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ASSESSMENT OF SMALL-SCALE HYDROPOWER POTENTIAL, THE CASE OF BIRR WATERSHED, ABAY BASIN, ETHIOPIA

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BAHIR DAR UNIVERSITY
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MSc. IN HYDRAULIC ENGINEERING

MSc THESIS ON:

ASSESSMENT OF SMALL-SCALE HYDROPOWER POTENTIAL, THE CASE OF BIRR WATERSHED, ABAY BASIN, ETHIOPIA

By:
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BAHIRDAR, ETHIOPIA

ASSESSMENT OF SMALL-SCALE HYDROPOWER POTENTIAL, THE CASE OF BIRR WATERSHED, ABAY BASIN, ETHIOPIA

BY:

EYOSIAS AGALU

A Thesis Submitted to the School graduate Studies at Bahir dar Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulic Engineering.

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MARCH, 2023
BAHIRDAR, ETHIOPIA

DECLARATION

This is to certify that the thesis entitled "Assessment of Small-Scale Hydropower Potential, The Case of Birr Watershed, Abay basin, Ethiopia "submitted to partial fulfillment of requirements for the degree of Masters of Science in Hydraulic Engineering under Faculty of Civil and Water Resources Engineering, Bahirdar Institute of Technology, is record of original work carried out by me and has never been submitted to this or any other institutions to get any other degrees or certificates. The assistance and help I received during course of this investigation has been duly acknowledged.

Eyosias Agalu Melesse — 22/3/2023

Name of student — Signature — Date

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Approval of thesis for defense result

I hereby confirm that the changes required by the examiners have been carried out and **incorporated in the** final thesis.

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As member of examining board of final MSc open defense, we certify that we have read and **evaluated the** thesis prepared by Eyosias Agalu entitled "**Assessment of small-scale hydropower potential, the case of Birr watershed, Abay basin, Ethiopia**" and recommend that it be accepted as fulfilling the thesis requirements for degree of masters of science in Hydraulic engineering.

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DEDICATION

To my grandmother, who passed away without seeing my success by the sacrifices she made in my life!!!

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GOD, matchless keeper of the world, you did a lot for me through my life. I can’t give you thanks for you through my infirm words. Just let your name is blessed and praised forever above all in this world.

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ABBREVIATIONS

AHEC	Alternative Hydro Energy Center
AHP	Analytical Hierarchy Process
ASTER	Advanced Spaceborne Thermal Emission and Reflection
CETC	CANMET Energy Technology Centre
CI	Consistency Index
CN	Curve Number
CUP	Calibration Uncertainty Program
DED	Department of Economic Development
DEM	Digital Elevation Model
EEPCO	Ethiopian Electric Power Corporation
EEU	Ethiopian Electric Utility
ESHA	European Small Hydro Association Renewable Energy Association
EREDPC	Ethiopian Rural Energy Development and Promotion Center
FDC	Flow Duration Curve
GIS	Geographical Information System
GPS	Geographical Positioning System
HP	Hydropower Potential
HRU	Hydrological Response Unit
IEA	International Energy Agency
IHA	International Hydropower Association
JICA	Japan International Cooperation Agency
LiDAR	Light Detection and Ranging
LULC	Land Use Land Cover
MCDA	Multi Criteria Decision Analysis
MHP	Micro Hydropower Plants
MK	Mann-Kendall
NDP	Non-Dimensional Parametrization
NED	National Elevation Data
NEP	National Electrification Program
NGO	Non-Governmental Organization

NMA	National Metrological Agency
NSE	Nash–Sutcliffe model efficiency coefficient
PBIAS	Percent of bias
Q	Stream flow
RI	Radom Index
RMSE	Root Mean Square Error
R-R	Rainfall-Runoff
RoR	Run of River
RS	Remote Sensing
SCS	Soil Conservation Service
SHPS	Small Scale Hydro Plants
SPLASH	Spatial Plans and Local Arrangement for Small Hydro
SUFI	Sequential Uncertainty Fitting
SWAT	Soil and Water Assessment Tool
UNECA	United Nations Economic commission for Africa
USDA	United States Department of Agriculture
VALP’s	Validation points
WREAN	Western Regional Energy Agency & Network

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ABSTRACT

Ethiopia is experiencing an energy crisis, particularly in rural areas, while having a wealth of renewable resources, such as hydropower. Among integral steps in hydropower development, the preliminary task is the identification of viable potential project locations with sufficient head and flow and preliminary assessment of hydropower potential. Applying a Geographical Information System (GIS) in combination with hydrological modeling as a remedial strategy to alleviate the difficulties related to on-site measurements in remote and in-accessible hydropower locations is quick and cost-effective approach. The main objective of this study was identifying high potential run-of-river hydropower locations to quantify power potential of Birr watershed, upper Blue Nile basin, Ethiopia by using Geographical Information System coupling it with the Soil and Water Assessment Tool. Head has been identified using Geographical Information System (GIS) from digital elevation model and stream flow at identified location was simulated by using SWAT. Accuracy of model performance was verified using Birr gauging station flow and physical similarity approach of regionalization was also applied for calibrating flow at ungauged watershed. The accuracy of regionalization was further validated by using stream flow from Lah gauging station. Goodness of fit and the degree to which the calibrated model accounted for the uncertainties were assessed with NSE, R^2 , PBIAS,and RMSE of SUFI-2 algorithm. Results indicated that, calibration and validation for stream flow performed very well both for the sub - catchment and the whole catchment. Through the approach, 19 ideal locations with head varying from 10m to 37m were identified and the overall hydropower potential of the Birr watershed was estimated as 75 MW and 877 KW, respectively, when 30% and 95% reliable flow were used for hydropower production. Additionally, it has been estimated that the medium and mean annual power potential of the watershed is 23 MW and 64.9 MW respectively. The results revealed presence of enormous potential from small scale hydropower development in the study area. Furthermore, using a multi-criteria decision-making method, potential sites were ranked based on important variables that directly influence small scale hydropower development in terms of financial and technical aspects. Sites found near the outlet of study area have got higher priority rank due to existence of sites in high head and stream flow area and suitability of geological formation for hydropower development.

Key words: Birr watershed, Hydrological Modeling, small-scale hydropower, SWAT, GIS

1. INTRODUCTION

1.1 Background

Energy crisis across the world has raised due to high increase in population, industrialization, increase in life standard of human beings and depletion of natural non-renewable energy sources (Abdullah et al., 2014; Coyle & Simmons, 2014; Manieniyan et al., 2009; Nalule, 2018). This energy crisis in combination with a natural and human made problem is causing severe social, environmental and economic influence in sustainable life hindering achievement in economic development across the world (Coyle & Simmons, 2014). According to International Energy Agency report IEA (2021),770 million people worldwide do not have access to electricity as of today, primarily in developing nations in Asia and Africa. Additionally, by 2050, the world's demand for power will have doubled (Miskat et al., 2021). Incontestably, there is greater prompt today than heretofore to identify and explore renewable and sustainable alternative energy sources with less environmental impact like small scale hydropower projects (Kober et al., 2020; Zaidi et al., 2018).

Water as main sources of energy has long history since early stage of industrial revolution for grinding mill cereals (Coyle & Simmons, 2014). After wards, advancement in technological innovations and development of electromechanical equipment’s like turbine and generator led to use water as source of electricity (Smil, 2019). Now a days, hydropower is most widely used reliable renewable energy sources which is cost effective and efficient technology in energy production across the world. Hydropower has been one of the main role players in many African power systems and is the most used renewable energy source (Kalitsi, 2003). Hydropower is interesting because of the large scale of potential development, environmentally friendly nature and the low average costs of electricity generated than any other energy generation technology (Hailu & Kumsa, 2021). Furthermore, it is possible to generate constant power throughout the year by constructing storage dam which can serve for many decades. The lake that forms behind the dam can be used for water sports and pleasure activities, irrigation and water supply purpose. Despite of its advantage’s hydropower has also some short comings in respect of technological, economic, social and environmental aspects. Construction of dam is extremely expensive which means the plant have to generate many return periods and transmission cost is high due to existence of hydropower plant sites in remote and inaccessible valley far away from towns and cities.

Construction of artificial reservoir takes wide area which may result relocation of inhabitants causing some social crisis and series environmental and ecological problems (Warnick et al., 1984) One type of hydropower development which offers excellent advantages against the negative factors is small-scale hydropower. After weighing the benefits and drawbacks of using hydropower to produce electricity, Paish (2002) came to the conclusion that small-scale hydropower plants are the best options because they offer a useful, sustainable, and affordable source of energy without having a significant negative impact on the environment.

Birr river is one of large perennial river which is not utilized for hydropower while it is possible to electrify rural communities by developing small scale hydropower scheme from river with few environmental and social impacts. The river is utilized for few small-scale irrigations and the high wet season flow simply flows by holding the fertile soil without giving other benefits to the inhabitants in and near of the watershed. Like any other rural communities of Ethiopia, the communities near and in of Birr watershed are suffering energy shortage for light and cooking. Although high concern is not given to small scale hydropower development for rural electrification in Ethiopia, identification of potential hydropower sites and estimation of hydropower potential of the catchment is important input for policy makers.

Identification of potential project locations with minimal cost and the evaluation of available hydropower potential are essential first steps in the development of hydropower. However, selecting the ideal site with the greatest potential and the minimal negative social, economic, and environmental effects is not an easy task. To determine hydropower potential of a river earlier studies were more dependent on at-site investigations or classical approach (Kusre et al., 2010). Site survey-based assessment of hydropower potential consumes time and money, very difficult and challenging task due to existence of sites in remote inaccessible mountainous areas with rough terrain (Kusre et al., 2010; Zaidi et al., 2018). Due to its simplicity, low cost, and rapid assessment of a site's hydropower potential, GIS and RS-based techniques have recently growing in popularity (Ayele, 2020; Bayazıt et al., 2017; Feizizadeh & Haslauer, 2012; Gergeľová et al., 2013; Larentis et al., 2010; Romanelli et al., 2018). Use of this technology can overcome challenging barriers in inaccessible sites, increase reliability in large extent with short period of time (Kayastha et al., 2018). In recent years the SWAT model has been used widely in assessment of hydropower potential of a catchment by integrating it with GIS and RS technique (Guiamel & Lee, 2020; Kusre et al., 2010; Pokharel et al., 2020; Rospriandana & Fujii, 2017).

1.2 Statement of problem

Ethiopia is endowed with abundant renewable energy resources, which can meet the intent of nationwide electrification (Berhanu et al., 2014). Despite of this, the total electric access rate is around 45% and less than 10% of the rural people are connected to the national grid (Hailu & Kumsa, 2021) which is lowest electricity consumption per capital in Africa and experiencing significant energy shortage (Mondal et al., 2018). The majority of rural residents lack access to electricity and rely on biomass energy, which is diminishing slightly across the nation and radically in some areas (Girma, 2020; Mondal et al., 2018) which is bringing serious social and economic impacts. Therefore, those non-electrified people of country can access electricity by constructing isolated (off-grid) power plants from local available river. Similarly, the rural communities in and near of Birr watershed are suffering shortage in electricity while they can access clean and sufficient electricity from Birr river with ideal topography if small scale hydropower scheme is developed.

In developing small scale hydropower plant, identification of hydropower site and region potential with simple technologies which do not consume much time and cost has to be adopted. In recent years site investigation and assessment of hydropower potential by using advent technology of Geographical Information System and Remote Sensing coupling it with hydrological models has become usual activity across the world although it is phenomenon activity in our country (Guiamel & Lee, 2020; Khan & Zaidi, 2015; Kusre et al., 2010; Pokharel et al., 2020). Even some studies conducted in site investigation and assessment of hydropower potential in Ethiopia were limited to only GIS and RS technology without integrating it with hydrological models (Ayalew, 2021; Ayele, 2020; Desalegn, Damtew, et al., 2022; Teshome et al., 2020). But the usefulness of GIS and remote sensing technologies in assessing hydropower potential of region are enhanced if process based hydrological models could be integrated into it (Kusre et al., 2010; Punys et al., 2011).Therefore, this study is aimed at identification of potential site for run-of river hydropower development and quantification of hydropower potential of Birr catchment by integrating Geographical Information System with Soil and Water Assessment Tool model.

1.3 Objective of the study

1.3.1 General objective

The general objective of the study was to asses small scale hydropower potential of Birr catchment by using Geographical Information System coupling it with Soil and Water Assessment Tool.

1.3.2 Specific objectives

<u>The specific objectives were:</u>

- To assess hydropower development sites for small scale hydropower generation in Birr watershed.
- To determine stream flow at proposed sites along the river by using SWAT model.
- To estimate theoretical and technical hydropower potential of the Birr watershed.
- To prioritize suitable sites for development of small-scale hydropower by considering different technical and financial criterions for selection.

1.4 Research questions

- Are there feasible small-scale hydropower development sites in Birr watershed?
- How much is dependable flow of study river at selected small-scale hydropower locations?
- How much is theoretical and technical hydropower potential of Birr watershed?
- Which locations offer the highest priority for small-scale hydropower production in terms of both technical and financial factors?

1.5 Scope and limitations of the study

In planning and development of hydropower plant for power production at specific site assessment of Pico to higher hydropower plant capacity with impounding reservoir is important. This study is limited to run of river small scale hydropower potential assessment of study area only.

Although there are number of benefits of GIS integrated process based hydrological models for site investigation and assessment of hydropower potential of area, there are some disadvantages. requirement of large volumes of data related to elevation, climate, land use and land cover and soil. Such limitation may lead to inaccurate estimation of parameters like head and stream flow. Therefore, to minimize these uncertainties in parameter estimation in site measurements of stream flow and head with perspective method specially by using surveying equipment is important. However, because of financial limitations, primary data collection to measure head for DEM analysis confirmation was performed GPS only.

For accurate rain fall run off modeling, checking the performance of many hydrological models is better approach. However, evaluating performance of many models and drawing a conclusion in a single study is time consuming and needs a lot of effort. By these reasons this study is limited to model of Soil and water assessment Tool (SWAT).

1.6 Significance of study

Assessment of power potential of Birr river is important for institutions like Ethiopian electric Utility (EEU), Ethiopian rural energy development and promotion center (EREDPC), National electrification program (NEP) and other governmental and non-governmental organizations which are involved in implementing agencies of grid expansion and off-grid electrification for rural area providing highly feasible selected site and its potential to generate electricity from run of river plants. Studying spatial and temporal availability of water resources is also important for proper planning and managing of water resources for present and future uses. In addition to this result is significant for future water resources project development in area as a scenario in predicting stream flow by using model.

2. LITERATURE REVIEW

2.1 General

Economic development and sustainable life of a community is highly dependent on energy. The energy needs and consumption of the world is rapidly increasing in rapid rate specially in developing countries. In addition, electrical energy shortage and depletion of fossil fuel and other non-renewable energy sources is serious in most of the developing countries, contributing to low economic and social development (Nalule, 2018). The situation is worse in rural communities, which are often marginalized from grid-based electricity supply because of socio-economic and technical reasons (Kaunda et al., 2014). Great interest of energy demand specially from renewable and sustainable sources and depletion of resources have increased the need for development of small-scale hydropower plants and other energy options like solar and wind (Thin et al., 2020). Today, small hydropower projects offer emissions-free power solutions for many remote communities throughout the world (Singh & Management, 2020). Many rivers of the world have a plentiful hydropower potential but so far this potential has not been optimally utilized except in a few technologically advanced countries (Zaidi et al., 2018).

Small scale hydropower development does not require construction of high dams and impoundment of large reservoir. Because the majority of scheme is developed by using run of river. This source of energy is major global electricity generation potential with few social and environmental impacts (Tian et al., 2020). Small-scale hydro plants (SHPs) provide an alternative solution to electric grid extension that serves widely scattered communities and local areas which are far from national electric grid as an efficient power supplement with few environmental problems (Ajanovic et al., 2019; Tian et al., 2020). In Run-of-river developments a dam with a short penstock (supply pipe) directs water to the turbines, using the natural flow of the river with very little alteration to the terrain stream channel at the site and little impoundment of the water (Warnick et al., 1984).

It is difficult to identify suitable sites for hydropower development and assess site potential during the planning stage of hydropower projects. Site selection shall be determined based on the water resources and topography with the purpose of sustainable development, utilization, and along with comprehensive consideration of all other socio-economic factors during preliminary site investigation. Geographical information systems and hydrological modeling’s are strong instruments in determining head and stream flow of specific locations which are main parameters to define hydropower potential of site (Kusre et al., 2010; Rospriandana & Fujii, 2017).

2.2 Turbine selection for hydropower

One of the most important elements in hydropower development which are considered as ‘heart’ of hydropower project are turbines. Hydraulic turbines are mechanical equipment’s that convert potential energy (water power) in to mechanical energy (shaft power). Shaft power is used to run generator directly coupled to the shaft of the turbine, thus producing electrical power.

Turbines are broadly classified as impulse and reaction type machines. In the former category, all of the available potential energy (head) of the water is converted into kinetic energy with the help of a contracting zones. The kinetic energy is in the form of a high-speed jet that strikes the buckets, mounted on the periphery of the runner. Impulse turbines are more efficient for high head plants. In reaction turbines, only a part of the available energy of the water is converted into kinetic energy at the entrance to the runner and a substantial part remains in the form of pressure energy. Both pressure and velocity energies are extracted from the flowing water and then converted into shaft power by the runner.

The dominant factors that decide the type of turbine to be used for power generation in hydropower development are head and flow. The choice is also influenced by the intended operating speed of the generator or other loading device for the turbine. Whether or not the turbine will be predicted to generate electricity under part-flow conditions should be considered as it will have an influence on the choice. It is necessary for manufacturers to evaluate technical performance of the turbines, for example, in form of performance curves. This is because the turbine technical performance is one of the factors to look for when selecting a turbine for the particular SSHP site. Turbine performance analysis involves determining its best efficiency point and how the efficiency changes when the turbine operates outside the best efficiency point. Best efficiency point is the operational point, described in terms of runner speed, head and flow, that gives maximum turbine efficiency as shown in Table 2.1.Each type of turbine has a particular range of application and it is often difficult to decide which is the best option (Leyland, 2014).

Table 2. 1 Application ranges of turbines (WREAN, 2000)

Hydraulic Turbines		H(m)	Q(m^3/s)	P(KW)	N_S(r.p.m)
Reaction turbines	Kaplan and propeller – axial flow	2-40 2-20	3-40 3-50	1000-2500 50-5000	200-450 250-700
	Francis with high specific speed- diagonal flow	10-40	0.7-10	100-5000	100-250
	Francis with low specific speed – radial flow	40-200	1-20	500 - 15000	30 - 100
Impulse turbines	Pelton	60 - 1000	0.2 - 5	200 - 15000	<30
	Turgo	30 - 200		100 - 6000	
	Cross-flow	2 - 50	0.01 – 0.12	2 - 15	

For most run-of-river small hydro sites where flows vary considerably, turbines that operate efficiently over a wide flow range are usually preferred (e.g. Kaplan, Pelton, Turgo and crossflow designs). Alternatively, multiple turbines that operate within limited flow ranges can be used. Kaplan is the most flexible turbine that can work between 15% and 100% of the maximum design discharge (CETC, 2004; ESHA, 2004). For very low head sites, flow direction in the reaction turbine runner has to be more axial for best turbine performance results. Kaplan turbine runner is a typical axial flow machine in which runner blades and guide vanes or both can be made adjustable. If both runner blades and guide vanes are made adjustable the Kaplan turbine is described as double-regulated turbine. The double regulation makes it possible, at any time, for the runner to adapt to any head and discharge variation (Kaunda et al., 2014). Single regulated Kaplan allows a good adaptation to varying available flow but is less flexible in the case of important head variation. They can work between 30% and 100% of the maximum design discharge (ESHA, 2004).

Efficiency of turbine is important factor to determine power output of hydropower development. The turbine efficiency is defined as the ratio of power delivered to the shaft to the power taken from the flow. Small hydro turbines can attain efficiencies of about 90% (CETC, 2004). The efficiency of turbine can be obtained from manufacturers/organizations involved in hydropower development. The efficiencies given in Table 2. 2 are recommended by the Japan International Cooperation Agency (JICA). Hydraulic turbines (runner) are designed for optimum speed & maximum efficiency at design head. But in reality, head and load conditions change during operation & it is extremely important to know the performance of the unit at other heads.

Table 2. 2 Small-scale turbine types and their average efficiencies

Type of turbine	turbine efficiency
Pelton turbine	82
Crossflow turbine	77
Francis turbine	84
Propeller turbine	82
Tubular turbine	84

For preliminary power studies, it is usually sufficient to use a fixed efficiency value and ignore the minimum discharge constraint and possible head range limitations (J. Paul Guyer, 2017).

2.3 Hydropower status of Ethiopia

Ethiopia is one of the countries with huge exploitable energy sources from water. The country is well thought out to be the water tower of east Africa with huge hydropower potential estimated up to 45,000 MW (Melesse et al., 2014). As the result of suitable topography and abundant stream flow hydropower has been cheapest and main energy sources in Ethiopia. Despite the huge amount potential of the hydropower resources of Ethiopia, the country's energy sector has been highly dependent on the biomass sources which covers 90 percent of energy consumption (Girma, 2016; Hailu & Kumsa, 2021).

According to report by IHA (2020), with a current electrification rate of 45 per cent, Ethiopia has a plan to increase 25 GW of installed capacity by 2030, with 22 GW coming from hydropower. As of the report, Ethiopia has added 254 MW Energy in 2020 making it second country by adding huge amount of power in Africa next to Angola. Ethiopia ranked first from Africa in 2021 based on total installed hydropower capacity with its total installed capacity of 4074MW (IHA, 2021). This potential is excluding current generated power from Great Ethiopian Renaissance dam (GERD). This massive project in Ethiopia has already begun producing an extra 750 MW of power, which is expected to boost the current potential.

According to Inclusive Green Growth in Ethiopia (UNECA, 2015), out of eleven river basins found in the country, there are 300 selected hydropower sites from eight basins with technical possible power potential of 7877 MW of which 102 are large scale (more than 60 MW) and the rest are small scale (less than 40 MW). There are around 173 SHP sites in Ethiopia of which 74 sites are in Abay basin (Dametew, 2016). Abay river basin is the largest river basin of the country which drains out huge amount of surface water. This basin also contains largest hydropower potential and number of Existing, under construction, and near-planned hydropower projects in Ethiopia (Berhanu et al., 2014).

2.4 Small-scale hydropower and its potential in Ethiopia

2.4.1 General

Small hydropower(SHP) system is one of the renewable energy technologies for generating electricity and mechanical power (Korkovelos et al., 2018; Sharma et al., 2013). Micro-hydroelectric plants (MHP) are now the most durable and dependable method of energy generation outside of the grid, according to the major development organizations involved in the delivery of electricity in rural regions in many countries (Purece et al., 2020). Usually, Small scale hydropower, are used in the rural electrification and does not necessarily supply electricity to the national grid. They are used in isolated and off-grid systems for decentralized electrification. There is no internationally accepted definition of small hydropower and the general tendency all over the world to define small hydro by power output. The category is arbitrary, and to date, there are no widely accepted divisions of degrees of the smallness of hydropower (Castillo-Botón et al., 2020). Classification is dependent of total power available from water for specific place and time. Different countries are following different norms keeping the upper limit ranging from 5 to 50 MW as indicated in Table 2. 3. However, a value of up to 10 MW total capacities has become more generally accepted for definition (Kaunda et al., 2012).

Table 2. 3 small scale hydropower category of some countries

Country	High small hydro capacity rage
United Kingdom	5 MW
Sweden	15MW
Colombia, Australia	20MW
India, China	25MW
United states, Brazil	30 MW
Philippines, New Zealand	50 MW
Ethiopia	10MW

Sources; (AHEC, 2012; Girma, 2016; Meder et al., 2011; Nielsen et al., 2012)

2.4.2 Classification of small-scale hydropower

Within the SHP category, the systems are further categorized into Pico, micro, mini, and small systems. Again, the such classification is arbitrary as well. But most conventional classification of small-scale hydropower which is applied in various small-scale hydropower development manuals (ESHA, 2004, 2011; JICA, 2003) is given in Table 2. 4.

Table 2. 4 Small scale hydropower categories

Small-scale hydropower categories	Pico	Micro	Mini	small
Capacity in power output	Up to 20KW	20 to 100 KW	100KW to 1MW	1-10MW

Small scale classification can be also broadly classified in to two. The first category is storage type of small-scale hydropower in which reservoir is created to meet deficient demand during surplus one. The second in which power generation without reservoir by diverting available river flow via weir or barrage is known as run of river type of small-scale hydropower. It simply allows water to pass through a conduit at about the same rate the river is flowing except for passage through natural and environmental conditions (Zaidi et al., 2018). For small capacities of SHP, run-of-river types are ideal and gaining popularity nowadays because with absence of a reservoir, investment cost per kW of installed electricity is reduced (for small SHP systems, the main emphasis is on reducing investment cost), short implementation time, small site requirement and less environmental and social impacts (Kaunda et al., 2012).

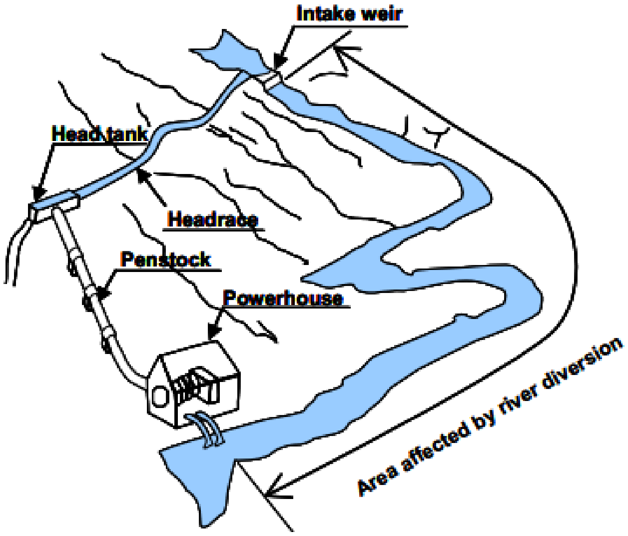


Figure 2. 1 RoR hydropower system (Adhikary et al., 2014; Zaidi et al., 2018)

2.4.3 Advantage and disadvantages of run of river plant

Automatic isolated or autonomous small hydro plants provide an alternative solution to electric grid extension that serves widely scattered communities, as a high efficiency power supplement in urban areas, small industries and for domestic purposes. Namely, there is a great disparity between urban and isolated rural zones, with a consequent imbalance in the accessibility of energy.

In addition to advantages of all hydropower plants, small scale hydropower plants in addition have the following advantages.

- These plants do not need impoundment minimizing human and animal displacement
- These plants are setup nearer to load centers according to requirement since the cost of power transmission is minimum and contribution for rural electrification
- It has almost no environmental impact.
- When compared to solar and wind capacity factor of the plant is high.
- The predictivity of small hydropower plants is very high.

Despite of above listed advantages, small scale hydropower has some drawbacks. Electricity generation in RoR plants is heavily reliant on a consistently sufficient river discharge because they do not require a reservoir. Seasonal variations in stream size are common in many places. There will probably be less flow and hence reduced power output throughout dry seasons. To make sure that the necessary energy requirements are met, careful planning and research will be required.

2.4.4 Small scale hydropower potential of Ethiopia

There are many small rivers with mountainous topography suitable for development of small-scale hydropower in the country. But the market for SHP is still not well developed in the country in which less than 1% of total available potential has been developed (Shanko, 2009). An estimated potential of the Ethiopia from small (1- 10 MW) to micro (11-500KW) hydropower development is estimated to be 1500 to 3000MW. But the country’s power generation dominated by large hydropower (almost 90%). According Shanko (2009), most of the potential sites are located in the Western and South Western parts of the country with variations from place to place depending on mean annual rainfall received by the area which ranges between 300 mm to over 900 mm. At the time, there were only three SHP schemes functional (Sor, Yadot and Dembi) with a cumulative installed capacity of 6.15 MW.

Reconnaissance made in early 1980s identified 18 sites as potential for MHP development in various parts of the country. In late 1980s, in collaboration with a team of experts from Peoples Republic of China, 57 MHP sites were surveyed. The study identified 29 small-hydro power sites as most promising for a short-term development goal based on engineering criteria which include hydraulic and structure layout, construction, access road and financial indices. Designs have also been prepared for these sites. These 29 sites are estimated to have a total installed capacity of 6190 kW. The feasibility of these sites need to be updated both from the engineering and socioeconomic perspectives (Shanko, 2009). As indicated in the report, detail of these studies is available in Ethiopian Rural Energy Development and Promotion Centre (EREDPC) library.

Absence of expertise to fabricate parts, work, and maintain small hydro power plant in the country and inaccessibility of small and micro hydro power spare parts in local market are barriers that hindered the development of small-scale hydropower in Ethiopia (Girma, 2016). In addition, the following are constraints/obstacles for development and implementation of small-scale hydropower projects in Ethiopia.

- Exposure of the country for draught which leads the development of small-scale projects to be less attractive and non-profitable.
- Due to rapid growth in population there is increasing interest in water resources at upstream and downstream for irrigation and other water demand.

- Ethiopia’s prone to natural and human made hazards which has caused some economic difficulties including shortage of foreign exchange to import goods and implement additional infrastructures.
- Lack of appreciation among policy makers of the role of small-hydro as a complementary strategy in both on-grid and off-grid electrification and creation of non-farming income in rural areas.

2.4.5 Small scale hydropower policy of Ethiopia

Formal policy sector in Ethiopia was launched in 1994. To ensure a reliable energy supply and to lessen reliance on fossil fuels, the policy promotes the utilization of local resources and renewable energy sources. The policy sets hydroelectric resource development as top priority due to availability of high potential location suitable to generate electricity at relatively cheaper cost. The government of Ethiopia launched its rural electrification strategy in 2002 as a large governmental program for electrification, consisting of three parts: grid extension by the public utility, Ethiopian Electric Power Corporation (EEPCo), private sector led off-grid electrification and promotion of new energy sources (Liu et al., 2013). Furthermore, the amended policy in 2013 promotes private independent power producer (IPP) to participate in energy generation by developing sufficient incentives and feed in low tariff. The revised policy also gave due attention for rural electrification by using renewable energy based off-grid technology (Teferra, 2002).

The organizations responsible for conducting the grid expansion and off-grid electrification programs for rural areas are Ethiopian Electric Power Corporation (EEPCO) and Ethiopian Rural Energy Development and Promotion Center (EREDPC), respectively. EREDPC is mandated for off-grid access expansion by promoting private sector led off-grid rural electrification through participation of the private sector, cooperatives, community-based organization, and local government where EEPCO cannot cover them due to economic terms.

Small scale hydropower development gets little attention from the government side and have been left to private sector and NGO who are willing to support rural electrification program and contributes a small portion in the energy pool of the country (Girma, 2016). Investment legislation (proclamation No. 37/1996) and its amendment (proclamation No. 116/1998) took a step toward the privatization of the electricity market by allowing domestic and foreign investors to invest in hydropower without size restrictions and domestic investors to invest in non-hydro generation with a capacity of up to 25 MW. Non-hydro generating more than 25 MW remained the sole purview of the state. The amended proclamation 280/2002, along with the related regulation 84/2003, eliminates the final remaining barriers to investment in the power sector but preserves EEPCO's monopoly in the transmission and distribution of electricity for interconnected systems (ICS). Hence, ICS power generation may be carried out by EEPCo or by private sectors that sell electricity to EEPCo. The government is now encouraging the involvement of the private sector in power generation and selling their produce to EEPCO, as a single buyer, for transmission, distribution and commercialization.

Although EEPCO had complete ownership and control of the electric power generation, certain remote towns' mayors and local council offices mobilize the locals to raise money and install their own diesel gensets and isolated grid systems to supply electricity to residential areas and urban service sectors. Beside this, even if there is no practical legal and regulatory framework at present enabling and facilitating the involvement of the private sector in producing and selling of electricity, there exists some type of collaboration with the private sector and the public. In rural communities, it is not unusual to find a number of people using small diesel or gasoline generators to produce electricity for their own use and to sell any excess to the nearby neighborhoods. The widespread customs (Shanko & Ababa, 2002).

2.5 Assessment of hydropower potential of watershed

2.5.1 General

Different steps are involved in development of hydropower plant scheme including feasible site identification and assessment of hydropower potential of site by determining head and flow rate of the river. Assessment of hydropower potential of specific site requires a lot of effort and sometimes such activity requires involvement of many professionals from different disciplines and represents a relatively high proportion of overall project costs. A high level of experience and expertise is required to accurately conduct this assessment. Over the last several decades, a variety of computer-based assessment tools in which integration of GIS and hydrological models is common, have been developed to address this problem and enable a prospective developer to make an initial assessment of the economic feasibility of a project before spending substantial sums of money (Punys et al., 2011).

Hydropower potential of the specific site is function of two main variables, hydraulic head which is the height difference between intake and tail race of the system and stream flow at specific location. Therefore, assessment of hydropower potential of the site is the task which pays great attention on determining these parameters which are entirely dependent on topography and hydrologic condition of the of the site.

The determination of the potential head for a proposing hydropower plant is a surveying problem that identifies elevations of water surfaces as they are expected to exist during operation of the hydro-plant measurement of the elevation and it requires a lot of effort and the task is time consuming due to in-accessibility of hydropower sites as well. Thanks to modern technology, in recent years GIS has overcome this challenging activity by enabling identification of available head from digital elevation model (DEM).

2.5.2 Concept of Potential

Evaluation of hydropower potential begins with defining and classifying the types of potential. According to Blok and Nieuwlaar (2016), potential is the term used to indicate what is possible to be done and it is dependent on how wide we cast our net, what constraints we set for ourselves and what are defined limitations for the aim. General category of potential can be theoretical potential, technical potential, economic potential, profitable potential, market potential, and policy-enhanced potential. In the context of hydropower, three typical definitions sufficient to define types of potential (Permata, 2022) are theoretical hydropower potential, technical hydropower potential and economic hydropower potential.

According to Hoes et al. (2017), the gross theoretical potential expresses the total amount of electricity that could potentially be generated if all available water resources were devoted to the use. The technically exploitable potential represents the hydropower capacity that is attractive and readily available with existing technology. Technical potential takes into consideration the technical constraints during energy conversion process, water conveyance system, when connecting the hydropower to the existing power grid, resulting in a more realistic selected location of hydropower. The economically feasible potential is that amount of hydropower generating capacity that could be built after conducting a feasibility study on each site at current prices and producing a positive outcome. Economic feasibility strongly varies depending on local conditions and social perspectives, and, therefore, requires in-depth studies at each potential site, which is impossible to conduct during preliminary studies.

2.5.3 Application of GIS and RS in assessment of hydropower potential

The technology for assessing hydropower potential has advanced thanks to faster growth in the creation of tools for terrain processing from Digital Elevation Model (DEM) and accessibility of satellite imaging information. It is now possible to extract terrain characteristics from DEM like as drainage network position, length and slope, estimate the elevation difference between two places (in this case, the intake and tail race) using GIS and remote sensing data, and to integrate that information with models to assess the hydrological process. As a result, technology has advanced throughout time, enabling the use of GIS and RS to pinpoint viable sites for hydropower construction and estimate watershed potential at various sizes.(Fasipe et al., 2021; Romanelli et al., 2018; Sammartano et al., 2019; Tim & Mallavaram, 2003; Zaidi et al., 2018).

Kayastha et al. (2018), Proposed and applied Geographical Information System (GIS) approach to assess primary potential hydropower site, explicitly identified highly possible hydropower locations spatially, over a large area in a short time in Bhote Koshi Watershed, Nepal. In the study, 30m resolution DEM was used to generate topographic profile of the boundary stream network. As indicated in the result section of study, the proposed approach can be used for rapid identification of hydropower potential for future hydropower development.

In northern part of Pakistan, the case study of Kunhar river, the applicability of new approach used to evaluate different installation schemes along a river to assess run-of-the-river hydropower potentials using geospatial data techniques by using GIS and RS to select sites exhibiting higher total hydropower potential is applied and presented by (Zaidi et al., 2018). In this study open source Advanced Spaceborne Thermal Emission (ASTER)'s digital elevation model (DEM) and regional hydrologic gauged data are used for identifying the best locations for hydropower plants and draw the conclusion that demonstrating this approach is substantially more cost effective and robust compared to other field-based assessment.

Gergeľová et al. (2013) assessed contribution of GIS technology to the design solutions for potential hydropower assessment and proposed that, model can be an important tool for decision-making in relation to its implementation activities in Hornad river basin which covers the second largest river system in eastern Slovakia. In Egypt, multi- criteria analysis of hydropower site selection and estimation of mini and micro hydropower potential by selecting eight sites is investigated by using application of GIS and RS (Eshra et al., 2021). A number of countries (e.g., Canada, Nigeria, Italy, Brazil, Norway, Scotland and the US) have re-assessed their hydropower capacities based on spatial information of their water stream catchments, developing tools for automated hydro-site identification and deploying GIS-based tools, so-called Atlases, of small-scale hydropower resources on the Interne(Cuya et al., 2013; Fasipe et al., 2021; Palla et al., 2016; Punys et al., 2011; Romanelli et al., 2018). However, a reliable assessment of real SHP site feasibility implies some "on the ground" surveying, but this traditional assessment can be greatly facilitated using GIS techniques that involve the spatial variability of catchment characteristics (Larentis et al., 2010; Palla et al., 2016; Punys et al., 2011; Romanelli et al., 2018).

In order to find potential locations for small-scale hydropower generation and estimate hydropower potential of Gumara catchment of Abay basin in Ethiopia, Ayele (2020) used GIS and RS technologies. Geographical information systems (GIS) techniques were utilized in the study to process satellite photos, delineate the watershed and stream network, and identify 20 possible sites for small scale hydropower projects. In the study, flow rate is determined using the area ratio method of stream flow transferring from gauged to ungauged locations which is not recommended for wide watersheds in which spatial variation of catchment characteristics is significant and not good approach while it is possible to use hydrological models (Emerson et al., 2005).

Teshome et al. (2020) assessed the hydropower potential of Guna Tana landscape, Abay basin covering an area of 3528.16 km² by using GIS. In the study DEM which is freely downloaded from Alaska (vertex.daac.asf.alaska.edu.) with spatial resolution of 12m is used as input parameter to identify head difference between locations for site selection for hydropower potential assessment. As indicated in the study result, twenty potential sites were identified within the catchment and maximum power in the Ribb river was 48,389.98 kW, while in the Gumara river it was 41,984.01 kW. In the study, ten sites from Ribb and ten sites from Gummara river were identified as potential sites with different head and similar stream flow in which it is improbable to have. Similarly, the study misses utilization of hydrological models which advances GIS technology for assessment of hydropower potential.

In many countries, and particularly developing countries, insufficient information on stream networks and topography as well as a lack of expertise and project funding are often burdening for the implementation of new hydropower projects. To identify hydroelectric power opportunities even in remote areas, the hydrological model uses globally available remote sensing data. Stream networks and catchment areas are derived from a digital elevation model (DEM). Hydrological modeling and a GIS-based terrain analysis allow an estimation of the theoretical hydroelectric power potential of catchment (Pokharel et al., 2020).

2.5.4 Application of hydrological modeling in hydropower potential assessment

All rainfall-run off models and hydrologic models in general are simplified representations of the real-world system. They primarily serve to estimate stream flow and to grasp how hydrologic processes work in the area (Sorooshian et al., 2008). Rainfall-runoff models are classified based on model input and parameters and the extent of physical principles applied in the model. It can be classified as lumped and distributed model based on the model parameters as a function of space and time and deterministic and stochastic models based on predictivity of behavior (Devia et al., 2015). A model is deterministic if its behavior is entirely predictable. Given a set of inputs, the model will result in a unique set of outputs. A model is stochastic if it has random variables as inputs, and consequently also its outputs are random.

Hydrological models have many of importance, they are used to estimate runoff from series of rainfall and the meteorological information needed to estimate potential evaporation, estimate river flows at ungauged sites, fill gaps in broken records or extend flow records for longer records of rainfall. A general assessment of the water resources available in a region or a river basin is essential for finding sustainable solutions for water-related problems concerning both the quantity and quality of the water resources (Xu & Singh, 2004). The development of hydrologic models and recent advances in the use of geographic information systems (GIS), have made a good alternative approach for water resources and environmental assessment. Although many watershed models are available now a days to asses water resources of large and small basin they have their own unique properties (Devia et al., 2015). During past decades there has been surprising increase development and use of hydrologic models for simulation of complex hydrological process(Zuo et al., 2016).The selection of model should be ultimately depended on objective of study and availability of resources and data and time scale of analysis (Brannan et al., 2003).

Using hydrological model for river flow estimation, can effectively improve the identification of hydropower sites and assessment of hydropower potential(Kusre et al., 2010; Sammartano et al., 2019).The hydrological model was set up to assess the stream flow at various hydropower potential points. In Birr watershed there are only two gauged stations to monitor stream flow. However, feasible site for hydropower development does not necessarily locate at gauged stations. The potential site may be upstream or downstream of stream flow monitoring site in which flow prediction by using suitable methods is requires. Therefore, SWAT model was used in this study to predict the stream flow at ungauged potential hydropower site.

Thin et al. (2020) estimated run-of-river hydropower potential of Myitnge River Basin by integrating a Geographic Information System (GIS) and Soil & Water Assessment Tool (SWAT) model. In the investigation the hydrological model (SWAT) was designed in order to obtain the values of monthly discharge for all potential hydropower sites. According to the researcher,44 RoR potential sites are identified by considering only topographic factors and reduced to only 20 sites after modeling the stream flow with the help of SWAT. In India, Assessment of hydropower potential using GIS and hydrological modeling technique in Kopili River basin in Assam was proposed and applied by (Kusre et al., 2010). The researcher used soil and water assessment tool to predict stream flow at various locations. In this study the performance of model was calibrated with observed flow data and prediction accuracy is measured through three well known efficiency criteria's. Pokharel et al. (2020) assessed hydropower potential using by SWAT modeling and Spatial Technology in the Seti Gandaki River, Kaski, Nepal.

DİLNESA (2020) used GIS integrating it with hydrological model to estimate hydropower potential of Temcha watershed, Blue Nile basin, Ethiopia. In the study the researcher used Digital Elevation Model from USGS with spatial resolution of 30m to determine head for hydropower potential estimation. Minimum head considered in potential assessment is not clearly explained in the study. Hydropower potential of watershed without stream flow for calibration is not assessed in the study while it can be done via approaches of regionalization. In addition, prioritization of potential sites to give the ranks for viable sites is not conducted in the study.

2.5.4.1 Model selection

The SWAT hydrological model has been successfully used on numerous occasions in many parts of the world for long-term continuous simulations of flow in various catchments with variable hydrologic, meteorological conditions (Akoko et al., 2021). For the purpose of understanding the processes of LULC change impact affects, the SWAT is capable of modeling hydrological processes based on time and space variations (Leta et al., 2021). Numerous earlier research that analyzed hydrological parameters in various places have verified the SWAT model's capacity to simulate stream flow at ungauged watersheds. It has been demonstrated to be a useful instrument all over the world for the assessment of water resources at a wide variety of scales and under various circumstances (Fan & Shibata, 2015; Tufa et al., 2021; Van Griensven et al., 2012).The

SWAT model is capable of simulating hydrological processes from complex catchments with little available data, and it models the main hydrologic elements as accurately as possible(Gull & Shah, 2022). Furthermore, in assessing hydrologic characteristics of gauged and ungauged catchments all around the world, SWAT has demonstrated exceptional efficiency (Liu & Jiang, 2019; Zhang et al., 2019). The model effectively transfers flow parameters from gauged basin to that of ungauged when utilized for hydrological simulations in specific watersheds at any designated watershed departure. The prominent advantage of SWAT model is that it proficient of constant simulation over a long period as much as 100 years (Awasthi et al., 2021).

2.5.4.2 Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) model was developed by the USDA Agricultural Research Service. SWAT can be used to simulate a single watershed or a system of multiple hydrologically connected watersheds. It requires specific information about soil, topography, weather, and land management practices within the watershed. Each watershed is first divided into sub basins and then in hydrologic response units (HRUs) based on the land use and soil distribution. SWAT model considers many parameters impacting on hydrology and simulates the flow and the transport of sediments or polluting elements. It has been developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watersheds with varying soil, land use, and management conditions over long periods of time (Arnold et al., 2012; Dile et al., 2016). The hydrological model is based on the following water balance equation for soil water content (Arnold et al., 2011).

$$SW_t = SW_{t-1} + P_t - Q_t - ET_t - SP_t - QR \qquad 2.1$$

Where, SW_t is the soil water content for the current time step, SW_{t-1} is the soil water content for the previous time step, P_t is the precipitation, Q_t is the surface runoff, ET_t is the evapotranspiration, SP_t is the percolation or the seepage, and QR_t is the return flow.

Detail simulation process of model is briefly described by Arnold et al. (2011). The Simulation of the hydrology of a watershed is done in two separate divisions. One is the land phase of the hydrological cycle that controls the amount of water and sediment loadings to the main channel in each sub watershed. Hydrological components simulated in land phase of the hydrological cycle are canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. The second division is routing phase of the hydrologic cycle that can be defined as the movement of water and sediments through the channel network of the watershed to the outlet. the watershed was partitioned in to hydrologic response units (HRU), which are unique occurrence of soil type, land cove and slope class combinations within the watershed to be modelled. Any parcels of lands within one sub basin that share an equivalent combination of those three features are going to be considered one HRU. HRUs are utilized in most SWAT runs since they simplify a travel by lumping all similar soil and land use areas into one response unit. The overall hydrologic balance is simulated for each HRU, including canopy interception of precipitation, partitioning of precipitation, snowmelt water, and irrigation water between surface runoff and infiltration, redistribution of water within the soil profile, evapotranspiration, lateral subsurface flow from the soil profile, and return flow from shallow aquifers (Awasthi et al., 2021).

According to review conducted by Awasthi et al. (2021), Soil & Water Assessment Tool (SWAT) model is one of the remarkable distributed hydrological models which has been extensively used in hydrological research and to predict the future streamflow of rivers and sediment flow and agricultural production. The reviewers examined the major constraints of modeling using SWAT after praising it as a powerful simulation model for hydrological modeling. The first and main limitation discussed in the paper is time scale problem. Many researchers used month or year as time scale for simulation and daily scale is taken rarely in the study. As concluded by reviewer's effective simulation of hydrological process is achieved by using long time series as time scale for simulation whereas simulation accuracy decreased with the shortening of time step, especially the simulation of daily runoff has systematic errors. On other hand, the review conducted by Brighenti et al. (2019) proposed sub-daily time scale as best simulation process. As discussed by reviewers, 28 scientific articles were reviewed and found that using sub-daily data improves hydrograph peak simulation, while for medium flows use of daily data was better. Monthly time scale of simulation can also accurately predict stream flow of river specially in data scarce areas (Jodar-Abellan et al., 2019; Nigussie et al., 2019).

According to review conducted by Akoko et al. (2021), more than 200 hydrological modeling studies in Africa were conducted by using SWAT model between the years 2015 and 2019. The reviewer grouped these studies into five areas, namely applications considering: water resources and streamflow, erosion and sedimentation, land-use management and agricultural-related contexts, climate-change contexts, and model parameterization and dataset inputs. Water resources studies were applied to understand hydrological processes and responses in various river basins.

Data availability from local sources for modeling is comparatively low; and many researchers prefer to use global data in their analyses. Therefore, using local data and high-resolution spatial data will improve model efficiency.

Application of SWAT model for a variety of problems such as sediment modelling, land use and climate change impact modelling and water resources management in the Blue Nile basin was conducted by different researchers (Galata et al., 2021; Getachew et al., 2021; Kidane et al., 2019; Tigabu et al., 2020; Worku et al., 2021). Hydrological modeling and water resource studies was conducted by Takele et al. (2022). In the study Digital Elevation Model (DEM) with spatial resolution of 12.5m was obtained from Alaska satellite facility (ASF) and Land use/land cover data with spatial resolution of 100m was obtained from Copernicus Global Land Service. The researcher also used Soil map from World Food and Agriculture Organization (FAO). Finally, performance of model is evaluated by using the sequential uncertainty fitting (SUFI-2) algorithm in SWAT-CUP. The coefficient of determination (R^2), Nash–Sutcliffe efficiency (NSE), and percent of bias (PBIAS) were used to measure the performance of the model. There are many articles available online that used SWAT as a technique for hydrological modeling. (https://www.card.iastate.edu/swat_articles/).

2.5.4.3 Regionalization

On watersheds within a given region, measurable data like daily streamflow values or periodic measurements of water quality elements are frequently rare or nonexistent. But for investigations of natural and artificial systems in poorly monitored watersheds, accurate estimates of continuous streamflow in ungauged catchments are essential (Steinschneider et al., 2015). Techniques must be applied to these ungauged catchments so that parameter values can be properly calculated. Regionalization is the process of transferring catchment parameters from nearby or adjacent watersheds to a watershed of interest (Van Liew & Mittelstet, 2018).

Within a certain simulation model, parameters can be regionalized using a variety of methods. Regional averaging is a widely used method that involves averaging model parameters from calibrated watersheds within a specified region and then applying those averages to uncalibrated watersheds within that region (Merz & Blöschl, 2004). The spatial separation between a watershed of interest that is not gauged and nearby calibrated watersheds which are presumptively similar in terms of their watershed attributes and corresponding parameter values is the foundation of the second regionalization technique, known as nearest neighbor (spatial proximity). In this method, it is assumed that the ungauged basins are already located in homogeneous regions and geographically similar regions (Samuel et al., 2011). The donor strategy is a third regionalization technique that is frequently mentioned in the literatures. The principle of this approach is to locate a donor watershed within a given region that, in terms of its watershed features, is most comparable to the relevant ungauged watershed and to transpose the calibrated parameter set to that watershed. There have been reports of kriging and regression approaches to regionalization in various literatures (Merz & Blöschl, 2004; Van Liew & Mittelstet, 2018; Vandewiele & Elias, 1995). However, kriging method requires refined model parameter datasets and it is not recommended for basin with small number of monitored data (Gitau & Chaubey, 2010).

Bárdossy (2007),demonstrated how near-equal model performance may be attained across a large range of parameter combinations as long as one parameter balances out the effect of the other. This is true even for a simple two-parameters of modeling. He stated that in order to retain the impact of their interactions, parameters from gauged catchments should be moved to an ungauged location as complete sets (as is done in the spatial proximity and physical similarity techniques).In other hand other strategies, including as regression and global averaging, have been devised to take into account equifinality by establishing links between parameters and catchment characteristics either a priori or iteratively throughout the calibration process. While both of these techniques enhance parameter identifiability, they have had only modest success in enhancing regionalization outcomes. While using regression approach the structural flaws in hydrologic models must be considered because they prevent the identification of parameters to represent particular hydrologic processes and prevent meaningful relationships between the elements of conceptual models and physical catchment characteristics that can be used for regionalization.

In order to produce SWAT parameter values that the model can apply to ungauged watersheds with a particular level of accuracy, (Gitau & Chaubey, 2010) examined two regionalization approaches (global average and regression) at three gauged watersheds in Arkansas. In the study, these two techniques were chosen since they are popular methodologies and the given data was adequate for the necessary analysis. The researcher compared the result by using the approaches for each catchment, finally, result suggested that any one method worked better for some watersheds but not for others.

In order to regionalize parameters in the Soil and Water Assessment Tool (SWAT) on eleven watersheds located in the Dissected Plains, Plains, and Rolling Hills Landforms in the eastern part of the State of Nebraska, USA, Van Liew & Mittelstet (2018) compared all five methodologies mentioned above. The researcher used different number of calibration and validation catchments for every land forms and findings of study show that the average regionalization, nearest neighbor and donor methods performed unsatisfactory results.

For hydrological modeling of an ungauged urban watershed using the SWAT model, the river flow data at the outlets of the Vadodara city watershed were based on observed data from Khanpur station, which is 37.2 km away from the city with relatively similar catchment characteristics (E. Sisay et al., 2017). The area ratio approach of regionalization is used in the study to convert stream flow from gauged station to non-gauged.

Using the Soil and Water Assessment Tool, Roth et al. (2016) assessed a model parameter transfer from a 100-hectare large sub watershed (Minchet) with observed stream flow data to a 4800 ha of catchment (Gerda) in the highlands of Ethiopia. In the study both Minchet river is called Gerda at exit of basin. Both locations have observed stream flow. The intension of researcher was to evaluate effectiveness of physical similarity approach of regionalization in the catchment. Firstly, calibration and validation were done at small Minchet watershed and then determined watershed parameters were completely transferred to the point where hydrological data monitoring at Gerda is found by applying physical similarity technique. Finally, validation was conducted by using both stream flow data's from Minchet and Gerda outlet at downstream. Results show that calibration and validation for streamflow performed very good for the sub catchment as well as for the entire catchment which is 48 times larger than calibrated catchment using model parameter transfer.

2.6 Identification of best site for hydropower development

Dam site selection is the procedure of considering many factors to identify ideal locations for particular types of dams and reservoirs. Identification of the best hydropower site is a decision-making process that involves the examination of various criterions. Even though head and stream flow are main factors to be considered in estimating power potential of the site in hydropower development, there are many basic factors which have to be taken in to account. The site which have sufficient stream flow and head is not necessarily best and suitable for development of hydropower scheme. Project site should be feasible in many prospects including economic, technical, environmental and social impact criterions. The topography and geology shall be suitable for planning the relevant structures of the hydropower station and for the purpose of Power evacuation/transmission: the hydropower station has to be close to the load areas or close to the power grid access and transportation with different options shall be evaluated and available. In addition to this, avoiding natural resources, protected areas, heritage areas and cultural heritage sites is other criteria during planning hydropower development at the site.

2.6.1 Fundamental factors in hydropower site Prioritization

Selecting a suitable site for a dam requires comprehensive consideration of many factors which include the watershed properties, such as slope, soil, geology, land cover and catchment, as well as social-economic factors, such as proximity to road and proximity to river among others.

The set of qualitative and quantitative criteria's to be considered are dependent on type of hydropower development, size of project and even factors are site specific. Construction of dam that creates the reservoir causes complex environmental, social and economic impacts. When intended hydropower development is composed of creation of artificial reservoir, the number of criteria's to be considered during site selection are more than that of small-scale hydropower development to avoid social, economic and environmental influences.

One of main factor to be considered during site selection for reservoir construction is land use land cover (Abushandi & Alatawi, 2015; Dai, 2016). The land cover of an area represents how the land is now used, its pattern, the significance of that usage in relation to the people, and its relationship to the current development. Site selection for construction of reservoir should be far away from settlement to avoid displacing the community near the project and should avoid deforestation of existing forest. In addition to this protected area natural heritage, parks and high-grade agricultural land should not be influenced by constructed reservoir.

Topography is one of another basic factors considered in the construction of hydropower project with an appropriate reservoir. Topography becomes a dominant control on flow routing through upstream catchment (Abushandi & Alatawi, 2015). Topography is crucial not only during site selection for purpose of dam safety but also the available power gain from hydropower defined by topography. The higher topography the higher is available head corresponding to higher power. The existence of the secondary valley or stone abutments with suitable topography around the main river for constructing dam spillway is important (Yasser et al., 2013). Slope also affects the safety of dams and power houses since large degrees of slope has a higher risk of landslide and gives more pressure on foundations (Njiru et al., 2018).

Geology is another crucial factor that has great influence on safety of dam and power house. The life span of dam , powerhouse and other system components is highly dependent on geological formation of the site. Geology also reflects availability of construction material around the site. Competent rock foundations, which include igneous rocks like granite among others, offer a comparatively strong resilience to erosion, filtration, and pressure. A site with an impermeable geological/dam foundation and no leaks is one of the most crucial elements since it makes building easier and ensures a sturdy structure.

The optimal site for small-scale hydropower development is chosen with an view toward maximizing the project's benefits rather than avoiding its negative effects on the environment. Because small scale hydropower plants are having no/less environmental impact since there is no need of creating reservoir that accommodate large area. Power which can be generated from the location, available stream flow, available head (topography), Geology, and accessibility of site (road proximity) are considered in prioritization of site for small scale hydropower development. The dam site should be easily accessible, so that it can be economically connected to the required users. The nearer the dam to the major roads buffer i.e. ≤1000 m was recommended by Njiru et al. (2018). Site prioritization is not necessarily an optimization problem either, as all classes of criteria are analyzed and evaluated relatively.

2.6.2 Application of GIS based hierarchy process in site prioritization

Despite of its strength in spatial analysis, GIS alone lacks the skills to integrate all decision-related aspects of land suitability evaluation. Instead, it should be combined with other instruments for evaluation and assessment, such as methods of AHP Multi-Criteria Decision Analysis (Njiru et al., 2018). AHP is a multicriteria decision-making process that represents the issues with hierarchical organizations. Priorities for alternatives are created depending on the user's judgment or experts opinion (Saaty, 1987). Multi-Criteria Decision Analysis technique is based on the three analysis principles of binary comparison, summarizing, prioritizing, and choosing. It is used in GIS to specify weights for the chosen criteria and has the capacity to handle conflicting judgments (Njiru et al., 2018). For the purpose of choosing the best location to build a dam, the usage of GIS and AHP Multi-Criteria Decision Analysis recommended by (Njiru et al., 2018) is one of the most powerful and simplest techniques for solving complex problems (Yasser et al., 2013).

By combining GIS and AHP Multi-Criteria Decision Analysis, Njiru et al. (2018) sought to analyze hydrological data for the selection of a dam site and determine the hydrologic characteristics of the area that would be suitable for a dam building. The approach was based on considering seven characteristics, including topographic (slope), geological, soil, catchment area, land cover, proximity to rivers, and proximity to roadways. In the study, slope factor was considered as most influential in which maximum rank was given from other criteria. Each criterion is given priority in the order by using information from past studies on the location of dams and the guidance of specialists on the factors affecting that decision.

Yasser et al. (2013) chose the dam site using a multi-criteria decision-making process to construct an earthen dam with multiple uses in Harsin city at the Iran's western region. In order to achieve that, first, the powerful set of criteria were used to locate the earth dam site and then extensive literature review and the opinions of the experts was used to give ranks for criteria's the study, around nine attributes were used to select best site of dam for multipurpose reservoir.

Based on the grid based raster map of in-stream power, discharge, head, and accessibility of Gumara watershed, Ayele (2020) prioritized suitable hydropower potential sites of the Gumara river basin. The results for the raster map standardization of the Gumara watershed's in-stream power, discharge, head, and accessibility maximum weight is given for power followed by stream flow and head during MCDA. Least weight is given for Accessibility in the analysis. Geology which critically affects dam site is not considered in the study.

In order to locate potential sites for the construction of a multi-purpose dam at the Chemoga watershed, Gebresilasie et al. (2022) suggested and applied Remote Sensing and Geographic Information System (RS and GIS) methodologies, the dam suitability stream model, and multi-criteria decision analysis. Six influencing factors were used to identify suitable dam sites for multipurpose dam building using the model's suitability stream and overall suitability output maps. Lists of fundamental influencing factors that were considered in analysis include stream order, slope, runoff potential, land use, geology, and distance to road. The study's biggest weight was placed on stream order above all other parameters.

In Ethiopia, GIS based AHP approach as MCDA is proposed and applied for dozens of studies including site selection for multipurpose reservoir (Gebresilasie et al., 2022),Land suitability analysis for surface irrigations (Balew et al., 2021; Girma et al., 2020; Hagos et al., 2022; Muluneh et al., 2022; Negasa & Wakjira, 2021; Nigussie et al., 2019; Wubalem, 2021), construction of check dams(Murugesan et al., 2021), impact of large hydropower project on downstream countries (Soliman et al., 2016), best site for rain water harvesting (Gashaw et al., 2022), land fill site selection (Sisay et al., 2021), landslide susceptibility evaluations (Abay et al., 2019; Desalegn, Mulu, et al., 2022; Melese et al., 2022; Tesfa & Engineering, 2022), modeling erosion hotspot areas (Andualem et al., 2020; Halefom et al., 2019; Sinshaw et al., 2021), ground water potential assessment and mapping (Abrar et al., 2021; Gebru et al., 2020; Haile et al., 2022; Melese & Belay, 2022) were conducted. As far as my knowledge is concerned, studies on application of Geographical information system and integration of analytical hierarchy process for selection of small-scale hydropower site by considering basic influencing factors including geology are not proposed and applied yet.

3. MATERIALS AND METHODS

3.1 Description of study area

3.1.1 Location

In the study, Birr watershed which is one tributary of Abay river has been considered. Birr river originates from locations of higher elevation near Adamas mountain and joins Abay river at latitude 1138238.06 m N and longitude 286382.49 m E after joining the Temcha river at latitude 1142322.67 m N and longitude 293856.19 m E. The total area of Birr catchment till its confluence Temecha river is 3159 square kilometers. In the study, the confluence points of Birr and Temecha rivers was used as the catchment outlet. Geographically, the catchment area lies between 10° 20'N and 11° 10 N latitude and between 37° 0' E and 37° 40' E longitude. Six administrative weredas of west Gojjam zone of the Amhara national regional state drained by river include Sekela, Quarit, Degadamot, Jabi tehnan, and Womberima weredas, as well as very minor portions of Banja wereda of Awi zone.

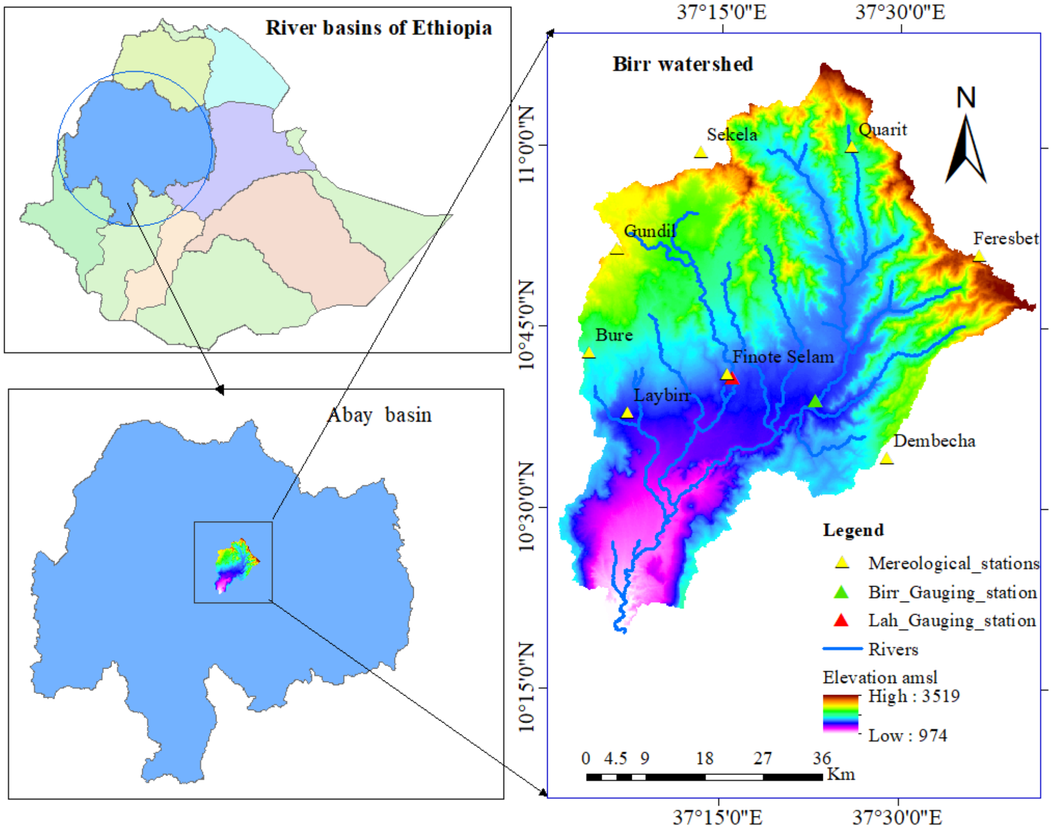


Figure 3. 1 Location map of Birr watershed

3.1.2 Climate

According to traditional agro-climatic zones classification of Ethiopia Alemu et al. (2009), which are classified based on linking factors of altitude, annual rainfall and temperature, the Birr watershed is grouped under *Woinadega*, *Dega* and *Wurch*. Daily precipitation of eight stations in and near of the catchment were collected and analyzed from 1990 to 2019. The catchment has unimodal distribution of precipitation. As observed from data analysis, the study area's mean annual precipitation ranges from 1189 mm to 1552 mm. June and July are the principal months where the highest record of precipitation occurs in the catchment. The Gundil station records the highest annual precipitation whereas the Laybirr stations of the area show lower annual precipitation record.

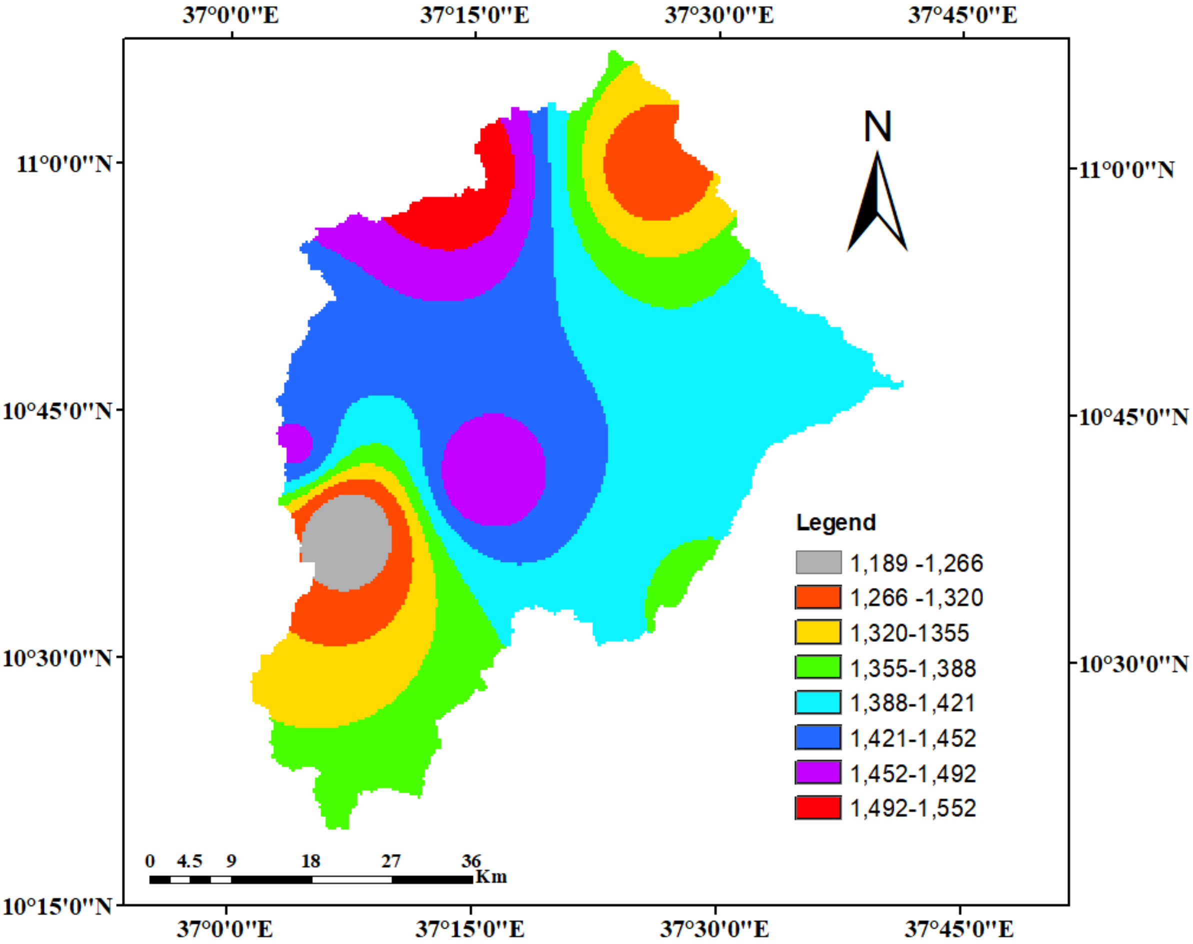


Figure 3. 2 Annual precipitation of Birr watershed

The maximum temperature of the area is monitored in the lower areas of the catchment, supporting its inverse relationship with elevation, according to recorded temperature data at metrological stations. The area's maximum mean daily temperature ranges from 24°C to 31°C, and these temperatures are measured at the Sekela station in Gish Abay and the Laybirr station close to Birsheleko, respectively. The catchment's minimum mean daily temperature ranges from 10 to 15 degrees Celsius.

3.1.3 Topography

It is crucial to thoroughly research and analyze the topography of the area in order to assess its hydropower potential. The head is a key element in the assessment of hydropower potential and should be determined by care full topographic analysis. It also determines how much surface flow and underground flow enters the stream (Wang et al., 2018).

To extract the topography and do further terrain analysis, a free digital elevation model with a spatial resolution of 12.5 m was obtained from the Alaska Satellite Facility (https://asf.alaska.edu). The region's topographic height ranges from 3519 meters above sea level (amsl) near Adamas mountain to 974 meters above sea level at the outlet of the Birr watershed. Slope of watershed is yet another crucial topographical parameter that influences the spatial distribution of water resources. Furthermore, hydropower plants generate electricity by using the difference in elevation of a river.

Table 3. 1 Slope of study area (Jahn et al., 2006)

Slope description	Slope class	Area(km^2)	Percentage
Flat to very gentle sloping	0-2	154.9	4.9
Gently sloping	2-5	632.6	20.0
sloping	5-10	801.9	25.4
Strong sloping	10-15	402.1	12.7
Moderately steep	15-30	621.8	19.7
steep	30-60	461.5	14.6
Very steep	>60	83.4	2.6

The river gradient is studied by Digital Elevation Model so that the topographic features can be determined and used most effectively. The higher portion of the watershed is categorized as sloping topography based on the slope of the Birr catchment that was extracted from the DEM. It accounts 25.4 % of total area where as 4.9% of area accounts flat topography as shown in Table 3.1

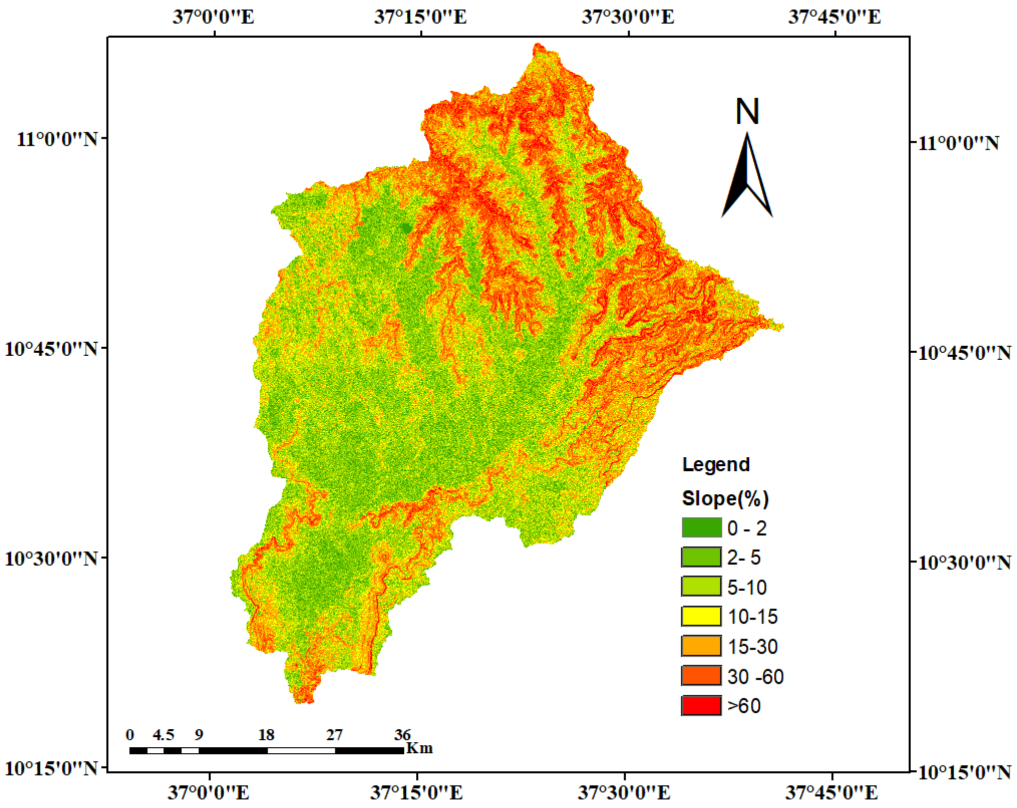


Figure 3. 3 Slope class of Birr watershed

3.1.4 Land use land cover

According to a land use and land cover map that was obtained from Amhara design and supervision works enterprise, most area of study area is covered with cultivated crops which accounts for 68.8% of the area's land use activity. The remaining main land use and land cover types of Birr watershed is built up area (1.7%), forest land (7.28%), grass land (11.71%), shrub and bush land (10.36%) and very small portions of water body and marsh land which accounts for 0.11% and 0.02% respectively.

3.1.5 Soil type

Another element that influences watershed hydrology is soil characteristics. Physical properties of the soil affect the catchment's hydrology, hence precise knowledge of these components is crucial in studying hydrology of specific area. According to soil map obtained from Amhara design and supervision works enterprise seven dominant soil groups in the area most of which are characterized by clay texture are Chromic Luvisols(18.86%), Chromic Vertisols(31.44%), Dystric Nitosols(11.5%), Eutric Nitosols(19.11%), Lithosols(8.85%), Orthic Acrisols(1.34%) and Pellic Vertisols(8.89).

3.1.6 Geology

To determine the risk of landslides and settlement of any structure, a geological overview is required. Any power plant site requires a suitable landform, which is frequently determined by the underlying geology that specifies the underlying structure and indicates the risk of slips, leakage, and whether or not hard rock excavation will be required. In a region where landslides are a risk, a hydropower scheme might not be practical. According to Abay basin geological data acquired from Abay basin authority conducted by Ethiopian geological survey, there are six types of geological formation in the study area, over 93% of area is covered by different types of basalt. Almost all northern part of catchment and western portion are classified under termaber basalts and quaternary basalts respectively. The remaining portions of watershed specially along Birr river reach are composed of high-grade metamorphic rock and Adigrat sand stones.

3.1.7 River networking and water resources utilization

Digital Elevation Model of 12.5m resolution was used to extract drainage networking with in watershed. Birr river is large perennial river which originates from highland parts of Adamas mountain and joins Abay river after joining with many tributaries. The tributaries Lah, Leza, gungun, Tikurwuha, Geray, and Guysa drain the watershed and join the Birr river at various locations. The accuracy of extracted river network from DEM was verified by comparing it with Ethiopian river network retrieved from world bank water data sources((https://wbwaterdata.org/). As hydropower plants consume river water, investigation of river usage conditions is important to look into the river utilization situation when planning a project. The use of rivers involves the production of hydropower, as well as inland transportation, drinking, irrigation, and industrial water supply. Still there are no intended/implemented hydropower projects in the area. But there are completed irrigation projects in Birr watershed. Geray small scale irrigation is one of the schemes in the area which is located 10’ 60’’ latitude and 37’26’’ longitude in Arbaetuensisa Keble located 5 km from Finoteselam in West Gojam zone. The maximum diverted discharge from the stream used for design of main canal for the scheme is 1.54 m^3/s. The study conducted by (Checkol & Alamirew, 2008) reported the flow in main canal as 1.1 m^3/s. Another irrigation project with diverted flow 0.3 m^3/s is Lah shemibekoma small scale irrigation. The flow retained at U/S of potential hydropower sites for irrigation demand has to be deducted in assessing firm power only. For remaining potential with 30 % and 50% dependable flow, the diversion irrigation water has not to be deducted from available flow. This is due to reason that irrigation water is demanded for four months per year (33%) only which implies entire flow is available over 66% of the year.

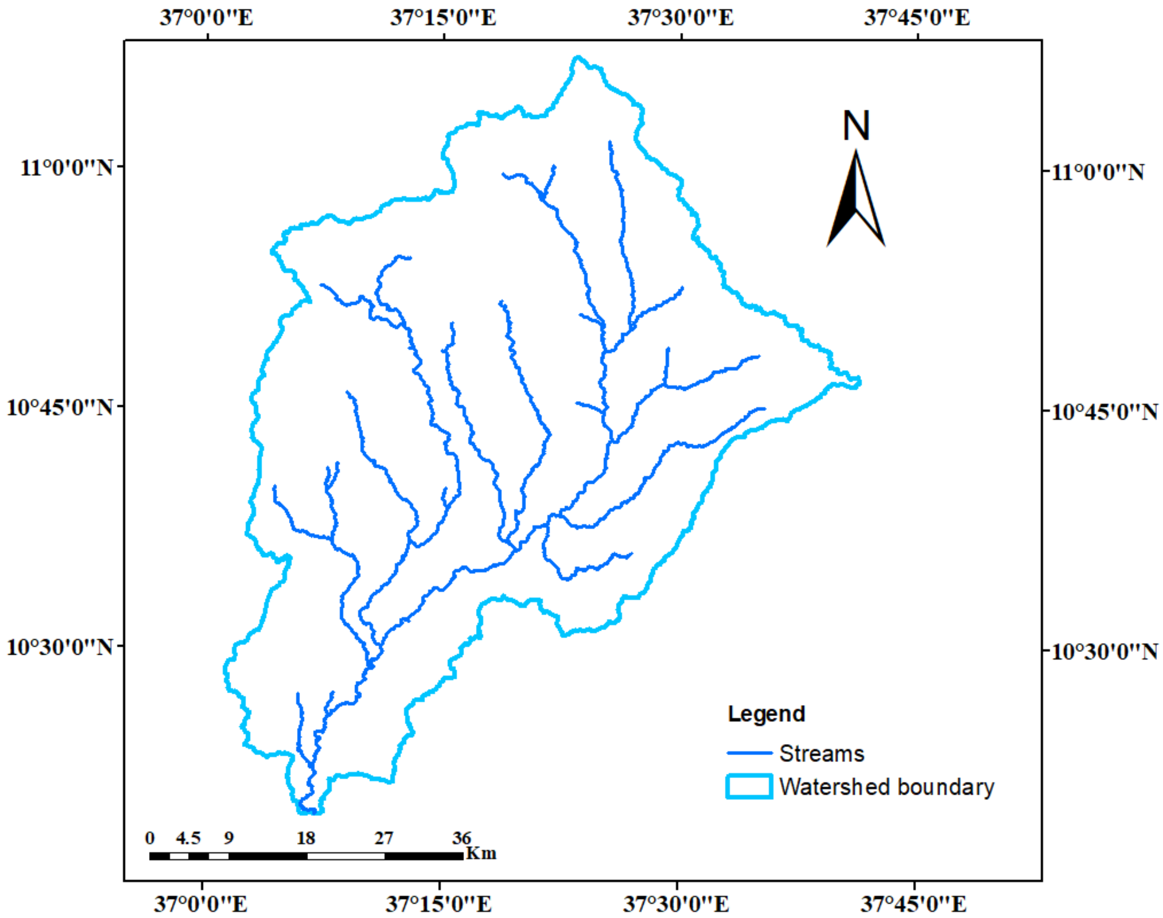


Figure 3. 4 River networking with in Birr watershed

3.1.8 Accessibility

The Birr watershed is traversed by the main trunk route between Dembecha and Bure. Additional gravel-made roads connecting Jiga to Genetambo-Quarit, Burie to Birsheleko, Kuch to Ayehu, Yechereka to Enamora-Kurfa,Mankusa to laybirr,Mankusa to Agut allow access to the Birr watershed. Road map data from the Ethiopian geospatial information agency is retrieved, and it is helpful as one of the deciding factors for determining which hydropower sites should be prioritized. The road system around the watershed is shown in the following figure.

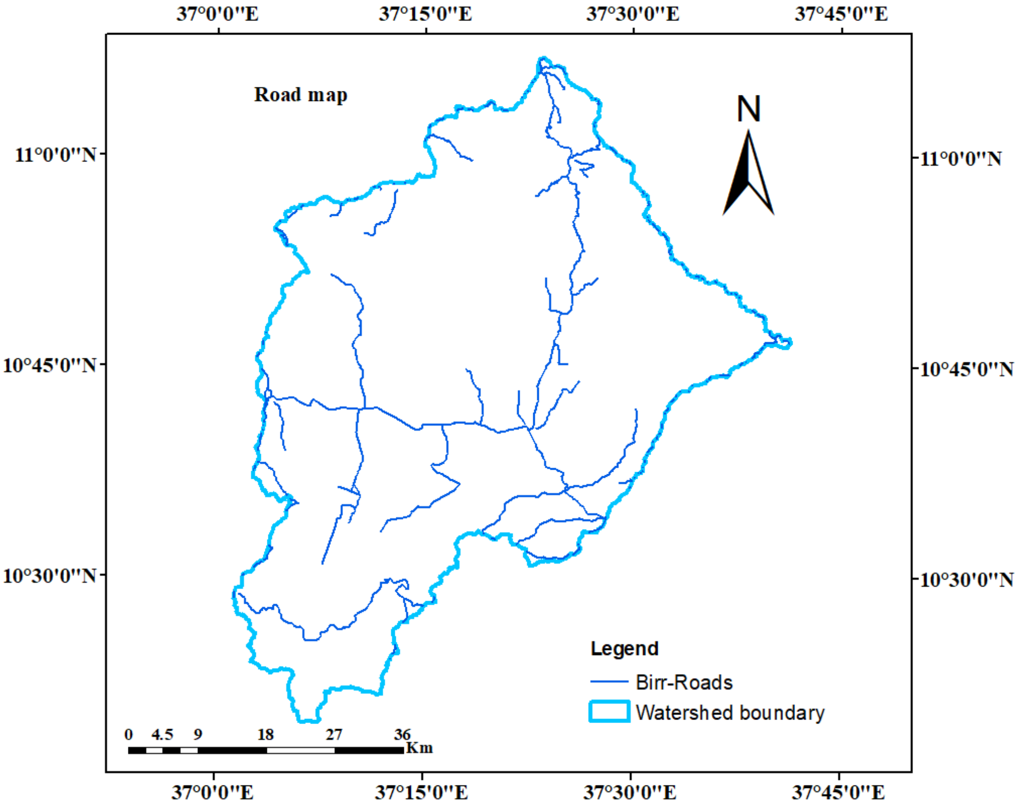


Figure 3. 5 Road networking of study area

3.1.9 Sunshine, relative humidity and wind speed

Nearly all of the energy that reaches the surface of the earth comes from solar radiation. Thus, the length of the daily daylight hour affects radiation and potential evapotranspiration in turn which affects formation of surface and sub surface flow. Large amounts of liquid water can be converted into water vapor using solar radiation, the world's most powerful energy source. The location and season of the evaporating surface affect the amount of radiation that may be able to reach it. The potential radiation varies at different latitudes and during different seasons as a result of variations in the sun's position. The sunshine hour of station collected from NMA is converted to solar radiation using angstrom formula which is applicable approach to predict global solar radiation to great extent in so many locations (Agbo, 2013; Njoku et al.). Maximum and minimum solar radiation of the area was estimated as 20.4 and 18.7 MJ m^{-2} day^{-1}.

Wind speed of the area is another metrological parameter which is utilized by SWAT to estimate stream flow of the area from rainfall series data. The removal of vapor is mostly dependent on wind and air turbulence because they move a lot of air across the evaporating surface. When water is vaporized, water vapor progressively fills the air above the evaporating surface. The driving power for removing water vapor and the rate of evapotranspiration are both reduced if this air is not consistently replaced with drier air. The wind speed of Birr watershed ranges between 0.3m/s to 1.4 m/s as observed at Laybirr station.

Relative Humidity (RH) is a percentage measure of the quantity of atmospheric moisture in the air compared to what it would be if it was saturated. It is one of metrological data required by SWAT for simulating stream flow. Maximum and minimum average monthly relative humidity of the study area which is recorded at Laybirr station is 79% and 45.5% recorded at the months of July and April respectively.

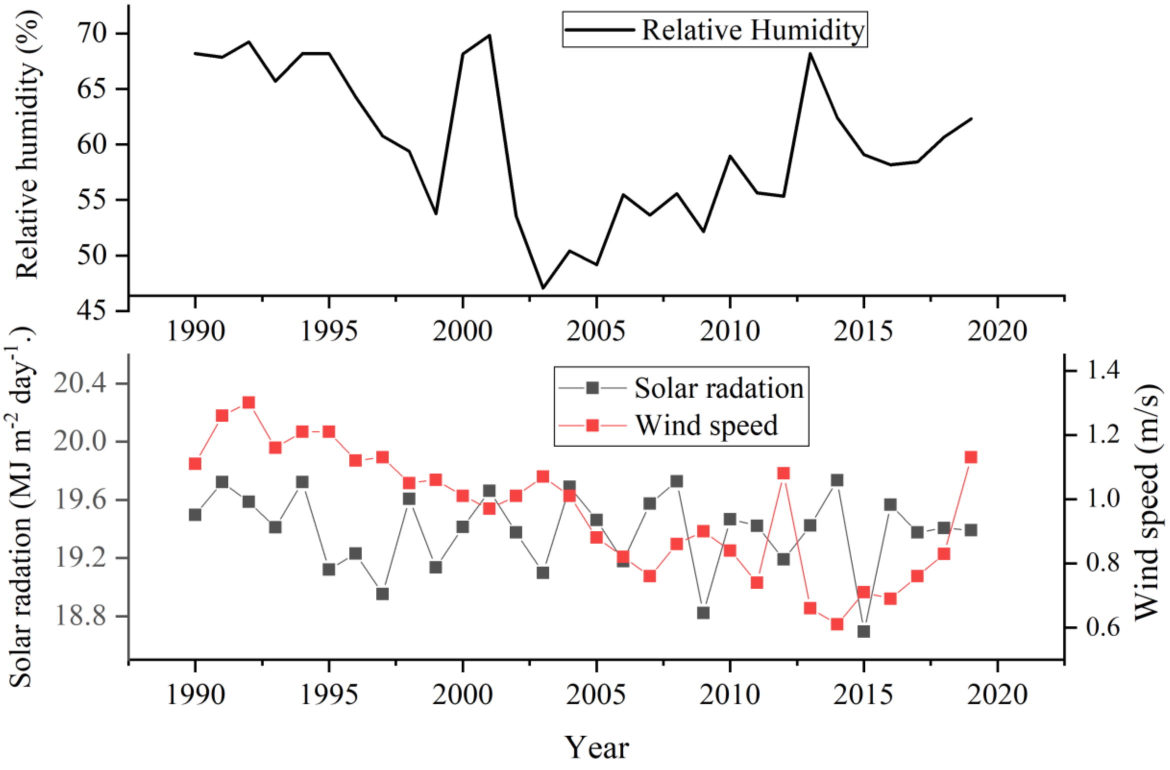


Figure 3. 6 Relative humidity, solar radiation and windspeed

3.2 Data collection and analysis

3.2.1 Hydro-metrological data collection

Assessment of hydropower potential by using GIS and hydrological modeling requires weather time series data of precipitation, maximum and minimum temperature, wind speed, solar radiation and relative humidity. The fundamental driving force behind the model is rainfall, and the location of rainfall stations has a significant impact on how well it can simulate and predict the future. The modeling of surface and groundwater in a river basin will be impacted by the temporal distribution of precipitation and other weather data. Therefore, it is preferable if well-represented precipitation patterns at the catchment size are used (Brighenti et al., 2019). Eight weather stations which contribute in the catchment are selected based on data availability, extent of contribution to the catchment and quality of data. Figure 3. 7 shows percentage of areal contribution of selected metrological stations for study area.

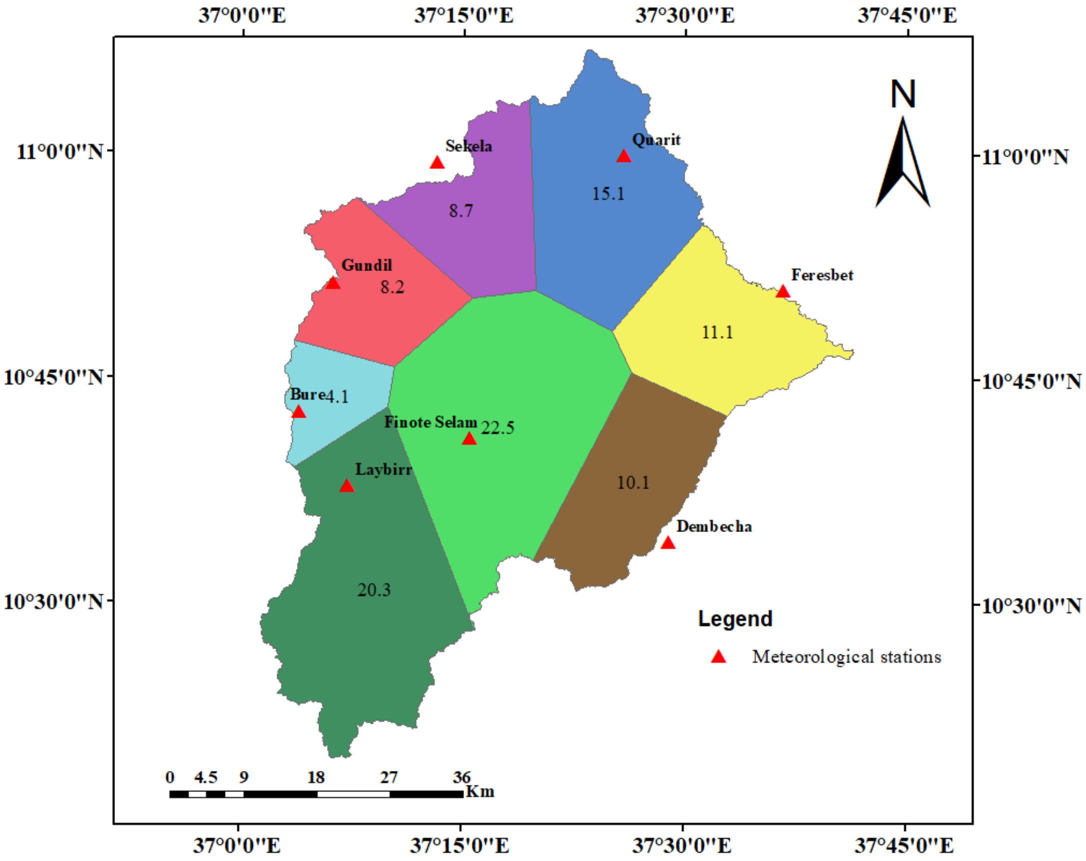


Figure 3. 7 Meteorological stations' contributions to the study region

To assess hydropower potential of the Birr watershed by using GIS and Hydrological models, collection of long periods data of recent time was tried to increase accuracy of work. Therefore, precipitation and temperature data of eight stations of 30 years (1990-2019) were collected from national metrology agency. Furthermore, only the laybirr station has access to the remaining weather time series data that serve as the SWAT model's fundamental inputs. SWAT weather generator is used to fill in the series for the remaining stations that are lacking wind speed, solar radiation and relative humidity. The following table summarizes observed mean annual precipitation of stations.

Table 3. 1 Annual precipitation of stations

Stations	Bure	Gundil	Quarit	Feresbet	Dembecha	Finoteselam	laybirr	Sekela
Longitude	37.13	37.10	37.25	37.61	37.49	37.05	31.12	37.21
Latitude	10.71	10.86	10.59	10.85	10.56	10.72	10.63	10.99
Annual pcp	1463	1449	1287	1414	1383	1489	1189	1561

Hydrological data (stream flow) was used for calibration and validation of stream flow generated by using Soil and Water Assessment Tool (SWAT). Daily observed stream flow monitored at Birr gauging station near Jiga (1990-2006) and Lah near Finoteselam were obtained from Abay basin authority. It is true that using recent hydro-meteorological data would increase the correctness of results when studying and analyzing hydrology. It would be desirable to calibrate model performance using hydrological data from the same year as metrological data used for simulation, if data availability does not prevent its use. Since considered simulation period for this study spans from 1990 to 2019, it could be preferable that if it was calibrated using the corresponding year's observed stream flow. Additionally, testing models by using observed data from numerous stations improves the outcome and verifies the accuracy of the model. Nevertheless, study catchment is one of data scarce area in terms of space and time regardless of its potential for different water resources utilizations. There are only two hydrological data monitoring stations with in study area. One which have relatively best hydrological data from others in terms of data quality, spatial and temporal coverage is monitored at Birr gauging station near Jiga. Data from this station contains stream flow of the river draining 978Km^2 of the catchment and it has data from time period only up to 2006 and from then till now stream flow of station is not available. As observed from collected data, maximum annual precipitation is recorded in year 1992 and minimum is recorded in year 1990. Mean annual stream flow of Birr river monitored at Birr gauging station near Jiga is 196 m^3/s. Annual stream flow of river at Birr gauging station in m^3/s is shown in Figure 3.8

Another station in the watershed with few year's accurate observations is monitored at Lah hydrological gauging station found near Finoteselam. The area of Lah watershed at this gauging station is 289Km^2. The station has five years continuous records of stream flow (1997-2001) only. Mean annual stream flow of river is 80 m^3/s and the series of recorded stream flow data were used for validation of regionalization approach which is used to calibrate model output at ungauged catchments.

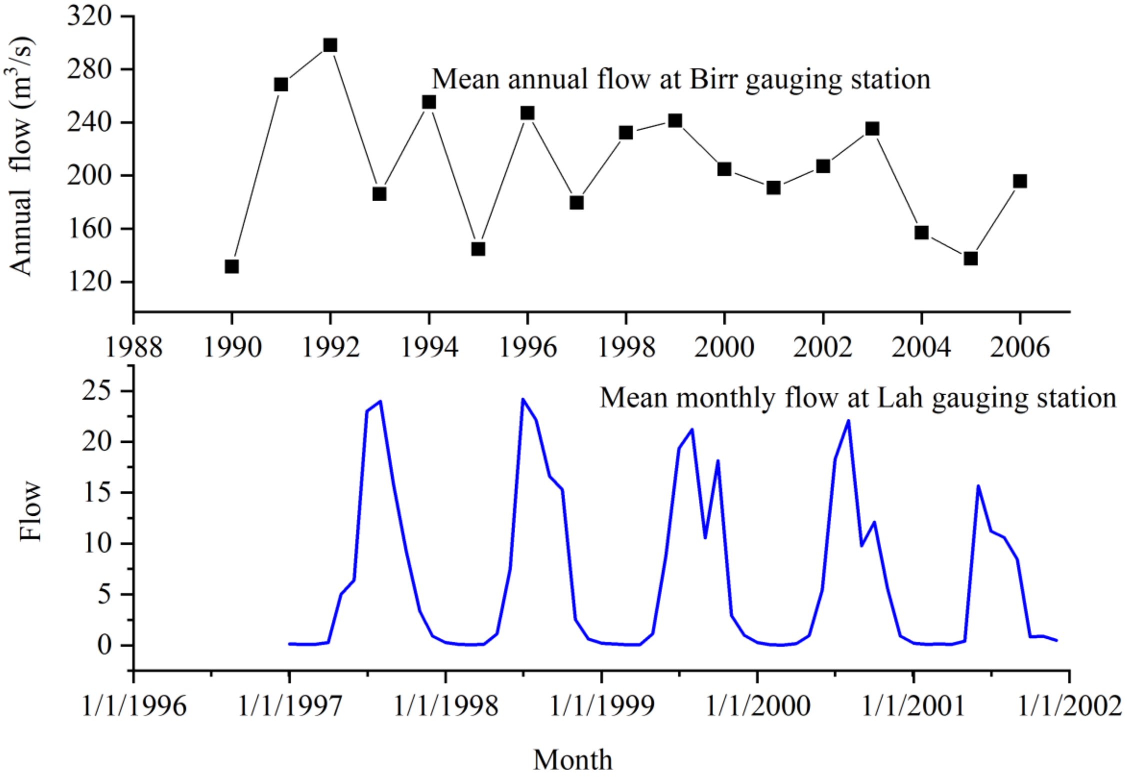


Figure 3. 8 Annual stream flow of Birr(top) and monthly flow of Lah(bottom) station

3.2.2 Hydro-metrological data analysis

Outcome of any hydrological model depends on quality and completeness of input data. Adequacy and reliability of metrological data plays important role in accurate identification of stream flow by using hydrological models in turn estimation of hydropower potential of the site. Before using any hydro-meteorological data's it is necessary first to check their continuity and consistency. Data quality process was applied to observed stream flow, rainfall and temperature. Data continuity can be disrupted by missing data caused by damaged or malfunctioning measuring devices, missing observations from monitored data, and incorrect interpretation of collected data (Subramanya, 2008). The longer data period of recent time would have been more useful to minimize uncertainties associated with model simulation. However, it is assumed that shorter and relatively older data period would not reduce the usefulness of the present modeling work (Kusre et al., 2010).

3.2.2.1 Filling missing data

All eight of the selected stations' precipitation and temperature data, which covers the years 1990 to 2019, has varying degrees of missing values. Dembecha and Laybirr have minimal missing values compared to other metrological stations. On the other side, Quarit and Sekela have significant missing values. Therefore, estimating or filling in this missing record before hydrological modeling is essential step. The missing metrological record is estimated from the observation of data at some other station as close to as evenly space around station without missing record as much as possible. There are several approaches which are used to estimate the missing values. Some of which are station average, normal ratio, inverse distance weighting, and regression methods. The choice of the method for the specific study depends on the magnitude of data missed and available record in neighboring stations to fill missing. The most well-adapted methods to estimate missing mereological and climatic data are discussed below.

Arithmetic mean method

This is the most straightforward technique frequently employed to estimate missing mereological data in which flat topography of watershed is dominant (Hall, 1969). As stated in the equation below, missing data is calculated by averaging the data from the matching nearest meteorological stations.

4. $$v_o = \frac{\sum_{i=1}^{n} v_i}{N} \tag{3.1}$$

Where v_o is estimated value of data in missing station, v_i is the value of the same parameter at nearest station and N is number of nearest weather station.

The Arithmetic mean method is satisfactory if the gauges are uniformly distributed over the area and the individual gauge measurements do not vary greatly about the mean (Te Chow, 2010).

Inverse distance method

The most common and widely used method for predicting missing data in hydrology is the inverse distance method (Sattari et al., 2017; Wei, 1973). The distance between the nearest neighboring stations is taken into consideration when estimating missing data using the inverse distance method. The following mathematical formula is used to determine the missing value by using Inverse distance method .

$$v_o = \frac{\sum_{i=1}^{n} \left(\frac{v_i}{D_i} \right)}{\sum_{i=1}^{n} \frac{1}{D_i}} \qquad 3.2$$

where D_i is the distance between the station with missing data and the nearest weather station. The remaining parameters are defined in equation 3.1.

Normal ratio method

This method is first suggested by Paulhus and Kohler (1952) and later moderated by Young (1992). Normal ratio is common method for estimation of rainfall missing data. If any nearby gauges have normal annual precipitation levels that are greater than 10% of the gauge under consideration, this approach is used as optional approach. Given below is the mathematical equation for calculating lost data using the normal ratio approach.

$$P_x = \frac{N_x}{M} \left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \ldots \frac{P_m}{N_m} \right] \qquad 3.3$$

Where P_x is annual precipitation at missed station $P_1, P_2, P_3 \ldots$ annual precipitation at nearing stations N_1, N_2, N_3 are normal annual precipitation at neighboring stations.

According to the description above, this study's missed metrological data in gauging station is conducted by using the normal ratio and inverse distance approaches, depending on the availability of data from nearby stations.

In the case of stream flow, it is sometimes difficult to get nearer gauging stations which can help to fill missing data. For this reason, missed stream flow is predicted from historical time series data of station itself by using multiple imputation method which is included in excel through XLSTAT. The APPENDIXES 1A and 1B contains the final filled hydrological data of both stations.

3.2.2.2 Checking data consistency

Inconsistencies in data series may appear in the rainfall data of stations in the same region if the circumstances pertinent to the recording of rain gauge stations had changed significantly during the period of record (Subramanya, 1994). To check a given weather station data time series observational data is relatively consistent, homogeneous and the periodic data are proportional to an appropriate simultaneous period, the double mass curve technique is a reliable procedure. This technique compares long-term annual or seasonal precipitation of a group of comparison stations to the station being evaluated.

In analysis of hydro-metrological data of many stations, cumulative of one variable is plotted against the cumulative of composed of other stations to give more definite results. The number of stations that are included in pattern is limited by the areal coverage of each station or proximity measure of stations. Stations which are included in analysis pattern should be near enough as much as possible to see the influence. If less than ten stations are used in the pattern consistency of each station should be tested by plotting it with pattern and one which is not consistent should be neglected from analysis (Searcy & Hardison, 1960).

Average seasonal records of one station and average seasonal data of all stations is arranged in reverse chronological order (latest at first entry and oldest at last entry). Then accumulated precipitation of one station and accumulation of average of base station is estimated and plotted for long periods of record. Graph of cumulative of one quantity versus cumulative of other quantity during the result will be straight line all over the period if data is proportional and consistent.

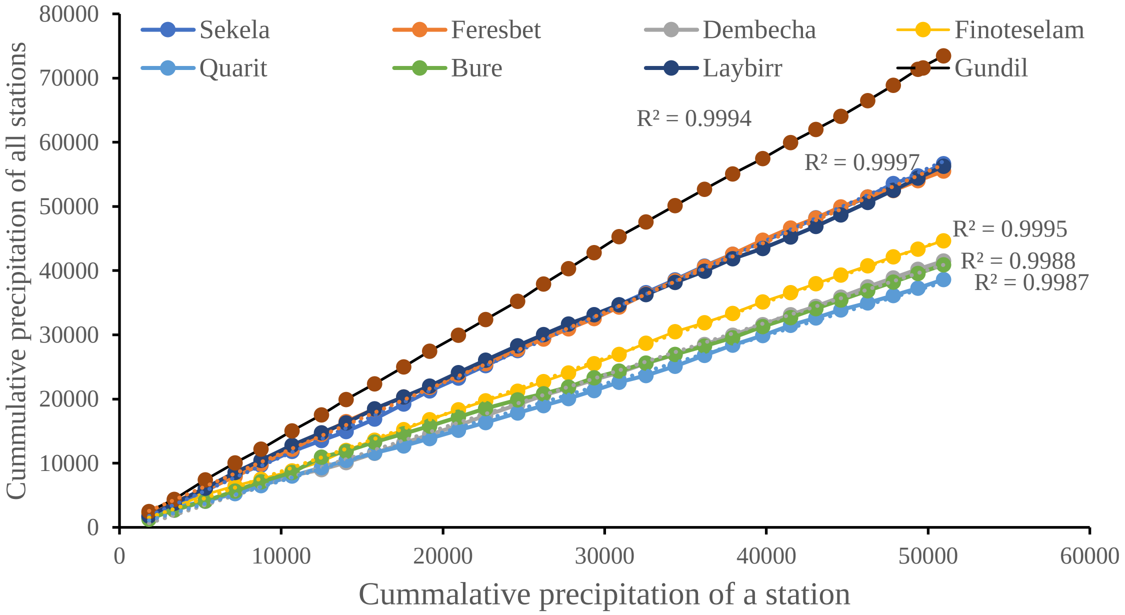


Figure 3. 9 Consistency of precipitation data

The slope will provide the constant proportionality between two quantities. Break in slope shows the occurrence of inconsistency in records and it is corrected by following relationship (Subramanya, 1994).

$$p_{cx} = p_x \frac{M_c}{M_a} \qquad 3.4$$

Where p_{cx} and p_x are corrected precipitation and original recorded precipitation M_c and M_a are correct slope of the double mass curve and original slope of double mass curve respectively.

In the case of hydrological data, most of the time, there are not enough nearby stream-gauging stations to permit the comparison of their data, making it impossible to apply the double-mass test to stream-flow records. As a result, the examination of the consistency of the yearly flow records is typically based on a simple-mass curve analysis, which involves creating a graph of the cumulative annual flows and plotting them against time usually as ordinates and abscissa. Once more, records are seen to be consistent if the representation that is so achieved follows a straight line

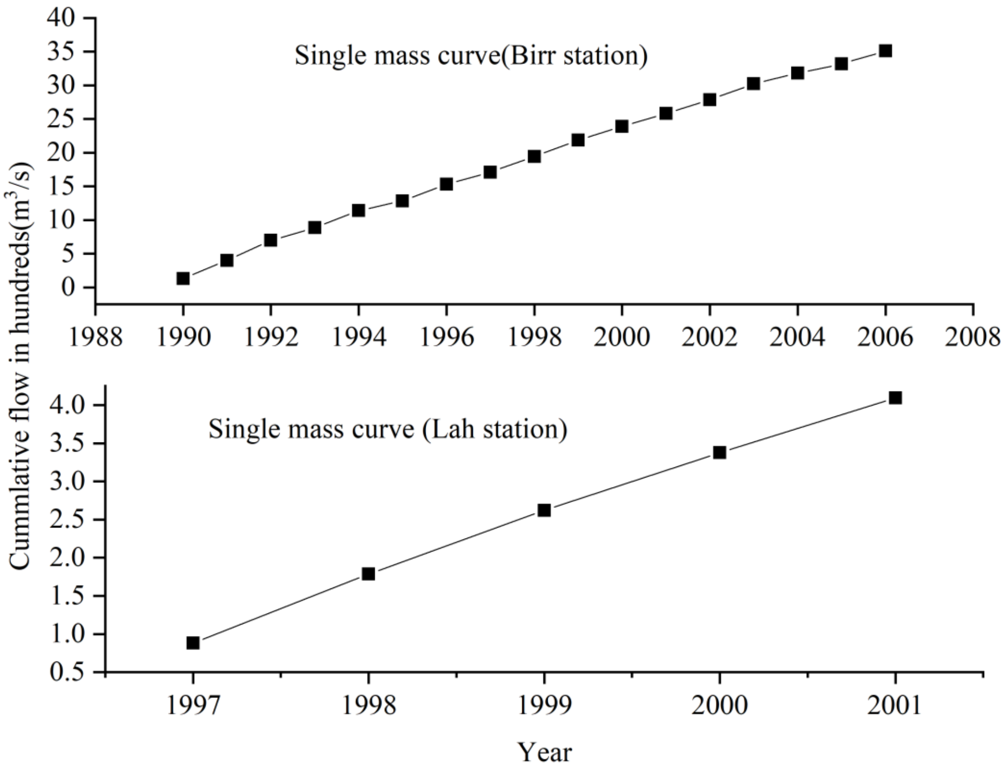


Figure 3. 10 Consistency of stream flow

3.2.2.3 Homogeneity test

A homogeneous climate series is defined as one where changes are caused only by changes in weather and climate. Long-term climatic data are impacted by non-climatic factors such as shifting station placements, analytical formulae, and other man-made causes, rendering the data inaccurate for actual records (Yeşilırmak et al., 2009). In general, when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments (Kang & Yusof, 2012). Evaluating the homogeneity of group stations and the homogeneity of the chosen gauging stations' monthly rainfall records is crucial when choosing the representative meteorological station for the analysis and further hydrological modeling. In the study, Non-dimensional Parametrization (NDP) was used to evaluate homogeneity of selected metrological stations. On-dimensional precipitation value(pi) is estimated by using following formula,

$$Pi = \left[\frac{P_i^{-}}{P^{-}} \right] \times 100 \tag{3.5}$$

Where; P_i^{-} average monthly precipitation for stations i and P^{-} average yearly precipitation of the station. The results of comparing the non-dimensional precipitation value (pi) of each station's monthly values is indicated in figure below. This graph makes it clear that the stations are homogenous and the kind of rainfall in the watershed area is unimodal.

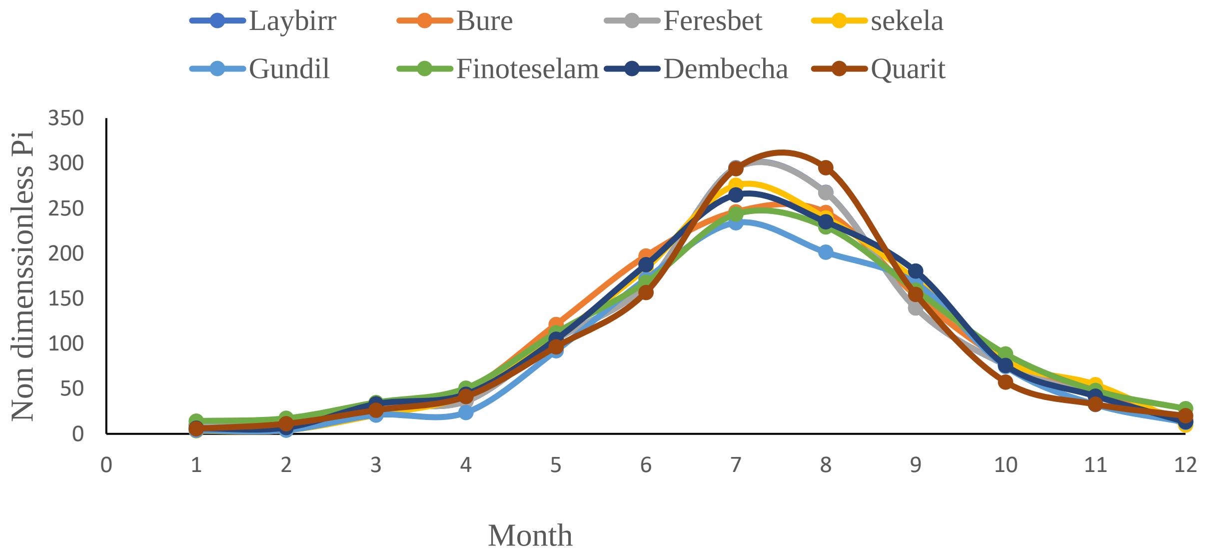


Figure 3. 11 Homogeneity test

3.2.2.4 Trend test

There are parametric and non-parametric methods for conducting trend tests on time series data from hydrological and metrological systems. Parametric tests (for example, linear trends and t-test for slope) are considered as strongly accurate for small sample sizes (Meals et al., 2011). However, this method is predicated on the idea that time series records are regularly distributed, which is uncommon for data from the fields of hydrology and metrology. However, for hydrological and metrological time series where normal distribution is an uncommon occurrence, non-parametric trend testing is used (Ahmad et al., 2015).

Mann-Kendall test is one of the most popular non-parametric trend test technique in which many researchers used for metrological data quality analysis (Arrieta-Castro et al., 2020; Bahati et al., 2019; Chauluka et al., 2021; Jaweso et al., 2019). This test is straightforward, highly accurate, distribution-dependent, and adaptable to outliers in the data. The Mann-Kendall method is unaffected by irregularities in the timing of the measurement points and is independent of the duration of the time series data (Kamal & Pachauri, 2018). In the MK test, the null hypothesis H_o means that there is no significant trend in the data series and (H1) means that there has been a trend (increasing or decreasing) over time. Mathematical equation to estimate Mann-Kendall Statistics S, $V(S)$ and standardized test statistics Z are given in equation below:

$$s = \sum_{j=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \tag{3.6}$$

Where n is number of data points and x_j & x_i are data values in time series i and j respectively and sgn is sign function and it is function of equation

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} +1 & \text{if } (\mathrm{x}_j - x_i) > 0 \\ 0 & \text{if } (\mathrm{x}_j - x_i) = 0 \\ -1 & \text{if } (\mathrm{x}_j - x_i) < 0 \end{cases} \tag{3.7}$$

Variance is computed when $n \geq 10$ by equation

$$\operatorname{var}(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t-1)(2t_i+5)}{18} \tag{3.8}$$

$$Z=\begin{cases}\frac{s-1}{\sqrt{\operatorname{var}(s)}} & \text{if s>0}\\ 0 & \text{if s=0}\\ \frac{s+1}{\sqrt{\operatorname{var}(s)}} & \text{if s<0}\end{cases} \qquad 3.9$$

The representation for a group of data points with the same data value is called m, and it shows the total number of equal observations for extent i at a given date. A set of sample data with the same value is referred to as a tied group.

Positive Z values indicate an upward trend, whereas negative Z values indicate a downward trend. Additionally, a significance value is calculated to determine whether the dataset exhibits an upward or downward trend. The MK test's null hypothesis is that there is no trend, and its alternative hypothesis assumes that the time-series exhibits a monotonic trend. At the test significance level of α, the null hypothesis can only be rejected when $p < \alpha$. The selected significance level for this study is 0.05. The Mann-Kendall non-parametric trend test technique is now included in Excel via XLSTAT. In this study, trend test of annual and monthly data series was done and there is no any significant trend in annual stream flow data series where as significant trends were observed in first three months which is also consistent with results presented by (Malede et al., 2022).

3.2.2.5 Test for outliers

Values that depart from the norm in observations that appear to be lower or higher than other records are known as outliers. Outliers in the observation lead to inaccurate output results. For hydrological and meteorological data, one aspect of quality management is the detection of outliers. In particular for small sample sizes, the retention or removal of these outliers can have a considerable impact on the magnitude of statistical parameters generated from the data before conducting the outliers test (Te Chow, 2010). According to the Lach (2018), the major errors (outliers) should be eliminated from the sample before evaluating data analysis since they could considerably alter the results of the analysis and result in an incorrect interpretation.

There are many methods used to identify outlier from data series. Three distinct methods (based on Chebyshev's inequality, the Grubbs test, and quantiles of the normal distribution) are proposed by Čampulová et al. (2018) to identify residual outliers. Wheeler (2017) evaluated the analysis of individual values (ANOX), the GRUBBS' TEST for outlier (Grubbs, 1950), the DIXON'S TEST

FOR GAPS, and the W-ratio test and found that the GRUBBS' TEST for outlier (Grubbs, 1950) detects outliers in the best way compared to other approaches. By considering a few catchment areas of the Godavari river basin in Maharashtra, India, Tiwari and Tripathi (2022),compared the effectiveness of the Grubbs-Beck test and the multiple Grubbs-Beck tests to discover discordant observations. When used with the Weibull distribution, the Multiple Grubbs-Beck tests have been shown to be more reliable than the original Grubbs-Beck tests.

Detecting outlier observations with the Grubbs test (Grubbs, 1950) is given by

$$G = \max\left|\left(\frac{X_i - \overline{X}}{S}\right)\right| \tag{3.10}$$

X_i is the ith observation and $\overline{X}$ is the sample mean, s is the sample standard deviation

Multiple Grubb’s-beck test is a generalization of Grubb’s beck test, it is used for detecting the multiple discordant that is based on the extremes value distribution or approximate normal distribution (Tiwari & Tripathi, 2022).

With the use of XLSTAT, multiple Grubb's-beck test is used in this investigation to identify outliers. Every time, the assumption that every observation in the sample originates from the same normal population was evaluated, and a significance threshold of 0.05 was considered. Outliers were found using the monthly stream flow of the Birr gauging station, and the results revealed that there is no any outlier except May ,August and September that have the highest outlier record (1996 and 1992 respectively) for data monitored at Birr gauging station. Furthermore, there are no observed outliers in monthly stream flow measured at Lah gauging station. Before using the data for additional calibration and validation, these outlier values are disregarded and considered as missing values.

3.2.3 Spatial data collection and analysis

Studying catchment hydrology and topography needs a collection and in-depth analysis of good quality spatial data for reliable results. GIS based Assessment of hydraulic head requires good quality data from digital elevation model and also hydrological modeling approach of simulating stream flow needs well studied land use and land cover data of area as well as its soil type data and geological formation.

3.2.3.1 Digital Elevation Model (DEM)

Boundaries, terrain, geometric data on stream networks and hydrologic data are needed for a hydropower potential assessment of watershed. By using commonly accessible GIS software, these attributes can be extracted from DEM. Digital elevation model plays important role in two applications when implementing integration of GIS and hydrological model for assessment of hydropower potential of the catchment. The first is in detecting topographic features to determine head and the second is for model-based simulation of stream flow in the locations that are not gauged.

Careful selection of sources and types of Digital Elevation Model (DEM) for automated extraction of topographic parameters and hydrological modeling is very important task. There are various sources of DEM in which some of them are freely available and others are not freely available and commercial. Shuttle Radar Topography Mission (SRTM), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER),National Elevation Data (NED) and Light Detection and Ranging (LiDAR) are some of well-known free sources of elevation model which have got great acceptance for hydrological modeling and topographic analysis. From those, the NED provides seamless raster elevation data of the conterminous United States (CONUS), Alaska, Hawaii, U.S. island territories, Mexico, and Canada satellite facilities with different resolutions and best vertical accuracy than ASTER and SRTM DEMs (Gesch et al., 2014). Both quality and resolution must be considered in the selection of a DEM for hydrologic modeling. Quality refers to the accuracy of the elevation data while resolution refers to the precision of the data; specifically, to the horizontal grid spacing and vertical elevation incrementation. DEM horizontal resolution and its ratio to vertical resolution can have a significant bearing on computed land surface parameters that involve differences in elevations (Garbrecht et al., 2000). Digital Elevation Model (DEM) from Alaska satellite facility is one source of NED DEM which is available freely with better vertical resolution and spatial resolution (12.5 *12.5). Vertical accuracy of DEM is essential specially for extraction of topographic characteristics of an area (Mukherjee et al., 2013; Vaze et al., 2010).

Quality in DEM resolution has significant impact on simulated output and topographic analysis. The results by Roostaee and Deng (2020) showed that the demarcated drainage area reduced with decreasing DEM resolutions, especially in low gradient watersheds which caused the simulated flow to drop despite the fact that not all coarse DEMs result in reduced watershed area (Roostaee

& Deng, 2020). On other hand finest DEM may delay the performance of the hydrological model (Goyal et al., 2018). Therefore, it's crucial to choose the right DEM resolution while performing topographic information extraction and stream flow simulation since input data are the main cause of uncertainty in hydrologic modeling and the DEM input dominates the model-based simulated flow (Patil et al., 2011). Elevation model (DEM) of spatial resolution of 12.5m that describes terrain features of Birr watershed was used in this study. DEM has been used to identify the stream network, compute channel properties, identify the sub-basin area and hydrologic response units (HRUs). Ultimately, it has been used to generate a contour map of the area to assess the elevation of hydropower locations. The Digital Elevation Model of Birr watershed is shown in Figure 3. 1.

3.2.3.2 Land use land cover

Land use and land cover data of study catchment is one of basic input for generation of HRU in SWAT-based assessment of stream flow. The area's land use and land cover has a significant impact on the catchment's hydrology. The kind of land use and land cover, either by impeding or facilitating the infiltration process, strongly influences the generation of surface runoff or subsurface runoff in the watershed. By creating a user lookup table that identifies and connects the names of land use categories with SWAT data base, the land use and land cover map acquired from Amhara design and supervision works company was produced in such a way that its property appears in SWAT user database. Land use land cover map of Birr watershed is shown in Figure 3. 12. The following table shows spatial coverage of land use land cover types of Birr watershed.

Table 3. 2 Land use land cover types of Birr watershed

Land use land cover type	SWAT_ Name	Area (Km^2)	Percentage of coverage
Built Up Area	URBN	53.87	1.70
Cultivated Land	AGRL	2187.05	68.82
Forest Land	FRST	231.30	7.28
Grass Land	PAST	372.05	11.71
Marsh Land	WETL	0.54	0.02
Shrub and bush land	RNGB	329.08	10.36
Water Body	WATR	3.39	0.11

3.2.3.3 Soil type

Soil type of area is another fundamental spatial data which has very strong impact on catchment hydrology. When analyzing watershed hydrology, it's vital to consider the soil's texture as well as other crucial aspects including its surface cover, depth to impermeable layers, amount of available water, hydraulic conductivity, bulk density, and amount of organic carbon. In addition to land use land cover of the area, it is the type soil which determines formation of surface flow or subsurface flow either by hindering or facilitating the infiltration process with in a system. Soil profiles are divided into multiple layers, which influence soil water processes like plant water uptake, lateral flow and percolation to lower layers as well as infiltration and evaporation. SWAT model works generates the simulated parameters by dividing the catchment into sub basins and further into Hydrologic Response Units (HRUs). These subdivisions (HRUs) are characterized by the different combinations of soil characteristics in addition to land use and slope of the area.

Soil data of spatial resolution 90m obtained from Amhara design and supervision works was used as input for prediction of stream flow of Birr watershed by using Soil and Water Assessment Tool (SWAT). Soil user database is generated by creating look up table to allow SWAT to use soil properties from database to estimate runoff process of watershed. According to data collected, there are seven significant soil groups in the study region, which are listed in the table below.

Table 3. 3 Soil type of Birr watershed

Major soil group	SWAT _Name	Soil group	Soil texture	Area of coverage	% areal coverage
Chromic Luvisols	CLSL	C	Sandy-Clay-Loam	595.65	18.86
Chromic Vertisols	CVSL	D	Clay	992.99	31.44
Dystric Nitosols	DNSL	C	Sandy-Clay-Loam	363.66	11.51
Eutric Nitosols	ENSL	C	Clay	603.77	19.11
Lithosols	LSL	C	Loam	279.47	8.85
Orthic Acrisols	OASL	C	Loam	42.39	1.34
Pellic Vertisols	PVSL	C	Clay	280.90	8.89

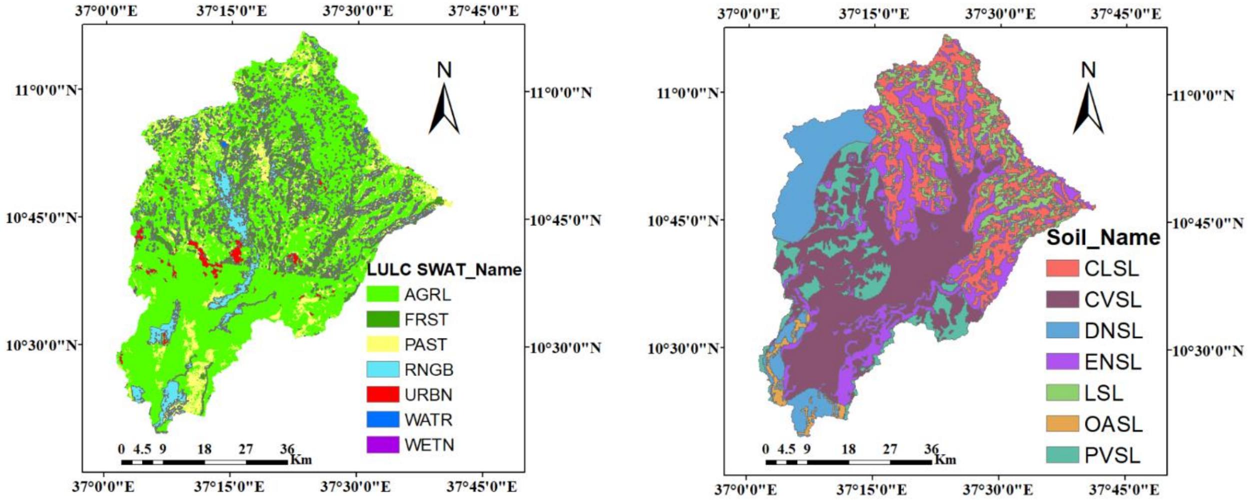


Figure 3. 12 Soil type(right) and land use land cover type(left) map of Birr watershed

3.2.3.4 Geology

One of the most important studies that should be conducted at various scales and phases before deciding the optimal location for a dam is geological investigation for choosing and locating dam and powerhouse sites (Sissakian et al., 2020). The permeability of the dam, which affects the ability of the dam to contain water, is affected by the geological characteristics and rock types within a certain region. Any potential power plant site needs to have a suitable landform, which is frequently decided by the underlying geology, which determines the underlying structure and indicates the risk of slips, leaks, and whether or not hard rock excavation will be necessary. When evaluating the hydropower potential of the site, it is desirable to be aware of the geological status of the power house, diversion structure and related components. Areal coverage of geological formation of study area is depicted in Figure 3. 13.

Figure 3. 13 Geological formation of study area

Types of geological formations	Area	% of area
Adigrate sand stone	129.28	4.07
Alluvium	32.17	1.01
Blue Nile Basalts	293.18	9.23
High grade metamorphic rocks	40.31	1.27
Lake	0.99	0.03
Quaternary basalts	1276.60	40.18
Termaber Basalts (2)	1404.73	44.21

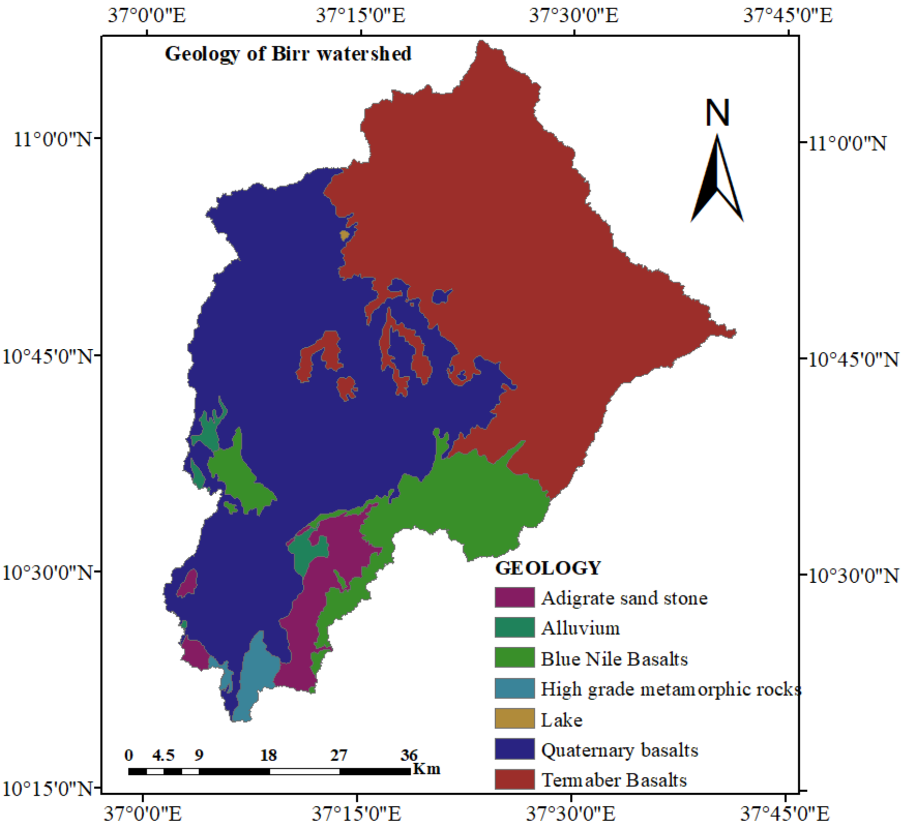


Figure 3. 14 Geological map of Birr watershed

3.3 Methodology

3.3.1 Procedural review

At a given location, the achievable amount of hydropower is a function of available hydraulic head and the flow rate which are dependent on local topography and hydrological process that happened with in catchment respectively. Therefore, thorough investigation of the river's topography and accurate stream flow modeling are necessary for an appropriate evaluation of hydropower potential. Hydrological models were used to estimate stream flow at ungauged locations where as GIS was used to extract terrain attributes from DEM such as drainage network position, length, slope, and elevation difference between locations and finally to prioritize the site based on different constraints b using Analytical hierarchy process(AHP).

Firstly, by means of GIS tools potential run-of-river hydropower locations with head greater than or equaled to 10m are extracted from DEM by means of generating contour map of 0.5 interval. Estimated head was verified by taking GPS readings at some accessible locations. After selecting alternative potential sites based on head, prediction of stream flow at those identified locations was conducted by using SWAT hydrological model. Performance of SWAT model was then evaluated by using observed stream flow at Birr gauging station near Jiga. Physical similarity technique of regionalization was used for calibrating SWAT-based simulated stream flow at locations in which observed stream flow are not available for calibration and validation. Accuracy of applied regionalization technique is further verified by validating the model output by using stream flow measured at Lah station near Finoteselam. Finally, by developing flow duration curve from well-calibrated stream flow from model to determine dependable flow at proposed potential sites, a preliminary site potential assessment was carried out. Detail methodological framework used in the study is indicated in Figure 3. 15.

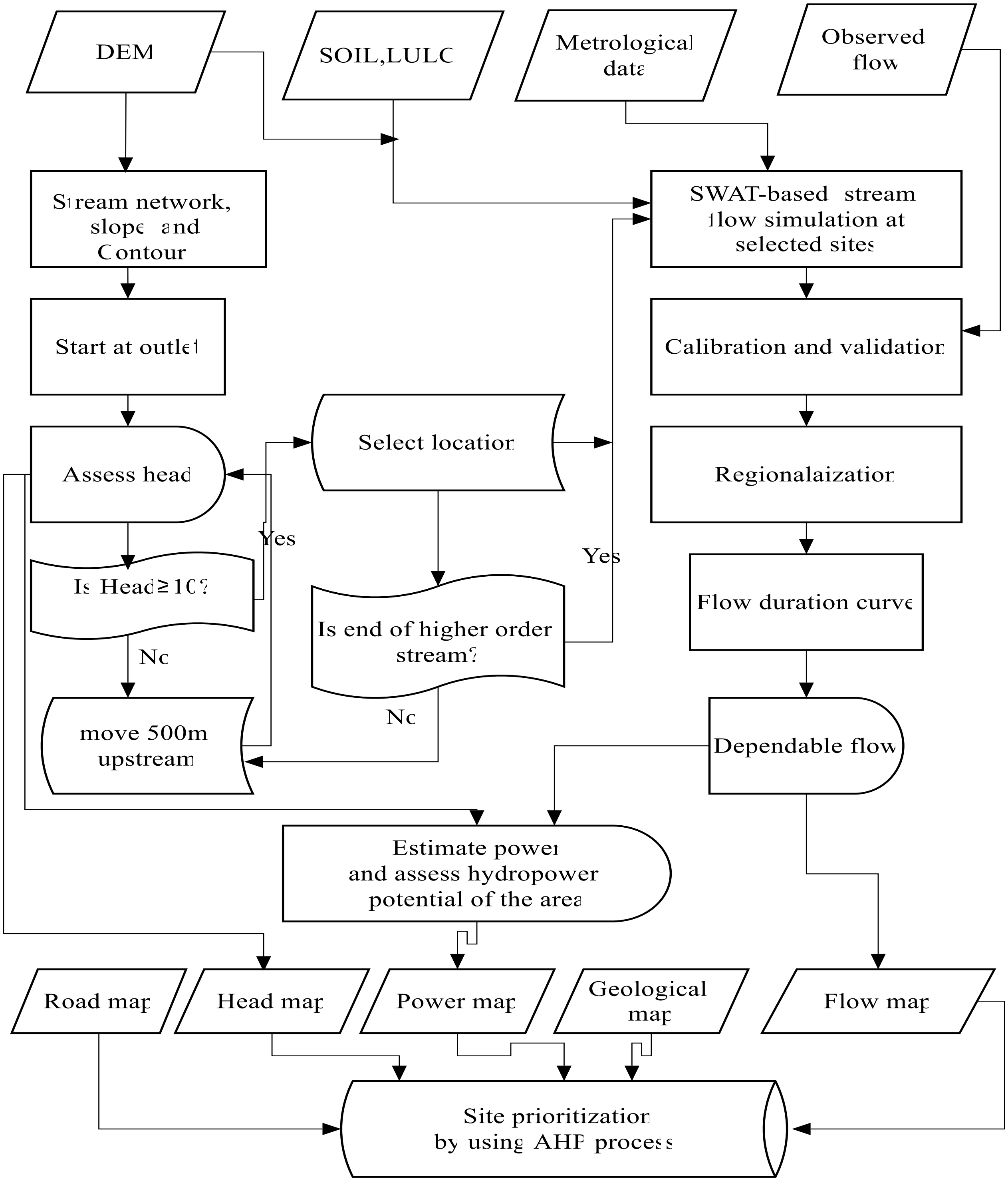


Figure 3. 15 The general conceptual frame of study

3.3.2 DEM analysis and identification of hydropower sites

The production of on-site hydropower is not feasible at all points along the river's flow channel. The site with considerable size of head with sloping sections and natural falls found in mountainous areas with perennial flow is only preferred for development. Application of GIS for the evaluation of hydropower potential has advanced significantly with the development of the Digital Elevation Model (Punys et al., 2011). A DEM, which defines the elevation of any point in a particular area at a specific spatial resolution was used to determine the head differences between intake and powerhouse. The watershed characteristics, river networks, and parameters for the Hydrological Response Units (HRUs) analysis by SWAT were created by using digital elevation model. River channels have been ordered following the Strahler method. In the Strahler stream-ordering approach, a headwater stream (stream with no tributaries) is regarded as a first order stream. A second order stream is a section that is located downstream of the intersection of two first order streams. Consequently, a n^{th} order stream is always found downstream of confluence of two $(n-1)^{th}$ order streams (Strahler, 1958).

As head is the elevation difference between intake and turbine location, careful consideration of the optimal distance between two points is essential. This decision was made for technical, hydrological, ecological and economic grounds. First of all, the effects on river flow regimes and as a result those on river ecosystems, will be reduced if the water that is diverted from the river channel is discharged back as close as feasible to the diversion point. Additionally, a shorter pipeline will result in lower expenditures for the conveyance system. In contrary, high hydraulic head can be obtained as the distance between intake and power house is increased. In reality, there is no set standard that determines the minimum or maximum distance between the intake and the powerhouse as well as between two consecutive hydropower sites. Different considerations to limit distances between the intake and the power house as well as two plants were employed in numerous studies undertaken in various countries (Korkovelos et al., 2018; Kusre et al., 2010; Sammartano et al., 2019; Thin et al., 2020; Zaidi et al., 2018). The following criteria were used to choose probable locations for the Birr run-of-river project:

I. In a small RoR, there are no space restrictions for water storage. Therefore a horizontal distance of 500 meters between an intake point and its turbine point is typically regarded as adequate (Zaidi et al., 2018).

II. Minimum Slope: Potential sites should have an average slope of 1:50, i.e., 2% along the river bed to ensure sufficient gross potential head to be available for the hydropower plant (Thin et al., 2020).This bound of slope and distance limit between intake location and turbine setting enabled to fix minimum head between intake and tail race to be 10m.

III. Order of stream: Only higher order streams are considered for selection of sites to ensure adequate amount of water flow for hydropower generation throughout the year (Sammartano et al., 2019)

IV. Minimum hydropower site interval: Distances between two consecutive hydropower sites should not be less than 500 m (Khan & Zaidi, 2015; Kusre et al., 2010). This is in order to give the river ecosystem a sufficient chance to sustain, and this will make sure that there is a sufficient gap between the tailrace of one site and the diversion arrangement of the next.

The river network of higher density was divided in to segments of 500m length by using tools in GIS. Then elevation difference between points starting from the outlet of watershed moving towards the upstream by proposing consecutive points as points of intake and the point where released water drains to water courses (tail race) was estimated. The elevation difference between these two points is termed as head. The ending point of the examined segment of the river becomes the starting point of the next segment to be assessed and the process continues up to the end of higher order stream. Gross head between two consecutive points in which the first point and second points will be considered as intake location and turbine setting respectively, has been determined by generating contour via Arc-GIS tool (Khan & Zaidi, 2015). These methods will be approximate but will be satisfactory at initial stage of hydropower development.

To validate the head estimated from DEM , on-site observations by using Garmin eTrex GPS and Topographer which have vertical accuracy less than 1m were taken at the most accessible and less forested sites. Garmin eTrex GPS is a very small, lightweight unit, field ruggedized with some armoring, high sensitivity receiver and waterproof unit that stores 500 waypoints with accuracy less than 3m (Mancebo & Chamberlain, 2000). The selection of validation sites along the stream is based on accessibility and suitability of the area for GPS. In the verification process, it is preferable to take on-site measurement of many potential locations unless different limitations hindered the activity. In this study, GPS observation of elevation at only two accessible and less forested stations (site 1 and site 2) were conducted. Furthermore, observation of additional five validation locations (of three are shown in Figure 3. 16 as “VALP’s”) along Birr river reach was conducted in order to generate relationship between DEM-based estimation of head and GPS-based observation of elevations. Set of validation points uploaded from GPS to google earth are depicted in following figure.

Figure 3. 16 GPS validation points on Google earth

3.3.3 Rainfall-runoff modelling with SWAT

The basic hydrologic data required for the evaluation of the energy production in a small hydropower scheme is long enough mean daily/monthly flow series at the water intake location. Accurate way of finding the flow in these points is recording stage and converting it in to flow rate at the points with suitable methods for long historical periods. The minor hydroelectric projects, however, often have small drainage areas and have no recorded stream flow series since they are situated in the upper zones of the large rivers. For an ungauged watercourse, where observations of discharge over a long period are not available, it involves the science of hydrology, the study of rainfall and stream flow, the measurement of drainage basins, catchment areas, evapotranspiration and surface geology. In the study area, there are only two-gauge stations, and the flow values at other suggested sites were unknown. The relative flow at each suggested site was predicted by using Soil and Water Assessment Tool (SWAT). In the simulation process the locations which have head greater than or equals to 10m are considered as outlets. Those outlets are added manually during SWAT- based delineation of watershed for simulation of stream flow at intake locations. The detail of methodology used in order to determine stream flow at un-ungauged intake locations is depicted in figure below.

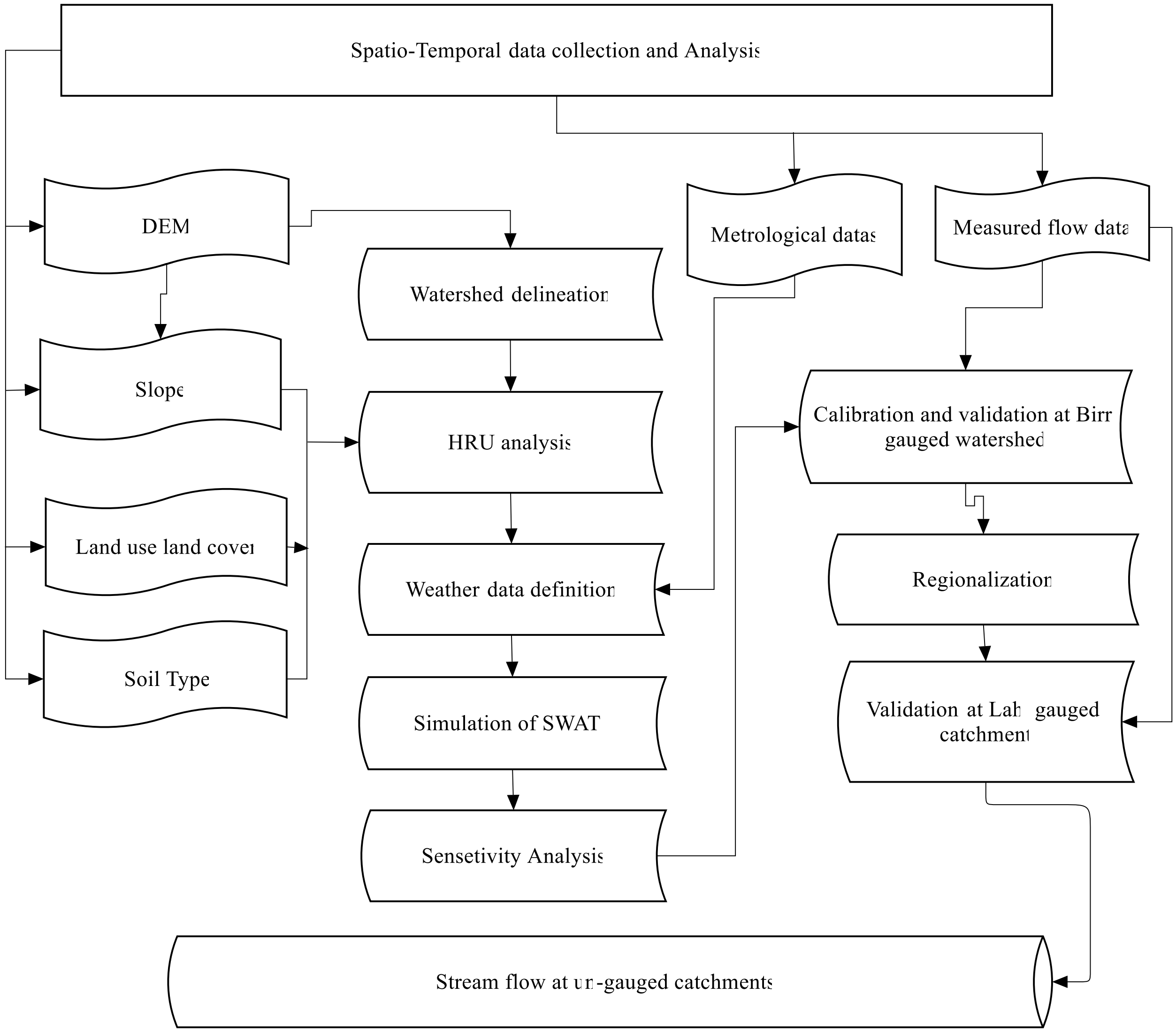


Figure 3. 17 Conceptual frame work of stream flow simulation at un-gauged catchments

3.3.4 Sensitivity analysis and performance evaluation of model

Performance of watershed models to simulate the parameters are evaluated through calibration and validation processes (Pak et al., 2015). To get the best fit between observed data and model predictions, model calibration entails modifying input sensitive parameters within a suitable range. By contrasting field observations with model predictions while maintaining the values of all input parameters, model validation is the process of validating the calibrated model (Parajuli & Ouyang, 2013).Finding the most sensitive parameters for a particular watershed or sub watershed is the first stage in the calibration and validation process in SWAT. It is essential to determine whether parameters have or do not have a major impact on the model simulation in order to reduce parameter uncertainty as well as overparameterization, which can undermine the model's physical representation (Nyeko, 2015). The calibrating process is the second phase. By better parameterizing a model to a specific set of local conditions, calibration attempts to lower the prediction uncertainty. By carefully choosing values for model input parameters (within their respective uncertainty ranges) and comparing the model's predictions (output) or a given set of assumed conditions with actual data for the same conditions, model calibration has been successfully completed. Validation of the interest component (Stream flow, sediment yields.etc.) is the last stage. The process of proving that a particular site-specific model is capable of producing sufficiently accurate simulations is known as model validation, but the definition of "sufficiently accurate" can vary depending on the project aims (Sisay et al., 2017).

Performance of the model was checked by combination of different statistical tests that can be used to judge the SWAT model. According to Coffey et al. (2013) and Gull and Shah (2022), strong statistical tests that are used to judge the SWAT model are R^2, NSE, root mean square error (RMSE), nonparametric tests, t-test, objective functions, autocorrelation, and cross-correlation. For this study, Nash– Sutcliffe efficiency (NSE), percent bias (PBIAS), Coefficient of determination (R^2)and RMSE that are recommended by Moriasi et al. (2012) were used as evaluation objective functions. The calibration, validation and sensitivity analysis were chosen to be performed using the SWAT Calibration Uncertainty Program (SWAT-CUP) in this study. The complete optimization and gradient search method known as SUFI-2 (Sequential Uncertainty Fitting) simultaneously calibrates many parameters and has a worldwide search capability. Additionally, it considers the ambiguity of the input data, model parameters, and model (Zhang et al., 2019). When using SUFI-2, the initial evaluation's goal is to arrive at satisfactory P-factor and R-factor outcomes. The P-factor, also known as the 95 percent prediction uncertainty or 95PPU, is the proportion of the observed data that is encompassed by the modeling results and the R-factor is the ratio of the thickness of the 95PPU envelope.

The Nash–Sutcliffe efficiency (Weick & Sutcliffe, 2001) shows how well the 1:1 line is fit by the observed versus simulated data display. It often falls between $-\infty$ and 1. Higher NSE values imply better model prediction accuracy whereas lower NSE values suggest poorer model prediction; if NSE is 0.5, the model is good. NSE is computed as shown below:

$$NSE = 1 - \frac{\sum_{t=1}^{T=t}\left(Q_s^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_m^t - \overline{Q_m}\right)^2} \qquad 3.11$$

where Q_m^t is observed value of streamflow, Q_s^t is the simulated value of streamflow, and $\overline{Q_m}$ is the average of the observed values of streamflow at a given time t.

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias and negative values indicate model overestimation bias (Mandeville et al., 1970). PBIAS is generally, expressed in percentage and is calculated using Equation 3.13.

$$PBIAS = \frac{\sum_{i=1}^{I=n} Q_m - \sum_{i=1}^{n} Q_s}{\sum_{i=1}^{n} Q_m}\% \qquad 3.12$$

The correlation coefficient(R^2) shows the strength of linear relationship among measured and predicted values. It ranges from 0 to 1; and typically values greater than 0.5 are considered acceptable.

$$\mathrm{R}^2 = \frac{\left[\sum\left(\mathrm{Q_m} - \overline{\mathrm{Q_m}}\right)\left(\mathrm{Q_s} - \overline{\mathrm{Q_s}}\right)\right]^2}{\sum\left(\mathrm{Q_m} - \overline{\mathrm{Q_m}}\right)^2 \sum\left(\mathrm{Q_s} - \overline{\mathrm{Q_s}}\right)^2} \qquad 3.13$$

The root mean square error (RMSE) has been used as standard statistical metric to measure model prediction error in meteorology, air quality, and climate research studies; a smaller RMSE value indicates better model performance(Moriasi et al., 2012). The RMSE does not provide information about the relative size of the average difference and the nature of differences comprising them.On other hand it can be used to determine how well the model simulates the average magnitudes for the output response of interest is and is useful for continuous long-term simulations (Moriasi et al., 2007)

$$RMSE = \sqrt{\frac{\sum_{n=1}^{n}\left(Q_m - Q_s\right)^2}{n}}$$

Table 3. 4 Performance evaluations for streamflow simulation (Moriasi et al., 2007).

Rate of performance	NSE	PBIAS	R^2
Unsatisfactory	$NSE \leq 0.5$	$PBIAS \geq \pm 25$	$R^2 < 0.50$
Satisfactory	$0.5 < NSE \leq 0.65$	$\pm 15 \leq PBIAS < \pm 25$	$0.50 < R^2 < 0.70$
Good	$0.65 < NSE \leq 0.75$	$\pm 10 \leq PBIAS < \pm 15$	$0.70 < R^2 < 0.800$
Very good	$0.75 < NSE \leq 1$	$PBIAS < \pm 10$	>0.80

The standard method for doing calibration and validation involves splitting the available observed stream flow into two phases, one for calibration and the other for validation. In the study, calibration and validation are performed by using observed data at Birr hydrological station from 1993 to 2001 and 2002 to 2006 respectively. The observed stream flow of year 1990, 1991 and 1992 were used for warm up period for model in calibration process.

3.3.5 Performance evaluation of models for ungauged catchments

In Ethiopia, the majority of streams are not gauged and even where there is a gauging station, the recorded data series are replete with errors and missing information. Hydrologic modeling in data scare and ungauged basin has always been difficult. In such areas, it is impossible to adjust parameters to reduce inaccuracies in modeling in such way that the difference between observed and simulated stream flow is minimum. The regionalization approach can be used to estimate the parameters of the hydrological model for ungauged basins (i.e., without any observations of river discharge) for calibration of model outputs.

In the study area, Birr gauging station covers only 978 km^2 while the entire catchment is 3159 km^2.Therfore performance of model evaluated at Birr gauging station is regionalized at exit of entire watershed. Among suggested approaches the physical similarity method of regionalization as used by (Roth et al., 2016) is applied in this study by considering limited number of gauging station and available data for calibration and validation. Firstly, sensitivity analysis and Performance evaluation of model was performed by using observed data monitored at Birr gauging station. Then after to evaluate the performance of model at ungauged parts of watershed, the range of identified parameters are completely transferred in to exit of entire watershed. Finally, the effectiveness of regionalization approach is verified by validating the output using stream flow from Lah gauging station.

3.3.6 Flow duration curve

A useful way of treating the time variability of water discharge data in hydropower studies is by utilizing flow duration curve. The flow–duration curve method is the better method for all preliminary or screening studies. The cumulative frequency curve for flow duration displays the percentage of specified discharge times that were equaled or exceeded within a certain period. It combines in one curve the flow characteristics of stream through the range of discharge without the regard to sequent of sequence of occurrence. Instead of the true time ordering of flows in a flow versus time plot, a flow duration curve simply rearranges the flows in order of magnitude. The daily, weekly, or monthly flows within a particular period are sorted according to magnitude and the percentage of time the flow equaled or exceeded the stated values is computed in order to create a flow-duration curve. The curve represents an average for the period under consideration rather than the distribution of flow within a single year because it was constructed to average the plotted points of specified discharges versus the percent of time during which they were equaled or exceeded. The flow-duration curve allows for one to estimate the river flow corresponding to different degrees of dependability and to show characteristics of flow (Searcy, 1959).

3.3.6.1 Preparation of data for FDC

The two main techniques for creating flow-duration curves are the calendar-year method (Saville & Watson, 1933) and the total period method. In the calendar-year method, the discharges for one year are ranked according to magnitude. This process is repeated for all year of record. The discharges for each order number are averaged and these average values are then used for plotting flow duration curve. In the total period method, all discharges are placed in classes according to their magnitude. The totals are cumulated, beginning with the highest class and the percentage of the totaled time is computed for each class. The data are then plotted with the discharge as the ordinate and the time in percent of total period as the abscissa. Compared to the calendar year method, which averages out exceptional events the total period method yields more accurate statistics (Searcy, 1959).Therefore, in this study, the entire simulated data’s of 27 year’s mean monthly flow (324 records) were used to draw flow duration curve.

For run-of-river power plants, the recommendation is to choose a design discharge that is available 100 to 120 days a year or about 30% of the time and can be computed as the 30% exceeded value of the flow duration curve for the available flow for power generation (Katherine, 2013). 95 % of time of exceedance was used to estimate the available firm power of study area. Mean theoretical and technical power potential of each site is estimated from mean flow rate (Q_m). The mean flow rate value derived from those percent's of exceedance using the following equation (Adedokun et al., 2013).

$$Q_m=0.025(Q_0+Q_{100})+0.05(Q_5+Q_{95})+0.075(Q_{90}+Q_{10})+0.1(Q_{20}+Q_{30}+Q_{40}+Q_{50}+Q_{60}+Q_{70}+Q_{80})$$

3.14

where, Q_m= mean discharge, Q5, Q10 = discharge corresponding to 5%, 10% exceed, Q_0, Q100 = discharge nearly 0 and 100% of time (any discharge of less than 5% and more than 95%) respectively

3.3.7 Estimation of hydropower potential

Working principle of hydropower is the same whether it is large or small. When water passes through a turbine device, it makes the turbine spin, and the attached electrical generator produces electricity and then in the process kinetic energy of moving water is converted in to power. Theoretical hydropower potential (HP) is typically understood as what is generally feasible without considering technical acquisition feasibility, environmental limits, or economic constraints. Potential sources of hydropower depend on rate of river water flow Q, Net hydraulic head H which is vertical distance between two points (diversion point and power house) and turbine Efficiency.

The following power equation is used to calculate the total theoretical power produced by a hydroelectric plant at a given head and flow rate.

$$p = \rho g Q H \qquad 3.15$$

Where, P is the generated electric power in watt, ρ is the density of water (1000 Kg/m^3), g is the acceleration due to gravity (9.81 m/s^2), Q is the river flow rate in m^3 /s, H is the net head in meters. The ecological quality of rivers must be maintained by maintaining a minimum flow. Rivers must not dry-up or have their physical regimes significantly altered in order to conserve the hydrological and ecological functions of their drainage networks. Often, a certain amount of flow must be left in the river throughout the year for environmental reasons. This residual flow varies from project to project based on their location, need, and habitat and is specified by the user and must be subtracted from all values of the flow-duration curve for the calculation of plant capacity, firm capacity and renewable energy available. Minimal flow during dry periods can be considered as environmental flow during the lean period with unregular conditions in hydropower development (Prakasam et al., 2021).

It would be more significant to determine technically available power from theoretical power. For estimation of technical hydropower potential, the value of net water power capable of being developed technically is computed from the potential water power by certain reduction factors to account for losses of head in the conveyance and losses associated with energy conversion (Turbines and generators losses). Total efficiencies in hydropower system is given by following equation (Purece et al., 2020).

$$\eta = \eta_{\text{turbine}} \times \eta_{\text{generator}} \times \eta_{\text{conveyance}} \qquad 3.16$$

Where: η is total system efficiency

Actually, the head losses in conveyance and energy conversion process depends on the length and diameter of water conveyance system, the material to be used in conveyance and depth of water at the tailrace channel and type of hydraulic turbines to be used. In preliminary assessment of hydropower potential of the area, average reduction factor of conversion of available theoretical power to technical power is recommended by Mosonyi (1960). Mosonyi (1960) puts the constant variable for technical power potential assessment of the site by integrating acceleration due to gravity with overall power coefficient factor c_o to be 7 to 8.5 during preliminary potential assessment.

$$P_{m(net)} = (7 \text{ to } 8.5) Q_m H \qquad 3.17$$

Where Q_m is arithmetic mean stream flow and $P_{m(net)}$ is technical power.

3.3.8 Prioritization of suitable hydropower sites based on MCDA approach

Setting up a best is hydropower site is complex, time consuming with large number of uncertainties due to its dependability on several influencing factors. Small hydropower project success is no longer solely determined by economic factors. Other factors need to be considered, including environmental, social, and technical aspects. As a result, the development of small hydropower projects can be examined as a standard multi-criteria decision analysis problem. Therefore, knowledge of the decision-making process, including its importance, engagement, and use of tools like MCDA or MCDM, may be useful to develop improved understanding and outcomes.

The AHP Saaty (2008), is strong and simple MCDMA tool which provides a framework for the decision-making process and deals with the integrated GIS spatial analysis for the relative suitability of land. It is now a well-established an integrated GIS-based MCDA method is used in spatial analysis for suitable site selection (Chandio et al., 2013). The core idea behind AHP is to use pairwise comparison judgments to help decision-makers convey how important each element in the hierarchy is by first breaking an issue down into its smallest possible components These judgments are then converted to numerical values, known as the weights (Saaty, 2016). Pairwise comparison weight assignment will probably lessen weight bias, making AHP a more cost-effective MCDA approach (Tsiko & Haile, 2011).

3.3.8.1 Establishing decision hierarchy and pairwise comparison matrix

Raster map of all criteria has been established and classified in to four classes based on suitability range for hydropower development. The first group is intended to represent locations that are particularly suitable for hydropower development, while the last category was intended to reflect locations that are less suitable. On a scale from 1 to 9, each criterion's relevance in relation to the others was evaluated. With 1 denoting elements of equal choice and 9 denoting factors with severe preference over the other, as shown in Table 3. 5. The fundamental presumption in this method is that the second factor will be given the reciprocal of the first factor if the first factor has one of the non-zero numbers listed above assigned to it when compared to the second factor. The intensity of each factors with relative to others was collected from different relevant literatures (Ajibade et al., 2020; Fesalbon et al., 2019; Punys et al., 2019; Rojanamon et al., 2009; Romanelli et al., 2018).

Table 3. 5 Saaty’s fundamental scales of relative importance(Saaty, 1987)

Intensity of Importance	Definition	Description
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice

9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocal	Reciprocal comparison	

After comparison between all possible criteria pairs is complete, the Weight (W) of criteria i is calculated using Equation

$$W_i = \frac{\sum_{j=1}^{n} P_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} P_{ij}} \qquad 3.18$$

Where P_{ij} indicates relative importance in pair-wise comparison of criterion i compared to criterion j, n = Number of factors, i & j = Criterion and W = Priority Weight

In most cases, the values used for pair-wise comparison are based on subjective judgment, which may produce biased and arbitrary conclusions. A numerical value known as the Consistent Ratio (CR) which can be computed by using Equation below to assess the consistency of the pair-wise comparison matrix has been employed. It is ratio of the Consistency Index (CI) to the average consistency index, known as Radom Index (RI) as shown in equation below.

$$CR = \frac{CI}{RI} \qquad 3.19$$

Where RI is random index generated by simulating random reciprocal matrices of different orders the average consistency indices (known as the random index (R.I.)) have been established as follows:

Table 3. 6 Random index value of matrix (Saaty, 1984).

n	2	3	4	5	6	7	8
RI	0	0.58	0.9	1.12	1.24	1.32	1.42

The calculation of consistency index (CI) is given as:

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad 3.20$$

Where n is number of factors and λ is eigen value

Estimated consistency index was then compared to a random index (RI). for three number of factors(n=3) and four number of factors (n=4), conventionally it is required that CR≤0.05 and 0.08, respectively to be acceptable. For n≥5, a consistency ratio of 0.10 or less is accepted as consistent. If the CR is >0.1, the comparison matrix should be revised again (Saaty, 1977).

4. RESULTS AND DISCUSSIONS

4.1 Categorization of streams

River networking and stream ordering to assess hydropower potential of site plays important role in identifying streams and tributaries for small scale hydropower development which have sufficient flow for generation of power generation with sufficient head. It is determined from threshold flow accumulation which is user-defined parameter that directly affects the structure and density of extracted river networks from DEMs.The Strahler method of stream ordering was used to characterize streams of Birr watershed. The threshold value of flow accumulation of the streams in the analysis was set carefully in order to obtain all perennial rivers with in watershed for RoR hydropower development and taken as 20,000. This value was limited after trying many lower limit flow accumulations thresholds and simulation of stream flow to verify the availability of stream flow throughout the year. According to analysis, maximum order of the river channel in the study has been identified as four. The longest river which is grouped under 4th order of stream according to Strahler method of ordering in the study, the Birr, has a maximum length of 87 km. This reach contains around 74 % of available hydropower potential sites within the catchment. There are eight more tributaries that are considered to have enough stream flow accumulation for RoR hydropower generation and are categorized as third orders of stream. But only one tributary (Lah) of length 17047m has enough available head to support RoR development. Therefore, this reach contains 26% of the potential sites (5 in number). The other seven higher order streams in the research area lack viability as hydropower sites due to insufficient head.

Finally, resolved threshold value of accumulation for river networking was verified after well-calibrated simulation of stream flow by using SWAT. All higher order recognized streams with in Birr watershed are perennial and suitable for RoR hydropower development. These results are indicators of the accuracy of considered threshold flow accumulation during stream ordering. If stream flow at any of ideal location along stream is non-perennial, the river network at that point should not be considered as higher order and the suitability of location for RoR hydropower development is not recognized. For the reason, threshold flow accumulation to identify higher order stream network could have been increased. Stream order of all available rivers in Birr watershed are in depicted in figure 4.1.

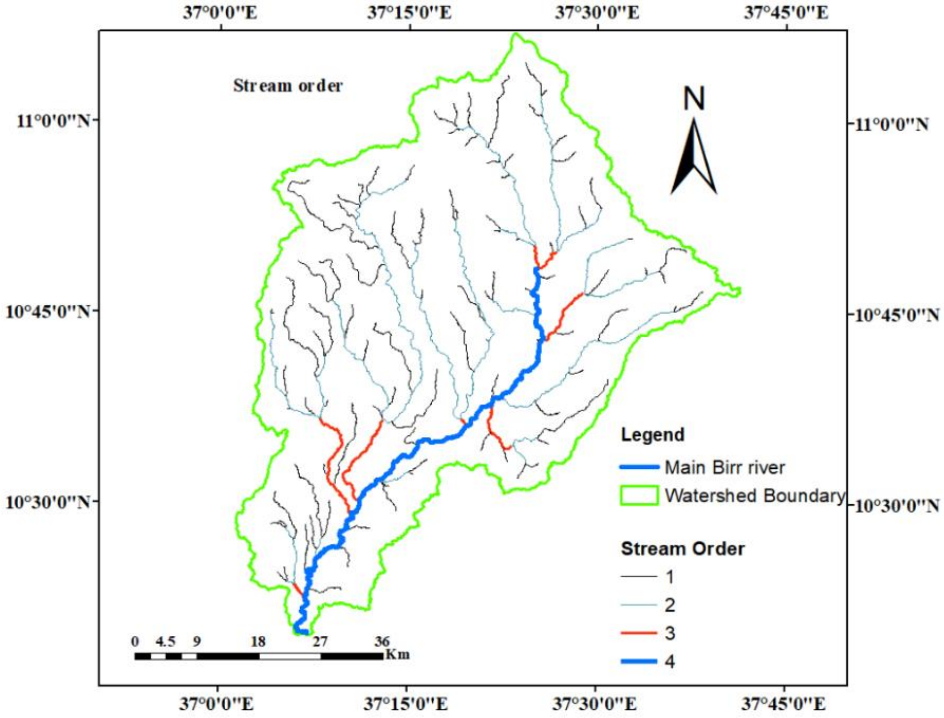


Figure 4. 1 Stream orders (Strahler Method) of Birr watershed

4.2 Identification of suitable sites for RoR hydropower development

The objective of GIS-based location selection for RoR hydropower development is to find the locations with enough head along higher-order streams. The reach along the river with a head drop of 10m between the intake point and power house is considered as ideal site for the RoR hydropower development as discussed in section 3.3.2. It is clear that as a distance between intake and powerhouse is increased, achievable hydraulic head will be maximum. But the criteria of maximum distance are set in order to limit the length of conveyance canal/pipe to convey water from diversion to powerhouse. Through this analysis,19 favorable locations for run-of-river hydropower development which have available gross head between 10 and 36 meters have been identified. Maximum available head along stream line is observed at site 19 which is found near the confluence of Birr and Temecha rivers. Identified run-of-river hydropower sites in Birr watershed and gauged and un-gauged sub-catchments are depicted in figure below.

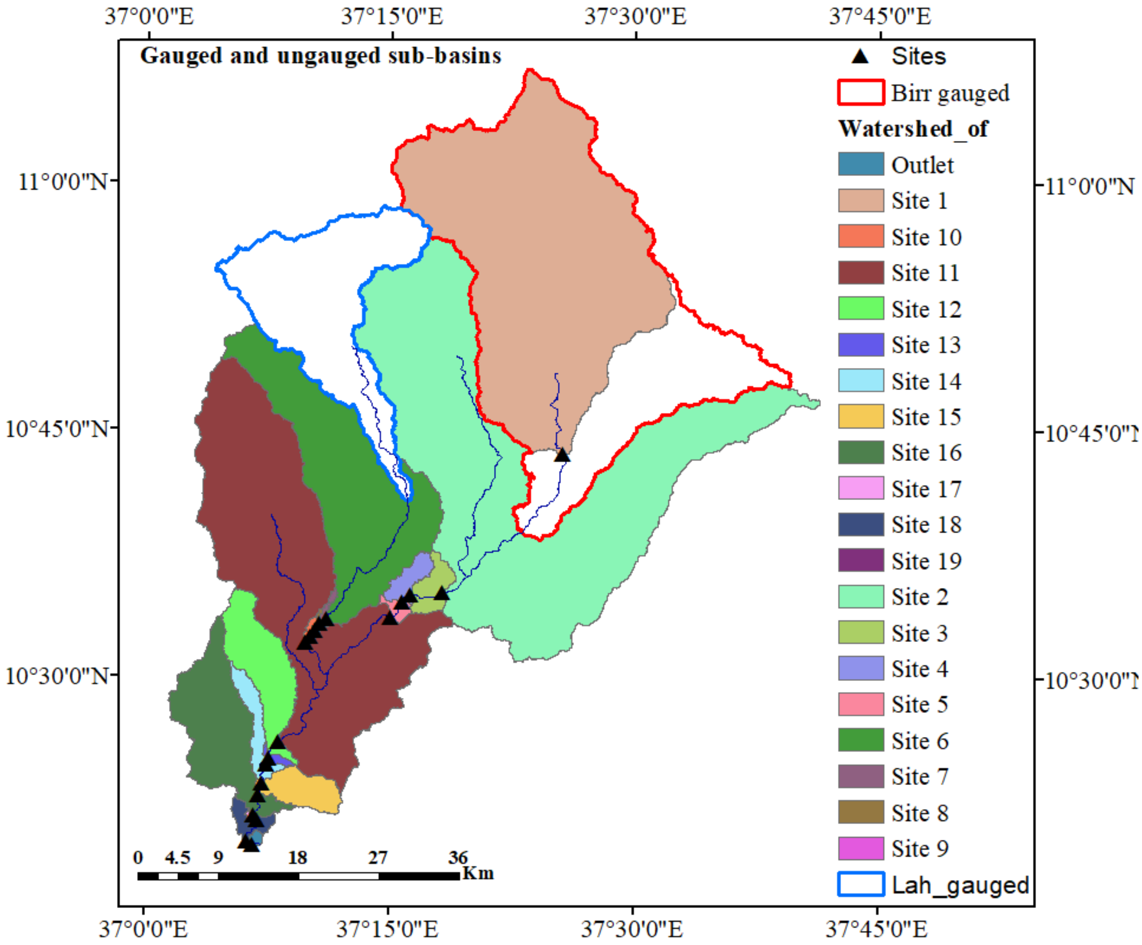


Figure 4. 2 Map that shows hydropower potential locations

Due to abrupt change in elevation along the stream and making the topography of area suitable for hydropower, the majority of feasible sites for hydropower production with sufficient head are found near the outlet of study area. The designated label for list of identified hydropower sites with optimum head along stream lines are shown in APPENDIX 5 and geographical coordinate of each sites is depicted in Table 4.1

.

Table 4. 1 Potential hydropower sites

Sites No	Intake location		Power house location		Head
	Latitude	Longitude	Latitude	Longitude	
1	10.727152	37.427027	10.722818	37.427281	12
2	10.586889	37.304717	10.585177	37.300740	11
3	10.584337	37.271907	10.581369	37.268868	20
4	10.576628	37.263096	10.572817	37.262649	13
5	10.560719	37.251311	10.562241	37.247272	10
6	10.561640	37.183986	10.558316	37.181726	11
7	10.555186	37.178555	10.551815	37.175736	14
8	10.547693	37.174022	10.543619	37.172353	28
9	10.541459	37.169045	10.539088	37.165377	18
10	10.534869	37.163981	10.531211	37.165931	19
11	10.434637	37.136881	10.431753	37.135018	15
12	10.418199	37.127684	10.414836	37.126951	10
13	10.412193	37.124764	10.412614	37.120934	10
14	10.392264	37.119836	10.389044	37.118278	23
15	10.381003	37.116264	10.377642	37.115351	16
16	10.360327	37.111594	10.356791	37.111629	10
17	10.355299	37.115277	10.351025	37.115092	11
18	10.33351	37.105364	10.331362	37.107098	13
19	10.330757	37.111383	10.331588	37.115680	39

4.3 Verification of DEM-based estimated head

After identifying viable locations and estimating available head for small scale hydropower development from DEM, actual observation of head by using GPS on easily accessible viable potential locations and additional validation points was conducted. That was for the sake of confirming DEM-based estimation of elevation by actual measurement. Those additional five stations were not considered as viable hydropower locations in the study, rather used as validation locations and utilized for generating the relation for further DEM based analysis.

Table 4. 2 Comparison of DEM-based and GPS-based head

Locations	Site1	Site2	Valp1	Valp2	Valp3	Valp4	Valp5
Geographic location	10.72281 37.42728	10.585177 37.300740	10.719623 37.429046	10.715822 37.427287	10.712933 37.424153	10.687613 37.421436	10.683700 37.419655
Dem-based head	12	11	6	1	6	7	4
GPS-based head	14	9	7	2	6	9	2
Difference	-2	2	-1	-1	0	-2	2

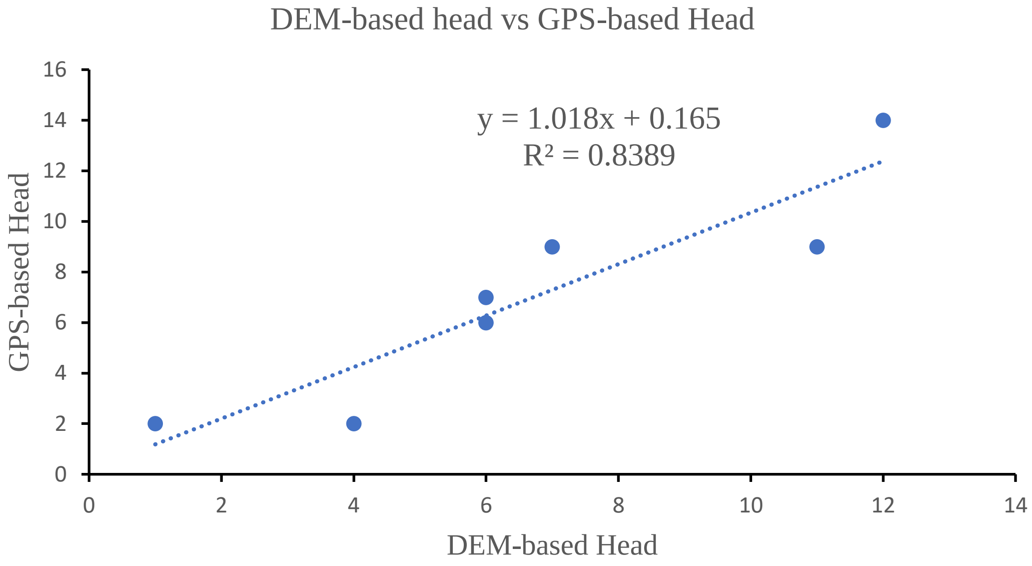


Figure 4. 3 Comparison of DEM-based and GPS-based head

Accordingly, Good agreement between both methods was observed as shown in Figure 4. 3 with tolerable correlation coefficient (R2) and corresponding RMSE of the results is 1.6. The results are indicators that verify how GIS process-based estimation of head is advanced option for hydropower potential assessment of specific site.

Final adjusted head for hydropower potential estimation of locations has been estimated based on relation obtained from DEM-based and GPS-based elevations. As shown in figure 4.3, the mathematical relation was derived from conducted sample points.

$$\text{Final adjusted head} = 1.018 \times DEM \text{ based head} + 0.165$$

Final corrected head of all 19 identified viable hydropower locations are given in Table 4. 3.

Table 4. 3 Final adjusted head of hydropower stations

Site	DEM-based head	Corrected head	Site	DEM-based head	Corrected head
1	12	12.4	11	15	15.4
2	11	11.4	12	10	10.3
3	20	20.5	13	10	10.3
4	13	13.4	14	23	23.6
5	10	10.3	15	16	16.5
6	11	11.4	16	10	10.3
7	14	14.4	17	11	11.4
8	28	28.7	18	13	13.4
9	18	18.5	19	36	36.8
10	19	19.5			

4.4 Estimation of flow by using SWAT

4.4.1 Model setup and flow simulation

The second and most important parameter to be precisely and accurately evaluated in order to determine the hydropower potential of the location is river flow. There are only two gauging station with in catchment which covers only small portion of study area. Since all of potential hydropower sites with sufficient head along river reach are found at non-gauged locations, stream flow at all points was estimated by using SWAT.

The outlets of the contributing area are head-based defined intake locations, and stream flow simulations at those locations were carried out by using SWAT. After preparing spatial data of Digital elevation model (DEM), Soil, land use land cover and metrological inputs (precipitation, temperature, relative humidity, solar radiation and wind speed for the period of 1990 to 2019 for model, 978 km^2 area of watershed was delineated by taking Birr gauging station near Jiga as an outlet. This watershed was divided into three sub basins and 17 HRUs. Simulated stream flow in this small catchment was calibrated and validated until reasonable objective function was achieved. Next to that entire catchment of 3159 km^2 was divided in to 27 sub basins and 172 HRUs to simulate the stream flow of area by taking confluence point of Birr and Temcha as an outlet. Then following model setup, the default stream flow simulation of monthly time setup of year 1990 to 2019 including 2-year warm up period in the catchment was carried out for catchment in order to determine the flow for estimation hydropower potential.

Stream flow which is retained to meet irrigation water in upstream of potential sites has been deducted from SWAT based simulated stream flow. Deduction of stream flow for irrigation is not for entire year rather for the dry periods only in which water is required for irrigation. At U/S of 14 potential sites(site 6- site14) there are two functional irrigation projects. Geray is one of the irrigation projects which is constructed at non-perennial river and meets the irrigation water by storing water during rainy seasons. From inflow-outflow hydrograph analysis to determine storage capacity of reservoir and find out the remaining stream flow, my results showed that, to meet the full irrigation demand for four-month dry seasons, all stream flow of river must be stored for entire periods of the year (Appendixes 1D). Therefore, Geray river flow has been deducted from SWAT-based simulated flow for all periods of a year. Another small-scale irrigation project found at U/S of those potential hydropower sites is Lah small scale irrigation project. In this irrigation project, 0.3m^3/s of flow is diverted from Lah river without any storage to meet irrigation water demand during dry months. This amount of flow has been deducted from available stream flow only during dry seasons (January, February, March and April). For remain five locations (site1-site 5), there is no any irrigation/other water utilizing project at U/S of the sites, all available stream flow excluding environmental flow was considered during hydropower potential assessment.

From all potential locations, six stations found in non-perennial Lah river lack firm power during dry years unless some peonage is constructed. From SWAT-based simulated flow of potential sites it is observed that, the maximum mean monthly flow which is observed at site 19 is 133.6 m^3/s. In this site, 3.4 m^3/s of minimum monthly flow is observed at month of April. Identified site with less stream flow from all sites was site 6. In this site minimum and maximum stream flow has been identified as 0.28 m^3/s and 27.7 m^3/s respectively. For most of consecutive identified potential locations which are close each other (minimum distance 500m), it is observed that the flow obtained does not have an exaggerated difference basically during dry periods. Mean monthly flow of all 19 small scale hydropower potential sites of Birr watershed are indicated in APPENDIXES 0.

4.4.2 Sensitivity analysis, calibration and validation

To determine the variables that most influence model output, a sensitivity analysis was conducted prior to calibration and validation by using data monitored at Birr gauging station near Jiga. Global sensitivity analysis of 19 flow parameters gathered from several articles was conducted by using SWAT-Cup using SUFI-2. Stream flow monitored at Birr gauging station from 1990-2006 including warm up periods of two years was used for sensitivity analysis. Using SWAT-CUP, 1000 simulations were run for each iteration until the objective function was optimal. The p-value and t-statistic from the global sensitivity analysis determine the rank of the sensitive parameters. The greatest absolute value of the t-stat, which is used to identify a measure of sensitivity for each parameter, and a p-value used to assess significance of sensitivity that is close to zero are both indicators of greater sensitivity. Parameters having P value less than 0.05 are considered as most sensitive parameters. Accordingly, out of 19 parameters, eight flow parameters listed in Table 4. 4 were selected as sensitive that highly affect the catchment outputs.

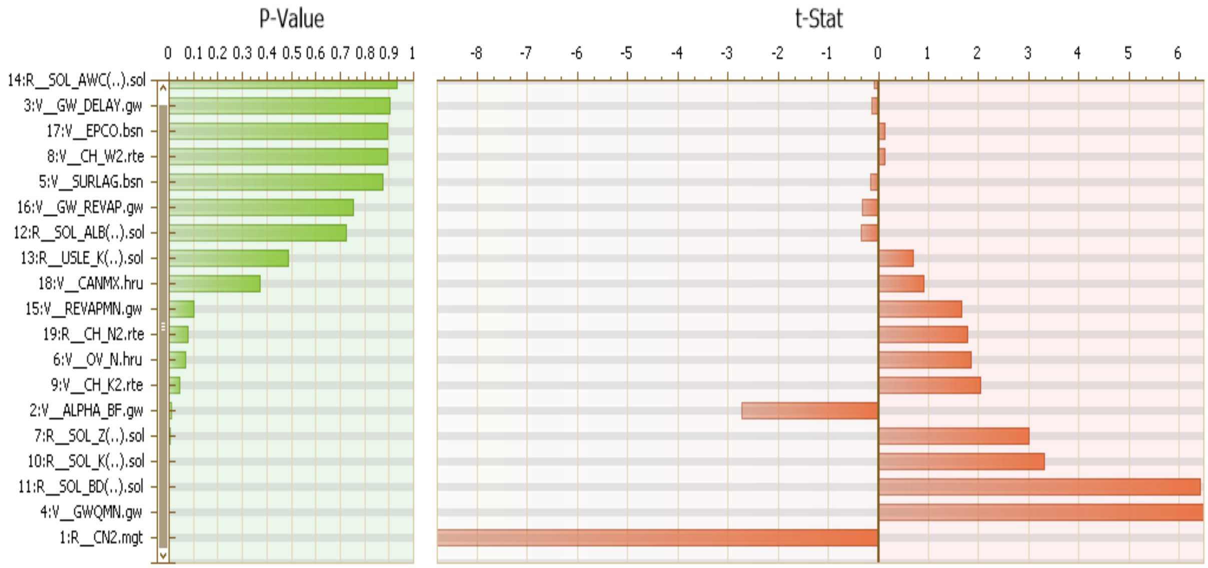


Figure 4. 4 Flow sensitive parameters of Birr watershed

Initial SCS CN II value (CN2), threshold depth of water in a shallow aquifer for return (GWQMN) and moist bulk density (SOL-BD) are top sensitive parameters of the catchment. Soil saturated hydraulic conductivity (SOL-K), depth from soil surface to bottom of layer (SOL-Z), base-flow alpha factor (ALPHA BF) have been also identified as best influencing sensitive parameters of the watershed as shown in Figure 4. 4. Most of parameters identified as sensitive are consistent with parameters identified at neighboring Temcha watershed studied by (DİLNESA, 2020).

In the process identified model parameters are altered within optimum range until model output matches with observed stream flow. The following table shows sensitive parameters and perspective range for calibration and validation.

Table 4. 4 Rank and optimum values of sensitive parameters

Sensitive Parameter name	Definition	Parameter range	Optimum value	Sensitivity ranking
R__CN2.mgt	SCS runoff curve number	-0.2 -0.2	-0.12	1
V__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0-5000	997	2
R__SOL_BD(..).sol	Soil moist bulk density (g/cm3 @Mg/m3)	-0.2-0.2	0.03	3
R__SOL_K(..).sol	Saturated hydraulic conductivity (mm/hr.)	-0.25-0.25	0.16	4
R__SOL_Z(..).sol	depth from soil surface to bottom of layer (mm)	-0.25-0.25	0.02	5
V__ALPHA_BF.gw	Baseflow alpha factor (days)	0-1	0.21	6
V__CH_K2.rte	Effective hydraulic conductivity in main channel alluvium (mm/hr)	-0.01-50	0.1	7
V__OV_N.hru	Manning's "n" value for overland flow	0.01-1	0.144	8

Once the SWAT model has been calibrated and optimum match between simulated and observed flow was achieved, additional accuracy of model was evaluated during the validation phase by using data that had not been used during the model's calibration without any change in parameter range. Monthly observed flow data at Birr gauging station near Jiga of five years (2002-2006) were used for validation of model. The observed and simulated monthly stream flows during calibration period and validation period are shown in Figure 4. 5. Performance of model evaluated during calibration and validation was measured by using statistical objective functions of R^2, NSE and PBIAS. Statistical results showed "*good*" efficiency during both calibration and validation. During the calibration phase, the Nash-Sutcliffe efficiency (NSE), correlation coefficient (R^2), percent of bias (PBIAS) and root mean square error(RMSE) were all 0.79, 0.75, -19.6% and 9.89 respectively. The statistical analysis results also showed that the observed and simulated stream flow were reasonably consistent and showed good efficiency during validation, with monthly R^2 values of 0.79, NSE of 0.79 , PBIAS of -7.6% and RMSE of 10.71 though there is little bit overestimation of root mean square error (RMSE).

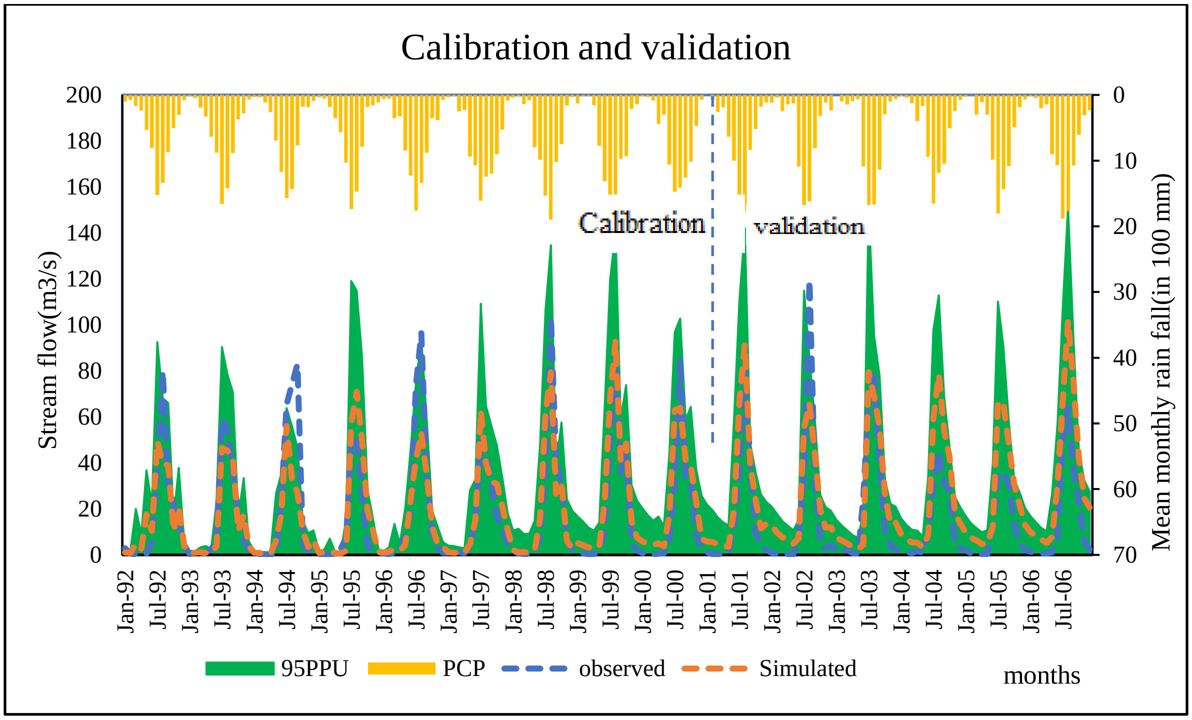


Figure 4. 5 Calibration and validation results of SWAT output

SWAT tended to underestimate the runoff during very high flow periods, despite the statistical examination showing the good stream flow modeling for both the calibration. This may be partially due to the current curve number technique's inability to anticipate runoff accurately for days with high storms. When numerous storms take place in a single day, each storm's runoff curve number and soil moisture level are unique in actual aspect. However, SCS-CN approaches interpret a rainfall event as the whole amount of rain that falls during a given day, which may result in an underestimate of runoff (Te Chow, 2010). Additionally, during validation SWAT has showed its limitation of ability to cupture low flow due to deficiencies in its groundwater modeling (Mapes & Pricope, 2020; Raja et al., 2022).

After calibration and validation of model was applied at gauging station, well-situated range of parameters was used to simulate stream flow at ungauged catchment by using basic principles of regionalization.

4.4.3 Regionalization

In the study area observed stream flow monitored at Birr gauging station near Jiga has relatively accurate and long-time record which was used to calibrate and validate the model. But evaluation performed at that point is not valid for entire catchment since it covers only small portion of area. In these situations, parameters should be transferred from gauged to ungauged watersheds using the proper regionalization techniques. Applying and contrasting various regionalization methodologies for analysis in the study is restricted by the number of available gauging stations for observed stream flow in the area. Additionally, the donor catchment (using the Birr gauging station as the exit) and the receiver (entire study area) exhibit similar catchment characteristics, making it conceivable to employ the physical similarity approach of regionalization. The well-calibrated range of sensitive parameters at the gauging station were totally translated into the outlet of the entire catchment by the physical similarity approach of regionalization in order to test the model over the entire study area. In both catchments (donor and receiver) dominant land use type is cultivated land which accounts 68.83% and 67.78% respectively. Regarding dominant soil type similarity of the area, some variance among both catchments were observed. Four primary soil types are distributed proportionally throughout the donor catchment region whereas six soil types were available with in receiver catchment as shown in Table 4.6. The betwixt, however, is sufficient and does not prevent the situation from adopting the regionalization method of physical similarity.

Table 4. 5 LULC similarity between donor and receiver catchment

Major LULC	% of area of donor catchment	% of area of receiver catchment
Built Up Area	0.489	1.696
Cultivated Land	68.780	68.834
Forest Land	9.714	7.280
Grass Land	11.310	11.710
Marsh Land	0.135	0.123
Shrub and Bush Land	9.572	10.357

Table 4. 6 Soil type similarity between donor and receiver catchment

S.No	soil type	% of area of un-gauged catchment	% of area of gauged catchment
1	Chromic Luvisols	18.857	38.097
2	Chromic Vertisols	31.435	14.209
3	Dystric Nitosols	11.512	0
4	Eutric Nitosols	19.114	24.566
5	Lithosols	8.847	23.126
6	Orthic Acrisols	1.342	0
7	Pellic Vertisols	8.893	0.001

Observed stream flow data from Birr (1993–2006) and Lah (1997–2002) were utilized for further validation process to confirm the accuracy of regionalization technique applied in the study. Accordingly, better statistical objective functions by using previous parameters were achieved with measured stream flow at Birr gauging station. The objective functions of R^2, NSE , PBIAS and RMSE were 0.7,0.66 , -0.026% and 10.20 respectively at Birr gauging station which show good statistics of performance. This result is confirming output that verified how the approach of regionalization used in the study was successful.

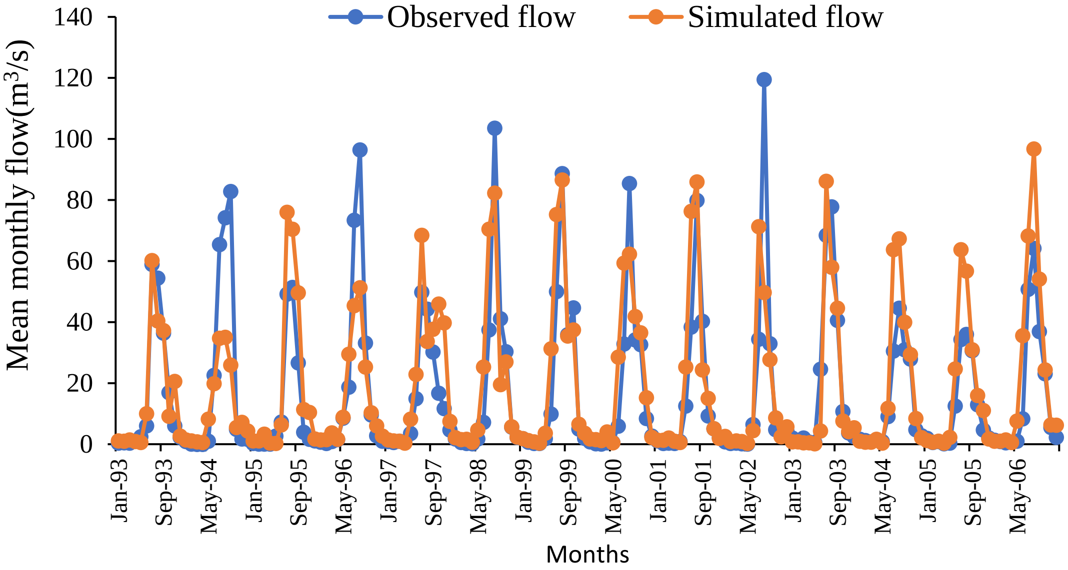


Figure 4. 6 Validation by using Birr stream flow

Observed stream flow of Lah river of 1997-2001 was used for further validation. Result of statistical objective functions also show good agreement between observed and simulated stream flow with R^2, NSE ,PBIAS and RMSE values of 0.78, 0.78 , –0.07% and 2.64 respectively.

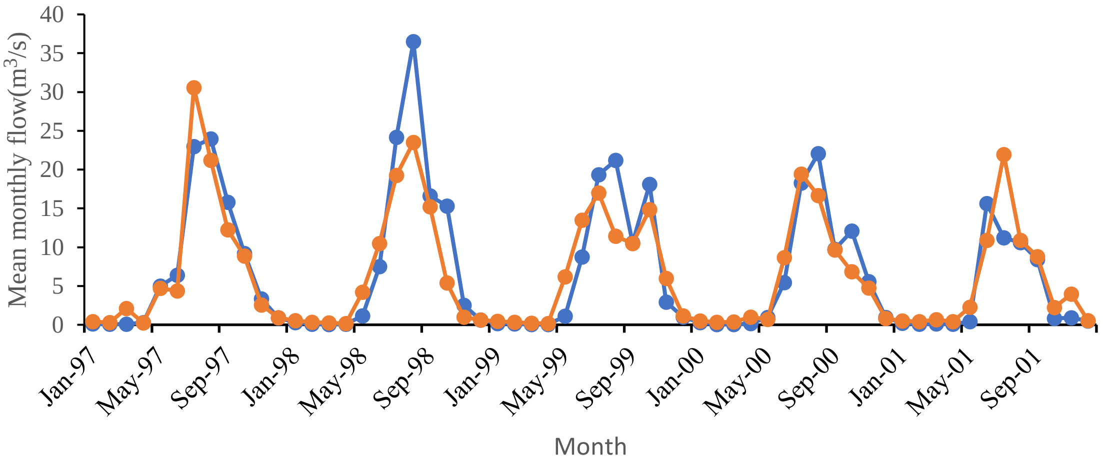


Figure 4. 7 Validation by using Lah stream flow

Final results of objective functions during calibration, validation and regionalization process are shown in table below.

Table 4. 7 Summary results of objective functions during calibration and validation

Statistical performance	Calibration		Validation		
	Birr	Lah	Birr (2002-2006)	Birr (1993-2006)	Lah
NSE	0.79	-	0.79	0.66	0.78
R^2	0.75	-	0.79	0.7	0.78
PBIAS (%)	-19.6	-	-7.6	-0.026	-0.07
RMSE	9.89	-	10.71	10.20	2.64

Table 4. 8 Summary of mean annual stream flow at hydrological stations

Hydrological station	Calibration/validation	Observed(m^3/s)	Simulated(m^3/s)
Birr near Jigga	Calibration(1993-2001)	203	205
	Validation(2002-2006)	187	214
	Validation (1993-2006)	196	209
Lah near Finoteselam	Validation(1997-2001)	80	76

4.5 Flow duration curve

Hydropower potential at selected hydropower location was performed by constructing flow duration curve by using total period method ranking for finding percentage of time that stream flow is likely to equal or exceed a value of intended stream flow for generation of hydropower at specific site. Maximum flow analysis is crucial from a design or installed capacity point of view; average flow analysis is crucial for considering energy output; and minimum flow analysis is necessary to forecast reliable firm capacity. The flow duration curve allows for the estimation of 95% of the flow's percent exceedance, which is important for estimating firm power, as well as 30% of the flow's exceedance, which is used to estimate maximum available stream flow for 100 to 120 days in which most of RoR plants are designed.

Some of flow duration curves generated for potential sites are flat whereas most are steep. Potential sites identified in upper parts of catchment show flat characteristics whereas found in lower parts show steep curve characterstics. Variation of FDC curve from flat to steep is related to factors of land use land cover, soil type and rainfall distribution in the area. A steep flow duration curve implies a flashy catchment – one which is subject to extreme floods and droughts caused by Rocky, shallow soil, lack of vegetation cover, uneven distribution of rainfall (frequent storms, long dry periods) in area. As general such sites are not recommended for RoR hydropower development. A flat flow duration curve which is good for RoR hydropower development due to even distribution of annual flow over the year are observed in sites found in upper portion of watershed specially in Lah river. This is due to existence of sites in long gently sloping area’s and even distribution of rainfall in the area. Samples of flow duration curve for some potential sites are indicated in Figure 4. 8 and FDCs of all potential sites are indicated separately in APPENDIXES 4.

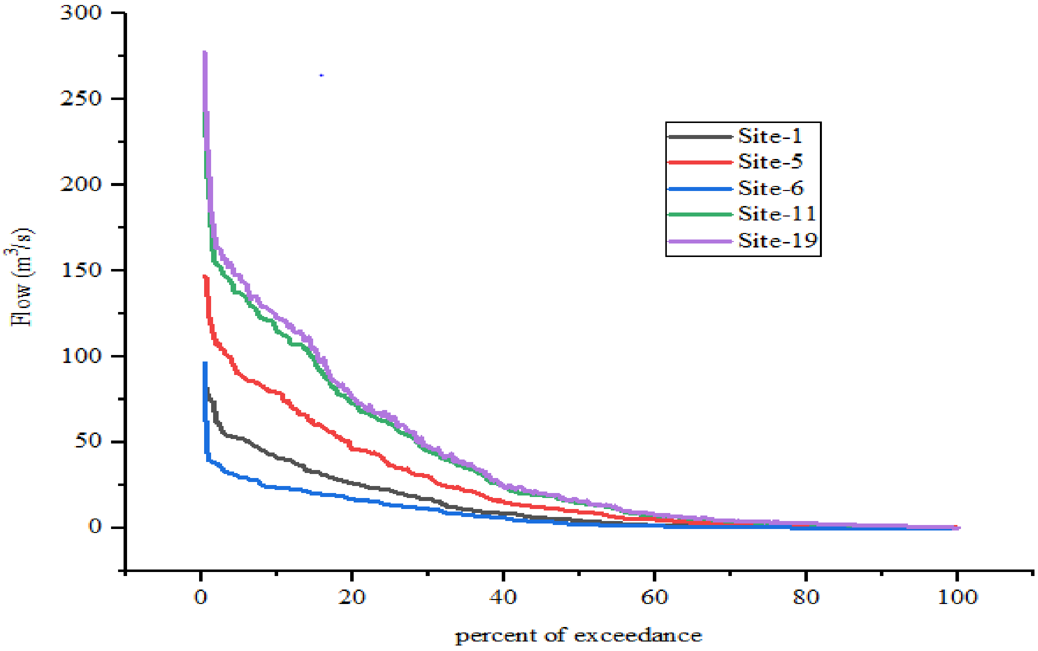


Figure 4. 8 Flow duration curves

4.6 Estimation of hydropower potential

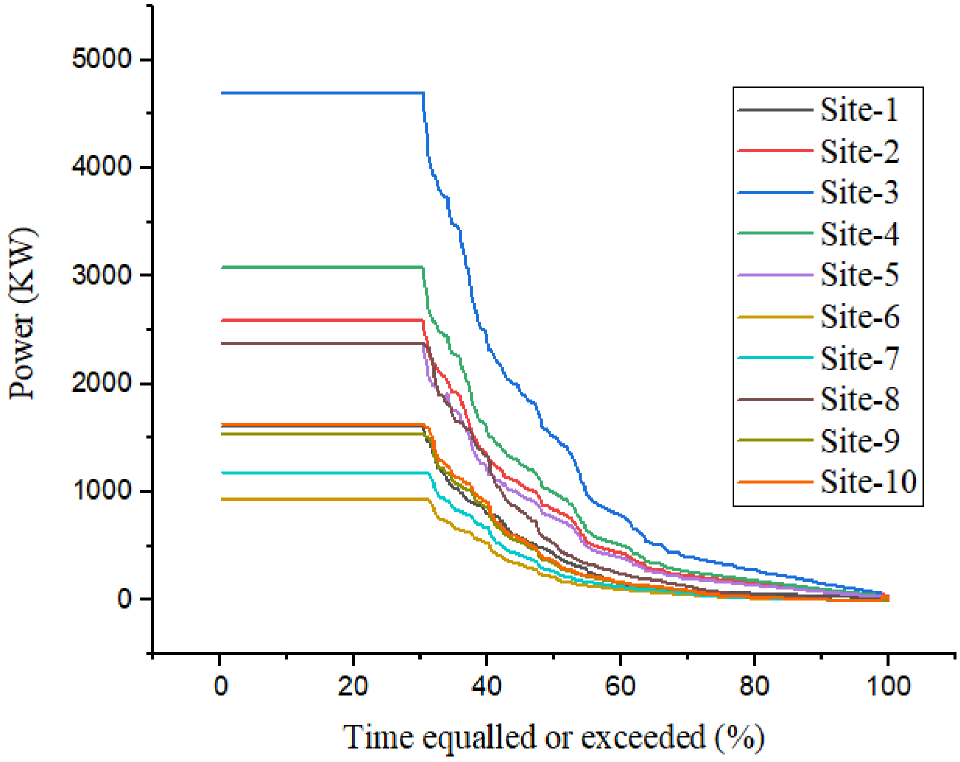
4.6.1 Theoretical hydropower potential

Theoretical hydropower potential depends on the available head and the stream flow without taking head losses in the conveyance and electromechanical equipment efficiency into account. After estimating head and dependable stream flow from flow duration curve at identified hydropower sites, power have been estimated by using power equation. The hydropower potential at a given location with discharge (Q) and hydraulic head (H) was calculated by using power equation 3.16. Once water power potential of each site was estimated by equation, total hydropower potential of study area has been determined by summing the power from each site.

As discussed in section 3.3.6, dependable flow of 30%, 50%, 95% and mean stream flow were used for estimation of hydropower potential of identified sites. Through the process, it has been identified that 94.9 MW, 29.2 MW, 1.1MW and 82.2 MW of theoretical power was estimated from all 19 hydropower stations for 30%, 50%, 95% and mean flow dependability of stream flow respectively. Site 19 has the area's maximum hydropower potential of 16.7 MW due to existence of location in the outlet of area with high head and stream flow. Variation of power among potential sites was significantly caused by variation of head along the stream. Due to the presence of high head and stream flow, the highest power potential locations are typically located close to the exit of catchment. However, some viable locations were seen at locations far from the outlet where a magnificent head along stream network are available. Estimated theoretical hydropower potential at each selected site for considered dependable flow is indicated in APPENDIXES 2 and total hydropower potential of Birr watershed corresponding to each dependable stream flow is shown in Table 4. 9.

4.6.2 Technical hydropower potential

Available technical water power at each site for all dependable flow was estimated by multiplying the product of available dependable stream flow and corresponding head by 7.75 (average of the interval recommended by (Mosonyi, 1960)). According to assessment findings, a total of 75 MW of power may be harnessed from the specified region utilizing water that is available for 120 days (30%), and overall mean hydropower potential of the catchment has been estimated as 64.9 MW. Total hydropower potential of Birr catchment for each dependable flow is given in Table 4. 9.



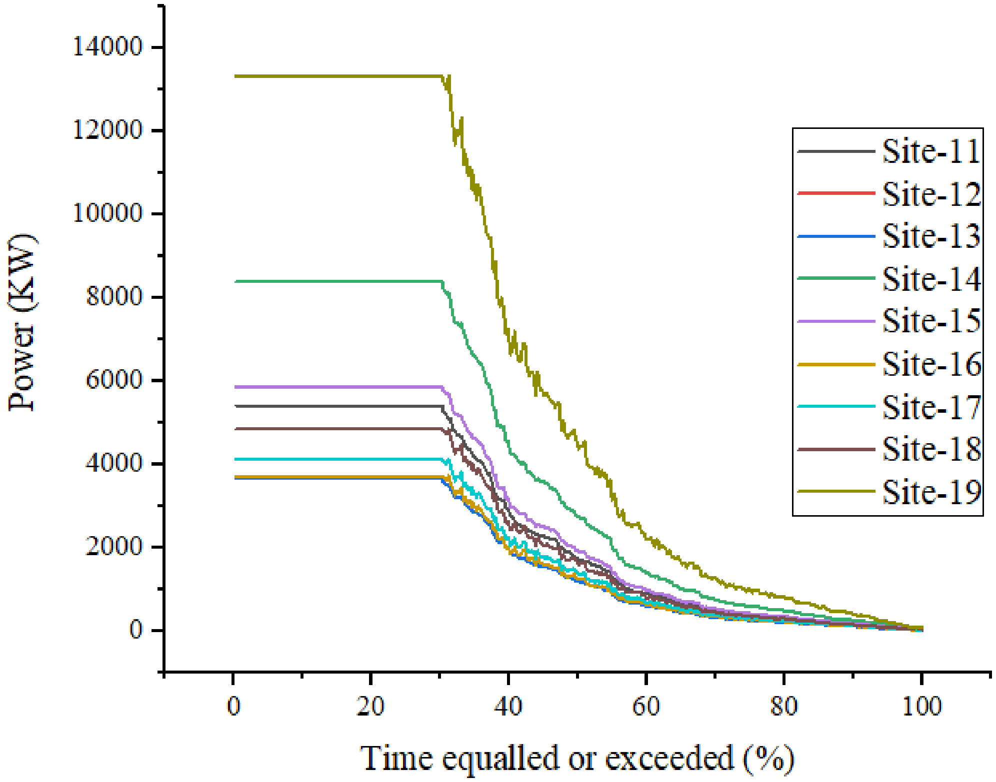


Figure 4. 9 Power duration curves of potential sites

Table 4. 9 Total hydropower potential of Birr catchment for different dependable flows

Power	P30%	P50%	P95%	P_m
Total theoretical power (KW)	94932	29187	1110	82181
Total technical power (KW)	74997	23058	877	64924

The unavailability of the Lah river throughout the year has caused achievable firm power minimum from study watershed. Small scale hydropower potential of Birr watershed has further categorized in to different classes according to classification base of Ethiopia discussed in section 2.4.2. It was found that the majority of firm power that might be produced from identified potential locations fell into the "micro" hydropower category with a capacity of 20 KW–100 KW. Available power from 30% of exceedance flow and mean flow of location-19 has been estimated over 10 MW which can be classified above small scale hydropower capacity in Ethiopian context. This result confirms how the study area has enormous hydropower potential even from RoR development without impounding and expensing cost for construction of storage structures along the stream. Remaining locations are categorized under mini and micro small-scale hydropower category. It was also observed that there is only one identified location (site -1) which can be classified as “Pico” small scale hydropower site for all 95% dependable flows in the study area with utilized head over 10 m along identified river reaches. The number of viable locations for small-scale run-off river hydropower production and the categories of generating potential of sites for various reliable flows are shown in the figure below.

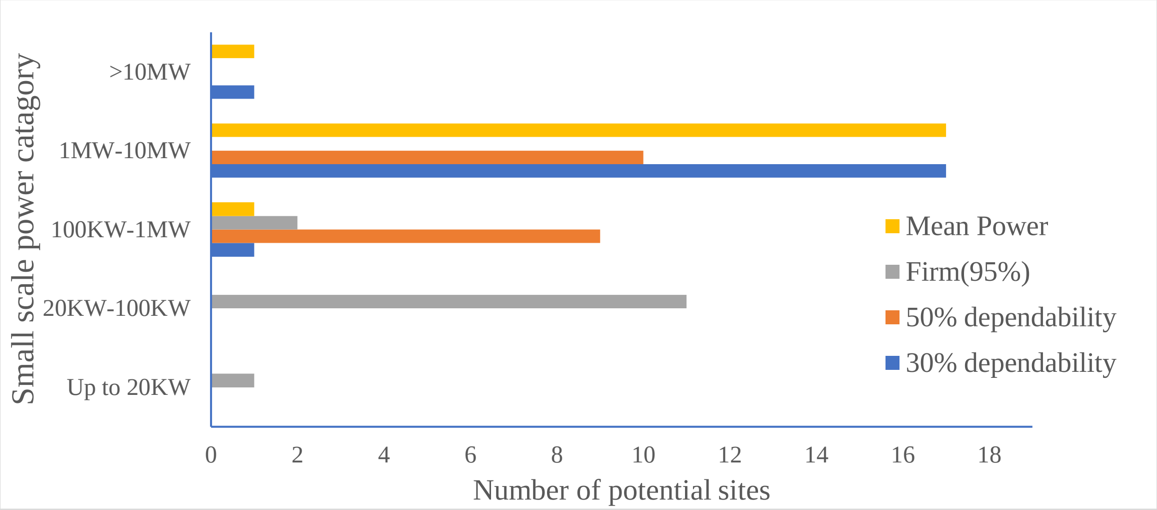


Figure 4. 10 Categories of available small-scale hydropower potential and number of locations

4.6.3 Total energy output of study area

Estimating available energy from selected hydropower sites that are characterized by annual values of potential energy in the river is also significant. The term "generated energy" and the unit "kilowatt hour" are used to describe the electric energy (PT) produced by the continuous operation of P (kW) for T (hours) in (kWh). Mean annual flow values from the flow duration curve at each site can be used to calculate the mean annual energy output in a small hydropower project with pure run-of-river exploitation. Estimated annual energy output from a site without considering capacity factor is given by

$$\text{Mean annual energy generation(KWh)} = \text{Mean power(KW)} \times \frac{24\ \text{hours(h)}}{1\ \text{day}} \times \frac{365\ \text{days}}{1\ \text{year}} \qquad 4.1$$

The technical power value at each site has been used to determine the yearly energy production for each chosen percentile by multiplying it by the number of hours per year that percentile of flow is available. The amount of energy for all regarded dependable flows (30%, 50%, and 95%) has been calculated utilizing generation period of 110, 183 and 346 days per year respectively. The study area's average (mean) annual energy output was projected to be 182 GWh, while the minimum energy output was estimated to be 7.3 GWh. Each site's yearly energy output is listed in the APPENDIXES 3, and the total annual energy output for each dependable stream flow of study area is given in the table below.

Table 4. 10 Total annual energy output of Birr watershed

Dependable flow	30%	50%	95%	Mean flow (Q_m)
Annual Energy out Put (MWh)	197993	101270	7283	182307

Nearby end user Kebeles that are found near potential locations and maximum distance between dam sites and center of kebele are indicated in Appendixes 5.

4.7 GIS and AHP based site prioritization for hydropower development

Prioritization of site for hydropower development is a decision-making process as it is function of many technical, economic and environmental constraints. The analysis did not consider the most important variables for selecting best site for storage hydropower development like land use and soil type when choosing the optimal location for RoR type of hydropower development. This is due to the fact that RoR hydropower development does not require a significant surface area for impoundment, so soil type, land use and land cover, and community settlement should not be considered during study. In addition, the distance of the site from nearby town was not taken in to account due to the main reason that, small scale hydropower developments are most of the time intended to electrify scattered rural areas which are far from national grid. For prioritizing hydropower locations in this study, stream flow, head, power, accessibility, and geological formation of the locations were key considerations. Suitability of each criteria for overall prioritizations of potential hydropower sites is discussed in following sections

4.7.1 Geological formation

According to geological formation map determined from Abay basin geologic map, the river segments of Birr and Lah which are identified to contain potential hydropower sites exist in good underlying geological formation area. Eight potential sites exist in high grade metamorphic rocks in which risk of slip, land slide and leaks are not dread (Petheram & McMahon, 2019; Uromeihy & Barzegari, 2007). Therefore, these locations are considered as suitable for hydropower development in terms of geological considerations. Other Eight viable hydropower sites of the area are found with in quaternary and Blue Nile basalt rock formation area. Basaltic rocks in general are easily susceptible to mechanical and chemical weathering by penetration of groundwater along the polygonal joints and fractures, loosening and decaying the rock layer by layer construction making them marginally suitable for construction of dam and other structures (Bell & Haskins, 1997). Out of the remaining three sites, two have been found in area composed of Adigrate sand stone rocks. Such rock types are moderately suitable for construction of hydraulic structures because of their existence on more erodible glacigenic and metamorphic rocks (Billi, 2015). Remaining one station is located within termaber basalts which are less suitable for foundation of structures due to composition of many fractures. The following table shows suitability of existing geological formation in the area.

Table 4. 11 Geological suitability of locations for hydropower development

Type of Geology	Suitability	Factor Rating	Number of sites
High grade metamorphic rocks	Highly suitable	S1	8
Adigrate sand stone rocks	Moderately suitable	S2	2
Quaternary and Blue Nile basalt	Marginally suitable	S3	8
Termaber basalts	Least suitable	S4	1

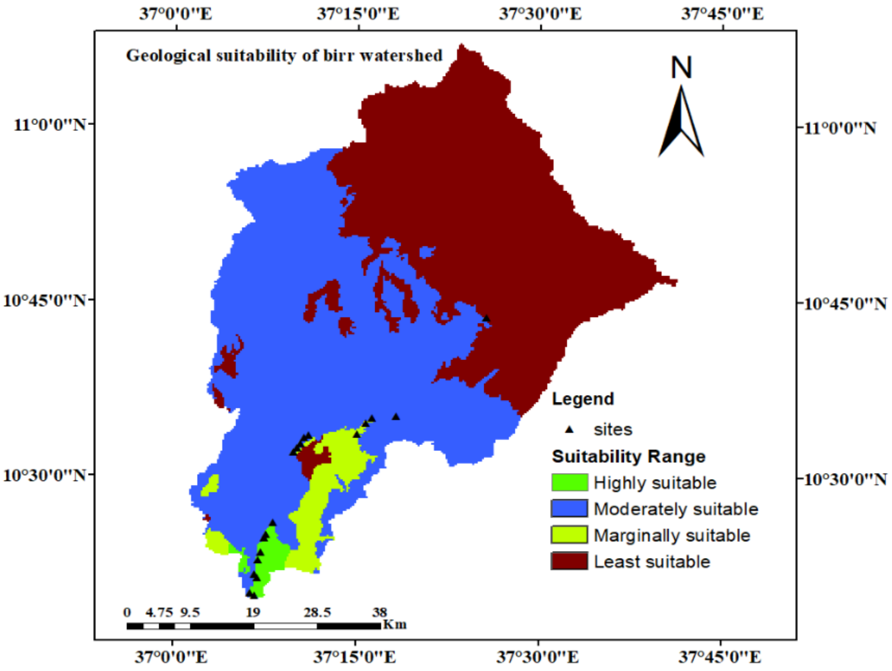


Figure 4. 11 Geological suitability map of Birr watershed

4.7.2 Discharge and head

As discussed in previous sections, well-calibrated SWAT-based Stream flow and GIS-based head at identified sites have been used to determine available power at each location. In this section, mean stream flow (Q_m) and head were used to generate discharge map and head map of area respectively for prioritizing potential sites. RoR type of hydropower can generate the energy with small amount of stream flow if sufficient head is available in the site. Since the study is potential assessment, consideration of upper and lower limit of stream flow at identified higher order streams is not valuable unless for the sake of ranking the sites. The range of available stream flow and head were therefore classified in to four possible equal interval groups to prioritize the sites one another. As generated power grows with increasing stream flow, the category with substantially larger stream flow was more often ranked as the best among those with small discharge which is also true for head. The map depicted in Figure 4. 12 is generated by using gross head at each sites and mean stream flow of sites.

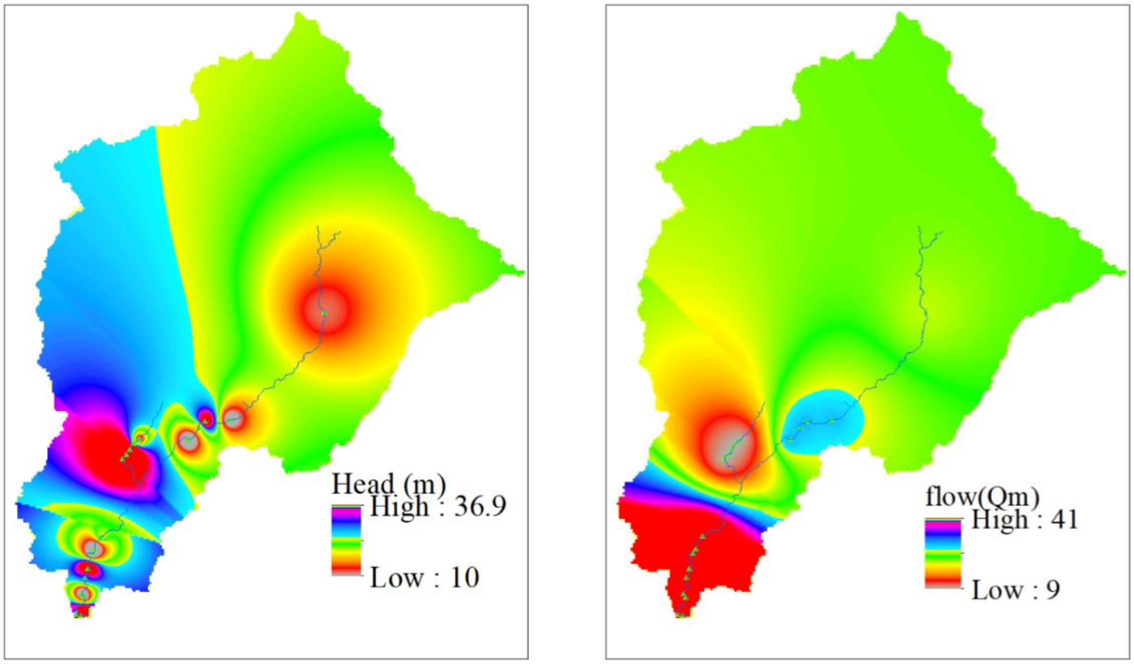


Figure 4. 12 Head (left) and stream flow (right) map of Birr watershed

Equal interval classification method of available hydraulic head and stream flow of viable potential sites for hydropower development with number of sites within given category are given Table 4. 12.

Table 4. 12 Discharge and head class for site prioritizing

Stream flow class	Number of sites	Available head class	Number of sites	Category	Representation
33.8- 41.8	9	29.2 – 36.8	1	High potential	S1
25.8- 33.8	0	22.8 - 29.2	2	Moderate potential	S2
17.9- 25.8	4	16.4 - 22.8	3	Marginal potential	S3
10- 17.8	6	10- 16.4	13	Low potential	S4

4.7.3 Power

Power which is directly proportional to stream flow and head has been used as one of main criteria for site prioritization. If other criteria are kept well suitable, the site with high head and high stream flow which will yield high power are preferable without any doubt. However, this does not necessarily imply that areas with more power output are the best for developing hydropower. Rather, it should be used as one of weighted comparison criteria to evaluate the suitability rank of all selected hydropower sites. Similar to head and stream flow, the estimated mean power (P_m) has been classified in to four equal classes. High head potential sites are those with the highest power output, and the ranking goes all the way down to low potential sites under classification.

Table 4. 13 Power reclassification for site prioritizing

Available power (Kw)	Number of sites	Category	Representation
8,780.7- 11693.0	1	High potential	S1
6,131 - 8,780.7	1	Moderate potential	S2
3,481.2 - 6,131	5	Marginal potential	S3
817 - 3,481.2	12	Low potential	S4

4.7.4 Accessibility of site

Most often, hydropower prospective sites are located in isolated valleys that are difficult to reach and develop. Accessibility is necessary for power plant construction, installation, maintenance, and disassembly at the hydropower functional life cycle. It is assumed that sites located far from the road networks were unsuitable for dam construction because it costs a large amount of money to construct access roads and expends additional cost making the project unfeasible. On other hand, the power locations which are found near the road network are easily accessible during construction, operation and maintenance during life period of the project and such locations are considered as convenient for hydropower development. Therefore, road map to evaluate accessibility is important input to be used as weighted comparison criteria for ranking potential sites.

Suitability evaluation of sites based on accessibility was examined by generating Euclidean distance map of the area which measures relative distance of any locations from nearby road network. As a general, there is no conservative rule that limits minimum and maximum distance of hydropower locations from road network. Therefore, generated distance map of area was classified in to four equal classes in which firs classes were easily accessible and the last category with long distance were least suitable for hydropower development. The road networks connecting Mankusa to Birsheleko and Noand to Kuch were routes which made most of potential sites accessible. Most of identified potential sites can be accessed via those road networks categorized under easily to marginally accessible sites. Most remote sites exist near the outlet of study area in which two potential sites with high head were identified. Most of identified potential sites are found in easily accessible area with maximum distance of 2880m.The longest distance of potential locations from road network has been identified between 8641 to11520 m.

Table 4. 14 Accessibility range of potential sites

Euclidean distance(m)	Number of sites	Accessibility	Representation
0 - 2,880	12	Easy	S1
2,881- 5,760	3	Medium	S2
5,761- 8,640	2	Marginal	S3
8,641 - 11,520	2	Hard	S4

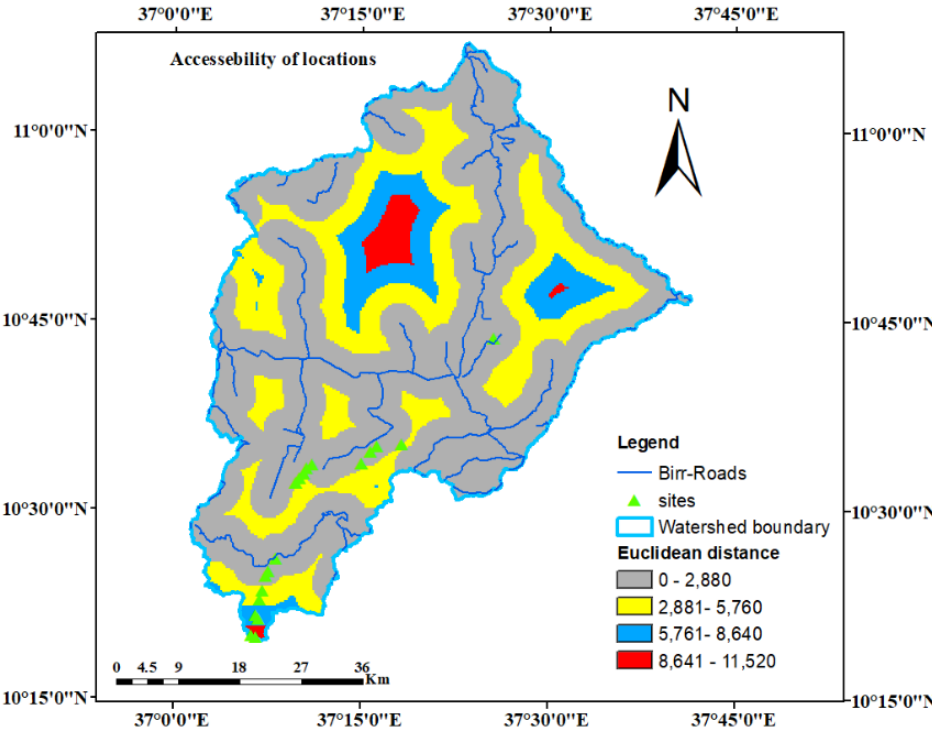


Figure 4. 13 Accessibility of Birr watershed

4.7.5 Weighting of factors for AHP multi-criteria decision analysis

AHP based multi criteria decision analysis has been used to compare relative significance of basic site selection factors for hydropower development. The analysis utilizes five different map layers as inputs in the suitability mapping; discharge, head, power, road proximity and geological formation of the area. After preparation of all five basic influencing factor’s thematic layers and conducting pairwise comparison between each factor by gathering importance of one factor to other from different literatures, weight of each factor has been estimated for overlay analysis. The value given for each factor was based on relative importance or significance of each factor for generating suitable dam site for hydropower development. Achievable power of a location is the main factor in which maximum weight was given whereas accessibility of site (distance from access road) takes the minimum weight of all criterions. For potential sites which have sufficient power which can meet the intended demand, accessibility should not hinder the development that much. For all process of AHP weight estimation Microsoft Excel program as described by Bunruamkaew (2012) has been used in this study.

Table 4. 15 Pairwise comparison matrix of factors

Factors	Power	Head	Discharge	Geology	Accessibility
Power	1	2	3	5	5
Head	0.5	1	2	5	5
Discharge	0.33	0.5	1	4	4
Geology	0.2	0.2	0.25	1	3
Accessibility	0.2	0.2	0.25	0.33	1
Total	2.23	3.90	6.50	15.33	18.00

Sources: (Ayele, 2020; Fesalbon et al., 2019; Punys et al., 2011; Romanelli et al., 2018)

Priority matrix standardized vectors of the number of criteria were derived from the pair wise comparison matrix table by dividing each column entry to the sum of column values after all element’s values of the pair wise comparison matrix were determined.

Table 4. 16 Standardization of factors matrix

Factors	Power	Head	Discharge	Geology	Accessibility	Priority weight (%)
Power	0.45	0.51	0.46	0.33	0.28	40.5%
Head	0.22	0.26	0.31	0.33	0.28	27.8%
Discharge	0.15	0.13	0.15	0.26	0.22	18.3%
Geology	0.09	0.05	0.04	0.07	0.17	8.2%
Accessibility	0.09	0.05	0.04	0.02	0.06	5.1%

Priority weight of variables represents the perspective factor's contribution to choose the optimal dam site for the development of hydropower. The variable with higher weight has greater contribution than others in selecting the hydropower site. In this case power as variable has been identified as most important factor than remaining aspects with weight of 40.5%. Accessibility range of sites was least contributing factor for prioritizing suitable sites for hydropower development in Birr watershed with importance factor of 5.1%. Consistency of pairwise comparison was evaluated by estimating CR value. Consistency Ratio (CR) is a numerical index proposed by (Saaty, 1984) for appraising the consistency of pairwise comparison matrix in AHP which can be estimated by using equation.

$$CR = \frac{CI}{RI}$$

Where,

RI=random index values=1.12 for n=5 from Table 3. 6

and CI=consistency index given by equation below

$CI = \frac{\lambda_{\max} - n}{n-1}$, where n=5(number of factors)

Finding the largest Eigen value $\lambda_{\max}$ is necessary in order to determine the consistency index value. Its value is obtained by multiplying the pairwise comparison matrix total row sum values by the standardized matrix average column values.

$$\lambda_{\max} = 2.23\times 0.405 + 3.9\times 0.278 + 6.5\times 0.183 + 15.33\times 0.082 + 18\times 0.051 = 5.283$$

$$CI = \frac{5.283-5}{5-1} = 0.071$$

$$CR = \frac{0.071}{1.12} = 0.06$$

According to Saaty (1984), a CR value of 0.1 or less can be regarded as reasonable. Therefore, the pairwise comparison of criterion has been evaluated as consistent.

4.7.6 Overlay analysis

After assigning relative significance weight for each five important factors, they were overlaid to determine the most suitable sites for hydropower development. Weighted sum overlay analysis has been conducted to generate final suitability map of the area and prioritize potential hydropower locations. It is observed that the majority of the best prioritized sites are located near the outlet and those areas are high elevation with high stream flow accumulation which corresponds to enormous power to be harvested. As power from water is being dependent of only head and stream flow, the high rank locations exist in the areas with high head and high stream flow which can justify the consistency of the overlay analysis. Identified areas are characterized by strong geological formation for construction of dam and powerhouse for small scale hydropower development.

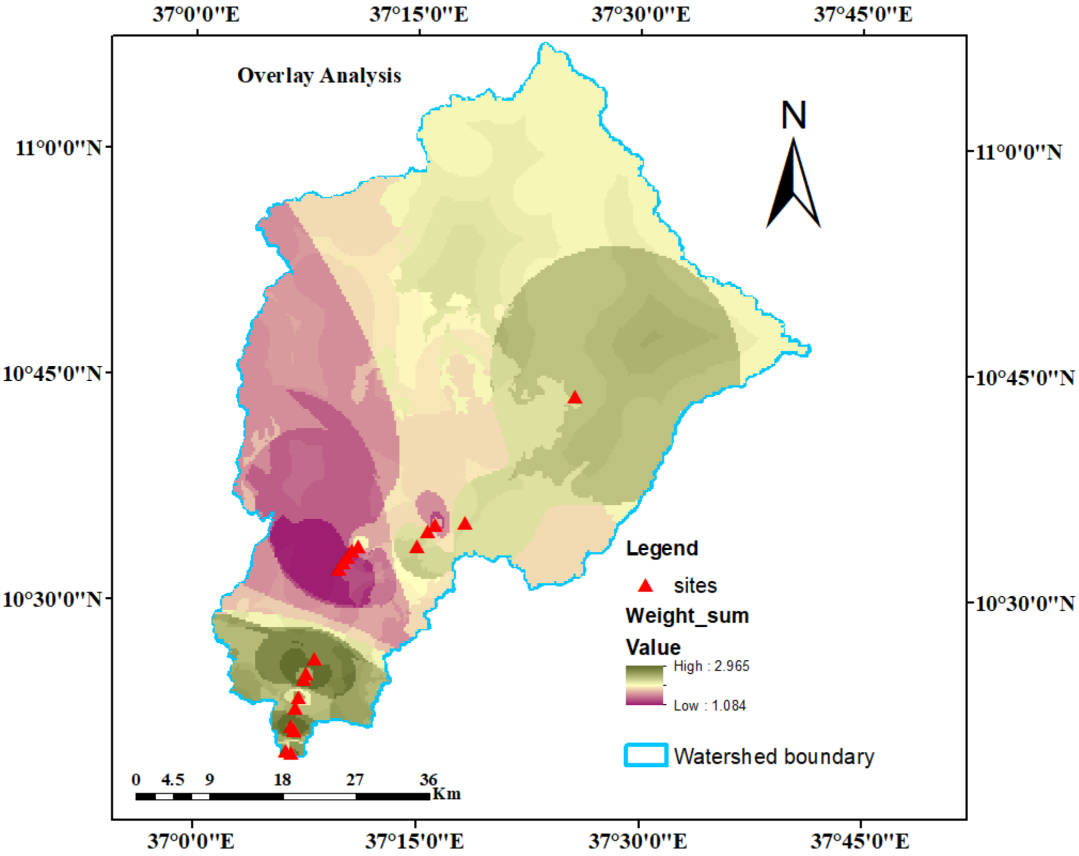


Figure 4. 14 Overlay Analysis map of site prioritization

The locations with higher sum value in figure above indicate higher preference of the location for hydropower development. The value of all previously recognized locations for small scale hydropower have been extracted from the map in GIS environment to rank the suitability of sites. It was observed that site-19 got highest suitability rank next to site-18. The least suitable sites that have been identified were site 7, 8,9 and 10. The rank of all sites is indicated in Table 4. 2. Some nearby sites have the same value in which the same rank of priority has been given for these locations.

Table 4. 17 Priority rank of hydropower potential sites

Site number	1	2	3	4	5	6	7	8	9	10
Suitability value	2.27	2.10	1.68	2.18	2.18	1.92	1.64	1.08	1.08	1.13
Suitability rank	10	13	15	11	11	14	16	18	18	17
Site number	11	12	13	14	15	16	17	18	19	
Suitability value	2.60	2.38	2.38	2.41	2.28	2.47	2.88	2.93	2.91	
Suitability rank	4	7	7	6	9	5	3	1	2	

As a general, sites which have high head and high amount of flow will yield maximum power output and are preferable for hydropower development. For being these parameters are criteria's in which maximum weight is given during pairwise comparison, prioritized sites are those corresponding to maximum value of these parameters. Non-suitability of geological formations in combination with existence of locations in the area in which low head and small stream flow are available, potential locations identified in Lah river got lower priority ranks.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Small scale hydropower which is considered as clean and non-polluting renewable energy source has got great interest among the world community to compensate declining energy supply from non-renewable energy sources. The life of rural communities of Ethiopia which are not connected to national grid is tied with biomass energy sources which is declining significantly across the country. The communities in and surrounding Birr catchment are suffering energy shortage while they can access clean energy from river draining through their backyard. Identification of potential locations and preliminary hydropower potential assessment of watershed is the primary task in developing and implementing hydropower project at specific area. Site survey-based estimation of hydropower potential and identification of hydropower sites consume time, money and are challenging tasks due to existence of hydropower sites in in-accessible mountainous locations with rough topography. Even if it has certain accuracy flaws, a GIS-based technique that integrates hydrological models can alleviate such problems. This study was aimed in estimating small scale hydropower potential of Birr watershed by identifying potential hydropower sites along the river reach. Head and stream flow which are basic parameters in estimating power from water have been estimated by using GIS and Soil and Water Assessment Tool respectively. The accuracy of simulated river flow was evaluated by using historical recorded stream flow data. The results from analysis show good agreement between simulated and actual observed stream flow data. Nonexistence of measured flow data at intended outlet of the watershed and limitation of gauging stations in study area have hampered the process of calibration and validation for evaluating model-based stream flow simulation. For evaluating the performance of model at ungauged portion of area, the method of physical similarity approach of regionalization in which well-calibrated variables in gauged area completely transformed in to un-gauged area was applied. The process was verified by comparing simulated flow after regionalization at another location with observed stream flow at that station. It was remarked that the proposed methodology was reasonable and can be taken as valid option to overcome limitations related to data scarcity in the area.

Total technical hydropower potential of Birr watershed estimated from 19 identified viable locations are 75 MW and 877 KW when 30% and 95% dependable flow respectively are utilized for hydropower development. It has also been estimated that annual power output capacity of catchment from all viable sites from 50% and mean flow is 23 MW and 64.9 MW respectively.

The results revealed the presence of enormous hydropower potential in the study watershed which can be developed without displacing animals and peoples by creating reservoir and without expending high capital for construction of large dams. Moreover, identified potential sites were ranked based on important criterions which directly affect small scale hydropower development in technical and economical aspect by using multicriteria decision making approach by utilizing power, head, stream flow, geological formation of site and accessibility of locations. Sites found near the outlet have got higher priority rank due to existence of those locations in the area with high head and stream flow and suitability of geological formation for construction of hydraulic structures and power house. In contrary sites found in Lah river have got lower priority ranks due to existence of those locations in low head and minimum stream flow in the river.

In conclusion, both methodologies applied here and results obtained could be a useful support for decision makers in the early identification of the most ideal sites for the installation of run-of-river plants in the studied area for rural electrification. Furthermore, it is believed that stream flow simulated by using Soil and Water Assessment Tool in ungauged and data scarce watershed is useful for further future water resources projects development.

5.2 Recommendations

In the study, it has been strived a lot to find exact point in which maximum head exists along river reaches by using GIS and also stream flow at identified locations was simulated by using SWAT. GPS was used as additional supporting tool to verify the head estimated by using GIS. On-site measurements of head using surveying equipment's like total station gives higher confidence of accuracy for better results. Head less than 10m can be also considered for small scale hydropower potential assessment since power can be generated using small heads if stream flow is available for entire periods.

In the study, only SWAT has been used to simulate stream flow. But it is recommended that applying many models and comparing performance to select best performing model at watershed and coming in to conclusion increases the accuracy. In addition, using recent stream flow data for evaluation of performance of model is recommended for future investigations. Furthermore, analysis concerning pondage for temporarily storing water during non-working hours, idle days and low load periods for use during hours of peak load demand, should be taken in to consideration in future studies.

REFERENCES

Abay, Barbieri, & Woldearegay. (2019). GIS-based landslide susceptibility evaluation using analytical hierarchy process (AHP) approach: The case of Tarmaber District, Ethiopia. *11*(1), 14-36.

Abdullah, Islam, & Technoledge. (2014). Case study and model of micro hydro power plant using the kinetic energy of flowing water of Surma and Meghna rivers of Bangladesh. *2*(1), 87-95.

Abrar, Legesse Kura, Esayas Dube, Likisa Beyene, & Landscapes. (2021). AHP based analysis of groundwater potential in the western escarpment of the Ethiopian rift valley. 1-14.

Abushandi, & Alatawi. (2015). Dam site selection using remote sensing techniques and geographical information system to control flood events in Tabuk City. *6*(1-1000189), 1-13.

Adedokun, Oladosu, & Ajiboye. (2013). Small hydro power potential capacity estimation For provision Of rural electricity In Nigeria. *6*(2), 117.

Adhikary, Kundu, & Technology. (2014). Small hydropower project: Standard practices. *4*(2), 241-247.

Agbo. (2013). Evaluation of the regression parameters of the Angstrom-Page model for predicting global solar radiation. *24*(2), 46-50.

AHEC. (2012). Standards/manuals/guidelines for small hydro development.

Ahmad, Tang, Wang, Wang, & Wagan. (2015). Precipitation trends over time using Mann-Kendall and spearman’s rho tests in swat river basin, Pakistan. *2015*.

Ajanovic, Haas, & Environment. (2019). On the long-term prospects of power-to-gas technologies. *8*(1), e318.

Ajibade, Nwogwu, Ajibade, Adelodun, Idowu, Ojo, Iji, Olajire, & Akinmusere. (2020). Potential dam sites selection using integrated techniques of remote sensing and GIS in Imo State, Southeastern, Nigeria. *6*(4), 1-16.

Akoko, Le, Gomi, & Kato. (2021). A review of SWAT model application in Africa. *13*(9), 1313.

Alemu, Nuppenau, & Boland. (2009). Technical efficiency of farming systems across agro-ecological zones in Ethiopia: An application of stochastic frontier analysis. *4*(4), 202-207.

Andualem, Hagos, Kefale, Zelalem, & Environment. (2020). Soil erosion-prone area identification using multi-criteria decision analysis in Ethiopian highlands. *6*(3), 1407-1418.

Arnold, Moriasi, Gassman, Abbaspour, White, Srinivasan, Santhi, Harmel, Van Griensven, & Van Liew. (2012). SWAT: Model use, calibration, and validation. *55*(4), 1491-1508.

Arnold, Neitsch, Kiniry, & Williams. (2011). *Soil and water assessment tool theoretical documentation version 2009*. Retrieved from

Arrieta-Castro, Donado-Rodríguez, Acuña, Canales, Teegavarapu, & Kaźmierczak. (2020). Analysis of streamflow variability and trends in the meta river, Colombia. *12*(5), 1451.

Awasthi, Kumar, & Water. (2021). Soil and Water Assessment Tool (SWAT) Modelling: A Review. *6*(8).

Ayalew. (2021). Assessment of Power Compeers Prospective of Gobecho Micro Hydropower Plant on Ganga River, Genale Dawa River Basin, Ethiopia. *10*(2), 25-31.

Ayele. (2020). GIS Based Assessment of Hydropower Potential (A Case Study on Gumara River Basin). *69*(1), 26-44.

Bahati, Lawal, Peter, & Matovu. (2019). Stream Flow and Rainfall Trend Analysis of the Ssezibwa Catchment.

Balew, Nega, Legese, & Semaw. (2021). Suitable potential land evaluation for surface water irrigation using remote sensing and GIS–MCE in the case of rib–gumara watershed, Ethiopia. *49*(9), 2273-2290.

Bárdossy. (2007). Calibration of hydrological model parameters for ungauged catchments. *11*(2), 703-710.

Bayazıt, Bakış, Koç, & Reviews. (2017). An investigation of small scale hydropower plants using the geographic information system. *67*, 289-294.

Bell, & Haskins. (1997). A geotechnical overview of Katse Dam and Transfer Tunnel, Lesotho, with a note on basalt durability. *46*(2), 175-198.

Berhanu, Seleshi, & Melesse. (2014). Surface water and groundwater resources of Ethiopia: potentials and challenges of water resources development. 97-117.

Billi. (2015). *Landscapes and landforms of Ethiopia*: Springer.

Blok, & Nieuwlaar. (2016). *Introduction to energy analysis*: Routledge.

Brannan, Mostaghimi, & Cho. (2003). Predicting runoff and sediment yield on a forest dominated watershed using HSPF and SWAT models. *9*(4), 59-64.

Brighenti, Bonumá, Srinivasan, & Chaffe. (2019). Simulating sub-daily hydrological process with SWAT: a review. *64*(12), 1415-1423.

Bunruamkaew. (2012). *How to do AHP analysis in Excel*.

Čampulová, Michálek, Mikuška, & Bokal. (2018). Nonparametric algorithm for identification of outliers in environmental data. *32*(5), e2997.

Castillo-Botón, Casillas-Pérez, Casanova-Mateo, Moreno-Saavedra, Morales-Díaz, Sanz-Justo, Gutiérrez, & Salcedo-Sanz. (2020). Analysis and Prediction of dammed water level in a hydropower reservoir using machine learning and persistence-based techniques. *12*(6), 1528.

CETC. (2004). *SMALL HYDRO PROJECT ANALYSIS*. Canada: Minister of Natural Resources Canada.

Chandio, Matori, WanYusof, Talpur, Balogun, & Lawal. (2013). GIS-based analytic hierarchy process as a multicriteria decision analysis instrument: a review. *6*(8), 3059-3066.

Chauluka, Singh, & Kumar. (2021). Rainfall and streamflow trends of Thuchila River, Southern Malawi. *34*, 846-855.

Checkol, & Alamirew. (2008). Technical and Institutional Evaluation of Geray Irrigation Scheme in West Gojjam Zone, Amhara Region, Ethiopia. *8*(1).

Coffey, Dorai-Raj, O'Flaherty, Cormican, Cummins, & Journal. (2013). Modeling of pathogen indicator organisms in a small-scale agricultural catchment using SWAT. *19*(1), 232-253.

Coyle, & Simmons. (2014). *Understanding the global energy crisis*: Purdue University Press.

Cuya, Brandimarte, Popescu, Alterach, & Peviani. (2013). A GIS-based assessment of maximum potential hydropower production in La Plata basin under global changes. *50*, 103-114.

Dai. (2016). *Dam site selection using an integrated method of AHP and GIS for decision making support in Bortala, Northwest China.* University of Twente,

Dametew. (2016). Design and Analysis of Small Hydro Power for Rural Electrification.

Desalegn, Damtew, Mulu, & Tadele. (2022). Identification of Potential Sites for Small-Scale Hydropower Plants Using a Geographical Information System: A Case Study on Fetam River Basin. 1-14.

Desalegn, Mulu, & Damtew. (2022). Landslide susceptibility evaluation in the Chemoga watershed, upper Blue Nile, Ethiopia. 1-27.

Devia, Ganasri, & Dwarakish. (2015). A review on hydrological models. *4*, 1001-1007.

Dile, Daggupati, George, Srinivasan, Arnold, & software. (2016). Introducing a new open source GIS user interface for the SWAT model. *85*, 129-138.

DİLNESA. (2020). GIS and Hydrological Model Based Hydropower Potential Assessments of Temcha Watershed. *International Journal of Environment Geoinformatics, 9*(1), 97-101.

Emerson, Vecchia, & Dahl. (2005). *Evaluation of drainage-area ratio method used to estimate streamflow for the Red River of the North Basin, North Dakota and Minnesota*: US Department of the Interior, US Geological Survey.

ESHA. (2004). Guide on How to Develop a Small Hydropower Plant. In.

ESHA. (2011). Guidelinesformicro hydropowerdevelopment. In: European Commission.

Eshra, Zobaa, & Aleem. (2021). Assessment of mini and micro hydropower potential in Egypt: Multi-criteria analysis. *7*, 81-94.

Fan, & Shibata. (2015). Simulation of watershed hydrology and stream water quality under land use and climate change scenarios in Teshio River watershed, northern Japan. *50*, 79-89.

Fasipe, Izinyon, & Ehiorobo. (2021). Hydropower potential assessment using spatial technology and hydrological modelling in Nigeria river basin. *178*, 960-976.

Feizizadeh, & Haslauer. (2012). GIS-based procedures of hydropower potential for Tabriz basin, Iran. 495-502.

Fesalbon, Blanco, & Sciences. (2019). Hydropower dam site selection and visualization using GIS and RS techniques: A case of Marinduque, Philippines. *42*, 207-214.

Galata, Tullu, Guder, & Change. (2021). Evaluating watershed hydrological responses to climate changes at Hangar Watershed, Ethiopia. *12*(6), 2271-2287.

Garbrecht, Martz, & systems. (2000). Digital elevation model issues in water resources modeling. 1-28.

Gashaw, Suryabhagavan, Nedaw, & Gummadi. (2022). Rainwater harvesting in Modjo watershed, upper Awash River Basin, Ethiopia through remote sensing and fuzzy AHP. 1-26.

Gebresilasie, Andualem, Mengie, Ayele, & Malede. (2022). Suitable dam site identification using GIS-based MCDA: a case study of Chemoga watershed, Ethiopia. *12*(4), 1-26.

Gebru, Gebreyohannes, Hagos, & GIS. (2020). Identification of groundwater potential zones using analytical hierarchy process (AHP) and GIS-remote sensing integration, the Case of Golina River Basin, Northern Ethiopia. *9*(1), pp. 3289-3311.

Gergeľová, Kuzevičová, & Kuzevič. (2013). A GIS based assessment of hydropower potential in Hornád basin. *18*(2).

Gesch, Oimoen, & Evans. (2014). *Accuracy assessment of the US Geological Survey National Elevation Dataset, and comparison with other large-area elevation datasets: SRTM and ASTER* (Vol. 1008): US Department of the Interior, US Geological Survey Sioux Falls, SD, USA.

Getachew, Manjunatha, & Bhat. (2021). Modeling projected impacts of climate and land use/land cover changes on hydrological responses in the Lake Tana Basin, upper Blue Nile River Basin, Ethiopia. *595*, 125974.

Girma. (2016). Techno-economic feasibility of small scale hydropower in Ethiopia: The case of the kulfo River, in Southern Ethiopia. *2016*.

Girma. (2020). Success, Gaps and Challenges of Power Sector Reform in Ethiopia. *6*(1), 33-42.

Girma, Gebre, Tadesse, & Engineering. (2020). Land suitability evaluation for surface irrigation using spatial information technology in Omo-Gibe River Basin, Southern Ethiopia. *9*(5).

Goyal, Panchariya, Sharma, & Singh. (2018). Comparative assessment of SWAT model performance in two distinct catchments under various DEM scenarios of varying resolution, sources and resampling methods. *32*(2), 805-825.

Grubbs. (1950). Sample criteria for testing outlying observations. 27-58.

Guiamel, & Lee. (2020). Potential hydropower estimation for the Mindanao river basin in the Philippines based on watershed modelling using the soil and water assessment tool. *6*, 1010-1028.

Gull, & Shah. (2022). Hydrological modeling for streamflow and sediment yield simulation using the SWAT model in a forest-dominated watershed of north-eastern Himalayas of Kashmir Valley, India.

Hagos, Mengie, Andualem, Yibeltal, Linh, Tenagashaw, & Hewa. (2022). Land suitability assessment for surface irrigation development at Ethiopian highlands using geospatial technology. *12*(5), 1-11.

Haile, Tafesse Yadeta, & Amena Gambe. (2022). Delineation of groundwater potential zones using geo-spatial and AHP techniques: Ambo area, Blue Nile Basin, Ethiopia. *8*(1), 1-17.

Hailu, & Kumsa. (2021). Ethiopia renewable energy potentials and current state. *9*(1), 1-14.

Halefom, Teshome, & Environment. (2019). Modelling and mapping of erosion potentiality watersheds using AHP and GIS technique: a case study of Alamata Watershed, South Tigray, Ethiopia. *5*(3), 819-831.

Hall. (1969). Hydrology for Engineers. *222*(5188), 65-65.

Hoes, Meijer, Van Der Ent, & Van De Giesen. (2017). Systematic high-resolution assessment of global hydropower potential. *12*(2), e0171844.

IEA. (2021). World Energy Outlook.

IHA. (2020). *Hydropower Status Report*. Retrieved from England

IHA. (2021). *Hydropower Status Report*. Retrieved from England:

J. Paul Guyer. (2017). *Introduction to Evaluation of Hydroelectric Power Potential of Sites*. California: The clubhouse press.

Jaweso, Abate, Bauwe, & Lennartz. (2019). Hydro-meteorological trends in the upper Omo-Ghibe river basin, Ethiopia. *11*(9), 1951.

JICA. (2003). Manuals and Guidelines for Micro-hydropower Development in Rural Electrification. In (Vol. 1). Taguig.

Jodar-Abellan, Valdes-Abellan, Pla, & Gomariz-Castillo. (2019). Impact of land use changes on flash flood prediction using a sub-daily SWAT model in five Mediterranean ungauged watersheds (SE Spain). *657*, 1578-1591.

Kalitsi. (2003). *Problems and prospects for hydropower development in Africa.* Paper presented at the The Workshop for African Energy Experts on Operationalizing the NGPAD Energy Initiative.

Kang, & Yusof. (2012). Homogeneity tests on daily rainfall series. *7*(1), 9-22.

Kaunda, Kimambo, & Nielsen. (2012). Potential of small-scale hydropower for electricity generation in Sub-Saharan Africa. *2012*.

Kaunda, Kimambo, Nielsen, & Reviews. (2014). A technical discussion on microhydropower technology and its turbines. *35*, 445-459.

Kayastha, Singh, Dulal, & Environment. (2018). A GIS approach for rapid identification of Run-Of-River (RoR) hydropower potential site in watershed: A case study of Bhote Koshi watershed, Nepal. *23*, 48-55.

Khan, & Zaidi. (2015). Run-of-river hydropower potential of Kunhar River, Pakistan. *12*(23).

Kidane, Tolessa, Bezie, Kessete, & Endrias. (2019). Evaluating the impacts of climate and land use/land cover (LU/LC) dynamics on the Hydrological Responses of the Upper Blue Nile in the Central Highlands of Ethiopia. *27*(2), 151-167.

Kober, Schiffer, Densing, & Panos. (2020). Global energy perspectives to 2060–WEC's World Energy Scenarios 2019. *31*, 100523.

Korkovelos, Mentis, Siyal, Arderne, Rogner, Bazilian, Howells, Beck, & De Roo. (2018). A geospatial assessment of small-scale hydropower potential in Sub-Saharan Africa. *11*(11), 3100.

Kusre, Baruah, Bordoloi, & Patra. (2010). Assessment of hydropower potential using GIS and hydrological modeling technique in Kopili River basin in Assam (India). *87*(1), 298-309.

Lach. (2018). *The application of selected statistical tests in the detection and removal of outliers in water engineering data based on the example of piezometric measurements at the Dobczyce dam over the period 2012-2016.* Paper presented at the E3S Web of Conferences.

Larentis, Collischonn, Olivera, & Tucci. (2010). Gis-based procedures for hydropower potential spotting. *35*(10), 4237-4243.

Leta, Demissie, & Tränckner. (2021). Hydrological responses of watershed to historical and future land use land cover change dynamics of nashe watershed, ethiopia. *13*(17), 2372.

Liu, Esser, & Masera. (2013). World small hydropower development report.

Liu, & Jiang. (2019). *Sediment yield modeling using SWAT model: case of Changjiang River Basin.* Paper presented at the IOP Conference Series: Earth and Environmental Science.

Malede, Agumassie, Kosgei, Linh, & Andualem. (2022). Analysis of rainfall and streamflow trend and variability over Birr River watershed, Abbay basin, Ethiopia. *7*, 100528.

Mandeville, O'connell, Sutcliffe, & Nash. (1970). River flow forecasting through conceptual models part III-The Ray catchment at Grendon Underwood. *11*(2), 109-128.

Manieniyan, Thambidurai, & Selvakumar. (2009). Study on energy crisis and the future of fossil fuels. *10*, 2234-3689.

Mapes, & Pricope. (2020). Evaluating SWAT model performance for runoff, percolation, and sediment loss estimation in low-gradient watersheds of the Atlantic coastal plain. *7*(2), 21.

Meals, Spooner, Dressing, & Harcum. (2011). Statistical analysis for monotonic trends. *6*, 23.

Meder, Bubenzer, & Nüsser. (2011). Application of environment assessment related to GIZ ECO Micro Hydropower Plants in the Sidama Zone/Ethiopia.

Melese, & Belay. (2022). Groundwater Potential Zone Mapping Using Analytical Hierarchy Process and GIS in Muga Watershed, Abay Basin, Ethiopia. *6*(1), 2100068.

Melese, Belay, & Andemo. (2022). Application of analytical hierarchal process, frequency ratio, and Shannon entropy approaches for landslide susceptibility mapping using geospatial technology: The case of Dejen district, Ethiopia. *15*(5), 1-21.

Melesse, Abtew, & Setegn. (2014). *Nile River basin: ecohydrological challenges, climate change and hydropolitics*: Springer Science & Business Media.

Miskat, Ahmed, Rahman, Chowdhury, Chowdhury, Chowdhury, Sait, & Park. (2021). An overview of the hydropower production potential in Bangladesh to meet the energy requirements. *26*(6).

Mondal, Alam, Gebremeskel, Gebrehiwot, & Ringler. (2018). *Ethiopian universal electrification development strategies*: Intl Food Policy Res Inst.

Moriasi, Arnold, Van Liew, Bingner, Harmel, & Veith. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *50*(3), 885-900.

Moriasi, Wilson, Douglas-Mankin, Arnold, & Gowda. (2012). Hydrologic and water quality models: Use, calibration, and validation. *55*(4), 1241-1247.

Mosonyi. (1960). *Water power development* (Vol. 2): Publishing house of the Hungarian Academy of Sciences.

Mukherjee, Joshi, Mukherjee, Ghosh, Garg, Mukhopadhyay, & Geoinformation. (2013). Evaluation of vertical accuracy of open source Digital Elevation Model (DEM). *21*, 205-217.

Muluneh, Tadesse, & Girma. (2022). Assessing potential land suitable for surface irrigation using GIS and AHP techniques in the Rift Valley Lakes Basin, Ethiopia. *8*(2), 1-22.

Murugesan, Alemayehu, Gopalakrishnan, Chung, Senapathi, Sekar, Elzain, Karthikeyan, & Research. (2021). Site selection of check dams using geospatial techniques in Debre Berhan region, Ethiopia—water management perspective. 1-20.

Nalule. (2018). *Energy poverty and access challenges in sub-Saharan Africa: The role of regionalism*: Springer.

Negasa, & Wakjira. (2021). Assessment of Irrigation Land Suitability for Surface Irrigation in Birbir River Watershed Using Geographic Information System Technique in Oromia Region, Ethiopia. *9*(2), 45.

Nielsen, Kimambo, & Kaunda. (2012). Hydropower in the Context of Sustainable Energy Supply: A Review of Technologies and Challenges.

Nigussie, Moges, Moges, & Steenhuis. (2019). Assessment of suitable land for surface irrigation in ungauged catchments: Blue Nile basin, Ethiopia. *11*(7), 1465.

Njiru, Siriba, & Protection. (2018). Site Selection for an Earth Dam in Mbeere North, Embu County—Kenya. *6*(7), 113-133.

Njoku, Ezeadi, Ezeka, Ikonne, Ezewuzie, Godwin, & Ezedeyimobi. Comparative Valuation of Global Solar Radiation on Horizontal and Tilt Surfaces in Owerri, Nigeria. *2582*, 7421.

Nyeko. (2015). Hydrologic modelling of data scarce basin with SWAT model: capabilities and limitations. *29*(1), 81-94.

Paish. (2002). Small hydro power: technology and current status. *6*(6), 537-556.

Pak, Ramos, Fleming, Scharffenberg, & Gibson. (2015). *Sensitivity analysis for sediment transport in the hydrologic modeling system (HEC-HMS).* Paper presented at the Proc., Joint Federal Interagency Conf.

Palla, Gnecco, La Barbera, Ivaldi, & Caviglia. (2016). An integrated GIS approach to assess the mini hydropower potential. *30*(9), 2979-2996.

Parajuli, & Ouyang. (2013). *Watershed-scale hydrological modeling methods and applications*: InTech.

Patil, Deng, & Malone. (2011). Input data resolution-induced uncertainty in watershed modelling. *25*(14), 2302-2312.

Paulhus, & Kohler. (1952). Interpolation of missing precipitation records. *80*(8), 129-133.

Permata. (2022). Hydropower Potential in Indonesia: Assessment of theoretical, technical and economic potential of hydropower.

Petheram, & McMahon. (2019). Dams, dam costs and damnable cost overruns. *3*, 100026.

Pokharel, Basnet, Sherchan, & Thapaliya. (2020). Assessment of Hydropower Potential using SWAT modeling and Spatial Technology in the Seti Gandaki River, Kaski, Nepal. In: DOI.

Punys, Dumbrauskas, Kvaraciejus, & Vyciene. (2011). Tools for small hydropower plant resource planning and development: A review of technology and applications. *4*(9), 1258-1277.

Punys, Kvaraciejus, Dumbrauskas, Šilinis, & Popa. (2019). An assessment of micro-hydropower potential at historic watermill, weir, and non-powered dam sites in selected EU countries. *133*, 1108-1123.

Purece, Pleşca, & Corlan. (2020). Technologies for obtaining energy from micro-hydropower resources.

Raja, Parsinejad, & Tajrishy. (2022). Multipurpose Calibration of SWAT Model in Estimating Runoff, Evapotranspiration, and Crop Yield (A Case Study: Mahabad Plain). *17*(4), 11-34.

Rojanamon, Chaisomphob, Bureekul, & Reviews. (2009). Application of geographical information system to site selection of small run-of-river hydropower project by considering engineering/economic/environmental criteria and social impact. *13*(9), 2336-2348.

Romanelli, Silva, Horta, & Picoli. (2018). Site selection for hydropower development: a GIS-based framework to improve planning in Brazil. *144*(7), 04018051.

Roostaee, & Deng. (2020). Effects of digital elevation model resolution on watershed-based hydrologic simulation. *34*(8), 2433-2447.

Rospriandana, & Fujii. (2017). Assessment of small hydropower potential in the Ciwidey subwatershed, Indonesia: a GIS and hydrological modeling approach. *11*(1), 6-11.

Roth, Nigussie, & Lemann. (2016). Model parameter transfer for streamflow and sediment loss prediction with SWAT in a tropical watershed. *75*(19), 1-13.

Saaty. (1977). A scaling method for priorities in hierarchical structures. *15*(3), 234-281.

Saaty. (1984). The analytic hierarchy process: Decision making in complex environments. In *Quantitative assessment in arms control* (pp. 285-308): Springer.

Saaty. (1987). The analytic hierarchy process—what it is and how it is used. *9*(3-5), 161-176.

Saaty. (2008). Decision making with the analytic hierarchy process. *1*(1), 83-98.

Saaty. (2016). The analytic hierarchy and analytic network processes for the measurement of intangible criteria and for decision-making. In *Multiple criteria decision analysis* (pp. 363-419): Springer.

Sammartano, Liuzzo, & Freni. (2019). Identification of potential locations for run-of-river hydropower plants using a GIS-based procedure. *12*(18), 3446.

Sattari, Rezazadeh-Joudi, & Kusiak. (2017). Assessment of different methods for estimation of missing data in precipitation studies. *48*(4), 1032-1044.

Saville, & Watson. (1933). An Investigation of the flow-duration characteristics of North Carolina Streams. *14*(1), 406-425.

Searcy. (1959). *Flow-duration curves*: US Government Printing Office.

Searcy, & Hardison. (1960). *Double-mass curves*: US Government Printing Office.

Shanko. (2009). *Target Market Analysis: Ethiopia"s Small-Hydro Energy Market*. Retrieved from Berlin, Germany:

Shanko, & Ababa. (2002). Overview of the Electricity Sector in Relation to Public Private Partnerships in ETHIOPIA.

Sharma, Singh, & Engineering. (2013). Run off river plant: status and prospects. *3*(2), 2278-3075.

Singh, & Management. (2020). A planning perspective on Hydropower Development in the Indian Himalayan Region. *28*, 89-106.

Sinshaw, Belete, Tefera, Dessie, Bizuneh, Alem, Atanaw, Eshete, Wubetu, & Atinkut. (2021). Prioritization of potential soil erosion susceptibility region Using fuzzy Logic and Analytical Hierarchy process, Upper Blue Nile Basin, Ethiopia. *4*, 10-24.

Sisay, Gebre, & Getahun. (2021). GIS-based potential landfill site selection using MCDM-AHP modeling of Gondar Town, Ethiopia. *40*(2), 105-124.

Sisay, Halefom, Khare, Singh, Worku, & Environment. (2017). Hydrological modelling of ungauged urban watershed using SWAT model. *3*(2), 693-702.

Smil. (2019). *Energy in world history*: Routledge.

Soliman, Soussa, & El-Sayed. (2016). Assessment of Grand Ethiopian Renaissance Dam impacts using decision support system. *18*(5), 08-18.

Sorooshian, Hsu, Coppola, Tomassetti, Verdecchia, & Visconti. (2008). *Hydrological modelling and the water cycle: coupling the atmospheric and hydrological models* (Vol. 63): Springer Science & Business Media.

Strahler. (1958). Dimensional analysis applied to fluvially eroded landforms. *69*(3), 279-300.

Subramanya. (1994). *Engineering hydrology*: Tata McGraw-Hill Education.

Subramanya. (2008). Engineering Hydrology. 7 West Patal Nagar. *110*(008).

Takele, Gebre, Gebremariam, Engida, & Environment. (2022). Hydrological modeling in the Upper Blue Nile basin using soil and water analysis tool (SWAT). *8*(1), 277-292.

Te Chow. (2010). *Applied hydrology*: Tata McGraw-Hill Education.

Teferra. (2002). Power sector reforms in Ethiopia: options for promoting local investments in rural electrification. *30*(11-12), 967-975.

Tesfa, & Engineering. (2022). GIS-Based AHP and FR Methods for Landslide Susceptibility Mapping in the Abay Gorge, Dejen–Renaissance Bridge, Central, Ethiopia. 1-15.

Teshome, Tibebu, & Addis. (2020). Assessment of Hydropower Potential Using Geospatial Technology in a Case Study of Guna-Tana Landscape Upper Abay Basin, Ethiopia.

Thin, Zin, San, Kawasaki, Moiz, & Bhagabati. (2020). Estimation of run-of-river hydropower potential in the Myitnge River Basin. *15*(3), 267-276.

Tian, Zhang, Yuan, Che, & Zafetti. (2020). Assessment power generation potential of small hydropower plants using GIS software. *6*, 1393-1404.

Tigabu, Wagner, Hörmann, & Fohrer. (2020). Modeling the spatio-temporal flow dynamics of groundwater-surface water interactions of the Lake Tana Basin, Upper Blue Nile, Ethiopia. *51*(6), 1537-1559.

Tim, & Mallavaram. (2003). Application of GIS technology in watershed-based management and decision making. *1*(5), 1-6.

Tiwari, & Tripathi. (2022). Outlier detection in a few catchments of the Godavari river basin: A case study.

Tsiko, & Haile. (2011). Integrating geographical information systems, fuzzy logic and analytical hierarchy process in modelling optimum sites for locating water reservoirs. A case study of the Debub District in Eritrea. *3*(1), 254-290.

Tufa, Sime, & Environment. (2021). Stream flow modeling using SWAT model and the model performance evaluation in Toba sub-watershed, Ethiopia. *7*(4), 2653-2665.

UNECA. (2015). *Inclusive Green Growth in Ethiopia: Selected case studies,United Nations Economic Commission for Africa* Retrieved from Addis Abab,Ethiopia

Uromeihy, & Barzegari. (2007). Evaluation and treatment of seepage problems at Chapar-Abad Dam, Iran. *91*(2-4), 219-228.

Van Griensven, Ndomba, Yalew, Kilonzo, & Sciences. (2012). Critical review of SWAT applications in the upper Nile basin countries. *16*(9), 3371-3381.

Vaze, Teng, Spencer, & Software. (2010). Impact of DEM accuracy and resolution on topographic indices. *25*(10), 1086-1098.

Wang, Shang, Jia, Han, Sauvage, Sánchez-Pérez, Kuramochi, & Hatano. (2018). Integrated effects of land use and topography on streamflow response to precipitation in an agriculture-forest dominated northern watershed. *10*(5), 633.

Warnick, Mayo, Carson, & Sheldon. (1984). *Hydropower engineering*: Prentice-Hall Englewood Cliffs, NJ.

Wei. (1973). *Reciprocal Distance Squared Method, A computer technique for estimating areal precipitation* (Vol. 8): US Department of Agriculture, Agricultural Research Service, North Central ….

Weick, & Sutcliffe. (2001). *Managing the unexpected* (Vol. 9): San Francisco: Jossey-Bass.

Worku, Teferi, Bantider, & Dile. (2021). Modelling hydrological processes under climate change scenarios in the Jemma sub-basin of upper Blue Nile Basin, Ethiopia. *31*, 100272.

WREAN. (2000). Guideline for Design of SMALL HYDROPOWER PLANTS. In. Belfast, North Ireland.

Wubalem. (2021). GIS-based land suitability analysis for surface irrigation using analytical hierarchy process method in East and West Bellessa, northwestern Ethiopia.

Xu, & Singh. (2004). Review on regional water resources assessment models under stationary and changing climate. *18*(6), 591-612.

Yasser, Jahangir, & Mohmmad. (2013). Earth dam site selection using the analytic hierarchy process (AHP): a case study in the west of Iran. *6*(9), 3417-3426.

Yeşilırmak, Akçay, Dağdelen, Gürbüz, & Sezgin. (2009). Quality control and homogeneity of annual precipitation data in Büyük Menderes Basin, Western Turkey. *18*(9a), 1748-1757.

Young. (1992). A three-way model for interpolating for monthly precipitation values. *120*(11), 2561-2569.

Zaidi, Khan, & Reviews. (2018). Identifying high potential locations for run-of-the-river hydroelectric power plants using GIS and digital elevation models. *89*, 106-116.

Zhang, Meng, Wang, & Yang. (2019). Simulated runoff and sediment yield responses to land-use change using the SWAT model in northeast China. *11*(5), 915.

Zuo, Xu, Yao, Jin, Xiao, & Ran. (2016). Assessing the effects of changes in land use and climate on runoff and sediment yields from a watershed in the Loess Plateau of China. *544*, 238-250.

APPENDIXES

1. Hydrological data (stream flow)

1A.Average monthly stream flow of Birr gauging station(m^3/s)

Year	1	2	3	4	5	6	7	8	9	10	11	12
1990	0.55	0.26	0.09	0.03	0.64	0.14	35.16	65.29	18.50	8.87	1.36	0.46
1991	0.21	0.10	0.04	0.03	0.03	3.03	59.89	130.84	60.99	6.73	2.86	3.78
1992	2.94	0.49	0.22	0.30	0.54	5.27	38.56	170.86	30.68	21.38	14.01	3.99
1993	0.41	0.49	0.39	1.06	2.45	6.07	59.00	54.50	36.43	16.98	6.02	2.27
1994	0.89	0.06	0.02	0.02	1.02	22.60	65.43	74.21	82.88	4.89	1.73	1.68
1995	0.30	0.11	0.09	0.11	2.68	7.34	49.23	51.42	26.66	3.91	1.70	1.15
1996	0.69	0.29	0.92	1.52	8.55	18.77	73.43	96.41	33.16	9.60	2.79	1.00
1997	0.97	0.56	1.05	0.87	3.56	14.99	49.88	44.25	30.27	16.76	11.68	4.71
1998	1.72	0.64	0.34	0.17	1.77	7.23	37.44	103.61	41.18	30.35	5.61	2.30
1999	1.84	0.70	0.29	0.29	1.87	9.91	50.07	88.68	35.92	44.75	5.02	1.94
2000	0.85	0.23	0.09	0.52	0.61	6.00	32.90	85.48	34.24	32.65	8.45	2.72
2001	1.14	0.27	0.35	0.32	0.93	12.51	38.39	79.90	40.29	9.33	5.12	2.16
2002	0.83	0.33	0.38	0.19	0.10	6.44	34.45	119.54	33.01	4.82	2.69	4.27
2003	2.08	1.32	2.03	0.74	0.58	24.62	68.44	77.81	40.61	10.76	3.74	2.46
2004	1.63	1.21	0.86	1.59	0.93	9.07	30.55	44.64	31.02	27.90	4.78	2.76
2005	2.01	0.63	0.93	0.24	0.35	12.56	34.36	36.05	30.64	12.92	4.65	2.05
2006	1.31	0.88	0.47	0.72	1.08	8.39	50.76	64.19	36.93	23.12	5.54	2.29

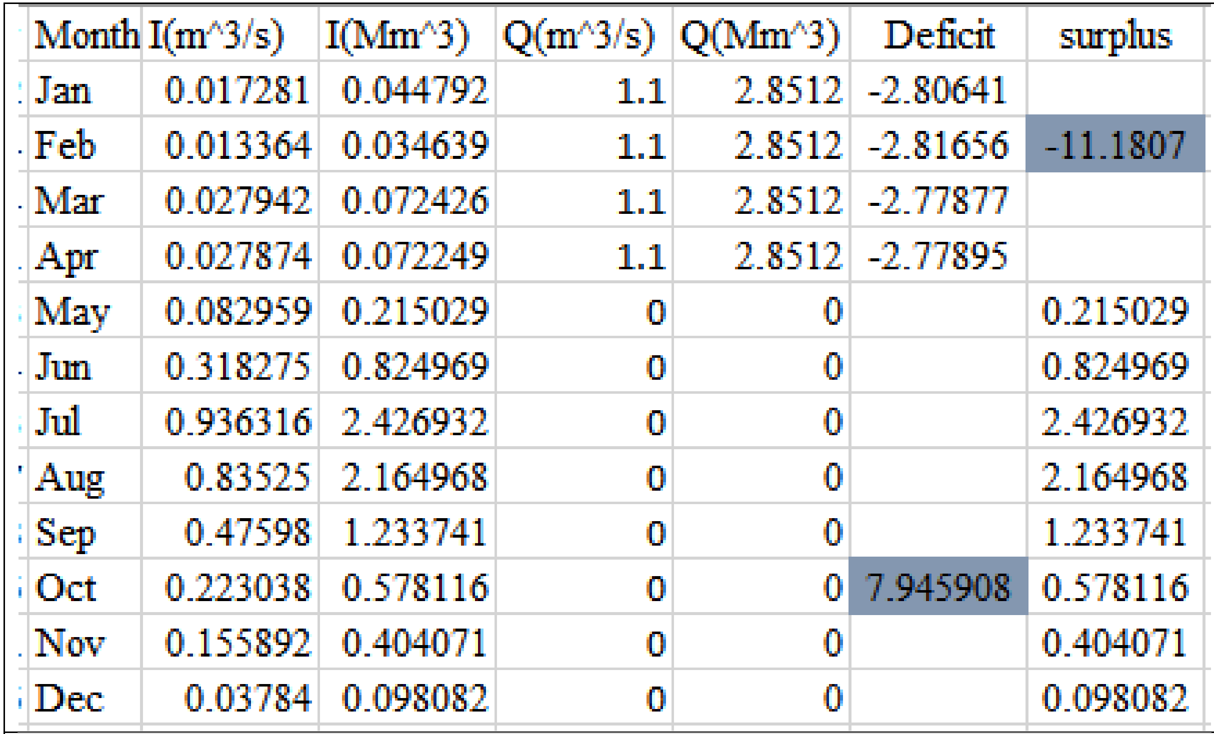
1B. Average monthly flow of Lah river gauging station(m^3/s)

Period	1	2	3	4	5	6	7	8	9	10	11	12
1990	2.99	2.82	2.73	2.83	3.01	3.47	6.22	7.76	7.02	3.65	3.02	2.99
1991	2.75	2.66	2.57	2.54	2.53	3.66	6.13	8.47	5.92	4.36	3.74	3.25
1992	3.16	3.04	2.90	2.86	3.12	4.65	5.36	6.50	5.90	4.94	3.68	3.28
1993	2.76	2.64	2.66	3.08	3.23	4.97	6.25	6.15	5.62	4.63	3.55	2.93
1994	2.69	2.66	2.58	2.63	3.15	4.62	8.00	6.80	4.99	3.76	3.18	2.99
1995	2.63	2.58	2.66	2.62	2.70	4.22	11.99	9.64	5.10	3.67	3.14	2.84
1996	2.70	2.55	2.56	2.88	3.41	4.45	6.38	6.25	5.25	4.08	3.30	2.80
1997	0.13	0.08	0.08	0.28	5.00	6.41	22.98	23.97	15.79	9.22	3.34	0.90
1998	0.27	0.07	0.05	0.09	1.15	7.52	24.18	36.48	16.61	15.30	2.53	0.62
1999	0.18	0.12	0.05	0.05	1.11	8.75	19.35	21.20	10.56	18.12	2.92	0.97
2000	0.28	0.04	0.03	0.15	0.96	5.44	18.27	22.05	9.75	12.10	5.58	0.93
2001	0.20	0.08	0.11	0.09	0.43	15.65	11.21	10.60	8.43	0.83	0.89	0.48
2002	2.62	2.47	2.48	2.59	2.99	4.29	9.20	8.59	4.75	3.92	3.28	2.86
2003	2.77	2.62	2.71	2.57	2.44	4.01	6.39	5.99	4.97	3.73	3.02	2.60

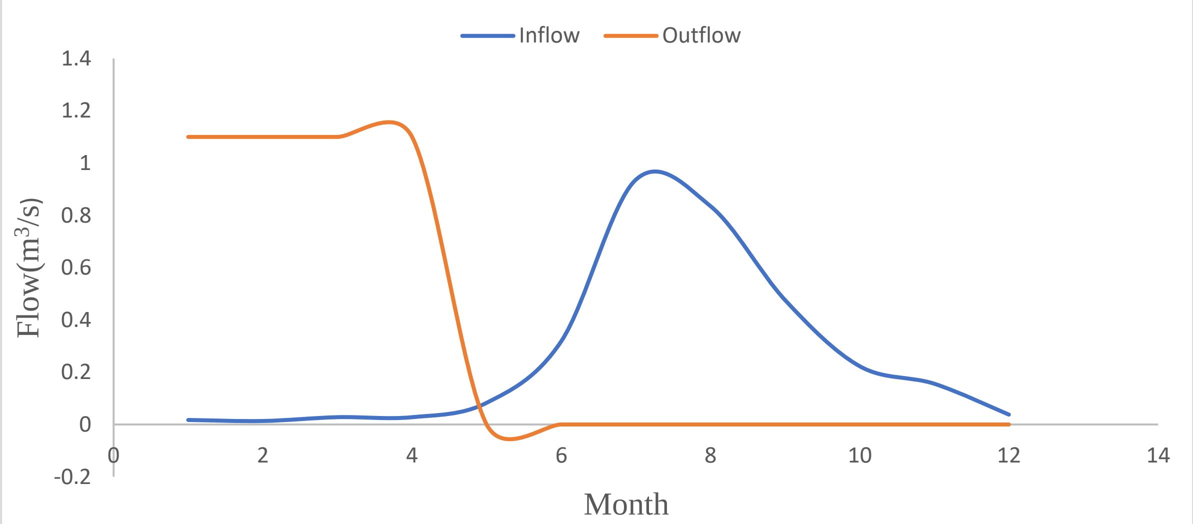
1C.Average Monthly flow of potential sites(m^3/s)

Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.756	0.582	1.397	1.638	4.050	17.284	46.319	39.958	24.718	10.946	8.484	1.808
2	2.252	1.694	2.772	2.143	6.422	26.806	82.396	78.016	44.902	21.572	13.797	5.446
3	2.254	1.709	2.773	2.166	6.519	26.865	82.826	78.690	45.125	21.669	13.863	5.465
4	2.260	1.791	2.777	2.266	6.579	26.909	83.116	79.153	45.272	21.739	13.910	5.481
5	2.354	1.809	2.800	2.458	6.705	26.932	83.271	79.393	45.358	21.767	13.924	5.480
6	0.782	0.452	0.835	0.580	3.433	14.729	27.700	25.953	16.529	6.793	2.814	1.188
7	0.793	0.460	0.845	0.599	3.489	14.735	27.753	26.035	16.555	6.805	2.822	1.190
8	0.812	0.469	0.894	0.677	3.512	14.739	27.785	26.085	16.570	6.811	2.826	1.195
9	0.840	0.505	0.935	0.775	3.754	14.740	27.800	26.108	16.578	6.813	2.827	1.196
10	0.880	0.585	1.090	0.857	3.805	14.745	27.837	26.166	16.595	6.821	2.832	1.291
11	3.811	2.661	4.250	2.917	10.647	46.484	126.208	121.690	71.151	33.314	19.304	8.750
12	3.931	2.748	4.345	2.949	10.749	47.143	128.479	123.989	72.609	34.054	19.688	9.103
13	3.934	2.843	4.540	2.999	10.945	47.147	128.530	124.052	72.640	34.063	19.692	9.102
14	3.949	2.895	4.690	3.085	11.081	47.321	129.154	124.684	73.018	34.245	19.777	9.181
15	3.962	2.900	4.780	3.121	11.135	47.407	129.623	125.472	73.297	34.378	19.855	9.208
16	4.177	2.910	4.942	3.254	11.215	48.485	133.318	129.269	75.740	35.607	20.501	9.687
17	4.272	2.990	5.123	3.314	11.319	48.489	133.333	129.294	75.745	35.627	20.498	9.784
18	4.361	3.090	5.451	3.378	11.367	48.507	133.525	129.645	75.866	35.670	20.520	9.799
19	4.457	3.180	5.651	3.412	11.452	48.596	133.595	129.697	75.874	35.970	20.517	9.978

1D.Analysis of Geray river flow reservoir



Month	I(m^3/s)	I(Mm^3)	Q(m^3/s)	Q(Mm^3)	Deficit	surplus
Jan	0.017281	0.044792	1.1	2.8512	-2.80641	
Feb	0.013364	0.034639	1.1	2.8512	-2.81656	-11.1807
Mar	0.027942	0.072426	1.1	2.8512	-2.77877	
Apr	0.027874	0.072249	1.1	2.8512	-2.77895	
May	0.082959	0.215029	0	0		0.215029
Jun	0.318275	0.824969	0	0		0.824969
Jul	0.936316	2.426932	0	0		2.426932
Aug	0.83525	2.164968	0	0		2.164968
Sep	0.47598	1.233741	0	0		1.233741
Oct	0.223038	0.578116	0	0	7.945908	0.578116
Nov	0.155892	0.404071	0	0		0.404071
Dec	0.03784	0.098082	0	0		0.098082



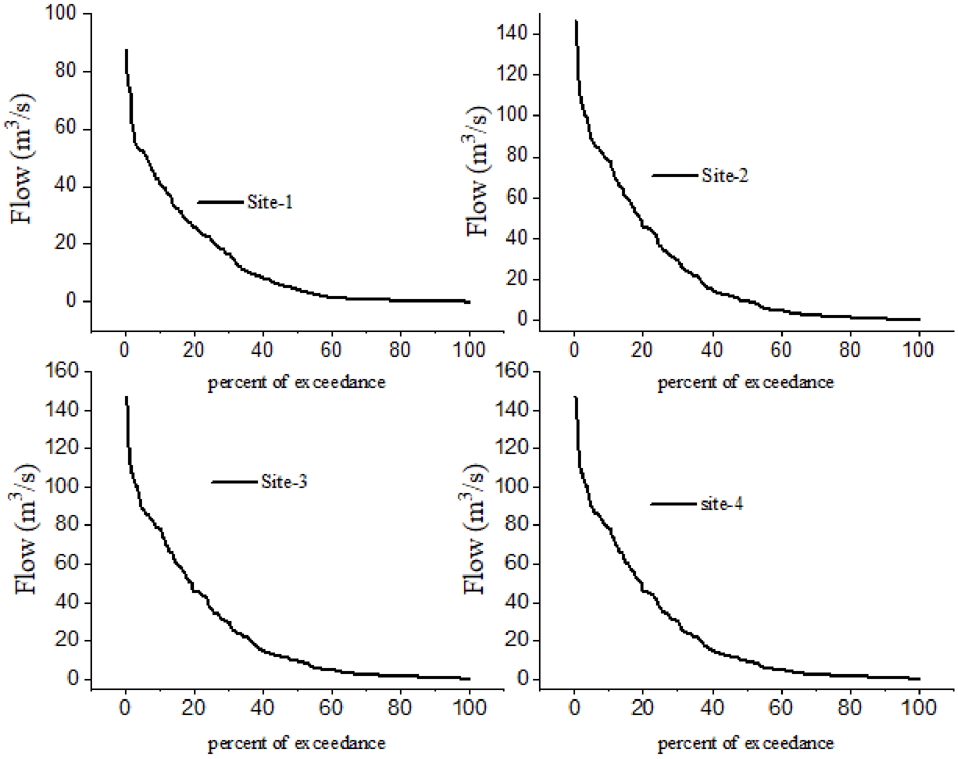
2. Dependable flow, Head and theoretical power of sites

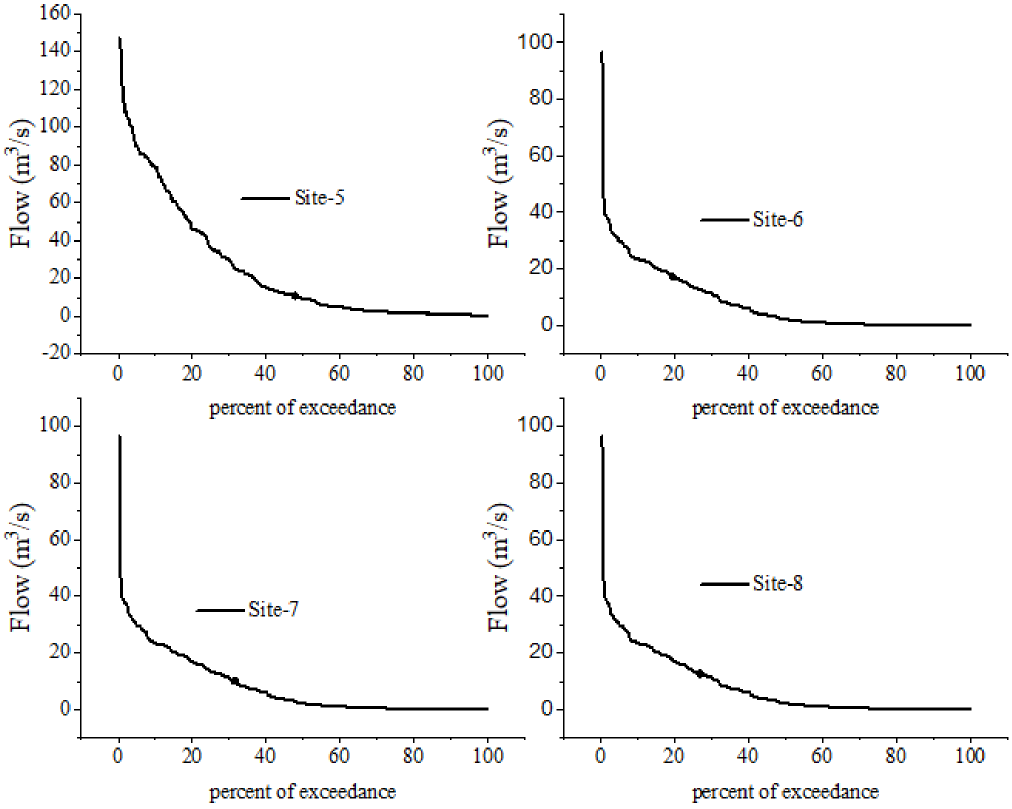
Site	Q30	Q50	Q95	Qm	Head	P30(KW)	P50(KW)	P95(KW)	Pm (KW)
1	16.735	4.192	0.192	13.668	12.4	2033	509	23	1660
2	29.375	9.256	0.457	24.732	11.4	3274	1032	51	2757
3	29.565	9.298	0.444	24.840	20.5	5953	1872	89	5002
4	29.640	9.332	0.448	24.904	13.4	3896	1227	59	3273
5	29.695	9.417	0.432	24.934	10.3	3014	946	44	2530
6	10.543	2.124	0.000	9.243	11.4	1179	238	0	1034
7	10.621	2.135	0.000	9.262	14.4	1500	302	0	1308
8	10.681	2.145	0.000	9.275	28.7	3007	604	0	2611
9	10.711	2.164	0.000	9.280	18.5	1944	393	0	1684
10	10.791	2.235	0.000	9.298	19.5	2064	428	0	1779
11	45.370	14.021	0.534	39.230	15.4	6854	2147	81	5927
12	45.731	14.608	0.571	39.699	10.3	4621	1486	58	4011
13	45.721	14.698	0.566	39.703	10.3	4620	1485	57	4012
14	45.871	14.748	0.547	39.864	23.6	10620	3414	127	9229
15	45.891	14.768	0.551	39.957	16.5	7428	2390	89	6468
16	46.501	15.148	0.573	40.869	10.3	4699	1531	58	4130
17	46.641	15.158	0.567	40.928	11.4	5216	1695	63	4577
18	46.711	15.178	0.600	40.993	13.4	6140	1995	79	5389
19	46.731	15.220	0.644	40.998	36.8	16870	5494	232	14800
Total						94932	29187	1110	82181

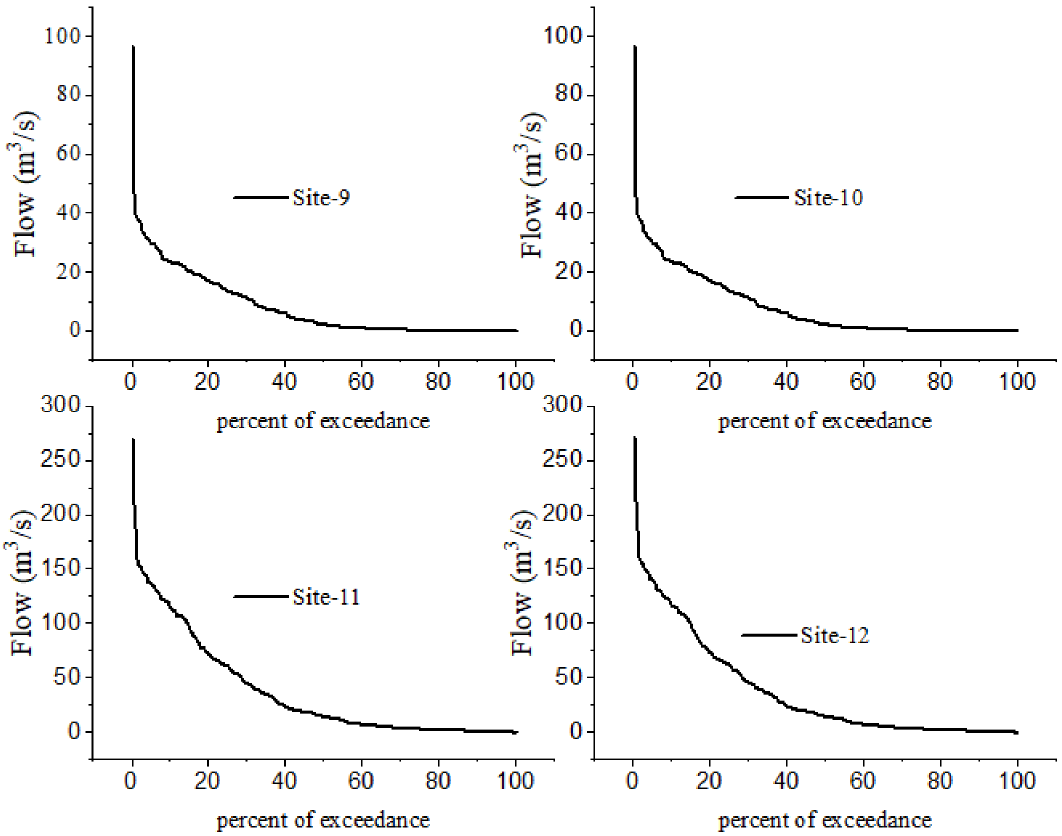
3. Technical hydropower potential (KW) and annual energy production of sites

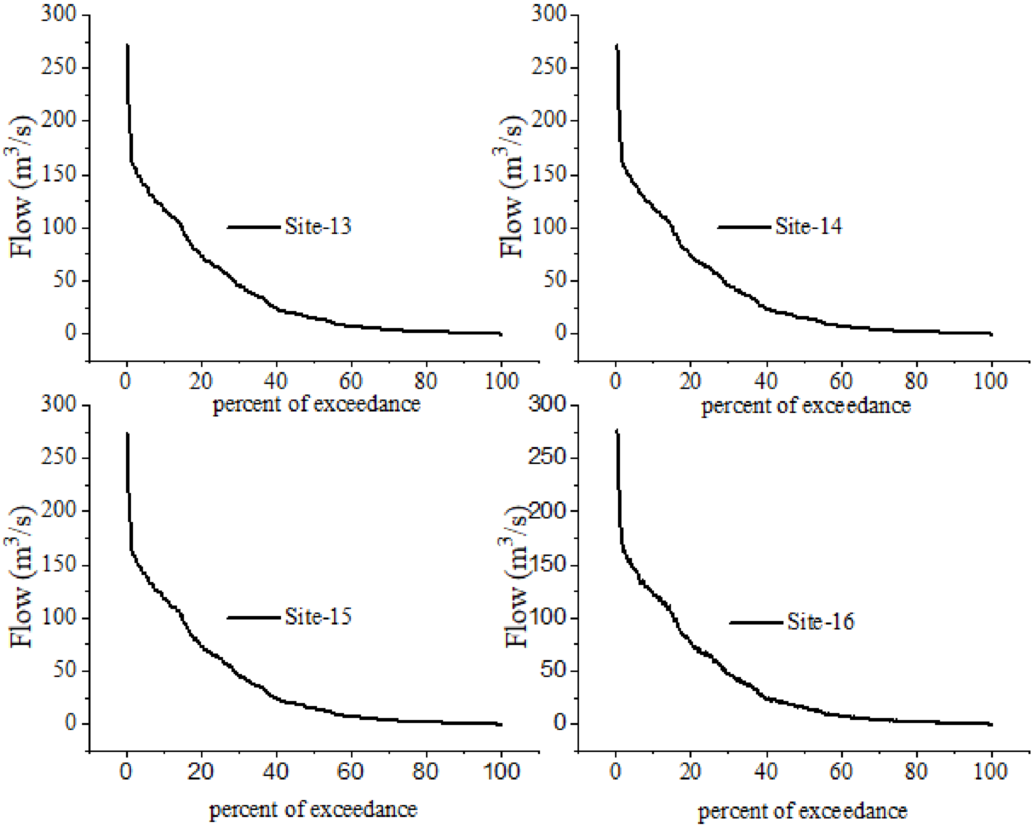
Sites	P30	P50	P95	Pm	E30	E50	E95	Em
1	1606	402	18	1311	4239	1767	153	3683
2	2587	815	40	2178	6829	3580	334	6116
3	4703	1479	71	3951	12416	6496	587	11095
4	3078	969	47	2586	8126	4256	386	7262
5	2381	747	35	1999	6285	3281	287	5613
6	931	188	0	817	2459	824	0	2293
7	1185	238	0	1034	3129	1046	0	2903
8	2376	477	0	2063	6272	2095	0	5793
9	1536	310	0	1331	4054	1363	0	3736
10	1631	338	0	1405	4305	1483	0	3946
11	5415	1696	64	4682	14295	7449	529	13147
12	3650	1174	46	3169	9637	5156	378	8899
13	3650	1173	45	3169	9635	5153	375	8899
14	8390	2697	100	7291	22149	11847	830	20473
15	5868	1888	70	5110	15492	8294	585	14348
16	3712	1209	46	3262	9799	5311	380	9161
17	4121	1339	50	3616	10879	5882	416	10154
18	4851	1576	62	4257	12806	6923	517	11954
19	13328	4341	184	11693	35185	19064	1525	32833
Total	74997	23058	877	64924	197993	101270	7283	182307

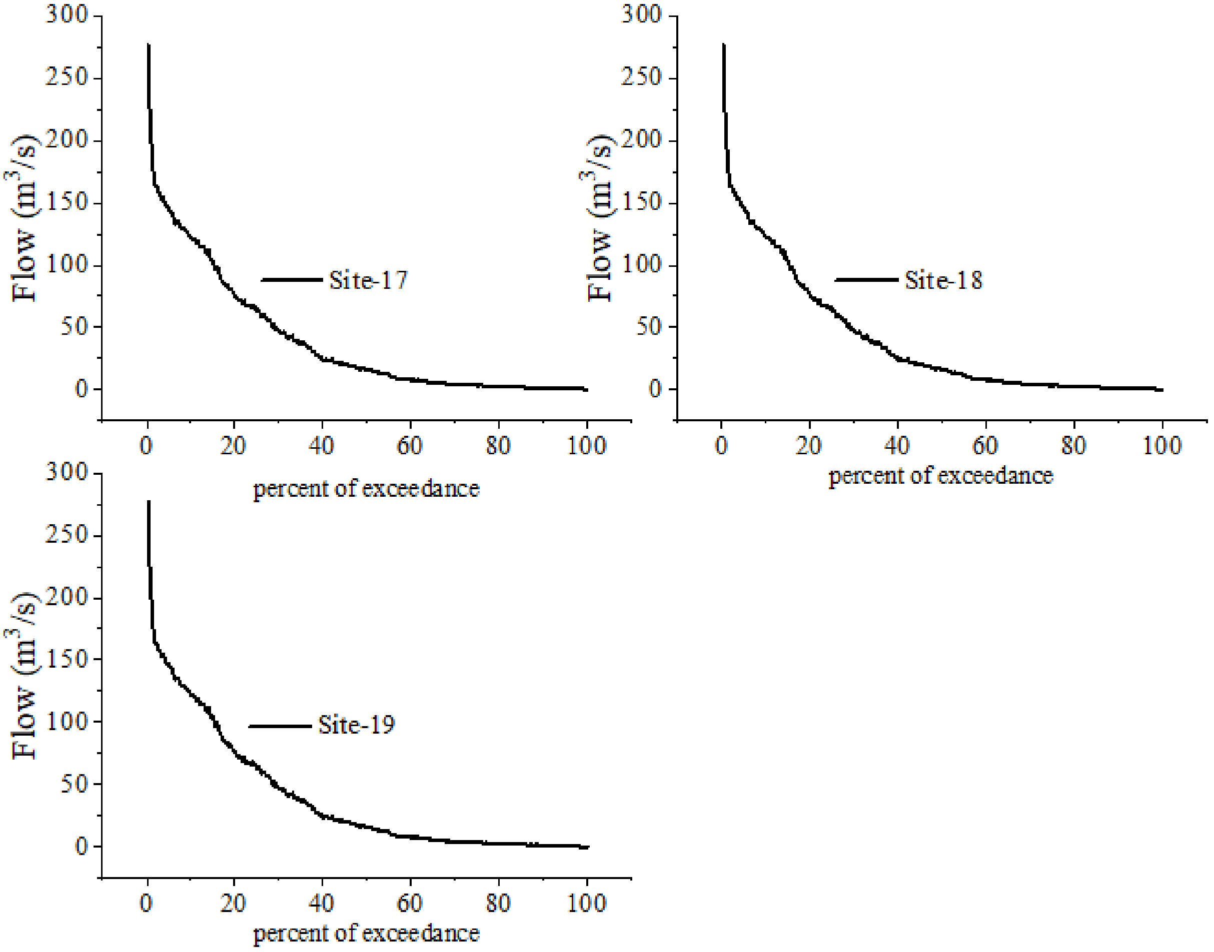
4. Flow Duration curves of potential sites



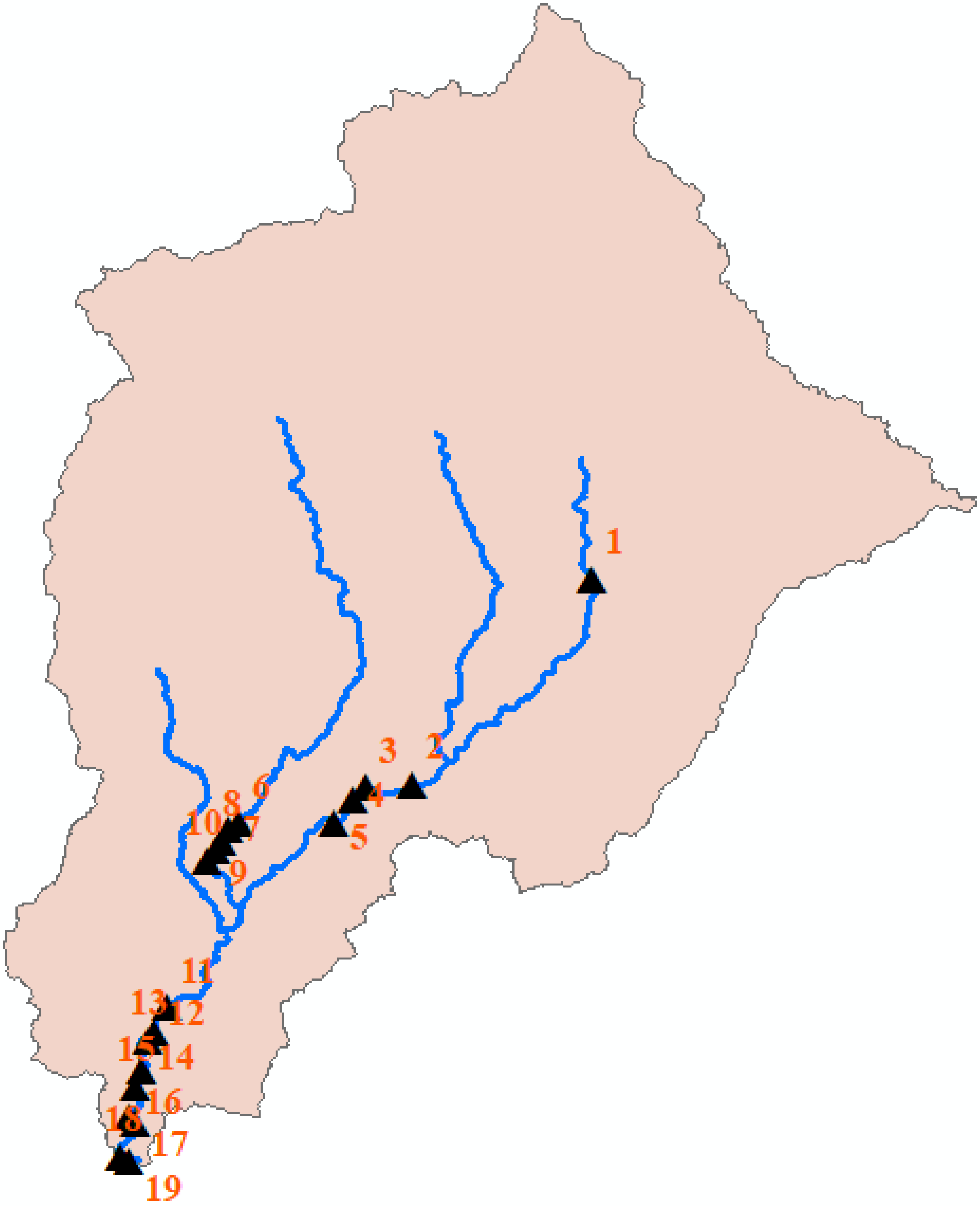



Flow (m3/s)
0
20
40
60
80
100
Site-9
Site-10
Site-11
Site-12
300
250
200
150
100
50
percent of exceedance


Flow (m3/s)
0
50
100
150
200
250
300
Site-13
Site-14
Site-15
Site-16
20
40
60
80
percent of exceedance


Flow (m³/s)
300
250
200
150
100
50
0
0
20
40
60
80
100
percent of exceedance
Site-17
Site-18
Site-19

5. Designated number of potential sites and nearby endusers



Sites	nearby end user kebeles	Maximum distance (Km)
1	Yeraber	2.4
	Shembed	2.1
2	Awont yedefas	3.8
	Yeweredageorgis	3.4
	Wolemadeg Michael	2.1
3	Awont yedefas	3.1
	Jejerab Georgis	3.7
4	Awont yedefas	4.2
	Jejerab Georgis	2.8
5	Awont yedefas	6.4
	Jejerab Georgis	1.9
6	Laybirr wubshet	6.1
	Ferap	2.8
7	Laybirr wubshet	6.5
	Ferap	3.7
8	Warikma	1.9
	Adanhegn	2.5
9	Warikma	1.3
	Adanhegn	2.4
10	Warikma	1.0
	Adanhegn	2.6
11	TachberMersha	5.0
	Kengena kuandel	4.5
12	TachberMersha	6.6
	Kengena kuandel	4.1
13	TachberMersha	7.3
	Kengena kuandel	4.2
14	Kengena kuandel	4.3
	Santombabesa	4.7
15	Kengena kuandel	4.7
	Santombabesa	4.3
16	Santombabesa	5.6
	Mwakre Lekabdese	2.4
17	Mwakre Lekabdese	2.1
18	Mwakre Lekabdese	4.4
19	Mwakre Lekabdese	4.2

6. Metreological data

6A .Average monthly relative humidity of Laybirr station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	58.95	49.49	55.18	64.54	69.05	77.09	85.52	84.29	82.22	70.61	68.89	51.30	68.19
1991	57.08	65.98	54.20	59.92	58.29	77.97	88.18	86.74	80.60	68.03	60.66	56.75	67.86
1992	58.17	67.00	63.20	52.83	58.82	75.45	81.71	86.00	78.08	76.27	68.18	64.95	69.24
1993	51.39	55.71	53.49	62.13	57.34	73.66	81.84	80.63	77.47	72.13	63.67	58.43	65.70
1994	58.95	49.49	55.18	64.54	69.05	77.09	85.52	84.29	82.22	70.61	68.89	51.30	68.19
1995	58.95	49.49	55.18	64.54	69.05	77.09	85.52	84.29	82.22	70.61	68.89	51.30	68.19
1996	57.45	53.31	51.22	53.88	59.99	74.11	81.00	81.42	80.73	63.39	58.67	55.68	64.27
1997	50.03	40.32	43.21	44.88	54.83	67.58	78.35	79.39	74.77	72.74	65.70	55.65	60.76
1998	46.74	37.32	39.61	31.80	55.77	72.53	83.74	85.48	79.47	75.48	59.30	43.52	59.39
1999	45.23	35.11	28.10	39.07	61.90	59.47	80.13	73.66	69.40	58.70	48.96	43.63	53.76
2000	58.95	49.54	55.18	64.54	69.05	77.09	85.52	84.29	82.22	70.61	68.89	51.30	68.14
2001	71.77	73.36	69.48	66.83	75.06	79.73	81.68	82.97	74.37	67.13	50.90	44.90	69.84
2002	43.52	30.07	36.52	41.60	50.50	70.73	74.19	71.84	70.70	58.58	48.63	44.16	53.56
2003	35.52	35.75	37.65	27.83	25.23	45.87	66.65	70.74	66.74	56.40	50.30	44.96	47.05
2004	46.37	32.99	33.49	35.08	44.59	60.50	71.29	65.68	59.20	57.32	50.80	46.45	50.40
2005	39.45	27.04	38.33	30.80	35.48	54.67	70.81	71.39	67.00	57.65	50.90	44.52	49.16
2006	37.23	35.61	38.88	28.27	46.48	62.60	74.23	78.13	75.37	65.97	57.77	63.26	55.47
2007	55.32	43.05	33.68	41.53	52.35	69.70	77.00	74.65	69.23	52.58	40.13	33.48	53.63
2008	48.39	31.93	33.71	46.60	54.71	67.57	77.19	78.23	70.73	59.61	50.77	46.43	55.58
2009	41.32	35.19	38.13	33.02	33.00	55.77	77.73	75.65	68.87	64.35	45.75	55.45	52.17
2010	50.97	57.75	43.65	34.77	58.42	65.07	77.19	79.10	69.67	63.32	57.30	49.71	58.94
2011	45.91	36.75	54.13	43.43	54.13	63.73	71.32	78.03	68.90	53.68	49.63	46.16	55.63
2012	48.50	39.30	37.64	34.95	46.07	63.88	76.39	74.89	70.48	56.60	57.84	56.81	55.35
2013	58.87	49.12	55.27	65.57	69.24	77.19	85.39	84.31	82.10	70.77	68.04	51.37	68.20
2014	52.23	48.12	47.04	48.13	58.88	69.38	83.29	80.26	75.64	73.54	58.86	52.02	62.39
2015	49.30	41.63	41.78	38.37	64.01	69.97	73.84	77.61	73.11	63.68	63.87	50.38	59.08
2016	51.32	42.53	40.60	41.61	65.36	72.59	79.40	74.27	73.03	57.69	53.44	45.54	58.18
2017	52.41	47.74	44.18	42.38	56.98	64.87	76.21	77.89	72.86	61.29	54.71	48.77	58.44
2018	51.45	49.97	48.22	39.20	57.50	70.28	80.11	78.99	74.32	64.91	58.39	53.68	60.67
2019	50.26	48.74	50.44	52.37	63.21	70.31	77.22	80.01	78.02	70.00	54.63	51.45	62.31
Total	51.07	45.31	45.89	46.50	56.48	68.78	78.94	78.84	74.32	64.81	57.45	50.44	59.99

6B Average solar radiation of Laybirr station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	19.40	20.27	22.17	21.53	20.81	18.69	15.65	15.66	18.14	19.98	18.96	19.14	19.19
1991	19.42	21.07	21.61	22.22	22.38	19.41	15.50	16.39	17.76	19.13	19.19	18.69	19.38
1992	19.40	20.44	21.85	21.18	20.43	18.15	15.19	16.06	17.26	18.57	19.08	18.68	18.85
1993	19.52	20.89	22.42	21.09	20.24	17.37	14.70	15.20	17.40	19.85	18.91	19.14	18.88
1994	19.82	20.86	22.40	21.74	20.84	18.39	14.54	15.46	17.75	20.93	19.12	18.63	19.19
1995	20.08	21.09	21.89	20.61	19.89	18.07	15.03	16.25	17.81	19.81	18.49	17.70	18.88
1996	18.31	21.22	20.90	20.24	20.26	17.51	15.12	16.02	18.88	18.99	18.43	18.24	18.66
1997	19.26	21.76	20.58	21.83	19.43	18.23	15.08	15.01	17.52	17.58	18.59	19.07	18.63
1998	19.08	21.75	22.84	22.13	19.36	18.34	14.41	15.22	17.48	16.59	19.94	19.00	18.81
1999	19.77	21.12	23.28	20.74	20.93	18.00	14.48	14.83	17.22	17.89	19.20	18.87	18.84
2000	19.71	21.61	21.81	22.18	21.12	18.15	15.20	15.82	16.83	18.36	19.17	18.90	19.06
2001	19.98	20.52	21.46	21.65	20.60	17.61	16.36	16.24	18.22	19.62	19.48	18.83	19.20
2002	20.09	21.31	22.14	22.40	22.25	19.04	16.38	17.42	18.15	21.02	19.53	19.79	19.95
2003	20.70	21.14	21.57	21.84	22.40	17.41	15.43	16.17	16.96	19.87	19.17	19.32	19.32
2004	20.43	22.51	22.57	21.14	22.48	18.54	15.88	16.05	17.25	19.78	19.62	19.79	19.66
2005	20.68	22.26	22.00	22.14	21.06	18.90	15.43	15.01	17.05	19.51	19.00	19.55	19.36
2006	20.10	20.87	22.27	21.57	20.42	17.61	15.06	15.26	16.51	19.97	19.51	19.35	19.03
2007	19.87	21.58	23.24	21.89	20.28	17.77	15.28	15.52	17.75	19.35	19.20	19.61	19.26
2008	20.01	21.62	22.83	22.22	20.89	18.25	15.87	15.59	18.45	18.94	19.03	19.07	19.38
2009	20.07	20.50	19.99	21.70	20.68	18.92	15.40	14.69	17.14	19.23	18.70	17.86	18.72
2010	21.15	23.04	21.72	23.36	21.12	21.00	17.96	17.36	18.95	20.53	18.58	19.20	20.31
2011	20.24	22.57	22.41	22.14	21.84	19.14	18.17	18.53	19.18	20.40	18.93	19.59	20.25
2012	20.13	21.93	22.38	23.90	22.30	21.42	20.45	20.74	22.58	22.01	20.97	21.53	21.69
2013	22.00	24.06	24.30	24.72	22.78	21.18	18.85	19.10	16.40	17.65	17.45	17.04	20.44
2014	20.14	23.13	24.70	25.01	23.03	22.02	21.80	21.51	22.51	22.70	20.89	19.76	22.26
2015	21.55	23.08	23.48	24.32	22.76	21.79	20.28	20.93	22.29	20.55	21.51	20.71	21.92
2016	21.83	21.98	24.63	23.53	22.05	22.10	19.90	21.02	22.53	21.81	19.91	20.39	21.80
2017	21.95	23.82	25.35	24.73	22.44	20.22	18.41	20.60	21.00	22.37	20.13	20.47	21.78
2018	20.65	21.51	22.76	22.50	22.16	20.80	18.95	20.09	20.12	21.81	20.05	20.23	20.97
2019	20.02	21.35	22.77	23.16	22.37	21.26	19.41	20.79	21.28	22.67	20.67	20.23	21.33
Total	20.18	21.70	22.48	22.31	21.32	19.18	16.67	17.15	18.61	19.91	19.38	19.28	19.83

6C Average wind speed of Laybirr station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.98	1.17	1.21	1.24	1.47	1.46	1.10	0.98	0.91	0.98	0.89	0.94	1.11
1991	1.37	1.54	1.34	1.35	1.46	1.20	1.22	1.11	1.14	1.17	1.14	1.13	1.26
1992	1.35	1.58	1.68	1.59	1.64	1.58	1.15	0.97	1.08	1.00	0.97	0.99	1.30
1993	1.17	1.25	1.37	1.37	1.44	1.38	1.09	1.03	0.95	0.93	0.95	1.02	1.16
1994	1.33	1.38	1.50	1.67	1.51	1.20	0.92	0.87	0.98	1.10	1.03	1.10	1.21
1995	1.34	1.47	1.69	1.54	1.47	1.35	0.92	0.86	0.94	1.01	0.96	0.99	1.21
1996	1.15	1.43	1.50	1.41	1.22	1.16	1.03	0.91	0.86	0.91	0.87	0.95	1.12
1997	1.23	1.42	1.54	1.53	1.27	1.22	0.97	0.86	0.93	0.87	0.85	0.91	1.13
1998	1.07	1.25	1.26	1.42	1.39	1.19	0.90	0.78	0.75	0.77	0.82	0.98	1.05
1999	1.02	1.30	1.31	1.41	1.42	1.18	0.96	0.86	0.81	0.77	0.85	0.89	1.06
2000	1.02	1.19	1.27	1.33	1.38	1.20	0.96	0.79	0.74	0.72	0.75	0.81	1.01
2001	0.94	1.08	1.21	1.32	1.27	1.05	0.81	0.66	0.76	0.81	0.82	0.93	0.97
2002	0.99	1.15	1.26	1.42	1.32	1.18	0.98	0.75	0.70	0.69	0.78	0.93	1.01
2003	0.97	1.19	1.24	1.53	1.61	1.28	0.88	0.84	0.78	0.80	0.82	0.93	1.07
2004	1.01	1.18	1.27	1.33	1.50	1.16	0.99	0.80	0.74	0.69	0.70	0.71	1.01
2005	0.78	0.98	1.08	1.15	1.23	1.15	0.81	0.73	0.72	0.62	0.65	0.74	0.88
2006	0.91	1.05	1.15	1.21	1.10	0.94	0.68	0.59	0.57	0.57	0.53	0.60	0.82
2007	0.64	0.79	1.06	1.09	0.98	0.71	0.57	0.53	0.52	0.70	0.70	0.78	0.76
2008	0.86	1.03	1.22	1.18	1.03	0.88	0.76	0.64	0.68	0.66	0.69	0.64	0.86
2009	0.85	0.97	1.18	1.19	1.53	1.09	0.77	0.58	0.68	0.65	0.64	0.69	0.90
2010	0.85	0.95	1.10	1.09	0.94	0.94	0.69	0.66	0.59	0.63	0.72	0.65	0.84
2011	0.65	0.93	1.18	1.39	0.90	0.81	0.64	0.51	0.51	0.52	0.55	0.60	0.74
2012	3.79	1.58	1.76	1.83	1.75	1.59	1.29	1.15	0.45	0.43	0.46	0.50	1.38
2013	0.59	0.68	0.80	0.94	0.93	0.63	0.48	0.48	0.50	0.62	0.60	0.68	0.66
2014	0.53	0.69	0.66	0.69	0.98	0.66	0.43	0.54	0.52	0.51	0.54	0.53	0.61
2015	0.67	0.84	0.91	1.06	0.84	0.80	0.74	0.56	0.54	0.48	0.52	0.53	0.71
2016	0.71	0.91	0.95	1.16	0.85	0.72	0.47	0.37	0.41	0.38	0.42	0.97	0.69
2017	1.00	0.85	1.00	0.96	0.77	0.81	0.73	0.61	0.55	0.51	0.58	0.73	0.76
2018	0.86	1.03	1.04	1.09	1.14	0.90	0.69	0.59	0.62	0.65	0.65	0.71	0.83
2019	0.71	1.07	1.06	1.06	1.30	1.31	1.36	1.36	1.48	1.24	0.56	0.61	1.09
Total	1.04	1.13	3.44	1.72	1.31	1.15	0.94	0.84	0.86	0.75	0.60	0.80	1.66

6D Average monthly precipitation of Laybirr station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.33	0.18	0.84	1.28	2.96	5.88	12.29	11.60	8.46	2.34	0.86	0.33	3.97
1991	0.04	0.19	0.52	0.97	2.11	5.30	10.58	7.69	6.17	4.30	2.79	1.26	3.52
1992	0.93	0.46	1.44	1.80	4.07	6.58	10.74	9.68	6.37	4.24	2.34	0.56	4.12
1993	0.17	0.39	1.38	2.70	4.61	6.12	12.45	9.34	7.28	3.55	2.31	0.41	4.25
1994	0.26	0.31	0.83	1.87	5.65	8.72	10.60	10.22	5.52	1.39	1.64	0.68	4.00
1995	0.19	0.37	1.15	2.54	3.48	7.64	12.65	10.35	6.38	1.34	0.87	0.83	4.01
1996	0.55	0.52	2.49	2.58	5.82	9.16	12.46	9.29	5.89	1.67	2.62	0.63	4.49
1997	0.24	0.11	1.82	1.72	6.49	7.77	11.64	8.68	8.76	6.59	3.83	0.66	4.89
1998	0.26	0.21	0.97	0.58	5.46	7.58	11.08	13.06	7.63	5.38	1.13	0.17	4.50
1999	0.73	0.13	0.11	1.28	5.47	9.66	11.20	11.04	6.96	7.12	1.76	1.06	4.74
2000	0.14	0.24	0.54	3.30	2.53	8.32	10.84	10.48	8.52	6.37	3.10	0.65	4.60
2001	0.00	0.55	1.53	1.56	4.74	7.50	11.13	12.50	6.11	3.83	1.29	0.77	4.33
2002	0.72	0.31	1.56	1.23	1.11	8.38	12.03	10.91	6.64	2.47	1.01	1.33	4.00
2003	0.00	0.73	1.01	0.65	0.49	8.17	13.36	11.99	9.05	2.14	0.86	0.42	4.09
2004	0.15	0.32	0.79	2.79	1.31	6.97	11.59	9.04	8.00	3.87	1.72	0.57	3.94
2005	0.16	0.03	1.91	0.97	2.24	7.59	13.20	9.89	7.69	3.79	1.57	0.58	4.16
2006	0.17	0.36	1.24	0.98	7.18	8.40	13.69	12.82	8.19	4.17	2.09	1.67	5.12
2007	0.59	0.65	0.96	2.16	5.84	10.24	10.23	9.55	7.75	2.97	0.85	0.19	4.35
2008	0.80	0.11	0.18	3.92	8.03	8.55	12.11	8.98	6.56	2.30	1.56	0.77	4.51
2009	0.15	0.63	1.91	2.55	2.24	6.26	12.45	11.78	5.35	3.66	1.24	0.98	4.13
2010	0.54	0.19	0.68	1.49	5.69	8.54	11.83	13.16	8.80	2.43	0.97	0.59	4.61
2011	0.76	0.34	1.76	1.48	5.30	8.72	10.66	11.67	7.66	1.57	2.21	0.56	4.42
2012	0.20	0.12	1.13	0.60	3.47	7.59	12.14	10.30	7.40	1.61	1.80	0.83	3.95
2013	0.20	0.06	0.79	0.67	6.61	8.40	12.33	13.87	5.89	3.53	2.04	0.61	4.62
2014	0.33	0.16	2.36	4.36	7.82	6.67	11.76	9.52	7.65	5.03	1.70	0.20	4.83
2015	0.05	0.35	1.50	1.26	7.76	7.03	8.51	9.17	6.56	3.34	2.10	1.30	4.11
2016	0.07	0.47	1.83	0.93	8.24	8.29	11.69	11.17	6.13	3.67	0.78	0.21	4.48
2017	0.03	1.25	0.88	2.59	6.94	8.40	13.71	11.88	6.41	3.62	1.38	0.19	4.80
2018	0.07	0.44	0.58	1.09	4.06	7.88	12.96	8.95	5.50	2.96	2.57	0.40	3.98
2019	0.20	0.64	1.87	2.33	3.86	9.48	11.02	11.04	10.37	2.30	4.30	1.07	4.89
Total	0.30	0.36	1.22	1.81	4.72	7.86	11.76	10.65	7.19	3.45	1.84	0.68	4.35

6E Average monthly precipitation of Gundil station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.37	0.21	0.89	1.22	3.27	6.62	13.27	12.18	9.04	2.61	1.04	0.43	4.29
1991	0.03	0.24	0.46	0.96	2.39	5.31	11.90	8.33	5.74	3.97	2.57	1.17	3.62
1992	0.74	0.59	1.65	1.75	4.57	6.49	11.61	9.68	6.90	4.06	2.72	0.59	4.30
1993	0.05	0.34	1.68	2.55	4.90	6.58	13.34	10.51	7.43	3.51	2.63	0.46	4.53
1994	0.20	0.28	0.85	1.96	6.04	9.11	10.88	11.13	6.10	1.53	1.55	0.76	4.23
1995	0.16	0.36	0.98	2.27	3.53	8.19	13.62	11.66	7.07	1.37	0.85	0.83	4.27
1996	0.50	0.53	2.73	2.65	6.11	9.68	13.37	10.84	6.72	1.85	2.93	0.52	4.89
1997	0.29	0.15	1.93	1.57	7.31	7.92	13.22	9.07	9.10	7.25	4.37	0.67	5.27
1998	0.31	0.18	0.97	0.72	6.29	8.12	12.01	14.55	7.90	5.68	1.18	0.22	4.88
1999	0.91	0.16	0.15	1.18	6.46	10.43	13.04	12.14	7.99	7.47	1.75	1.14	5.28
2000	0.15	0.31	0.69	3.48	2.39	9.18	11.50	10.90	10.21	7.74	3.69	0.52	5.07
2001	0.00	0.64	1.78	1.48	4.84	8.45	12.25	14.33	6.66	3.99	1.54	0.90	4.77
2002	0.90	0.31	1.86	1.21	1.10	9.36	13.62	12.31	7.00	2.66	0.98	1.66	4.45
2003	0.00	0.85	1.07	0.71	0.60	9.08	15.34	12.89	9.38	1.96	0.90	0.42	4.46
2004	0.17	0.40	0.98	3.16	1.25	7.67	13.18	9.99	8.76	4.21	1.98	0.64	4.38
2005	0.22	0.02	2.21	0.89	2.44	8.87	14.80	10.79	8.88	3.94	1.56	0.73	4.64
2006	0.16	0.35	1.40	1.16	6.99	8.68	14.60	14.14	9.24	4.99	2.35	1.80	5.53
2007	0.68	0.74	1.05	2.18	5.85	11.19	10.70	10.32	8.91	3.24	1.11	0.20	4.70
2008	0.99	0.14	0.23	4.24	8.25	8.49	13.17	10.09	7.23	2.81	1.86	0.90	4.89
2009	0.19	0.78	2.34	2.83	2.52	5.97	13.42	13.41	6.27	3.85	1.63	1.04	4.56
2010	0.54	0.24	0.73	1.59	5.43	8.95	12.68	16.04	10.50	2.60	1.13	0.71	5.13
2011	0.92	0.43	2.03	1.59	5.42	8.79	11.92	12.83	8.85	1.52	2.26	0.56	4.79
2012	0.22	0.15	1.18	0.52	3.68	8.24	13.70	11.46	8.86	2.00	2.01	0.96	4.43
2013	0.27	0.08	0.97	0.82	6.51	9.01	12.77	11.64	6.14	3.90	2.42	0.74	4.64
2014	0.44	0.21	3.02	4.93	8.75	6.90	12.36	9.82	8.54	5.97	1.97	0.25	5.30
2015	0.04	0.45	1.29	0.30	8.13	7.75	8.98	10.23	7.05	3.14	2.09	1.60	4.29
2016	0.09	0.60	1.38	1.09	8.26	9.22	13.86	12.38	6.58	4.13	0.67	0.10	4.89
2017	0.00	1.32	0.71	3.10	7.30	8.98	15.99	13.73	6.94	3.74	1.50	0.22	5.33
2018	0.09	0.40	0.45	0.71	4.28	8.27	13.27	9.77	5.99	3.15	2.49	0.53	4.15
2019	0.19	0.71	1.83	2.34	3.92	10.42	11.94	12.10	11.10	2.40	4.66	1.30	5.26
Total	0.33	0.41	1.32	1.84	4.96	8.40	12.88	11.64	7.90	3.71	2.01	0.75	4.71

6F Average monthly precipitation of Burie station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.37	0.21	0.82	1.16	3.21	6.36	13.00	12.30	8.85	2.55	0.93	0.37	4.21
1991	0.04	0.22	0.40	0.90	2.12	5.17	10.86	7.62	6.58	4.73	3.03	1.43	3.61
1992	1.06	0.52	1.48	1.69	4.40	6.31	11.17	9.84	6.82	4.06	2.51	0.60	4.22
1993	0.20	0.38	1.51	2.53	4.79	6.42	13.03	9.99	7.42	3.61	2.56	0.47	4.44
1994	0.26	0.35	0.84	1.94	5.85	8.95	10.85	10.92	5.90	1.48	1.53	0.74	4.16
1995	0.21	0.41	1.12	2.44	3.53	8.14	13.25	11.15	6.73	1.38	0.89	0.88	4.20
1996	0.57	0.52	2.57	2.65	6.05	9.61	13.04	10.10	6.24	1.73	2.91	0.58	4.73
1997	0.25	0.13	1.90	1.73	6.93	8.18	12.65	9.11	9.18	7.00	4.11	0.74	5.19
1998	0.27	0.24	0.92	0.65	5.70	7.99	11.52	13.83	7.77	5.52	1.24	0.19	4.69
1999	0.78	0.14	0.13	1.37	5.87	10.04	11.87	11.69	7.61	7.45	1.88	1.07	5.03
2000	0.13	0.27	0.60	3.37	2.62	8.80	11.35	10.84	9.19	7.03	3.46	0.68	4.87
2001	0.00	0.55	1.57	1.63	4.85	8.18	11.58	13.36	6.69	3.87	1.47	0.83	4.58
2002	0.77	0.30	1.63	1.21	1.14	8.82	12.70	11.89	6.96	2.60	0.92	1.45	4.23
2003	0.00	0.77	1.02	0.72	0.56	8.53	14.54	12.97	9.65	2.26	0.95	0.43	4.39
2004	0.14	0.35	0.85	3.01	1.33	7.27	12.31	9.49	8.56	3.85	1.84	0.63	4.15
2005	0.19	0.03	2.00	1.06	2.41	7.64	13.64	10.67	8.10	3.97	1.68	0.66	4.37
2006	0.19	0.37	1.36	1.08	7.14	8.45	13.89	13.61	8.34	4.28	2.16	1.79	5.26
2007	0.64	0.64	1.03	2.07	5.82	10.87	10.73	9.89	8.35	3.26	0.96	0.22	4.56
2008	0.90	0.12	0.20	4.19	8.41	8.71	12.51	9.46	7.00	2.43	1.65	0.81	4.72
2009	0.17	0.71	2.09	2.79	2.37	6.47	12.80	12.71	5.78	3.82	1.41	1.06	4.38
2010	0.62	0.20	0.73	1.55	5.85	9.07	12.31	14.22	9.69	2.51	0.98	0.68	4.90
2011	0.87	0.37	1.97	1.53	5.40	9.23	10.97	12.46	8.41	1.54	2.39	0.62	4.67
2012	0.19	0.13	1.22	0.48	3.38	8.13	13.10	10.76	7.81	1.77	1.74	0.82	4.14
2013	0.23	0.07	0.83	0.72	7.27	9.03	12.84	14.96	6.00	3.88	2.08	0.64	4.92
2014	0.38	0.18	2.64	4.98	8.18	6.91	12.22	9.75	8.20	5.36	1.78	0.23	5.10
2015	0.03	0.39	1.19	0.72	8.08	7.71	8.88	9.80	6.87	3.18	2.38	1.48	4.26
2016	0.08	0.51	1.93	1.04	8.42	9.03	12.92	12.12	6.51	3.93	0.57	0.08	4.79
2017	0.03	1.43	0.90	2.77	7.13	8.96	14.77	12.84	6.80	3.63	1.57	0.19	5.12
2018	0.08	0.40	0.51	0.65	4.11	8.48	13.60	9.23	5.48	3.19	2.77	0.45	4.11
2019	0.23	0.61	1.91	2.29	4.05	10.03	11.60	11.06	8.41	2.42	4.43	1.12	5.02
Total	0.33	0.38	1.26	1.83	4.90	8.25	12.35	11.29	7.59	3.61	1.96	0.73	4.57

6G Average monthly precipitation of Quarit station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.37	0.21	0.82	1.16	3.21	6.36	13.00	12.30	8.85	2.55	0.93	0.37	4.21
1991	0.04	0.22	0.40	0.90	2.12	5.17	10.86	7.62	6.58	4.73	3.03	1.43	3.61
1992	1.06	0.52	1.48	1.69	4.40	6.31	11.17	9.84	6.82	4.06	2.51	0.60	4.22
1993	0.20	0.38	1.51	2.53	4.79	6.42	13.03	9.99	7.42	3.61	2.56	0.47	4.44
1994	0.26	0.35	0.84	1.94	5.85	8.95	10.85	10.92	5.90	1.48	1.53	0.74	4.16
1995	0.21	0.41	1.12	2.44	3.53	8.14	13.25	11.15	6.73	1.38	0.89	0.88	4.20
1996	0.57	0.52	2.57	2.65	6.05	9.61	13.04	10.10	6.24	1.73	2.91	0.58	4.73
1997	0.25	0.13	1.90	1.73	6.93	8.18	12.65	9.11	9.18	7.00	4.11	0.74	5.19
1998	0.27	0.24	0.92	0.65	5.70	7.99	11.52	13.83	7.77	5.52	1.24	0.19	4.69
1999	0.78	0.14	0.13	1.37	5.87	10.04	11.87	11.69	7.61	7.45	1.88	1.07	5.03
2000	0.13	0.27	0.60	3.37	2.62	8.80	11.35	10.84	9.19	7.03	3.46	0.68	4.87
2001	0.00	0.55	1.57	1.63	4.85	8.18	11.58	13.36	6.69	3.87	1.47	0.83	4.58
2002	0.77	0.30	1.63	1.21	1.14	8.82	12.70	11.89	6.96	2.60	0.92	1.45	4.23
2003	0.00	0.77	1.02	0.72	0.56	8.53	14.54	12.97	9.65	2.26	0.95	0.43	4.39
2004	0.14	0.35	0.85	3.01	1.33	7.27	12.31	9.49	8.56	3.85	1.84	0.63	4.15
2005	0.19	0.03	2.00	1.06	2.41	7.64	13.64	10.67	8.10	3.97	1.68	0.66	4.37
2006	0.19	0.37	1.36	1.08	7.14	8.45	13.89	13.61	8.34	4.28	2.16	1.79	5.26
2007	0.64	0.64	1.03	2.07	5.82	10.87	10.73	9.89	8.35	3.26	0.96	0.22	4.56
2008	0.90	0.12	0.20	4.19	8.41	8.71	12.51	9.46	7.00	2.43	1.65	0.81	4.72
2009	0.17	0.71	2.09	2.79	2.37	6.47	12.80	12.71	5.78	3.82	1.41	1.06	4.38
2010	0.62	0.20	0.73	1.55	5.85	9.07	12.31	14.22	9.69	2.51	0.98	0.68	4.90
2011	0.87	0.37	1.97	1.53	5.40	9.23	10.97	12.46	8.41	1.54	2.39	0.62	4.67
2012	0.19	0.13	1.22	0.48	3.38	8.13	13.10	10.76	7.81	1.77	1.74	0.82	4.14
2013	0.23	0.07	0.83	0.72	7.27	9.03	12.84	14.96	6.00	3.88	2.08	0.64	4.92
2014	0.38	0.18	2.64	4.98	8.18	6.91	12.22	9.75	8.20	5.36	1.78	0.23	5.10
2015	0.03	0.39	1.19	0.72	8.08	7.71	8.88	9.80	6.87	3.18	2.38	1.48	4.26
2016	0.08	0.51	1.93	1.04	8.42	9.03	12.92	12.12	6.51	3.93	0.57	0.08	4.79
2017	0.03	1.43	0.90	2.77	7.13	8.96	14.77	12.84	6.80	3.63	1.57	0.19	5.12
2018	0.08	0.40	0.51	0.65	4.11	8.48	13.60	9.23	5.48	3.19	2.77	0.45	4.11
2019	0.23	0.61	1.91	2.29	4.05	10.03	11.60	11.06	10.25	2.42	4.43	1.12	5.02
Total	0.33	0.38	1.26	1.83	4.90	8.25	12.35	11.29	7.59	3.61	1.96	0.73	4.57

6H Average monthly precipitation of Dembecha station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.65	0.31	0.99	1.61	1.99	5.38	11.77	10.09	8.44	0.88	0.52	0.20	3.59
1991	0.09	0.44	0.06	0.32	1.67	6.61	13.85	10.99	3.83	1.84	0.35	0.37	3.40
1992	0.31	0.45	0.81	1.04	2.90	6.01	10.65	10.11	4.42	2.88	1.17	0.75	3.48
1993	0.03	0.35	1.26	2.83	3.48	5.09	10.39	10.21	6.46	2.48	1.74	0.35	3.75
1994	0.00	0.01	0.64	1.19	4.21	9.61	11.50	8.59	4.90	0.78	1.34	0.46	3.62
1995	0.00	0.29	0.51	3.48	4.21	5.33	9.73	10.41	4.00	0.70	0.51	0.96	3.37
1996	0.30	0.20	2.65	2.69	6.06	10.73	13.10	8.56	4.84	0.48	2.03	0.28	4.34
1997	0.13	0.00	1.52	1.50	6.35	7.53	8.87	8.68	8.62	4.59	3.07	0.27	4.29
1998	0.13	0.08	1.26	0.04	4.85	6.13	9.56	13.11	8.09	5.43	0.66	0.00	4.15
1999	1.37	0.00	0.00	1.00	3.86	9.07	13.28	9.80	7.65	5.82	1.08	0.66	4.50
2000	0.05	0.00	0.38	3.12	1.09	5.36	8.05	7.16	8.32	8.03	3.92	0.21	3.81
2001	0.00	0.34	2.57	0.91	4.02	5.25	7.43	10.32	5.14	2.68	1.19	0.74	3.41
2002	0.69	0.48	1.66	0.23	0.35	6.09	11.30	11.14	3.77	1.11	0.55	1.97	3.31
2003	0.00	0.59	1.00	0.50	0.05	6.88	12.40	10.74	6.14	2.37	0.11	0.47	3.46
2004	0.03	0.26	0.74	2.50	1.27	6.04	10.29	5.22	5.94	2.52	1.90	0.30	3.09
2005	0.13	0.02	2.40	0.47	1.79	5.32	10.15	9.58	8.62	2.44	0.94	0.22	3.53
2006	0.12	0.20	1.63	0.98	3.92	6.81	12.67	10.80	6.45	4.13	2.56	1.80	4.37
2007	0.67	0.81	0.79	2.18	4.76	7.54	9.27	8.74	7.47	2.39	0.63	0.00	3.79
2008	0.74	0.00	0.00	2.91	6.60	6.86	9.98	8.50	5.57	2.15	0.88	0.82	3.77
2009	0.00	0.51	1.55	1.53	1.68	4.21	10.77	12.15	4.09	1.90	0.30	0.44	3.29
2010	0.00	0.36	0.74	1.54	3.82	5.54	11.28	11.09	5.88	2.30	0.90	0.84	3.72
2011	0.32	0.29	1.69	1.65	3.87	5.05	9.28	9.64	7.50	0.50	1.51	0.51	3.50
2012	0.35	0.08	0.66	0.93	2.36	4.45	7.71	9.36	7.78	1.40	1.26	0.30	3.06
2013	0.09	0.03	0.20	0.47	3.59	7.89	8.49	7.87	3.53	1.90	2.55	0.05	3.07
2014	0.10	0.04	2.20	3.85	7.30	3.52	8.89	9.16	7.62	5.26	0.57	0.12	4.09
2015	0.02	0.59	1.06	0.45	6.31	6.70	5.88	7.65	5.84	1.62	2.55	2.29	3.43
2016	0.16	0.59	0.69	0.73	5.62	5.55	9.43	9.25	5.35	1.51	0.03	0.28	3.28
2017	0.00	0.88	0.57	2.71	4.42	3.81	9.88	10.60	5.98	1.39	0.60	0.35	3.46
2018	0.05	0.34	0.41	0.62	4.44	7.40	11.89	9.06	5.21	1.50	2.05	0.92	3.68
2019	0.00	1.29	2.09	2.91	3.69	7.63	8.17	10.98	6.79	0.52	3.64	1.14	4.08
Total	0.22	0.33	1.09	1.56	3.69	6.31	10.20	9.65	6.14	2.45	1.37	0.60	3.66

6I Average monthly precipitation of Finoteselam station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.51	0.36	0.77	1.33	2.44	4.39	10.17	10.48	9.37	2.20	0.70	0.13	3.59
1991	0.06	0.33	0.09	0.31	1.20	4.99	11.31	9.70	4.09	4.43	2.10	1.53	3.38
1992	0.98	0.76	0.60	1.01	2.31	5.21	8.77	9.54	6.85	4.04	2.08	0.71	3.58
1993	0.04	0.54	1.80	2.78	3.71	5.08	10.75	8.96	6.61	3.02	1.77	0.44	3.82
1994	0.26	0.32	0.68	1.49	4.39	8.84	11.06	9.02	4.74	0.94	1.35	0.33	3.64
1995	0.21	0.50	1.12	3.37	3.93	6.16	10.32	9.58	4.24	1.00	0.72	1.06	3.54
1996	0.58	0.44	2.78	2.69	5.88	9.95	12.08	7.65	4.41	0.71	2.10	0.62	4.17
1997	0.29	0.24	1.82	2.11	5.67	8.36	9.09	8.94	9.03	4.90	2.87	0.62	4.52
1998	0.35	0.30	0.88	0.72	5.35	6.47	9.56	12.04	6.84	4.47	1.31	0.44	4.09
1999	1.18	0.31	0.25	1.14	4.70	8.39	11.96	9.75	6.58	4.58	1.35	0.70	4.27
2000	0.29	0.30	0.50	3.32	1.27	6.19	8.97	8.22	9.31	7.60	3.89	0.29	4.19
2001	0.00	0.47	2.66	1.09	4.47	5.76	9.18	11.48	5.60	3.33	1.15	0.74	3.86
2002	0.91	0.41	1.86	0.67	0.50	6.83	10.97	11.42	4.32	1.50	0.55	2.14	3.54
2003	0.00	0.76	1.17	0.56	0.24	7.33	12.39	10.60	6.84	2.41	0.26	0.37	3.60
2004	0.03	0.26	0.92	2.83	1.10	6.30	10.80	6.29	6.31	2.73	1.80	0.37	3.32
2005	0.22	0.01	2.46	0.54	1.72	5.73	11.67	9.57	8.13	2.82	1.04	0.29	3.71
2006	0.11	0.46	1.60	0.80	4.88	6.84	11.24	10.03	6.70	3.81	2.86	1.57	4.27
2007	0.66	0.93	1.10	2.15	5.47	7.81	8.82	9.05	6.10	2.28	0.67	0.21	3.79
2008	0.76	0.22	0.21	3.68	7.25	6.76	10.13	7.81	5.15	2.20	1.15	1.42	3.91
2009	0.32	0.90	1.63	2.37	2.04	5.08	11.06	11.32	4.27	3.06	0.48	0.75	3.64
2010	0.53	0.47	0.79	1.66	5.11	5.66	10.97	11.43	6.12	2.49	1.12	0.81	3.96
2011	0.79	0.46	1.55	1.91	4.44	5.86	9.56	10.25	6.77	0.92	2.00	0.64	3.79
2012	0.44	0.31	0.96	0.92	4.37	5.66	8.55	9.62	7.79	2.19	1.58	1.08	3.64
2013	0.29	0.03	0.66	0.71	3.96	7.57	8.75	8.36	3.75	2.59	2.18	1.15	3.36
2014	0.13	0.18	1.89	3.81	7.22	3.69	8.52	8.66	6.43	5.25	0.85	0.12	3.93
2015	0.02	0.42	1.10	0.41	7.10	5.74	5.73	7.14	5.37	1.74	2.14	1.92	3.26
2016	0.11	0.40	1.07	0.48	5.22	6.77	9.47	9.72	5.09	1.99	0.16	0.20	3.41
2017	0.00	0.84	0.38	3.00	6.13	5.54	12.83	10.93	5.46	1.85	1.15	0.44	4.07
2018	0.04	0.46	0.54	0.41	3.94	7.26	9.83	7.29	4.76	2.20	1.50	0.66	3.26
2019	0.00	1.16	2.13	3.66	3.35	8.56	8.74	11.81	10.71	1.82	4.04	1.63	4.81
Total	0.34	0.45	1.20	1.73	3.98	6.49	10.11	9.56	6.26	2.84	1.56	0.78	3.80

6J Average monthly precipitation of Feresbet station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.47	0.32	0.70	1.29	2.33	5.72	11.94	10.69	8.26	1.80	0.53	0.15	3.71
1991	0.05	0.25	0.19	0.72	0.90	4.71	10.61	7.61	3.53	3.32	1.57	1.15	2.91
1992	1.05	0.79	0.57	0.91	2.33	5.40	8.85	9.08	5.24	3.51	1.76	0.64	3.36
1993	0.03	0.41	1.62	2.74	3.73	5.53	11.77	10.32	6.03	2.69	1.63	0.44	3.94
1994	0.29	0.35	0.74	1.45	5.02	8.93	11.06	10.69	5.18	1.09	1.55	0.36	3.92
1995	0.24	0.43	0.96	2.91	3.45	6.98	12.30	10.10	4.47	0.93	0.54	0.85	3.71
1996	0.54	0.62	2.85	2.32	5.56	8.61	13.57	9.46	5.30	1.20	2.37	0.51	4.43
1997	0.35	0.19	1.95	1.98	6.59	8.13	10.67	9.19	8.34	6.56	3.72	0.54	4.88
1998	0.37	0.26	1.12	0.71	5.66	6.36	10.42	13.62	7.22	5.06	1.45	0.33	4.42
1999	1.17	0.23	0.22	1.20	5.11	9.02	12.63	11.45	6.71	6.09	1.27	0.92	4.71
2000	0.22	0.22	0.69	2.65	1.57	6.85	10.28	9.84	10.35	7.42	3.67	0.44	4.52
2001	0.00	0.62	2.41	1.12	4.42	6.69	11.45	12.52	6.09	3.97	1.18	0.81	4.31
2002	0.94	0.39	2.05	1.17	0.68	7.63	11.26	11.95	4.98	2.14	0.73	2.29	3.88
2003	0.00	0.98	1.24	0.85	0.36	7.55	12.48	10.90	7.44	2.17	0.66	0.32	3.76
2004	0.02	0.31	1.12	3.16	0.90	6.39	11.46	7.43	6.94	3.17	1.69	0.51	3.60
2005	0.31	0.02	2.46	0.61	1.60	6.25	12.59	10.06	7.62	3.10	1.02	0.36	3.86
2006	0.10	0.38	1.79	1.08	6.17	6.88	13.27	11.50	7.18	3.93	2.58	1.60	4.74
2007	0.69	0.98	1.02	2.21	5.12	9.33	9.33	9.45	6.71	2.34	0.83	0.16	4.03
2008	0.89	0.20	0.17	4.06	7.68	7.73	10.91	9.17	5.47	2.60	1.13	1.18	4.28
2009	0.24	0.85	1.74	2.14	1.80	4.89	11.55	12.25	3.93	3.38	0.85	0.81	3.73
2010	0.66	0.36	0.89	1.70	5.98	5.67	11.38	12.98	7.41	2.09	1.20	0.75	4.29
2011	0.90	0.62	1.78	1.82	5.21	6.89	10.59	11.36	6.37	1.03	2.26	0.75	4.16
2012	0.33	0.23	1.39	0.73	4.65	6.41	10.78	10.86	7.82	2.33	2.28	0.95	4.08
2013	0.35	0.12	1.07	1.08	4.43	8.93	11.80	10.21	4.19	3.50	2.19	0.88	4.09
2014	0.60	0.19	2.39	4.17	8.33	4.95	10.37	9.75	6.67	5.40	0.89	0.25	4.54
2015	0.01	0.68	1.38	0.39	7.78	6.90	6.52	8.49	6.29	2.14	2.60	1.95	3.78
2016	0.14	0.65	1.26	0.68	7.07	6.76	11.59	10.74	5.30	2.57	0.24	0.15	3.95
2017	0.00	1.31	0.62	3.01	6.56	5.31	13.84	11.91	5.51	2.02	1.28	0.33	4.34
2018	0.12	0.51	0.58	0.72	4.20	7.66	11.25	8.46	5.63	3.04	2.13	0.70	3.77
2019	0.23	0.92	1.98	2.89	3.23	8.45	10.83	12.71	10.68	1.71	4.96	1.54	5.02
Total	0.38	0.48	1.30	1.75	4.28	6.92	11.25	10.49	6.43	3.08	1.69	0.75	4.09

6K Average monthly precipitation of Sekela station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.45	0.25	0.56	1.12	2.54	6.66	12.26	11.46	8.11	2.74	0.89	0.52	3.99
1991	0.04	0.22	0.34	0.93	0.86	4.12	10.22	7.26	4.58	3.60	2.17	1.17	2.98
1992	0.88	0.71	1.35	1.76	3.49	5.82	10.00	9.28	6.16	3.32	2.66	0.53	3.84
1993	0.06	0.40	1.39	2.73	3.89	5.93	12.07	10.27	6.80	2.65	2.55	0.37	4.12
1994	0.24	0.28	0.59	1.98	5.69	8.75	10.55	9.81	5.53	1.37	1.65	0.46	3.93
1995	0.19	0.41	1.00	2.53	3.22	7.25	12.76	11.10	6.25	1.45	0.81	0.73	4.00
1996	0.51	0.59	2.84	2.59	5.78	9.11	12.53	10.10	5.81	1.31	2.39	0.48	4.52
1997	0.31	0.18	1.56	1.58	7.08	7.84	11.38	8.88	8.72	6.94	4.47	0.62	5.00
1998	0.31	0.21	1.06	0.64	5.92	7.27	11.19	13.85	6.72	5.45	1.23	0.26	4.55
1999	0.94	0.19	0.17	0.96	5.59	9.62	13.20	12.25	7.19	6.47	1.22	0.97	4.94
2000	0.18	0.37	0.65	3.24	2.05	7.69	10.58	10.30	9.82	7.65	3.33	0.45	4.70
2001	0.00	0.57	1.93	1.41	4.38	7.57	12.17	13.34	6.10	3.89	1.16	0.89	4.49
2002	0.99	0.32	1.90	1.13	0.94	7.44	12.50	11.45	5.60	2.25	0.64	1.91	3.95
2003	0.00	0.79	0.99	0.80	0.56	7.92	13.97	11.33	8.05	1.94	0.72	0.48	3.98
2004	0.09	0.25	1.04	3.19	1.02	7.33	12.01	8.80	7.51	3.71	1.80	0.47	3.94
2005	0.26	0.02	2.08	0.78	2.29	7.43	12.74	10.44	7.84	3.36	1.36	0.36	4.11
2006	0.14	0.36	1.52	1.15	6.65	7.82	13.42	12.81	8.14	4.49	2.34	1.60	5.08
2007	0.55	0.81	1.05	2.22	5.27	9.96	10.03	9.59	7.58	2.98	1.05	0.24	4.30
2008	0.76	0.16	0.28	4.24	7.78	7.69	11.64	9.35	6.35	2.59	2.15	0.96	4.51
2009	0.23	0.76	2.29	3.15	2.64	5.42	12.16	11.81	5.11	3.21	1.75	0.67	4.13
2010	0.52	0.28	0.71	1.43	5.49	7.11	12.49	14.87	9.01	2.15	1.10	0.75	4.70
2011	0.84	0.50	1.95	1.70	5.26	7.68	11.49	12.01	7.01	1.16	2.23	0.67	4.40
2012	0.26	0.18	1.31	0.62	3.87	7.22	11.64	10.68	7.31	2.12	1.91	0.76	4.01
2013	0.28	0.09	1.00	0.87	5.28	8.73	11.51	10.77	4.56	3.76	2.42	0.86	4.21
2014	0.53	0.23	2.81	4.77	8.30	5.46	11.21	9.81	7.31	4.82	1.96	0.22	4.82
2015	0.05	0.54	1.21	0.31	7.59	7.45	7.70	9.27	6.66	2.64	2.08	1.56	3.95
2016	0.11	0.72	1.28	1.14	7.34	7.94	13.32	11.62	5.12	3.28	0.74	0.12	4.42
2017	0.00	1.20	0.77	3.01	6.93	6.78	15.12	12.55	5.29	2.84	1.57	0.26	4.73
2018	0.11	0.41	0.47	0.67	4.67	7.64	11.91	8.78	6.48	2.93	2.51	0.58	3.95
2019	0.23	0.73	1.59	2.61	3.69	8.27	11.57	12.18	10.51	1.87	4.67	1.25	4.95
Total	0.34	0.42	1.26	1.84	4.53	7.43	11.85	10.87	6.91	3.30	1.92	0.71	4.31

6L Average monthly maximum and minimum temperature of stations

Month	Laybirr	Gundil	Sekela	D/tsion	Dembcha	F/selam	Quarit	Bure
January	26.9	26.1	24.7	24.6	27.6	30.7	25.4	27.8
February	28.6	27.8	26.9	25.8	28.8	31.9	27.6	29.6
March	29.3	28.6	27.9	26.4	29.3	32.8	28.4	30.5
April	29.1	28.3	27.3	26.2	29.1	31.8	28.7	30.3
May	27.3	26.6	26.4	25.8	27.2	29.2	27.4	28.3
June	24.3	23.8	23.8	23.9	24.4	26.7	23.8	24.7
July	21.7	21.2	21.3	21.5	22.5	24.0	20.7	22.2
August	21.8	21.4	21.3	21.3	22.7	24.1	20.9	22.2
September	23.1	22.6	22.2	22.0	23.7	25.7	22.2	23.6
October	24.2	23.8	22.5	22.8	25.2	28.2	23.1	24.2
November	25.0	24.3	22.5	23.4	26.0	28.8	23.5	25.3
December	25.7	24.9	23.2	23.8	26.7	29.4	24.0	26.3

Month	Sekela	D/tsion	Dembcha	F/selam	quarit	burie	Laybirt	Gundil
January	9.1	8.4	8.9	11.5	10.2	11.9	10.0	9.6
February	10.3	9.1	9.8	12.4	11.9	13.5	11.2	10.9
March	11.9	10.4	11.3	14.2	13.3	14.6	12.8	12.4
April	12.7	10.9	12.0	14.9	14.0	15.4	13.5	13.1
May	12.8	11.0	12.0	15.1	14.1	15.7	13.7	13.3
June	12.1	10.5	11.5	14.4	13.5	14.5	13.0	12.7
July	11.4	10.5	11.2	14.1	12.7	13.8	12.5	12.1
August	11.4	10.6	11.1	13.9	12.2	13.8	12.4	11.9
September	11.2	10.0	10.8	13.8	12.0	13.3	12.0	11.7
October	10.1	9.3	10.3	13.1	10.4	12.5	11.1	10.7
November	9.4	8.6	9.4	12.7	9.5	11.3	10.2	9.9
December	9.3	7.8	8.7	12.0	9.4	11.2	9.7	9.5