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Assessing the Ecological Health of Zarima River Using Macroinvertebrate and Fish Communities, North Gondar, Ethiopia

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BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF FISHERIES AND AQUATIC SCIENCES

GRADUATE PROGRAM

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MSc Thesis

BY

ELSA BELETE BERIE

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A THESIS SUBMITTED TO THE DEPARTMENT OF FISHERIES AND AQUATIC SCIENCES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF A MASTER OF SCIENCE IN FISHERIES AND AQUACULTURE

Advisors: Dr. Mengistu Asmamaw, Bahir Dar University

Professor Abebe Getahun, Addis Ababa University, Ethiopia

December, 2024

Bahir Dar, Ethiopia

DECLARATION

This is to certify that this thesis entitled "**Assessing the Ecological Health of Zarima River using Macroinvertebrate and Fish Communities, North Gondar, Ethiopia**" submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in "**Fisheries and Aquaculture**" to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by **Mrs. Elsa Belete,** ID. No BDUR1401263 is an authentic work carried out by her under our guidance. The matter embodied in this project work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

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Mengistu Asmamaw (PhD)

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ANRS	Amhara National Regional State
CCA	Canonical Corresponding Analysis
H'	Shannon Index of Diversity
ISO	International Standards Organization
IRI	Index of Relative Importance
LWR	Length Weight Relationship
NGO	None Governmental Organization
PAST	Paleontological Statistics Software Package
PCA	Principal Component Analysis
USEPA	United State Environmental Protection Agency

APPROVAL SHEET

The undersigned certify that they have read and hereby recommend to the College of Agriculture and Environmental Science Studies, Bahir Dar University, to accept the Thesis submitted by Elsa Belete, and entitled "**Assessing the Ecological Health of Zarima River using Macroinvertebrate and Fish Communities, North Gondar, Ethiopia**", in partial fulfillment of the requirements for the award of a Master's Degree in **Fisheries and Aquaculture" Program**.

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ABSTRACT

The study was conducted in the Zarima River between March and July 2023. The objectives of the study were to assess the ecological health of Zarima River using macroinvertebrates, fish community, and physicochemical parameters and determine the length-weight relationship the most dominant fish species. Physicochemical sampling were collected using in situ multi parameter probe. Macroinvertebrate specimens were collected using a D-shaped sweep net with a mesh size of 500 µm. Gillnets with diﬀerent mesh sizes 6, 8 and 10 cm and monofilament nets of various mesh sizes(4 and 6 cm) were used to collect fish specimens in both dry and wet seasons. Immediately after capture, the total length(TL), forked length and total weight(TW)of each individual were measured in centimeters and grams, respectively, and their relationship was determined using the power function. A one-way ANOVA and independent t-test were used to describe the mean difference and statistical difference in physicochemical parameters across the sampling sites and seasons respectively. Moreover, canonical correspondence analysis(CCA)was used to visually display patterns in macroinvertebrate and fish distribution in relation to their environmental variables. Also, a principal component analysis was run to ordinate sampling sites in relation to the distribution of macroinvertebrate and fish communities. A total of 292 macroinvertebrate and 253 individual fishes were collected. While Gomphidae was the most dominant(67.47%) taxon among the macroinvertebrates, Cyprinidae was the best-represented family of fishes. Zarima River had higher diversity(H'=1.22) of fish in dry season but lower in wet season which was(H'=0.97). Likewise, L. intermedius was the top(88.1%) in Index of Relative Importance value, indicating its influence in terms of number, weight, and frequency of occurrence in Zarima River. Furthermore, the length-weight relationship for the most abundant species showed that the relationship was strong by discussing the b-value for Garra species(b=3.1015)attain positive allometric growth. However Labeobarbus intermedius and Labeo forskalii attain negative allometric growth. The Zarima River's diverse aquatic ecosystem, influenced by seasonal and environmental factors, to recommend it need regularly monitor the river's water quality macroinvertebrates and fish populations across different seasons to track changes and respond to potential stressors.

Keywords: Abundance, Diversity**,** Ecology, Fish, Health, Macroinvertebrate, Zarima River.

CHAPTER 1: INTRODUCTION

1.1.Background of the Study

Freshwaters are essential resources to contribute to sustaining life and the origins of civilization in human history(Bănăduc *et al*., 2022). Humans depend on water resources for domestic use, agriculture, industry, transportation, waste disposal, energy production, and extraction of freshwater resources including fish production. Furthermore, freshwater ecosystems are also home to a wide range of animals, plants, and microorganisms(McAllister*et al*., 1997). Freshwater ecosystems are disproportionately sensitive to extensive watershed alteration resulting in the decline in freshwater biological organisms. In effect, freshwater biodiversity is extremely threatened over terrestrial ecosystems(Ricciardi and Rasmussen, 1999).

Freshwater ecosystems are considered as the most endangered and threatened worldwide(Dudgeon *et al*.,2006)suffering from both natural drivers(Stendera *et al*.,2012)and anthropogenic disturbances like human population density and consequent water competition for domestic and agricultural uses(Banda *et al*., 2022). The geomorphology and biotic structures of streams are dominantly influenced by disturbances(Bae and Park, 2009 Stendera *et al*., 2012). Freshwater ecosystems constitute a small fraction of the earth but provide substantial ecosystem service and sustain human well-being(MEA, 2005). Humans rely on freshwaters for a wide range of services, including domestic water supply, irrigation, food and energy production, transportation, recreation, etc(Vári *et al*., 2022).

However, they are facing a multitude of challenges and are the most threatened ecosystems in the world(Sánchez *et al*., 2020; Vári *et al*., 2022). Especially streams and rivers are the most vulnerable ecosystems extremely affected by anthropogenic impacts leading to ecological impairment of streams and rivers(Shahraki *et al*., 2021). Likewise, increasing pollution sourced from improved watershed degradation in developing countries as well as overexploitation and industrialization in developed countries have posed water quality degradation, growing risk to public health, biodiversity loss, and impairment of ecosystem services in the freshwater ecosystem(Simachew Bantigegn, 2020).

Habitat degradation and biodiversity loss have been well documented globally for the last few decades and much more focus was given to terrestrial ecosystems(Myers *et al*., 2000), Other biomes like freshwater lakes, wetlands, and streams have been neglected(Myers *et al*., 2000). Although the present decade(2005-2015) has been stated as 'Water for life' by the United Nations General Assembly, human population growth has threatened freshwater environments more than ever(Balian *et al*., 2008;Dudgeon *et al*., 2006). Studies show that freshwater habitat impairment due to anthropogenic and natural derivers restrict stream community networks resulting in a wide range of ecological constraints. Therefore, the alarmingly growing habitat degradation and associated losses of biological diversity in freshwater ecosystems require scientific investigation for sustainable intervention options(Brauer and Beheregaray, 2020)

Ethiopian rivers and streams have been negatively impacted by uncontrolled rapid development activities that release excessive wastes that overcome the assimilative flexibility of the water systems. The degradation of streams and rivers in urban areas is increasing at an alarming rate, because of rapid human population increase and associated waste production(Zinabu and Elias, 1989; Getachew,Beneberu *et al*., 2014). The increasing impact of human activities on the freshwater-bodies of Ethiopia requires an efficient and cost-effective method for ecological health assessment(Amare Mezgebu *et al*., 2019).Thus, continuous monitoring and evaluation of stream conditions are crucial to recognizing the effects of watershed degradation on stream's water quality(Barbour *et al*., 1999). Monitoring stream ecological quality involves a collection of physical, chemical, and biological attributes of streams. Currently, the biomonitoring approach is perceived as a healthy approach due to its time-integrated evaluation of water quality assessment(Boothroyd and Stark, 2000). It is the use of long-term local organisms to assess the consequences of irregular as well as cumulative pollution and alteration of habitats(Barbour *et al*., 1996).

In recent periods, various aquatic biological communities, such as macroinvertebrates, Fish, macrophysics, diatoms, phytoplankton, etc., have been used to assess ecosystem integrity throughout the world(Karaouzas *et al*., 2019 and Ruaro *et al*., 2020). However macroinvertebrates and fish are the most used biological communities for the assessment and monitoring of running aquatic ecosystems(Ruaro *et al*., 2020;Eriksen *et al*., 2021;Feio *et al*., 2021). These biotic communities are different in their sensitivity and scale of spatiotemporal responses to various stressors and thereby supplement each other due to their variable features(Herlihy *et al*., 2020).

As bio indicators, macroinvertebrates have the advantage of the ease of sampling, presence in all aquatic habitats, limited mobility, varying degrees of tolerance, ability to respond to short and long-term stressors, etc.(Serra *et al*., 2019). On the other hand, fish are more sensitive to hydro morphological disturbances, have more socioeconomic benefits, their ecological preference is mostly known, and thereby effective in reflecting broader spatial and temporal scale disturbances (Barbour *et al*.,1999;Herlihy *et al*.,2020). Thus, the current study applies the macroinvertebrate and fish-integrated bioassessment methods concurrent with physicochemical methods to generate reliable information on the major sources of threats and to inform sustainable management interventions of the Zarima River, northwestern Ethiopia.

1. 2. Statements of the Problem

Freshwater ecosystems are facing degradation from human activities in the form of alterations of flow regimes, changes in land-use, and intensive water abstraction, in turn generating adverse effects on biodiversity and ecological functionality(Raphahlelo *et al*., 2022). Because of this, freshwater ecosystems around the world have gradually gotten worse over the past few decades as a result of increased human pressure that has decreased aquatic biodiversity. Moreover, a greater risk of water insecurity as a result of the deterioration of freshwater ecosystems(Vollmer *et al*., 2016). The majority of the degradation of water quality in multiple rivers is caused by anthropogenic activities, where it is usual to dump debris from various sources, including agriculture and medical institutions, alongside household and industrial waste(Endaweke Assegide *et al*., 2022).

Human activity has caused varied degrees of disturbance and harm to freshwater rivers worldwide (Gál *et al*., 2019; Sabater *et al*., 2018). Rivers have become one of the most vulnerable ecosystems due to the excessive outflow of home, commercial, and agricultural sewage, the breakdown of the riparian zone structure, the misuse of water resources, and the building of dams. It is vital to carry out a detailed evaluation of how river and stream ecosystems are adapting to these human-caused changes(Raphahlelo *et al*.,2022). One tool that can be used to evaluate the state and extent of harm to aquatic ecosystems is biological monitoring(Birk *et al*.,2012).

Understanding the abiotic elements of ecosystems and biological communities as ecological indicators is helpful in the following areas: (i) assessing the effects of human activity on running waters; (ii) knowing how freshwater communities are altered by climate change; and (iii) figuring out the true species richness and biodiversity of some specific stream reaches that may be poorly known(Dale and Beyeler,2001; Chaves *et al*., 2005).

The Zarima River's ecological health is under threat by human activities and environmental changes, including agricultural runoff, deforestation, and urbanization use pressures that risk the river's water quality, habitat integrity, and overall ecosystem function. Conservation and preservation of resources depend on the development of dynamic methods for monitoring, evaluating, and managing the ecological integrity of a river system, which could be strengthened by including the use of ecological indicators(Dale and Beyeler,2001). However, no research has been conducted in the Zarima River that uses the fish and macroinvertebrate communities as a basis for assessment. Consequently, a combined study employing fish communities and macroinvertebrates is required to evaluate the ecology of the river. The benthic invertebrate and fish communities were employed as bio-indicators to assess the regional variation of the water quality of the Zarima River from the perspective of the long-term consequences of pollution mitigation. Therefore, to ensure proper management and sustainable use of the River ecosystem, this study evaluated the ecology status of the Zarima River for utilizing fish and macroinvertebrate communities.

1. 3. Objectives of the Study

1.3.1. General Objective

The general objective of this study was to assess the ecological health of Zarima River using macroinvertebrates and fish communities.

1.3.2. Specific Objectives

The specific objectives of this study were:

- To describe the abundance and diversity of macroinvertebrate assemblages in the Zarima River
- To explain the abundance and diversity of fish assemblages in the Zarima River
- To identify physiochemical parameters that influence the abundance and diversity of macroinvertebrate and fish communities in the Zarima River

1.4. Research Questions

- Are there variations in the diversity and abundance of macroinvertebrate assemblages between sampling sites and seasons in the Zarima River?
- Are there variations in the abundance and diversity of fish assemblages between sampling sites and seasons in the Zarima River?
- What are the physicochemical water quality parameters that influence the abundance and diversity of macroinvertebrate and fish communities in the Zarima River?

1.5. Significance of the Study

The result of this study may have the following importance for its users. Firstly, when the river ecology is known properly, the people who live around the Zarima River might be beneficial. The current study would recommend sustainable management of the Zarima River basin. Furthermore, it mentions the broader long-term generation of river ecosystem services, which the local communities directly rely on. Contribution of the Zarima catchment area, for instance by mentioning its role for Tekeze hydropower generation as well. Secondly, this study might be baseline information for future researchers on this area and to protect the river from contamination of waste matters. Nowadays fishery resources are declining due to different environmental conditions, illegal fishing practices, habitat modifications, and extraction of gravel and sand for developmental activities. Consequently, this study may serve to explore the diversity of different fish species in the Zarima River. And also encourage the local community to conserve the environment for healthy living. Therefore, the results of the study will be used by Environmental Authorities, the Ministry of Water Resources, the Ministry of Health, other organizations, and researchers involved in water resource protection and development for regulatory measures and further research.

1.6. Scope and Limitation of the Study

The current study was delimited only on the Zarima River, where samples were taken at 6 sampling sites from dry to wet seasons, mainly due to resource constraints and unstable security issues. Therefore, the chance of obtaining many species in the rivers became low. However, more base line information would have been obtained if the study had covered more sampling sites and seasons that could contribute to broader spatiotemporal characterization of the Tekeze River basin.

The researcher believes that it would be better if the study covered assessing the ecology of Zarima River by using macroinvertebrate and fish communities in Zarima River in different areas at different times.

CHAPTER 2: LITERATURE REVIEW

2.1. Ecology of Riverine Ecosystem

Ecology is the study of interactions among organisms and their biophysical environment(Balasubramanian, 2017). River ecosystems are flowing waters that drain into lakes and oceans, and include the biotic(living)interactions among plants, animals, and microorganisms, as well as abiotic(nonliving)physical, and chemical interactions of its many parts(Angelier and Minnick, 2019). It is a component of bigger catchments or watershed networks, where smaller headwater streams flow into mid-sized streams, which finally flow into bigger river networks. A river is a natural running water body, that origin from a high land in the continent and flows according to the slope of the earth's surface, and at last, drains into a lake, ocean, or any other body(Tripathy *et al*., 2021).

Rivers are ecosystems of great ecological value with rich fauna that consists of communities with complex structures, and high biological value. River ecosystems are prime examples of lotic ecosystems. The word lotic, which comes from the Latin lotus, which means washing, means flowing water. Lotic waters range from springs only a few centimeters wide to major rivers kilometers in width(Allan *et al*., 2021). In general, lotic ecosystems, including related lotic systems like streams and springs, are covered in large part by this page. In difference to lentic ecosystems, which are found in relatively quiet terrestrial waters like lakes, ponds, and wetlands, lentic ecosystems rotate around aquatic life.

The river acts as a baseline for thousands of people in terms of fishing for livelihood and food (Tahira *et al*., 2020). Due to their unique typology, they are delicate and vulnerable to changes in their environment, particularly those taken on by anthropogenic disturbances, which frequently indicate irreversible deterioration of their biological tissue(Beasley and Kneale, 2003). Environmental threats to rivers include loss of water, dams, chemical pollution, and introduced species(Alexander, 2018). For example, dam produces negative effects that continue to downgrade the watershed.

2.2. Physico-Chemical Parameters in Rivers

Rivers have been the most important freshwater resource and our ancient civilizations have succeeded along the banks of rivers. Its water has multiple uses like agriculture, industry, transportation, aquaculture, and public water supply, and they have been used for cleaning and disposal purposes. Enormous loads of waste from industries, domestic sewage, and agricultural practices find their way into rivers resulting in large-scale deterioration of the river water quality (Mahesh and Prabhahar, 2012). A riverine ecosystem is one of the most productive ecosystems in the world that supports a large proportion of the earth's biodiversity. Numerous plants and animals survive and grow in water and thus, it serves as the home of aquatic organisms. However, anthropogenic activities in the river system and its catchment harm the existence of aquatic biota and obstruct the facility of good water quality of the rivers(Lammessa Berisa *et al*., 2019). The anthropogenic activities in the river system include pollution from industrial development, agriculture, water construction, the introduction of invasive species, and alteration of riparian habitat(Steward *et al*., 2018; Li *et al*., 2020).

The species living in essentially any water body like streams and rivers have a diversity of morphological, ecological, and behavioral adaptations to their natural habitat(Herrmann, 1999). Being a diverse component of riverine habitats, they respond quickly to changes in physical, chemical, or biological parameters. Testing water requires the use of various physicochemical characteristics. Selection of the tested parameters is only dependent on the purpose of using that water and to what extent we need its quality and purity. The term "physicochemical" describes objects that are dependent on or generated by the combined operations of physical and chemical properties, encompassing the concepts of both physics and chemistry. To acquire a precise understanding of the water quality, it is crucial to compare the obtained results with standard values using the physicochemical parameter. Water quality analysis is important to protect the natural ecosystem(Patil *et al*., 2012).

The physicochemical parameters of the river such as water temperature, pH, dissolved oxygen, oxygen saturation, conductivity, salinity, Secchi disc depth, nitrate, nitrite, phosphate, sulfate, chloride, total hardness, calcium, and magnesium. Each freshwater body has an individual pattern of physical and chemical characteristics which are determined largely by the climatic, geomorphological, and geochemical conditions prevailing in the drainage basin and the underlying aquifer.

2.2.1. Temperature

The physical, chemical, and biological health of streams are influenced by temperature, making it a crucial characteristic in aquatic ecosystems. It is a critical water quality and environmental parameter subsequently, it governs the kinds and types of aquatic life, regulates the maximum dissolved oxygen concentration of water, and influences the rates of chemical and biological reactions(Dessalegn Geleta & Worku Firomsa, 2022). Natural thermal characteristics of riverine ecosystems were dependent on hydrological, regional, climatological, and structural features of the region and catchment area. Most aquatic organisms have limited optimal temperature ranges which affect survival, spawning success, and metabolic rates. In cold water systems, small fluctuations in temperature can have profound effects on an individual's vital rates, which at the population level can mediate connectivity patterns(Laurel and Bradbury, 2006).

2.2.2. pH

pH measurement reveals whether water is acidic(pH $<$ 7) or alkaline(pH $>$ 7). Neutral pH is found in pure waters, with equal hydrogen ions(H^+) and hydroxyl ions(OH^-). It is a crucial factor in determining the quality of water since it affects a variety of biological and chemical activities in a water body and all processes involved in water supply and treatment(Rahmanian *et al*., 2015). A pH value outside the range of 6.5 to 8.5 reduces the biodiversity in a lake and River because it stresses the physical system of most organisms and can reduce reproduction. Low pH can also allow toxic elements and compounds to become mobile and "available" for uptake by aquatic plants and animals thereby producing conditions that are lethal to aquatic life, particularly to sensitive species(USEPA, 1991).

2.2.3. Dissolved oxygen

Dissolved Oxygen is one of the most substantial parameters related to the sustainability of aquatic life and it determines the spatial and temporal distribution of aquatic organisms as this is essential for their respiration(Araoye, 2009). It is the conventional and widespread indicator for the health of the aquatic ecosystem, which refers to the level of free, non-compound oxygen present in water. Dissolved Oxygen concentrations in lotic water vary seasonally or even over a 24-hour period. It is important to many aquatic life forms, like fish, invertebrates, microorganisms, and plants(Li, and Liu,2018). Premlata, (2009) also mentioned the factors that affect the concentration of DO in water which include temperature, depth, salinity, photosynthesis, and availability of nutrients. The long days and warm temperatures of summertime appear to accelerate the process of photosynthesis by phytoplankton, which uses CO^2 and releases oxygen. This possibly accounts for the greater qualities of O^2 recorded during summer(Krishnamurthy, 1990). An essential component of evaluating the quality of water is figuring out the DO concentrations.

2.2.4. Conductivity

Conductivity is the measure of the ability of water to pass an electric current. Conductivity in rivers is affected primarily by the geology of the area through which water flows. The electrical conductivity of water is a useful and easy indicator of salinity or total salt content(Merkebu Demissie, 2017). It can be used as an index of total dissolved solids and, in some cases, as a predictor of concentrations for individual ions. There is a high degree of correlation between electrical conductivity and TDS both signify the amount of dissolved solid(Mihir Kumar *et al*., 2014). Conductivity has plentiful influences on the survival and productivity of fish because it affects the osmotic pressure that is exerted on the cellular membranes of fish. The normal range of conductivity required for the productivity of fish is 50-1500 μS/cm(Hameed-Ur-Rehman *et al*., 2015).

2.3. Biological Community in Rivers

Biological communities reflect the overall ecological quality of aquatic ecosystems and integrate the effect of different stressors providing a broad measure of determined impact and an ecological measurement of fluctuating environmental conditions. Bioindicators are “an organism (or part of an organism or a community of organisms)that contains information on the quality of the environment (or a part of the environment)(Markert *et al*., 2003). The ideal indicator at least should have the characteristics as follows: (1)taxonomic soundness(easy to be recognized by no specialist); (2) wide or diverse distribution;(3)low mobility(local indication); (4)well-known ecological characteristics;(5)numerical abundance;(6)suitability for laboratory experiments;(7) high sensitivity to environmental stressor;(8)high ability for quantification and standardization(Füreder and Reynolds, 2003).

According to the guidelines of the Water Framework Directive, biological components including fish and benthic macroinvertebrates have been employed to evaluate the ecological quality of rivers(Maria *et al*., 2011). Biological monitoring is advantageous in that it can integrate and reflect accumulative changes over time, which is in difference to several other methods, such as flow regimen, energetic resources, and biotic interactions(Alba-Tercedor, 1996). An additional advantage is that assessments of river health can take into account the rich range of fauna present in aquatic environments,which includes fish, mammals, periphyton, algae, macroinvertebrates, zooplankton, and microbes(Herman and Nejadhashemi, 2015).

Benthic macroinvertebrates are the most often utilized biological communities among those that are thought of as bioindicators of water quality because, they have several traits that make them simple to study and determine different reactions in the face of unfavorable environmental conditions(Bonada *et al*., 2006). Different groups of macroinvertebrates are excellent indicators of human impacts especially contamination(Asaminew Kassah *et al*., 2011). Because of their relatively long life cycles and poor movement ability, macroinvertebrates play a significant role in the structure and function of the river ecosystem, which is vulnerable to environmental changes (Clarke *et al*., 2008). They are responses to the change in aquatic ecosystem conditions that is universally recognized, and their answers are used in indices to monitor freshwater ecosystems for integrity, helping in decision-making in management(Tampo *et al*., 2020;Edegbene *et al*., 2021).

Currently, macroinvertebrates used as bioindicators have been widely adopted in many countries because they integrated multiple desired properties, including ubiquity, varying degrees of tolerance to alarms, and cost-effectiveness of sampling, which makes them a popular choice for biomonitoring assemblages(Ko *et al*., 2020) around the world to indicate the river's ecological status. Over the years, macroinvertebrates have been widely used as biological indicators (Koehnken *et al*., 2020) as they are better established in lotic systems.

The structure of the benthic communities in an aquatic ecosystem reflects its ecological conditions, including habitat heterogeneity and water quality(Burger *et al*., 2007). In addition to that, fish are also a typical biotic assemblage that is included in biological evaluations of streams due to their long lifespans and mobility. So, they are good indicators of temporal changes in habitat conditions. Fish assemblages typically include species that occupy different trophic levels, the trophic structure is reflective of overall stream quality. Fish are recreational and commercial value to humans, fish are relatively easy to collect and identify to species, and environmental requirements, life history, and distribution of fish are well known, and such data is usually easily obtainable (Barbour, 2001).

2.2.5. Total Dissolved Solids

The total concentration of dissolved materials in the water is referred to as total dissolved solids, or TDS, in a river. This includes organic and inorganic materials such as minerals, salts, and ions. The TDS in rivers can range from 100 to 20,000 mg/L and maybe even higher in groundwater. Seawater, for example, contains about 35,000 mg/L of TDS(Ali. *et al*., 2020). Increased anthropogenic activity, stagnation, and water concentration are typically the causes of the greater total dissolved solids values in natural waters, which degrade water quality(Manickam *et al*., 2014). Furthermore, TDS is caused by development and urbanization linked to surface obstruction caused by an increase in population, as well as contamination from rapid and uncontrollable environmental changes. These factors harm the sustainability of scarce water resources by causing extreme turbidity, accelerated eutrophication, and the growth of harmful blue-green algae, among other things(Adjovu *et al*., 2023).

2.2.6. Secchi Depth

Secchi depth is a measure of water transparency or clarity, determined by lowering a white disk into the water until it is no longer visible from the surface. The depth at which the secchi disk disappears is called the Secchi depth and is related to water turbidity(Solomon Wagaw *et al*., 2023). In the Ethiopian highland lakes, Secchi depth has been measured and found to vary widely, from 0.87 meters in Lake Tana to 12 meters in Lake Dendi. The higher Secchi depths are associated with lower phytoplankton biomass, indicating an inverse relationship between Secchi depth and algal abundance. Factors like lake morphology, catchment erosion, and internal lake processes can also impact Secchi depth(Bizuneh Woldeab *et al*.,2023). Secchi depth is an inexpensive and straightforward method to assess water clarity, though more advanced instruments can provide more detailed measurements. It has been used for over a century and remains a standard technique, as it provides an indicator of water quality and the impact of human activities on the surrounding land.

2.3.1. Macroinvertebrates

Aquatic macroinvertebrates are invertebrate organisms that are found in most rivers and streams and are large enough to see with the naked eye(Hauer and Resh, 2017). These are organisms that reside on or in the substrate at the bottom of a body of water(Alebachew Tadie, 2018). These animals often consist of mollusks, annelids, insects, crabs, and arachnids. They are reflected as good indicators of water quality(Basu *et al*., 2018)and are affected by physical, chemical, and biological conditions(Poikane *et al*., 2016). These organisms are extremely important in the food chain of aquatic environments as they are important players in the processing and cycling of nutrients and are major food sources for fish and other aquatic animals. They are a link in the transfer of material and energy from producers to top-level consumers and also act as excellent bioindicators of stream health(Qazi and Ashok, 2012).

The macroinvertebrates have been found as the most common faunal assemblages for bio assessment, and provide a more reliable assessment of long-term ecological changes in the quality of the aquatic system compared to its rapidly changing physicochemical characteristics(Lock, 1981). Moreover, macroinvertebrates can be used as indicators of water quality, serving as a very useful and relatively inexpensive tool widely used throughout the world(Sumudumali and Jayawardana, 2021).

They are one of the most important biomonitoring tools because they integrate various desirable characteristics, such as ubiquity, different levels of tolerance to perturbations, and sampling cost-effectiveness(Agboola *et al*., 2019;Ko *et al*., 2020). Also common in freshwater ecosystems and a good indicator of changes in environmental conditions that are favored by many ecological researchers(Urbanič *et al*., 2020).

Because they are easily sampled and are a very biodiversity group that may inhabit waters contaminated to different extents from clean to highly pollute. Various macroinvertebrate groups are good markers of human influences, particularly pollution. Most of them have quite narrow ecological requirements and are very useful as bioindicators in determining the characteristics of aquatic environments(Benettiand Garrido, 2010; Pérez-Bilbao and Garrido, 2009), to locate the sections of a dirty river where organic input self-purification is taking place. Well-developed water quality monitoring programs involve the measurement of physical, chemical, and biological parameters and provide valuable information on the impact of water quality on the benthic macroinvertebrates which respond differentially to biotic and abiotic factors in their environment and consequently, the structure of macroinvertebrate has long been used as bioindicators to assess the water quality of a water body(Reynoldson *et al*.,1989).

Diverse charges are used to measure ecosystem conditions, such as species density and the presence/absence of several species in assemblage structures(Hilty and Merenlender, 2000). For example, macroinvertebrates have proven to be useful bio-indicators to determine the integrity status of freshwater ecosystems, as their community consists of a broad range of species with different tolerances to water pollution(Liu *et al*., 2017). They are known to respond to more local-scale stressors, due mainly to their type of life history and their limited mobility(Maria *et al*., 2011). For these reasons, benthic macroinvertebrates are often the taxa of choice for biomonitoring in streams and rivers(Hellawell, 2012). Since they are good indicators of several anthropogenic pressures such as water pollution and geo-morphological alterations(Negishi *et al*.,2002).

Macrobenthic invertebrate species are differently sensitive to abiotic and biotic parameters in their environment. So they are used as bioindicators of the state and water quality of the aquatic environment(Soad and Abdel, 2019). Using macroinvertebrates as bioindicators in lakes, reservoirs, rivers, streams, and other bodies of water has the advantage that they can be seen with unaided eyes, retained by a 500µm pore diameter mesh sieve, have a long and are highly sensitive to heat pollution, organic pollution, substrate alteration, and toxic substances.

Because of their broad range of sensitivity to pollution and relative lifespan, they are also frequently utilized as markers of the integrity of aquatic ecosystems(Du *et al.*, 2021). In aquatic environments, both natural and artificial factors can affect the distribution of macroinvertebrate communities(Yu *et al.*, 2020). Also, the composition and stabilization of the substrate adjust the distribution and abundance of benthic macroinvertebrates at local or large scales(Foster *et al.*, 2020).

Fishes are probably the best-known inhabitants of lotic systems. A species of fish's capacity to survive in moving waters is based on how quickly and how long it can swim at that speed. Different species have varying degrees of this ability, which is dependent on the type of habitat they can live in. Fish only spend brief amounts of time in the full current because swimming continuously uses a significant amount of energy. Instead, individuals remain close to the bottom of the banks, behind obstacles, and sheltered from the current, swimming in the current only to feed or change locations (Angelier and Minnick, 2019). Certain animals have evolved to only exist on the system's bottom and never go to open water. These fishes are dorsal-ventrally flattened to reduce flow resistance and often have eyes on top of their heads to observe what is happening above them. Some also have sensory barrels positioned under the head to assist in the testing of the bedrock(Brown *et al.*, 1987).

Lotic systems typically connect, forming a path to the ocean (spring → stream → river → ocean), and many fishes have life cycles that require stages in both fresh and salt water. Salmon, for example, are Anadromous species that are born in freshwater but spend most of their adult life in the ocean, returning to freshwater only to spawn. Eels are catadromous species that do the opposite, living in freshwater as adults but migrating to the ocean to spawn(Giller and Giller, 1998). Fish constitute a large portion of the biodiversity of aquatic ecosystems, and consequently, play significant roles in maintaining the aquatic ecosystem services which benefit the human communities(Arthington *et al.*, 2016). The fish communities of the river systems are rich and diverse forming an important resource that serves as a basis for fisheries and human food. Unfortunately, fish in rivers remain relatively poorly studied as compared with equivalent populations in lakes and reservoirs(Welcome, 2015).

2.4. Fish Assemblage in Water Bodies

The spatial distribution of fish assemblages on a river is influenced by the heterogeneity of environmental physiography, the behavioral characteristics of the intra and inter-specific interactions, and environmental sustainable conditions(Dray *et al*., 2012). The limnological and structural characteristics of habitat are considered the main ones responsible for differences in the structure of the fish assemblages in the diverse types of environments in the same aquatic ecosystem or biogeographically region(Kovalenko *et al*., 2012). The key determinants of current dynamics in river systems and the generation of habitat heterogeneity along rivers' longitudinal gradients are elevation, slope, and rain regimes(Winemiller *et al*,2008; Esselman and Allan,2011). Likewise, many of these geomorphological characteristics of the basin are also influencing water physicochemical factors, such: as dissolved oxygen, pH, temperature, salinity, and conductivity, which can affect fish communities(Wootton, 2012).

Moreover, landscape factors such as the watershed area or land-use activities can be strongly correlated with the composition, structure, and distribution of species(Junqueira *et al*., 2016). Land use, such as urbanization and agriculture, strongly influences this linkage and changes flow regimes, temperature, water chemistry, and substrate type(Hughes *et al*., 2014). As a result, they cause many environmental changes such as physical habitat loss, sedimentation, bank erosion, bed destabilization, contaminant loadings, canopy opening, and nutrient enrichment(Allan, 2004). Additionally, changes in land use have an impact on catchment conditions, which in turn alter local habitat conditions either directly or indirectly(Macedo *et al*., 2014). Local habitat conditions are a fundamental factor in determining the structure and composition of stream biota(Brown *et al*., 2009). For instance, site channel structure and hydraulic factors, such as substrate, canopy shade, fish cover, depth fluctuation, and slope, have a significant impact on fish assemblages(Wang *et al*.,2006).

2.5. Bioindicators-Based River Water Quality Assessment

Freshwater ecosystems support 6–10% of all species and are more at risk of ecological degradation than any other ecosystem on the planet(Dudgeon *et al*., 2006; Vörösmarty *et al*., 2010). Freshwater (which constitutes 2.5 % of the global water) is a scarce commodity due to increased pollutants from either point or non-point sources(Ipinmoroti *et al*., 2018). Pollutants affect the physical, chemical, and microbial quality of water making it unhealthy for use by fish, livestock, and other organisms(Rodrigues and Cunha, 2017). The worldwide focus of river health management is the preservation of water quality and quantity. In an attempt to assess river health, enormous efforts are being taken to monitor different types of biological indicators and water quality stressors that produce complex data that as such have limited information to achieve good ecological outcomes(Goonan *et al*., 2012; Harris, and Heathwaite, 2012).

Organisms that have certain traits utilized as indices or qualities, such as presence or absence, population density, dispersion, and reproductive success, are known as bioindicators(Birk *et al*., 2012). They are used for the biological assessment of water bodies. Biological assessment is the evaluation of the ecosystem condition that is grounded on surveys of the structural and functional organization of the local biota(Bork, 2017). It is now recognized as one of the most valuable tools available for water resource managers. This is mainly due to its contribution to the understanding of species' environmental relationship. It is thought that aquatic species are useful indicators of the state of freshwater ecosystems(Linfei *et al*., 2020).

In Ethiopia, various reports are available on the use of benthic macroinvertebrates as a potential indicator of water quality(Baye Sitotaw,2006; Solomon Akalu, 2006; Admasu Tassew, 2007; Abebe *et al*. 2009; Amanuel Aklilu, 2011; Assefa and Ayalew, 2014; Aschalew Lakew, 2015). In addition to physical chemistry, biological organism monitoring of aquatic ecosystems is making good progress in both tropical and temperate locations these days reported by Assefa Workiye *et al*. (2020)because of their relatively short lifespans and their differences in tolerance to pollutants and other aspects of water quality, they are a preferred choice in river ecological health studies(Mohammad Anwar *et al*., 2020). Because ecological indicators are used to evaluate the degree of degradation, the level of contact with the stressors, and the intensity of ecological responses to the exposure(Hunsaker *et al.*, 1990; Suter, 2016).

An effective and cheap technique for assessing the ecological health of Ethiopia's freshwater bodies is necessary due to the growing influence of human activity on these bodies of water(Workiye Worie *et al*., 1970). For example, benthic macroinvertebrate-based bio-monitoring studies conducted in many streams and rivers of Ethiopia established their potential use for water quality and ecological health assessments(Harrison and Hynes, 1988; Solomon Akalu, 2011; Getachew Beneberu *et al*., 2014; Solomon Akalu, 2018; Amare Mezgebu and Aschalew Lakew, 2019). Because benthic macroinvertebrates often stay at specific locations within rivers and streams throughout most of their life cycles. Unlike nekton, macro-invertebrates are easy to collect and identify. These features make macroinvertebrates among the cheapest and most rapid monitoring(Aschalew and Otto, 2015).

Following the Act of the Federal Water Pollution Control Act Amendments of 1972, the U.S. EPA has long employed biological indicators in ecological evaluations of surface water quality. In 1991, the U.S. EPA issued a policy statement regarding the Use of Biological Assessments and Criteria in the Water Quality program(Young *et al.,* 2014). As an example, many nations have long used macroinvertebrates to monitor the ecological health of river ecosystems(Hellawell,2012). However, many countries have protocols on how to use macroinvertebrates to monitor the ecological status of river ecosystems. Bio assessments in the USA and Europe are a mandatory tool for water resources management and are thus supported by strong legislation of the Clean Water Act and Water Framework Directive US EPA(US Environmental Protection Agency, 2013).

Key players in the aquatic food webs that connect higher trophic levels with organic matter and nutritional items(such as leaf litter, algae, and detritus) are benthic macroinvertebrates. Due to their primarily sedentary lifestyles, these species are reflective of ecological conditions particular to a given place. The use of macroinvertebrates as bioindicators for freshwater quality has a lengthy history(De Pauw *et al.,* 2006). In addition, fish are useful organisms for measuring environmental degradation for many reasons: one, fish are sensitive to a wide array of direct stresses. Second, fish integrate the adverse effect of complex adverted stresses on other components of the aquatic ecosystem, such as habitats and macroinvertebrates, the virtue of their dependence on that component for reproduction, survival, and growth(Karr, 1981). Third, because fish are relatively long-lived, their population shows the effect of reproductive failure and mortality in the many age classes.

2.5.1. Fish as a bio-monitoring organism

Fish have been widely documented as useful indicators of environmental water quality because of their differential sensitivity to pollution(Okwuosa *et al*.,2019; Zawadi *et al*.,2020).Their assemblages are important biological indicators for the assessment of the aquatic ecosystem (Zogaris *et al*.,2023). Having a systematic understanding of fish physiology, ecological requirements, and taxonomy is essential to using fish as indicators. As numerous researchers have noted over the years, fish(like tilapia, Oreochromis mossambicus) are known to be helpful and reliable indicators of long-term effects and broad habitat conditions when tracking long-term changes of a specific water body, such as a river system(Benejam Vidal,2008). Tilapia is the common name for around 70 species of perch-like fishes(family Cichilidae) native to the fresh waters of tropical Africa(Bhassu *et al*., 2004).

Fish communities are a key element in fluvial ecosystems, their position at the top of the food chain and their sensitivity to a whole range of impacts make them serve as a reliable assessment of biological integrity and a defined goal for ecosystem conservation(Alonso *et al*.,2011). They are among the main target groups when conducting biomonitoring and ecological assessments of aquatic environments(Meng *et al*., 2023). Their assemblages are considered to be a highly suitable metric for assessing river health(Karr, 1981). They have many advantages as biological-integrity indicators of a watershed system(Plafkin, 1989). Because of their multiyear life spans and mobility, most fish species are good indicators of long-term effects and larger-scale habitat conditions. In addition Mamun *et al*.(2019) supposed that fish are important aquatic organisms in the aquatic ecosystem, with long life cycles, a wide distribution, obvious morphological characteristics, easy identification, and strong activity abilities. They can survive in most aquatic ecosystems, and they can broadly reflect the information based on environmental changes in the an aquatic ecosystem.

Fish communities include a range of species and trophic levels, which can reflect a relative degree of environmental disturbance. Some species of fish are very sensitive to changes in water chemistry, such as pH or dissolved oxygen, which may be caused by pollutants, tidal flow, natural change, or other factors. It is widely known that long-term exposure to environmental stressors such as pollution or low oxygen causes detrimental effects on important fish features such as metabolism, growth, resistance to diseases, reproductive potential, health, condition, and survival of fish(Baron*etal*., 2002). Nevertheless, using fish as a bioindicator has some weaknesses, including the point that fish are highly mobile, making sampling difficult. To record daily and seasonal fluctuations, large groups of personnel, various tools, and an extended period in the field are required(Figueroa *et al*., 2003). Likewise, the selective character of sampling gear is necessary, mostly for big sampling operations.

CHAPTER 3: MATERIALS AND METHODS

3.1. Description of the Study Area

The study area, Zarima River, is located at 13°20'28"N latitude, and 37°52'44"E longitude, in Zarima Kebele, Addiarakay Woreda, North Gondar Zone, Amhara Regional State, Ethiopia. It is found 916 km away from Addis Ababa, and 142 km and 40 km away from Gondar and Debark towns, respectively. Zarima River originating from the hills of Semen mountain National Park in about 3200 m.a.s.l topography flows to meet the Tekeze River in about 780 m.a.sl, stretching about 115 km distance. Zarima River is one of the largest perennial rivers flowing into the Tekeze River and has several stream rivers such as Aenbera, Maynebera, Maytira, Mengero, and Dekiko. The study catchment area covers 318 km square(Figure.1).

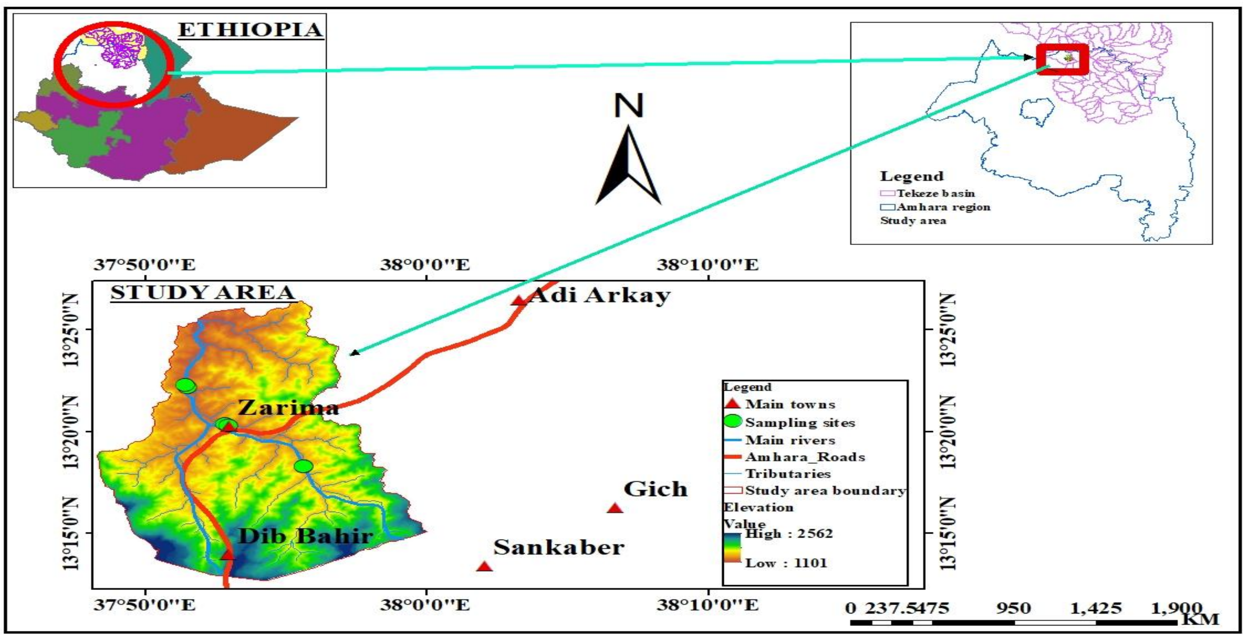

Figure 1: Map of the study area and sampling sites

Climate

According to Conway (2000), the local climate classification in Ethiopia is based on elevation and temperature. In other words, depending on elevation for any area there is an associated mean annual temperature range. This enables identifying the traditional climate zone of a given area. The three traditional climate zones of Ethiopia are Kola (elevation less than 1800 m a.s.l and mean annual temperature 20-28 ^{o}C), Woina Dega (elevation between 1800 m and 2400 m a.s.l and mean annual temperature16-20 ^{o}C), and Dega (elevation between greater than 2400m a.s.l and mean annual temperature 6-16 ^{o}C). Based on the above local climate classification the climate zone of the study area is Kola (elevation is less than 1800m a. s.l).

Flora and Fauna

The sampling sites for this study were covered by non-woody vegetation (such as grass, many shrubs such as: -Kutikato, Agame*(Carissa spinarum)*, Girar(*Acacia*), Mesnko Bariya Atate (*Maytenus arbutifolia)*, Zana, et,c), and woody trees like "Warka"(*Ficus sycomorus)*, Meker, Gaba, Wanza, Dokma(*Syzygiu guineense)*, Kirekra, Shola *(Ficus)*, Tertera, Tekur Zafe and Awuma. The commonly observed bird species in Zarima River include cattle egret(*Bubulcus ibis*), great white pelican(*Pelecanus onocrotalus*), crocodile, snake, African fish eagle(*Haliacetus vocifer*), and Egyptian goose(*Alopochen aegytiaca*).

3.2. Study Design and Sample Site Selection

A preliminary survey was conducted in March 2023, five days before the actual data collection to gather general information on the physical characteristics of the Zarima River, such as topography, watershed features, land use types, accessibility of sampling sites, and human pressure. A cross sectional study design was used to select sampling sites. Sampling sites were selected by considering the nature and velocity of the flowing river, accessibility, interference by human beings and other farm animals, substrate type of the sediments, and suitability for setting gillnets. A Geographic Positioning System(GPS)was used to record the altitude and longitude coordinates of sampling sites.

Table 1**.** GPS coordinates of sampling sites in the Zarima River.

Sampling site	Cod	Coordination	
		Latitude	Longitude
Melay Gotie Foot Road Above	CHB-1	13.30482°	37.927408°
Melay Gotie Foot Road Below	CHB-2	13.30491°	37.92745°
Behind Zarima Town(Tabiya Bahir)	TB	13.33813°	37.882914°
Above Zarima Bridge	AZA-B	13.3398°	37.880807°
Above Felka Bridge	AF-B	13.37017°	37.858679°
Below Felka Bridge	BF-B	13.3722°	37.927408°

Sampling stations were classified following the rapid bio-assessment protocol criteria based on major stressors around the river(Barbour, 1999). Sampling sites were grouped into three categories: - Chewuberr sites(S1 and S2) located at the head of the Zarima River and is surrounded by Agriculture activity (local people Cultivated deferent crops in the nearby area).Also used it for washing their clothes and for swim. Zarima Town sites (S3 and S4) characterized by grazing on the left side and the right side covered by vegetation. Fisheries are dominant practices on the site. The Zarima Town waste disposal discharge into these sites. The site was polluted rather than other sampling sites. The cause of domestic waste, urban waste, and irrigation practices. Felka sites(S5 and S6) bounded by a few big trees and agricultural practices. Sometimes fishing activities are practiced and used for cattle drinking. Six sampling points were sampled in two sampling periods, spanning from the upstream at Chewuberr Kebele (S1) to the downstream at Felka Kebele (S6).

3.3. Methods of Data Collection and Sampling Techniques

Physicochemical Parameters

Physico-chemical parameters samples were collected on sites along the river twice a month during the dry and wet seasons. The parameters were measured in the morning before starting fish and macroinvertebrates collection to avoid the effect of diurnal variations and the water disturbance effects. The measurement was taken within 10 m intervals in each sampling point with three replications. The physicochemical parameters such as water temperature , pH , conductivity, water transparency, oxygen content were measured using in situ multi parameter probe(model HQ40d HACH Company) were measured in all sampling sites , depth, width and length(using meter).

Macroinvertebrate sampling

Macroinvertebrates were collected to provide a quantitative description of the community composition at each sampling site. They were sampled using a D-shaped sweep-net specified by the International Standards Organization(ISO); with a mesh size of 500 µm. As noted by Getachew and Seyoum, (2010), sampling was done first started downstream and then upstream to ensure the minimum disturbance during the sampling process. In each sampling reach, a total of 5 minute sampling effort was employed to collect samples from all available habitats across a 10-meter stretch(Gabriels *et al*., 2010). The samples of all members of a group in one site were composited in a single bottle and preserved with 4% formalin with a label identifying the

Sampling ID, date, and collector name and were sorted from the detritus and transported to the Bahir Dar University fishery, limnology and water quality laboratory.

Laboratory Analysis and Identification of Macro-invertebrates

The preserved macro-invertebrate samples were processed in the laboratory for further analysis. All information from the sample container was carefully copied to the sample log sheet. A complete sample was passed through a set of sieves(1000 and 500 µm mesh size) in order to remove formalin and separate size classes of macro-invertebrate groups under tap water. After, that the samples were transferred to a white enamel or plastic tray and a one sample was randomly placed in a petri dish while organisms trapped in the smaller fraction of the sieve was sorted with the help of dissecting microscope and identified at the family level by used the aquatic invertebrates of South Africa aquatic invertebrates identification key(Gerber and Gabriel, 2002). All macroinvertebrates were identified to family level at Bahir Dar University limnology and water quality laboratory. Finally placed in vials containing 70% ethyl alcohol for future use.

Fish Sampling Methods and Fish Identification

Fish samples were collected in both dry(March 2023) and wet season(July 2023). Each site was sampled twice (one time in the dry season and one time in the wet season). Samples were collected using gillnets of various mesh sizes(6, 8, and 10 cm stretched mesh)by setting the net at the deeper part of the river and monofilament nets with various stretched mesh sizes(4 and 6cm). The nets were set at all sampling stations during the sampling period with the help of local fishermen. Gillnets and monofilaments were set during the daytime for three hours across the width of the river during the dry sampling period. Monofilaments were used to sample small-sized fish species. Then, the total length, fork length, and weight of all specimens of fish were measured on site using a measuring board and a sensitive balance respectively. Photo of fish specimens was taken for each species. On the field, fish species were identified an experienced technical in fish identification from the Bahir Dar Fishery and other aquatic research center. After taking the necessary information, all specimens except a few for further identification were released back into their habitats. To avoid the chance of recapturing the collected samples were retained in a container until assessing the nearby sampling areas. Not readily identified are preserved in 10% formalin for later identification in the laboratory, (Song *et al.*, 2015).The individual specimen was preserved with 10% formalin put in a plastic jar and transported to the laboratory of Bahir Dar Fisheries and other Aquatic Life Research Center for further identification and to serve as a reference specimen. The fishes were identified at the species level using keys developed by Abebe Getahun(2017).

Laboratory studies

Specimens were soaked in tap water for one day to wash the formalin from the specimens and then specimens were identified to species level using taxonomic keys developed by Abebe Getahun(2017). Additional the specimens were also compared with previously identified specimens, especially *Labeobarbus* species, available at Bahir Dar Fish and Other Aquatic Life Research Center.

3.4. Data Analysis

The collected data were organized in Microsoft Office Excel 2013. SPSS version 20 software was used to compute descriptive statistics of the physicochemical parameters. Descriptive statistics were used to describe variables based on their numeric counts, percentages, means, and standard errors. One-way ANOVA and independent t-test were used to evaluate the difference in physicochemical data among the sampling site and the sampling seasons. Canonical correspondence analysis was used to describe the relationships between aquatic environmental factors and the structures of the biological Community, by using canoco version 4.5 The species diversity and relative abundance of fishes were assessed using the Shannon diversity index (H') and the Index of Relative Importance(IRI), respectively.

IRI is a measure of the relative abundance or commonness of the species based on the number and weight of individuals in catches, as well as their frequency of occurrence(Kolding, 1989). Also, the relationship between the total length and total weight of the most dominant fish species was computed using the power function(TW= an X TL^b) as in(Bagenal,1978).

The Shannon index of diversity(H'): H’ is calculated as follows:

$$H' = -\sum_{i=1}^{s} pi * Lnpi \ldots\ldots \text{(Eq-1)}$$

The Shannon index was used to indicate the diversity of fishes at different sampling sites.

Where, "H"= the Shannon- Weiner Diversity Index

S = total number of species

Pi = pi - the proportion of species i = in/N = (number of individuals i/number of individuals of all species). Or

Pi = S / N

S = number of individuals of one species; N = total number of all individuals in the sample

Ln = natural logarithm.

Shannon(1949) stated that the index value above 3 indicates that the structure of the habitat is stable and balanced; values below 1 indicate that there is pollution and degradation of habitat structure. Shannon(1949)states the diversity index value, H‟ ≤ 1 = Low diversity, 1 < H‟≤ 3 = Moderate diversity, and H ‟≥ 3 = high diversity.

The other formula used was Shannon's equitability (E), or evenness which can be calculated from the ratio of observed diversity using the equation(Pielou, 1966).

E=H/Hmax or i / LnS……………………………………………………………………. (Eq-2)

Where,

S = Number of species recorded

i = Shannon's Diversity Index

Simpson's Dominance Index (D)

Simpson's Dominance Index is a measure of diversity that takes into account the number of species present, as well as the relative abundance of each species. As species richness and evenness increase, so does diversity increases. The value of D ranges between 0 and 1, 0 representing infinite diversity and 1 representing no diversity, so the larger the value of D, the lower the diversity. For this reason, Simpson's index of diversity is often as its complement(1-D).

Diversity within the benthic macro-invertebrate and fish community was described using Simpson's diversity index ("D") (Margalef's, 1958) which was calculated as:-

Simpson's dominance index, D = n (n -1)/N (N-1)…………………………………………. (Eq-3)

Simpson's index of diversity, 1-D = 1- n (n-1)/N (N- 1) ……………………….................. (Eq-4)

Where,

n = number of individuals of each species in the sample;

N= total number of individuals of all species in the sample

Margalef's richness index, d= S- 1 / In N………………………………………………… (Eq-5)

S= total number of species, N = total number of individuals.

Relative abundance an Index of Relative Importance" IRI(Kolding, 1989) was used to find the most important species in terms of number, weight, and frequency of occurrence in catches from the different sampling sites. IRI gives a better representation of the ecological importance of species rather than the weight, number, or frequency of occurrence alone.

An Index of relative importance (% IRI) was calculated as:

$$\%IRI = \frac{(\mathrm{Wi}+\%\mathrm{Ni})*\%\mathrm{Fi}}{\sum_{\mathrm{j}-1}^{\mathrm{s}}(\%\mathrm{Wj}+\%\mathrm{Nj})*\%\mathrm{Fj}} * 100 \qquad \text{(Eq-6)}$$

Where *%Wi*= percentage weight of each fish species in total catch

%Ni = percentage number of each fish species in total catch

%Fi = percentage frequency of occurrence of each species in the total number of settings

%Wj= percentage weight of total species of the total catch

%Nj= percentage number of total species of the total catch

%Fj= percentage frequency of occurrence of total species in the total number of settings

Length-weight relationship

The relationship between the total length and total weight of the most dominant fish species was computed using the power function as in Bagenal and Tesch (1978) as follows:

TW= an X TL^{b}……………………………………………………………………………….. (Eq-7)

Where

TW= Total weight (gm.)

TL= Total length (cm)

a = Intercept of the regression line and b = Slope of the regression line

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Diversity and Distribution of Macroinvertebrates in Zarima River

4.1.1. Composition and abundance of macroinvertebrates in Zarima River

A total of 292 individual macroinvertebrates were collect during the study period. This belonging to five orders of class insecta namely Ephemenoptra, Diptera, Coleoptera, Odonata, and Hemiptera, and one order of non-insect classes(Gastropoda), under 12 families were collected during the study period presented in Table 3. Fluctuations were observed in the total number of macro-invertebrates collected from each sampling station. At every study site station in the dry season(March)the greatest number of macro-invertebrates was recorded(Table 2). The distribution reflected changes in the water quality along the river as stream conditions are known to influence macroinvertebrate distribution(Mengistu Asmamaw *et al*., 2021).The numbers of families recorded at Site CHB-1, Site CHB-2, Site TB, Site AZA-B, site AF-B and site BF-B were 5, 7, 2, 3, 6, and 4 respectively. Site TB and AZA-B showed lower taxa richness, because, several human induced associated impact problems like the irrigation activity above this sites, and waste disposal from the nearby Zarima Town of the river at the study sites. This result line with the study conducted by(Gurmessa Tessema and Agumassie Tesfahun ,2018)in Teltele stream, Ambo West Showa, Ethiopia. However, the higher macroinvertebrate taxa richness was record at sites 1 and 2 could be a combination of better water quality, diverse and complex habitats, reduced human impact, optimal nutrient availability, and favorable flow regimes.

In the current study, the macro-invertebrate communities' composition was high when compared to other similar findings; 6 orders and 11 families reported by(Gurmessa Tessema and Agumassie Tesfahun ,2018)in Teltele stream, Ambo West Showa, Ethiopia. However, the present study's result indicated fewer orders and families as compared to the previous investigations. Merkebu Demssie(2017)reported 11 orders and 36 families in Sutana River,Injibara,North Western Ethiopia, while Ferengi Beksisa *et al*.(2017)and (Sisay Misganaw *et al*., 2017)which both reported 10 orders and 37 families in the upper Awash River, and 9 orders and 34 families in Wedecha River, Debrezeit, Ethiopia respectively. Sisay Misganaw (2018)reported 37 families in River Shinta, Gondar, Ethiopia, while Mengstu Asmamaw *et al*. (2021)14 orders, and 75 families in Dinki watershed, central highlands of Ethiopia. Abrehet Kahsay (2022)reported 36 families in Enfranz River and(Yadesa, Seyoum, and Demeke, 2022) reported 7 orders and 23 taxa in Ketar River, Ethiopia.

This could be several reasons including:- differences in sampling methods and effort, habitat heterogeneity, water quality, Seasonal variations, and geographical differences(Kathryn *et al*., 2023)can contribute to the observed variations in macroinvertebrate diversity between studies. Macroinvertebrate abundance of individual taxa in the sample varied, with 15 individuals(5.14%) recorded at the S6 site, and 78 individuals(26.71%) at the AZA-B site, which had the highest abundance. Among the macro-invertebrates the Gomphidae(Club-Tail Dragonflies)was the predominant taxon that contributed the largest percentage with 197 individuals(67.47%) across all sampling sites. This was followed by Gerridae(Hemiptera)(Water or True Bugs)with 36 individuals(12.33%), Dyfiscidae(Coleoptera-Beetles)with 28 individuals(9.58%), and Chironomidea(Diptera-Two-winged or "True flies")with 11 individuals(3.77%). Other families each had fewer than 10 individuals. Gomphidae was found common in all sampling sites(Table 3).

In the present study, the macroinvertebrate composition at study sites was dominated by Odonata, followed by Coleoptera and Hemiptera, which indicates good water quality, diverse habitats, sufficient dissolved oxygen, and a balanced aquatic ecosystem. High Odonata percentages, in particular, are a positive indicator of the ecological health of the river and the moderate water quality of the river. This suggests that the study sites were in relatively good ecological condition. Generally, the absence of Plecoptera in any of the sites is due to the environmental quality, habitat suitability, seasonality, and sampling method. For example, Plecoptera has specific habitat requirements, including clean, well-oxygenated water and suitable substrate for egg-laying and nymph development. Macroinvertebrates' absence from a particular site is considered an alarming sign which leads to the indication of pollutants in that area (Karim *et al*., 2024). Overall, the absence of Plecoptera in the study sites could provide valuable insights into the environmental conditions and ecological dynamics of those locations. It may require further investigation into the factors influencing their absence.

Table 2. Taxa identified from the six sampling sites of Zarima River during the study period (present +, and Absent -).

Site code	Order	Family	Dry	Wet
CHB-1	Hemiptra	*Gerridae*	+	-
	Odonata	*Gomphidae*	+	+
	Coleoptera	*Dyfiscidae*	+	-
	Dipteria	*Psychodidae*	+	-
		Tabanidae	+	-
CHB-2	Coleoptera	*Dyfiscidae*	+	-
		Elmidae	+	-
TB	Odonata	Gomphidae	+	+
	Coleoptera	*Dyfiscidae*	+	-
AZA-B	Odonata	*Gomphidae*	+	+
	Coleoptera	*Dyfiscidae*	+	-
	Mollusca	*Planorbidae*	+	+
AF-B	Coleoptera	*Dyfiscidae*	+	-
		Notonectidae	+	-
	Odonata	Gomphidae	+	-
	Dipteria	Chironomidea	+	+
BF-B	Dipteria	Chironomidea	+	+
		Psychodidae	+	-
	Ephemenoptra	Baetidae	+	-

Table 3. Composition and relative abundance of benthic macroinvertebrates encountered in River Zarima during dry and wet seasons.

Taxon	Site						
	CHB-1 No.	CHB-2 No.	TB No.	AZA-B No.	AF-B No.	BF-B No.	Total No.
Coleoptera (Beetles)							
Dyfiscidae (Predaceous Diving Beetles)	8	1	5	12	2	0	28
Elmidae (Rife Beetles)	0	1	0	0	0	0	1
Notonecefidae	0	0	0	0	1	0	1
Ephemeroptera (Mayflies)							
Baetidae(Small Minnow Mayflies)	0	0	0	0	1	0	1
Diptera (Two winged or "True Flies")							
Chironomidea(Blood-red, including pink)	0	2	0	0	3	6	11
Psychodidae (Moth Flies)	2	1	0	0	0	1	4
Tipulidae	0	1	0	0	0	0	1
Tabanidae (Horse Flies, Deer Flies)	2	0	0	0	0	0	2
Hemiptera (Water or True Bugs)							
Gerridae (Water Striders)	36	0	0	0	0	0	36
Mollusca (Snails)							
Planorbidae	0	2	0	2	5	0	9
Odonata (Damselflies and Dragonflies)							
Gomphidae (Club-Tail Dragonflies)	15	20	60	64	31	7	197
Total number of taxa	5	7	2	3	6	4	12
Total abundance	63	28	65	78	43	15	292
Percentage (%)	21.58	9.58	22.26	26.71	14.73	5.14	100

4.1.2. Macroinvertebrate diversity indices

The diversity indices of macroinvertebrates in different sites of the Zarima River are present in Table 4. Simpson's dominance index(D) shows a higher value in the TB(0.82), but low in down the River(0.48)at BF-B. That was, the bigger the value of D, the lower the diversity. So the TB site had lower diversity than other sampling sites due to the presence of urban waste disposal around the sampling site and the unavailability of suitable biotopes for macroinvertebrates(Kekana *et al*., 2023). However, the value of Simpson's index of diversity(B) for the sampling site of the TB(0.18) was low. Assessments between the study sites showed a variation in Shannon diversity indices(H'). The lowest value(0.33) of the Shannon–Weaver species diversity index(H′) was recorded at the TB of the sampling site by the cause of several human-induced associated impact problems, the waste material disposal, and the urban waste discharge into sampling site caused the abundance, and diversity of macroinvertebrates to be low in this sampling site. On the other hand, high values were recorded at the site CHB-1 and CHB-2 river upper streams.

The higher H' values at CHB-1 and CHB-2 compared to the other sites, suggests that the upstream region has greater species diversity and a more balanced distribution of species. This could be due to factors such as lower levels of pollution or disturbance in the upstream region, the presence of more diverse habitats and microhabitats, better water quality, and the availability of resources to support a wider range of species. Higher Shannon indices indicate less stress in ecosystems, higher abundance, and a more even distribution of species in the ecosystem. In the present study, the diversity and abundance of benthic macroinvertebrates were observed to be the highest in the least impacted river, whereas they declined with increasing impacts of waste site. This implied that macroinvertebrates have different ecological requirements and exhibit different degrees of tolerance to various anthropogenic impacts. The evenness index values were below 1, which is indicative of increasing stress in the river system(Kekana *et al*., 2023).

According to Margalef, (1956) the higher diversity values reflect the suitability of habitat for the organism on one hand while on the other the high species diversity has been reported to be correlated with a longer food chain and complex food web of the ecosystems and also more stable community. The larger the index value it indicates the more healthy the body of water.

In the present study, the upstream sampling sites CHB-1 and CHB-2 had higher Margalef's index values of 4.75 and 6.70 respectively, which indicate that they had greater species richness and overall healthier river water conditions compared to the other sampling sites(TB, AZA-B, AF-B, BF-B) which have lower index values ranging from 1.74 to 2.7.

The higher index at CHB-2 suggests it has the most diverse and healthy river ecosystem among the sites examined. Generally, low macroinvertebrate diversity was observed in the river subdivision with overall water degradation and anthropogenic disturbance. Thus, man-made activities may have caused changes in the physicochemical parameters which led to the depletion of benthic macroinvertebrate biota in the Zarima River. This result line with the study conducted by Mekonen Teferi *et al*. (2012)in a highland stream, in Northern Ethiopia.

Table 4. Macroinvertebrate diversity indices from different sampling sites of the Zarima River during the study period.

	Sampling Site					
Indices Parameters	CHB-1	CHB-2	TB	AZA-B	AF-B	BF- B
Shannon-weaver index (H’)	1.02	1.09	0.33	0.65	0.80	0.80
Pielo’s evenness index (J’)	0.20	0.56	0.47	0.59	0.73	0.72
Simpson’s dominance index (D)	0.49	0.51	0.82	0.61	0.49	0.48
Simpson’s diversity index (B)	0.51	0.49	0.18	0.39	0.51	0.52
Margalef’s richens index(R)	4.75	6.70	1.74	2.7	2.57	2.49

4.2. Fish Species Diversity and Distribution

A total of eleven fish species representing four families were identified from Zarima Rivers during the study period(Table 5). These were *Labeobarbus intermedius, Gara dembecha, Labeobarbus nedgia, Labeo forskalii, Labeo horie, Labeobarbus beso, Garra spp, Raiamas loati, Coptodon rendalli, Clarias gariepinus* and *Oreochromis niloticus*. The Cyprinidae were the most dominant families. The freshwater fish fauna of Ethiopia contains a mixture of Nilo Sudanic, East African, and Endemic forms. The Nilo-Sudanic forms are the dominant forms in terms of diversity and are represented by a large number of species found in the Baro-Akobo, Omo-Gibe, Tekeze, and Abay drainage basins(Tadlo Aweke, 2015). The freshwater fish fauna of Zarima River contains a mixture of highland East African(e.g., *L. intermedius*, *C. gariepinus and O. niloticus*). This result line with the study conducted byYibeletal Aynalem *et al*. (2018) in Gilgel Abay and Andassa Rivers. In addition, it contains a mixture of Nilo Sudanic(e.g. *L. forskalii*). *Clarias gariepinus*, which was present in the wet season and *Raiamus loati* that was present in the dry season(Table 5).

Table 5**.** Fish species distribution in the dry and wet seasons in Zarima Rivers {Present (+), Absent (-)}

Fish Species	**Family**	**Dry**	**Wet**
Clarias gariepinus	Clariidae	-	+
Garra dembecha	Cyprinidae	+	+
Labeobarbus intermedius	Cyprinidae	+	+
Labeobarbus beso	Cyprinidae	+	+
Garra spp	Cyprinidae	+	+
Labeobarbus nedgia	Cyprinidae	+	+
Raiamas loati	Cyprinidae	-	+
Oreochromis niloticus	Cichilidae	+	+
Coptodon rendalii	Cichilidae	+	+
Labeo horie	Cyprinidae	+	+
Labeo forskalii	Cyprinidae	+	_

The fish species composition of the Zarima River was high diverse than those reported from some other freshwater rivers of Ethiopia. For instance, Genanaw Tesfaye (2006), who reported 10 species in the Sanja and Angereb Rivers, while Taju Mohammed (2014), who reported 9 species from Gilgel Gibe and Gojeb Rivers, Omo-Turkana Basin, Southwest Ethiopia. Dereje Tewabe *et al*.(2016)reported 7 species in Wonchit River, while AssefaTessema and Adem Mohamed, 2016 reported 10 species in Gerado, and Drima Rivers. Simagegnew Melaku *et al*. (2017)reported 8 species from Geba and Sor Rivers and Baro-Akobo Basin ,while Tadlo Awoke (2019) reported 8 fish species in the upper part of the Blue Nile River below the fall. Assefa Tessema(2024)reported 6 species from Terie River, Beshilo Basin, Ethiopia. However, the fish species composition in Zarima River during the study period was low as compared to results obtained by Moges Beletew (2007)reported 17 species from Beshilo, Dura, and Ardi Rivers, While Mohammed Omer (2010),who reported17 species from the head of Blue Nile River(Lake Tana to Tisisat fall). Dereje Tewabe *et al*. (2016)reported 12 from Jemma River, while Yibeletal Aynalem *et al*. (2018)reported 13 species from Gilgel Abay and Andassa Rivers, Baro Akobo Basin, Gambella region. Abebe Getahun (2020)reported 23 from Beles and Gilgel Beles Rivers.

The lower fish species diversity in the present study might be due to the length of the sampling periods (this investigation was carried out in two seasons over a relatively short period while others studied over a long period), the efficiency and types of gears used, and the effect of Chemicals (especially Bonbe", Berbra" and Sharia)used for fishing by fishermen(personal communications). The second reason for the less fish diversity reported now might be the effect of flow variability on fish assemblage. For instance, sometimes large floods might wash fish eggs that have already been placed and damage fish habitat. The maximum number of fish species in the study was recorded during the dry season shown in Figure 2. This was because of water depth reduction to the minimum level due to insufficient rainfall during the study period(starting of the dry season), allowing fishermen to apply their fishing gear more effectively due to habitats suitable for gill net sampling during the dry season(Abebe Getahun *et al*., 2020b).Conversely, the low fish was recorded during the wet season due to several factors: including high turbidity, rapid runoff, and lower temperatures. Additionally, the higher water discharge during the wet season causes fish to disperse more widely in the larger volume of water making them more difficult to catch(Kolding, 1989). The variation in fish catches between wet and dry seasons may also be influenced by the efficiency and timing of the gill net setting.

During the wet season, the efficiency of gill nets can be reduced due to debris such as logs, leaves, and roots brought by flooding. In general, there are a number of explanations for the differences in abundance between the rainy and dry seasons. Among other things, variations in temperature, fishing effort, fish behavior, size, life history stages, available nutrients, and habitats may have contributed to the variation in fish abundance seen in this study(Assefa Tessema and Adem Mohamed, 2016).

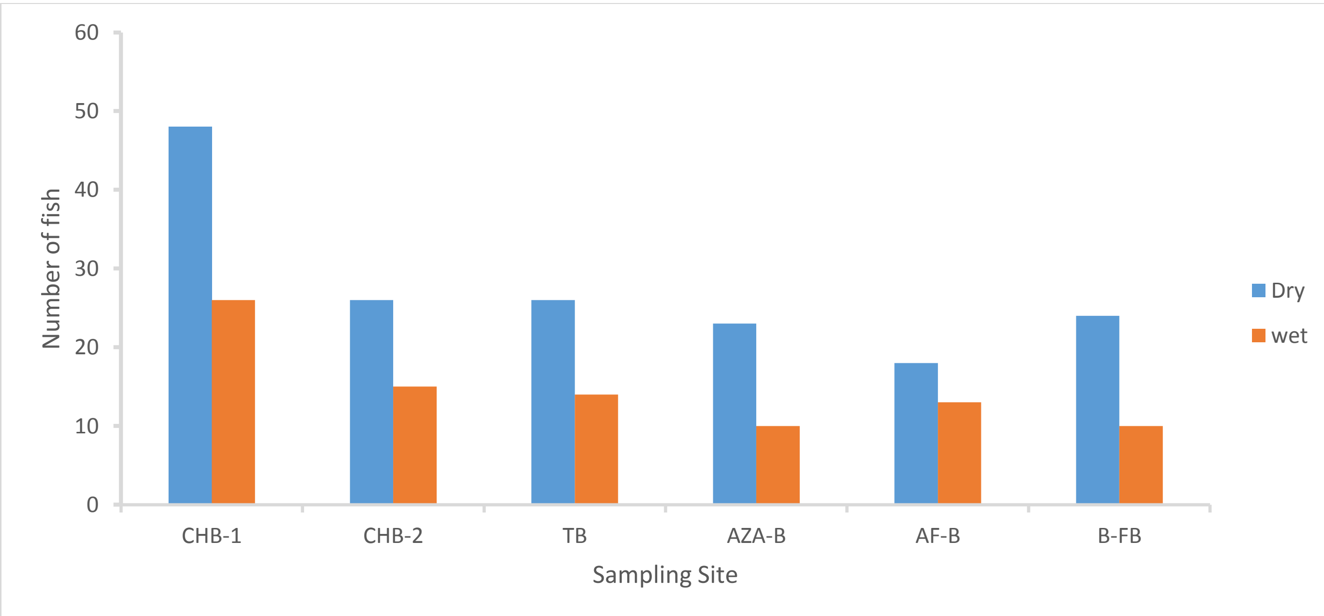

Figure 2: Number of fish species in each site for both seasons

4.2.1. Fish diversity indices

The diversity indices of fishes in different sites of the Zarima River during the dry season were given(Table 6). Simpson’s dominance index(D)shows a higher value in the CHB-1 and CHB-2 (0.384 and 0.557), but a low in the AF-B and BF-B(0.301 and 0.243)during the dry season. That was, the bigger the value of D, the lower the diversity. So, the value of Simpson’s index of diversity(B)for the sampling habitat of the BF-B(0.757)was high.

The lowest value(0.617)of the Shannon Weaver species diversity index(H′) was recorded at the CHB-1. On the other hand, high values(2.004) were recorded at the CHB sampling of the river. During the dry season, species richness index values varied from 1.824 to 0.891 in the CHB-1 and CHB-2. Fish richness and diversity serve as important indicators of a healthy stream ecosystem, which is influenced by a complex web of ecological factors, including regional climate, watershed characteristics, riparian zone quality, and water quality(Yuhan, 2023).

Table 6. Fish diversity indices from different sampling sites of the Zarima River during the dry season

	Sampling Site					
Parameters	CHB-1	CHB-2	TB	AZA-B	AF-B	BF- B
Shannon-weaver index(H’)	2.004	0.617	1.281	1.021	1.089	1.340
Simpson’s dominance index(D)	0.384	0.557	0.265	0.360	0.301	0.243
Simpson’s diversity index(B)	0.616	0.443	0.735	0.640	0.699	0.757
Margalef’s richens index(R)	2.742	2.693	3.693	2.681	2.654	3.685
Pielo’s evenness index(J’)	1.824	0.891	0.924	0.930	0.991	0.967

The diversity indices presented(Table 7) provide a complete overview of the fish diversity across different sampling sites of the Zarima River during the wet season. Each index suggested a single understanding of the community structure and biodiversity of the sites. For example, the Shannon-Weaver index, which measures species diversity, shows relatively similar values across the sites, ranging from 0.919 at CHB-2 to 0.991 at AZA-B. This result suggests that the fish communities at these sites have a similar level of species diversity. The highest value at AZA-B(0.991) indicated slightly greater diversity, meaning this site has a more balanced distribution of species. The Simpson’s Dominance Index(D)ranges from 0.178 at BF-B to 0.352 at CHB-2, indicating the degree of dominance by a single or few species. Higher dominance was seen at CHB-2, which may suggest that a particular species was more widespread here compared to other sites. Conversely, BF-B has the lowest dominance, implying a more evenly distributed fish community.

Margalef’s Richness Index values told the species richness across the sites, with the highest richness observed at CHB-1(4.693) and the lowest at AZA-B(2.566). CHB-1, with its higher richness, indicates a greater number of species, which could be attributed to favorable environmental conditions or less anthropogenic pressure. The lower richness at AZA-B may suggest fewer species present, possibly due to environmental stressors or habitat degradation due to the waste disposal of Zarima Town enter to this site without treatment.

Pielou’s Evenness Index (J’) was similar across the sites, with values close to 1, indicating that species were relatively evenly distributed at all sites. This evenness suggests a lack of dominance by any single species.

Table 7. Fish diversity indices from different sampling sites of the Zarima River during the wet season

	Sampling Site					
Parameters	CHB-1	CHB-2	TB	AZA-B	AF-B	BF- B
Shannon-weaver index (H’)	0.970	0.919	0.966	0.991	0.961	0.985
Simpson’s dominance index (D)	0.188	0.352	0.308	0.267	0.218	0.178
Simpson’s diversity index (B)	0.812	0.648	0.692	0.733	0.782	0.822
Margalef’s richens index(R)	4.693	2.631	2.621	2.566	3.610	3.566
Pielo’s evenness index (J’)	0.970	0.919	0.966	0.991	0.961	0.986

4.2.2. Relative abundance of fish species in Zarima River

A total of 253 specimens were collected from six sampling sites of Zarima River during the present study period. The percentage composition of the species identified at Zarima River was shown (Tables 8 and 9). The species collected were analyzed based on the Index of Relative Importance (IRI), which was a measure of the relative abundance or commonness of the species based on the number, weight, and frequency of individuals in the catches(Kolding, 1989). According to IRI the most important species in the total catches were L. intermedius % IRI values(88.1 and 70.6) in CHB-2, and AZA-B during the dry season given(Table 10). The % IRI of L. forskalii in the dry season was(25.9%, 47.1%, and 51.5%) in TB, AF-B, and BF-B, respectively. The % IRI value of *Garra spp* was 46.1(CHB-1), 30.1(TB), and 25.8(BF-B)during the dry season. Nevertheless, it had the highest % IRI value in CHB-2 and AF-B sites during wet seasons 59.6 and 55.2 respectively(Table 9).

Labeobarbus intermedius was the most important species in Zarima River both in dry and wet seasons with a % of IRI value, at CHB-2 88.1 and 40.1in the dry and the wet seasons respectively. This species was high important species and this indicates that the environmental conditions of the Zarima River were favorable for L. intermedius, supporting its feeding, breeding, and growth needs because of adequate food availability, suitable spawning grounds, and appropriate water quality parameters. The diversity of fish depends on the influence of the physicochemical factors and availability of fish feed, fish assemblage, and other anthropogenic factors(Sewunet Tegegne, 2020).

Table 8. Catch composition and index of relative importance(IRI) at Zarima River during the dry season.

Site	Fish	N	%N	W	%W	F	%F	IRI	%IRI
CHB-1	Asalema (*Garra spp)*	25	52.08	203.2	11.38	5	50	3173	46.1
	Barike(*Labeobarbus. beso)*	15	31.25	1192	66.77	3	30	2940.6	42.7
	Gibnie(*O. niloticus)*	8	16.67	390	21.84	2	20	770.2	11.2
Total	3	48	100	1785.2	100	10	100	6883.8	100
CHB-2	Barike(*L. intermedius)*	18	69.23	2409	93.95	5	62.5	10199	88.1
	Asalma(*Garra spp)*	8	30.77	155	6.05	3	37.5	1381	11.9
Total	2	26	100	2564	100	8	100	11580	100
TB	Barike (*L. nedgia)*	7	26.92	634	30.1	4	40	2281	41.2
	Motematie(*L. forskalii)*	9	34.62	783	37.18	2	20	1436	25.9
	Gibini(*Coptodon rendalii*)	2	7.69	164	7.79	1	10	155	2.8
	Asalema (*Garra spp)*	8	30.77	525	24.93	3	30	1671	30.1
Total	4	26	100	2106	100	10	100	5543	100
AZA-B	Motematie(*L. forskalii)*	6	26.09	882	30.80	3	27.27	1551.4	19.8
	Barike(*L. intermedius)*	12	52.17	1413	49.34	6	54.5	5537.4	70.6

							5		
	Asalema (*Garra spp)*	5	21.74	569	19.86	2	18.18	756.3	9.6
Total	3	23	100	2864	100	11	100	7845.1	100
AF-B	Barike (*Labeobarbus.beso)*	6	33.33	584	49.37	4	33.33	2756.4	39.3
	Motimatie(*L. forskalii)*	7	38.89	476	40.24	5	41.67	3297.3	47.1
	Asalema(*Garra dembecha)*	5	27.78	123	10.39	3	25	954.3	13.6
Total	3	18	100	1183	100	12	100	7008	100
BF-B	Barike (*Labeo horie)*	5	20.83	716	22.16	3	21.43	921.3	16.4
	Motematie (*L. forskalii)*	9	37.5	1415	43.79	5	35.71	2902.9	51.5
	Asalem (*Garra spp)*	6	25	838	25.94	4	28.57	1455.4	25.8
	Gibinie(*O.niloticus*)	4	16.67	262	8.11	2	14.29	354.1	6.3
Total	4	24	100	3231	100	14	100	5633.7	100

Table 9. Catch composition and(IRI) at Zarima River during the wet season.

Site	Fish Local and scientific name	N	%N	W	%W	F	%F	IRI	%IRI
CHB-1	Anbaza (*Clarias gariepinus)*	5	19.13	1738	66.52	3	20	1713	40.74
	Barike (*Labeo horie)*	3	11.54	150	5.74	2	13.33	230.3	5.48
	Gibnie (*O. niloticus*)	4	15.39	80	3.06	3	20	369	8.77
	Kakile (*Raiamas* loati)	7	26.92	560	21.43	4	26.67	1289.5	30.66
	Asalma (*Garra dembecha)*	7	26.92	85	3.25	3	20	603.4	14.35
Total	5	26	100	2613	100	15	100	4205.2	100
CHB-2	Barik (*Labeo horie)*	4	26.67	188	43.22	2	33.33	2329.4	31.21
	Asalma (*Garra spp*)	8	53.33	155	35.63	3	50	4448	59.6

	Gibinie (*O.niloticus*)	3	20	92	21.15	1	16.67	686	9.19
Total	3	15	100	435	100	6	100	7463.4	100
TB	Barike (L.*intermedius)*	6	42.86	229	39.21	2	33.33	2735.4	40.1
	Kakilie (*Raiamas* loati)	3	21.43	191	32.71	1	16.67	902.5	13.2
	Gibinie (*O.niloticus)*	5	35.71	164	28.08	3	50	3189.5	46.7
Total	3	14	100	584	100	6	100	6827.4	100
AZA-B	Gibnie(*Coptodon rendalii)*	3	30	158	30.50	2	50	3025	46.45
	Barike (*L. nedgia)*	4	40	168	32.43	1	25	1810.8	27.8
	Kakilie (*Raiamas loati*)	3	30	192	37.07	1	25	1676.8	25.75
Total	3	10	100	518	100	4	100	6512.6	100
AF-B	Barike(*Labeobarbus nedgia)*	3	23.08	101	23.49	1	14.29	665.5	12.2
	Gibinie (*O.niloticus*)	3	23.08	77	17.91	2	28.57	1171.1	21.5
	Asalema (*Garra spp*)	5	38.46	136	31.62	3	42.85	3003	55.2
	Kakilie (*Raiamas* loati)	2	15.38	116	26.98	1	14.29	605.3	11.1
Total	4	13	100	430	100	7	100	5444.9	100
BF-B	Barike(*Labeobarbus nedgia)*	3	30	137	40.66	1	20	1413.2	29.0
	Kakile (*Raiamas loati*)	2	20	67	19.88	1	20	797.6	16.4
	Asalem (*Garra dembecha)*	3	30	51	15.13	1	20	902.6	18.5
	Gibinie(*Coptodon rendelii*)	2	20	82	24.33	2	40	1773.2	36.4
Total	4	10	100	337	100	5	100		100

4.2.3. Length-weight relationship

The relationship between fork length and total weight for the most dominant fish species was best described by the regression equations in terms of the line fitted to the data as shown in Figure 3.

Figure3 describes that *Garra* species in Zarima River attains positive allometric growth having a b-value greater than 3(b>3) has been well described as shown below. The values obtained for the length-weight relationship showed that *L. forskalii* (b = 2.42) and *L. intermedius* (b = 2.06) had negative allometric growth. Accordingly, the LWR of the current study *L.intermedius* and *Labeo forskalii* shows negative allometric growths in Zarima River, where both species' b-value was less than three(b-value 2.42 for *L.intermedius* and b-value 2.06 *for L. forskalii*)(Figugre 3). For three fish species, the length-weight relationships showed a high coefficient of determination (r^2), indicating that the length increased as the fish's weight increased(Koffi *et al*., 2014).

This was in agreement with previous studies on different fish species from various water bodies. The b values obtained in this study area for *L. intermedius* show negative allometric growth unlike that reported by Yibeletal Aynalem *et al*. (2018), and Tadlo Awoke *et al*. (2015)in the Blue Nile River, Ethiopia. However, this value was close to the values reported for some freshwater fish species by Genanaw Tesfaye (2006) in Angereb and Sanja Rivers, while Taju Mohammed(2014) in Gilgel Gibe and Gojeb Rivers, Omo-Turkana Basin, Southwest Ethiopia. Simagegnew Melaku *et al*. (2017b)in Geba and Sor Rivers, Baro-Akobo Basin Southwest Ethiopia and by Shibabaw Gebru (2020) fish diversity and production in Tekeze Reservoir, Tekeze Basin, Ethiopia. The b values obtained in this study for *L. forskalii* show a negative allometric growth line as reported by Tadlo Awoke (2019).

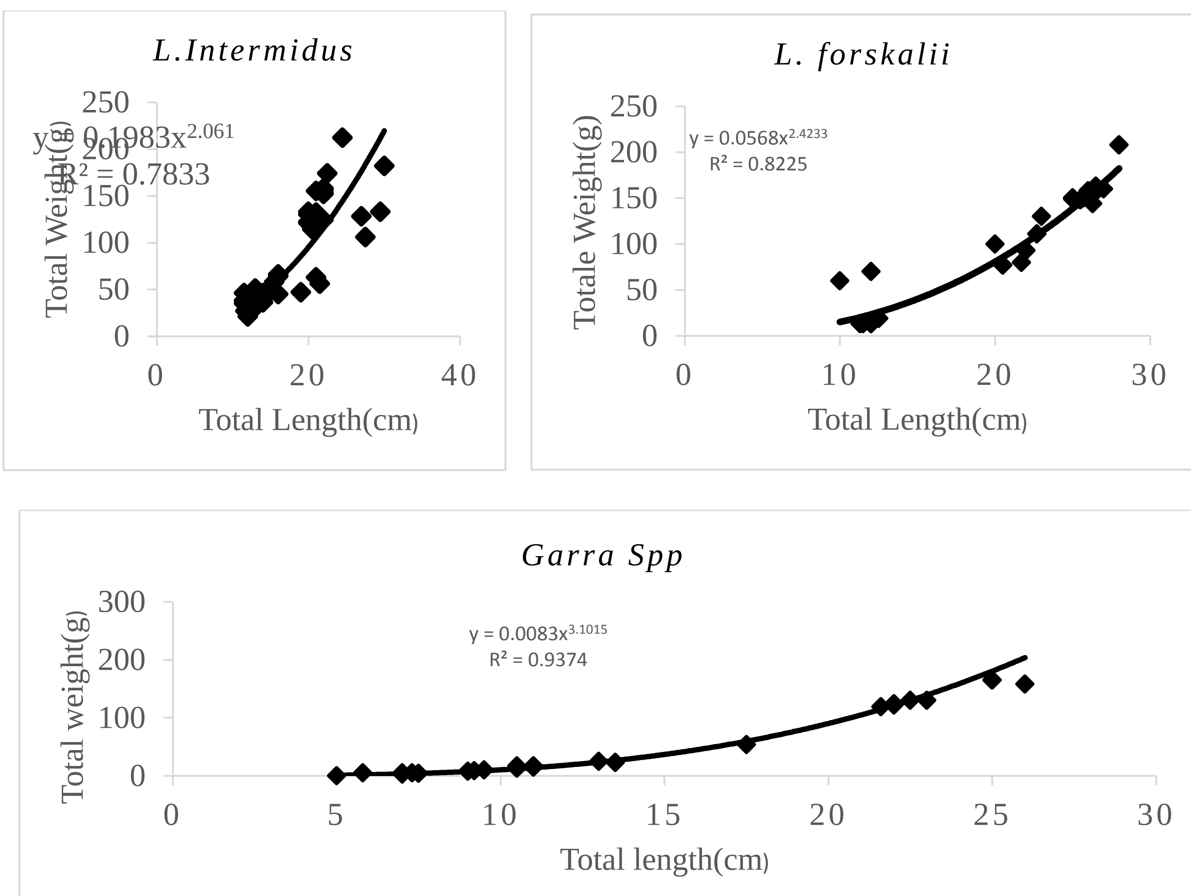

Figure 3: Length-weight relationship of *L. intermedius*, *L. forskalii*, and *Garra spp*

4.3. Physico-Chemical Parameters

The mean values of the common environmental variables(water temperature $F=3.21(p<0.05)$ and Trans=16.58, depth $F=16.15$ were $p<0.001$)were statistically significant between sampling sites but not in DO- $F=1.64$, pH- $F=2.15$, EC-$F=0.6$, TDS- $F=1.98$ and salinity-$F=1.58$ (all, $p>0.05$) (Table 10). The mean values of environmental variables showed great variability across spatial and temporal scales. The mean values of water temperature were higher at upstream sites. However, the lowest water temperature was recorded at the third sampling site around Zarima Town. This may be the shading effect on both sides of the site, with tree branches on the right side and rugged mountains on the left side preventing direct sunlight from reaching the water surface as a result the water temperature of the third sampling site was low from another sampling site. This is in agreement with the study conducted by Felegush *et al*. (2020), in Gumara River. It governs the kinds and types of aquatic life, regulates the maximum dissolved oxygen concentration of water, and influences the rates of chemical and biological reactions(Dessalegn Gelta, and Worku Firomsa , 2022). Their changes can directly impact fish physiology, metabolism, and behavior influencing their ability to thrive in aquatic environments(Jobling, 2012). Its fluctuations can alter oxygen solubility, affecting oxygen availability for fish respiration(Fry, 1971). In addition, its variations can disorder reproductive cycles, and habitat availability, and increase vulnerability to diseases(Rahel and Olden, 2008).

The mean values of electrical conductivity and total dissolved solids(TDS) were higher in the middle streams. This could be because of domestic effluent discharges from Zarima Town, and surface run-off from irrigation activities which might have increased the concentration of ions. This result shows that electric conductivity and TDS increase with an increase in anthropogenic impact or human activities. This result line with the study conducted by Ferengi Beksisa *et al*.(2017) in the spring and Stream Sites of the Upper Awash River at Chilimo, Ethiopia, a side that increases in conductivity possibly occurs as additional wastes containing ions that enter the stream. In addition, increased TDS is caused by climate change, development, and urbanization associated with surface inflexibility resulting from increased population, and contamination caused by rapid and uncontrolled environmental changes. The higher values of total dissolved solids in natural waters are generally due to increased anthropogenic activity, stagnation, and concentration of water which obstruct water quality(Manickam *et al*., 2014).

The electrical conductivity of the river at all sites were lower than the permissible limit by WHO for drinking and irrigation purposes. Thus, the results indicated that the river receives a low amount of dissolved inorganic substances in ionized form their surface catchments area and it is confirmed by the study conducted by Dessalegn, and Worku, (2022) Awetu River, Ethiopia. According to the result of this study, the Zarima River mean value of conductivity was(171.078±13.1μS/cm) which was higher than the conductivity value of Awetu River(111.7 μS/cm) reported by Dessalegn and Worku and the mean conductivity value of Lake Tana(132.8 µs cm-1) reported by Dejen and much lower than mean conductivity value of Chibirna(313.1 ± 27.19 µs cm-1), Shini Rivers (239.5 ± 10.2 µs cm-1) Gizachew *et al.*, (2015)and the conductivity value of Gumara River(185.24 ± 2.09 µs cm-1)reported by Flegush *et al*. (2019)in Gumara River.

Table 10. Physicochemical characteristics of Zarima River across the study sites by mean-values± standard error and minimum and maximum values in parenthesis (One-way ANOVA).

Site	Water temperature (^{o}C)	DO (mg/l)	PH	EC (µS/cm)	TDS(ppm)	Salinity(ppt)	Tras(cm)	Depth(cm)
CHB-1	26.92±2.7 (26-28)	6.71±0.53(5-8)	7.92±0.30(7-9)	167.00 ±4.31(155-180)	81.17±1.76(75-87)	0.01±0.00(0-0)	20.17±3.70(10-30)	25.33±4.06(15-36)
CHB-2	28.65±4.8 (28-31)	5.72±0.32(4-7)	7.37±0.24(7-8)	165.05 ±3.32(140-198)	81.88±2.18(73-88)	0.00±0.00(0-0)	21.67±3.44(14-34)	27.67±3.53(20-40)
TB	25±1.05 (21-27)	7.31±0.66(5-9)	6.75±0.9(3-10)	175.90 ±9.41(150-192)	89.12±2.71(80-98)	0.01±0.00(0-0)	18.83±2.33(13-26)	23.00±2.91(15-31)
AZA-B	27.70±1.04 (24-31)	5.43±0.20(5-6)	6.70±0.71(5-9)	174.68 ±6.67(160-180)	86.17±2.94(75-93)	0.01±0.0(0-0)	19.50±2.57(13-29)	24.50±2.67(17-32)
AF-B	26-03±1.28 (22-29)	6.33±0.40(5-7)	8.14±0.46(7-	171.83 ±3.33(1	85.00±1.71(7	0.01±0.0(0-0)	41.42±3.33(34-	49.33±4.20(39-

			10)	60-183)	8-90)		55)	60)
BF-B	25.90±1.60 (24-28)	6.63±0.84(5-10)	8.73±0.38(8-10)	172.00 ±3.04(140-198)	86.67±0.91(85-90)	0.01±0.0(0-0)	49.67±4.11(40-62)	55.50±373(45-65)
F-Value	3.21*	1.64	2.15	0.6	1.98	1.58	16.58***	16.15***

Not,*p<0.05, ***p<0.001

Water temperature, EC, TDS, and salinity show no significant differences between the dry and wet seasons. However, dissolved oxygen, pH, transparency, and depth show highly significant seasonal differences(Table 11). The highest DO value was recorded during the wet season due to the variation in depth and temperature. Premlata (2009) also mentioned the factors that affect the concentration of DO in water which include temperature, depth, salinity, photosynthesis, and availability of nutrients. During the wet season, the depth increases and the temperature decreases while the dissolved oxygen increase in the river water by the cause of rain fall. The survival of fish species is highly dependent on the availability of adequate concentrations of DO. Fish living in various life stages can be affected by low DO levels in terms of growth, survival, and migration. Different species and life stages had different requirements for DO concentration. However, DO levels below 3 mg/l are stressful to most aquatic organisms, and levels 5 to 6 mg/l are usually required to perform their biological functions(Geneviève and James, 2008).

pH is a crucial factor in determining the quality of water since it affects a variety of biological and chemical activities in a water body and all processes involved in water supply and treatment (Rahmanian *et al*., 2015). Throughout the dry season, the pH was at its minimum, and wet season it was at its maximum(Table 12). This result line with the study conducted byTadlo Awoke, *et al*. (2015).

During the dry season, the maximum conductivity value was recorded could be because of domestic effluent discharges from Zarima Town, and surface run-off from irrigation activities which might have increased the concentration of ions. This result shows that electric conductivity increases with an increase in anthropogenic impact or human activities. This result line with the study conducted by Ferengi Beksisa *et al*. (2017) in the spring and Stream Sites of the Upper Awash River at Chilimo, Ethiopia, a side that increases in conductivity possibly occurs as additional wastes containing ions that enter the stream.

Several factors such as irrigation activities, and urbanization may increase during the dry season, leading to higher inputs of pollutants and dissolved ions into water bodies, thereby increasing conductivity. This result line with the study conducted byYirga Kebede *et al*. (2016) in the Gilgel Abay River in the Lake Tana Basin, Ethiopia.

In general, electrical conductivity is low during the wet season due to the presence of greater dilution of ions in the water, intense rainfall events during the wet season can mobilize soil particles, sediments, and pollutants, reducing the concentration of dissolved ions in the water. And also witnesses fluctuations in the hydrological regime, including variations in flow velocity, water depth, and mixing processes, which can influence conductivity levels during the wet season. Overall, the different conductivity patterns between the dry and wet seasons highlight the seasonal dynamics and complex interactions within aquatic ecosystems. Understanding these seasonal variations is essential for assessing water quality, ecosystem health, and the impacts of climate change and human activities on freshwater resources.

Table 11.Mean water quality parameters of Zarima River in dry and wet seasons.

Parameter	Season	Mean	± SE	t-test	df	p-value
Water temp	Dry Wet	23.13 27.01	0.99 0.59	1.09	34	0.03*
DO	Dry Wet	5.59 7.12	0.13 0.36	3.97	34	0.00**
pH	Dry Wet	6.96 8.23	0.36 0.25	2.9	34	0.006**
ECU	Dry Wet	176.03 166.12	3.18 2.59	2.42	34	0.02*
TDS	Dry Wet	86.52 83.49	1.51 1.03	1.65	34	0.11
Salinity	Dry Wet	0.01 0.01	0.001 0.001	0.69	34	0.49
Transparency	Dry Wet	21.92 35.14	2.81 3.35	3.01	34	0.005**
Depth	Dry Wet	26.56 41.89	3.01 3.40	3.38	34	0.002**

*, significant; **, highly significant, NS, none significant

4.3.1. The effect of environmental variables on the abundance of macroinvertebrate and fish community

The Canonical corresponding analysis ordination shows the relationships between taxa abundances, and measured physicochemical variables. The positioning of the physicochemical Parameters in Figure 4 show that the first axes were positively correlated with water temperature, pH and dissolved oxygen. Environmental variables like Transparency**,** Depth**,** and TDS, and EC were negatively associated with this axis. The second gradient was positively correlated with conductivity, transparency, depth, and TDS.

Among different environmental factors TDS, DO, pH, transparency, depth and electric conductivity were the most determinant factors that affect the abundance of different macroinvertebrate species because such variables had a long arrow(Braak and Verdonschot, 1995). Species or taxa positioned near the origin(the center of the plot)are less strongly influenced by the environmental variables, while those farther from the center are more strongly associated with specific environmental conditions. For example, Baetidae and Chironomidea seem to be positively associated with high PH, transparency and water depth, whereas Elmidae and Gerridae look to be influenced by dissolved oxygen(DO)(Figure 4). The principal component analysis(PCA) showed that the common of the degraded sites were found in the second axes (Figure 5). In Figure 5, Gomphidae have their maximum abundance at Site TB and AZA-B, and Gerridae at Site CHB-1.

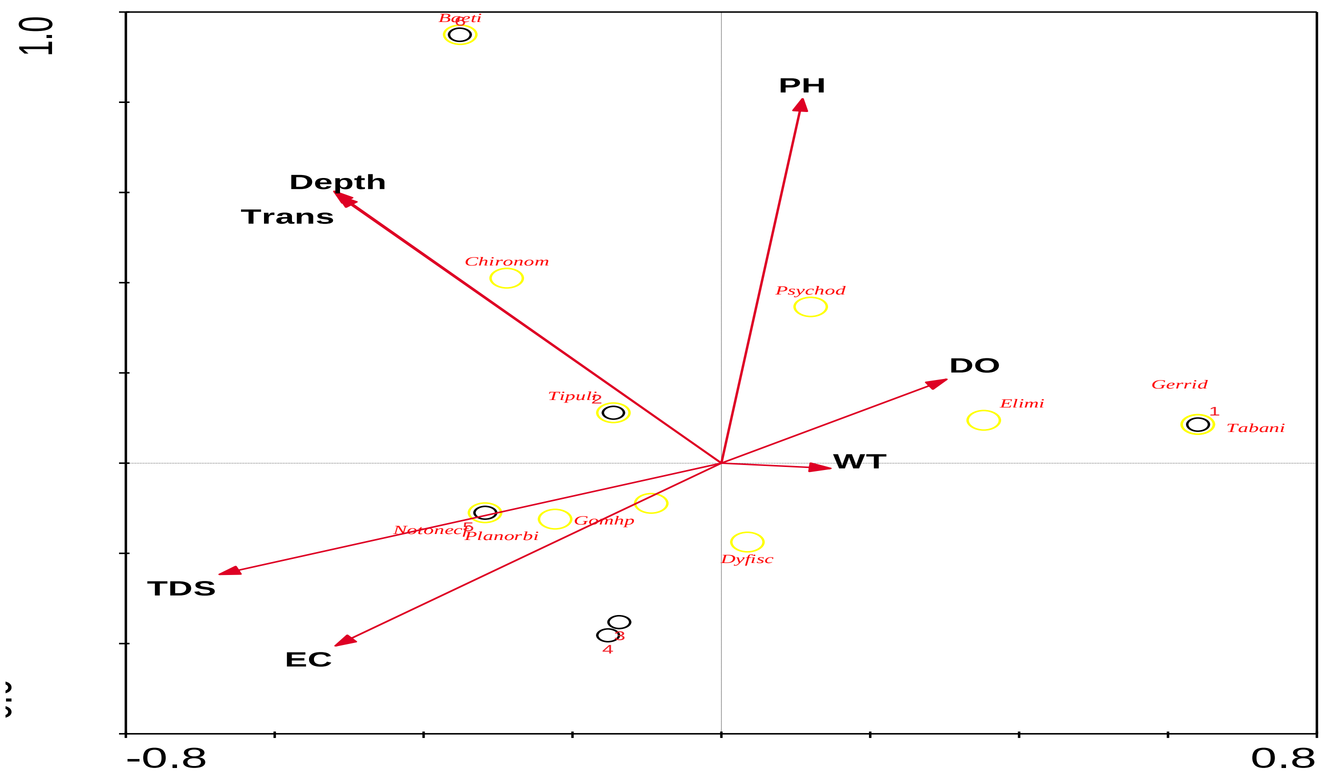

Figure 4: Canonical correspondence analysis of physicochemical variables and macroinvertebrate families

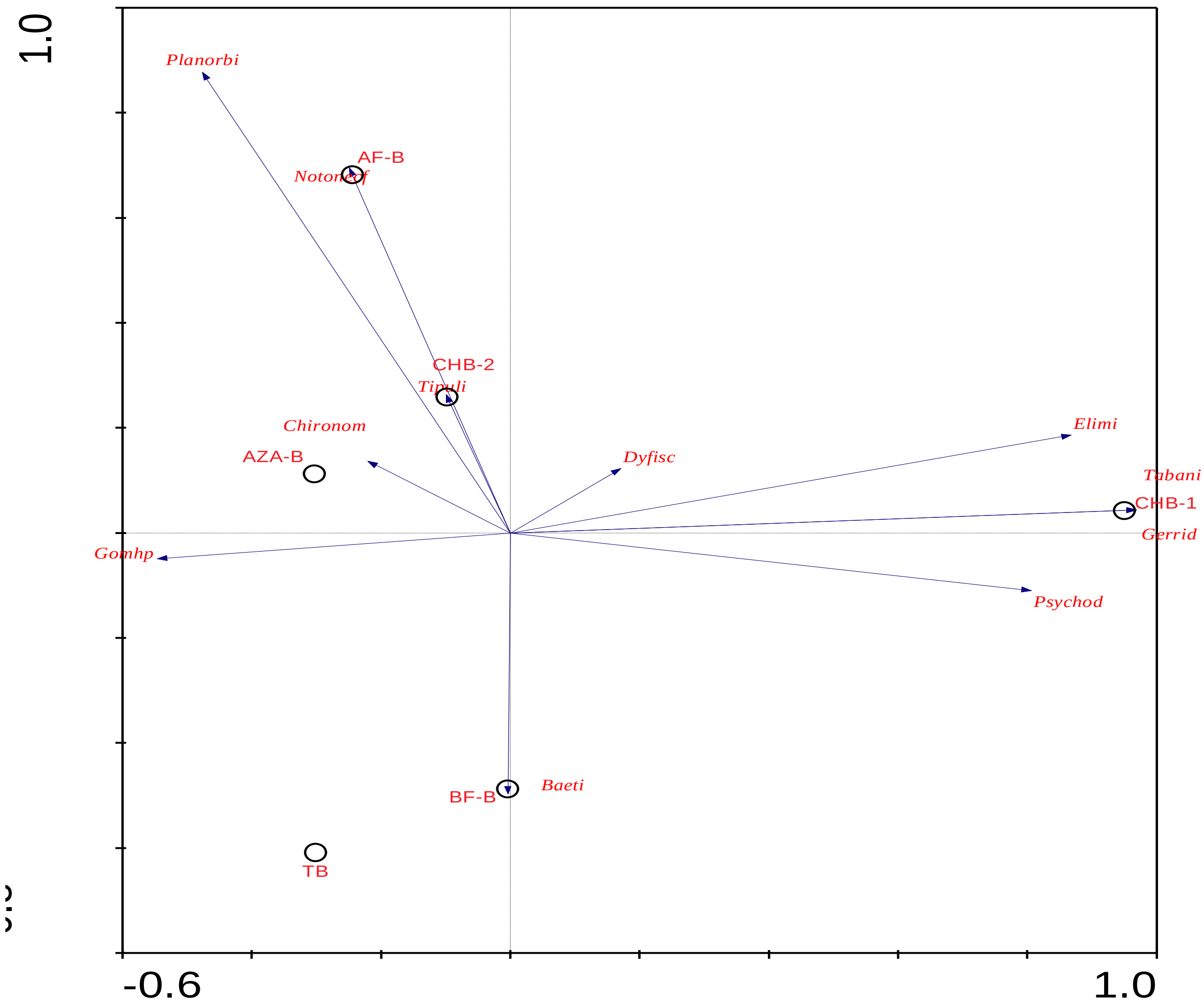

Figure 5: Principal component analysis(PCA) species-sample biplot.

The macroinvertebrate assemblages (green arrow), and sampling points were represented in black circles. The abundance difference of fish was mainly due to environmental variables, and their relationship was shown in the ordination triplot(Fig 6). The first axis showed a negative correlation with pH, transparency, and DO, and water depth. The second axis also positively correlated with DO, pH and TDS. Based on the CCA, most environmental variables and fish species were found in the second axis(Fig 6). Among different environmental factors, water temperature, TDS, DO, salinity, pH, and electric conductivity were the most determinant factors that affect the abundance of different fish species because such variables had a long arrow(Braak and Verdonschot, 1995).The abundance of C.gariepinus, L.horie, G.dembecha, and Labeobarbusbeso were positively correlated with the level of PH, DO, and depth.

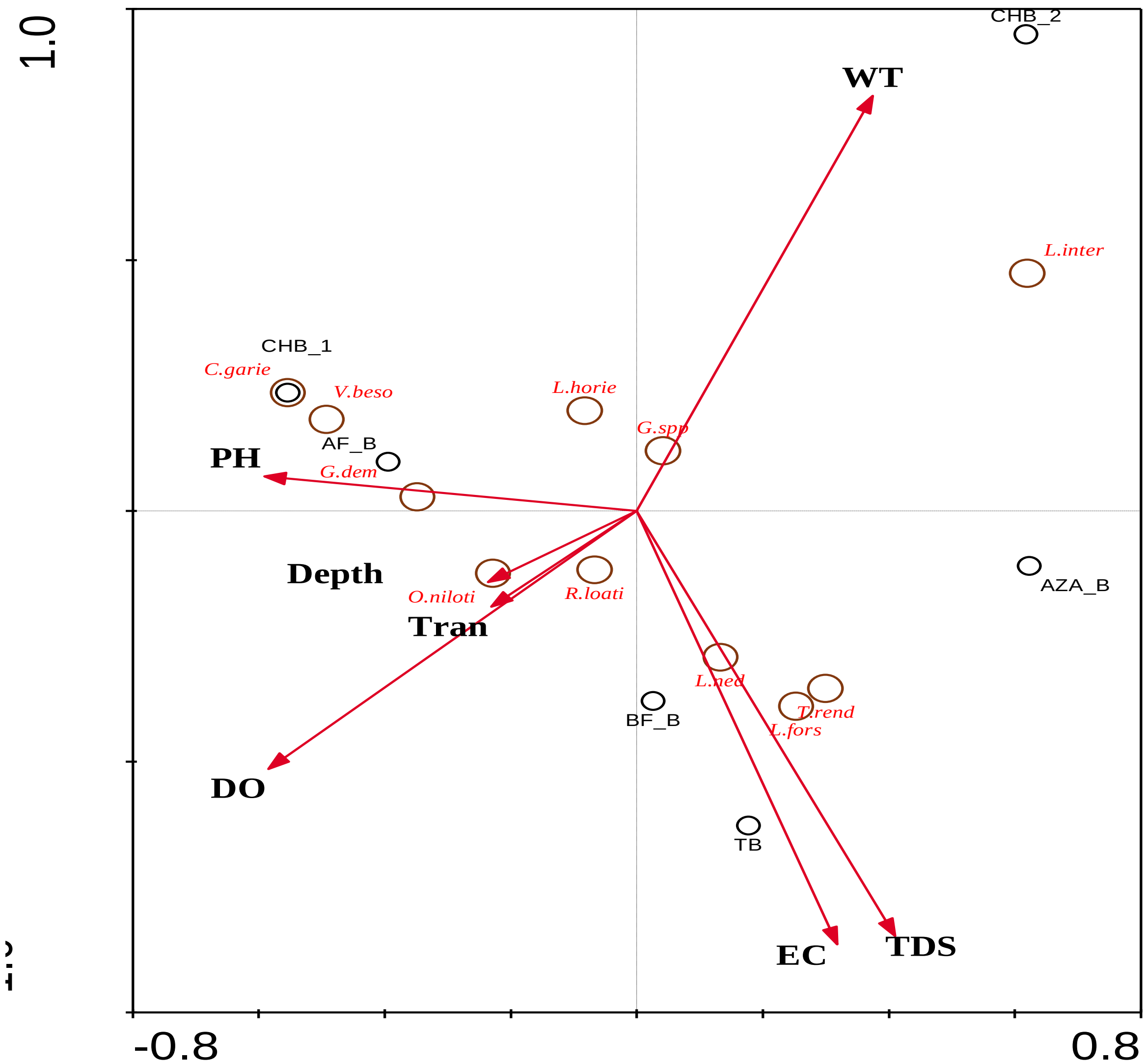

Figure 6: Canonical correspondence analysis of physicochemical variables and fish species

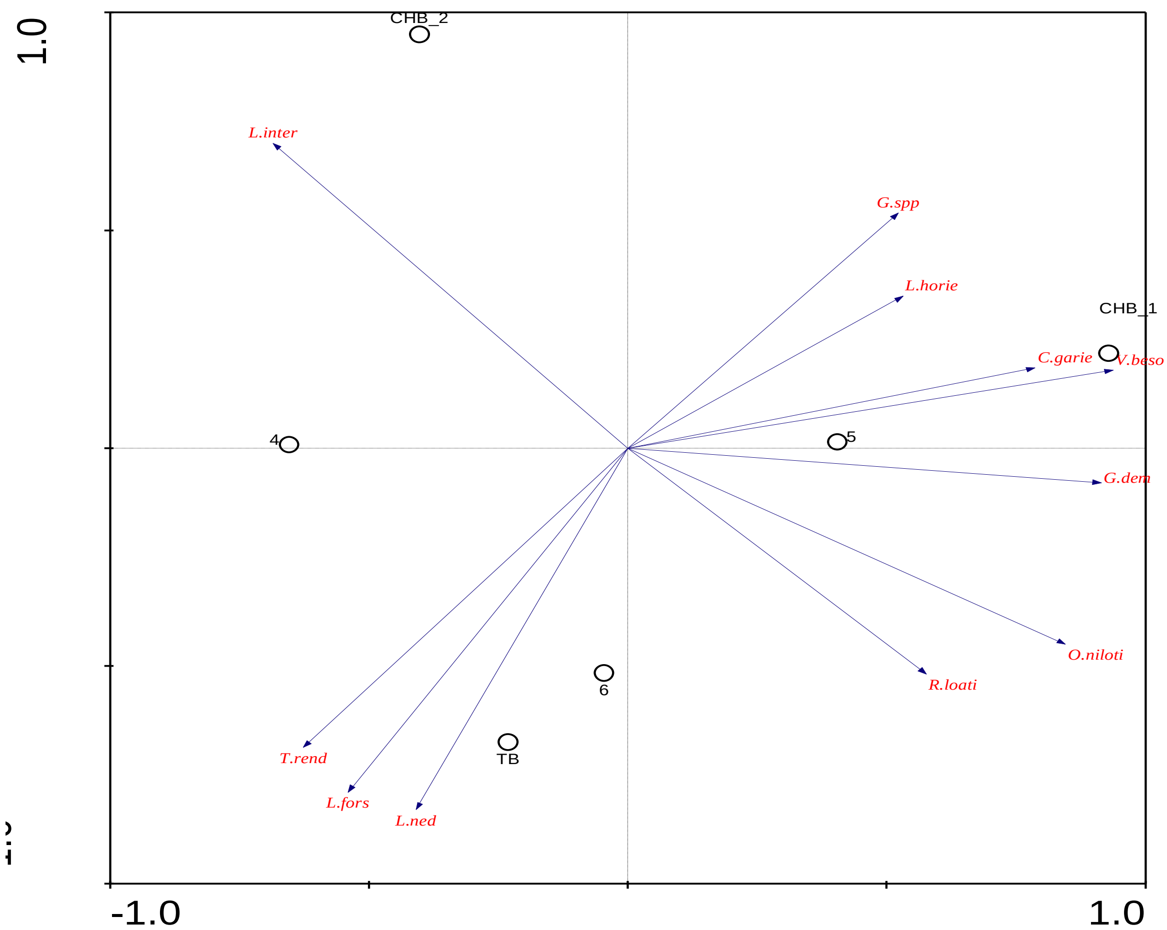

Figure 7: Principal component analysis(PCA) species-sample biplot in Zarima River, Ethiopia.

The fish assemblages(green arrow), and sampling points were represented in black circle.

Sites labeled with stream cod were ranked by distance from the source. Species (triangles) were weighted averages of site scores. Quantitative environmental variables were indicated by arrows. **Abbreviation**: physicochemical: WT-Water temperature, DO- dissolved oxygen, TDS- Total dissolve solid, EC- electrical conductivity, and Tran- Transparency and fish species name*: C. garie- Clarias gariepinus, L. inter- Labeobarbus intermedius, L. ned- Labeobarbus nedgia, O. nilotic- Oreochromis niloticus, G. spp- Garra spp, R. lotai- (Raiamas loati), L.horie-Labeo horie, C.rend-Coptodon rendalii, G. dem- Garra dembecha, L-fors- L. forskalii and L. beso- Labeobarbus beso.*

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

From Zarima River eleven fish species across four families were identified, with the Cyprinidae family being the most dominant. The length weight relationships for *L.intermedius*, *L. forskalii* and *G.spps* were curvilinear. *G.spps* showed nearly positive isometric relation, but *L.intermedius*, and *L. forskalii* showed negative allometric relation. The 292 individual macroinvertebrates collected were classified into five insect orders(Ephemeroptera, Diptera, Coleoptera, Odonata, and Hemiptera) and one non-insect order (Gastropoda). Gomphidae was the most dominant taxon among the macroinvertebrates. The diversity and abundance of benthic macroinvertebrates declined from the least impacted upstream sites to the most affected downstream sites. Over all, the composition and abundance of macroinvertebrates, and fish in the Zarima River varied based on the ecological health and the physical component of the river across various sampling sites. On the other hand, species variation between differ sampling sites indicates the effects of environmental factors to influence the distribution of macroinvertebrate and fish collections. In general, the river's fish diversity has potential for development because, relative to other major river systems in Ethiopia, it is located faraway from industry and less human activity. The Zarima River shows significant seasonal and spatial variations in water quality parameters, caused by both natural processes and human activities. However, the physicochemical parameters of the Zarima River were found in the optimum condition for the survival, growth, and reproduction of macroinvertebrates and fish communities.

5.2. Recommendations

Detailed studies and research are required on:-

- To have a better knowledge of the macroinvertebrate and fish community detailed studies and investigations are required on the diversity and abundance of macroinvertebrates and fish species in Zarima River should be conducted throughout the year using more sites and different sampling methods.
- To have a better information of the Zarima River water quality detailed studies are require on water quality parameter should be conducted including nitrate, phosphate, silicate, and chemical oxygen demand, etc., and their potential impacts on the aquatic resources should be investigated.
- Educate local communities about sustainable fishing practices, biodiversity importance, and the long-term benefits of ecosystem preservation to promote local stewardship.

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APPENDIXS

Appendix 1. Activities during field data collection

A) Measuring water physicochemical

Parameters at the fifth site

(B) Collection of macroinvertebrates at third site

(C) Gillnets Setting at second site

Appendix 2. Fish species collected during sampling

A)Labeobarbus.beso B)Coptodon rendalli

C) *Raiamas loati*

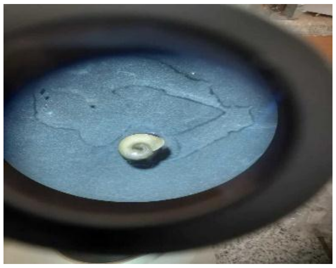
D) *Gara dembecha*

F) *Garra* spp

G) *Clarias gariepinus*

H) *Labeobarbus* nedgia

Appendix 3. Macroinvertebrates family collected during sampling



A) Planorbidae

B) Gomphidae

C) Chironomidea