondary school students' environmental knowledge and attitudes, this research contributes to the existing body of literature on the level of secondary school student's knowledge, attitude and factors influencing pro-environmental behaviours, particularly concerning deforestation and climate change. It calls for targeted interventions and policies to build students' responsibility and self-efficacy through a comprehensive strategy that combines enhanced curriculum content, active learning methodologies, robust extracurricular programs, media engagement, and continuous professional development for educators. These findings also suggest that economic and social incentives can strengthen their commitment to environmental protection and support broader efforts to address deforestation and climate change.

Positioned within the critical global context of combating deforestation and climate change, this research focuses on the role of secondary school students in Ethiopia. It aligns with national and international frameworks dedicated to enhancing environmental education and promoting sustainability. By examining the intersection of student knowledge, attitudes, and behaviors, the research contributes to broader efforts aimed at fostering environmental responsibility and supporting sustainable practices within the education system. By promoting awareness and understanding of biodiversity among students, it supports the Convention on Biological Diversity (CBD) objectives, fostering pro-environmental attitudes and behaviours that contribute to biodiversity conservation and sustainable use. Additionally, it aligns with the UNESCO Global Action Programme on ESD by integrating sustainable development principles into the educational curriculum, emphasizing the importance of equipping students with the necessary knowledge, skills, attitudes, and values for a sustainable future. The study also addresses the objectives of Ethiopia's Education Sector Development Programme V (ESDP V) by aiming to improve the quality and relevance of education, particularly in environmental education encompassing climate change and deforestation issues, to develop a knowledgeable and responsible citizenry. Furthermore, it supports Ethiopia's climate-resilient green economy strategy (CRGE) by promoting climate resilience through education and examining the determinants of environmental knowledge and attitudes among students to provide direction into how education can contribute to the country's green economy goals and climate resilience initiatives.

This study also provides direction for future research, as it concentrates solely on addressing environmental issues related to deforestation and climate change from the perspective of secondary school students' knowledge, attitudes, and influencing factors. Future research should focus on pedagogical aspects, particularly the problem-based learning approach, and explore its application in teaching about deforestation and climate change in the classroom. Additionally, longitudinal studies could provide more convincing evidence.

6.10. Conclusion

Deforestation and climate change are among the most popular long-term emergencies at different levels. According to this survey, secondary school students' knowledge and attitudes toward environmental issues—particularly deforestation and climate change—are decreasing, which is worrying. The majority of the students showed negative attitudes toward addressing these issues. Additionally, a considerable portion of the students had low levels of knowledge, with more than half scoring below 50%.

Binary logistic regression and chi-square analysis revealed that nine of the ten variables were statistically significant correlates of students' attitudes and knowledge about the environment, with a particular focus on deforestation and climate change. The study revealed that demographic factors such as age, gender, and residence play pivotal roles, with older students and females displaying higher levels of knowledge and more positive attitudes. In addition, compared with their urban peers, students from rural areas encounter more difficulties in acquiring environmental knowledge. Parental education levels and family income also influence students' exposure to environmental issues, with higher levels correlating with more positive attitudes and a higher level of knowledge. Furthermore, social norms and access to information are significant factors affecting students' environmental knowledge and attitudes. In the same vein, educational factors such as grade level and participation in school-based environmental clubs positively impact both knowledge and attitudes. The findings also highlight systemic and contextual barriers to students' understanding of deforestation and climate change. Fragmented environmental knowledge, limited access to resources, and a lack of context-specific examples in the curriculum hinder student's ability to connect environmental issues to their local realities. Many students viewed deforestation and climate change as distant or unrelated to their immediate lives, underscoring a lack of personal relevance and emotional connection to these issues.

Overall, this study emphasizes the need for educational policymakers to enhance secondary school curricula to address environmental issues effectively. Specifically, because deforestation and climate change lessons are covered mainly in secondary school geography curricula in Ethiopia, appropriate and inclusive approaches are recommended to integrate these topics into geography curricula across different grade levels, emphasizing secondary education. Other crucial actions include improving extracurricular activities, fostering partnerships between local organizations and schools, and holding workshops to challenge gender stereotypes. Furthermore, providing teachers with specialized training in environmental education methodologies can increase their effectiveness in encouraging pro-environmental behaviors among students.

CHAPTER SEVEN

7. Geography Teachers' Implementation of Problem-Based Learning for Deforestation and Climate Change Education in Metekel Zone Secondary Schools, Northwest, Ethiopia

Abstract

Environmental problems related to deforestation and climate change pose serious socio-economic and ecological threats. In Ethiopia, rapid forest loss and climate impacts demand sustainable solutions through education. Problem Based Learning (PBL), which fosters critical thinking, collaboration, and real-world problem-solving, is well-suited to address both environmental and pedagogical challenges. This study examines geography teachers' implementation of PBL for deforestation and climate change education in secondary schools in Metekel Zone, Northwest Ethiopia. A convergent mixed-methods design and multi-stage sampling were used to collect data from 134 geography teachers, 7 department heads, 7 principals, and 3 education experts through surveys, interviews, focus group discussions, and classroom observations. Quantitative data were analyzed using descriptive statistics, one-sample t-tests, Pearson correlation, and binary logistic regression; qualitative data were thematically analyzed. Policy-relevant findings reveal low teacher belief in PBL, limited heuristic strategies, and weak contextualization of environmental content. A strong correlation between belief and practice shows that stronger teacher beliefs foster greater PBL use. Regression analysis identified structural and systemic factors shaping PBL adoption. Positive factors include teacher adaptation, emotional intelligence, student environmental identity, motivation, and content knowledge. Barriers include large class sizes, traditional methods, and the time-intensive nature of PBL. Thematic analysis also highlighted curriculum rigidity, student resistance, and limited resources. The study recommends policy actions including targeted teacher training, flexible curricula, and systemic support to promote PBL in environmental education. Addressing class size, infrastructure, and student engagement is essential for sustaining PBL practices. These findings offer actionable insights for policymakers and educational planners aiming to integrate PBL in response to environmental challenges.

Keywords: Problem-Based Learning, geography education, deforestation, climate change, teacher beliefs, Metekel Zone

7.1.Introduction

Deforestation and climate change are interconnected global ecological crises with profound consequences for biodiversity, ecosystems, and human livelihoods and agricultural productivity (Alves de Oliveira et al., 2021; FAO, 2015; IPCC, 2023). Deforestation is a leading cause of biodiversity loss, as destroying forests eliminates habitats critical for countless species, reducing ecosystem resilience and impeding natural recovery from environmental disturbances (FAO, 2015; IPCC, 2023; Köhl et al., 2015; G. Sharma et al., 2019; Wang et al., 2022). Additionally, forests play a pivotal role in sequestering carbon dioxide (CO2), and their removal disrupts this function, contributing substantially to global CO_2 emissions, with deforestation accounting for approximately 10-15% of human-induced emissions annually (Alves de Oliveira et al., 2021; Andrew, 2019; Kohler, 2013; Yoro & Daramola, 2020). This is particularly alarming in tropical regions, where deforestation releases billions of tons of CO_2 annually, exacerbating climate change (Basallote et al., 2015; Lee & Blanchard, 2019; Tubiello et al., 2007). The cascading effects of deforestation and climate change compromise essential ecosystem services, such as water regulation, soil fertility, and carbon storage, leading to reduced water availability, heightened drought risks and declining agricultural productivity as hydrological cycles are disrupted (FAO, 2015, 2019).

Tackling these environmental challenges requires a range of approaches, including community-driven solutions, sustainable farming methods, and educational initiatives that promote environmental awareness and action (Adom et al., 2024; Al Blooshi et al., 2020; Arora, 2019; Seddon et al., 2021). Education, especially environmental education, plays a crucial role in equipping individuals with the knowledge, skills, and attitudes needed to confront these pressing issues (Ardoin et al., 2020; Chawla & Flanders Cushing, 2007; Fraser et al., 2015). Aligned with Sustainable Development Goal 4 (SDG 4), which emphasizes inclusive, equitable, quality education and lifelong learning, and grounded in the 1977 Tbilisi Declaration (Hoffmann, 1978), environmental education aims to nurture environmentally literate individuals who are not only well-versed in ecological matters but are also committed to adopting sustainable practices.

In this context, students should not merely be viewed as passive recipients of knowledge but as active agents of change who can critically engage with environmental problems and promote sustainability through informed action. Prior research affirms that involving students as central participants in environmental education cultivates a stronger sense of agency, responsibility, and stewardship (Alan, 2008; Chawla & Flanders Cushing, 2007). When students are encouraged to take ownership of environmental challenges, such as those related to deforestation and climate change, they are more likely to engage in pro-environmental behaviors and participate in collective environmental decision-making processes (Krasny & Roth, 2010; Schusler et al., 2009). Thus, environmental education must emphasize student-centered learning experiences that empower learners to act as informed advocates for environmental sustainability.

Building on this foundation, constructivist teaching methods have proven to be effective in promoting critical thinking and collaborative problem-solving skills among students (Ertmer, 2005; Kambara, 2022). These approaches create problem-centered environments where cognitive and social interactions enhance meaningful learning. As one prominent constructivist strategy, PBL immerses students in real-world problems, fostering deeper understanding and encouraging active participation (Hmelo-Silver, 2004). PBL nurtures critical thinking, teamwork, and intrinsic motivation, while helping students apply theoretical knowledge to real-life situations (Capon & Kuhn, 2004; Yew & Goh, 2016). By anchoring learning in context, PBL also equips students to face professional challenges and engage in lifelong learning (Savin-Baden, 2000). In geography education, PBL offers a valuable opportunity to explore the complex connections between human activities and natural systems (Silviariza et al., 2020; Weiss, 2017).

Although PBL is well-established for encouraging critical thinking and student engagement, its successful implementation has been affected by multiple interconnected factors, which interact and act in combination to shape classroom instruction. One of these factors is teachers' beliefs, as their views on PBL significantly impact their teaching methods and openness to adopting the approach (Assen et al., 2016). As defined by (Davidson et al., 2003; Zheng, 2013), teachers' beliefs constitute a complex cognitive framework encompassing knowledge, theories, attitudes, perceptions, assumptions, metaphors, and conceptualisations related to various dimensions of teaching. These dimensions extend beyond pedagogy to include conceptions of learning, the roles of teachers and students, instructional materials, classroom activities, curricula, and professional identity (Bauml, 2009; Van Driel et al., 2007; Zheng, 2013). Harendita (2017), also indicated that recognised as the foundation of effective teaching, teachers' beliefs play a crucial role in shaping pedagogical decisions, instructional strategies, and overall classroom dynamics. Given such a critical role, extensive research has explored the complex relationship between teachers' beliefs and their actual instructional practices, showing how inconsistencies between the two can impact the effectiveness of teaching and learning (Assen et al., 2016; Chan, 2016; Ertmer, 2005; Ertmer et al., 2012; L. Song et al., 2007). These studies confirmed that teachers who strongly believe in the benefits of PBL such as fostering critical thinking, student engagement, and problem-solving are more likely to integrate it into their teErtmer 2012saching. However, concerns regarding the practicality of PBL, its alignment with curriculum standards, and the challenges associated with its implementation hinder its adoption. Research suggests that shifts in teachers' beliefs and attitudes are often accompanied by corresponding changes in their instructional approaches, emphasising the importance of professional development programs aimed at fostering positive perceptions of PBL and supporting its effective integration into classroom practice (Ertmer, 2005; Lee & Blanchard, 2019; Pecore, 2012).

Additionally, the heuristic approach to problem-solving is instrumental in the effective implementation of PBL, as it fosters critical thinking, creativity, and active student engagement (Eisenmann et al., 2015; Novotná et al., 2015). By encouraging students to explore concepts, pose questions, and construct their own understanding, this approach aligns closely with the core principles of PBL. Unlike traditional lecture-based instruction, which primarily relies on passive knowledge transmission, the heuristic method emphasizes discovery, exploration, and problem-solving as central components of the learning process (Barak, 2013). This student-centered approach not only promotes inquiry-based learning but also cultivates learner autonomy, empowering students to take ownership of their educational experiences (Novotná et al., 2015).

Furthermore, contextualizing lessons can significantly enhance PBL's effectiveness by connecting theoretical knowledge to real-world scenarios (Abu-Rasheed et al., 2023; K. Smith et al., 2022). By relating subject content to students' prior experiences, community challenges, and everyday life, contextualization boosts engagement and critical thinking. For instance, when educators create tasks based on community experiences and real-life problems, they foster problem-solving and inquiry-driven learning (Giamellaro, 2014; Rivet & Krajcik, 2008; Son & Goldstone, 2009).

Similarly, a range of structural factors which are related to classroom-level teaching conditions and teacher and student dynamics significantly impact teachers' ability to implement PBL effectively in teaching deforestation and climate change. One critical factor is teachers' adaptation to PBL methodologies. Teachers who are well-adapted to PBL can design real-world problem scenarios, facilitate student collaboration, and promote critical thinking, whereas inadequate adaptation indicates the need for targeted professional development to equip teachers with the necessary skills for effective PBL implementation (Yu & Zin, 2023). Similarly, level of teacher's content experience is crucial for connecting abstract concepts to practical applications within PBL settings. Teachers with a strong grasp of content knowledge are better equipped to contextualise learning and make it relevant (Brooks, 2010; Healy, 2024). Likewise, level of emotional intelligence of teachers is vital for PBL success, aiding in managing dynamics, fostering relationships, and overcoming challenges (Edannur, 2010; Perry & Ball, 2007). Recognising students' environmental citizenship and identities enhances PBL by fostering critical thinking, responsibility, and engagement while empowering students to address sustainability challenges through improved problem-solving and collaboration (Blatt, 2014; Georgiou et al., 2021). Student motivation and engagement are equally critical as they significantly shape PBL implementation by promoting participation, persistence, self-regulation, and academic success (Brandmiller et al., 2024; Hardré et al., 2008).

In the same vein, several systemic factors which encompass issues related to curriculum design, institutional support, and accountability frameworks also affect PBL implementation. Large class sizes as one of such factors complicate group management and equitable participation, reducing their effectiveness (Fortes & Tchantchane, 2010). Additionally, the time-intensive nature of PBL poses difficulties for teachers balancing preparation with curriculum demands (Othman et al., 2016). Traditional assessment methods and the persistence of conventional teaching practices further restrict opportunities for critical thinking and active learning (Bentil & Student, 2018; Ssemugenyi, 2023). Resource limitations, such as inadequate facilities and lack of training, and the extensive geography curriculum are other notable constraints. These challenges hinder teachers' ability to integrate PBL effectively into lessons (Chang & Kidman, 2019; Solano et al., 2023). Without a clear understanding of these factors, attempts to improve the use of PBL in teaching deforestation and climate change to geography educators may prove challenging or ineffective.

In Ethiopia, the education and training policy strongly emphasises problem-solving and the necessity of addressing practical challenges, including environmental issues (MoE, 1994, 2023). This focus is particularly pertinent given Ethiopia's vulnerability to critical environmental problems such as deforestation and climate change (Araro et al., 2020; Muluneh et al., 2017). Constructivist methods like PBL offer a promising avenue for fostering students' deep understanding of these challenges while cultivating a sense of responsibility and proactive engagement in addressing them. However, significant gaps between policy and practice hinder the implementation of PBL in classrooms. Limited stakeholder engagement worsens the gap, reducing the potential impact of these policies on education (Delelu et al., 2024; Mesfin, 2023). Furthermore, systemic and practical challenges have hindered the incorporation of PBL into teaching practices, emphasising the need for better alignment between environmental education strategies and policy objectives (Awayehu, 2024; Teferra et al., 2017).

The Metekel Zone in northwest Ethiopia is a region of ecological and economic significance, serving as a key area for the Abay River and the GERD. Despite its importance, the region faces escalating environmental challenges, including severe deforestation driven by agricultural expansion, charcoal production, resettlement, and forest fires. Compounding these issues is the low level of environmental awareness among the local population, which significantly hampers conservation efforts (Wagino & Amanuel, 2021). Secondary school geography teachers in the Metekel Zone are strategically positioned to address these challenges by fostering environmental awareness and incorporating local environmental issues, such as deforestation and climate change, into their lessons. PBL, a constructivist instructional method, enables these teachers to engage their students in active learning and tackle real-world challenges effectively. However, according to the Benishangul Gumuz Region Education Bureau (2024), teaching practices in many secondary schools remain largely traditional, dominated by teacher-centred methods that limit student engagement and critical thinking.

While numerous studies on PBL (Golightly, 2018; Putra & Masruri, 2019; Ruhimat et al., 2018; Wijayanto et al., 2023; Wondie, 2010, 2018; Yeung, 2010) demonstrated its effectiveness in various contexts, they often overlook the specific beliefs and practices of secondary school geography teachers in implementing PBL to tackle environmental issues related to deforestation and climate change in the study region. Additionally, many of these studies focus on well-resourced educational settings, neglecting those with limited resources. This oversight is crucial, as challenges such as inadequate teacher training, poor infrastructure, and heavy curriculum demands make PBL adoption more difficult in resource-constrained environments. The Metekel Zone, a region characterized by such limitations, serves as an example of an underexplored context in the research.

Furthermore, studies conducted in Ethiopia related to the issue under investigation (Ayalew, 2015; Melesse et al., 2018) have focused on the previous geography curriculum, which has now been replaced. The new Ethiopian secondary school geography curriculum presents unique challenges and opportunities for integrating PBL, particularly in addressing environmental issues. However, there is a lack of research on how geography teachers' beliefs and practices align with the new curriculum to effectively teach topics like deforestation and climate change. There has also been limited investigation into how structural and systemic factors such as teacher-related variables, classroom environmental factors, curricular demands, institutional factors and methodological challenges affect geography teachers' ability to implement PBL effectively in these lessons. These factors, which present significant obstacles to PBL in geography education, especially regarding environmental topics, remain largely unexamined in the existing literature.

This research, therefore, aims to fill these critical gaps by assessing secondary school geography teachers' stated beliefs regarding the use of PBL approaches such as problem-solving, lesson contextualisation, and heuristic methods in teaching environmental issues related to deforestation and climate change. It also evaluates their actual classroom practices and investigates the various structural and systemic factors influencing their performance in implementing PBL in the Metekel Zone.

More specifically, the study was guided by the following research questions: (i) How do secondary school geography teachers' beliefs, practices, and contextualization of the lessons to problem-solving approaches influence their performance in teaching deforestation and climate change lessons? (ii) Is there a correlation between secondary school geography teachers' beliefs regarding problem-solving approaches and their practical implementation in the classroom when teaching deforestation and climate change lessons? (iii) What structural and systemic factors affect geography teachers' effective implementation of PBL while teaching deforestation and climate change in Metekel Zone secondary schools?

7.2.Theoretical Framework

This study adopts an integrated theoretical framework combining constructivist learning theory and the theory of planned behavior (TPB) to investigate geography teachers' implementation of PBL for deforestation and climate change education in Metekel zone secondary schools, Northwest, Ethiopia. The dual framework bridges the pedagogical and psychological dimensions of the study, ensuring a wide-ranging outlook of geography teachers' implementation of PBL and the factors influencing its implementation in this context.

Constructivist learning theory emphasizes active, student-centered learning through real-world problem-solving, which aligns closely with the core principles of PBL (Kantar, 2014; Loyens & Gijbels, 2008). While playing a crucial role in pedagogy, this theory highlights the importance of involving both teachers and students in a collaborative exploration of complex environmental issues, with an emphasis on contextualizing education for sustainable development (Nguyen-Le, 2022). It suggests that meaningful learning happens when students actively construct knowledge through interactions with their environment and peers (Azzarito & Ennis, 2003; Loyens & Gijbels, 2008). In the context of PBL, this means promoting critical thinking, teamwork, and applying knowledge to real-world challenges, making it particularly valuable for addressing critical environmental issues. Empirical research confirms the effectiveness of constructivist approaches in boosting students' problem-solving abilities, environmental awareness, and overall engagement (Hmelo-Silver, 2004; Kantar, 2014; Kwan & Wong, 2015; Strobel & van Barneveld, 2009).

Complementing this pedagogical foundation, the theory of planned behavior provides a behavioral lens to examine the various structural and systemic factors influencing teachers' adoption and implementation of PBL. TPB posits that behavior is shaped by three key constructs: attitudes toward the behavior, subjective norms, and perceived behavioral control

(Ajzen, 1991). In the context of this study, attitudes refer to geography teachers' beliefs and perceptions of the benefits and challenges of using PBL to teach deforestation and climate change issues. Positive beliefs and attitudes of teachers may stem from the perceived benefits of PBL, such as fostering critical thinking and collaborative skills among students, as well as its potential to contextualize environmental issues. Conversely, negative beliefs and attitudes could arise from perceived challenges, such as increased preparation time, reliance on conventional methods, potential classroom management difficulties, the time-intensive nature of PBL and uncertainty about achieving learning outcomes.

In addition to attitudes, subjective norms represent the social pressures and expectations that influence teachers' decisions to implement PBL. These norms include the influence of colleagues who may or may not support innovative teaching practices, the expectations of students who may prefer or resist active learning approaches, and the directives of school administrators who might prioritize standardized curricula over innovative pedagogies. The presence or absence of a supportive professional culture can significantly shape teachers' willingness to adopt PBL (Ren, 2024). Building on this, perceived behavioral control (PBC) reflects teachers' confidence in their ability to successfully implement PBL, accounting for both internal and external factors. Internally (i.e., self-efficacy), PBC refers to teachers' belief in their own ability to design and deliver effective PBL lessons. This includes their knowledge of and adaptation to PBL, their emotional intelligence, their perception of students' environmental identity, and their ability to facilitate student discussions on complex environmental issues like deforestation and climate change. Externally (i.e., control over situational factors), PBC involves contextual barriers or supports such as large class sizes, limited access to instructional resources, rigid curriculum requirements, and insufficient professional development opportunities. Together, these internal and external factors determine the extent to which teachers feel capable of executing PBL effectively.

The integration of these theories is particularly relevant for addressing the study's objectives. Constructivist learning theory provides the overarching rationale for employing PBL as an instructional strategy, while TPB offers a framework to understand the behavioral and contextual determinants that influence teachers' practices. By embedding brief clarifications of each TPB component (attitudes, norms, and perceived control), this framework becomes accessible to readers unfamiliar with educational psychology. Together, these theories allow for a multidimensional exploration of PBL implementation, bridging the gap between pedagogical ideals and the realities of resource-constrained educational settings.

7.3.Conceptual Framework

Rooted in constructivist learning theory (Khadidja, 2020) and the theory of planned behavior (Ajzen, 1991), the conceptual framework of this study examines how teachers' beliefs, structural conditions, and systemic factors influence PBL adoption (Figure 7.1).

Teachers' belief regarding problem-based practice, heuristic problem-solving approaches, and the contextualization of content to students' real-life experiences is one of the critical components of this framework. This component reflects the internal cognitive and affective orientations that guide teachers' decisions, such as their understanding of PBL, attitudes toward innovation, and belief in its relevance to environmental issues. These beliefs shape their perceptions of PBL's effectiveness, confidence in facilitating inquiry-based learning, and ability to connect environmental issues to students' daily lives (Ertmer et al., 2012; Hmelo-Silver, 2004; Novotná et al., 2015). Consequently, they play a decisive role in shaping pedagogical choices and determining the success of PBL integration.

Beyond individual beliefs, the effective application of PBL in geography lessons on deforestation and climate change is influenced by both systemic and structural factors. Systemic factors, which encompass institutional and policy-related elements, shape the broader educational framework that either facilitates or constrains PBL integration. These include national or regional curriculum policies, assessment protocols, and administrative expectations that dictate how teachers structure their lessons and what content takes priority. These include curricular factors, such as traditional assessment systems, extensive content requirements, and alignment with curriculum standards, all of which impact the feasibility of incorporating student-centered approaches like PBL (Solano et al., 2023; Ssemugenyi, 2023). Similarly, teaching methodology factors, including the reliance on conventional instructional methods and the time-intensive nature of PBL, influence teachers' instructional decisions and willingness to adopt innovative strategies (Mulryan-Kyne, 2010). In contrast, structural factors present more immediate, classroom-level challenges that affect teaching conditions and active learning engagement. These refer to tangible, day-to-day elements such as class size, availability of materials, classroom layout, and access to digital tools, which directly influence the feasibility of collaborative, student-centered activities like PBL. Classroom environment factors, such as large class sizes and inadequate logistical support, create significant barriers by limiting opportunities for student participation and group-based problem-solving activities (Hornsby & Osman, 2014). Additionally, teacher-related factors, including adaptation to PBL, content expertise, emotional intelligence, and perceptions of students' environmental identity and motivation, directly shape teachers' effectiveness in implementing PBL strategies. This component includes both the psychological readiness and professional capacity of the teacher—such as their comfort with student-led inquiry, their ability to navigate emotional and social dynamics in the classroom, and their responsiveness to students' values and environmental concerns (Georgiou et al., 2021; Healy, 2024; Perry, 2007). By examining these interconnected factors, the conceptual framework provides insights into the barriers and facilitators of PBL adoption, offering a pathway to enhance environmental education on deforestation and climate change in secondary schools.

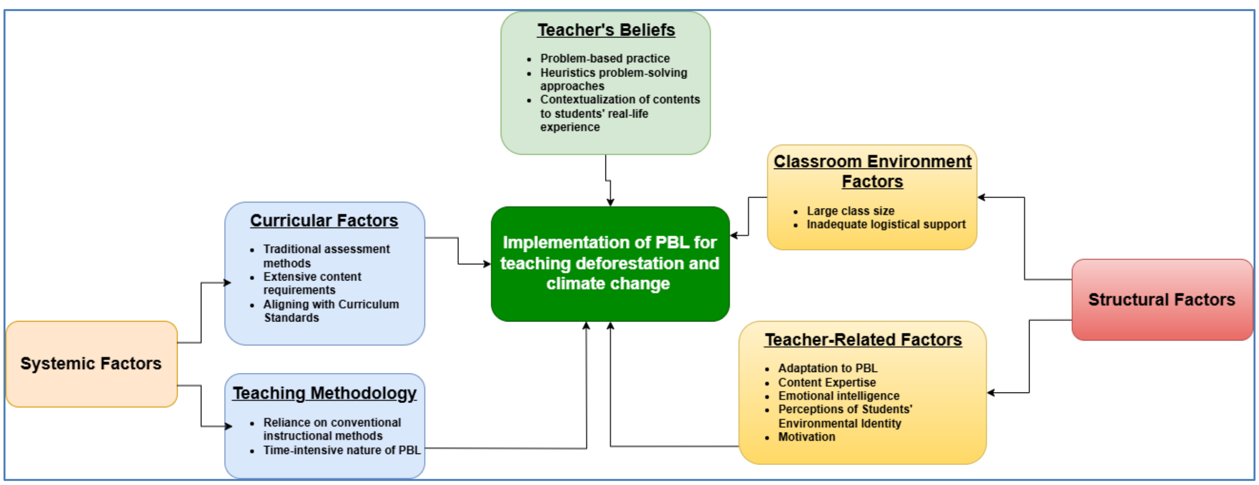


Figure 7.1: Conceptual framework of the study developed by the author based on literature review

7.4. Materials and Method

7.4.1. Description of the Study Area and Schools

The study was conducted in Metekel Zone, located in the northwestern part of Ethiopia, within the Benishangul Gumuz Regional State. Geographically, it spans between 10° 15′ N and 11° 45′ N latitude and 34° 45′ E and 36°45′ E longitude. Metekel Zone is bordered by Kamashi to the south and southwest, Sudan to the west, and the Amhara region to the north and east. This large zone consists of seven districts—Bullen, Dibate, Dangur, Guba, Mandura, Pawe, and Wembera—and encompasses 170 villages over an area of 22,028 km². According to the Ethiopian Central Statistics Authority (CSA, 2024), the total population of Metekel Zone is 534,305, with 268,288 males and 266,017 females. The population is predominantly rural, with 71.3% (380,786 individuals) residing in rural areas and 28.7% (153,519 individuals) in urban areas, underscoring the region's reliance on rural livelihoods.

In terms of education, the zone hosts government primary and secondary schools across both rural and urban areas. According to the 2023/24 education statistics from the Benishangul Gumuz Education Bureau, Metekel Zone is home to 38 government secondary schools, comprising 24 for grades 9-10 and 14 for grades 9-12. These schools are staffed by 134 geography teachers, who utilize a variety of teaching methods and depend heavily on curriculum materials provided by the Ethiopian Ministry of Education, such as textbooks, teacher guides, and syllabi.

7.4.2. Research design

In this study, the researcher employed a QUAN + qual convergent mixed-methods design to comprehensively examine geography teachers' beliefs, practices, and the various structural and systemic factors affecting their performance in implementing PBL for deforestation and climate change lessons. While both quantitative and qualitative data were collected, the QUAN component played a more prominent role in the analysis. This design was chosen for its ability to collect and analyze both quantitative and qualitative data concurrently, facilitating a holistic understanding of the research problem (Plano, 2017).

7.4.3. Population, Sampling techniques and sample size

This study examines geography teachers' beliefs and practices regarding the implementation of PBL, and the various structural and systemic factors influencing their effectiveness in applying PBL to lessons on deforestation and climate change. The target population comprises secondary school geography teachers in the Metekel Zone who teach grades 9–12, representing the entire population of interest within the study area. Participants included geography educators with different academic qualifications: some holding Master's degrees, the majority with Bachelor's degrees in geography. To ensure a representative sample, a multistage sampling technique was employed to systematically select respondents for the study. Accordingly, the following procedures were followed.

Selection of the study zone: Metekel Zone was purposively selected because of its acute vulnerability to deforestation and climate variability, as well as its ecological and socio-economic significance. The zone lies within the Tana–Beles sub-basin, a critical watershed contributing nearly 60% of the Abay River flow and sustaining the Grand Ethiopian Renaissance Dam (GERD), yet it faces increasing pressures from land-use change, agricultural expansion, resettlement programs, recurrent forest fires, and limited environmental awareness among the local community. From an educational perspective, despite these severe environmental challenges, public awareness remains low, and environmental issues appear weakly integrated into the secondary school geography curriculum, providing a critical context for exploring curriculum integration, students' knowledge and attitudes, and teachers' implementation of Problem-Based Learning (PBL) for deforestation and climate change lessons. Practical considerations also guided the site selection, as the researcher's familiarity with the area and professional experience in geography and education facilitated access to participants, ensured feasibility of fieldwork, and provided deeper contextual insights. Taken together, these ecological, socio-economic, educational, and practical reasons justify the selection of Metekel Zone as the study site.

Selection of sample districts:

Given the study's focus on deforestation and climate change in Metekel Zone, and on geography teachers' beliefs, practices, and influencing factors in implementing PBL, data were collected across all seven districts to ensure comprehensive coverage. Each district was purposively selected, as they all include secondary schools within their respective kebeles.

Selection of 'Kebeles'

When selecting secondary schools based on students' residence, all 38 *kebeles* that host secondary schools (grades 9-12)—were included in the sample for teacher data collection. This broad inclusion was necessary due to the small number of teachers available, as excluding any *kebeles* could affect the quality of the data. Therefore, all 38 *kebeles* were purposefully selected for this study.

Selection of Schools and Grade Levels

Based on the 2023/24 annual statistics from the Benishangul Gumuz Education Bureau, Metekel Zone comprises 38 government secondary schools, with 24 offering grades 9-10 and 14 providing education from grades 9-12. To ensure comprehensive and reliable data, the study included all secondary schools within the zone, specifically focusing on those offering grades 9-12 across all *kebeles*. This approach was chosen to capture a diverse range of perspectives and experiences from teachers across the entire zone, thereby enhancing the robustness of the findings.

Selection of geography teachers, department heads, and school principals and zonal and district level educational experts:

The study employed a cluster sampling approach in which secondary schools were first identified and selected as sampling units. Within the selected schools, all geography teachers teaching grades 9–12 were included in the study to ensure comprehensive coverage and to minimize sampling bias within clusters. The total number of eligible geography teachers in these schools was 134; therefore, a census of teachers within the selected schools was conducted rather than drawing a sub-sample. Accordingly, 134 questionnaires were distributed, and all were returned, yielding a 100% response rate (Appendix 5). Furthermore, using purposive sampling technique, 3 zonal and 7 district level education experts (one from each district) and 7 school directors were selected to provide information as key informants and focus group discussion participants. The distribution of participants in the study is presented in Table 7.1 below.

Table 7.1: Number of samples for geography teachers, department heads, school principals and education experts

No	Name of the district	Geography teachers (grade 9-12)			Geography department heads			School directors			District level Education experts		
		M	F	T	M	F	T	M	F	T	M	F	T
1	Dangur	10	2	12	1	-	1	1	-	1	1	-	1
2	Bullen	20	3	23	1	-	1	1	-	1	1	-	1
3	Guba	3	0	3	1	-	1	1	-	1	1	-	1

4	Wombera	33	3	36	1	-	1	1	-	1	1	-	1
5	Dibati	19	0	19	1	-	1	1	-	1	1	-	1
6	Mandura	21	1	22	1	-	1	1	-	1	1	-	1
7	Pawe	18	1	19	1	-	1	1	-	1	1	-	1
	Total	124	10	134	7	-	7	7	-	7	7	-	7

Source: Benishangul Gumuz Region Education Bureau (2024)

7.4.4. Instruments and the data collection procedure

Various data collection tools were employed to gather data for the study. These included a structured questionnaire, in-depth interviews, focus group discussions, and classroom observations.

Survey Questionnaire: The primary data for this study was collected from secondary school geography teachers using questionnaires. These questionnaires included closed-ended items and were divided into two parts. The first part focused on teachers, gathering information about their beliefs and actual use of problem-solving practices in teaching environmental issues related to deforestation and climate change in secondary school geography classes. This section comprised 20 items, adapted with minor modifications from (Hamza & Farrow, 2000), to evaluate teachers' perceptions of their implementation of problem-solving methods in the classroom. The adaptations were made to align with the Ethiopian secondary school geography curriculum, which prioritizes inquiry-based learning and problem-solving approaches in environmental education. Therefore, the survey questions were carefully designed to reflect these curriculum requirements and assess the extent to which teachers internalized and applied problem-solving methodologies in their teaching.

The items were categorized into three main groups: problem-based practice, heuristic approach to problem solving, and contextualizing content of deforestation and climate change for students. The first category, problem-based practice, included six items designed to evaluate the degree to which teachers promoted problem-solving skills in their students. These items measured whether teachers encouraged students to focus on skill development rather than rote memorization, provided open-ended problems requiring inquiry and discovery, and created opportunities for students to explore multiple solutions independently before being guided by the teacher.

The second category, heuristic approaches to problem-solving**,** consisted of eight items that evaluated teachers' instructional strategies in helping students develop problem-solving skills. This section examined whether teachers facilitated student-centered instruction, encouraged diverse problem-solving approaches, and promoted strategy formulation through fact-finding and inquiry-based learning. The third category, contextualizing content for students, included six items that assessed the degree to which teachers related geography lessons on deforestation and climate change to real-world contexts. This section focused on whether teachers linked subject content to students' everyday experiences, provided word problems based on real-life situations, and encouraged students to apply classroom concepts in practical scenarios. Each item is organized on a five-point rating scale, where respondents indicate their level of agreement: 1 for strongly disagree, 2 for disagree, 3 for undecided, 4 for agree, and 5 for strongly agree.

To analyze the extent to which teachers integrated a problem-solving approach, this study applied a median-based threshold. This classification method ensured methodological rigor and aligned with best practices in Likert-scale research, as highlighted by (Boone & Boone, 2012; Norman, 2010), who advocate for non-parametric techniques and data-driven thresholds to enhance classification accuracy. Furthermore, the study incorporated established educational frameworks, including the UNESCO Guidelines on Environmental Education (Hopkins & Mckeown, 2002; Mochizuki & Vickers, 2024), the Theory of Planned Behavior (Ajzen, 1991), and the Ethiopian Ministry of Education's curriculum standards (MoE, 2018). These frameworks collectively affirm that a problem-based approach is evident when student-centered learning, active inquiry, and the practical application of knowledge are effectively implemented.

Building on this approach, a median-based threshold of 3 was established for this study to classify teachers' efforts in adopting a problem-solving approach. Using this threshold, we summed the number of respondents who rated each descriptor as 1 (strongly disagree) and 2 (disagree) on one side, and those who rated them as 4 (agree) and 5 (strongly agree) on the other side. The frequencies of these ratings were then calculated as a percentage of the total respondents. Thus, descriptors rated positively (strongly agree and agree) by a majority of respondents indicate the use of a problem-solving approach in teaching environmental issues related to deforestation and climate change in secondary school geography classes. Conversely, descriptors rated negatively (disagree and strongly disagree) by a majority of respondents suggest the absence of problem-solving practices in these classes. The "undecided" descriptor does not indicate either the presence or absence of a problem-solving approach when teaching environmental issues related to deforestation and climate change in secondary school geography classes.

Additionally, one-sample t-test was conducted to assess whether significant differences existed between the expected and observed means in three key areas: integrating problem-based scenarios into deforestation and climate change lessons, utilizing the heuristic approach, and contextualizing these topics within real-world settings. These tests aimed to determine whether the mean scores of geography teachers' PBL practices significantly deviated from the test value of 3, which served as a neutral benchmark on a standardized Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). The test value of 3 represented a baseline level of practice, providing a reference point against which observed mean scores were compared. The analysis sought to assess the relative importance of application of problematic situation, teaching via heuristics approach and contextualizing of deforestation and climate change lesson and their contributions to the effective implementation of PBL

The second part of the questionnaire explored structural and systemic factors affecting PBL implementation in teaching deforestation and climate change. Aligned with the study's objectives, it covered four key areas: teacher-related, classroom, curricular, and methodological factors. The instrument comprised 42 items, the majority being multiple-choice and closed-ended, with a few open-ended questions. It facilitated efficient and standardized data collection for analysis and was designed following an extensive review of the literature to ensure both clarity and content validity.

Key Informant interview:

were employed to gather in-depth insights into geography teachers' beliefs, practices, and the structural and systemic factors influencing the implementation of PBL in teaching deforestation and climate change. This method is widely recognized in educational research for capturing diverse stakeholder perspectives (Kumar & Analyst, 1989; Lokot, 2021). Nine key informants were purposively selected to ensure varied viewpoints: three geography teachers, two department heads, two school principals, one district, and one zonal education expert (Table 7.2). The interviews explored classroom practices, institutional support, curriculum integration, and policy-level challenges affecting PBL. Face-to-face interviews were conducted at participants' workplaces, each lasting 45–60 minutes and audio-recorded with consent to ensure accuracy. The interview guide focused on key themes aligned with the study's objectives, such as teacher beliefs, classroom dynamics, institutional support, and methodological concerns. Probing questions were used to prompt deeper reflection, in line with qualitative research best practices (Patton, 2015). These interviews provided rich qualitative data that enhanced the study's findings and contributed meaningfully to research in geography education.

Table 7.2: Demographic distribution of key informants in the study

Participant code	Position	Gender	Age	Education level	Work Experience in years
Teacher 1	Geography Teacher	M	37	Bachelor's degree	9
Teacher 2	Geography Teacher	M	43	Master's degree	21
Teacher 3	Geography Teacher	F	48	Bachelor's degree	27
Department head 1	Department Head	M	48	Master's degree	26
Department head 2	Department Head	F	39	Bachelor's degree	23
School principal 1	School Principal	M	34	Bachelor's degree	13
School principal 2	School Principal	M	40	Master's degree	18
Education Expert 1	District Education Expert	F	37	Bachelor's degree	16

Education Expert 2	Zonal Education Expert	M	45	Bachelor's degree	21

Focus group discussions (FGDs)

FGDs were used to complement and validate data from questionnaires and in-depth interviews. The primary objective of the FGDs was to explore geography teachers' beliefs and practices in implementing PBL in greater depth and to gather insightful data on the structural and systemic factors influencing the adoption of PBL for teaching deforestation and climate change lessons in the Metekel Zone. Three districts—Pawe, Dangur, and Mandura—were purposely selected due to their severe deforestation issues and low environmental awareness, making them ideal for exploring PBL implementation. The study used a purposive sampling approach to ensure a diverse range of contextually relevant stakeholders, including geography teachers, students, education specialists, and school principals, as recommended in qualitative research (Ames et al., 2019). Three FGDs were conducted, each with six participants, totaling 18 respondents. This group size is effective for balancing dynamics and achieving data saturation (Guest et al., 2006, 2017). Each session lasted about 90 minutes, in line with best practices for maintaining engagement and facilitating in-depth discussion (Nyumba et al., 2018). The discussions were led by a principal investigator, an experienced geography educator familiar with the local context, and a note-taker documented key insights. Open-ended questions based on the study's themes were used to guide the discussions, allowing participants to freely share their experiences and perspectives. The discussion points were focusing on teachers' beliefs about PBL, teachers' practices and the various structural and systemic factors affecting effective implementation of PBL and the way forward.

Classroom Observation

Classroom observations were conducted to assess geography teachers' use of PBL and identify structural and systemic factors affecting its implementation during lessons on deforestation and climate change. A structured checklist with a four-point scale (1 = hardly ever, 2 = sometimes, 3 = often, 4 = almost always), previously used in the teacher questionnaire, ensured consistent assessment of teaching practices. Open-ended notes captured additional classroom behaviors and contextual factors not covered by the checklist.

Observations took place in seven purposively selected full-cycle secondary schools, involving 28 geography teachers observed twice over eight weeks—once during a deforestation lesson and once during a climate change lesson. A team of seven trained geography education professionals, including a principal investigator, conducted the observations. Inter-rater reliability was established through training, pilot testing, and cross-evaluation, yielding a Cohen's kappa of 0.72, indicating substantial agreement.

Video recordings (with teacher consent) complemented live observations. Observers evaluated the application of PBL and student problem-solving engagement. Data analysis combined descriptive statistics for checklist ratings and thematic analysis of qualitative notes and videos, allowing triangulation and deeper understanding of classroom dynamics influencing PBL implementation.

7.4.5. Validity and reliability of the instruments

To ensure face and content validity, feedback from three experienced geography teachers and research advisors guided the refinement of the questionnaire, leading to clear, relevant, and objective-aligned items. Consequently, this iterative process produced a well-validated instrument for final use.

In addition, to test reliability, a pilot study was conducted with nine geography teachers from three non-sample secondary schools. Using Cronbach's Alpha, reliability coefficients were 0.872 (problem-based practice), 0.812 (heuristics), 0.7 (contextualizing content), and 0.827 (total scale), indicating the questionnaire is highly reliable for assessing teachers' perceptions of problem-solving approaches.

Similarly, a pilot study was conducted to validate and ensure the reliability of a questionnaire on structural and systemic factors affecting PBL implementation in teaching deforestation and climate change. Involving teachers from four schools, the study assessed practicality and led to minor refinements. Cronbach's alpha of 0.762 indicated good internal consistency.

Moreover, to enhance the rigor of qualitative data collection, the study applied established strategies for reliability and validity. Reliability was ensured through inter-coder agreement and methodological triangulation, with all three authors independently coding data and resolving differences by consensus. Data were collected via interviews, focus groups, and observations to reduce bias. Validity was ensured through member checking, prolonged engagement across Metekel zone, and peer debriefing. Participants reviewed findings for accuracy, while an audit trail documented decisions, enhancing transparency and credibility.

7.4.6. Methods of Data analysis

The researchers employed both quantitative and qualitative data analysis methods to ensure an extensive grasp of the study. Quantitative analysis provided objective measurement and statistical insights, while qualitative analysis offered in-depth exploration of participants' experiences, enriching the overall findings.

7.4.6.1.Quantitative data analysis

Descriptive and inferential statistics, using SPSS version 27, were employed to analyze data from structured questionnaires. Teachers' beliefs about PBL practices, heuristic approaches, and contextualizing deforestation and climate change content were analyzed using percentages. A one-sample t-test assessed whether teachers' beliefs about PBL significantly differed from a predefined benchmark. The Pearson Product-Moment Correlation Coefficient (r) measured the relationship between teachers' beliefs in problem-solving and their classroom practices, helping to identify patterns that affect PBL implementation. To explore diverse structural and systemic factors influencing teachers' use of PBL in teaching deforestation and climate change, binary logistic regression was applied. This method predicted the likelihood of high or low PBL implementation, based on various predictor variables. Teachers with high PBL implementation were coded as 1, while those with low implementation were coded as 0, with the low-implementation group serving as the reference for the model.

The independent variables represent the various structural and systemic factors that influence the effective implementation of the PBL approach when teaching these topics in secondary school geography classes. The binary logistic regression coefficients can be used to estimate ratios for each of the independent variables in the model (Eq. 7.1).

Quantitatively, the relationship between an occurrence and its dependence on several variables can be described as:

$$\ln\left[\frac{P}{1-P}\right] = \beta 0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \; \ldots + \; \beta_k X_k \qquad \text{Equation (7.1)}$$

In this equation, the expression P/(1-P) represents the odds ratio, where P denotes the probability that secondary school geography teachers have a high level of PBL implementation when teaching environmental issues related to deforestation and climate change, indicating the presence of the PBL approach in their lessons. Conversely, 1−P represents the probability that teachers have a low level of PBL implementation, making them less likely to apply the PBL approach in teaching these environmental topics. Additionally, β0 represents the intercept, while X1, X2, X3, ...,Xk represent the independent variables, and β1, β2, β3, ..., βk are the regression coefficients.

7.4.6.2.The variables and their description

The dependent variable, "teacher's level of implementation of the PBL approach in teaching deforestation and climate change lessons," assesses whether secondary school geography teachers utilize PBL in teaching lessons on deforestation and climate change to enhance student learning. To assess the extent of PBL implementation among teachers, this study employs a median-based benchmark using five key indicators: student-centered learning, real-world problem integration, collaborative learning, facilitative teacher role, and cross-disciplinary knowledge integration. Each indicator is scored 1 for "yes" (implemented) and 0 for "no" (not implemented), yielding a total score ranging from 0 to 5. This assessment is based on a close-ended questionnaire developed for this purpose. The median score of the sample serves as the threshold for classification, with teachers scoring at or above the median categorized as high PBL implementers (1), and those below the median classified as low implementers (0). This benchmark provides a data-driven, context-specific, and statistically robust classification method, ensuring validity by accounting for variations in instructional practices. A median-based approach aligns with best practices in research by mitigating biases associated with arbitrary cut-off points and ensuring meaningful differentiation in teacher performance (Boone & Boone, 2012; Field & Wilcox, 2017).

On the other hand, it was proposed that the effective implementation of PBL, as the dependent variable, is influenced by multiple independent variables grouped into four main categories of structural and systemic factors: teacher-related factors, classroom environment factors, curricular factors, and teaching methodology factors, as illustrated in table 7.3. Among teacher-related factors, a teacher’s level of adaptation to PBL plays a crucial role. This refers to the extent to which geography teachers have integrated PBL into their lessons on deforestation and climate change. Adaptation is assessed using five indicators, with teachers categorized as either adapted or not based on a median split. Similarly, a teacher’s content experience, which reflects their depth of knowledge on environmental issues, is evaluated through five key indicators, distinguishing between those with high and low content experience. Emotional intelligence (EI) is another essential teacher-related factor, as it shapes how educators manage emotions—both their own and their students’—during PBL activities. Teachers with high EI are more effective in facilitating discussions on sensitive environmental topics. Additionally, teachers’ perceptions of student motivation and engagement influence PBL implementation, as students’ enthusiasm and active participation are critical for its success. Another important aspect is how teachers perceive students' environmental identity, which refers to the extent to which students feel connected to and responsible for environmental issues. Teachers who believe students have a strong environmental identity tend to observe greater engagement, collaboration, and ethical responsibility, which enhances the effectiveness of PBL.

Classroom environment factors also play a significant role. Large class sizes can limit personalized instruction and group collaboration, making it challenging to implement PBL effectively. Similarly, inadequate logistical support—such as a lack of resources, space, and technology—further hinders PBL’s success in geography lessons related to deforestation and climate change.

Curricular factors, particularly the extensive content requirements of the secondary school geography curriculum, present another challenge. The pressure to cover a broad range of topics within a limited timeframe often makes it difficult for teachers to fully integrate PBL. Additionally, the alignment of PBL with curriculum standards influences its implementation, with teachers being classified based on how well their PBL activities conform to official guidelines. Another curricular constraint is the reliance on traditional assessment methods, which may not align with the formative assessment strategies essential for PBL. Teaching methodology factors also influence the adoption of PBL. Many teachers continue to rely on conventional, lecture-based methods, limiting opportunities for student-centered learning. Moreover, PBL is often seen as time-intensive, posing an additional challenge within an already crowded curriculum. These methodological barriers, along with other constraints, are hypothesized to negatively affect the successful implementation of PBL in geography lessons on deforestation and climate change.

Table 7.3: Explanation of independent variables and their connection to the dependent variable

Independent Variables	Description and Measurement	Variable Type	Expected Sign
Teacher-Related Factors			
Teacher's level of adaptation of PBL	1 = Adapted to PBL; 0 Not adapted to PBL	Dummy	+
Level of teacher's content experience	1 = High content experience; 0 Low content experience	Dummy	+
Level of emotional intelligence of teachers	1 = High emotional intelligence; 0 Low emotional intelligence	Dummy	+
Teachers' perception of students' environmental identity	1 = If teachers perceive that it affects effective implementation of PBL; 0 otherwise	Dummy	+
Teacher's perception of student motivation and engagement	1 = teachers whose students demonstrate high motivation and engagement; 0 otherwise	Dummy	+
Classroom Environment Factors			

Large class size	1 = If it affects effective implementation of PBL ; 0 otherwise	Dummy	-
Inadequate logistical support	1 = If it affects effective implementation of PBL ; 0 otherwise	Dummy	-
Curricular Factors			
The traditional assessment system	1 = If it affects effective implementation of PBL ; 0 otherwise	Dummy	-
The extensive content requirements of the geography curriculum	1 = If it affects effective implementation of PBL; 0 otherwise	Dummy	-
Alignment with curriculum standards	1= Teachers whose PBL activities are closely aligned with curriculum standards; 0 otherwise	Dummy	+
Teaching methodology factors			
The reliance on conventional teaching methods	1 = If it affects effective implementation of PBL; 0 otherwise	Dummy	-
The time-intensive nature of PBL	1 = If it affects effective implementation of PBL; 0 otherwise	Dummy	-

7.4.6.3.Qualitative data analysis

Qualitative data from KIIs and FGDs were analyzed using thematic analysis, following (Braun & Clarke, 2006) six-phase framework. This included familiarization, coding, theme development, refinement, definition, and synthesis, enabling a structured and in-depth interpretation of participants' perspectives aligned with the study's objectives.

Themes were developed using both deductive and inductive approaches, ensuring alignment with research objectives while allowing new insights. The main themes included teachers' beliefs and practices, structural and systemic factors, and classroom dynamics. These addressed pedagogical orientations, institutional conditions, and classroom-level influences on PBL implementation in teaching deforestation and climate change.

To ensure depth and credibility in data interpretation, a constant comparative method was employed, enabling iterative refinement of emerging themes. Thematic content analysis further allowed for a nuanced understanding of the qualitative data, complementing the quantitative findings and providing a holistic exploration of the factors influencing PBL implementation. Additionally, the use of probing questions during KIIs and FGDs facilitated an in-depth examination of participants' viewpoints, allowing for a richer and more comprehensive dataset.

7.5.Results

7.5.1. Influence of secondary school geography teachers' beliefs, practices, and contextualization of lessons on their performance in teaching deforestation and climate change lessons using PBL

This section explores how teachers' beliefs about problem-solving approaches, their teaching practices, and their ability to contextualize lessons impact their effectiveness in delivering deforestation and climate change content. It provides a comprehensive analysis of each component to illustrate how these factors shape teachers' performance in successfully implementing PBL for the subjects under investigation.

7.5.1.1. Teachers' beliefs about problem-based practice

Effective implementation of PBL relies significantly on teachers' beliefs and practices, which shape the learning experiences they create for students. In the context of geography education in Metekel Zone secondary schools, data reveal a limited application of PBL for teaching deforestation and climate change. Table 7.4 shows that only 29% of teachers prioritize skill development over conceptual understanding, while 57% focus on theory, limiting practical skill-building. Additionally, 24% promote inquiry-based learning, 27% engage students in solving non-routine problems, 28% encourage independent solution exploration, and 23% emphasize higher-order skills like synthesis and analysis. These findings indicate relatively low beliefs and practices among teachers regarding the effective implementation of PBL.

To further explore these quantitative results, a thematic analysis was conducted on qualitative data gathered through KIIs and FGDs. The data obtained from the two sources revealed that while some participants acknowledged the potential benefits of problem-based practice in improving student engagement and critical thinking, most lacked confidence in implementing it effectively. Participants cited limited training, insufficient instructional resources, large class sizes, rigid curricula, and time constraints as major barriers. Additionally, traditional assessment methods and weak administrative support discouraged them from fully adopting PBL. Teacher 2 witnessed the challenge of shifting from traditional lecture-based teaching to student-centered methods, explaining: "For years, we have been teaching through direct instruction, covering vast content under strict time constraints. PBL requires a different mindset—one that allows students to explore, question, and collaborate but we are not adequately prepared for this transition due to limited training, and rigid curricula."

Additionally, the lack of instructional resources was a major concern that significantly hindered the effective implementation of PBL. The KII participants emphasized that without appropriate teaching materials, conducting inquiry-based activities becomes impractical and challenging for both teachers and students. They highlighted that PBL requires well-structured problem scenarios, access to up-to-date and relevant case studies, real-world environmental data, and well-developed instructional guides. However, as the classroom observation also confirmed, many schools lack these essential resources, making it difficult for teachers to design and facilitate engaging and meaningful problem-solving activities. For example, department head 2 stated:

> PBL requires structured problem scenarios, real-world data, and well-developed instructional guides. However, we do not have access to updated case studies, environmental reports, or digital resources to facilitate meaningful student engagement. Without these materials, it becomes nearly impossible to create an interactive learning environment where students can analyze real-world problems and develop critical thinking skills.

In addition to this, the participants also pointed out that limited access to digital tools, such as computers, projectors, and online learning platforms, further restricts teachers' ability to incorporate multimedia and interactive resources into their lessons. Some teachers noted that even when they attempt to adapt PBL using locally available resources, the lack of standardized materials results in inconsistencies in lesson quality and depth of student engagement.

The FGD participants supported these findings by providing in-depth explanations that reinforced the concerns raised in the quantitative findings and KIIs. Many teachers in the FGDs elaborated on their hesitation towards PBL implementation, citing not only a lack of resources and institutional support but also deeply ingrained teaching habits that prioritize content coverage over inquiry-based learning.

In the same vein, classroom observation analysis of teachers' beliefs about problem-based practices as shown in Figure 7.2 reveals a consistent pattern of low engagement with key active learning practices. The mean scores across all items indicate that teachers are not emphasizing problem-based approaches or skill-building activities as frequently as desired, aligning with the findings from the quantitative analysis, FGD, and KII. For example, the mean score for encouraging students to practice skills rather than concepts is 1.54 (SD = 0.744), and for providing problems that require inquiry and discovery, it is 1.46 (SD = 0.576), suggesting limited use of inquiry-based problem-solving. Similarly, the mean scores for encouraging students to tackle unfamiliar, non-routine problems (1.54, SD = 0.744) and offering opportunities for self-directed exploration (1.46, SD = 0.576) indicate that fostering student independence is not a priority. Although slightly higher mean scores were observed for learning by doing (1.57, SD = 0.634) and promoting synthesis and analysis (1.61, SD = 0.737), these still reflect a limited focus on higher-order thinking.

Table 7.4: Teachers' beliefs about problem-based practice

No.	Practice Descriptors	Positive (Agree + Strongly Agree)	Negative (Disagree + Strongly Disagree)	Undecided
1	Encouraged students to practice on skills	39 (29.1%)	77 (57.5%)	18 (13.4%)

	rather than concepts			
2	Provided problems that needed inquiry and discovery rather than activities that need memorization	32 (23.9%)	82 (61.2%)	20 (14.9%)
3	Encouraged students to practice on unfamiliar and non-routine problems rather than routine problems	36 (26.9%)	79 (59%)	19 (14.2%)
4	Gave opportunities for students to explore solutions in their own ways before being shown by the teachers	38 (28.4%)	74 (55.2%)	22 (16.4%)
5	Encouraged students to learn by exploring, manipulating, experimenting, risking, testing, and modifying ideas	34 (25.4%)	71 (53.0%)	29 (21.6%)
6	Encouraged synthesis and analysis	35 (26.12%)	72 (53.73%)	27 (20.15%)

Source: survey data from Metekel zone secondary schools (2024)

Open-ended classroom observations on “What challenges face geography teachers in integrating inquiry-based learning into their teaching?" and "How do they perceive the balance between content delivery and fostering student independence in their lessons?" revealed that teachers often feel constrained by curriculum requirements and time limitations.

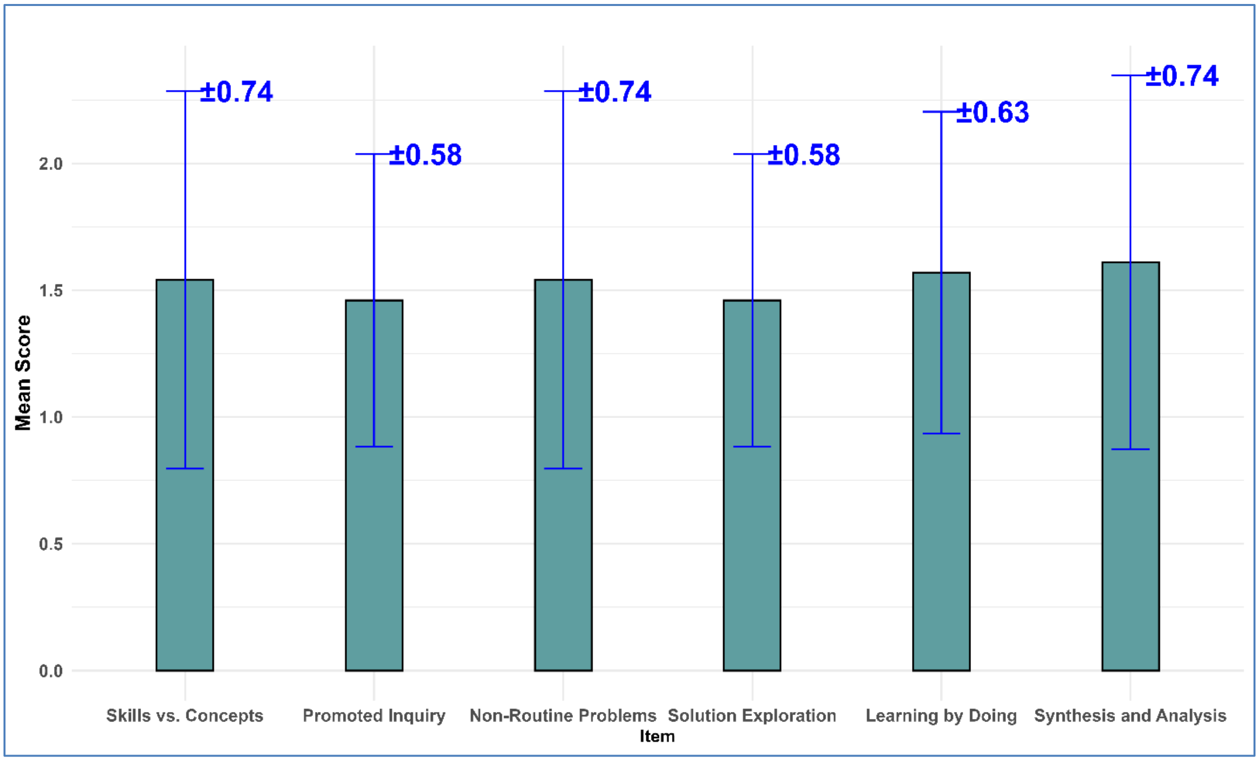


Figure 7.2: Observation result on teachers' beliefs about problem-based practice

7.5.1.2. Teacher's belief about application of heuristic approaches to problem-solving

Heuristic approaches in PBL, which prioritize flexible and adaptive thinking alongside problem-solving strategies, are widely recognized as essential for equipping students to address multifaceted, real-world challenges. However, an analysis of geography teachers' beliefs regarding the use of these methods in teaching deforestation and climate change in the present study reveals inconsistent application of such practices. The findings in table 7.5 reveal that the majority of geography teachers hold negative beliefs regarding the heuristic approach in their instructional practices. Across all descriptors, a significant proportion of teachers disagreed or strongly disagreed with implementing heuristic-based teaching strategies, with negative responses ranging from 58% to 61%. This indicates a prevalent reluctance or lack of confidence in promoting heuristic problem-solving methods in deforestation and climate change lessons. Notably, the lowest level of agreement (22%) was observed for modeling the problem-solving process, suggesting that teachers may struggle with demonstrating or guiding students through heuristic problem-solving. Similarly, only 23% of teachers believed they effectively helped students plan for the future in a meaningful way, further emphasizing the limited application of heuristic-based teaching. The highest level of agreement (28%) was seen in encouraging student-centered instruction and discussing useful problem-solving strategies, though these figures remain relatively low. The high percentage of undecided responses (12%–19%) suggests some uncertainty among teachers regarding the heuristic approach.

Table 7.5: Teachers' Beliefs on Heuristics Approach

No.	Practice Descriptors	Positive (Agree & Strongly Agree)	Negative (Disagree & Strongly Disagree)	Undecided
1	Helped students to plan for the future in a meaningful way to them	31 (23%)	81 (60%)	22 (16%)
2	Encouraged application of algorithm before they apply heuristic on non-routine problems	34 (25%)	78 (58%)	22 (16%)
3	Encouraged student-centered instruction	37 (28%)	79 (59%)	18 (13%)
4	Encouraged students to use a variety of approaches to solve problems	35 (26%)	78 (58%)	21 (16%)
5	Encouraged fact-finding, information gathering, and strategy formulation	36 (27%)	79 (59%)	19 (14%)
6	Presented tasks or lessons from individual experience	35 (26%)	82 (61%)	17 (13%)
7	Modeled the problem-solving process	30 (22%)	79 (59%)	25 (19%)
8	Discussed useful problem-solving strategies	38 (28%)	80 (60%)	16 (12%)

Source: Survey data from Metekel zone secondary schools (2024)

Qualitative data revealed that teachers were hesitant to use the heuristic approach, citing institutional constraints, curriculum overload, lack of training, and limited resources. Although some acknowledged its benefits, integration into lessons on deforestation and climate change was minimal. A major barrier was the demanding geography syllabus, which left little time for student-led inquiry. As one key informant teacher noted, the pressure to cover extensive content quickly forces reliance on direct instruction over discovery-based learning.

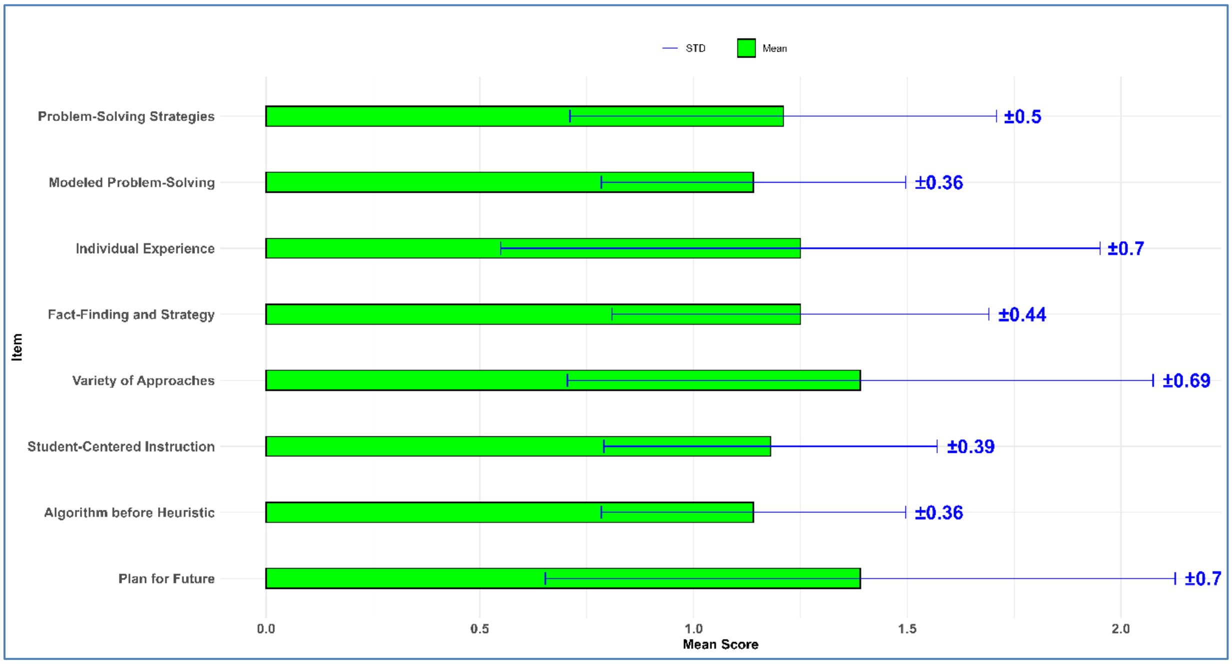


Figure 7.3: Observation result on teachers' practices in promoting heuristic approach

FGD participants noted that while PBL suits deforestation and climate change lessons, the limited two-period weekly allocation in grades 9 and 10 hinders effective implementation. They stressed the need for a more flexible curriculum and adequate time for inquiry-based activities. Teachers also cited a lack of institutional support, with rigid academic structures prioritizing exam results over critical thinking. A school principal acknowledged the focus on standardized assessments, which sidelines heuristic teaching. Without strong administrative backing, teachers are reluctant to adopt heuristic methods, as school leaders rarely promote or support such approaches.

Observation results (Figure 7.3) show that teachers generally demonstrate low engagement in promoting heuristic strategies, with all practices scoring below the midpoint. The highest mean scores 1.39 for helping students plan for the future and encouraging varied problem-solving approaches still reflect limited implementation. Minimal engagement was observed in practices like applying algorithms before heuristics and modeling problem-solving (mean = 1.14). Other strategies, such as student-centered instruction and discussing problem-solving methods, also scored low. Observations revealed a reliance on direct instruction due to heavy content demands. Time constraints, rigid curricula, and student habits hinder the consistent use of heuristic methods, despite teachers' interest in professional development.

7.5.1.3. Teacher's belief on contextualizing the content to students' real life

Teachers' belief about contextualizing environmental topics is a crucial factor influencing students' engagement with and understanding of deforestation and climate change issues. It is hypothesized that teachers' willingness to integrate real-world connections into these lessons directly affects students' ability to apply critical thinking and problem-solving skills to environmental challenges related to deforestation and climate change. The findings of the present study support this hypothesis, showing that negative beliefs among teachers to contextualize the contents of deforestation and climate change in to students' real life limit the relevance of these topics in students' lives. As depicted in table 7.6, few teachers effectively connected content to real-world issues (23.9%), encouraged critical thinking (27.0%), integrated students' experiences (24.3%), used real-world problems (27.9%), applied concepts to real life (25.4%), fostered independent learning (34.4%), witnessing the fact that teachers in the study region believed that they do not contextualize the lesson in deforestation and climate change content to students' real life to the expected level.

The FGD and KII Participants also confirmed that they often struggle to integrate real-world connections into their lessons, which directly affects students' ability to apply critical thinking and problem-solving skills to environmental challenges. KII participants expressed concerns that contextualizing deforestation and climate change lessons remained a challenge due to a lack of locally relevant case studies, inadequate teaching aids, and limited student exposure to practical environmental projects. Teacher 1 remarked, "... integrating real-world examples is difficult because we lack concrete resources or strategies to make content engaging." Similarly, teacher 3 highlighted the issue of inadequate student participation in practical applications, stating, "Students rarely get opportunities to apply concepts to real-life situations, which limits their ability to internalize environmental knowledge."

Department heads also echoed these concerns, emphasizing the structural barriers that hinder effective contextualization. Department head 1 noted, "Although we encourage students to take ownership of their learning, these opportunities are infrequent and not systematically reinforced".

The findings from the FGD provided strong qualitative support for the quantitative data, particularly highlighting the challenges teachers face in fostering students' ability to connect abstract theoretical content with their lived experiences. Several teachers emphasized that, despite their efforts to contextualize lessons and integrate real-world examples, many students still struggle to grasp the relevance of deforestation and climate change topics to their own environments. As one teacher noted during the discussion, "We try to incorporate real-world examples, but the students often find it hard to relate because they have not encountered such scenarios firsthand." This disconnect was commonly attributed to the lack of exposure students have to diverse environmental contexts, particularly those outside their immediate locality.

Table 7.6: Teachers' beliefs on contextualizing the content of deforestation and climate change

No.	Role Descriptors	Positive (Agree + Strongly Agree	Negative (Disagree & Strongly Disagree)	Undecided
1	Related subject content (climate change and deforestation issues) to real world	27 (23.9%)	84 (74.3%)	23 (20.4%)
2	Allowed students to practice their past experience	33 (27.0%)	81 (66.2%)	20 (16.4%)
3	Presented tasks or lessons from individual experiences	29 (24.3%)	86 (72.0%)	19 (15.9%)
4	Gave word problems from real life to be converted to known facts	34 (27.9%)	84 (68.9%)	16 (13.1%)
5	Asked students the application of the concept in real life	31 (25.4%)	83 (68.0%)	20 (16.4%)
6	Fostered self-initiated learning	42 (34.4%)	73 (59.8%)	19 (15.5%)

Source: survey data from Metekel zone secondary schools (2024)

Moreover, teachers expressed concern that limited access to contextual teaching resources significantly hampers their ability to make learning experiences meaningful and engaging. One participant articulated this challenge, stating, “Without access to digital resources or case studies from our local environment, it is difficult to create meaningful learning experiences.” This sentiment reflects a broader issue related to the scarcity of localized instructional materials and infrastructure that support experiential learning approaches, such as Problem-Based Learning. The teachers’ testimonies underscore the pressing need for resource investment and curriculum adaptation to better align environmental education with students’ socio-cultural and ecological realities, thereby enhancing the effectiveness of PBL in addressing complex issues like deforestation and climate change.

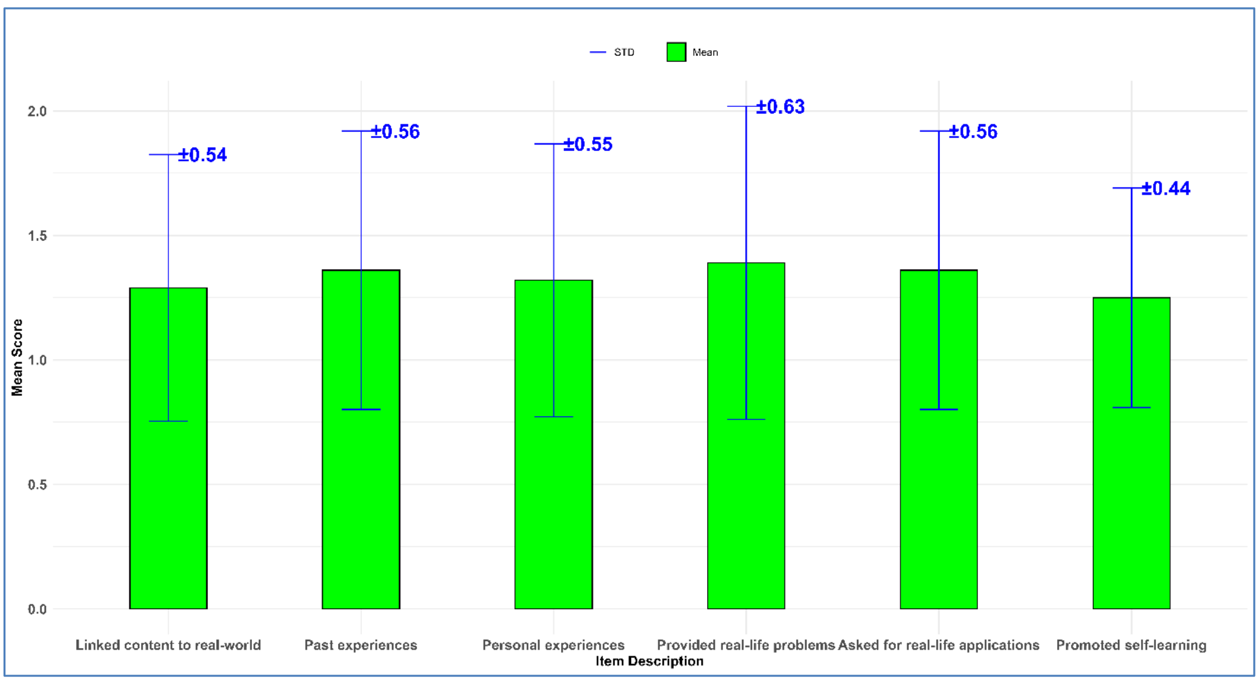


Figure 7.4: Observation result on teachers' beliefs on contextualizing content of deforestation & climate change

The observation results as indicated in Figure 7.4 supports the findings from quantitative data and FGDs and KIIs revealing a low approach by teachers in contextualizing the content of deforestation and climate change. Teachers displayed minimal efforts in relating the subject matter to real-world situations, with mean scores ranging from 1.25 to 1.39. The lowest mean score of 1.25, for fostering self-initiated learning, verifies a significant lack of emphasis on encouraging students to independently engage with the content. Other areas, such as relating content to real-life applications (mean = 1.29), allowing students to practice past experiences (mean = 1.36), and presenting tasks based on individual experiences (mean = 1.32), also reflect a limited approach. The small standard deviations indicate that these beliefs are consistent across the teachers observed. The responses from open-ended classroom observation notes corroborate the results, indicating teachers rarely incorporate real-world examples into their lessons on deforestation and climate change. Observers noted that while teachers occasionally asked students to apply concepts to real-life situations, it was more of a theoretical discussion rather than a hands-on or self-initiated exploration.

Beyond the descriptive and qualitative analysis presented in tables 4, 5 and 6, a one-sample t-test was conducted to assess the extent of teachers' beliefs regarding the use of the problem-solving approach. While both the descriptive and qualitative findings confirm a predominance of negative perceptions, the t-test offers statistical validation of these variations. One-sample t-test was performed to determine whether significant differences exist between the expected and observed means across three key areas: applying problem-based situations in teaching deforestation and climate change, employing the heuristic approach, and contextualizing these lessons. The results are presented in Table 7.7 below.

The one-sample t-test results in table 7.7 reveal that teachers' beliefs about problem-based practice, the heuristic approach, and contextualizing the lesson fall significantly below the expected test value of 3. The consistently negative t-values indicate that teachers generally do not strongly support the use of these instructional strategies in their teaching practices. This suggests a reluctance or lack of confidence in implementing student-centered, inquiry-based methods in deforestation and climate change lessons.

Table 7.7: One-sample t-test results on teachers' beliefs about problem-based practice, heuristic approach, and contextualizing the lesson (test value = 3)

Category	Observed Mean	Std. Dev.	df	Sig. (2-tailed)	Mean Difference	t-value
Problem-Based Practice	2.56	1.401	133	.000	-0.44	-3.884

Heuristic Approach	2.49	1.385	133	.000	-0.51	-4.341
Contextualizing the Lesson	2.47	1.355	133	.000	-0.54	-4.590

Among the three categories, problem-based practice received the highest observed mean ($M = 2.56$, $t = -3.884$, $p < .001$), indicating that teachers perceive some value in this approach but still fall short of fully endorsing it. The heuristic approach ($M = 2.49$, $t = -4.341$, $p < .001$) and contextualizing the lesson ($M = 2.47$, $t = -4.590$, $p < .001$) were rated even lower, reflecting stronger reservations about their practicality and effectiveness in classroom settings. These findings suggest that while some teachers recognize the potential benefits of these methods, they may lack the necessary training, resources, or institutional support to implement them effectively.

7.5.2. Correlation between secondary school geography teachers' beliefs regarding problem-solving approaches and their practical implementation in the classroom

This section investigates whether there is a significant relationship between teachers' theoretical beliefs about problem-solving approaches and their actual implementation in geography lessons on deforestation and climate change. To analyze this relationship, the Pearson product-moment correlation coefficient was utilized as presented in Table 7.8.

The results of the Pearson correlation analysis revealed a significant and strong positive relationship between teachers' belief toward implementing PBL and their actual classroom practice in PBL implementation ($r = 0.726$, $p < 0.01$). This finding indicates that teachers who hold more positive beliefs about the effectiveness and relevance of PBL are more likely to exhibit corresponding behaviors in their classroom practices. The strength of the correlation ($r = 0.726$) suggests that teachers' beliefs are a critical determinant of their practical application of PBL methodologies. Moreover, the significance of the relationship ($p < 0.01$) underscores the reliability of this correlation, eliminating the likelihood that the observed association is due to random chance. The results presented in the table align with previous findings, demonstrating consistency across multiple data sources. Specifically, the outcomes in tables 3- 9 reveal that both teachers' beliefs and their actual classroom practices related to PBL implementation fall below the anticipated or desired levels. This alignment underscores a persistent gap between the theoretical orientation of teachers and their practical application in classroom settings, suggesting a need for targeted interventions to bridge this discrepancy.

Table 7.8: Correlation between teachers' beliefs and actual classroom practices in PBL implementation

Variables	Teachers' beliefs toward implementing PBL	Teachers' actual classroom practices in PBL Implementation
Teachers' beliefs toward implementing PBL	1.000	0.726
Teachers' actual classroom practices in PBL Implementation	0.726	1.000
Sig. (2-tailed)	—	0.000
N	134	134

Note: Correlation is significant at the 0.01 level (2-tailed).

7.5.3. Structural and systemic factors affecting geography teachers' effective implementation of PBL: binary logistic regression

In this section, we performed a binary logistic regression model to explore the various structural and systemic factors that significantly influence teacher's level of implementation of the PBL approach in teaching secondary school geography lessons on deforestation and climate change. The explanatory variables and their reference groups are explained in table 7.9. The analysis revealed that out of twelve variables, eight are statistically significant at the 0.05 significance level, reflecting their impact on teachers' level of implementation of PBL. Of these, five variables have a positive effect on the implementation of PBL as indicated by their positive P values. Three of them present significant challenges, negatively impacting teachers' level of implementation of PBL. In addition to the significant predictors, the other four variables, while not statistically significant, are noteworthy due to their potential influence on PBL outcomes.

The model summary showed that the predictors explained 39.5% to 54.8% of the variance in the dependent variable, as evidenced by the Cox & Snell R Square and Nagelkerke R Square values. The model exhibited strong fit and reliability in explaining the outcome variable, correctly classifying 85.8% of the cases. The Hosmer and Lemeshow test was performed to evaluate the goodness of fit for the logistic regression model. The chi-square value was 25.985 with 8 degrees of freedom, and the significance level was 0.06. Given that the p-value exceeds the 0.05 threshold, we conclude that the model fits the data well, and there is no evidence to suggest a poor fit. The absence of multicollinearity in the model was confirmed, as the variance inflation factors (VIFs) for all predictors were below the threshold of 10, indicating that the predictors are not highly correlated with each other.

To begin with, the teacher's level of adaptation to PBL emerged as a pivotal factor for effective implementation in secondary school geography lessons on deforestation and climate change. Teachers classified as "adapted to PBL" had nearly six times higher odds of successful implementation compared to those "not adapted" (Exp (B) = 5.883, p = .006). Data from our KIIs and FGDs, and classroom observations, provide deeper insights into the quantitative results. Teachers who had adapted to PBL frequently incorporated interactive strategies such as student collaboration, real-world environmental data analysis, and technology-enhanced learning. In FGDs, teachers highlighted that adaptation to PBL allowed them to utilize real-world datasets, including satellite imagery, maps of forest cover change, and local deforestation statistics, to foster students' critical thinking and problem-solving skills. One teacher from the KII (Teacher 3) noted, "Adapting to PBL has enabled me to design lessons where students actively explore deforestation and climate change issues using real-world data rather than passively receiving information." Classroom observations reinforced these findings, showing that teachers classified as "adapted to PBL" facilitated inquiry-driven discussions and encouraged students to work collaboratively on problem-solving tasks. These teachers integrated geographic information systems (GIS) and climate modeling tools, making learning more interactive and contextually relevant. In contrast, teachers classified as "not adapted" exhibited a stronger reliance on traditional lecture-based instruction, with minimal integration of real-world data or student-led inquiry.

Despite the benefits of PBL, challenges were noted. FGD and KII data showed that curriculum constraints and student resistance hindered full implementation. Teachers cited extensive content requirements as a barrier, limiting consistent use of PBL. One teacher noted that the rigid curriculum structure left little room for student-centered learning. FGDs also indicated that students used to rote learning struggled with PBL's self-directed approach. Furthermore, teachers' content expertise significantly influences their ability to implement PBL effectively. The binary logistic regression analysis revealed that teachers with higher content experience were approximately five times more likely to achieve successful PBL implementation compared to those with lower content experience (Exp(B) = 5.055, $p = .008$). This finding emphasizes the key role of subject-matter expertise in facilitating multifaceted, problem-solving learning and effectively contextualizing environmental issues such as deforestation and climate change within the PBL framework. Responses from KII further corroborate this result, confirming that teachers with advanced qualifications, specialized training, and sustained professional development are better equipped to design and implement interdisciplinary, and real-world problem-solving activities. Teacher 2 highlighted that teachers with extensive training in geography and environmental education tend to integrate PBL effectively, allowing students to engage deeply with deforestation and climate change issues. He noted, "Teachers with strong content knowledge, especially those who have acquired such expertise after their master's degree, can facilitate meaningful discussions and guide students in analyzing real-world environmental problems using satellite imagery and case studies." Conversely, participants noted that limited content knowledge, often observed among teachers with minor qualifications in geography, hinders the depth and efficacy of PBL integration. Teacher 1 emphasized that without sufficient training, teachers struggle to connect PBL activities to real-world environmental challenges. He remarked, "While PBL is an effective method, those without advanced subject knowledge resort to traditional teaching methods due to a lack of confidence in guiding students through complex environmental problems. Classroom observations confirmed findings from quantitative data, FGDs, and KIIs, showing that teachers with strong content knowledge effectively implemented PBL. They connected deforestation and climate change to real-world contexts, used tools like satellite imagery, and encouraged critical thinking, boosting student engagement. In contrast, teachers with limited content experience relied on traditional methods and lacked confidence, hindering effective PBL use and reducing student participation.

Initially, it was postulated that teachers with higher emotional intelligence more effectively implement PBL when teaching deforestation and climate change as environmental issues. The data in the present study support this hypothesis. The binary logistic regression model revealed that teachers with higher emotional intelligence (EI), with an odds ratio of 7.594 ($p = .003$), are significantly more likely to implement PBL effectively, demonstrating enhanced capacity to manage classroom dynamics, address students' emotional needs, and foster innovative problem-solving. Qualitative insights further substantiated these results. FGDs emphasized those teachers with high EI adeptly mediated group interactions, resolved conflicts, and cultivated inclusive spaces for meaningful discourse. A participant noted, *"*My emotional intelligence allows me to manage interpersonal aspects of PBL, such as facilitating group work, resolving conflicts, and creating an atmosphere where students feel comfortable expressing their ideas." KIIs echoed these observations, emphasizing the role of empathy and calm in enhancing student engagement during emotionally charged lessons. For example, department head 1 remarked that remaining calm and supportive encouraged open participation, fostering deeper connections to environmental challenges. Classroom observations further reinforced these findings. Teachers with high EI were observed to demonstrate greater adaptability in managing student interactions, effectively moderating discussions, and responding calmly to challenges arising in PBL activities. These challenges included frequent disruptions among students, resistance to acknowledging deforestation as a critical issue in the Metekel Zone, and skepticism toward national reforestation initiatives like Ethiopia's Green Legacy Program. Some students dismissed deforestation as a minor concern, while others resisted discussions on afforestation efforts, perceiving them as socially motivated rather than as viable solutions to environmental degradation. Teachers with high EI exhibited proactive strategies for managing these challenges. They acknowledged students' frustrations and guided discussions toward constructive solutions, ensuring that debates remained focused on environmental science rather than social viewpoints. By fostering an inclusive and respectful classroom atmosphere, these teachers helped students critically analyze the real-world impacts of deforestation and climate change. Additionally, their ability to de-escalate conflicts and encourage open dialogue was instrumental in engaging students who were initially resistant to environmental topics.

Similarly, the perception of students' environmental identity among teachers is a critical factor influencing the effective implementation of PBL. Teachers who recognize a strong environmental identity in their students are 16.418 times more likely to implement PBL successfully ($p = .002$), as revealed by the binary logistic regression analysis. This discloses the substantial role of teachers' awareness in fostering a supportive, engaging environment where students can connect with real-world environmental issues. FGDs further substantiated these findings. Teachers reported that students with a strong environmental identity were more motivated, actively participated in problem-solving tasks, and demonstrated ownership of projects, particularly on issues related to deforestation and climate change. One teacher noted, "Students aware of environmental problems tend to show more interest and contribute ideas from personal experiences." Conversely, students with underdeveloped environmental identities struggled to see the relevance of PBL tasks, affecting their engagement and collaboration. This observation was further supported by KIIs, which emphasized the role of environmental awareness in shaping student engagement. A school principal 1 noted that students who identified strongly with environmental issues were more likely to take initiative in discussions, lead group activities, and apply classroom knowledge to real-world environmental challenges. Another key informant, education expert 2 highlighted that fostering environmental identity among students could enhance their sense of responsibility, encouraging them to actively participate in conservation-related initiatives both inside and outside the classroom.

In addition, teacher's perception of student motivation and engagement ($B = 1.662$, $p = 0.005$) showed a significant positive association with the effective implementation of PBL, further emphasizing the critical role of student involvement in enhancing PBL outcomes. This finding suggests that motivated and engaged students are pivotal for the success of PBL, especially in contexts involving complex environmental education topics such as deforestation and climate change. Findings from FGDs further support this result. Teachers in the FGDs consistently highlighted that when students exhibit enthusiasm for PBL activities, they are more likely to participate actively in discussions, collaborate effectively in group tasks, and propose innovative solutions to environmental problems. However, the discussions also revealed that a lack of motivation among students can hinder the effectiveness of PBL. Teachers reported instances where students disengaged from environmental discussions, either due to a lack of personal connection to deforestation issues or skepticism about reforestation efforts. KIIs with school administrators and department heads reinforced these observations. Department head 2 explained, "Teachers who perceive their students as motivated and engaged tend to use more interactive and student-centered methods, making PBL more effective. Conversely, when students display resistance or apathy, teachers often struggle to maintain meaningful discussions. Classroom Observations further corroborated these findings. In classrooms where students were visibly engaged—asking questions, actively debating environmental policies, and working collaboratively in problem-solving exercises—teachers were more successful in implementing PBL. In contrast, in classrooms where students disrupted lessons, resisted discussing deforestation as a less important issue, or dismissed climate change concerns, teachers faced significant challenges in sustaining PBL activities.

Similarly, large class size affects effective PBL implementation in deforestation and climate change lessons. The binary logistic regression model indicates a negative relationship, with a coefficient of -1.243 ($p = 0.038$) and an odds ratio of 0.289, suggesting that larger classes substantially reduce the likelihood of successful PBL implementation. Data from our FGDs and KIIs indicate that large class sizes significantly hinder the effective implementation of PBL. Teachers reported that oversized classes reduce teaching quality, complicate assessments, and limit their ability to monitor student progress and provide timely feedback. Compared to smaller classes, where teachers can better facilitate PBL activities through closer supervision and targeted support, larger classes create logistical challenges that diminish the approach's effectiveness. This was further supported by insights from KIIs, where teacher 1 stated, "PBL quality declines when class sizes become unmanageable," emphasizing the negative impact on instructional effectiveness.

Another participant teacher 2 noted, "Tracking and assessing each student's progress accurately is nearly impossible with so many students," highlighting the assessment difficulties posed by large classes. The overwhelming workload restricts the variety of exercises teachers can incorporate and limits their ability to offer personalized feedback, further weakening the student-centered nature of PBL. Classroom observations supported these findings, revealing several critical challenges linked to large class sizes. Observers reported that in all secondary schools of Metekel Zone, class sizes surpassed 50 students per class, making it difficult for teachers to sustain student engagement. As a result, many students remained passive rather than actively participating in PBL activities. The observations highlighted difficulties in group work coordination, as teachers found it challenging to circulate among students and provide individualized guidance. Additionally, students in overcrowded classrooms were observed to receive significantly less direct support from teachers, reducing the effectiveness of inquiry-based discussions.

The logistic regression model also shows that reliance on conventional teaching methods significantly hinders PBL implementation, with a negative coefficient (-1.318), odds ratio of 0.268, and a significant p-value (0.024). Qualitative data from FGDs and KIIs reveal that traditional, teacher-centered approaches persist due to time constraints, lack of institutional support, and syllabus pressure. Teachers acknowledge PBL's benefits but often revert to conventional methods for efficiency in covering large content. Interviews with teachers and school principals highlight the need for training and administrative support to shift to PBL, illustrating that this reliance is a systemic issue, not just teacher resistance. Classroom observations confirmed these findings, as teachers were frequently seen relying on lecture-based instruction rather than facilitating student-centered PBL activities. Observers noted that in most lessons, teachers dominated classroom discussions, with minimal opportunities for students to engage in problem-solving tasks. In several instances, teachers attempted to introduce PBL elements but quickly reverted to traditional methods due to time constraints and pressure to complete the syllabus.

Likewise, the time-intensive nature of PBL emerged as a significant barrier. Logistic regression analysis indicated a negative association ($B = -1.171$, $p = 0.044$), with a 69% decrease in the likelihood of successful implementation ($Exp(B) = 0.310$). FGDs and KIIs revealed that rigid academic schedules, extensive curriculum demands, and inadequate time allocations posed significant obstacles to effective PBL integration. Participants proposed solutions, including "PBL weeks," standardized resources, and policy changes to create flexible teaching schedules, which could mitigate these challenges and enhance PBL’s practical application.

The results of other explanatory variables in this study provide additional insights into geography teachers' performance in implementing PBL for deforestation and climate change lessons. While binary logistic regression analysis indicates that inadequate logistical support had a slight negative impact on PBL implementation (odds ratio = 0.910), this effect was statistically insignificant ($p = 0.878$), suggesting that teachers generally adapt well despite limited resources. However, qualitative data present a contrasting perspective, revealing that inadequate logistical support significantly hinders the effective implementation of PBL. Findings from the FGDs and classroom observations verified that logistical constraints pose a critical obstacle to PBL adoption. Participants expressed frustration over the lack of essential teaching materials, limited access to field-based learning opportunities, and insufficient digital resources. These limitations, they explained, greatly restrict their ability to conduct interactive and experiential learning activities. Consequently, teachers often struggle to integrate PBL effectively and, in many cases, revert to traditional lecture-based methods—not out of preference, but out of necessity. KIIs further reinforced these concerns, with geography teachers emphasizing that the absence of teaching aids and instructional materials severely hampers their ability to facilitate active learning. Teacher 2 noted that, despite the expectation to implement PBL in our school, the lack of essential resources makes it nearly impossible to conduct meaningful, problem-based activities. Likewise, teacher 1 echoed this concern, explaining that in the context of Metekel zone, inadequate logistical support not only weakens instructional effectiveness but also reduces student engagement, ultimately shifting lessons from interactive to passive learning experiences.

Similarly, the traditional assessment system's effect was also insignificant (Exp (B) = 1.024, $p = 0.967$), suggesting conventional assessments don’t hinder PBL adoption in the study region. However, qualitative findings from FGD, KIIs and classroom observation on the contrary, revealed that many teachers felt pressured by traditional assessments, stating that these assessments limit their flexibility in implementing PBL effectively, as they focus more on rote memorization than on critical thinking skills fostered by PBL. Similarly, the logistic regression model analysis suggests that the extensive curriculum content had a minor negative impact on the likelihood of implementing PBL (Exp (B) = 0.681, $p = 0.550$), indicating that teachers are generally able to integrate PBL despite the demands of a content-heavy curriculum.

However, qualitative findings from FGDs and KIIs challenge this conclusion, revealing that the extensive curriculum significantly hinders PBL implementation. FGD participants strongly emphasized that the overwhelming volume of curriculum content leaves little room for student-centered, inquiry-based approaches like PBL. Teachers expressed concerns that they are pressured to cover vast amounts of material within a limited timeframe, forcing them to prioritize content delivery over active learning strategies. Numerous teachers expressed concern that the current educational framework prioritizes content coverage over deep, inquiry-based learning, thereby discouraging the adoption of student-centered pedagogies like PBL. Participants reported feeling pressured to adhere strictly to the curriculum timeline, fearing that allocating time to problem-solving activities might prevent them from completing the required syllabus within the academic calendar. These concerns were further substantiated by insights from the KIIs. For instance, Teacher 3 reflected on the tension between curricular demands and innovative teaching approaches, stating, “We are required to complete the syllabus on time, and if we spend more time on PBL, we risk falling behind. This pressure makes it difficult to implement student-centered approaches.” This quote highlights how time constraints and accountability for curriculum completion compel teachers to rely on traditional lecture-based instruction, which is more efficient for covering extensive content but less effective for fostering critical thinking and real-world problem-solving skills. Similarly, department head 1 emphasized the systemic nature of the challenge, explaining that although many teachers are aware of and support the pedagogical value of PBL, the expansive nature of the curriculum restricts their ability to engage students in meaningful, in-depth exploration of environmental issues such as deforestation and climate change. He noted, “The rigid structure of the curriculum is a significant challenge. Teachers know the benefits of PBL, but with so much content to cover, they simply don’t have the time to facilitate extended discussions or guide students through complex problems.” These findings point to a fundamental misalignment between the goals of PBL and the current curriculum delivery model, suggesting that policy-level reforms may be necessary to create the flexibility required for transformative teaching practices to flourish.

Curriculum alignment showed a non-significant effect (Exp (B) = 0.476, $p = 0.152$), suggesting it is not a critical determinant for PBL implementation in the study area. However, classroom observations indicated that teachers often faced difficulties in seamlessly integrating PBL into their lessons due to rigid curriculum structures. In several observed lessons on deforestation and climate change, teachers attempted to implement PBL but struggled to align activities with standardized content, leading to incomplete or rushed discussions. Additionally, many FGD participants and zonal and district-level experts emphasized that curriculum alignment is essential for effective PBL integration. They argued that without clear alignment, teachers find it challenging to incorporate PBL within the required curriculum structure and goals, ultimately affecting its practical execution in classrooms.

Generally, these findings of this study are generalized and visually synthesized in figure 7.5, which presents an integrated summary of how the various systemic and structural factors as well as teachers' beliefs, practices, and contextualization efforts collectively influence their performance in implementing PBL for deforestation and climate change topics.

Table 7.9: Parameter estimates for levels associated with teachers' implementation of the PBL approach in teaching secondary school geography lessons on deforestation and climate change.

Predictor Variable	**B**	**SE**	**Wald**	**df**	**Sig.**	**Exp (B)**	**95% CI for Exp (B)**	
							Lower	**Upper**
Teacher's level of adaptation of PBL	1.772	0.641	7.643	1	.006	5.883	1.675	20.665
Alignment with curriculum standards	-0.742	0.518	2.056	1	.152	0.476	0.173	1.313
Level of emotional intelligence of teachers	2.027	0.678	8.944	1	.003	7.594	2.011	28.677
Teachers' perception of students' environmental identity	2.798	0.883	10.049	1	.002	16.418	2.910	92.629
The traditional assessment system	0.023	0.574	0.002	1	.967	1.024	0.332	3.155
Large class size	-1.243	0.599	4.298	1	.038	0.289	0.089	0.934
Inadequate logistical support	-0.094	0.613	0.024	1	.878	0.910	0.274	3.024
Extensive content requirements of the	-0.385	0.643	0.358	1	.550	0.681	0.193	2.402

geography curriculum								
Teacher’s perception of student motivation and engagement	1.662	0.594	7.841	1	.005	5.272	1.647	16.879
Reliance on conventional teaching methods	-1.318	0.583	5.114	1	.024	0.268	0.085	0.839
Level of teacher’s content experience	1.620	0.606	7.146	1	.008	5.055	1.541	16.582
Time-intensive nature of PBL	-1.171	0.582	4.050	1	.044	0.310	0.099	0.970
Constant	-3.304	1.029	10.319	1	.001	0.037		
Model Fit Statistics								
Cox & Snell R Square	0.395							
Nagelkerke R Square	0.548							
Classification Accuracy	85.8%							
Hosmer and Lemeshow Test (χ^2 = 25.985, df = 8)	p = .060							
Multicollinearity Diagnostics (All VIFs < 10)	No concern detected							

Source: survey data

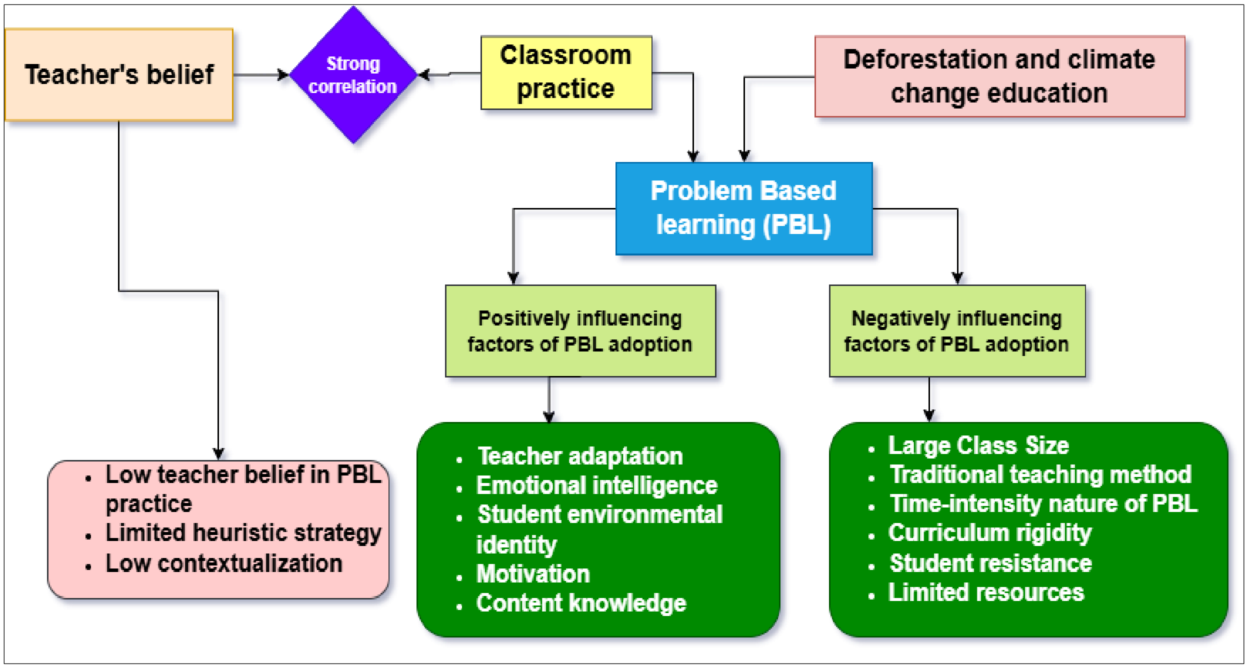


Figure 7.5: Visual Summary of the Influence of Teachers' Beliefs, Practices, Contextualization and the various factors affecting the Implementation of PBL for Deforestation and Climate Change Lessons developed by the author

7.6.Discussion

By focusing on secondary school geography teachers' beliefs, practices, and the factors that shape their teaching performance, this study sheds light on the specific challenges and opportunities teachers face in delivering PBL lessons. These emphases have broader relevance not only for geography but for other fields seeking to enhance teachers' instructional approaches through PBL.

The findings reveal a concerning gap between teachers' theoretical advocacy for PBL and its practical application in the classroom. Although the advantages of PBL in fostering critical thinking and student engagement are well-documented, our study shows that a significant proportion of geography teachers-ranging from, 53% to 61.2% across various descriptors, view themselves as ineffective in implementing problem-based teaching methods. This reflects a predominantly negative perception of PBL among these educators. This reluctance of teachers to adopt PBL due to low belief is not unique to this study. Similar challenges have been reported, in various settings. Darling-Hammond et al. (2020) argue that inadequate support, training, and resources often leave teachers unprepared for implementing PBL approach. In our study, teachers slightly expressed a willingness to engage students through PBL but faced challenges such as insufficient professional development, limited access to PBL materials, and the pressure of covering extensive curricula within limited time frames. These challenges are also echoed globally, particularly in low-resource and rural contexts. For instance, in South African rural schools, teachers' pedagogical beliefs and the lack of institutional support have been identified as significant barriers to adopting such methodologies (Ramnarain & Hlatswayo, 2018)**.**

We surveyed geography teachers about their beliefs on using heuristic approaches to teach deforestation and climate change in secondary schools, revealing mixed responses. Between 58% and 61% of teachers across all descriptors reported not employing heuristic methods, while the remainder either used them or remained neutral. The low adoption of strategies such as future planning, problem-solving, and student-centered instruction reflects reluctance to embrace approaches critical for tackling environmental challenges. This aligns with prior studies, such as (Hmelo-Silver, 2004; Yadav et al., 2021), which emphasize the effectiveness of heuristic methods in fostering critical thinking but note a gap between recognition and practical application.

Contextualizing the content is essential for making education more relevant, and a means to facilitate student learning (Rivet & Krajcik, 2008). Teachers' beliefs play a crucial role in this process, as their commitment to linking classroom content to real-world issues can significantly enhance students' understanding and engagement (Stipek et al., 2001; Zheng, 2013). However, the current study reveals a significant gap, with only 23.9% of teachers reporting efforts to contextualize deforestation and climate change topics, while 74.3% did not. This finding contrasts with (Fernandes et al., 2013), who argue that placing content within relevant frameworks enhances its significance, promoting a deeper, more impactful learning experience.

Examining the connection between teachers’ beliefs about implementing PBL and their actual classroom practices was the other focus of this investigation. Pearson correlation analysis of 134 teachers revealed a strong positive correlation ($r=.726$, $p<.01$), indicating that more positive beliefs about PBL are significantly associated with increased implementation of PBL practices in the classroom. This aligns with prior studies emphasizing the role of teacher beliefs in shaping instructional practices. For instance, research by Akdemi & Özçelik (2019) highlighted that positive teacher attitudes significantly predict the successful integration of student-centered approaches such as PBL. Similarly, Fullan et al. (2014) argued that fostering constructive teacher mindsets is essential for bridging the gap between pedagogical theory and classroom implementation.

The examination also confirms how teacher-related factors affect the implementation of PBL in geography lessons on deforestation and climate change. Our findings revealed that full adaptation to PBL is a key predictor of successful implementation, with adapted teachers more likely to succeed. These findings align with previous research by Pecore (2012) and Tawfik et al. (2021), which show that fully adapted teachers are more effective in engaging students and fostering problem-solving skills. In relation to content experience as a teacher-related factor in implementing PBL, the results confirms that teachers with higher content experience were more likely to implement PBL effectively compared to their counterparts with low content experience. These findings align with empirical studies that emphasize the importance of robust content knowledge for effective pedagogical practices. For instance, Kleickmann et al. (2013) demonstrate that strong content knowledge enhances pedagogical content knowledge, fostering effective teaching strategies. Our findings also indicate that emotional intelligence (EI) has a significant impact on PBL success. This aligns with Brackett et al. (2012), who found that teachers with higher EI are more adept at managing classroom dynamics, meeting students' emotional needs, and promoting collaboration.

The investigation also emphasizes the critical role of teachers' perceptions of students' environmental identities in enhancing PBL effectiveness. Teachers who view students as having a strong environmental identity are notably more successful in applying PBL, as they foster a learning environment that aligns with students' environmental interests and promotes active engagement. Previous research corroborates this relationship, suggesting that an environmental identity fosters meaningful connections to real-world issues (Dresner et al., 2015; Heimlich & Ardoin, 2008).

Regarding teachers' perceptions of student motivation and engagement we found that this variable plays a pivotal role in the successful adoption of PBL for secondary school geography, especially concerning deforestation and climate change. This aligns with previous research, which shows that when teachers perceive students as motivated, they are more inclined to implement interactive methods like PBL, creating opportunities for deeper student engagement in environmental topics (Van Uden et al., 2013).

The study reveals that large class size significantly hinders the implementation of PBL in deforestation and climate change lessons. The model shows that increasing class size substantially decreases the chances of effective PBL implementation. This aligns with Mulryan-Kyne (2010), who notes that larger classes restrict individualized interaction, undermining student-centered approaches like PBL. Our findings from qualitative data also verified that as teachers expressed difficulties in providing timely feedback and assessing individual progress in classes averaging over 75 students. Whisenhunt et al. (2019) indicated that while strategies such as group work can enhance engagement in student centered learning; they often require significant resources, which may not be available.

The study demonstrates a strong negative association between reliance on conventional teaching methods and the successful implementation of PBL in deforestation and climate change lessons in secondary school geography. The findings suggest that traditional, teacher-centered methods inhibit PBL, which relies on student-centered, interactive learning. This aligns with findings from (Akınoğlu & Tandoğan, 2007; Mulryan-Kyne, 2010), who indicate that conventional methods limit active learning and student engagement, crucial to PBL's effectiveness**.** In many low-resource and rural contexts globally, including parts of Sub-Saharan Africa, Southeast Asia, and Latin America, conventional teaching methods remain dominant due to limited access to ongoing professional development, inadequate teacher preparation, and lack of resources—challenges well documented by (Westbrook et al., 2013)**.** This study's findings suggest a need for professional development programs to encourage more student-centered methods, particularly in resource-limited settings aligning with (Lawrence, 2022).

This research confirms that the time-intensive nature of PBL significantly limits its use in teaching environmental issues such as deforestation and climate change in secondary school geography classes. Quantitative analysis reveals a strong negative impact on PBL's success ($B = -1.171$, $p = 0.044$), reducing the likelihood of effective implementation by 69%. This aligns with (Swanwick, 2010), who noted that PBL's extensive time demands often challenge traditional, time-constrained curricula.

The present investigation enriches the existing literature by evaluating the beliefs, practices, and the diverse structural and systemic factors influencing geography teachers' performance in implementing PBL specifically for deforestation and climate change lessons. Furthermore, it offers key insights for stakeholders in education and environmental management by emphasizing the need for targeted training programs for geography teachers to enhance PBL in addressing deforestation and climate change. In addition, policymakers can leverage these findings to shape initiatives that improve teachers' PBL proficiency, while educational administrators can design professional development that equips teachers with effective strategies. Moreover, curriculum developers can incorporate real-world environmental contexts to increase student engagement and critical thinking.

A significant empirical implication of our findings is that targeted training and support programs focused on enhancing geography teachers' PBL proficiency can greatly improve its application in deforestation and climate change lessons. By doing so, equipping teachers with skills to adapt PBL within large class sizes and resource constraints, and emphasizing emotional intelligence, student-centered methods, and real-world contexts, these programs address key challenges. Thus, ongoing professional development that combines content expertise with collaborative problem-solving skills could empower teachers to foster critical thinking, engagement, and environmental awareness more effectively via workshops, mentorship, and access to digital resources.

This study acknowledges several limitations that may affect its findings. First, the absence of longitudinal data restricts insights into how geography teachers' beliefs and practices regarding PBL evolve over time. Future research could benefit from longitudinal studies that track changes in teachers’ instructional behaviors and students’ responses to PBL approaches over extended periods, particularly regarding environmental attitudes and behaviors. Besides, while teacher beliefs and various structural and systemic factors are emphasized, some structural elements of the curriculum, such as the presence of dedicated courses, clarity of syllabus and learning outcomes, and appropriateness of teaching strategies, remain unexplored. Additionally, the effectiveness of enforcement mechanisms to ensure curriculum implementation has not been examined. Finally, focusing solely on geography teachers may overlook the perspectives of other stakeholders, such as students, which are crucial for understanding PBL effectiveness. Future research should also consider mixed-method designs involving student voices and school leaders to offer a more holistic understanding of the conditions under which PBL can be effectively implemented. Moreover, cross-regional comparative studies across rural and urban schools or low-resource contexts could provide insights into context-specific barriers and facilitators for PBL integration. Therefore, addressing these limitations through broader and more comprehensive research approaches could enhance the understanding of factors affecting PBL in geography education related to deforestation and climate change.

This study is particularly relevant to several key organizations dedicated to education and environmental sustainability. First, UNESCO focuses on promoting education for sustainable development, making it a vital stakeholder in enhancing teaching practices related to environmental issues. Second, the United Nations Environment Programme (UNEP) emphasizes the importance of integrating environmental education into curricula, aligning with this study's goal of improving geography teachers' competencies in addressing deforestation and climate change. Lastly, the Ethiopian Ministry of Education plays a crucial role in implementing educational policies that incorporate environmental education, thereby ensuring that the insights from this study can inform national strategies and teacher training programs effectively. Together, these organizations can leverage the findings to foster more effective environmental education initiatives.

7.7.Conclusion

This study explored the beliefs, practices, performance, and challenges faced by secondary school geography teachers in implementing PBL for deforestation and climate change education. Findings revealed a notable gap between teachers’ support for PBL and its practical application, with low belief levels and inconsistent practices. Statistical analysis showed significant deviations from expected PBL standards, particularly in promoting inquiry, problem-solving, and real-life contextualization.

Despite this, a strong positive correlation was found between teachers’ beliefs in PBL and its classroom implementation. Key determinants of effective PBL included teachers' adaptation to the method, content expertise, emotional intelligence, and perceptions of students' environmental identity. However, systemic barriers—such as large class sizes, traditional methods, rigid curricula, and time constraints—hindered PBL use.

To address these challenges, the study recommends implementing professional development programs aimed at enhancing teachers' content expertise, emotional intelligence, and student-centred teaching strategies. These programs should incorporate practical workshops, mentorship opportunities, and access to digital and other instructional resources to support teachers in integrating real-world environmental issues such as deforestation and climate change into PBL lessons. Specifically, the training should include localized environmental case study workshops, region-specific inquiry-based learning modules, and scenario-based PBL simulations focused on deforestation and climate change. These programs should be continuous, context-sensitive, and supported through school-based mentorship schemes and peer-learning communities.

Policymakers and educational administrators are encouraged to integrate these findings into strategic frameworks by establishing national and regional PBL implementation taskforces, allocating specific funding for environmental education training, and revising teacher education curricula to include practical PBL methodology modules. Curriculum developers should ensure that the geography curriculum embeds locally relevant environmental content that lends itself to problem-based inquiry and cross-disciplinary learning.

In conclusion, this study makes a significant contribution to the growing body of literature on PBL and environmental education. By addressing the identified challenges and supporting teachers in adapting PBL to their unique classroom contexts, the study advocates for a transformative approach to teaching critical environmental issues connected to deforestation and climate change. Additionally, it confirms the global relevance of integrating PBL into environmental education with particular focus on deforestation and climate change, given the universal implications of these gravest environmental concerns. The adoption of PBL has the potential to equip students worldwide with the skills, knowledge, and ethical responsibility needed to tackle these challenges. By and large, this research demonstrates the necessity of fostering a generation of problem-solvers capable of addressing critical environmental issues, reinforcing the global applicability of PBL in bridging local classroom practices with global environmental solutions.

CHAPTER EIGHT

8. Synthesis

8.1.Overview

This chapter synthesizes the key findings of the study, bringing together the spatiotemporal forest cover, climatic, curricular, pedagogical, and learner-based dimensions into a coherent framework that illustrates how environmental sustainability education can be strengthened through evidence-based, action-oriented approaches. The synthesis integrates the ecological realities of deforestation and climate variability with curriculum content, teachers' pedagogical practices, and students' environmental orientations, thereby highlighting the interdependence between environmental research and educational transformation. At its core, this synthesis situates environmental degradation not merely as an ecological issue but as a pedagogical challenge requiring new forms of learning that cultivate critical thinking, systems awareness, and participatory responsibility among learners. By interlinking the natural and educational subsystems, the chapter reveals how the degradation of forest ecosystems and climatic instability can be counteracted through education that nurtures both knowledge and action competence.

8.2.Integrating Ecological Evidence with Educational Practice

The spatiotemporal analysis revealed a substantial decline in forest cover in the Metekel Zone, decreasing from 51.37% in 1986 to 17.20% in 2019, primarily as a result of agricultural expansion, resettlement, fuelwood extraction, and charcoal production. Concurrently, rainfall exhibited a downward trend of 5.32 mm per decade, while maximum and minimum temperatures increased by 0.33°C and 0.31°C per decade respectively. These changes directly reduced crop productivity and threatened local livelihoods. This progressive decline of forest resources, together with climatic variability, signals a shift from ecological stability to vulnerability, creating an urgent need for environmental literacy that connects scientific evidence with local realities. The study thereby underscores that ecological data are not only indicators of environmental change but also instructional resources capable of deepening students' understanding of the complex interdependencies between human behavior, land use, and climate systems.

This ecological evidence serves as an empirical foundation for environmental education. When integrated into classroom instruction, it provides students with tangible, place-based data that deepen understanding of the complex interactions between land use, climate systems, and human activity. Embedding local environmental evidence within pedagogy transforms abstract concepts into experiential learning opportunities, fostering students' ability to interpret maps, analyze environmental trends, and relate them to community livelihoods. Such integration strengthens the epistemic bridge between geography as a science and geography as a means of cultivating environmental citizenship.

8.3.Curriculum Integration: Gaps and Opportunities

Analysis of the secondary school geography curriculum indicated moderate emphasis on climate change but limited treatment of deforestation. Only 3.85% of the total MLCs and 3.2% of total topics directly addressed deforestation, whereas climate change received approximately 18% coverage. The majority of the learning objectives focused on the cognitive domain (60.8%), with far less attention to affective (27.5%) and psychomotor domains (12.5%). This imbalance reflects an epistemological orientation that privileges knowledge acquisition over behavioral transformation, implying that while students may learn about environmental issues, they are not adequately supported to develop the values and skills necessary for stewardship.

This imbalance suggests that the curriculum remains largely theoretical, privileging factual recall over value formation and practical engagement. Moreover, thematic coverage lacks continuity across grade levels, reducing opportunities for cumulative learning and action competence. The absence of vertical coherence weakens the progression of environmental concepts from basic understanding to applied problem-solving. Likewise, the curriculum's centralized and uniform design neglects local ecological variations, making it difficult for teachers to contextualize lessons within the realities of specific regions such as Metekel. This top-down design results in a detachment between national curriculum intent and the lived experiences of learners.

8.4.Student Environmental Knowledge, Attitudes, and Determinants

Student surveys revealed generally low environmental knowledge and unfavorable attitudes toward deforestation and climate change, with only 18.5% demonstrating high knowledge and 32.8% showing positive attitudes, while over half scored low in both areas. Binary logistic regression identified factors such as age, gender, residence, parental education, and family income, access to environmental information, grade level, and participation in environmental clubs as significant determinants. The results indicate that socio-demographic and informational factors strongly shape students' environmental orientations, reflecting the influence of social capital, access to information, and opportunities for participation. Learners involved in environmental clubs and exposed to more information exhibited higher knowledge and positive attitudes, underscoring the value of experiential and participatory learning. When related to the spatiotemporal evidence of extensive deforestation, rising temperatures, and declining rainfall in the Metekel Zone, these findings reveal a critical gap between environmental realities and students' understanding. Thus, improving student outcomes requires not only curriculum reform but also expanded access to informal learning spaces and school–community engagement platforms that transform students from passive recipients of information into active contributors to environmental solutions.

8.5. Teachers' Practices and the Implementation of Problem-Based Learning

Findings from surveys and classroom observations indicate that geography teachers generally value PBL, yet only 24–29% actively implement inquiry-based or real-world problem-solving strategies. While factors such as teachers' adaptation to PBL, emotional intelligence, motivation, and awareness of students' environmental identity support implementation, constraints including large class sizes, traditional teaching methods, and time limitations impede progress. This gap is particularly significant in light of spatiotemporal evidence from the Metekel Zone, showing notable deforestation, rising temperatures, and declining rainfall. Such localized environmental data provide rich opportunities for problem-oriented learning. Enhancing teacher capacity through professional development that combines geospatial evidence with adaptive and reflective pedagogy can enable educators to link scientific realities with critical thinking, transforming geography education into an action-oriented tool for understanding and addressing environmental change.

8.6. The Interconnected Framework of Ecological and Educational Dimensions

The integration of findings across the study's dimensions highlights a cyclical relationship between environmental realities and educational processes. This dynamic operates within a socio-ecological feedback system, wherein environmental degradation generates the need for educational reform, and the quality of education determines the society's capacity to respond to that degradation.

Ecological evidence, such as patterns of deforestation and climate variability, defines the broader environmental context that calls for an educational response. This context is then translated into structured learning objectives through the curriculum, which serves as the formal bridge between environmental realities and classroom instruction. The effective delivery of these curricular objectives depends on teachers' pedagogical practices, as they interpret and implement the content through their chosen teaching approaches. In turn, students' environmental knowledge and attitudes emerge as reflections of both the curriculum and pedagogy, shaping their future behaviors and engagement within their communities. This cyclical framework aligns with the DPSIR model, situating education as the "Response" mechanism that mediates between scientific understanding and societal adaptation. At the same time, the Theory of Planned Behavior (TPB) provides a behavioral lens through which to interpret how environmental knowledge, attitudes, and perceived behavioral control translate into sustainable actions. Together, these frameworks illustrate that sustainability education functions as both a cognitive and behavioral process—one that is responsive to ecological evidence and driven by human agency. Hence, education becomes both a reflection of and a response to environmental change, enabling individuals and communities to co-create solutions grounded in scientific understanding and collective responsibility.

8.7.Toward Action-Oriented Environmental Sustainability Education

The synthesis demonstrates that effective environmental sustainability education must move beyond information transmission toward participatory, evidence-based, and locally grounded learning. The study establishes that integrating spatiotemporal data with Problem-Based Learning fosters the development of action competence—the ability of learners to investigate issues, analyzes causal relationships, and implements contextually appropriate solutions. Such education equips learners not only to comprehend the causes and effects of environmental degradation but also to envision and enact alternative futures. It empowers them to act as change agents capable of addressing local manifestations of global environmental challenges.

For geography education in Ethiopia, this implies incorrating adequate content with proper pedagies and designing curricular modules that incorporate real environmental data (e.g., forest cover maps, rainfall trends), field-based inquiry activities, and collaborative problem-solving projects linking schools with community initiatives. These strategies enhance place-based learning, encourage interdisciplinary thinking, and cultivate civic responsibility. Integrating local datasets and participatory learning projects also aligns education with Ethiopia's broader sustainability agendas, ensuring that classroom learning contributes directly to community adaptation and conservation efforts. Such integration would ensure that students not only understand environmental change intellectually but also develop the skills, attitudes, and agency to act upon it. Through this approach, geography classrooms become laboratories of sustainability where learners develop the competence, confidence, and creativity required for environmental stewardship.

CHAPTER NINE

9. General Conclusion and Recommendations

9.1.General Conclusions

Ethiopia faces severe environmental challenges, notably rapid deforestation and increasing climate variability, threatening ecosystems, livelihoods, and sustainable development. The Metekel Zone is particularly affected, yet it has received limited research attention and remains underrepresented in educational curricula and policy responses. The absence of context-specific empirical evidence coupled with curricular and pedagogical gaps constrains secondary school geography education from fostering environmental understanding, shaping attitudes, and enhancing students' capacity for meaningful action.

This interdisciplinary study demonstrates that the biophysical dynamics of deforestation and climate variability in Metekel are closely linked to educational gaps, creating a cycle that both accelerates environmental degradation and weakens youth adaptation and sustainable resource management. Integrating locally grounded evidence into the curriculum provides pathways for action-oriented pedagogy, enabling students to connect classroom learning with real-world environmental challenges.

Remote-sensing analyses revealed profound spatiotemporal dynamics in land use and land cover during the last three decades. Forest cover declined dramatically from over half of the area in 1986 to less than one-fifth by 2019, reflecting sustained, accelerating loss rather than temporary fluctuations. Agricultural expansion, fuelwood and charcoal demand, resettlement programs, and weak governance were proximate drivers, while demographic pressure, insecure tenure, and market incentives acted as underlying causes. Low ecological awareness among local communities further compounded the trend. Forest loss impacts carbon sequestration, biodiversity, watershed stability, and infrastructure, linking local land-use practices to regional ecosystem functions and national development goals. These dynamics highlight the critical need for curricula that enable students to interpret environmental trends, examine drivers, and explore sustainable alternatives.

Shifts in other land categories such as shrubland, grassland, settlements, and apparent increases in waterbodies indicate widespread landscape restructuring. Degraded forests are transitioning into less resilient forms, while settlement expansion reflects demographic and urban pressures. Although initiatives such as Ethiopia's Green Legacy Program and community-driven conservation exist, their scale is insufficient. Embedding these initiatives in school curricula can enhance student engagement and broaden community impact.

Climate variability in Metekel is persistent and intensifying, with rising minimum and maximum temperatures and declining rainfall, unevenly distributed across districts. Agriculture is particularly vulnerable: some crops benefit from warming, but maize and other sensitive staples suffer from extreme temperatures and erratic rainfall, threatening food security. Socio-ecological pressures, including soil degradation, population growth, resettlement, weak governance, and institutional limitations, amplify these vulnerabilities. Incorporating livelihood-linked climate impacts into geography teaching helps students understand the direct connections between environmental change and human well-being.

Communities demonstrate adaptive potential through crop diversification, drought-tolerant varieties, and soil conservation, but efforts are fragmented and under-supported. Integrating these adaptive practices into curricula offers concrete examples of resilience, enhancing action competence and inspiring school-based environmental initiatives.

The study also revealed that Ethiopia's secondary school geography curriculum integrates deforestation and climate change unevenly. Deforestation is often minimally covered and omitted entirely in grade 12, while climate change receives limited progression across grades. The curriculum emphasizes cognitive knowledge over affective or action-oriented domains, and learning activities primarily prioritize knowledge recall rather than participatory, solution-oriented engagement. Progressive pedagogies, such as PBL, Inquiry-Based Learning (IBL), experiential approaches, ICT-supported methods, and community-linked projects, are inconsistently applied, with teacher-centered approaches dominating due to structural, resource, and training limitations.

Analysis of teachers' practices in implementing PBL for deforestation and climate change confirmed this gap. Teachers conceptually recognize PBL's value but rarely apply it effectively. Classroom practices are constrained by rigid curricula, large classes, limited resources, and traditional assessments. Teacher beliefs strongly influence practice: those with stronger PBL beliefs were more likely to adopt innovative strategies. Student factors, including environmental identity and motivation, also facilitate PBL adoption. However, systemic barriers including time-intensive preparation, extensive content demands, and inadequate resources limit translation of content into experiential learning opportunities.

In addition to teacher-related constraints, the study's student-focused findings revealed that secondary school learners exhibit low knowledge and negative attitudes toward deforestation and climate change. Many students scored below expected knowledge thresholds, and demographic and contextual factors such as age, gender, residence, parental education, social norms, and access to information, grade level, and participation in environmental clubs were significant predictors of their knowledge and attitudes. Limited environmental relevance in the curriculum, fragmented learning resources, and weak emotional or personal connection to local environmental issues further restricted students' ability to engage meaningfully with deforestation and climate change concepts.

The results highlight a paradox: while national education policy promotes problem-solving and practical engagement, classroom realities remain dominated by traditional methods. This disconnect is particularly concerning given the accelerating environmental degradation in Metekel. The gap between policy intent and classroom practice underscores institutional and pedagogical shortcomings, leaving students underprepared to analyze and respond to pressing local environmental crises.

9.2.Recommendations

The study revealed that the environmental and educational challenges in the Metekel Zone are deeply interconnected. Forest degradation and climate variability are intensifying, while the secondary school geography curriculum, student preparedness, and teacher practices remain insufficient to address these realities. Thus, recommendations are made in line with the objectives of the study, merging the key findings with the corresponding actions required.

- The study showed a major decline in forest cover in the Metekel Zone, dropping from over half the area in 1986 to less than one-fifth by 2019, driven by agricultural expansion, firewood harvesting, charcoal production, and large-scale investments, with significant ecological and socio-economic consequences. To reverse this trend, local and regional governments should enforce policies, engage communities in conservation through awareness, education, and community-based forest management, and incorporate remote-sensing data into secondary school geography lessons to foster student involvement in local deforestation analysis. Expanding afforestation and reforestation programs, especially through schools and youth clubs, alongside agroforestry and sustainable agriculture, is vital to restore degraded areas while maintaining food security. Promoting alternative livelihoods such as beekeeping, eco-tourism, and non-timber forest enterprises, coupled with renewable energy adoption, can reduce pressure on forests. Finally, continuous geospatial monitoring and integrating forest conservation into broader development plans are essential to safeguard both ecological integrity and community resilience in the Metekel Zone.

- The study shows that climate variability in the Metekel Zone, characterized by rising temperatures, erratic rainfall, and extreme events, poses serious risks to agriculture, food security, and livelihoods. Irregular rainfall and higher temperatures disrupt planting, reduce soil moisture, and alter crop cycles, lowering yields of maize, teff, and sorghum. These challenges are further intensified by population growth, deforestation, overgrazing, and unsustainable land use. In response, promotion of climate-resilient agriculture is urgent, including the adoption of drought-tolerant varieties, improved soil and water conservation techniques, agroforestry, small-scale irrigation, and crop rotation strategies. Adaptation strategies must be locally tailored, informed by spatiotemporal climate evidence, and supported through agricultural extension services. Schools should integrate these climate data and adaptation practices into the geography curriculum, expand access to climate information, including early warning systems and school-based climate literacy equipping students to interpret local climate shifts and design community-based solutions. Institutional support such as linking farmers, schools, and local governance is also critical to sustain adaptive capacity and build resilience to long-term climatic stress.
- The curriculum review demonstrates that while climate change is progressively integrated into the Ethiopian secondary school geography curriculum, deforestation remains underrepresented and eventually excluded by the final grade. Moreover, across all grade levels, the curriculum places disproportionate emphasis on cognitive knowledge, with minimal attention to affective and psychomotor domains. Similarly, action-oriented

competencies, practical learning activities, and innovative teaching strategies are inconsistently applied, limiting the potential of action-oriented environmental education to translate into meaningful engagement and action. To address these gaps, the curriculum requires revision to ensure systematic and progressive coverage of both deforestation and climate change across grade levels. Curriculum developers should embed affective, behavioral, and action-oriented domains alongside cognitive learning. Locally grounded case studies such as deforestation and climate variability in Metekel Zone should be used as teaching examples, supported by maps, satellite images, and datasets. Textbooks should integrate experiential and project-based tasks, encouraging inquiry, problem-solving, and school–community projects. Linking curriculum content with Ethiopia's national strategies such as CRGE and the Green Legacy Initiative will further strengthen alignment between education and policy. Ultimately, the Ministry of Education and curriculum developers bear the primary responsibility for addressing these gaps and ensuring that curriculum reforms translate into meaningful learning and action.

- The assessment showed that most students scored below acceptable levels in environmental knowledge and held weak attitudes toward stewardship. These gaps stemmed from socio-demographic factors, limited access to information, weak curriculum, resource shortages, and low personal agency. To address this, schools and teachers should strengthen environmental clubs, integrate practical activities, and expand access to reliable information through media clubs and community organizations. NGOs and local leaders can support disadvantaged groups, particularly rural students and those from lower-income or less-educated families, by ensuring equitable access to resources, opportunities for peer learning, and mentorship programs. Families and communities should actively engage in awareness programs, while policymakers must provide sufficient instructional time, contextualized curricula, and inclusive extracurriculars. Ministry of education, Regional Education bureau and teacher-training institutions should promote localized, experiential learning and train teachers accordingly. Finally, long-term success depends on partnerships among NGOs, media, and local government at *kebele* level to build environmentally conscious students ready to support climate action and forest conservation.

- Findings revealed a significant gap between teachers' support for PBL and its classroom implementation, marked by low belief levels, inconsistent practices, and limited inquiry, problem-solving, and real-life contextualization. While teachers' beliefs positively influenced PBL use, effective implementation depended on content expertise, emotional intelligence, and responsiveness to student needs. Systemic barriers such as large class sizes, rigid curricula, traditional methods, and time constraints further limited adoption. To address these challenges, the study recommends targeted professional development led by the Ministry of Education, regional bureaus, teacher training institutions, schools, and NGOs, focusing on content knowledge, pedagogical skills, and emotional intelligence through workshops, case studies, mentorship, and peer-learning communities. Curriculum developers should integrate locally relevant environmental content, while policymakers should establish PBL taskforces, allocate funding, revise teacher education curricula, and support alternative assessments. Coordinated action among teachers, schools, and policymakers is essential to strengthen PBL adoption and enhance students' engagement with real-world environmental issues.

9.3.Contributions of the study and future Research areas

This study makes several important contributions at the intersection of environmental change research and environmental sustainability education. Empirically, it provides one of the first integrated spatiotemporal assessments of deforestation and climate variability in the Metekel Zone, combining Landsat imagery and climate datasets across more than three decades to reveal localized evidence of forest loss, rainfall variability, and rising temperatures. This long-term analysis offers valuable insights into how biophysical change undermines forest cover, agricultural productivity, food security, and rural livelihoods, thereby adding region-specific knowledge to the broader literature on climate–livelihood interactions in Ethiopia. Educationally, the study contributes a systematic evaluation of how deforestation and climate change are represented in the Ethiopian secondary school geography curriculum, textbooks, and teaching practices. It demonstrates the imbalance in curricular emphasis, the dominance of cognitive knowledge over attitudinal and action-oriented learning, and the marginalization of deforestation content by the final grade level. By triangulating curriculum analysis with teacher and student surveys, the study generates new empirical evidence on student knowledge gaps, attitudinal challenges, and the determinants that shape environmental orientations. It also enriches the literature by documenting geography teachers' beliefs and practices regarding PBL, witnessing the tension between recognition of its value and limited classroom application due to structural, resource, and assessment constraints. Methodologically, the study advances a mixed-methods framework that integrates biophysical analysis with pedagogical evaluation, demonstrating the value of interdisciplinary research in linking ecological evidence to curriculum reform and classroom innovation. Practically, the findings provide actionable recommendations for curriculum developers, teacher training institutions, and policymakers to enhance environmental sustainability education in Ethiopia.

While this dissertation makes significant contributions, it also identifies areas that warrant further investigation. Future studies should employ higher-resolution satellite imagery, such as Sentinel-2, and advanced machine learning techniques to improve spatial accuracy in detecting forest cover change and to better link ecological processes to livelihood outcomes. Longitudinal educational research is also needed to track how teachers' PBL practices and students' environmental knowledge, attitudes, and behaviors evolve over time, thereby offering a dynamic understanding of pedagogical change and learning outcomes. Beyond geography teachers, research should include other subject teachers and school leaders to provide a more holistic perspective on barriers and enablers of sustainability education. Comparative studies across regions, between rural and urban schools, or between resource-rich and resource-constrained contexts could further illuminate context-specific challenges and best practices for integrating PBL and environmental content. In addition, future inquiry should examine curriculum enforcement mechanisms and institutional supports to assess how policy intentions are translated into classroom realities, while also exploring the role of community participation, local environmental knowledge, and indigenous practices in enriching the cultural relevance of curriculum reform. Finally, interdisciplinary research linking education with broader policy and community-based interventions such as reforestation programs, sustainable land management initiatives, and resilience-building strategies would provide a fuller picture of how education can act both as a driver and a mediator of sustainability.

Babilography

Tamiru Toga Wahelo is an Ethiopian educator, researcher, and academic specializing in Geography and Environmental science and Education. He was born on April 8, 1990, in Durame Town, Kambata Tembaro Zone, Ethiopia. He received his Bachelor of Education (B.Ed.) degree in Geography and Environmental Studies from Jimma University in September 2007. Building upon this foundation, he pursued his Master's degree in Socio-Economic Geography at the Department of Geography and Environmental Studies, Bahir Dar University, and successfully completed it in July 2012. Currently, he is pursuing a Doctor of Education (DED) in Geography and Environmental Education at Bahir Dar University, where he has been engaged in advanced research since April 2019.

Following his undergraduate studies, Tamiru began his professional career as a Geography Teacher in the secondary schools of Metekel Zone, Ethiopia, serving from 2007 to 2012. During this period, he demonstrated exceptional commitment to teaching and mentoring students in geography and environmental studies. Earlier in his career, Tamiru also served as a School Director in Pawe District from 2002 to 2003, where he was responsible for the academic administration and overall leadership of the school. In this capacity, he promoted effective school management, strengthened teacher–student relationships, and worked to enhance the quality of education within his community.

Alongside his instructional duties, he also served as the Head of the District Teacher Association in Pawe District, where he played a pivotal role in promoting teacher collaboration, professional development, and quality instruction across schools.

Tamiru's outstanding contribution to geography education was nationally recognized when he received the Hero Educator Award for distinguished service in preparatory secondary school geography instruction. This prestigious award was jointly presented by the Ethiopian Ministry of Education and New Generation University College in recognition of his excellence in teaching, innovation in pedagogy, and dedication to student learning.

In 2014, Tamiru joined the Department of Social Sciences at Gilgel Beles College of Teacher Education as a Lecturer, where he taught courses related to geography and environmental education. His exemplary performance in teaching, research, and academic leadership led to his promotion to the rank of Assistant Professor in Socio-Economic Geography, recognizing his distinguished scholarly and professional contributions. During his tenure, he also served as Head of the Department of Social Sciences, providing visionary leadership, coordinating academic programs, mentoring junior staff, and fostering a culture of inquiry-based and research-oriented teaching.

Between 2013 and 2016, Tamiru extended his contribution beyond the classroom by serving as the Chairperson of the Committee for the Pawe Kale Hiwot Youth and Children Development Project (ET-176). In this leadership role, he coordinated youth and children's development initiatives that aimed to enhance educational access, social empowerment, and community participation. His efforts in this project reflected his dedication to linking education with community-driven development.

Tamiru has actively contributed to the academic and research community through scholarly publications and conference presentations. He has published research papers in reputable academic journals and presented his work at various national conferences, including those organized by Debre Markos University, Bahir Dar University, and Gilgel Beles College of Teacher Education. His research interests focus on environmental sustainability education, spatiotemporal analysis of deforestation and climate variability, PBL in geography education, and curriculum innovation for contextual and action-oriented pedagogy.

Through his extensive experience as a teacher, lecturer, researcher, and educational leader, Tamiru Toga Wahelo has demonstrated a deep commitment to advancing environmental awareness and pedagogical excellence in Ethiopia. His professional journey reflects a consistent dedication to integrating environmental science with education to foster critical thinking, problem-solving, and sustainable learning among students.

Tamiru can be reached at togatamiru@gmail.com

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Appendix 1: FGD and KII discussion Theme and points for spatiotemporal trends and drivers of forest cover change

Theme/Discussion Point	Main Issues Explored	Description	Relevant Questions/Topics Discussed
Causes of Deforestation	Agricultural expansion, illegal logging, charcoal production, population growth	Examines the drivers behind deforestation, focusing on human activities and socioeconomic factors	What are the primary causes of deforestation in your area?
Consequences of Deforestation	Soil degradation, loss of biodiversity, changes in microclimate, water scarcity	Focuses on the impact of deforestation on the environment and community livelihoods	What environmental changes have you noticed due to deforestation?
Mitigation Measures	Reforestation efforts, community-based forest management, policy enforcement	Identifies existing and potential strategies for addressing deforestation and promoting conservation	What actions have been taken to mitigate deforestation?
Community Perception of Forest Change	-Participants' understanding and observations of changes in forest cover over time Awareness, attitudes, and beliefs about forest conservation and sustainability	Explores the community's understanding of forest cover change and their role in conservation efforts	How have you observed the forest cover in your area changing over the past years?
Historical and Cultural Context	Traditional practices, changes over time, intergenerational knowledge	Provides a historical perspective on how forest management practices and perceptions have evolved	How have traditional practices influenced forest cover over time?
Recommendations for Forest Management	Suggestions from participants on improving forest management and conservation efforts	provides suggestions from participants on improving forest management and conservation efforts	What do you think should be done to improve forest conservation in your

			area?
Challenges in Forest Conservation	Obstacles faced by the community in forest conservation efforts	Identify obstacles faced by the community in forest conservation efforts	What challenges do you face in conserving the forest?

Appendix 2: FGD and KII discussion theme for effective qualitative data collection for spatiotemporal climate variability and its impact on local community livelihoods

Theme/Discussion Point	Main Issues Explored	Description
Theme 1: Causes of Climate Change Over Time (Causal Factors)	Changes in farming practices (e.g., overgrazing, monocropping, deforestation for agriculture, intensive tillage, shifting agriculture)	This explores whether activities such as overgrazing, monocropping, deforestation for agriculture, intensive tillage, and shifting agriculture have contributed to climate variability or land degradation.
	Long-term climate change trends (gradual build-up or recent phenomenon)	Investigates whether climate change is seen as a recent phenomenon or a gradual shift over time, focusing on the long-term factors (e.g., human activities, industrialization, and land use change) that might explain its impact on crop yields and overall agricultural productivity.
	Changes in natural vegetation or land cover (e.g., deforestation, desertification)	Looks at deforestation, desertification, and land cover changes to determine how these contribute to climate change and its effects on agriculture in the region.
	Impact of chemical fertilizers and pesticides (e.g., soil health, water quality)	Discusses how the use of chemical fertilizers and pesticides in farming has affected the environment, specifically soil health, water quality, and overall climate variability, contributing to broader environmental impacts.
Theme 2: Impacts of Climate Change and Variability on Livelihood	Impact of climate changes on daily farming (e.g., changes in rainfall, temperature)	Examines how changes in rainfall and temperature directly affect daily farming activities, crop yields, and food security in the community.
	Shifts in seasons (e.g., earlier or later rains, longer drought periods)	Investigates the impact of changing seasons (e.g., earlier or later rains, longer droughts) on livelihood activities, particularly those related to farming.

	Extreme climate events (e.g., droughts, floods, extreme heatwaves)	Focuses on how specific climate events like droughts, floods, or extreme heatwaves have caused significant damage to livelihoods, particularly agriculture, and how communities have coped with these events.
Theme 3: Mitigation Measures and Adaptation Strategies	Traditional practices and indigenous knowledge (e.g., local farming techniques, crop rotation, water conservation)	Explores how indigenous knowledge and traditional practices (e.g., crop rotation, water conservation techniques) have been used by communities to adapt to changing climate conditions and maintain agricultural productivity.
	Adoption of drought-resistant or early-maturing crops (e.g., hybrid crops, new varieties)	Investigates the adoption of specific crop varieties designed to resist drought or mature faster, including their performance in terms of yield compared to traditional crop varieties.
	Crop diversification as a strategy (e.g., variety in crops to reduce risk)	Looks at whether crop diversification is being used as an adaptation strategy to mitigate the risks posed by climate change and how successful this has been in terms of crop yields and sustainability.
	Agroforestry or mixed farming systems (e.g., integrating trees with crops or livestock)	Examines how agroforestry or integrated farming practices (combining trees with crops or livestock) help buffer against climate impacts and improve agricultural yields, ensuring sustainability.
	Future strategies and innovations (e.g., new farming technologies, policy recommendations)	Investigates future strategies, practices, or innovations that could be helpful in mitigating the ongoing or future impacts of climate change on agriculture, focusing on sustainable agricultural practices and innovations.

Appendix 3: Grade-Level Distribution of deforestation and Climate change education Competencies in Ethiopian Secondary School Geography Curriculum

Grade	Competency	Dimension	Description
9	Identify the elements of climate	Dimension 1	Introduction to understanding climate components and recognizing climate patterns' impacts.
	Explain factors controlling the distribution of climate in Ethiopia	Dimension 2	Explains why climate is distributed in certain ways in Ethiopia, focusing on underlying causes.
	Assess how seasonal variations in climate affect people's lives in two contrasting regions of Ethiopia	Dimension 1	Focuses on understanding the effects of seasonal climate changes on people's lives.
	Identify the major measurements of weather and climate	Dimension 1	Understanding how we measure and assess climate, crucial for identifying effects.
	Describe the major types of natural vegetation in Ethiopia	Dimension 1	Understanding Ethiopia's natural vegetation and its significance.
	Describe and explain how the growth and decline of population affects the availability of natural resources, and how the availability of natural resources in turn affects the pattern of population growth	Dimension 2	Examines interrelations between population changes and resource availability, with a focus on forests.
	Assess the impacts of rapid population growth on environment and socioeconomic development	Dimension 1	Analyzes deforestation as a major impact of rapid population growth.

	Explain how natural resource degradation affects people's lives	Dimension 1	Examines deforestation as a major component of resource degradation.
	Discuss the solution to problems of resources degradation, including the green legacy movement of Ethiopia	Dimension 3	Explores conservation strategies, including national reforestation initiatives.
10	Identify the major climate types and regions of the world	Dimension 1	Introduction to the types and regions of climate globally, recognizing impacts.
	Identify the major climate types and regions of Africa	Dimension 1	Focus on Africa's climate, offering foundational knowledge about global climate distribution.
	Distinguish the controls of climate in Africa	Dimension 2	Addresses the underlying factors controlling Africa's climate.
	Explain benefits of climate for life of people in Africa	Dimension 1	Describes how climate positively affects people's lives in Africa.
	Explain the major challenges of climate change on African development vision	Dimension 2	Discusses how climate change impedes development, addressing root causes.
	Demonstrate the major vegetation distribution zones of Africa	Dimension 1	Identifies major forest zones and their ecological importance.
11	Differentiate between the criteria used to classify climates	Dimension 1	Understands the classification of climate and its effects on regions.
	Classify climates of a region based on Köppen's and Trewartha's climate	Dimension 1	Assists in understanding the effects of climate through

	classification methods		classification systems.
	Evaluate the merits and demerits of Köppen's climate classification	Dimension 1	Assesses the utility of Köppen's system in understanding climate effects.
	Illustrate the distribution of Köppen's climatic regions in the form of a map	Dimension 1	Visual representation of Köppen's climatic regions to understand climate distribution.
	Identify the Trewartha's climate classification methods	Dimension 1	Explains Trewartha's classification, helping to understand global climate differences.
	Recognize the difference and similarity between Trewartha's and Köppen-Geiger climate classification system	Dimension 1	Compares Trewartha's and Köppen's methods for a deeper understanding of global climate.
	Describe world climatic regions	Dimension 1	Describes the characteristics of climatic regions, reinforcing understanding of their effects.
	Identify the factors responsible for formation of world climatic regions	Dimension 2	Explains the underlying factors shaping the world's climate regions.
	Describe the local climate types of Ethiopia; and compare the methods used in climate classification locally against that of Köppen	Dimension 1	Examines local climate types in Ethiopia and compares them to global classification systems.
	Compare the methods used in climate classification locally against that of Köppen	Dimension 1	Comparative analysis between local and global classification methods.

	Examine the impacts of extreme climates on poverty	Dimension 1	Analyzes how extreme climates, like droughts or floods, affect poverty.
	Examine the threats deforestation poses on our world	Dimension 1	Analyzes the environmental and socio-economic consequences of deforestation.
12	Define climate change	Dimension 1	Defines climate change, highlighting its environmental impacts.
	Describe the natural and human-induced climate change by giving examples	Dimension 2	Explains both natural and human-induced causes of climate change.
	Illustrate the global trends in climate change	Dimension 1	Focuses on global patterns and impacts of climate change.
	Identify the major causes of climate change	Dimension 2	Identifies human activities like deforestation and industrialization as primary causes.
	Examine the impacts of climate change on human beings and other life forms	Dimension 1	Focuses on the effects of climate change on people and ecosystems.
	Assess the impacts of climate change on the physical features such as water, forest	Dimension 1	Analyzes how climate change impacts water sources, forests, and other physical features.
	Propose and sketch the major climate change adaptation and mitigation strategies	Dimension 3	Involves students proposing solutions to mitigate and adapt to climate change.
	Participate in climate change mitigation	Dimension	Encourages real-world

	and adaptation-related practices	3	involvement in climate change solutions.
	Assess the pillars of climate change resilient green economy of Ethiopia through considering indigenous knowledge	Dimension 3	Focuses on developing a resilient green economy, integrating indigenous knowledge.
	Review the major international conventions and agreements in view of their strengths and limitations	Dimension 4	Evaluates global efforts to address climate change, considering their strengths and limitations.
	Explain components, and magnitude of environmental problems (Climate change is part of it)	Dimension 1	Focuses on understanding climate change as part of broader environmental issues.
	Explain why climate change became a global issue and a serious cause for public concern	Dimension 4	Explores why climate change has become a global concern and envisions potential solutions.

Appendix 4: Knowledge and attitude tests for Students

Bahir Dar University

School of Teacher Education

College of Education,

Department of Social Science

Geography and Environmental Education, Doctor of Education (DED) Program

Part I: Knowledge and attitude tests for Students

Dear respondents, the purpose of this s Knowledge and attitude tests is to gather data for a PhD/DED dissertation entitled **"Integration of action-oriented environmental sustainability, climate and forest cover change education into the secondary school geography curriculum: Evidence from Metekel Zone, Northwest Ethiopia"** required for partial fulfillment of the Degree of Doctor of Education in Geography and Environmental Education.

Information you will give serve only the aforementioned academic purpose and thus your genuine response to questions is very important in achieving the goal of the study. Hence you are kindly requested to give information genuinely. I would like to thank you in advance for your cooperation and time to give information on this survey.

General Instruction:

- ✓ There is no need to write your name down.
- ✓ Please give your response by encircling the letter of your choice, by writing true or false responses or by using a tick mark (√) from the different alternatives provided against each item for close ended questions and by writing short notes on open ended ones in each section.
- ✓ If you are not satisfied with the provided options you can write your own.

- ✓ The study will require about 90 minutes of your time.
- ✓ There are no anticipated risks in this study.
- ✓ Thank you in advance for your willingness and cooperation!!!

1.1. Standardized knowledge test on level of student's environmental knowledge related to deforestation and climate change

Instruction: Choose the best answer from the given alternatives and encircle the letter of your choice.

1. Which of the following are the major environmental problems facing rural areas of Ethiopia?

A. Solid waste, liquid waste and overgrazing

B. Land degradation, deforestation and its resulting climate change

C. Air pollution, water pollution and chemical waste

D. Solid waste, chemical waste and liquid waste

2. All of the following are underlying causes of climate change except one.

A. Using firewood and charcoal for cooking

B. Using fossil fuels

C. Reforestation

D. Cutting down trees

3. Which of the following is true about the rate of deforestation in Ethiopia recently?

A. Increasing

B. Remain the same

C. Decreasing

D. Not known

4. Which one of the following is the major cause of deforestation in Ethiopia?

A. Wildfire and desertification

B. Absence of forest conservation policy

C. High demand for agricultural land and fuel wood

D. All

5. Which one of the following is not true about the effects of climate change?

A. Climate change causes droughts and heat waves

B. Climate change affects water supply and water quality

C. Climate change causes biodiversity loss

D. Climate change minimizes flooding

6. How do you think that deforestation quickens climate change?

A. By releasing greenhouse gases into the atmosphere

B. Through maintaining the balance of nature

C. Through removal of animal dung and crop residues for cooking

D. "A" and "C" are correct

7. Which of the following is a solution to the problem of deforestation in Ethiopia?

A. Afforestation B. Reforestation C. Family planning D. All are important

8. What do you think is the most important environmental issue facing Metekel zone?

A. Exotic plants or animals B. Wetland destruction C. Forest degradation D. Unlimited development

9. Which one of the following can minimize both deforestation and climate change problems in Ethiopia?

A. Planting of trees on the degraded part B. Creating awareness C. Using controlled grazing D. All

10. Which one of the following is not the main consequence of deforestation in Ethiopia?

A. Flood and drought B. Loss of soil fertility C. Loss of biodiversity D. All of the above

11. Which of the following is not the consequence of deforestation on the physical environment?

A. Climatic change B. Loss of water C. Ecosystem preservation D. Loss of wildlife

12. Which one of the following contributes least to deforestation in rural areas?

A. Industrialization B. Lack of awareness C. Poverty D. Population growth

13. What should be done to reduce deforestation?

A. Expanding area closure B. Planting trees in farmlands and naked areas C. Telling communities the consequences of deforestation D. All are answers

14. Which one of the following statements is correct?

A. The remaining forests in the local area of Ethiopia should be conserved at all costs.

B. Cutting down forests has positive consequences like increasing income to local people.

C. Local people are not responsible to protect clearance of forests. D. All are correct

15. The mechanisms of addressing Ethiopian environmental problems include all of the following except:

A. Making efforts to prevent further population growth B. Protecting farmlands

C. Covering the land with vegetation D. Exacerbating soil erosion

16. Which one of the following is not a responsible cause for the vulnerability of Africa to climate change?

A. Weak adaptive capacity B. High dependence on ecosystem goods for livelihoods

C. Less developed agricultural production systems D. High technological advancement

17. What do you think is the single most important environmental issue facing developing countries like Ethiopia?

A. Endangered species B. Wetland destruction C. Water shortage D. Deforestation

18. Which of the following experiences have you engaged in within your local environment as a result of environmental lessons learned from school curricula?

A. Participating in outdoor experiences such as camping and fishing.

B. Having your parents or grandparents encourage you to care for the environment.

C. Involving in charcoal production and firewood collection activities

D. "A" and "B" are correct

19. Which one is much worse in the context of Metekel zone?

A. The water quality of local streams, rivers, and lakes.

B. The level of pollution or waste produced by nearby businesses, farms, and industries.

C. Environmental degradation caused by human-induced factors

D. The misuse of chemicals such as fertilizers and pesticides.

20. Which of the following best describes the environmental impact of human activity related to deforestation?

A) Enhancing biodiversity through habitat preservation

B) Implementing sustainable practices to mitigate ecological harm

C) Destroying habitats through agricultural expansion to meet food demand

D) Conserving natural ecosystems to ensure long-term environmental stability

21. Which of the following statements accurately describes the impact of climate change in Ethiopia?

A) Climate change affects rural areas more severely than urban centers.

B) Climate change poses serious problems on urban centers more than rural areas.

C) Climate change impacts are evenly distributed between urban and rural areas.

D) There is no significant difference in the impact of climate change between urban and rural areas in Ethiopia.

22. Which of the following statements accurately describes the role of forests in climate change mitigation?

A) Forests have a negligible impact on climate change regulation.

B) Forests exacerbate climate change through tree planting.

C) Forests play a vital role in climate change regulation and carbon sequestration.

D) Forests contribute marginally to climate change but have no impact on carbon sequestration.

23. Which of the following statements accurately reflects the consequences of human interference with nature?

A) Human interference with nature typically leads to positive outcomes.

B) Human interference with nature rarely produces any consequences.

C) Human interference with nature often results in disastrous consequences.

D) Human interference with nature has no impact on the environment.

24. Which of the following factors are identified as contributors to the clearance of forests and the acceleration of climate change by local populations?

A) Economic stability and environmental consciousness B) Government incentives for forest conservation C) Poverty, environmental unawareness, and population density D) Strict conservation policies and community engagement

25. Which of the following statements best reflects the prioritization between economic growth and environmental protection?

A) Economic growth should always take precedence over environmental concerns.

B) Protecting the natural environment is equally important as maintaining economic growth.

C) Environmental conservation should be prioritized over economic growth.

D) Economic growth is irrelevant in comparison to safeguarding the natural environment.

26. Which of the following statements is true about the relationship between population growth and deforestation rates in an area?

A) As the population in an area increases, the rate of deforestation decreases.

B) There is no correlation between population growth and deforestation rates.

C) As the population in an area increases, the rate of deforestation increases.

D) Population growth has a negligible effect on deforestation rates.

27. Which of the following statements best describes the relationship between climate change and climate variability?

A) Climate change and climate variability are entirely separate concepts.

B) Climate change and climate variability are interchangeable terms.

C) Climate change is the cause for climate variability.

D) Climate variability is the primary driver of climate change.

28. Which statement is correct about students' effort on addressing environmental issues?

A) Working as an individual can influence the solution of environmental issues.

B) Solving environmental problems requires government intervention.

C) Individual efforts are insignificant in combating environmental issues.

D) "A" and "B" are correct.

29. Which of the following is the disproportionate impact of climate change?

A) Climate change affects all countries equally. B) Wealthier countries are more vulnerable to climate change. C) The impact of climate change is particularly severe on Africa and other impoverished nations D) Climate change primarily affects developed countries.

30. Which of the following factors is proposed to play a role in determining solutions to environmental problems, including deforestation and climate change?

A) Scientific research and technological advancements B) Government policies and regulations C) Chance or random events D) "A" and "B" are correct.

1.2. Students' environmental attitude scale related to deforestation and climate change

For the following statements, please indicate how you feel about it by putting thick mark (√) in the column that best indicate your agreement or disagreement.

Strongly disagree=1, Disagree=2, Undecided=3, Agree=4, strongly agree=5

Strongly disagree=5, Disagree=4, Undecided=3, Agree=2, strongly agree=1 (for negative statements)

	Items related to positive environmental attitude	1	2	3	4	5
1	Considering the problem of deforestation in our country, we need to substitute the uses of fuel wood by other alternative energy sources.					
2	I can reduce negative environmental impacts including deforestation and climate change in schools, homes, communities and the world at large					
3	I am willing to have environmental problems solved even if this means sacrificing many goods.					
4	It is important for our future to have an economical use of resources.					
5	I think each of us can make a significant contribution to environmental					

	protection.					
6	I perceive myself as very concerned to stop deforestation in my community.					
7	I can influence the resolution of climate change in my community using action strategies.					
8	I would be willing to have the government reallocate existing money to protect the impact of climate change in my community.					
	Items related to negative environmental attitude	5	4	3	2	1
9	I pay very little attention as environmental issues are reported by the news media, including radio, TV, newspapers, and magazines.					
10	I believe that environmental problems like deforestation and climate change should be left to the experts.					
11	Humans can seriously abuse the environment through the purposeful clearing of forested land.					
12	I don't be upset about forest loss in my environment.					
13	Damaging forests do not affect the natural life negatively.					
14	It is not a matter if we, the younger, do not think about climate change issues.					
15	It is not my responsibility to protect the environment.					
16	Because of science and technology, people do not need to depend on environment.					
17	Although thinking for forest degradation is important, thinking for climate change is unnecessary.					
	Items related to environmental information and awareness					
18	I know that humans have the right to modify the natural environment to suit their needs.					
19	If deforestation and climate change continue at their present rate, we will soon experience a major environmental disaster in Ethiopia.					
20	I know that plants and animals have as much right as humans to exist.					
21	The so-called "ecological crisis" facing humankind has been greatly exaggerated.					
22	Tree planting help to fight excess emission of harmful carbon dioxide which					

	contributes to global warming.					
23	An increase of carbon dioxide in air may bring danger to the environment.					
24	We are approaching the limit of the number of people the Earth can support.					
25	Poor people should be responsible for environmental degradation than the rich.					
26	It is clear that environmental degradation is a result of unwise resource utilization.					
27	The Earth has plenty of natural resources if we just learn how to develop them.					

Appendix 5: Questionnaire on factors influencing students' environmental knowledge and attitudes towards addressing deforestation and climate change.

2.1. Socio-Economic and Demographic Data of Student Respondents

(Please indicate your response by placing a tick mark (√) in the appropriate box or space provided.)

1. What is your Gender?

Male -------------------- Female -----------------

2. In which grade are you currently enrolled? ----------------------------

3. Please indicate your age in years ----------------

4. What is your place of residence?

Rural ------------ Urban -----------

5. Which secondary school do you attend? ------------

6. What is your parents' income level?

Low ----------------------------------- Middle --------------------------- High -----------------------

7. What is your parents' educational background?

Illiterate ---------- primary (grade 1-8) ------------- Secondary (grade 9-12) and above -------------

***2.2.* For the following questions, please give your response by placing a tick mark (√) *next to* the appropriate alternative for *close-ended* questions, and by writing short notes for open-ended ones.**

1. Have you been involved in planting trees within your school compound or its surroundings?

Yes (1) ---------------------- No (0) ----------------------

2. Are you committed to refraining from engaging in charcoal production as well as fuelwood collection and sales?

   Yes (1) ---------------------- No (0) ----------------------

3. Do you dedicate yourself to personally engaging with and encouraging the local community to adopt renewable energy sources?

   Yes (1) ---------------------- No (0) ----------------------

4. Are you personally involved and committed to raising awareness among the local community about climate change adaptation strategies?

   Yes (1) ---------------------- No (0) ----------------------

5. Do you have the capacity to personally engage with and inspire the community to advocate for the adoption of sustainable land management practices aimed at preventing soil erosion and conserving ecosystems?

   Yes (1) ---------------------- No (0) ----------------------

6. Can you advocate for policies that promote forest conservation and climate action?

   Yes (1) ---------------------- No (0) ----------------------

7. Do you have the capacity to guide the community in controlling population growth?

   Yes (1) --------------------- No (0) ----------------------

8. Are there any school-based environmental clubs in your school?

   Yes (1) ---------------------- No (2) ----------------------

9. If your answer is yes, have you ever participated in a school-based environmental club?

   Yes (1) ---------------------- No (2) ----------------------

10. If your response to question number 9 is yes, which club do you belong to? --------------------

11. In which ways do you think the club activities help in addressing problems related to deforestation and climate change in the Metekel zone? ---

12. Do you, personally, have an interest in addressing environmental issues?

Yes (1) ---------------------- No (2) ----------------------

13. Do you think that norms, pressures, and traditions transmitted by the social environment in relation to alleviating environmental problems encourage you to become a more environmentally responsible individual?

Yes (1) ---------------------- No (2) ----------------------

14. Do you have access to information about environmental issues?

Yes (1) ---------------------- No (2) ----------------------

Appendix 5: Structured questionaire for secondary school geography teachees

Bahir Dar University

School of Teacher Education

College of Education,

Department of Social Science

Geography and Environmental Education, Doctor of Education (DED) Program

Structured questionnaire for secondary school geography teachers

Dear teachers, the purpose of this questionnaire is to collect relevant data on the study titled **“Integration of action-oriented environmental sustainability, climate and forest cover change education into the secondary school geography curriculum: Evidence from Metekel Zone, Northwest Ethiopia”** required for partial fulfillment of the Degree of Doctor of Education in Geography and Environmental Education. Since the responses of respondents are vital for the success of the study, spending some time to fill the questionnaire is strongly advised.

Thank you so much!

Directions:

1. Not important to write your name

2. Encircle the choice of your answer

3. Tick (√) appropriately and write where necessary

4. Give brief and clear answer to open ended questions

5. If you are not satisfied with the provided options you can write your own

3.1: Personal and Demographic Information.

1. Name of school ------------------------------------

2. Grade level you are currently teaching ----------------

3. Sex –

Male ---------------------   Female --------------------

4. Age--------------------------

5. Teacher's workload (number of periods per week) ----------------

6. Teaching experience -------------------------

7. Educational qualification -----------------------

3.2: Questionnaire on factors affecting effective implementation of PBL

1. What is the number of students per class you are teaching currently?

A) Below 40   B) 40-50   C) Above 50

2. Do you think that large class size affects effective implementation of PBL while teaching environmental problems related to deforestation and climate change?

A) Yes   B) No

3. If your answer for question number 2 is yes, indicate the effects of large class size on effective implementation of PBL while teaching lessons related to deforestation and climate change in the table below (Tick where applicable)

Effects of large class size on PBL	yes	no	I don't know
Affects the quality of my teaching through PBL			
Makes the PBL assessment difficult			
Affects the time for marking students' work			

Impacts on useful monitoring/evaluation of lessons			
Does not afford time for remedial teaching through PBL			
Limits the number of exercises given to students			
Difficult to give feedback on student's assignments			
Information from both side (teacher and students) could not be properly disseminated			
Ability of each students could not be known			

4. Do you think that the traditional assessment system affects effective implementation of PBL?

A) Yes B) No

5. If your answer for question number 4 is yes, how does it affect the use of PBL in teaching environmental problems related to deforestation and climate change?

----

6. Do you consider the time-intensive nature of PBL a significant barrier in your teaching of deforestation and climate change issues in geography classes?

A) Yes B) No

7. If yes, how does it affect the implementation of PBL while teaching environmental problems related to deforestation and climate change?

----

8. Do you think that the traditional lecture method is still viewed as the dominant method of delivery in your school?

A) Yes B) No

9. Does teacher's reliance on conventional teaching methods affects the implementation of PBL while teaching environmental issues related to deforestation and climate change?

A) Yes B) No

10. Do you think that inadequate logistics affect effective implementation of PBL while teaching environmental problems related to deforestation and climate change?

A) Yes B) No

11. Do you think that the existing secondary school geography curriculum has wide coverage that cannot be covered in the allocated time?

A) Yes B) No

12. If yes, do you think that the loaded nature of the geography curriculum negatively affects effective implementation of PBL while teaching deforestation and climate change issues?

A) Yes B) No

13. If your response for question number 12 is yes, how does it affect the implementation of PBL? --

----

14. Do you integrate real-world environmental data into your PBL activities on deforestation and climate change?

A) Yes B) No

15. Do your PBL lessons on environmental issues often include student collaboration and group problem-solving?

A) Yes B) No

16. Do you use PBL to connect classroom learning with local or global environmental issues?

A) Yes B) No

17. Do you feel confident in your knowledge of the causes and impacts of deforestation?

A) Yes B) No

18. Are you knowledgeable about the scientific principles behind climate change?

A) Yes B) No

19. Do you integrate your knowledge of deforestation and climate change into PBL activities?
A) Yes B) No

20. Can you effectively relate the content of climate change to local or global real-world issues during PBL activities?

A) Yes B) No

21. Have you participated in professional development opportunities focused on environmental issues such as deforestation and climate change in the past year?

A) Yes B) No

22. Are you aware of how your emotions influence your teaching approach, especially when addressing environmental issues like deforestation and climate change?

A) Yes B) No

23. Do you remain calm when students express strong emotions during PBL activities on deforestation and climate change?

A) Yes B) No

24. Are you motivated to find innovative ways to engage students in PBL activities related to deforestation and climate change?

A) Yes B) No

25. Do you consider your students' feelings when designing PBL activities on environmental issues?

A) Yes B) No

26. Are you able to facilitate discussions that allow students to express their emotions about deforestation and climate change?

A) Yes B) No

27. Are you aware of how your emotions influence your teaching approach during PBL activities on deforestation and climate change?

A) Yes B) No

28. Are you motivated to find new ways to engage students in PBL activities related to deforestation and climate change?

A) Yes B) No

29. Do you consider your students' emotional responses when designing PBL activities on environmental issues?

A) Yes B) No

30. Do you effectively facilitate discussions that allow students to express their emotions regarding deforestation and climate change during PBL?

A) Yes B) No

31. Do the PBL activities you implement in your geography lessons on deforestation and climate change align with the curriculum standards?

A) Yes B) No

32. Are the PBL methods you use to address environmental issues supported by the current geography curriculum standards?

A) Yes B) No

33. Do the curriculum standards for geography include assessments that align with the PBL activities you use for teaching deforestation and climate change?

A) Yes B) No

34. Do the objectives of the geography curriculum support the use of PBL in teaching complex environmental topics such as deforestation and climate change?"

A) Yes B) No

35. Do the guidelines provided in the geography curriculum encourage the use of PBL approaches in lessons on environmental issues?

A) Yes B) No

36. Do you believe that your students' sense of connection to and responsibility for environmental issues, particularly deforestation and climate change, significantly influences their participation in PBL activities?

A) Yes B) No

37. Do your students consistently show high levels of motivation and active engagement during PBL activities on deforestation and climate change?

A) Yes B) No

38. Do your students exhibit a strong sense of environmental identity during PBL activities focused on deforestation and climate change?

A) Yes B) No

39. Does your students' commitment to environmental issues enhance their participation in PBL tasks related to deforestation and climate change?

A) Yes B) No

40. Are your students more motivated to engage in PBL projects when they are aware of the personal impact of deforestation and climate change?

41. Do your students' personal connections to environmental topics increase their involvement in PBL activities in geography lessons?

A) Yes B) No

42. Does your students' motivation to participate in environmental projects improve the effectiveness of PBL in your geography classes on deforestation and climate change?

A) Yes B) No

3.3: Questionnaire on teachers' beliefs and actual practice of problem solving approach in teaching environmental problems related to deforestation and climate change.

Direction: The questionnaire in the tables below indicates secondary school geography teachers' problem-based practice (table 1), practicing heuristic approach of problem solving (table 2), and contextualizing the content to students (table 3) while teaching environmental problems related to deforestation and climate change in the geography classroom.

Each item requires you to indicate your level of agreement (1= strongly disagree 2= disagree, 3= undecided, 4= agree and 5= strongly agree). Please indicate how often you have had following experiences for each case in the subsequent tables. (Thick on the option that describes the status of your Practices)

Teachers' Beliefs about Problem Based Practice

No	Practice descriptors	1	2	3	4	5
1	Encouraged students to practice on skills rather than concepts					
2	Provided problems that needed inquiry and discovery rather than activities that need memorization and appreciation of algorithm					
3	Encourage students to practice on unfamiliar and non-routine problems rather than routine problems					

4	Give opportunities for students to explore solutions by their own ways before being shown by the teachers					
5	Encouraged students to learn by exploring, manipulating, experimenting, risking, testing and modifying ideas					
6	Encouraged synthesis and analysis					

Teachers' Beliefs on Heuristics Approach

No	Role descriptors	1	2	3	4	5
7	Helped students to plan for the future in meaningful way to them					
8	Encouraged application of algorithm before they apply heuristic on non- routine problems					
9	Encouraged students-centered instruction					
10	Encouraged students to use variety of approach to solve problems					
11	Encouraged fact findings, information gathering and strategy					
12	Presented tasks or lessons from individual experience					
13	Modelled problem solving process					
14	Discussed useful problem solving strategies					

Teachers' Beliefs on Contextualizing the Content

No	Role descriptors	1	2	3	4	5

15	Related subject content (climate change and deforestation issues) to real world					
16	Allowed students to practice their past experience					
17	Presented tasks or lessons from individual experiences					
18	Gave word problems from real life to be converted to known facts					
19	Asked students the application of the concept in the real life situation					
20	Fostered self-initiated learning					

Appendix 6: key informant interview (KII) Questions

Spatiotemporal Climate Variability and Livelihoods (Crop Production)

Part I: General information

Interviewee --Age --

Educational Status ---------------------------------Role in the community--------------------

District -- *Kebele* ---

Part II: Main guiding questions

1. What are the causes and consequences of climate change in your district?
2. From your perspective, how have farming practices such as overgrazing, mono cropping, deforestation, shifting cultivation, or intensive tillage contributed to climate variability in this area?
3. Do you see climate change as a gradual process over many years or as a more recent phenomenon? What factors help explain this?
4. How have changes in natural vegetation or land cover, including deforestation and desertification, affected local climate conditions?
5. In your opinion, how has the use of chemical fertilizers and pesticides influenced soil health, water quality, and climate variability in the zone?
6. How have changes in rainfall and temperature patterns affected crop production, food security, and daily farming activities in your community?
7. What are the impacts of shifting seasons — such as late rains, longer droughts, or irregular growing periods — on farmers' activities and livelihoods?
8. Could you describe specific extreme events, such as droughts, floods, or heat waves, and how they have affected livelihoods in your area?
9. What indigenous practices or traditional farming techniques are used locally to adapt to climate change, and how effective have they been?
10. Are farmers adopting drought-resistant or early-maturing crops, crop diversification, or agroforestry practices? If so, how effective are these strategies compared to traditional approaches?
11. Looking ahead, what future strategies, technologies, or policies do you think are most needed to build resilience against climate variability in your community?

KII questions for Spatiotemporal Forest Cover Change

Part I: General information

Interviewee --Age --

Educational Status ---------------------------------Role in the community--------------------

District --------------------------------------- *Kebele* ---

Part II: Main guiding questions

1. What are the main drivers of deforestation in your district, such as agricultural expansion, logging, charcoal production, or population growth?

2. To what extent are these drivers influenced by socio-economic pressures or gaps in policy enforcement?

3**.** What major environmental impacts have you observed from deforestation, including soil degradation, loss of biodiversity, water scarcity, or changes in microclimate?

4. How has forest loss affected local community livelihoods, including access to fuel wood, grazing land, non-timber forest products, or income sources?

5. What conservation or reforestation efforts are currently being implemented in your area, and who is responsible for them?

6. How effective are these initiatives, and what challenges do they face in practice?

7. How do communities perceive changes in forest cover, and are people generally aware of the need for conservation?

8. How have traditional practices and intergenerational knowledge influenced forest use and conservation over time?

9. What obstacles or challenges hinder successful forest conservation in your district?

10. What recommendations would you make to improve forest management, promote conservation, and ensure sustainable use of forest resources?

Interview questions for KII on The Level of Secondary School Students' Knowledge, Attitudes, and Determinants related to deforestation and climate change.

Part I: General information

Interviewee ---Age ---

Educational Status ----------------------------------Role in the community---------------------

District -- *Kebele* --

Part II: Main guiding questions

1. How do school based environmental clubs enhance environmental awareness?

2. How could student's interest help students to promote environmental awareness of the local community?

3. How could the difference in grade level, gender and age of students affect students' involvement in responding towards their local environmental problems with particular focus to deforestation and climate change?

4. What differences did you notice in the environmentally friendly behavior of students from rural and urban areas? What are the underlying reasons for these disparities?

5. How does the content within secondary school geography curricula empower students to cultivate environmentally conscious behavior, thereby aiding in efforts to address environmental issues such as deforestation and climate change?

6. Are the local community fully involved in policy making, implementation and evaluation of environmental issues? If not, why?

7. How do secondary school students contribute to motivating their community to engage in local policymaking and implementing initiatives concerning forest resource management and climate change?

8. In what ways does the educational background of a student's parents influence the pro-environmental actions taken by the student?

9. How do you perceive the influence of social norms in your community on environmental responsibility?

10. Have you experienced any pressures, either positive or negative, from your social environment regarding environmental behavior? If so, please describe.

11. What measures did you take to reduce the problem of environmental degradation and how did you take these measures?

Interview questions for Key Informant Interviews on Geography teachers Implementation of PBL in Teaching Deforestation and Climate Change in Secondary School Geography

Part I: General information

Interviewee ---Age ---

Educational Status ----------------------------------Role in the community---------------------

District -- *Kebele* --

Part II: Main guiding questions

A. Teachers' Beliefs and Practices

1. What is your opinion on the importance of the problem-solving approach in teaching environmental issues such as deforestation and climate change?
2. How often do you use PBL in your geography lessons, and can you share examples of how you have successfully implemented it?
3. When implementing PBL, do teachers usually present the ill-structured problems, or do students come up with problems themselves? What are the advantages and disadvantages of each?
4. How do you form and manage student groups during PBL activities?

B. Teacher-Related Factors

5. How have you adapted to the use of PBL in your teaching, and what challenges or opportunities have you faced in this adaptation?
6. How does your level of content knowledge and experience in teaching topics like deforestation and climate change influence your ability to implement PBL?

7. How does your emotional intelligence (e.g., managing classroom dynamics, being aware of students' feelings) affect your ability to facilitate PBL?
8. How do you perceive your students' environmental identity and motivation? In what ways do these factors influence their participation and engagement in PBL activities?

C. Classroom and Logistical Factors

9. How does large class size affect your ability to implement PBL effectively, and what strategies do you use to manage this challenge?
10. Do you think there is sufficient logistical support (resources, materials, or technology) for PBL implementation? If not, how does the lack of support affect your practice?

D. Curricular and Systemic Factors

11. How does the current geography assessment system affect the use of PBL in your classroom?
12. Do you think the geography curriculum allows adequate space for PBL, or is it too content-heavy? How do you balance curriculum coverage with PBL implementation?
13. How do you align your PBL activities with curriculum standards, and what challenges have you faced in doing so?

E. Methodological and Time-Related Factors

14. To what extent does reliance on conventional teaching methods (such as lectures) affect your ability to use PBL in geography lessons?
15. How does the time-intensive nature of PBL, in terms of planning and classroom implementation, influence your decision to use it more frequently?

F. Way Forward

16. In your opinion, what possible solutions or support systems (such as training, resources, policy changes, or curriculum adjustments) could help address the challenges and enhance the effective implementation of PBL in teaching deforestation and climate change?

Interview questions for Key Informant Interviews on Integrating Deforestation and Climate Change in the Ethiopian Secondary School Geography Curriculum

Interviewee --Age --

Educational Status ---------------------------------Role in the community--------------------

District --------------------------------------- *Kebele* ---

Part II: Main guiding questions

A. Curriculum Representation and Balance

1. How do you evaluate the way deforestation and climate change are represented across the geography curriculum from grades 9–12?
2. To what extent does the curriculum balance the three domains of learning—knowledge (cognitive), attitudes (affective), and skills (psychomotor)—in teaching these topics?

B. Action-Oriented and Practical Dimensions

3. How far do the MLCs encourage students to understand not only the effects but also the root causes of deforestation and climate change?
4. Do you think the curriculum adequately incorporates change strategies and action knowledge (e.g., student participation in environmental projects, local conservation practices)? Why or why not?
5. What opportunities or gaps do you see in linking classroom learning with local environmental issues and student-led action?

C. Learning Activities and Embedded Questions

6. How would you assess the quality and quantity of textbook activities and questions related to deforestation and climate change?
7. Do these activities and questions encourage students to think critically, develop values, and practice skills, or are they mainly focused on factual recall?
8. What types of activities or questions would you recommend to make learning more action-oriented and locally relevant?

D. Teaching Methods and Pedagogical Practices

9. Which teaching methods do you find most commonly used for these topics in practice? Are they more teacher-centered or student-centered?
10. How effective has PBL and other participatory approaches (e.g., group projects, field visits, ICT-based learning) been in engaging students with deforestation and climate change?
11. What barriers prevent teachers from consistently applying student-centered or action-oriented methods?

E. Opportunities, Challenges, and Recommendations

12. In your view, how well are teachers prepared and supported (through training, resources, or policy) to implement action-oriented environmental education?
13. What systemic challenges (e.g., assessment systems, curriculum overload, lack of resources) most limit the effective integration of deforestation and climate change in geography education?
14. What specific improvements would you suggest for curriculum designers, textbook authors, and policymakers to strengthen the integration of deforestation and climate change and ensure students gain knowledge, attitudes, and skills for sustainability?

Appendix 7: Focus group discussion guiding questions

Main guiding focus group discussion questions for Spatiotemporal Climate Variability and Livelihoods (Crop Production)

1. What changes in rainfall, temperature, or seasonal patterns have you noticed over the years, and how have they affected farming in your community?
2. Do you see these changes as new developments or gradual shifts that have built up over time?
3. Which farming practices or human activities in your community may be contributing to climate change or land degradation?
4. How have changes in rainfall and temperature affected crop yields, livestock, and food security in your area?
5. Can you share examples of extreme events—such as droughts, floods, or heatwaves—that have directly harmed your livelihoods?

6. What coping strategies or traditional practices do you and your community use to deal with these climate changes?
7. Have you tried drought-resistant crops, crop diversification, or agroforestry? If yes, how effective have they been?
8. What challenges limit your ability to adapt effectively to climate variability?
9. What new practices, technologies, or external support would help your community better cope with future climate changes?
10. If you could suggest one key action to improve resilience to climate variability in your community, what would it be?

Main guiding focus group discussion questions for Spatiotemporal Forest Cover Change

1. What changes in forest cover have you observed in your community over the past decades?
2. How do people in your community generally perceive these changes as positive, negative, or mixed?
3. What are the main human activities driving deforestation in your area?
4. How has forest loss affected the environment, farming, and local livelihoods?
5. Can you share examples of how deforestation has impacted water, soil, or biodiversity in your community?
6. Are there community- or government-led conservation activities in your area, and how effective have they been?
7. How do community members understand and describe their role in forest conservation?
8. How have traditional practices or cultural values related to forests changed compared to your parents' or grandparents' time?
9. What major challenges or obstacles prevent successful forest conservation in your district?
10. If you could give one recommendation to decision-makers, what would you suggest as the most urgent action to protect forests in your area?

Main guiding focus group discussion questions on The Level of Secondary School Students' Knowledge, Attitudes, and Determinants related to deforestation and climate change issues.

A. Students’ Knowledge and Understanding

1. How would you describe the level of secondary school students’ knowledge about deforestation and climate change?
2. What specific topics or issues do students understand well, and where do you see major gaps in their knowledge?
3. How effectively do the school curriculum and textbooks provide knowledge about deforestation and climate change?

B. Students’ Attitudes and Values

4. How do students generally feel about environmental issues like deforestation and climate change—do they see them as serious problems?
5. To what extent do students connect these environmental problems with their own lives and communities?
6. What evidence have you seen of positive or negative attitudes toward environmental protection among students?

C. Determinants and Influencing Factors

7. What factors (such as age, gender, residence, parents’ education or income, grade level, or peer influence) appear to shape students’ knowledge and attitudes?
8. How important are school-based environmental clubs, extracurricular activities, or peer-led initiatives in influencing students’ environmental knowledge and attitudes?
9. What role do family background, community practices, and local cultural norms play in shaping students’ environmental awareness and actions?
10. How do access to information (such as media, internet, or school resources) and teaching methods influence students’ knowledge and attitudes toward deforestation and climate change?

D. Barriers and Opportunities

11. What are the main challenges or barriers that prevent students from gaining adequate knowledge and developing positive attitudes toward environmental problems?
12. What strategies, programs, or changes (in teaching, curriculum, extracurricular activities, or community engagement) would help strengthen students' environmental knowledge, attitudes, and participation in addressing deforestation and climate change?

Main guiding focus group discussion questions for Geography teachers

Focus Group Discussion Questions for Geography Teachers

1. How do you view the relevance and usefulness of PBL in teaching deforestation and climate change?
2. Can you share examples of how you have implemented PBL in your geography lessons?
3. How does PBL help students develop problem-solving skills related to real-life environmental challenges?
4. What strategies do you use to promote inquiry and independent learning on deforestation and climate change?
5. How do you connect lessons on deforestation and climate change to students' local experiences or community issues?
6. Do your beliefs about PBL align with your classroom practices? If not, what causes the difference?
7. What classroom challenges (e.g., class size, resources, motivation) affect your use of PBL?
8. How do curriculum design, time limits, assessment, and institutional support influence PBL implementation?
9. How do students respond to PBL when learning about deforestation and climate change? What motivates or hinders them?
10. What types of support or resources would help you implement PBL more effectively?

Appendix 8: Observation check list

Observation check list Forest Cover Dynamics, Climate Change Impacts

A. Forest and Vegetation Conditions

1. Forest cover density (dense, moderate, sparse, none)
2. Dominant vegetation types (tree, shrub, grassland, mixed)
3. Evidence of forest degradation (logging, burning, grazing, clearance)
4. Visible signs of biodiversity presence (wildlife, bird species, plant diversity)

B. Deforestation and Reforestation Practices

5. Evidence of active deforestation (charcoal production, fuelwood collection, farmland expansion, illegal logging)
6. Presence of afforestation or reforestation projects (yes/no; specify type: government, NGO, community)
7. Survival rate of planted trees (high, medium, low)
8. Local community participation in tree planting (observed/not observed)

C. Land Use and Land Cover Change

9. Current land use (forest, farmland, grazing, settlement, investment farm, mixed use)
10. Signs of recent land conversion (forest → agriculture, forest → settlement, forest → industry/investment)
11. Agricultural practices observed (shifting cultivation, mechanized farming, subsistence farming)
12. Soil condition (erosion visible, degraded, stable, improved)

D. Settlement and Human Activities

13. Settlement pattern (scattered, clustered, resettlement site)
14. Expansion into forest areas (yes/no; evidence: new houses, cleared plots)
15. Community use of natural resources (firewood, water, wild foods, grazing)
16. Investment-driven activities (large farms, logging concessions, industrial use)

E. Climate Change Impacts

17. Visible signs of climate stress (drought effects, crop failure, drying streams, flooding, heat stress)
18. Local adaptation strategies observed (soil bunds, irrigation, agroforestry, water harvesting, mixed cropping)
19. Presence of climate-resilient infrastructure (check dams, terraces, tree belts, irrigation canals)

F. Mitigation and Conservation Measures

20. Protected areas or conservation zones (present/absent; condition: well maintained/poorly maintained)
21. Community-led conservation initiatives (forest guards, bylaws, awareness campaigns)
22. Government or NGO-supported mitigation projects (observed/not observed; specify)

G. Documentation and Recording

23. GPS coordinates of site
24. Photographic records taken (yes/no; specify features)
25. Additional notes on unique observations

Open-ended Classroom Observation checklist

1. In what ways does the teacher integrate real-life examples or local environmental issues when addressing deforestation and climate change?
2. To what extent are students engaged in solving non-routine or unfamiliar problems during the lesson?
3. How does the teacher create opportunities for self-directed or independent learning? Please describe.
4. What specific strategies are used to foster inquiry, discovery, and exploration of the subject matter?
5. How are students encouraged to draw on prior experiences or personal perspectives to connect with the lesson content?

6. In what ways does the teacher promote heuristic approaches (e.g., planning, experimenting with multiple strategies, reflecting on problem-solving)?
7. How is instructional time distributed between direct content delivery and student-centered/problem-based learning activities?
8. What challenges or barriers to implementing PBL or contextualized learning are observable (e.g., curriculum load, time constraints, classroom management)?
9. How does the teacher model or scaffold the problem-solving process (e.g., guiding questions, worked examples, or step-by-step support)?
10. How do students respond to the learning approach—do they appear engaged, inquisitive, collaborative, or passive?

Appendix 9: Published Articles

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RESEARCH

Spatiotemporal trends and drivers of forest cover change in Metekel Zone forest areas, Northwest Ethiopia

Tamiru Toga Wahelo · Daniel Ayalew Mengistu · Tadesse Melesse Merawi

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Abstract The spatiotemporal dynamics of forest cover are essential for understanding the patterns and processes of forest change over time and space. This research focused on the spatiotemporal trends and drivers of forest cover change in the Metekel Zone of Northwest Ethiopia. Landsat 5, Landsat 7, and Landsat 8 imagery, covering the period from 1986 to 2019, were used for land use/cover classification. Land use/cover classification was performed using random forest (RF) and support vector machine (SVM) algorithms in the Google Earth Engine (GEE) platform, with training samples obtained through visual image interpretation. Spectral indices, such as the normalized difference vegetation index, soil-adjusted vegetation index, leaf area index, and normalized difference water index, were analyzed to examine forest cover dynamics over time. In addition, key informant interviews (KIIs) and focus group discussions (FGDs) were conducted. Findings revealed that forest cover decreased significantly from 51.37% in 1986 to 17.20% in 2019, driven largely by human activities such as agricultural expansion, increased demand for firewood, and urban expansion. Findings from spectral indices further corroborated the finding that forest cover in the study region (mainly in the southwestern part) substantially decreased from 1986 to 2019. Concerning forest depletion, the lack of local community awareness has become a key challenge. This problem is attributed to communities prioritizing immediate needs such as fuel and land for agriculture over long-term forest conservation. To combat ongoing deforestation, the Metekel Zone Administration, in collaboration with the land administration office and other stakeholders, revisited and strengthened existing forest policies and control systems. It is also suggested that community awareness, chiefly among youth, should be enhanced through the strategic expansion of formal and nonformal educational initiatives, which empower the youth as agents of change and promote the dissemination of knowledge throughout the community.

Keywords Machine learning algorithms · Vegetation dynamics · Deforestation · Google Earth Engine

T. T. Wahelo (✉)
School of Educational Sciences, Department of Social Science, Bahir Dar University, Bahir Dar, Ethiopia
e-mail: togatamiru@gmail.com

D. A. Mengistu
Geospatial Data & Technology Center and Department of Geography & Environmental Studies, Bahir Dar University, Bahir Dar, Ethiopia
e-mail: dan952003@yahoo.com

T. M. Merawi
School of Educational Sciences, Department of Teacher Education and Curriculum Studies, Bahir Dar University, Bahir Dar, Ethiopia
e-mail: tmelesse3@gmail.com

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ARTICLE

Geo WILEY

Curbing environmental problems related to deforestation and climate change: The level of secondary school students' knowledge, attitudes and determinants in Metekel Zone, Northwest Ethiopia

Tamiru Toga Wahelo[1] | Daniel Ayalew Mengistu[2] | Tadesse Melesse Merawi[3]

[1]Department of Social Science, School of Educational Sciences, Bahir Dar University, Bahir Dar City, Amhara Regional State, Ethiopia

[2]Department of Geography & Environmental Studies, Geospatial Data & Technology Center, Bahir Dar University, Bahir Dar City, Amhara Regional State, Ethiopia

[3]Department of Curriculum Studies, College of Education and Behavioral Sciences, Bahir Dar University, Bahir Dar City, Amhara Regional State, Ethiopia

Correspondence
Tamiru Toga Wahelo, Department of Social Science, School of Teacher Education, College of Education, Bahir Dar University, Bahir Dar City, Amhara Regional State, Ethiopia.
Email: togatamiru@gmail.com

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Abstract
Environmental problems, notably deforestation and climate change, pose significant threats to humanity and demand urgent intervention. In Ethiopia, where these challenges are pronounced, addressing these issues requires a solid foundation of knowledge and positive attitudes, especially among young people. This study examines secondary school students' level of environmental knowledge and attitudes and the determinants related to deforestation and climate change in the Metekel Zone, Ethiopia. A cross-sectional survey was used for the study, and a total of 372 secondary school students selected through a multistage sampling technique from seven government secondary schools in the Metekel Zone were participants. Data were collected via standardised tests, questionnaires interviews and focus group discussions, and analysed via descriptive statistics, chi-square tests and binary logistic regression. The findings revealed that the knowledge levels and attitudes of secondary school students towards environmental issues related to deforestation and climate change were low. The results from the regression model revealed significant correlations between students' knowledge and attitudes, except for personal interest in environmental matters. A notable correlation comprises age, gender, residence, the educational level of the students' parents, the family income level, and the social environment, access to information, the students' grade levels and the students' participation in school-based environmental clubs. The study also identifies key barriers to students' environmental knowledge and attitudes, including curriculum challenges, resource gaps, low awareness, emotional detachment and limited personal agency. To inspire pro-environmental behaviours among students, enhancing environmental education in various disciplines to address gender, age and grade

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Geography teachers' implementation of problem-based learning for deforestation and climate change education in Metekel Zone Secondary Schools, Northwest, Ethiopia

Tamiru Toga Wahelo[a,*,1], Daniel Ayalew Mengistu[b], Tadesse Melesse Merawi[c,2]

[a] Bahir Dar University, College of Education, School of Teacher Education, Department of Social Science, P.O. Box 79, Bahir Dar City, AmharCal State, Ethiopia
[b] Bahir Dar University, Geospatial Data & Technology Center and Department of Geography & Environmental Studies, P.O. Box 79, Bahir Dar city, Amhara Regional State, Ethiopia
[c] Bahir Dar University, College of Education, School of Educational Sciences, Department of Teacher Education and Curriculum Studies, P.O. Box 79, Bahir Dar City, Amhara Regional State, Ethiopia

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ABSTRACT

Environmental problems related to deforestation and climate change pose serious socio-economic and ecological threats. In Ethiopia, rapid forest loss and climate impacts demand sustainable solutions through education. Problem-based learning (PBL), which fosters critical thinking, collaboration, and real-world problem-solving, is well-suited to address both environmental and pedagogical challenges. This study examines geography teachers' implementation of PBL for deforestation and climate change education in secondary schools in Metekel Zone, Northwest Ethiopia. A convergent mixed-methods design and multi-stage sampling were used to collect data from 134 geography teachers, 7 department heads, 7 principals, and 3 education experts through surveys, interviews, focus group discussions, and classroom observations. Quantitative data were analyzed using descriptive statistics, one-sample t-tests, Pearson correlation, and binary logistic regression; qualitative data were thematically analyzed. Policy-relevant findings reveal low teacher belief in PBL, limited heuristic strategies, and weak contextualization of environmental content. A strong correlation between belief and practice shows that stronger teacher beliefs foster greater PBL use. Regression analysis identified structural and systemic factors shaping PBL adoption. Positive factors include teacher adaptation, emotional intelligence, student environmental identity, motivation, and content knowledge. Barriers include large class sizes, traditional methods, and the time-intensive nature of PBL. Thematic analysis also highlighted curriculum rigidity, student resistance, and limited resources. The study recommends policy actions including targeted teacher training, flexible curricula, and systemic support to promote PBL in environmental education. Addressing class size, infrastructure, and student engagement is essential for sustaining PBL practices. These findings offer actionable insights for policymakers and educational planners aiming to integrate PBL in response to environmental challenges.

1. Introduction

Deforestation and climate change are interconnected global ecological crises with profound consequences for biodiversity, ecosystems, and human livelihoods and agricultural productivity (Alves de Oliveira et al., 2021; FAO, 2015; IPCC, 2023). Deforestation is a leading cause of biodiversity loss, as destroying forests eliminates habitats critical for countless species, reducing ecosystem resilience and impeding natural recovery from environmental disturbances (FAO, 2015; IPCC, 2023; Köhl et al., 2015; Sharma et al., 2019; Wang et al., 2022). Additionally, forests play a pivotal role in sequestering carbon dioxide (CO2), and their removal disrupts this function, contributing substantially to global CO_2 emissions, with deforestation accounting for approximately 10–15 % of human-induced emissions annually (Alves de Oliveira et al., 2021; Andrew, 2019; Kohler, 2013; Yoro and Daramola, 2020). This is particularly alarming in tropical regions, where deforestation releases

* Corresponding author.
E-mail addresses: togatamiru@gmail.com (T.T. Wahelo), dan952003@yahoo.com (D.A. Mengistu), tmelesse3@gmail.com (T.M. Merawi).
[1] ORCID: https://orcid.org/0009-0001-0766-4462
[2] ORCID: http://orcid.org/0000-0002-5535-1356

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Spatiotemporal climate variability and its impact on local community livelihoods: A focus on crop production in Metekel Zone, Northwest Ethiopia

Tamiru Toga Wahelo [a,*], Daniel Ayalew Mengistu [b], Tadesse Melesse Merawi [c]

[a] Bahir Dar University, College of Education, School of Teacher Education, Department of Social Science, Po box:79, Bahir Dar City, Amhara Regional State, Ethiopia
[b] Bahir Dar University, Geospatial Data & Technology Center and Department of Geography & Environmental Studies, Po box:79, Bahir Dar City, Amhara Regional State, Ethiopia
[c] Bahir Dar University, College of Education, School of Educational Sciences, Department of Teacher Education and Curriculum Studies, Po box:79, Bahir Dar City, Amhara Regional State, Ethiopia

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ABSTRACT

Climate variability poses a critical challenge to agriculture and livelihoods in vulnerable regions. This study investigates the spatiotemporal climate variability and its impacts on crop production and livelihoods in the Metekel Zone, Northwest Ethiopia. Data from meteorological stations (1981–2019), crop yield records from central statics agency, and qualitative data from focus group discussions (FGDs) and key informant interviews (KIIs) were collected. The study used purposive sampling to select nine key informants and conducted three FGDs with 18 participants across four districts. Temporal variability was assessed using the Coefficient of Variation, Standardized Precipitation and Temperature Indices, and Mann-Kendall trend tests. Spatial variability was analyzed through Inverse Distance Weighting, and the Autoregressive Distributed Lag model was used to quantify the effects of climate variables on crop yields. The Driver Pressure State Impact Response (DPSIR) framework was applied to explore socio-economic and environmental drivers of change. Findings reveal significant warming trends, with annual maximum and minimum temperatures increasing by 0.33 °C and 0.31 °C per decade, and a decline in rainfall by 5.32 mm per decade. Temperature-sensitive crops in Dangur District and Bullen districts are most affected, while rainfall variability impacts yields in Dibate District and Wombera districts. Thematic analysis highlighted concerns over reduced crop productivity, deforestation, and soil degradation, intensified by population growth and agricultural expansion. To address these challenges, the study recommends adopting climate-resilient crop varieties (millet, and sorghum), sustainable agricultural practices (crop diversification), and enhanced climate awareness (adaptation) through education. Policymaking should focus on promoting environmental sustainability to safeguard local livelihoods and ensure agricultural resilience amidst climate variability.

1. Introduction

Climate change and variability, marked by changes in temperature, precipitation patterns, and extreme weather events [1], represent some of the most pressing global environmental challenges, with significant consequences for agriculture, food security, and livelihoods [2,3]. These shifts, driven by both natural and anthropogenic factors, have led to major disruptions in global weather systems [4]. Since the pre-industrial era, the global average temperature has risen by about 1.1 °C, intensifying occurrences such as extreme rainfall, rising sea levels, and disturbances to ecosystems [5]. This warming trend is mainly attributed to increased concentrations of greenhouse gases (GHGs) in the atmosphere, including carbon dioxide [6,7], methane [8], and nitrous oxide [9]. As GHG emissions continue to alter atmospheric dynamics, extreme weather events, such as heat waves, floods, and droughts, are becoming severe [10]. These climatic disruptions jeopardize not only natural ecosystems but also human systems, particularly agricultural productivity, which is highly sensitive to climate variability [11–13]. This poses a significant challenge to achieving SDG 2 (Zero Hunger), which seeks to eliminate hunger and improve food security through sustainable

* Corresponding author.
E-mail addresses: togatamiru@gmail.com (T.T. Wahelo), dan952003@yahoo.com (D.A. Mengistu), tmelesse3@gmail.com (T.M. Merawi).

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