EVALUATION OF SURFACE WATER QUALITY AND SUITABILITY FOR DRINKING AND IRRIGATION: THE CASE OF ATEBELA RIVER, SEBETA TOWN

Mohammed Aman Kuru

A thesis submitted to
The Department of Water Resource Engineering
School of Civil and Architecture Engineering

Presented for Partial Fulfillment of the Requirement for the Degree of Master's in Water Resources Engineering (Specialized in water supply and environmental Engineering).

Office of Graduate Studies
Adama Science and Technology University

January, 2024
Adama, Ethiopia

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ADVISOR APPROVAL SHEETS

I, Keneni Alemu (Ph.D.), the advisor of the thesis entitled "*Evaluation of Surface Water Quality and Sustainability for Drinking and Irrigation"* developed by Mohammed Aman Kuru hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis

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We, the undersigned, members of the board of Examiners of the thesis by Mohammed Aman Kuru have read and evaluated the thesis entitled "Evaluation of Surface Water Quality and Sustainability for Drinking and Irrigation and examined the candidate during open defense this is, therefore to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of master of science in Water resource Engineering in speciation of water supply and environmental engineering

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DECLARATION

I hereby declare that this Master Thesis entitled "**Evaluation of Surface Water Quality and Sustainability for Drinking and Irrigation: The Case of Atebela River, Sebeta Town** "is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledge through citation.

Mohammed Aman	____________________	__________________
Name of the student	Signature	Date

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LIST OF ACRONYMS AND ABBREVIATIONS

T	Temperature
WQI	Water Quality Index
NGO.	None Governmental Organization
EC.	Electrical Conductivity.
TDS	Total Dissolved Solids
WHO	World Health Organization
FOA	Food and Agriculture Organization
TSS	Total Suspended Solids
NH3	Ammonia
TH	Total Hardness
COD	Chemical Oxygenated Demand
BOD	Biochemical Oxygenated Demand
CCME	Canadian Council Of Ministers of the Environment
NSF	National Sanitation Foundation
RSC	Residual Sodium Carbonate
SAR	Sodium Adsorption Ratio
SSP	Soluble Sodium Percentage
PI	Permeability Index
KR	Kelly Ratio
SAWARD	Agriculture and Rural Development Office
AWQI)	Analysis of Water Quality Index
SPSS	Statistical Package for Social Sciences
K	Potassium
Mg	Magnesium
F	fluoride
MoWIE	Ministry of Water Irrigation and Energy
APHA-	American Public Health Association
UNICEF-	United Nations Children ‘s Fund
USEPA-	United States Environmental Protection Authority

ABSTRACT

Ethiopia's surface waters, vital for domestic, agricultural, and commercial needs, are increasingly under threat from contamination due to the country's growing population, rapid urbanization, industrial growth, and poor water management practices. One notable example is the Atebela River, which flows through Sebeta town, serving as a primary receptor for both industrial and municipal wastewater discharges. Despite the evident risks to public health and the environment, there exists a significant research gap concerning the spatio-temporal variability and complexity of water quality indicators in this region. Hence, this study endeavors to address this gap by focusing on the Atebela River, aiming to identify potential pollution sources, assess the physical and chemical quality of its water, and determine its suitability for various purposes. Sampling was conducted at 17 sites, selected based on factors such as accessibility, homogeneity, mixing, identifiable and particularly the presence of potential pollution sources. Particularly, priority was given to sites downstream from industrial zones, urban centers, and agricultural activities known to discharge waste into the river. Physico-chemical studies for APHA 2018 were conducted using standard procedures to ensure accuracy and consistency in results. The findings indicate that the primary sources of pollution in the Atebela River are industrial effluents that share lion, municipal waste, medical waste, and agricultural inputs. Spatial variations in physico-chemical parameters were observed, influencing the river's suitability for drinking water and irrigation purposes. To quantify these variations, water quality indices were developed, providing valuable insights into the overall health of the river ecosystem and its potential impacts on human health and agriculture. The results show that the river exceeds the standards of suitability as irrigation water and drinking water and with cooperation from every participant concerned, it seeks to improve and control pollution from both point sources and non-point sources. Overall, this study underscores the urgent need for improved pollution control measures and better water management practices to safeguard Ethiopia's surface waters and ensure sustainable development in the region

Keywords: Atebela River, water quality Index, River pollution, Heavy metal, Irrigation water quality.

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Water is an essential resource for life; everybody depends on it. However, it is one of the most threatened resources on the planet. Currently, the global water crisis driven by both water quantity and water quality has been identified as a major problem of this century (van Vliet et al., 2021). The vital water required for human and terrestrial existence is astonishingly scarce, constituting a mere 0.6% of Earth's overall water resources. This precious fraction is distributed across groundwater and surface water reservoirs, including rivers, lakes, and reservoirs (Howard, 2021). Indeed current worldwide population growth strongly increases the demand for clean water for different sectorial water uses (e.g. irrigation, domestic, energy, and manufacturing uses (van Vliet et al., 2021). Furthermore, climate change-induced factors increase the frequency and intensity of hydro-climate extremes such as drought and floods which have given rise to an alarming decline in fresh water resources. Moreover, the subsequent over exploitation of aquifers and an increase in water pollution have led to an increase in water demand.

Surface water, which includes rivers, lakes, reservoirs, and wetlands, serves as a pivotal source for both agricultural and human use (Brankov et al., 2012). However, global rapid population growth, urbanization, rapid industrialization, and agriculture expansion aggravated surface water pollution throughout the World. This problem is more frequent and realistic in developing countries including Ethiopia. In this part of the world, low sanitation infrastructure development coupled with low environmental regulation enforcement laws worsen the ecosystem damage. Hence, the quantity of wastewater being generated and its overall pollution load are increasing steadily (Yohannes & Elias, 2017)
The UN estimates that the amount of wastewater produced annually is about 1500 km^3, six times more water than exists in all the rivers of the world (Cosgrove & Loucks, 2015). Furthermore, increased usage of chemical fertilizers and pesticides, and untreated wastewater in irrigation, pollute groundwater and surface water. Industry in many areas still discharges waste directly into water courses. Most of the industries in developing countries are discharging their wastes directly into the nearby streams, rivers, lakes, oceans, and open lands without any treatment (Mathewos and Abebe, 2022). In poorer urban areas, a large proportion of wastewater is discharged untreated directly into the closest drainage channel or water body. Household effluent, human waste, toxic chemicals, and medical waste are

exposed to the air, contaminating the environment in often densely-populated residential zones.

In Ethiopia, the level of wastewater management is low, even by sub-Saharan standards, (Ravina et al., 2021) due to a general lack of sanitation infrastructure, skill, and knowledge of wastewater treatment (Troyer et al., 2016). As a result, large volumes of untreated wastewater both industrial and municipal wastewater are discharged to the environment every day. A survey by the Ministry of Water Irrigation and Energy (MoWIE) showed that only 7.3% of all sewage generated in Addis Ababa is treated at the secondary level (MoWIE 2015). Apart from the lack of effective treatment systems, the release of untreated wastewater into the ecosystem is an emerging threat to the country since most of the population depends on freshwater resources for livelihood (Gill et al., 2015). Furthermore, indiscriminate sewage water discharge constitutes a considerable threat to surface water quality by providing a breeding ground for many disease-causing organisms.

Urban and semi-urban rivers in Ethiopia have become major recipients of wastewater from both municipal and industrial sources, with industries often located near or along waterways. Weak enforcement of laws allows industries to discharge liquid waste directly into rivers, while others dispose of effluents into open ditches or municipal drainage systems, eventually reaching city rivers (Grum et al., 2017). For example, in Addis Ababa, the Akaki Rivers serve as dumping sites for industrial and municipal wastes. Unfortunately, downstream communities rely on these rivers for various activities, including domestic consumption and irrigation.

Similarly, the Atebela River, coursing through Sebeta town, serves as the primary receptor for industrial and municipal wastewater discharges. Sebeta Town hosts a multitude of small, medium, and large-scale industries, including commercial farming, agro-processing, beverage production, textile manufacturing, tanneries, and more. So, substantial pollution loads from both point and non-point sources find their way into the Atebela River daily. Unfortunately, the downstream local community heavily relies on Atebela River water for essential daily activities such as irrigation, washing, and even drinking. Recent studies indicate a surge in public complaints, underscoring the adverse effects of industrial waste and the indiscriminate dumping of solid waste into the river (Firomsa Gudeta et al., 2018). Moreover, there is a prevalent incidence of waterborne and water-related illnesses contributing to morbidity and mortality in the area. The need for urgent and inclusive environmental management strategies is evident to safeguard both the Atebela River ecosystem and the well-being of the downstream population. However, the evaluations performed did not take into account the evaluation of the Atebela River's water quality and appropriateness for drinking and irrigation purposes. The purpose of this investigation is to evaluate the physicochemical quality of drinking water and identify the potential source of pollution in the atebala river upper Awash River. The study will provide valuable information that can be used to protect the quality of drinking water and enhance communities.

1.2. The Statement of the Problem

Ethiopia's surface waters, key for domestic use, agriculture, and commercial expansion, face severe contamination challenges due to the country's growing population, rapid urbanization, industrialization, and poor water management practices (Melesse et al., 2013). Due to this, rivers across Ethiopia have become primary recipients of wastewater discharge from both municipal and industrial sources. In Addis Ababa, for instance, the Little Akaki and Large Akaki rivers, flowing through or on the outskirts of the city, serve as dumping grounds for industrial and municipal wastes (Eriksson & Sigvant, 2019). This situation reflects a common trend in many developing towns, where communities residing near or downstream utilize such water for domestic needs, including irrigation.

The Atebela River, crossing through Sebeta town, bears the effect of industrial and municipal wastewater effluents. Sebeta Town, covered various small, medium, and large-scale industries such as commercial farming, agro-processing, beverage production, textile, and tanneries, contributes significantly to the daily influx of pollution into the Atebela River. Unfortunately, the downstream community is deeply dependent on the Atebela River for essential daily activities such as irrigation, washing, and even drinking (Firomsa Gudeta et al., 2018). This dependence stresses the severe environmental effects stemming from the unregulated discharge of industrial waste, both untreated and partially treated, along with insufficient management of liquid waste. Moreover, the absence of viable alternatives for treated water sources compounds the challenges faced by residents, both in their domestic lives and agricultural practices. Despite the evident public health risks and environmental degradation, research is scarce on the spatio-temporal variability and complexity of water quality indicators in the study area.

Therefore, this study aims to evaluate the physical and chemical quality of Atebela River water, evaluating its suitability for various purposes It seeks to evaluate the spatial variability of pollutant loads along the water course, develop a Water Quality Index (WQI) that has been developed for drinking because it can easily condense complex water quality data sheets into a single form, and thoroughly assess the effects that current water sources have on local communities' socioeconomic conditions, public health, sanitation, and ecosystem. This research addresses the critical need for a general consideration of the water quality challenges in the study area and proposes effective strategies for sustainable water management.

1.3. Objectives of the Study

1.3.1. General objective

The main objectives of the research were to identify potential sources of pollution and evaluate the physic-chemical water quality and its suitability for drinking and irrigation purposes.

1.3.2. Specific objectives

The specific objectives of the study are:

- ✓ To identify potential sources of pollution in the Atebela River.
- ✓ To characterize the physicochemical parameters of Atebela River water
- ✓ To develop the water quality index WQI of the study area

1.4. Research Questions

The following questions have been formulated to achieve the research objectives.

- ✓ What are the potential sources of pollution that affect the Atebela River?
- ✓ What are the physiochemical parameters of Atebela River water?
- ✓ What is the water quality index of Atebela River water?

1.5. The Significance of the Study

The study into the physical and chemical characteristics of the Atebela River, an essential water source in semi-urban areas, has generated scientifically substantiated evidence. This research lengthily evaluates the river's suitability for various purposes, including drinking and irrigation, shedding light on its broader socio-economic and ecological implications. The local community heavily depends on the Atebela River for untreated drinking water and irrigation, unaware of its suitability for these purposes. This oversight underscores the urgency for engagement by concerned stakeholders to address the imminent threats posed by surface water pollution. The formulation of a Water Quality Index (WQI) specific to the selected water source, aligned with established standards, becomes vital in guiding the development of effective strategies for surface water protection. This includes addressing the effects of improperly managed solid waste runoff and the discharge of untreated industrial effluents into the river. A well-defined mitigation plan joined with a healthy monitoring framework, is essential for managing these issues effectively.

The outcomes of this study extend far beyond the realm of academia. They provide a crucial foundation for local communities, industries, and authorities to collaboratively design preventive measures. By fostering stakeholder engagement, the study aims to enhance public sanitation, prevent surface water pollution, and restore the overall functionality and services of the ecosystem.

Moreover, the findings act as a valuable resource for scholars, offering a basis for in-depth analyses of water quality and suitability for specific applications. The study's insights empower individuals, non-governmental organizations (NGOs), and local authorities to assume proactive roles in ensuring water quality enhancement. Overall, this research contributes significantly to the collective efforts directed toward sustainable water management and environmental conservation.

1.6. Scope and Limitation of the Study

The geographical scope of this study is to evaluate surface water quality and suitability for drinking and irrigation purposes for the case of the Atebela River in Sebeta town; Oromia regional state; Ethiopia.

Geographically bound between 8°50'20 " to $8^0$54'41"N latitude and from 38°34'9" to $38^0$36'25" E longitude at 2,356 above Sea Level. The study would be made to evaluate surface water quality and its suitability for drinking water by the local community and suitability analysis for irrigation purposes based on the WHO, the Food and Agricultural Organization (FAO), and Ethiopian drinking water standards (ES) and identification of potential point sourced pollution sources.

1.7. Thesis Organization

Chapter I: This section contains the introduction part which includes the background of the research, a statement of the problem, general objective, specific objectives, research questions, and the scope of the research.

Chapter II: - This section contains different reviewed literature organized under different topics that were related to the objective of this research work.

Chapter III: - This section outlines the method and procedures of how the research objective is executed. It includes a description of the study area, sample collection procedure, sources of data, etc.

Chapter IV - contains the results and discussion part of the research outputs.

Chapter V: -Is the conclusion and recommendation part of the research work?

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

This chapter provides an overview of some relevant definition concepts, and theoretical and empirical research based on the various factors influencing the development of water quality indices and the water's suitability for drinking and irrigation purposes. Finally, the study's conceptual framework was developed.

2.2. Water quality

Water quality is a term that describes the chemical, physical, and biological characteristics of water based on the standards of its usage. Water quality is important for human health as well as for the health of ecosystems. Some of the factors that affect water quality are the concentration of dissolved oxygen, bacteria levels, the amount of salt, the presence of pollutants, and the temperature of the water. Different uses of water require different levels of water quality. For example, drinking water needs to be free of harmful contaminants, such as heavy metals, pesticides, and pathogens. Swimming water needs to have low levels of bacteria and algae to prevent infections and irritation. (Eriksson & Sigvant, 2019)

Water quality can be measured by various methods, such as laboratory tests, field kits, sensors, and indicators. Water quality can also be improved by various treatments, such as filtration, disinfection, and aeration. However, many waterways in developing countries are heavily polluted because of human activities that affect surface water quality due to direct and indirect wastewater discharges, the use of agricultural chemicals, poor sewage facilities, and insufficient wastewater management amenities. (Adane et al., 2023)

2.3. Surface water quality

Water quality is influenced by many factors, like precipitation, climate, soil type, vegetation, geology, flow conditions, groundwater, and human activities. Drinking and irrigation water quality is a global issue due to contaminated water sources and inadequate sanitation practices, which affect human and environmental health and economic development. Both are uniquely vulnerable to pollution. Water quality is directly determined by analyzing the physical, chemical, and biological properties of the water by combining the influence of each water quality parameter into a single description. The water quality of any specific area and source frequently concerns the most important component of drinking and irrigation water, which can be assessed using physical, chemical, and biological parameters as well as consumer satisfaction. (Radaideh, 2022)

In general, water quality is the prime concern in developing nations due to poor governance, a lack of management infrastructure, a lack of stakeholder engagement and awareness, etc. (Abdary et al., 2022). The greatest threat to water quality is posed by point sources of industries and municipalities (Telila & Dawa, 2020). They also describe that water quality deals with the physical, chemical, and biological characteristics of water, as well as all other hydrological properties. It influences its suitability for a particular use, i.e., how well the quality fulfills the requirements of the user. Hence, the characteristics of water quality have become important in water resource planning and development for drinking, industrial, and irrigation purposes. Therefore, the suitability of water sources for human consumption has been described in terms of the Water Quality Index (WQI), which is one of the most effective ways to describe the quality of water. WQI utilizes the water quality data and helps in the modification of the policies, which are formulated by various environmental monitoring agencies (Abdary et al., 2022).

2.4. Potential Sources of Water Pollution and Types

These pollutants can be categorized as either point sources or non-point sources. Point-source pollution is pollution that comes from a single, identifiable source, such as a factory, a sewage plant, or a ship. Point-source pollution can affect both air and water quality and can introduce harmful chemicals, metals, pathogens, and other pollutants into the environment. Point-source pollution is easier to identify and regulate than non-point-source pollution (Vinod et al., 2018). Non-point-source pollution is pollution that comes from many sources or from sources that are not easily identified, such as runoff, atmospheric deposition, or natural processes. Non-point-source pollution can carry sediment, nutrients, pesticides, oil, trash, and other pollutants into water bodies, affecting their quality and ecology. Non-point-source pollution is harder to identify and control than point-source pollution and often requires changes in land use practices and public awareness (Tourism, 2013). Additional contaminants comprise plastic waste, packing materials, wood debris, waste paper, and cardboard, all of which have the potential to trap aquatic life. Chemical contaminants may include organic substances such as detergents, food processing wastes, insecticides, and herbicides, as well as inorganic substances such as fertilizers containing nitrate and phosphate, ammonium inorganic acids of industrial origin, and heavy metals (present in urban runoff and mine tailing area runoff). Protozoa, helminths, viruses, and other harmful microorganisms are examples of common biological pollutants. These are connected to poor sanitation and are frequently spread as water contaminants. They come from places like recreational grounds, animal feces, leaking septic tanks, and sewage treatment plants. Amoeba and parasitic worms like E. histolytica and helminths are also responsible for water contamination. (Gupta, 2017)

2.5. Factors that affect water quality

The importance of water quality is only going to grow in the future. Water quality is influenced by a wide range of factors. The two primary ones are those caused by humans and geology. Weathering and wind erosion are examples of geogenic forces that occur naturally. Water quality is significantly impacted by anthropogenic influences or causes that are created by humans (Gupta, 2017). Numerous living things, ecosystems, and other people may all suffer harm as a result of this man-made influence. Fossil fuel combustion results in increased chemical content that runs off into bodies of water, degrading the quality of the water and making it more hazardous. By ruining their natural habitat and polluting their surroundings, waste disposal can make it more difficult for organisms to survive.

2.6. Theoretical literature review

2.6.1. Physical Water Quality Parameters

Water quality is essential for future generations due to both natural and human-produced factors. Geogenic factors, such as wind erosion and weathering, and anthropogenic factors, like agriculture, industrialization, and urbanization, contribute to changes in water's physical characteristics (Gupta, 2017). Key parameters for evaluating water quality include temperature, turbidity, electrical conductivity (EC), total dissolved solids (TDS), and using standard analytical methods.

Temperature

Temperature has a significant impact on several related water variables and functions. Temperature fluctuations have a complex interaction with palatability, viscosity, solubility, smells, and chemical reactions. The temperature affects biological oxygen demand (BOD) and other significant water treatment processes including sedimentation and chlorination. Temperature variations have a major influence on the rate and efficiency of these processes. Furthermore, the bio-sorption process of heavy metals that have been dissolved is potentially significantly impacted by the temperature of the water. The overall quality of water resources is impacted by the temperature-dependent capacity of water to absorb and hold these metals through biological interactions. It is important to remember that people's preferences for water temperature also affect how acceptable it is in general. Most individuals believe that water tastes best when it is between 10 and 15 degrees Celsius. This ideal temperature range contributes to the perceived quality and happiness of consumers as well as improving the sensory experience of drinking water.

In summary, the primary element in determining the chemical, biological, and physical properties of water is its temperature. Its influence extends beyond treatment procedures to affect people's taste preferences, making it an important factor in water management and quality evaluation. (Axelsson, 2022). Temperature changes are frequently caused by the weather, groundwater inflows, impoundments, urban storm water runoff, and the absence of shade. Organic materials in water can decompose more quickly in hotter temperatures.

Turbidity

Turbidity serves as a measure of water cloudiness, gauging the extent to which light can penetrate through it. This haziness is primarily caused by suspended particles such as clay, silt, organic matter, plankton, and other particulates present in the water. For drinking water, turbidity is aesthetically undesirable as it imparts an unappetizing appearance. The ramifications of turbidity extend beyond mere visual concerns and encompass several critical points: Increased Treatment Costs: Turbidity elevates the cost of water treatment for various purposes, as the presence of suspended particles necessitates more rigorous and complex treatment processes. Microbial Shelter:

The suspended particles can act as shelters for harmful microorganisms, shielding them from disinfection processes and posing a potential threat to water quality and safety. Impact on Aquatic Life. Turbidity can adversely affect aquatic life. Suspended materials may clog or damage fish gills, reducing their resistance to diseases, impeding growth rates, and influencing the maturation of eggs and larvae. Additionally, it can disrupt fishing methods' efficiency. Adsorption of Pollutants: Particles in turbid water serve as adsorption media for heavy metals such as mercury, chromium, lead, cadmium, and various hazardous organic pollutants, including poly chlorinated biphenyls (PCBs), poly cyclic aromatic hydrocarbons (PAHs), and pesticides. (Lencha & Tränckner, 2021).

Temperature and Dissolved Oxygen Impact Higher turbidity raises water temperatures due to the absorption of more sunlight by suspended particles. This can reduce the concentration of dissolved oxygen (DO) since warm water carries less dissolved oxygen than cold water, impacting aquatic ecosystems and the availability of oxygen for organisms. Turbidity is quantified using a nephelometric turbid meter, expressing results in terms of NTU (Nephelometric Turbidity Units) or TU (Turbidity Units). One TU is equivalent to 1 mg/L of silica in suspension. Generally, turbidity exceeding 5 NTU becomes visible to the average person, and in muddy water, it can exceed 100 NTU. Groundwater typically maintains low turbidity levels due to natural filtration as water percolates through the soil. A high degree of turbidity can impair the irrigation system's efficiency, reduce the soil's hydraulic conductivity, and contaminate the soil's surface through surface flow. High turbidity levels in bodies of water, such as lakes, rivers, and reservoirs, can stunt the growth of submerged aquatic plants and have an impact on species that depend on them (Lencha & Tränckner, 2021).

Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) encapsulates the total particulate matter dissolved in a given volume of water, encompassing a spectrum of both organic and inorganic substances. This critical water quality indicator is measured in milligrams per liter (mg/L) or analogous concentration units and can be approximated through conductivity measurements using specialized instruments like conductivity meters, EC meters, or multi-parameter water quality analyzers. The diverse composition of TDS incorporates minerals (e.g., calcium, magnesium, sodium, potassium), salts (e.g., chlorine, sulfates, nitrates), acids, alkalis, organic matter (e.g., humic acid, organic acids), and suspended particles (such as colloidal particles and suspended solids). Human-induced activities, including industrial discharges, agricultural fertilizer use, and urban drainage, contribute to the introduction of varied dissolved substances, elevating TDS levels in water. (Li & Wu, 2019).

Considerable attention to TDS levels is imperative as it significantly impacts water suitability for drinking, agriculture, and industrial applications. It influences the taste, odor, and appearance of drinking water, directly affecting its acceptability. Higher TDS content may introduce a saltier taste and a slippery sensation, potentially diminishing water acceptability. Elevated TDS can compromise water cleanliness, affecting clarity and overall quality. When released into the environment, high TDS water poses threats to aquatic organisms, soil quality, and overall water ecosystems. Changes in TDS levels play a pivotal role in influencing water treatment processes, necessitating advanced methods to effectively eliminate dissolved substances. Certain industrial processes and agricultural practices demand low TDS water to avert detrimental impacts on equipment, products, and crop growth. Instruments such as conductivity meters and intelligent sensors are employed to measure TDS. Conductivity meters gauge water conductivity and convert it to TDS concentration using a calibrated curve, while intelligent sensors seamlessly integrate with water quality analyzers to automatically compute TDS concentration. The consequences of elevated TDS levels are far-reaching, including undesirable taste and odor, potential health implications, skin and hair issues, scale formation in pipes and appliances, and agricultural challenges. Rigorous monitoring and the implementation of appropriate water treatment measures are imperative to ensure consistent water quality and suitability for specific applications. (Guidelines, 2021)

Electrical Conductivity

Conductivity is a measure of water's ability to conduct electricity and serves as an indicator of the concentration of dissolved ionic solids and salinity. These dissolved ions, including salts of calcium, magnesium, and sodium, can influence water hardness and alkalinity. While high conductivity itself doesn't pose a direct risk to human health, it can lead to corrosion in industrial equipment and plumbing systems, scale build-up, a mineral-like taste in drinking water, and issues related to dissolved solid concentration in agriculture. The elevated conductivity may stem from natural sources such as minerals and rocks or human activities like industrial processes and runoff from roads.

Generally, natural sources seldom result in exceeding recommended limits and pose minimal risks to consumers. The accepted limit for drinking water conductivity is set at 2500 micro-Siemens per centimeter (µS/cm). It's important to note that high conductivity, in isolation, may not be a cause for immediate concern due to its limited direct health impacts.3 However, the presence of dissolved ion soluble solids can contribute to water hardness and alkalinity, potentially affecting consumer satisfaction. Managing and understanding these aspects of water quality are crucial for addressing issues related to taste, agricultural practices, and the longevity of infrastructure.(Corwin & Yemoto, 2017)

2.7. Chemical water quality parameters

The chemical water quality parameters for drinking and irrigation water are different. The parameters for drinking water are set to ensure that the water is safe for human consumption. The parameters for irrigation water are set to ensure that the water does not harm crops or soil quality. Some of the most significant chemical parameters that are used for evaluating the chemical quality of water are as follows: (Prosun et al., 2018)

Total suspended solids (TSS)

TSS, or total suspended solids, refers to particles in water that exceed 2 microns in size, while those smaller than 2 microns are considered total dissolved solids (TDS). Primarily contained inorganic materials, TSS can also include algae and bacteria. TSS involves a range of substances such as sand, sediment, and plankton, contributing to water's opacity.

Contaminated water sources, often from decaying plants or animals, release organic particles, constituting suspended solids. While some settle at the bottom, others remain suspended, affecting water clarity. TSS content inversely correlates with water clarity higher TSS levels result in murkier water (Of et al., 2016). Accurate measurement of TSS in wastewater involves TSS sensors or monitors, indicating the presence of suspended solids within a range of 1,000 mg/L to 8% solids. It's crucial to distinguish TSS sensors from TDS meters, the latter measuring dissolved solids, not suspended ones. For precise results, laboratory tests using the EPA method are recommended. (Sun et al., 2023). Erosion of river and stream banks increases TSS levels as released particles settle, causing water to appear murky. Runoff, flowing through eroding soil, produces similar outcomes. Elevated TSS in drinking water or wastewater poses environmental and health risks. In terms of water quality, high TSS reduces dissolved oxygen levels, raises water temperature, and hampers organisms' survival. Sunlight blockage disrupts photosynthesis, further lowering oxygen levels. In drinking water, TSS can affect human health; bacteria and algae may cause gastrointestinal issues, while pollutants like metals can lead to severe health effects. Common TSS, such as sand and silt, may harm plumbing and appliances but primarily cause aesthetic issues. (Sun et al., 2023)

Total Alkalinity.

Alkalinity, denoting water's resistance to pH changes that could render it more acidic, is key for safeguarding both human health and piping in drinking water systems. The term buffering capacity encapsulates this ability, signifying the water's capability to neutralize acids. A buffer solution allows the addition of acid without altering the concentration of available H+ ions, thus maintaining a stable PH. In practical terms, imagine adding a weak acid solution to two vials of water, both initially at pH 7. One with zero alkalinity will experience an immediate pH drop, while the other, possessing buffering power (e.g., alkalinity of 50 mg/l), will exhibit minimal to no pH change. The buffered solution's pH only shifts when its buffering capacity is overwhelmed. Factors like acidic sanitizers, rain, fill water, and product applications can impact the pH and alkalinity of well water (Gebreyohannes et al., 2015).

The primary source of alkalinity in surface water is calcium carbonate ($CaCO_3$), leached from soil and rocks, particularly in areas affected by urban development and mining. Limestone, rich in calcium carbonate, can elevate alkalinity levels when used to mitigate acidity at home. Alkalinity plays a pivotal role in wastewater and drinking water treatment, influencing processes like anaerobic digestion. If water surpasses the natural soil alkalinity level, it may become unsuitable for irrigation. Often confused with alkalinity, acid-neutralizing capacity (ANC) relates to both the solution and available solids, such as aquifer solids and suspended matter. Tit ration is the method for measuring alkalinity, involving the addition of a known-strength acid (tit rant) to a treated water sample until a specific pH is reached. The resulting alkalinity is expressed in milligrams per liter (mg/l) of $CaCO_3$.For drinking water, a pH scale of 0 to 14 is employed, with values below 7 indicating acidity, above 7 being alkaline or basic, and 7 representing neutrality (Renuka et al., 2015). A pH below 6.5 can contribute to fixture and pipe corrosion. Corrosiveness depends on factors like total dissolved solids, water temperature, alkalinity, and hardness. Water with a pH of 6.5 isn't a health risk, but corrosive water can dissolve metals like zinc, cadmium, lead, and copper, posing health concerns. Conversely, a pH above 8.5 may contribute to scale build-up, particularly in plumbing systems.

Aammonia

Ammonia is one of several forms of nitrogen that exist in aquatic environments. Unlike other forms of nitrogen, which can cause nutrient over-enrichment of a water body at elevated concentrations and indirect effects on aquatic life, ammonia causes direct toxic effects on aquatic life. In water, ammonia comes from the decomposition of organic matter like protein, amino acids, etc. Its concentration also increases during the water disinfection process using chloramine. In water, Ammonia (NH_3) is first oxidized into nitrite and then into nitrate.(Prosun et al., 2018).Therefore measuring the concentration of NH3, nitrite, and nitrate, can predict the time of contamination of organic matter in water. In recently contaminated water, the concentration of NH3 is much higher than nitrite and nitrate. The concentration of NH3 in the groundwater system is usually 3mg/ltr. If its concentration is greater than 50mg/ltr, it gives a characteristic taste and odor (Renuka et al., 2015).

Phosphate (PO43)

Phosphorus, as phosphate, is a plant nutrient that promotes the growth of algae and aquatic plants. Inorganic phosphates, such as those found in farm and home fertilizers, are attracted to soil particles and organic matter (Mereta et al., 2019). When soil particles with attached phosphates erode, they enter the water. Organic phosphates can be found in both human and animal waste. Phosphates can also be found in various detergents and wastewater from industrial processes. The amount of plant growth that occurs in a stream, lake, or reservoir is frequently limited. Adding phosphorus to bodies of water may cause excess plant growth. These plants can be large and grow from lake bottoms in shallow areas, or they can be microscopic algae (Mereta et al., 2019).

The amount of phosphorus in freshwater lakes and ponds determines the number of algae and plant growth that can occur. Phosphates can be produced in either particulate or dissolved form in bodies of water and ecosystems. The particulate phase includes living and dead plants, phosphorus precipitates, and phosphorus adsorbed to particulates (Ngatia, 2022). Organic phosphates are essential. The breakdown of organic pesticides containing phosphates may result in phosphate occurrence. Lakes and reservoir sediments serve as phosphorus basins. Phosphorus-containing particles settle to the substrate and are quickly covered by sediment (Kuenzler & Greer, 2008). Rainfall typically washes various amounts of phosphate compounds from agricultural lands or other topsoil into nearby receiving water. Phosphate will stimulate the growth of phytoplankton and water-living plants, which provide food for fish.

PH

The acidity or basicity of a water sample is determined by its pH value. 7 is considered neutral and the range is 0 to 14 (Maryani et al., 2016). The pH value influences the evaluation of the water quality for irrigation and drinking in multiple ways. The World Health Organization (WHO) states that the pH of drinking water should be between 6.5 and

8.5 Water with an excessively acidic or alkaline pH can taste harsh, irritate skin, damage pipes and appliances, and reduce the efficacy of disinfection. Excessively acidic water can also dissolve harmful metals like arsenic, mercury, and lead, which increases the toxicity and concentration of those metals in the water. (FAO, 2010).

The Food and Agriculture Organization recommends that irrigation water have a pH of between 6 and 8.5 The Food and Agriculture Organization (FAO) states that the pH of irrigation water should be between 6 and 8.5. (Sasakova et al., 2018). The availability and uptake of nutrients and minerals by plants, as well as the solubility of salts and pesticides in water, can all be impacted by too acidic or alkaline water. Overly acidic water can also accelerate the leaching of nutrients from the soil, whereas overly alkaline water can precipitate calcium and magnesium, which lowers the nutrients' availability to plants. Consequently, to guarantee the quality and suitability of water for drinking and irrigation, the pH value is a crucial parameter to monitor and control.

Fluoride

Fluoride is intentionally introduced into water as a preventive measure against tooth decay, contributing to improved dental health. Nonetheless, it is essential to balance the benefits with potential risks. Excessive levels of fluoride can lead to a dental condition known as fluorosis, impacting the appearance and strength of teeth. Dental fluorosis occurs when teeth are exposed to high concentrations of fluoride during their development, typically in childhood. This condition manifests as discoloration, pitting, or mottling of tooth enamel. While mild fluorosis may present as faint white streaks, severe cases can result in brown staining and enamel erosion (Gbolagade, 2021). To ensure public health and safety, regulatory authorities have established guidelines for acceptable fluoride levels in drinking water. The maximum permissible limit for fluoride in drinking water is set at 1.5 mg/L. This limit is carefully defined to provide the dental benefits of fluoride while minimizing the risk of adverse effects such as fluorosis. Regular monitoring and adherence to these standards are crucial to strike a balance between promoting oral health and preventing potential dental issues associated with excessive fluoride exposure

Total Hardness (TH)

Total hardness (TH) is a measure of the amount of dissolved calcium and magnesium in water. The hardness of water can have both positive and negative effects on drinking and irrigation. For drinking, hard water can harm the taste and quality of the water. It can also cause scaling in pipes and appliances, which can lead to higher maintenance costs. However, some studies suggest that hard water may have a protective effect against cardiovascular disease (Nafees, 2022). For irrigation, hard water can cause scaling in soil and irrigation systems, which can reduce the efficiency of the system and lead to higher maintenance costs. However, hard water can also provide plants with essential nutrients such as calcium and magnesium. It’s important to note that the acceptable levels of these parameters can vary depending on the intended use of water. For example, the acceptable levels of TDS and hardness for drinking water are different from those for irrigation water. (Metri et al., 2022).

Chemical oxygenated demand (COD)

The amount of oxygen required to oxidize the organic and inorganic compounds in water is measured by the chemical oxygen demand or COD. It serves as a gauge for the kind and quantity of contamination in water. Different factors, including COD, influence how water quality is assessed for irrigation and drinking. High COD levels can affect the color, taste, and odor of drinking water. Elevated quantities of carbon dioxide can potentially impede the process of disinfection and escalate the production of detrimental byproducts. Thus, low COD levels typically less than 10 mg/L are required by drinking water standards. High concentrations of COD in irrigation water can limit the amount of oxygen available to soil microbes and plant roots. In addition to making the water more poisonous and salinized, high COD levels can also have an impact on crop quality and output. As a result, modest COD levels, usually between 10 and 100 mg/L, are required by irrigation water regulations. The COD test, when used in conjunction with the BOD test, is useful in identifying hazardous circumstances and the presence of physiologically resistant organic compounds (Akbo & Ahsan, 2017).

Biochemical oxygenated demand (BOD)

Biochemical oxygen demand (BOD) is a measure of how much oxygen is needed by microorganisms to break down organic matter in water. BOD affects water quality for drinking and irrigation in different ways. For drinking water, high BOD levels can impair the taste, odor, and color of the water. High BOD levels can also interfere with the disinfection process and increase the formation of harmful by-products. Therefore, drinking water standards usually require low BOD levels, typically below 10 mg/L (Akbo & Ahsan, 2017). For irrigation water, high BOD levels can reduce the availability of oxygen for plant roots and soil microorganisms. High BOD levels can also increase the salinity and toxicity of the water, affecting crop yield and quality. Therefore, irrigation water standards usually require moderate BOD levels, typically between 10 and 100 mg/L. To measure BOD, various methods can be used, such as titration, colorimetric, or spectrophotometry. The most common method is the sealed tube method, which involves heating the water sample with a strong oxidizing agent and measuring the amount of oxygen consumed[3]. This method is fast, accurate, and easy to use, but it requires special equipment and reagents. The release of wastes with high BOD concentrations can cause water quality problems such as severe dissolved oxygen depletion and fish kills in the receiving water bodies (Deswati et al., 2021).

Iron

Iron is a common element in the earth's crust and can be present in natural waters in different forms, depending on the geology and the oxygen level of the water. Iron is an essential nutrient for plants and animals, but too much iron can cause problems for aquatic life and human health. Some of the effects of iron in water are Iron can promote the growth of algae, which can reduce the oxygen level, block the sunlight, and smother the benthic organisms in the water. Iron can cause aesthetic problems, such as discoloration of water, staining of plants and structures, and clogging of irrigation equipment (Deswati et al., 2021). Iron can affect the taste and odor of water, and may interfere with the disinfection process. Iron can cause health problems, such as iron overload, hemochromatosis, and bacterial infections the acceptable level of iron in water depends on the intended use and the water quality standards of the region. Generally, the recommended level of iron for drinking water is 0.3 mg/L or less, and for irrigation water is 0.1 mg/L or less. However, some plants and animals may require higher or lower levels of iron for optimal growth and development.

Potassium K+

Potassium is predominantly found in chemical compounds such as the potassium ion, K+. Approximately 95% of potassium is utilized in the production of fertilizers, while the remaining portion is primarily allocated to the synthesis of potassium hydroxide (KOH) (Gbolagade, 2021). This compound is generated through the electrolysis of potassium chloride solution and subsequently converted into potassium carbonate (K2CO3). Potassium carbonate plays a crucial role in glass manufacturing, particularly in the production of television screens, whereas potassium hydroxide is instrumental in the creation of liquid soaps and detergents. Additionally, a small fraction of potassium chloride finds applications in pharmaceuticals, medical drips, and saline injections. Beyond these industrial applications, potassium salts play diverse roles in baking, photography, leather tanning, and the production of iodized salts. Interestingly, the utility of these salts is primarily attributed to their negative anion rather than the potassium cation. Potassium assumes a pivotal role in plant nutrition, being one of the essential macro minerals alongside nitrogen and phosphorus. Its solubility in water doesn't lead to significant losses in undisturbed soils, as it quickly binds to clay particles, facilitating its retention for uptake by other plants. Potassium's primary functions in plants include maintaining osmotic pressure, influencing cell size, and impacting critical processes like photosynthesis, energy production, stomata opening, and nutrient translocation. A deficiency in potassium manifests in various symptoms, including restricted growth, reduced flowering, lower yields, and diminished produce quality. Conversely, excessive water-soluble potassium levels can harm germinating seedlings, impede the uptake of other minerals, and diminish crop quality. As a result, maintaining optimal potassium levels is crucial for soil health, robust plant growth, and balanced animal nutrition.

Manganese

Manganese has varying effects on how water quality is evaluated for irrigation and drinking. It can affect the color, taste, and odor of drinking water, making it less palatable to consumers. Additionally, manganese can impede the disinfection process and promote the production of hazardous byproducts. (Guidelines, 2021). Therefore, minimal manganese levels typically less than 0.05 mg/L are required by drinking water standards. Manganese can lower the amount of oxygen available to soil microbes and plant roots in irrigation water, which can have an impact on crop quality and output. Manganese can also make water more poisonous and salinized, which can lead to nutrient imbalances and stress on plants. Therefore, modest manganese levels typically between 0.05 and 0.2 mg/L are required by irrigation water requirements (Yohannes & Elias, 2017).

Boron

Boron, a chemical element present in both seawater and freshwater, serves as an essential nutrient for plant growth. However, excessive exposure to boron can have detrimental effects on plants, animals, and potentially humans. In the realm of water treatment, boron emerges as a critical regulatory concern for both drinking and irrigation water. Historically, the World Health Organization (WHO) set the maximum acceptable level of boron in drinking water at 0.5 milligrams per liter (mg/L) until 2008. Subsequently, in 2009, the WHO revised this limit to 2.4 mg/L (Cosgrove & Loucks, 2015). It is notable that despite these WHO recommendations, many countries opt for a lower maximum concentration due to the dual use of potable water for irrigation purposes. In agricultural settings, an excess of boron concentration can inflict damage on plants and crops. While boron is crucial as a trace element for plant growth, its toxicity becomes evident at higher concentrations, leading to leaf damage, premature ripening of certain species, and a reduction in fruit yield. For irrigation, water contaminated with boron can elicit a toxic response in plants cultivated hydroponically. The recommended boron concentration for optimal commercial plant nutrition is set at less than 1 part per million (ppm). Addressing boron in drinking water is best achieved through effective methods such as anion exchange filtration or a customized high-rejection reverse osmosis system. These advanced filtration techniques ensure the removal of boron, safeguarding the quality of water for consumption and agricultural use. Careful consideration of boron levels in both drinking and irrigation water underscores the importance of maintaining a balance that promotes plant health without compromising the well-being of ecosystems and human populations.

Barium

Barium, a chemical element naturally occurring in rocks, soil, and water, finds applications in various industrial processes such as drilling fluids, paints, and glass manufacturing. In the context of drinking water, elevated levels of barium can pose health risks, including issues like high blood pressure, heart rhythm changes, and muscle weakness. To safeguard public health, the US Environmental Protection Agency has established a maximum contaminant level (MCL) of 2 milligrams per liter (mg/L) for barium in drinking water(Jabeen et al., 2015). This precaution is aimed at mitigating the risk of nutrient runoff into water sources. Excessive exposure to barium is not only a concern for human health but can also be detrimental to plants. This can manifest as leaf damage, stunted growth, and a reduction in crop yield. For optimal commercial plant nutrition, maintaining barium concentration below 1 part per million (ppm) is recommended. These considerations emphasize the importance of carefully monitoring and managing barium levels in both water sources and agricultural practices. By adhering to established guidelines and adopting best practices, we can strike a balance between industrial applications of barium and the well-being of ecosystems, human health, and agricultural productivity.

Chromium

Chromium, a chemical element naturally occurring in the Earth's crust, plays a pivotal role in various industrial processes, including electroplating, leather tanning, and textile manufacturing. Its presence in surface water stems from runoff at industrial sites, discharge from wastewater treatment plants, and erosion of natural deposits. The quality of surface water for drinking and irrigation is influenced by the concentration and form of chromium. The United States Environmental Protection Agency (EPA) has established a maximum contaminant level (MCL) of 0.1 milligrams per liter (mg/L) for total chromium in drinking water (*Urban Wastewater Management Strategy*, 2015). This threshold encompasses all chromium forms, including chromium-6, a known carcinogen. For irrigation, the impact of chromium on crops hinges on its concentration in both soil and water. Elevated chromium levels can lead to crop damage and reduced yields. It's crucial to acknowledge that the effects on surface water quality vary based on location and conditions. Individuals concerned about the water quality for drinking or irrigation are advised to have it tested by a certified laboratory to ensure a comprehensive understanding of potential risks.

2.8. Water Quality Assessment Method

The degradation of surface water quality has emerged as a pressing global issue, prompting countries to prioritize water quality monitoring in their resource protection policies. In response, developing nations are intensifying efforts to evaluate river quality, a decisive step in preventing and controlling pollution. Monitoring and assessing water quality frequencies play a pivotal role in formulating effective management strategies against the backdrop of escalating urbanization and increased human activities around water resources.

Many water quality index (WQI) evaluation methods can be used and designed to determine the quality status of surface water for different purposes, locations, and expert assessments even when applied to the same surface water. The Canadian Council of Ministers of the Environment (CCME) WQI, Weighted Arithmetic WQI (CCME, 2001a) National Sanitation Foundation (NSF) WQI, Overall Water Quality Index (OWQI), Oregon WQI, and others are among those used globally (Banda & Kumarasamy, 2020). The CCME-WQI calculation is based on three significant terms (scope, frequency, and amplitude) to produce a single unit less (0-100) number representing overall water quality based on the selected benchmark value.(Tirkey et al., 2013)

The three terms to use combined are: The scope (F_1), represents the percentage of variables that do not meet their guideline values at least once during the time under consideration and are announced as failed variables relative to the total number of variables measured. The frequency, (F_2), communicates the percentage of individual tests that do not meet guideline values and are announced as failed tests. F1 and F2 are calculated directly and can be expressed as follows (Yousif & Chabuk, 2023)

Table 2.1. WQI according to CCME-WQI (Paun et al., 2016)

CCME	WQI
95–100	Excellent
80–94	Good
60–74	Fair
45–59	Marginal
0–44	Poor

Other water quality parameters and indexes necessary for irrigation practice such as Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), Soluble Sodium percentage (SSP), Permeability Index (PI), and Kelly ratio (KR) were evaluated with the following equations (Gbolagade, 2021):

2.9. Irrigation Water Quality Assessment Method

The wide chemical parameters used for estimating the level of suitability of water for irrigation are electrical conductivity, sodium percentage (%Na), and sodium adsorption ratio (SAR) (Tekile, 2023). Summary of water quality index determination method for suitability of water for irrigation (Atalay, 2018).

Table 2.2. Water quality index for irrigation (Atalay, 2018)

Parameter	**Formula**
Sodium adsorption ratio (SAR)	$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$
Residual sodium carbonate (RSC	$RSC = (HCO_3^{-} - CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$
Magnesium ratio (MR)	$MR = \left[\frac{Mg^{2+}}{Mg^{2+}+Ca^{2+}}\right] * 100$
Kelly's index (KI)	$KI = \frac{Na^{2+}}{Mg^{2+} + Ca^{2+}}$
Permeability index (PI)	$PI = \left[\frac{Na^{+}+HCO_3^{-}}{Ca^{2+}+Mg^{2+}+Na^{+}}\right]$
Potential salinity (PS)	$PS = Cl^{-} + 1/2SO_4^{2-}$

2.10. Empirical Literature Review

The different empirical studies related to surface water quality and suitability evaluation for drinking and irrigation purposes were accessed from unpublished and published research literature and some of them have been discussed below by classifying at a global scale in worldwide level and local scale at the country level**.** A large number of studies were published worldwide recently by applying many methods to evaluate water quality and suitability for drinking and irrigation purposes.

Some of the techniques could be reviewed from many of the studies that attempted to evaluate surface water quality based on the physcio chemical parameters that affect water quality at a site. ((Atalay, 2018)) had been done study on the assessment of surface water quality for irrigation purposes in a member district, Indonesia by analyzing physico chemical parameters (like ES, PH, Tw, HCO3-, NH3-N, and TDS) of surface water for the criteria of irrigation water quality and the result was evaluated based on water quality standards and FAO for irrigation water quality standards. Thus, the surface water of the study area was considered to be suitable for irrigation at the sampled location (Radaideh, 2022) and the suitability of Zarqa River water for irrigation by using the CCME-WQI approach. Using this approach, the Zarqa River WQI was calculated as 66.15 and 80.0 and this study revealed that even though the water of Zarqa River is unfit for drinking purposes, it is medium to highly suitable for irrigation. (Sharma et al., 2020) analyzed Yamuna River water pollution in India using 12 physico chemical parameters: TDS, Chlorides, Alkalinity, DO, Temperature, COD, BOD, PH, Magnesium, Hardness, Total Coliform, and Calcium using the water quality index. Similarly, (Yan SUNa,*, Zhuo Chen,*, 2021) used a WQI method to evaluate the suitability of the groundwater for drinking purposes using eighteen groundwater sampling points and fourteen parameters (EC, TDS, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, Cu, Fe, and F^-), and each parameter were also compared with WHO drinking guidelines to evaluate water quality for domestic use.

The water seemed to be okay for animal production and irrigation with careful handling, but it was bad for aquatic life and damaged the ecology. A substantial change in water quality measures between the dry and wet seasons was found using statistical analysis (p 0.05). The overall water quality status revealed issues that could constitute a serious risk; hence, steps should be implemented to enhance the quality and manage water to protect environmental safety and human health. (Haile and Mohammed, 2019) have assessed Lake Hawassa's water quality to locate probable sources of contamination and recommended the necessary countermeasures. By collecting samples from seven sampling sites, physicochemical water quality parameters have been determined, and the findings have been compared to WHO and FAO requirements.

The study also found that high levels of total dissolved solids (TDS, 928.3mg/L), electrical conductivity (EC, 1851.4 S/cm), turbidity (47.9 NTUs), fluoride (15.3 mg/L), and potassium (74.2 mg/L) indicated that the lake had also been contaminated by non-point source pollution brought on by urban storm water, agricultural runoff, overgrazing, deforestation, soil erosion, and land development. As a result, proactive steps should be taken to prevent lake pollution. Overall, Lake's water quality was poor and according to the modified Bascarón water quality index (MBWQI) methods (26.81-33.89) and weighted arithmetic methods (120.06- 228.29), respectively, the water quality is poor. (Li & Wu, 2019) &(FAO, 2010).

However, according to the Canadian Council of Ministers of the Environment (CCME) water quality index method, the quality was listed as marginal (44.2–51.1). According to this study WAWQI range (>100), the lake is unfit for all purposes. The physicochemical and biological properties of the lake indicate that it needs to be protected from eutrophication and pollution. (Lencha *et al*., 2022) have studied the fluxes for Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD5), Total Dissolved Solid (TDS), Total Nitrogen (TN), Nitrate and Nitrite-nitrogen (NOx-N), Total Phosphorous (TP), and Phosphate (PO4-P) have been determined using a combination of various models and monitoring data. Eight monitoring stations from rivers and point sources and six monitoring stations for storm water samples were used to collect and analyze water, wastewater, and storm water samples. Based on the comprehensive review of previous studies outlined in the preceding section, it is evident that the majority of research endeavors have focused on assessing water quality through the utilization of water quality indices and in-situ measurements of physical and chemical parameters. These studies have been conducted with specific objectives in mind, targeting various purposes ranging from environmental monitoring to resource management.

Despite the wealth of research in this domain, it is noteworthy that no similar study has been conducted specifically on the Atebala River. This gap in the existing literature underscores the need for dedicated investigations tailored to this particular water body, considering its unique geographical and ecological characteristics. By addressing this gap, future research endeavors can contribute valuable insights into the water quality dynamics of the Atebala River, facilitating informed decision-making and effective management strategies to safeguard its ecological integrity and ensure the well-being of communities reliant on its waters.

However, from all the reviewed previous studies and research in the previous section, most of the studies conducted determining the physical and chemical parameters of water quality using the water quality index and through in-situ measurements for specific purposes. Also, there is no similar study conducted on the Atebala River.

2.11. Conceptual Framework of Water Quality

A conceptual framework for evaluating surface water quality and suitability for drinking and irrigation is a set of principles, methods, and criteria that assess the quality of surface water sources for various purposes. It helps identify sources of water pollution, potential impacts, and risks of degradation and provides best management practices to improve water quality and protect human and environmental health.

Common methods include water quality indices (WQI), water quality standards and guidelines, and water quality models. WQI summarizes water quality based on physical, chemical, and biological indicators, while standards and guidelines specify acceptable levels for various uses. Water quality models simulate physical, chemical, and biological processes affecting water quality, predicting current and future conditions, and supporting planning and management of water resources.

Combining these methods and tools can form a comprehensive framework for addressing water quality management and protection in a changing specified area. these are contextualized to the current study to formulate a simplified view (framework) for identifying potential sources of pollutants and evaluating water quality and suitability for drinking and irrigation purposes. To evaluate water quality and its suitability some necessarily important water samples needed to be collected from relevant to a particular study area.

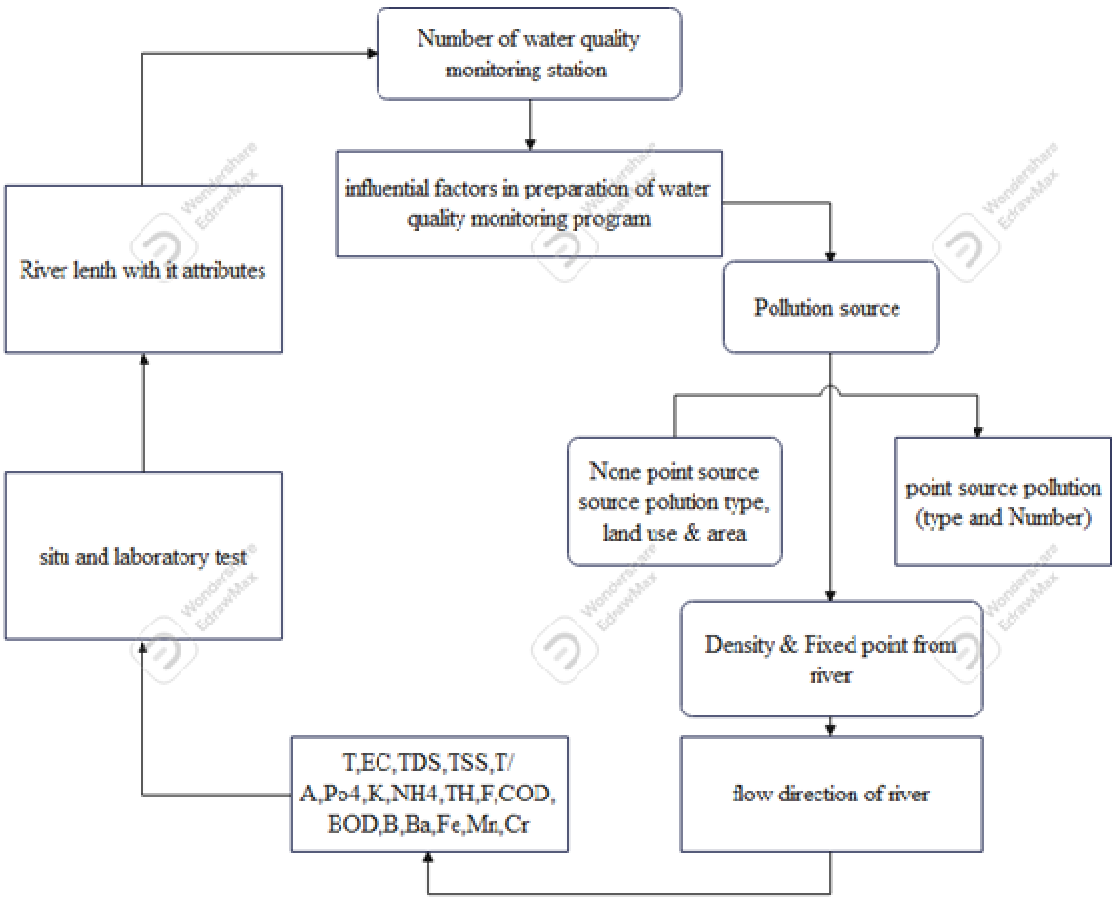

Figure 2.1. Frame Work of River Water Quality Assessment

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The research was carried out in the upper Awash River Basin of Ethiopia, with a specific focus on Sebeta Town and the Sebeta Hawas Basin or watershed (see Figure 1). This area is located upstream of Melkaqunxure and has coordinates between 8° 35' N and 8° 59' N in latitude and 38° 35' E and 38° 39' longitude.

The study has been incorporated into the Awash River system and covers an area of 11.2 km². The Atebla River flows through Sebeta Town, which is located about 11.2 kilometers southeast of Addis Ababa and is a tributary of the Awash River. It is located in the southwest Shoa Zone and is an indispensable component of Sheger City in the Oromia Regional State. It serves as the administrative center of the Sebeta Sub City within the Sheger district. Especially, Sebeta Town is known as one of the major small, medium, and large industrial zones.

Generally, the topography of the district reveals a diverse landscape, with approximately 70% characterized as plain land, 5% as mountainous (hilly) terrain, 20% as rugged terrain, and the remaining 5% as other features. The district's altitude varies significantly, ranging from 1800 meters to 3391 meters above mean sea level. Many rivers and springs grace the district, with some maintaining a steady flow throughout the year. Among these watercourses, the perennial rivers of utmost importance include the Upper Awash, Little Akaki, and Atebela. The focal point of this study, the Atebela River, stretches over 11.2 kilometers, originating from Wochecha Mountain and concluding its journey in the Upper Awash River. Atebela River plays a pivotal role as the primary conduit channeling all runoff from the catchment toward the Awash River.

The annual average rainfall is 1315.2 mm. The mean annual temperature is around 23.5°C. The lowest temperature occurs during the main rainy season; however, seasonal temperature variation is not pronounced. Eucalyptus trees are found in the mountains, in open spaces, and within homesteads, whereas shrubs and bush, riverine being the dominant, dense woodlands, grassland, and open shrubs are the prominent types of vegetation that are found in the study area. The main land use categories are cultivation of annual crops and livestock grazing and urban centers. Crop production has got a lion’s share of the existing land use than livestock rearing due to high teff production area. Nevertheless, it is an essential part of agricultural practices to back up crop production. Wheat and teff crops are entirely based on rainfall; besides, root crops and vegetables are produced along the Atebla River using an irrigation system.

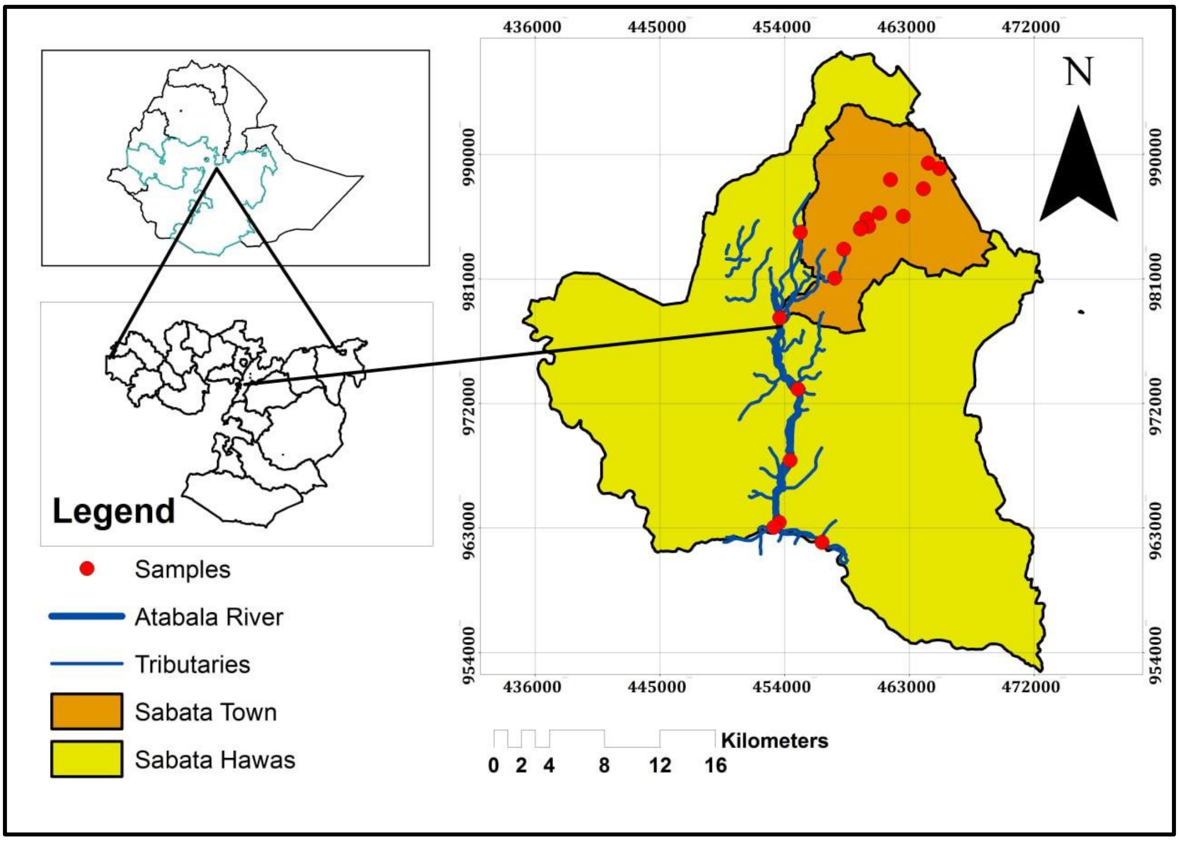

Figure 3.1. Description of the study area

3.2. Sample Site Selection

For the water quality analysis, sampling sites were purposely selected along the course of the river based on the accessibility, homogeneity, mixing, and identifiable of pollution sources. The chosen sampling sites were primarily located at the downstream areas of industries that discharge effluents into the river. A total of 17 sampling sites were exactly identified along the water course based on the length and property of the river passing through the Furi, Sebeta, and Sebeta Hawas districts. These included locations downstream of a bridge furi industrial discharge, the Ethiopian National Alcohol effluent discharge point, Arba Minch Textile site, Atebela River near an industry effluent at the old bridge, middle Atebela with industrial close presence, Atebela River at the confluence with Awash River, a farm field point, and the end of Atebla River before its joining to the Melkaqunxure

Table 3.1.List of sample sites with geographical reference points

S. No	Sample point	ID. No	Coordinate (X, Y)	Altitude
S-01	Furi Bridge	Sebeta town	465,159-988,979	2,251
S-02	Abadir Borehole site.	Sebeta	464,005-987,527	2,263
S-03	Daleti Steam site.	Sebeta	462,530-985,543	2,245
S-04	National Alcohol site	Sebeta	459,925-985,346	2,213
S-05	Arbaminch Textile	Sebeta	460,041, -984,804	2,196
S-06	Atebela River	Sebeta	459,497-984,705	2,178
S-07	Atebela River at Old Bridge	Sebeta	459,447-984,616	2,170
S-08	Awash River after Melka Kanture	Sebeta	455,100-984,371	2,143
S-09	Atebeba River in the middle	Sebeta	458,255-983,156	2,135
S-10	Atebela River	Sebeta Hawas	457,593-981,053	2,091
S-11	Atebela River	Sebeta Hawas	453,587-963,421	1,999
S-12	Awash River	Sebeta Hawas	453,192-963,078	2,005
S-13	Atebela River in Mogoro	Sebeta Hawas	456,671-961,980	1,993
S-14	Supper Double T	Sebeta Hawas	460,829-985,767	2,246
S-15	At melkaqunxure	Sebeta Hawas	461,627-988,172	2,354
S-16	Atebela at joining Awash	Sebeta Hawas	464357,989381	2,284
S-17	Awash river	Sebeta side	467429,971484	2,020

3.3. Methods of Data Collection.

The wastewater samples from the Atebela River were carefully collected in the months of April, May, and June of 2023, with consideration given to spatial dynamics in order to efficiently capture and modify spatial variants. Using the standard sampling procedure APHA 2018, water samples for the following quality analysis were collected in pre-washed 2000 mL PVC plastic bottles. Each container was appropriately labeled in the field. The collected water samples were temporarily kept in ice-packed coolers during transportation to the laboratory and then stored in a refrigerator at 4°C before analysis. To confirm accuracy and reliability, all analyses in this study were conducted in triplicate. To address both cross-sectional and longitudinal variations, water samples were taken from three distinct points (left, right, and center) at each sampling location. Following this, one-third of the water sample from each point was joined in a plastic bottle to create a merged sample for laboratory testing. Table 3.1 and figures 1-14 in the annex show the main potential source of pollution where the samples were collected.

This systematic and thorough sampling methodology, coupled with the stringent attention to reliability and quality control measures, lays a healthy foundation for the accuracy and validity of the subsequent water quality analyses conducted in the laboratories.

3.4. Sample Analytical Methods

A general evaluation was conducted to assess the suitability of water for both drinking and irrigation purposes. This involved an inclusive examination of major physicochemical parameters associated with potential water quality issues to gain valuable insights into its overall condition and compatibility with human consumption and agricultural practices.

The evaluation analyzed key factors, including pH levels, turbidity, total dissolved solids (TDS), electrical conductivity, and concentrations of essential ions such as Total Alkalinity, magnesium, fluoride, and potassium. Additionally, potentially harmful substances such as heavy metals, Boron, iron, Barium, Manganese, and chromium were investigated for irrigation. Various physicochemical parameters associated with water quality problems were assessed for infiltration and specific ion toxicity, including sodium, magnesium, potassium, EC, boron, chromium, and PH. The particular process adhered to stringent standards from sample collection and preservation to transportation and laboratory analysis, ensuring the integrity of samples and the accuracy of results. All physicochemical analyses followed the methods outlined in the (APHA 2018), enhancing the credibility of findings and facilitating comparison with other studies, providing an inclusive consideration of the Atebela River's water quality.

Standard analytical methods (APHA, 2018) were used to analyze water quality parameters. PH and temperature were measured in situ using the HQ40d portable multi-parameter meter. Turbidity levels were determined on-site using a turbid meter. TDS was measured by evaporating the liquid solvent, and TSS was determined by filtering a well-mixed sample. Potassium and ammonium levels were measured colorimetrically, while K+ was measured using flame photometry. Total hardness was determined through a titration method, and fluoride levels were measured using an ion-selective electrode or spectrophotometric method. BOD is measured by incubating a sample of water for 5 days at 200c and measuring the dissolved oxygen concentration before and after incubation. The difference between the two concentrations is the BOD. BOD values can be used to estimate the amount of organic pollution in a water body.

COD was measured by the colorimetric analysis after oxidizing the COD with acid and using indicator compounds, such as hexavalent dichromate. however, some compounds will interfere with the colorimetric analysis, and titration is required to determine COD levels., Boron, barium, iron, magnesium, and chromium were determined using atomic absorption spectroscopy (AAS) or inductively coupled plasma mass spectrometry (ICP-MS). High-purity and analytical-grade chemicals were used to ensure the reliability of the obtained results. Boron, barium, iron, magnesium, and chromium were determined using atomic absorption spectroscopy (AAS) or inductively coupled plasma mass spectrometry (ICP-MS). High-purity and analytical-grade chemicals were used to ensure the reliability of the obtained results.

3.5. Water quality indices

Water Quality Indices (WQIs) offer a complete assessment of water suitability for various purposes. Despite the challenge of condensing the quality of surface water into a specific index (Addisie, 2020; Radaideh, 2022), the water quality indices as highly valuable and effective tools for surface water quality assessment. (Meghalaya, 2016; Yousif & Chabuk, 2023): Presently, Water quality indices find widespread use among researchers, water managers, and scientists worldwide. Consequently, the current study employs a water quality index to evaluate the quality of surface water in the study area.

3.5.1. Analysis of the Water Quality Index (WQI)

The research evaluated the water quality in Atebela River, employing the Water Quality Index (WQI) and following the standards set by the Canadian Council of Ministers-Environment (CCME-WQI). This index's calculation strategically classified water quality into five distinct classes: excellent, good, fair, marginal, and poor. This multi-class categorization facilitates a nuanced and comprehensive understanding of the water quality, enabling effective interpretation and communication of the study's results. The selection of the CCME-WQI method was deliberate, selected for easy calculation, and was sufficiently flexible that it can be applied in a variety of situations to the specific local conditions of Atebela River. By utilizing this standard, the study aimed to ensure that the assessment accurately reflected the unique environmental factors and challenges present in the region. The adoption of the CCME-WQI method communicates the commitment to precision and applicability in evaluating Atebela River's water quality, making the findings more meaningful and actionable for both local stakeholders and the broader scientific community.

To obtain WQI of the study area through the CCME WQI assessment method, the following steps and formula were followed:

Step 1: calculating the scope value (F1 value)

$$F1 = \frac{Number\ of\ failed\ value}{Total\ number\ of\ variable} * 100 \qquad \ldots\ldots 3.1$$

Step 2: calculating the frequency value (F2 value)

$$F2 = \frac{Number\ of\ failed\ Test}{Total\ number\ of\ Test} * 100 \qquad \ldots\ldots 3.2$$

Step 3: calculating the Amplitude value (F3 value): to calculate F3, the following three sub-steps were followed: steps 3.1: when the test value must exceed the objective

$$Excursion\ i = \frac{Failed\ Test\ value}{Objective\ i} - 1 \qquad \ldots\ldots 3.3$$

Or if the cases in which the test value must not fall below the objective

$$Excursion\ i = \frac{objective}{Failed\ test\ value} - 1 \qquad \ldots\ldots 3.4$$

Steps 3.2: Normalized sum of excursions (NSE):

$$NSE = \frac{\sum_{i=1}^{n} Excursion\ i}{Total\ number\ of\ Test} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots.. \; 3.5$$

Steps 3.3: Determine the asymptotic function that scales the normalized sum of excursions from objectives (NSE) to yield a range between 0 and 100.

$$F3 = \frac{NSE}{0.01NSE + 0.01} - 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.... \; 3.6$$

Then following the above steps, the CCME WQI of the study area was calculated using the equation (Eq.)

$$CCME\ WQI = 100 - \frac{\sqrt{F1 + F2 + F3}}{1.732} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \ldots\ldots\ldots \; 3.7$$

Where, F1 (Scope) = Number of variables whose objectives are not met.

F1= [No. of failed variables/Total no. of variables] *100……………………………… 3.8

F2 (Frequency) = Number of times by which the objectives are not met.

F2= [No. of failed tests/Total no of tests] *100 ………………………… …………. 3.9

F3 (Amplitude) = Amount by which the objectives are not met.

Suitability Analysis for Irrigation

Sodium Adsorption Ratio (SAR): The Sodium Adsorption Ratio (SAR) is a parameter used to assess the suitability of surface water for irrigation, based on the concentrations of alkaline and alkaline cautions. It estimates the tendency of sodium to increase at cation exchange sites.

The SAR value is calculated using the formula

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \; 3.10$$

Soluble Sodium Percent (SSP) or (%Na): The soluble sodium content is another index used to classify irrigation water because irrigation water with a higher sodium level has less permeability (Adeyemi et al., 2019) and has proposed a classification scheme for rating irrigation waters based on soluble sodium percentage (SSP). The values of SSP less than 50mg/indicate good quality of water and higher values (i.e.>50meq/l) show that the water is unsafe for irrigation. From these figures, it is observed that 100 percent of the water in the dry season as well as the rainy season has good quality water and is safe for irrigation purposes.

Soluble Sodium Percent (SSP):

$$SSP = \frac{Na^{+}}{Total\ cation\ concetration} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.11$$

$$SSP = \frac{Na^{+}}{Total\ Cation\ Concetration} * 100$$

$$= \frac{Na^{+}}{Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ \ldots\ldots\ldots.\ 3.12$$

Or

Sodium percentage (%Na):

$$\%Na = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ \ldots\ldots..\ 3.13$$

Residual Sodium Carbonate (RSC):

$$RSC = [CO_3^{2-} + HCO_3^{-}] - [Ca^{2+} + Mg^{2+}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.14$$

Permeability Index (PI):

The Permeability Index (PI) values greater than 75mg/l indicate excellent quality of water for irrigation. If the PI values are between 25 meq/land and 75meq/l, it indicates good quality of water for irrigation. However, if the PI values are less than 25meq/l, it shows the unsuitable nature of water for irrigation (Table 4). Permeability Index (PI) of water is a function of sodium, calcium, Magnesium, and carbonate in the soil.

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} * 100 \ldots\ldots..\ \ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots\ \ldots\ldots\ldots\ 3.15$$

Kelly Index (KI) or Kelly (KR):

The Kelly's ratio of unity or less than one is indicative of good quality of water for irrigation whereas above one is suggestive of unsuitability for agricultural purposes due to alkali hazards. From these figures, both in dry season as well as rainy season were observed to be 100 percent good. The area has good quality water for irrigation purposes due to non-alkali hazards in the water.

$$KI\ (KP) = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad \text{.. .... 3.16}$$

Magnesium Adsorption Ratio (MAR):

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100 \quad \text{.. 3.17}$$

3.6. Statistical Analysis Methods

The Statistical Package for Social Sciences (SPSS software version 26) and Microsoft Office Excel 2010 were used for mathematical, statistical, and data analysis tasks. When evaluating regional variation in river water quality and identifying potential human drivers of water quality patterns at river monitoring sites, multivariate statistics can be a helpful tool. The data analysis for this study included the use of piper plot, principal components analysis (PCA), and cluster analysis (CA). The use of cluster analysis (CA) is widespread.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Potential source of pollution identified

The sources of pollutants in the study area were identified through careful field observations and thorough analysis of water samples to identify and know the social and environmental challenges arising from liquid, solid, and wastewater pollution. Accordingly, various sources of pollution, with industrial, municipal, mining, commercial, and agricultural activities are identified as major pollution sources. The diverse array of human activities in the area has resulted in the release of pollutants into water bodies, causing a range of environmental and social problems. Thus, the River faces a significant threat from various sources of pollution, primarily stemming from industrial, municipal, medical, and agricultural activities. Industrial waste, generated through manufacturing processes and emissions, poses a substantial risk to the river's water quality. This may include pollutants such as heavy metals, chemicals, and other harmful substances that can adversely impact aquatic ecosystems and human health. Some industries have been identified as significant contributors to the pollution of the Atebela River. These include textiles, beverages, breweries, alcohol production, food processing, agricultural input, metalworking, pulp and paper manufacturing, agrochemical production, paint manufacturing, and tanneries. These industries release various pollutants into the river, such as chemicals, heavy metals, organic compounds, and other harmful substances, posing a considerable threat to the water quality and overall ecosystem health of the Atebela River.(Sasakova et al., 2018)

Municipal waste, originating from urban areas along the riverbanks, contributes to the pollution load. Improper disposal of household waste, inadequate waste management systems, and untreated sewage can introduce contaminants into the Atebela River, compromising its overall ecological integrity. Medical waste disposal is another crucial concern, as improper handling and disposal of medical waste from healthcare facilities can introduce hazardous materials into the water. This includes infectious agents, pharmaceutical residues, and other potentially harmful substances, posing a direct threat to the health of aquatic organisms and downstream communities.

Agricultural activities also play a significant role in polluting the Atebela River. Runoff from farms carrying fertilizers, pesticides, and sedimentation can lead to nutrient enrichment and water quality degradation. The excessive use of agricultural inputs, such as fertilizers and pesticides, can result in nutrient imbalances and the introduction of harmful chemicals into the water, further exacerbating the pollution levels in the river.

Table 4.1. A potential source of pollution and its chemical constituent in the study area

S/No	A potential source of pollution	Chemical composition
1	Domestic Waste and Slaughter House	flowers, vegetables, and fruit, kitchen waste, leaves, batteries, paints, old medicines, and other chemicals glass, cardboard, paper, plastics, and metals, Soiled Waste: nappies, cloth soiled with bodily fluids, animal waste
2	Tenant textile and tanner	Chromium, Manganese, alkalis, residual color, starches, cellulose, and another toxic chemical released from
3	Food processing, Paint factor, and Alcohol and Brewery	Oil, Fat, Grease, Ammonia, Nitrogen
4	Agrochemicals	Phosphorous, Oil, Fat, Mercury, Chromium, Copper, Phenol, Ammonia, Nitrate, Fluoride, Cadmium
5	Metalwork, Iron and Steel	Cadmium, Lead, Zinc, Mercury, Nickel, Cyanide, Arsenic, Phosphorous, Fluoride, Iron, etc.
6	Malting, brewing, distilling, production of wines and other alcoholic liquors	BOD5 at 200C, COD, Suspended Solids, Total ammonia (as N), Total Nitrogen (as N), Total Phosphorus (as P), oils, fats, and grease.

The results show that based on the WHO,2022 water quality standard, most of the pollution sources have a high content of EC, TDS, and HCO_3^{2-} and PH Paint Factory and Tenant Textile) when compared with the WHO standard. Therefore, EC, TDS, HCO_3^{2-} and PH are the most important parameters caused by water pollution that influence the water quality of the study area.

4.2. Physic-Chemical Water Quality of Atebela River identified.

The physicochemical characterization of the surface water samples is detailed in Table 1, providing a comprehensive overview of the analytical data. Computed values and statistical metrics, including minimum, maximum, mean, and standard deviation, were generated using SPSS and are presented in Table 2. This statistical analysis enhances the interpretation of the data, offering valuable insights into the variability and distribution of key parameters across the sampled locations.

4.2.1. Suitability for drinking

Temperature

Surface water samples showed a temperature range of 18.12 to 23.9°C, with a mean of 18.70°C in the Atebela River system. Particularly, these values remained within the prescribed range set by the World Health Organization (WHO,2022) for drinking water. The elevated temperatures observed can be attributed to prevailing climatic conditions during the sampling period and limited river flow, particularly at certain points.

The temperature at sample points S-03, S-06, S-16, and S-17 exceeds the standard limit due to high levels of wastewater discharged from industries, domestic waste, and other sources. This irregularity is confirmed by laboratory results.

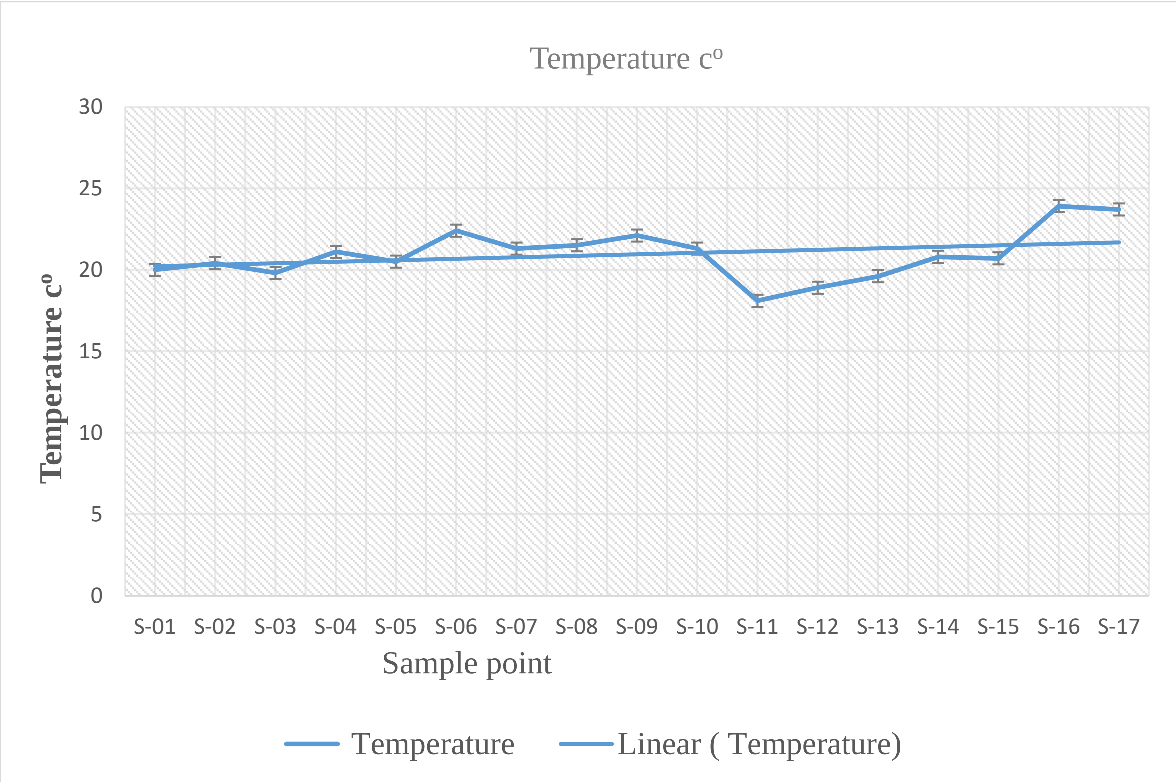

Figure 4.1. Temperature measured value

PH

The pH values of the water verified a wide variability, varying from 5.5 to 9. This difference implies that the water body's characteristics range from somewhat acidic to somewhat alkaline. The study's conclusions emphasized that most of the water samples' pH readings fell within acceptable ranges. The fact that two particular sites S-02 and S-09 deviated from these acceptable limits, due to highly polluted sources occurred in the sample point. However, is significant because it suggests possible areas of concern for environmental health and water quality management.

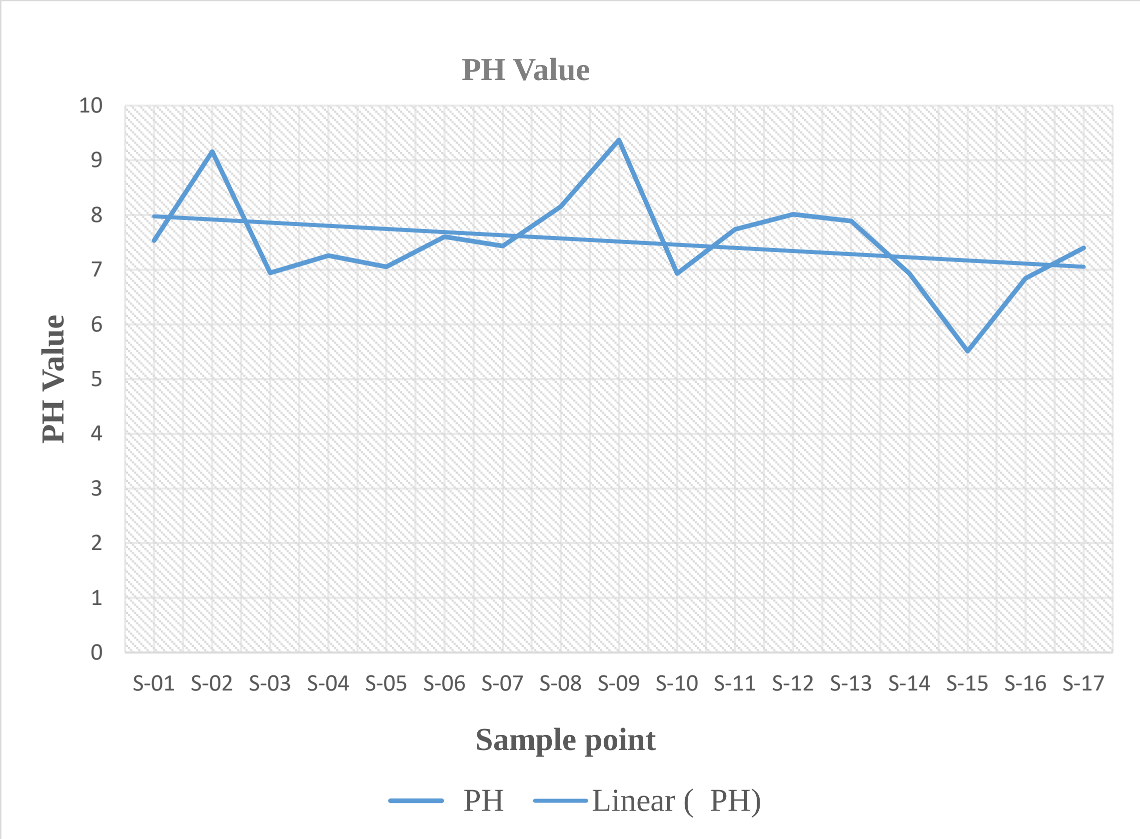

Figure 4.2. PH measured value

Electric conductivity

The analysis of electrical conductivity (EC) levels, measured in µmhos/cm at 25°C, revealed a considerable range from 257 to 3390, with an average value of 870.6. Notably, at sampling sites S-08 and S-09, the conductivity was notably influenced by point source wastewater discharge, signifying a localized impact on the overall conductivity of the river water in those areas. This underscores the importance of identifying and addressing specific point sources to mitigate their effects on water quality parameters.

While EC serves as a versatile indicator for assessing water quality in various contexts, it's crucial to delve deeper into its implications, particularly concerning drinking water.

Elevated conductivity levels are indicative of increased concentrations of ions such as calcium, magnesium, sodium, and potassium, which are essential elements to consider from a potable water standpoint. Excessive levels of these ions can lead to undesirable taste and may have health implications, necessitating careful monitoring and management to ensure the safety and palatability of drinking water derived from these sources.

Furthermore, beyond its relevance for drinking water, EC also plays a pivotal role in evaluating water suitability for agricultural purposes. As such, understanding the factors influencing EC variations, such as point source inputs, is vital for implementing targeted measures to maintain water quality standards across diverse usage scenarios. By comprehensively assessing EC levels and their associated implications, stakeholders can proactively address potential challenges and uphold the integrity of water resources for both human consumption and agricultural sustainability

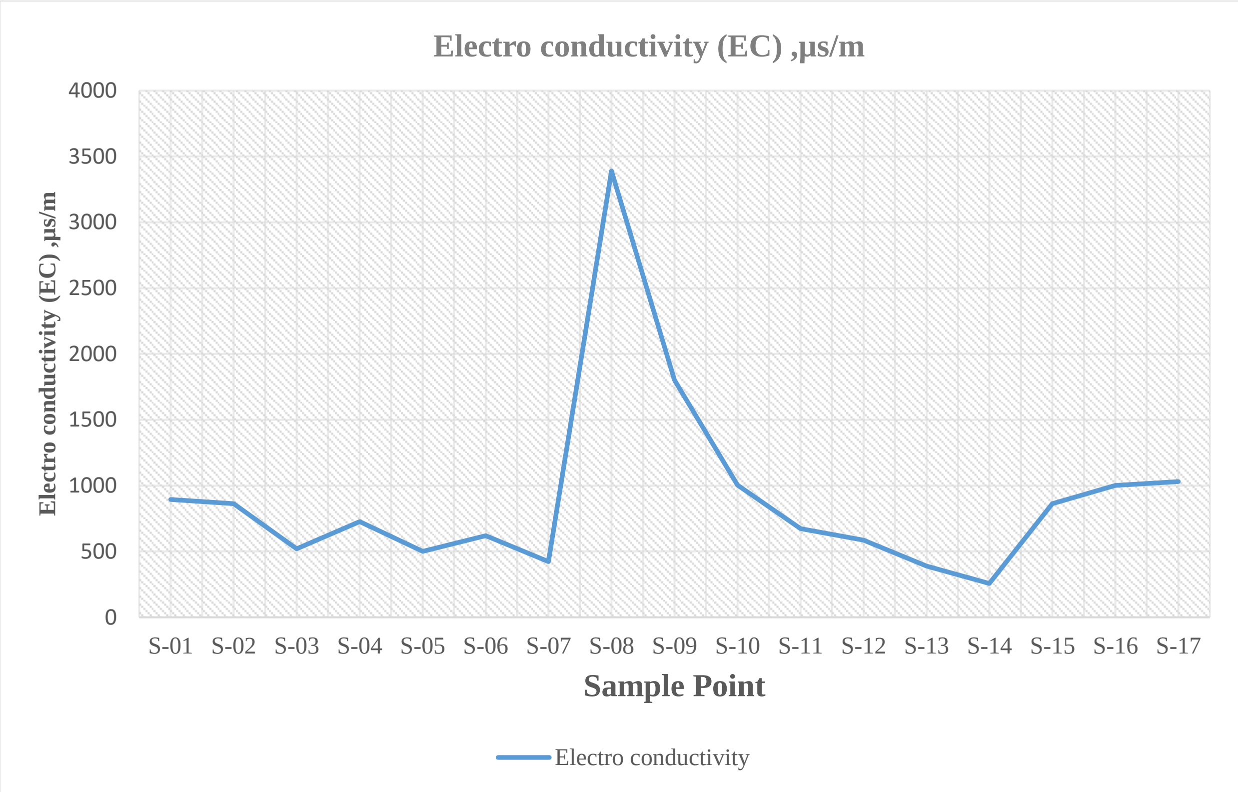

Figure 4.3. electric conductivity measured value

Total dissolved Solids (TDS)

The analysis of Total Dissolved Solids (TDS) in the water samples revealed a range spanning from 128.5 to 1695 mg/l, with an average concentration of 455.7 mg/l. Notably, water characterized by TDS levels below 1000 mg/l is generally deemed suitable for domestic use, reflecting its relatively low mineral content. Across all sampling stations, the

TDS concentrations remained within the established standard limit for drinking water, except for sites S-08 and S-10, where concentrations exceeded the prescribed threshold.
The elevated TDS levels observed at these specific sites can be attributed to a higher concentration of dissolved salts, including sodium, calcium, and magnesium, within the river water. This finding underscores the importance of monitoring these key elements to assess overall water quality comprehensively. Elevated TDS levels can potentially affect the taste and palatability of water, as well as have implications for human health if consumed at excessive levels over extended periods.
Moreover, beyond its immediate impact on drinking water quality, elevated TDS levels may also influence ecosystem health and agricultural practices in the surrounding areas. Excessive concentrations of dissolved solids can affect soil fertility, irrigation practices, and aquatic habitats, necessitating holistic management approaches to mitigate potential adverse effects on both human and environmental well-being.
Given these findings, targeted monitoring and management strategies are essential to address localized TDS exceedances and ensure the sustainable use and management of water resources. By understanding the factors contributing to TDS variations and their associated implications, stakeholders can implement effective measures to safeguard water quality and support the diverse needs of communities reliant on these vital resources.

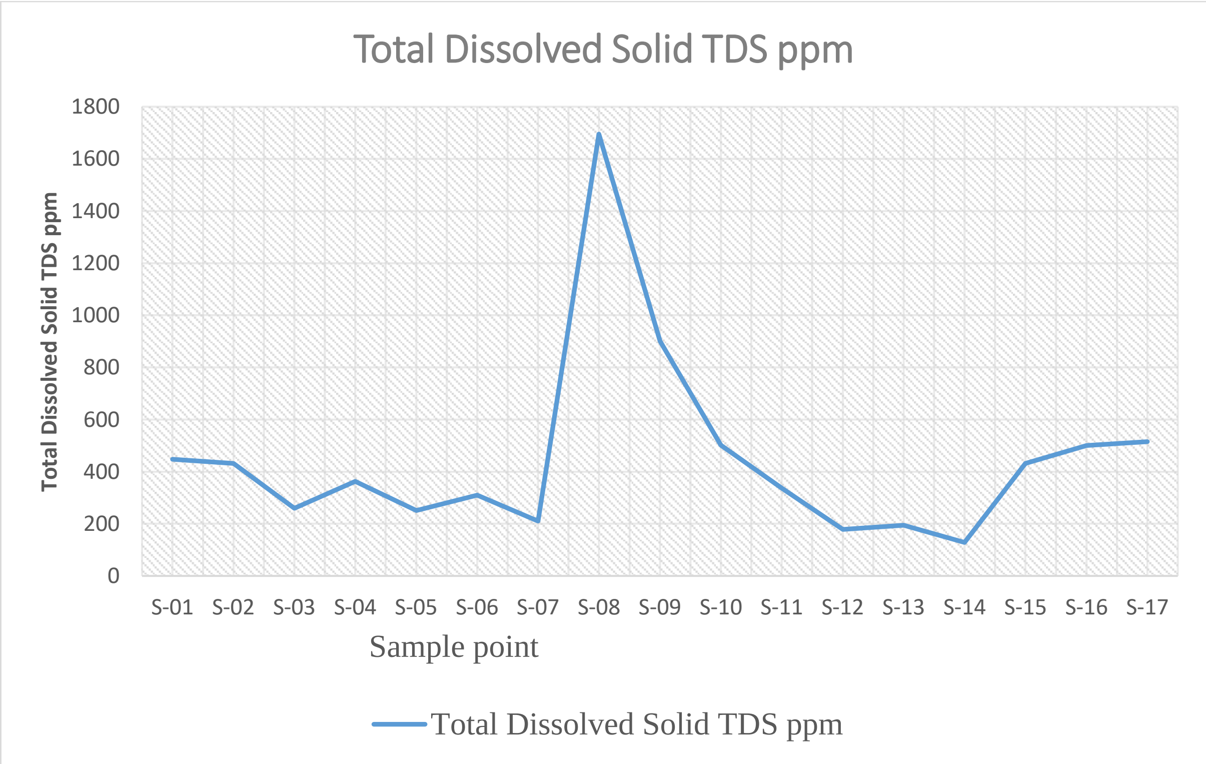

Figure 4.4. Total Dissolved solid TDS ppm measured value

Total suspended solid (TSS)

The total suspended solids (TSS) in the water showed a substantial range, spanning from 16 to 1380. Notably, during the study, elevated levels of total suspended solids were identified at many stations, specifically at S-02, S-04, S-05, S-06, S-07, S-08, S-09, S-10, S-14, S-15, S-16, and S-18. At these particular locations, the presence of high concentrations of suspended particles concentrated the total dissolved solids unsuitable for drinking purposes. This suggests a sensitive potential for water quality degradation at these sites, underscoring the importance of addressing and mitigating the sources contributing to the elevated levels of total suspended solids. Further investigations into the specific nature and sources of these suspended particles at each station would be valuable for implementing targeted remediation measures.

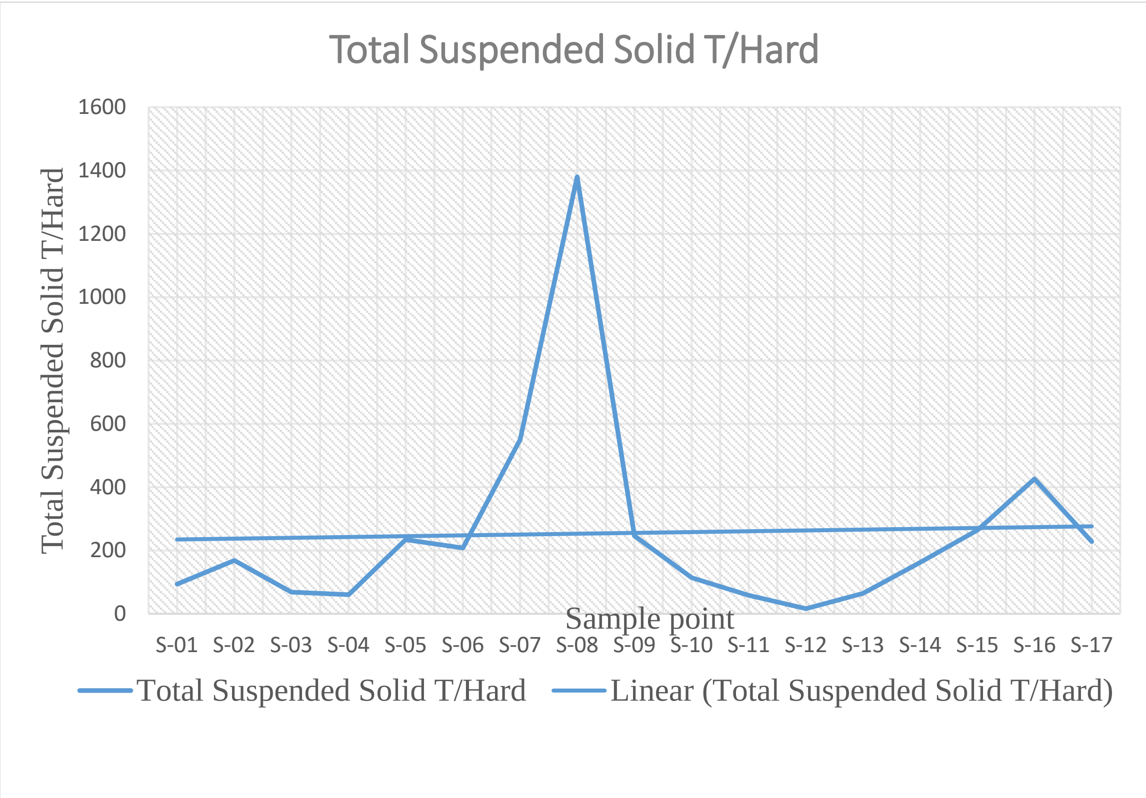

Figure 4.5. Total suspended solid measured value

Total Alkalinity

The total alkalinity of the water ranged from 100 to 420, with a mean value of 219.1 mg/l. especially, at several sampling stations, including S-01, S-02, S-08, S-09, S-10, S-11, S-15, and S-17, the total alkalinity values exceeded the standard limit established for drinking purposes. This indicates a potential concern for water quality at these specific locations. Total alkalinity is a crucial parameter as it reflects the water's buffering capacity and its ability to resist extreme changes in PH. The observed elevated levels may be indicative of excess bicarbonate, carbonate, and hydroxide ions in the water, potentially stemming from natural geological processes or anthropogenic activities. Considering the sources contributing to the heightened total alkalinity at these stations is essential for implementing targeted interventions. It is recommended to conduct further investigations to pinpoint the specific factors influencing total alkalinity, whether they are geological in nature, related to industrial discharges, or influenced by agricultural practices. This information can guide the development of effective strategies to manage and improve water quality, especially in areas where drinking water standards are exceeded.

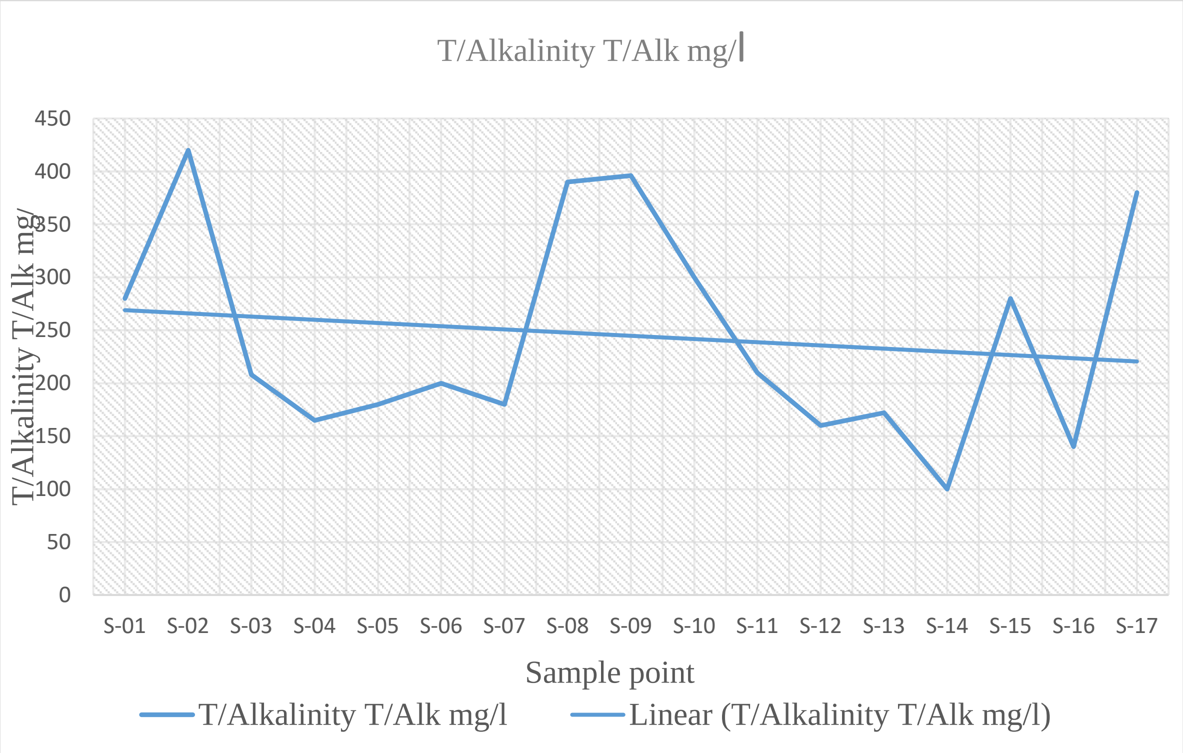

Figure 4.6. Total Alkalinity measured value

The analysis of phosphate levels in the water revealed a broad spectrum, spanning from 0.1 to 19.2 mg/l, with an average concentration of 8.1 mg/l. Of particular note, several sampling stations, including S-01, S-03, S-08, S-12, and S-15, recorded phosphate concentrations that surpassed the established standard limit intended for safe drinking water. This concerning trend underscores the need for heightened attention to phosphate control measures in these specific areas. Elevated phosphate levels pose a significant risk as they can fuel nutrient enrichment, potentially exacerbating water quality issues such as eutrophication. Given these findings, targeted interventions and stringent monitoring protocols are imperative to mitigate the adverse impacts of excessive phosphate levels on both human health and ecosystem integrity.

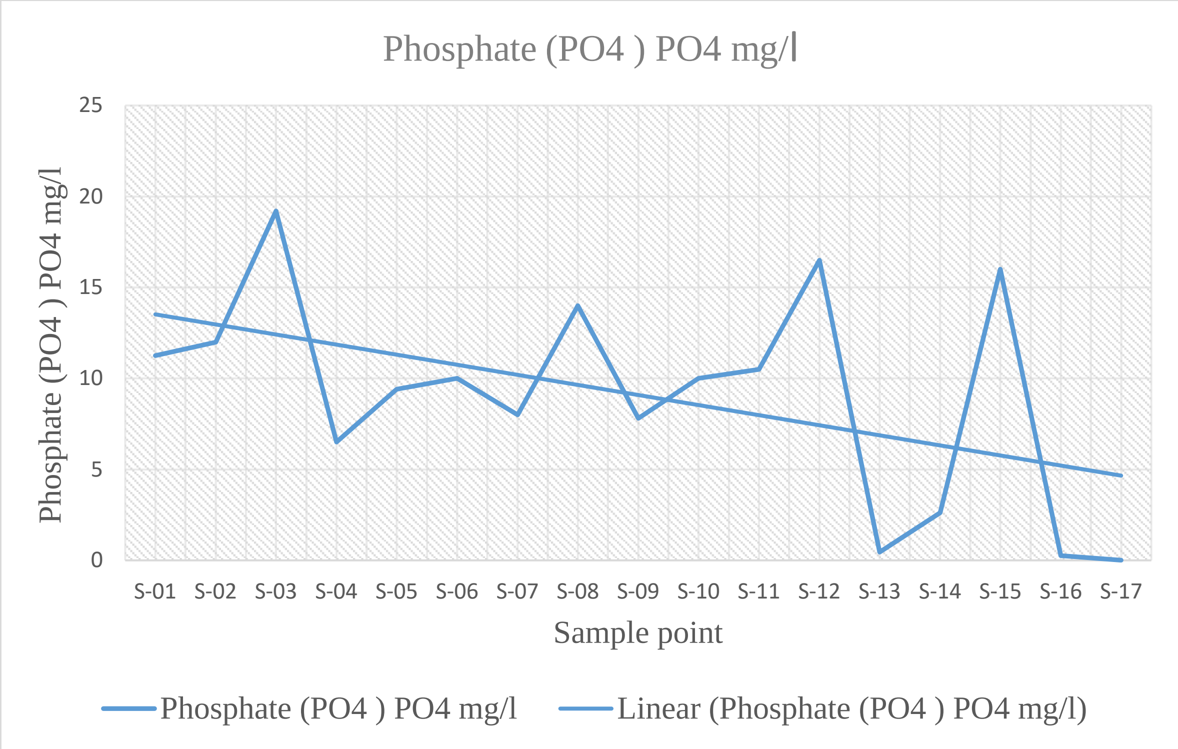

Figure 4.7. Phosphate measured value

Potassium

The examination of potassium levels in the water samples showcased a spectrum spanning from 5 to 64.4 mg/l, with an average concentration of 23.4 mg/l. Notably, a significant proportion of the sampling stations recorded potassium concentrations surpassing the established standard limit intended for drinking water purposes. However, noteworthy exceptions were observed at specific sampling stations, including S-03, S-13, S-14, and S-16, where potassium values remained within the acceptable range.

The prevalence of elevated potassium levels across most sampling stations underscores a potential concern regarding water quality and its suitability for consumption. Excessive potassium concentrations in drinking water can have various implications for human health, including potential adverse effects on individuals with specific medical conditions such as kidney disease. Therefore, diligent monitoring and management of potassium levels are crucial to ensure the safety and health of communities relying on these water sources for domestic use.

Conversely, the observed adherence to acceptable potassium levels at select sampling stations highlights the variability in water quality within the studied area. Factors contributing to these variations may include differences in geological formations, land use practices, and proximity to point sources of pollution. Understanding these nuances is essential for implementing targeted interventions to address elevated potassium levels where necessary and maintain water quality standards across diverse geographical locations. In conclusion, while the majority of sampling stations exhibited elevated potassium concentrations exceeding drinking water standards, exceptions observed at specific sites indicate localized variations in water quality. This underscores the need for comprehensive monitoring and management strategies tailored to address specific water quality challenges, ensuring the provision of safe and potable water for communities' consumption and well-being.

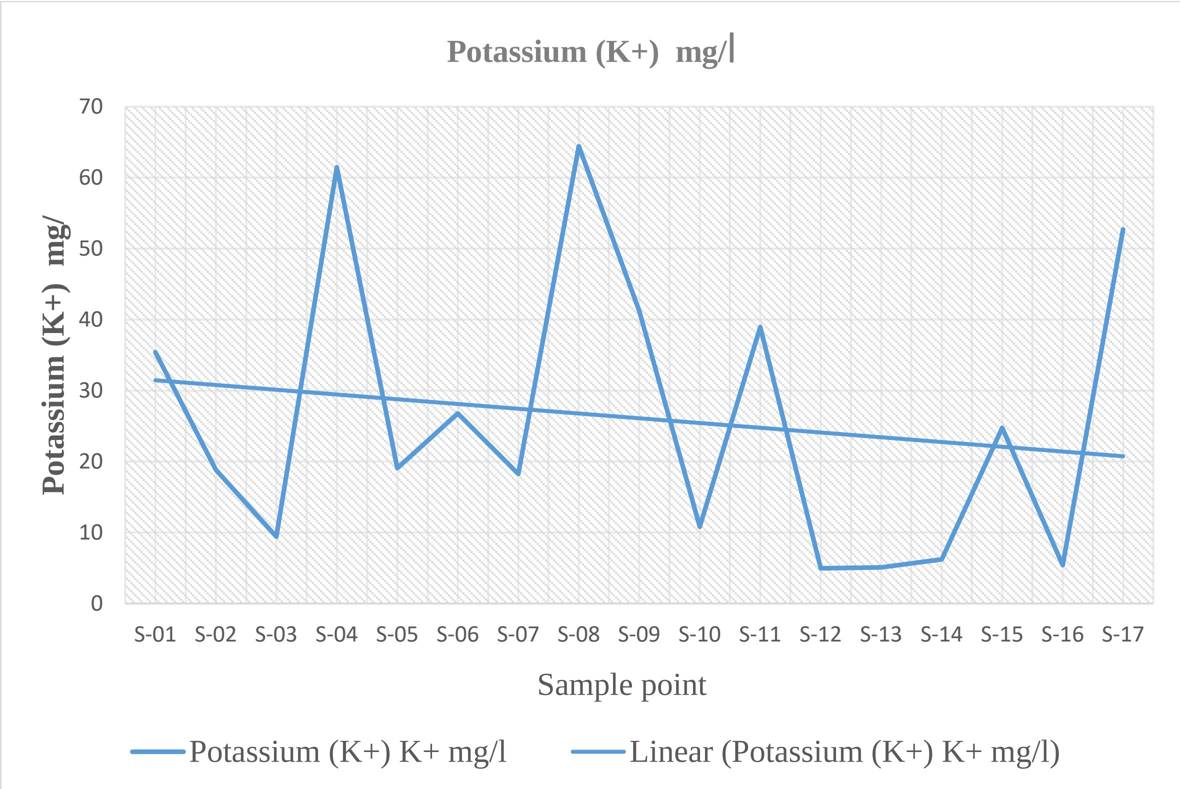

Figure 4.8. Potassium measured value

Ammonium

The ammonium levels in the water exhibited a range from 0.18 to 44.2, with a mean value of 9 mg/l. particularly, the majority of sampling stations recorded ammonium concentrations that exceeded the standard limit established for drinking purposes. However, a significant exclusion was observed at sampling station S-13, where the ammonium values fell within the acceptable range. Excessive ammonium levels in drinking water can pose potential risks to human health, necessitating a detailed investigation into the sources contributing to these elevated concentrations. Possible contributors may include agricultural runoff, industrial discharges, or wastewater inputs.

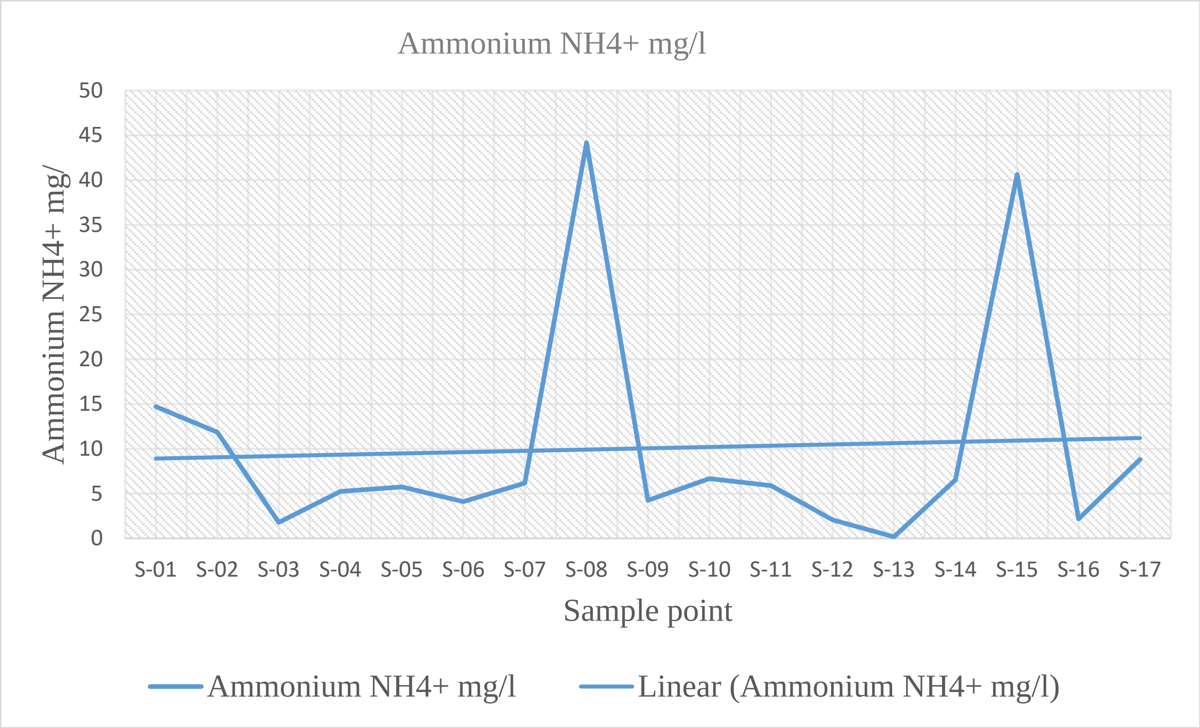

Figure 4.9. Ammonium measured value

Total hardness

The total hardness levels in the water samples collected from all sampling stations were determined to fall within the acceptable limits prescribed for drinking water quality standards. This finding indicates satisfactory conditions in terms of water hardness, suggesting minimal risk to public health from this parameter. Additionally, it's noteworthy that fluoride, although present at a lower concentration with an average of 1 mg/l, is recognized as an essential constituent of drinking water. This concentration, while modest, contributes to the overall beneficial composition of the water, aligning with guidelines that support the inclusion of fluoride within safe and beneficial ranges for dental health promotion. Thus, the combined assessment of total hardness and fluoride content underscores the overall suitability of the water samples for consumption, providing reassurance regarding their potability and contribution to human well-being.

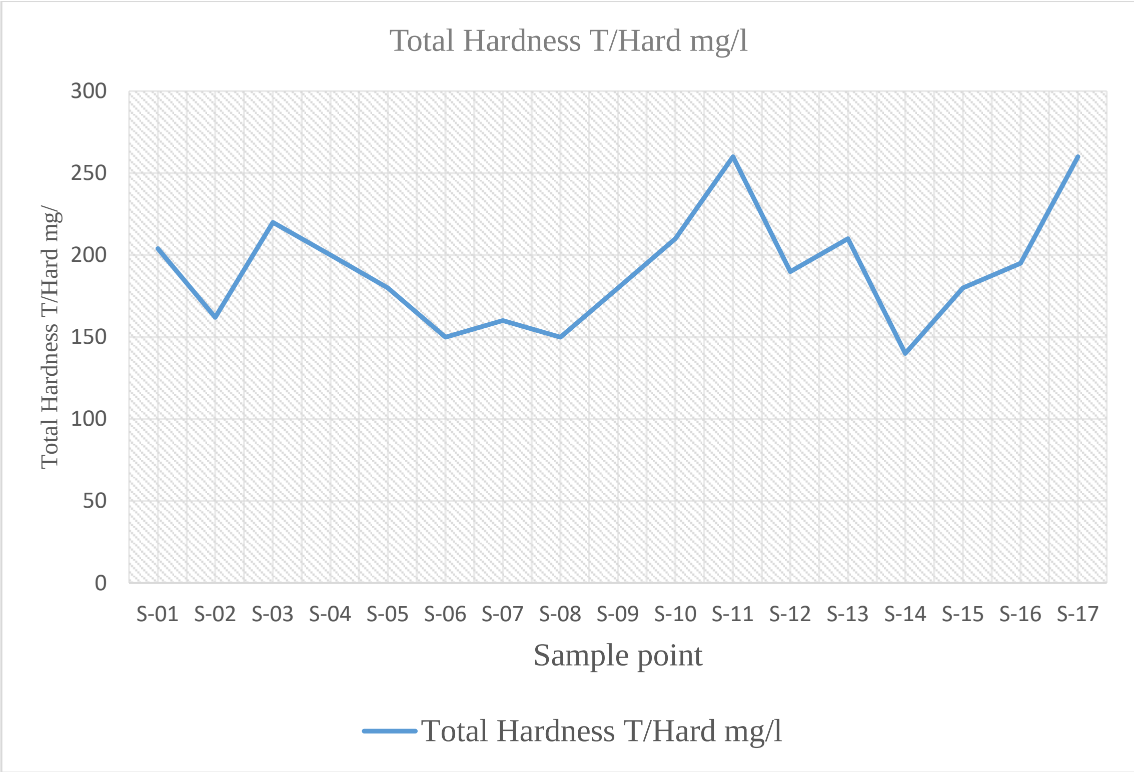

Figure 4.10. Total Hardness measured value

Fluoride

While low concentrations of fluoride can have positive impacts on human health, such as dental cavity prevention, elevated levels can lead to serious health issues like dental and skeletal fluorosis. In this study, fluoride concentrations were found to range from 0.01 to 1.6 mg/l, with an average value of 0.5 mg/l. Notably, the concentration of fluoride in the river water was significantly influenced by discharge from various point sources situated along its course. This underscores the importance of monitoring and controlling these point sources to maintain fluoride levels within safe limits and mitigate the risk of adverse health effects in communities relying on this water source. Effective management strategies are crucial to strike a balance between reaping the benefits of fluoride while safeguarding against its potential harmful effects.

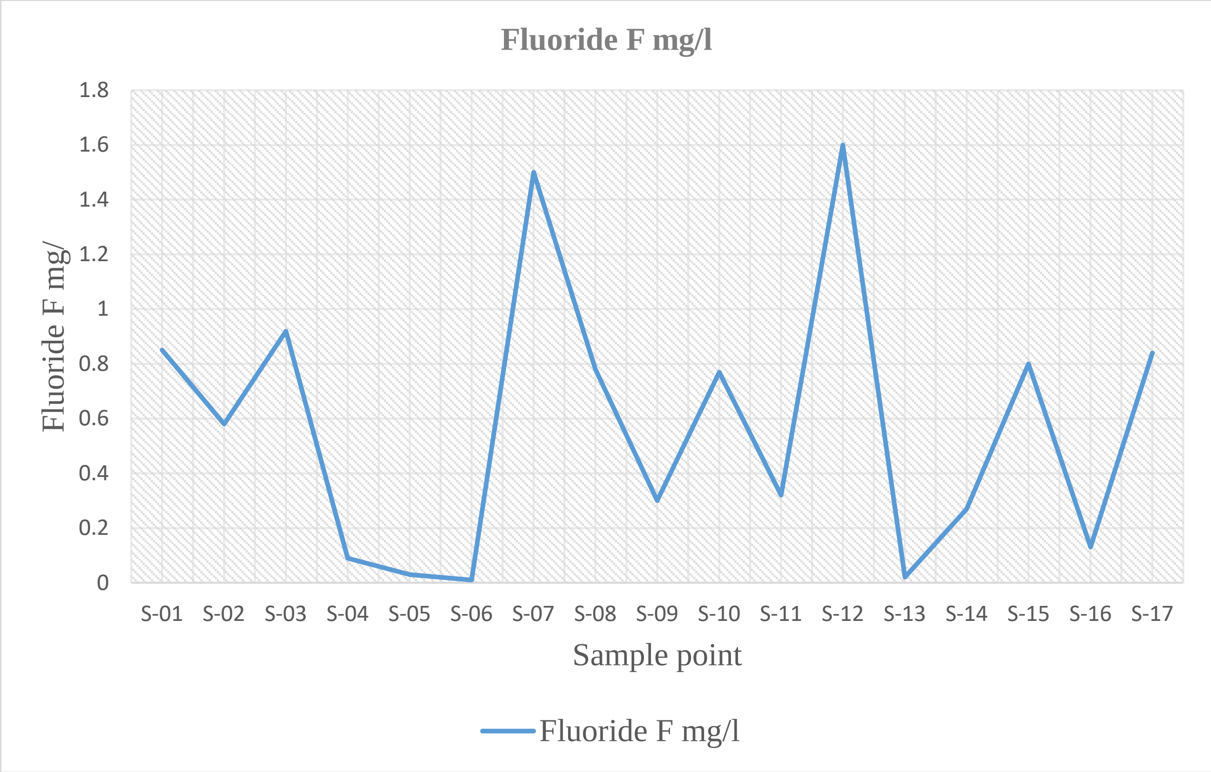

Figure 4.11. Fluoride measured value

COD and BOD_5

The measured concentrations of Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) have significantly exceeded the recommended limits for safe drinking water. The COD values ranged from 24 to 2200, with an average of 580.1, while BOD levels varied between 33 and 1380, averaging at 306.7. These readings far surpass the established thresholds for potable water, indicating a substantial presence of organic pollutants and raising serious concerns about the overall water quality. The elevated levels of COD and BOD underscore the urgent need for intervention and remedial actions to address the potential health and environmental risks associated with these pollutants. Excessive organic matter in water bodies can deplete oxygen levels, leading to adverse effects on aquatic ecosystems and posing significant challenges for drinking water treatment processes. Furthermore, the presence of organic pollutants can also compromise the safety of water for human consumption, potentially exposing individuals to health risks. Given the gravity of the situation, immediate attention is warranted to implement effective measures aimed at mitigating the impact of these elevated pollutant levels. This may include implementing stricter regulatory controls on industrial discharges, enhancing wastewater treatment processes, and implementing proactive measures to prevent further contamination of water sources. Additionally, ongoing monitoring and regular assessment of water quality parameters are essential to track progress and ensure the effectiveness of remedial actions taken. Overall, addressing the elevated levels of COD and BOD is paramount to safeguarding both human health and the ecological integrity of the affected water bodies. Collaborative efforts involving government agencies, environmental organizations, industries, and local communities are essential to effectively address this pressing environmental challenge and ensure the sustainability of water resources for future generations.

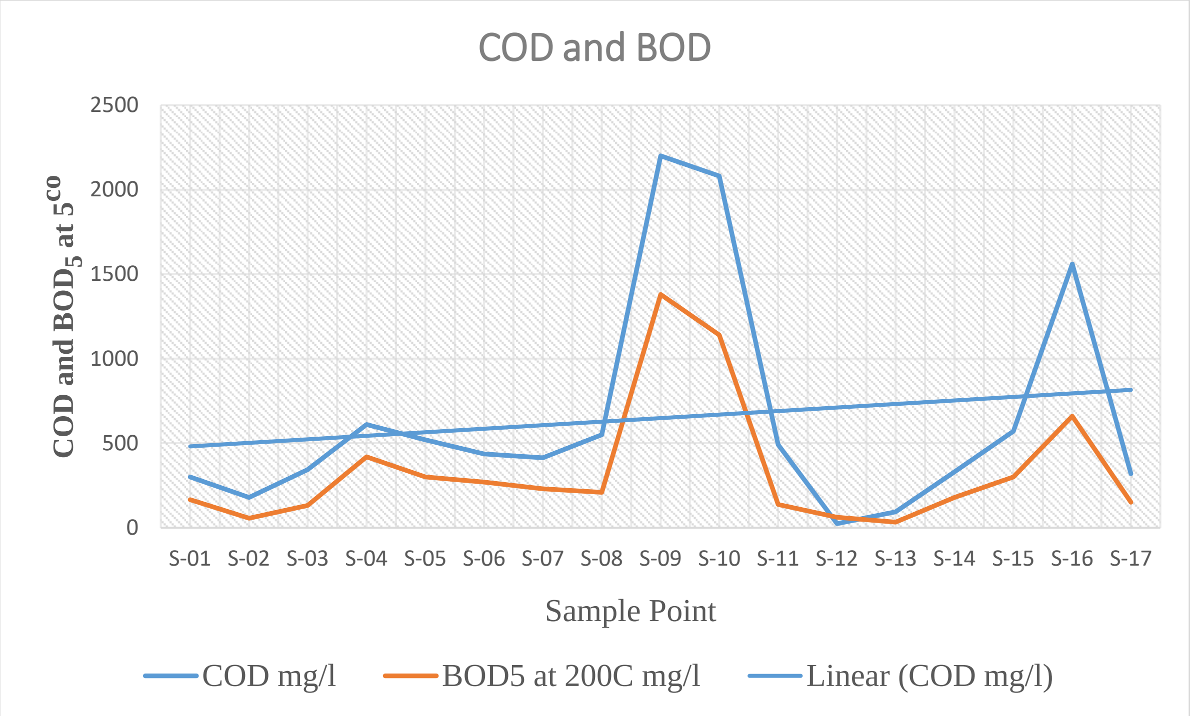

Figure 4.12.COD and BOD measured value

Heavy metals, including boron, barium, iron, magnesium, and chromium, were systematically sampled across different stations, revealing concentrations that spanned a considerable range. Specifically, the concentrations were found to be between 0.2 and 2.9, with an average of 0.4 for boron; 0.02 to 0.6, with a mean value of 2.3 for barium; 0.01 to 2.2, averaging at 0.9 for magnesium; and 0.01 to 0.9, with an average of 0.1 for chromium. This diverse spectrum of heavy metal concentrations reflects the dynamic nature of environmental conditions across the sampled locations. While boron exhibits a relatively narrow range, barium and magnesium display broader variability, and chromium demonstrates a notably lower concentration range. These findings underscore the need for a nuanced understanding of heavy metal distribution within the ecosystem, considering the potential sources and environmental factors influencing their presence.

The measured values provide a baseline for assessing the impact of heavy metals on water quality, ecological health, and potential risks to human activities such as agriculture and fisheries. Elevated concentrations of certain heavy metals may pose environmental hazards, affecting aquatic life and, consequently, human health when these water sources are used for drinking or irrigation.

To comprehensively address these concerns, ongoing monitoring and detailed analyses are essential. This will enable a more thorough exploration of the spatial and temporal variations in heavy metal concentrations, aiding in the identification of potential pollution sources and facilitating the implementation of targeted measures to mitigate adverse effects. Additionally, such data contribute valuable insights for formulating effective environmental management strategies and policies aimed at preserving water quality and ensuring the sustainable use of aquatic resources.

Boron, barium, iron, magnesium, and chromium, identified as heavy metals, were sampled at various stations, displaying concentrations ranging from 0.2 to 2.9 with a mean value of 0.4 for boron, 0.02 to 0.6 with a mean value of 2.3 for barium, 0.01 to 2.2 with a mean value of 0.9 for magnesium, and 0.01 to 0.9 with a mean value of 0.1 for chromium, respectively.

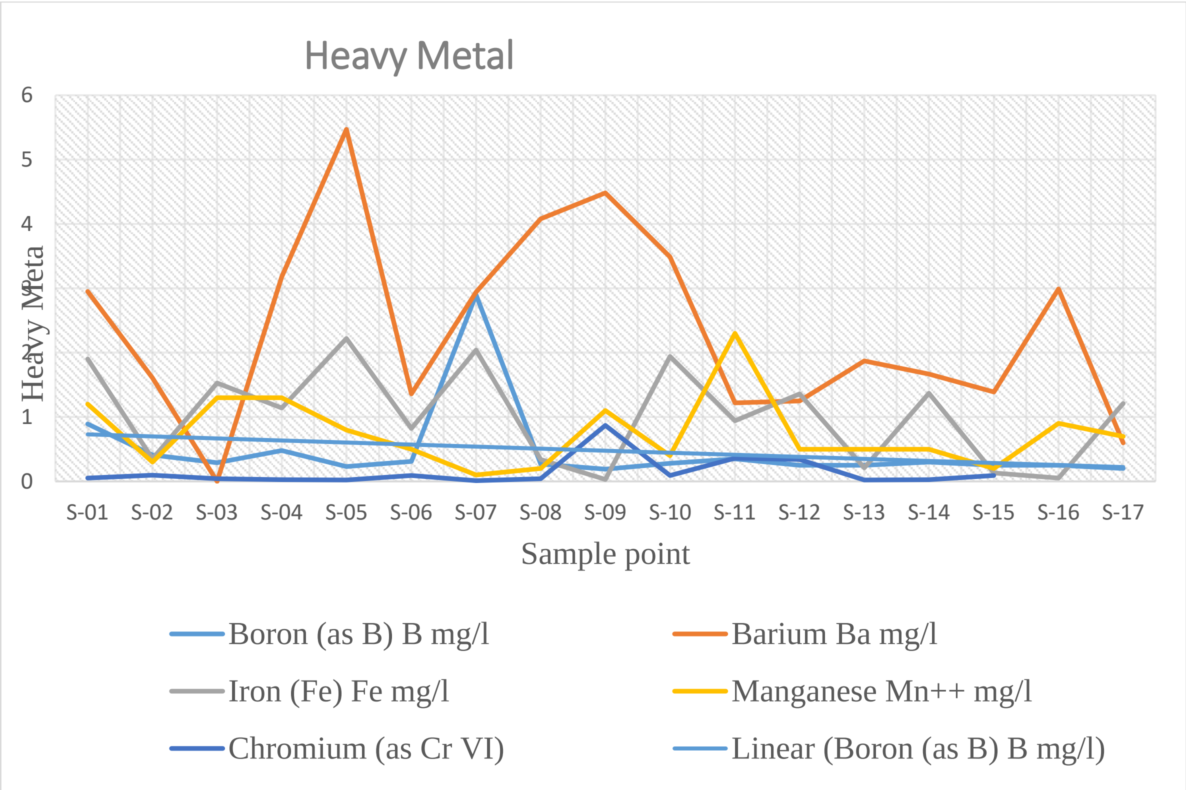

Figure 4.13. Heavy metal

Table 4.2. Results of physico-chemical analysis of Atebela River system surface water

S/No	Parameter	Unit	Waste Water quality results																
			S-01	S-02	S-03	S-04	S-05	S-06	S-07	S-08	S-09	S-10	S-11	S-12	S-13	S-14	S-15	S-16	S-17
1	PH		7.53	9.16	6.94	7.26	7.05	7.6	7.43	8.15	9.37	6.93	7.74	8.01	7.89	6.93	5.51	6.84	7.4
2	Temperature	^0C	20	20.4	19.8	21.1	20.5	22.4	21.3	21.5	22.1	21.3	18.1	18.9	19.6	20.8	20.7	23.9	23.7
3	Turbidity	NTU	130	70	80	170	100	420	80	210	160	570	570	120	22	100	220	525	220
4	Electro conductivity	µS/cm	895	863	520	726	502	621	422	3390	1801	1003	674	585	388	257	863	1001	1031
5	Total Dissolved Solid	ppm	448	432	260	363	251	311	211	1695	901	502	337	179	194	128.5	431.5	501	516
6	Total Suspended Solid	mg/l	94	168	68	60	234	208	550	1380	246	114	58	16	64	162	264	426	228
7	T/Alkalinity	mg/l	280	420	208	165	180	200	180	390	396	300	210	160	172	100	280	140	380
8	Phosphate (PO_4)	mg/l	11.3	12	19.2	6.5	9.4	10	8	14	7.8	10	10.5	16.5	0.46	2.62	16	0.26	0.01
9	Potassium (K^+)	mg/l	35.4	18.8	9.4	61.5	19.1	26.8	18.2	64.4	41.2	10.8	39	4.96	5.1	6.2	24.75	5.4	52.7
10	Ammonium	mg/l	14.7	11.8	1.77	5.25	5.76	4.09	6.17	44.2	4.24	6.67	5.9	2.06	0.18	6.53	40.64	2.19	8.82
11	Total Hardness	mg/l	204	162	220	200	180	150	160	150	180	210	260	190	210	140	180	195	260
12	Fluoride	mg/l	0.85	0.58	0.92	0.09	0.03	0.01	1.5	0.78	0.3	0.77	0.32	1.6	0.02	0.27	0.8	0.13	0.84
13	COD	mg/l	300	179	343	610	520	437	413	550	2200	2080	491	24	93.6	330	570	1560	320
14	BOD_5 at 20^0C	mg/l	165	56	132	420	300	270	230	210	1380	1140	138	62.4	33	180	300	660	150
15	Boron (as B)	mg/l	0.89	0.41	0.29	0.48	0.23	0.31	2.9	0.27	0.19	0.28	0.35	0.25	0.25	0.3	0.25	0.25	0.2
16	Barium	mg/l	2.95	1.61	ND	3.18	5.47	1.36	2.94	4.08	4.48	3.49	1.22	1.25	1.87	1.67	1.39	2.99	0.6
17	Iron (Fe)	mg/l	1.9	0.35	1.53	1.14	2.22	0.82	2.04	0.34	0.03	1.94	0.94	1.36	0.21	1.37	0.13	0.05	1.21
18	Manganese	mg/l	1.2	0.3	1.3	1.3	0.8	0.5	0.1	0.2	1.1	0.4	2.3	0.5	0.5	0.5	0.2	0.9	0.7
19	Chromium (as Cr VI)	mg/l	0.05	0.1	0.04	0.03	0.02	0.09	0.01	0.04	0.87	0.09	0.36	0.34	0.02	0.025	0.09	0.04	0.32

Table 4.3. Descriptive statistics for analyzed samples

Parameter	Average	Standard Dev Value	Mini.Value	Max. Value
PH	6.7	0.010	5.5	9.4
Temperature	18.7	0.1	18.1	23.9
Turbidity	198.3	245.3	22.0	570.0
Electro conductivity	870.6	31.3	257.0	3,390.0
Total Dissolved Solid	455.7	3.5	128.5	1,695.0
Total Suspended Solid	228.4	951.0	16.0	1,380.0
T/Alkalinity	219.0	195.8	100.0	420.0
Phosphate (PO_4)	8.1	0.5	0.1	19.2
Potassium (K^+)	23.4	7.6	5.0	64.4
Ammonium	9.0	1.7	0.2	44.2
Total Hardness	171.1	57.0	140.0	260.0
Fluoride	0.5	0.0	0.0	1.6
COD	580.1	4,128.2	24.0	2,200.0
BOD_5 at 20^0C	306.7	1,056.1	33.0	1,380.0
Boron (as B)	0.4	0.01	0.2	2.9
Barium	2.3	0.02	0.6	5.5
Iron (Fe)	0.9	0.05	0.0	2.2
Manganese	0.7	0.01	0.1	2.3
Chromium (as Cr VI)	0.1	0.00	0.0	0.9

4.2.2. Suitability for irrigation

The salinity, indicative of the total dissolved salt content, in the river samples was measured in terms of electrical conductivity (EC) expressed in dS/m. Downstream of the industrial effluent release points, the EC value of the river water at Station S-08 was determined to be 3.39 dS/m. This value exceeded the prescribed limit established by the Food and Agriculture Organization (FAO), signaling that the water is unsuitable for irrigation purposes (refer to Table 4.6). The elevated EC level implies a reduced availability of water to plants, even in instances where the soil may appear adequately moist. This phenomenon arises because plants can transpire pure water as usable plant water, a process that diminishes significantly with an increase in EC. Consequently, irrigation with water exhibiting high EC values is associated with diminished yield potential. Moreover, highly saline water has the potential to accumulate concentrations of elements that may be detrimental to plant health, including boron, sodium, and chloride. These elements, when present in excess, can exert toxic effects on plants (Tekile, 2023). Therefore, the use of water with elevated EC levels in irrigation poses the risk of compromising both water availability and plant health, underscoring the importance of adhering to recommended salinity limits for sustainable agricultural practices.

The electrical conductivity (EC) values observed in water samples from the remaining 15 sampling sites indicated a range of slight to moderate salinity hazards (0.26 – 2.8 dS/m) relevant to irrigation (Banda & Kumarasamy, 2020). The direct influence of EC, reflecting the water pollution status, was mirrored in the total dissolved solids (TDS) values. Elevated TDS levels can adversely impact the productivity of irrigation systems, potentially leading to the gradual loss of farmland due to issues associated with salt-affected soil.

The sodium concentrations in this study ranged from 19.5 to 1440 mg/l (see Table 4.6), with a mean value of 165.4. Notably, the percentage of sodium exceeded the FAO standard in most of the sample stations, except for S-12, S-13, and S-14. Station S-08, associated with agricultural activities and industrial processes, recorded the highest sodium concentration, potentially influenced by fertilizers and red ash chemicals. By FAO guidelines, elevated sodium levels in irrigation water can have detrimental effects on soil structure and plant health. This can lead to soil sodicity, making the soil prone to dispersion and compaction. These conditions negatively impact water infiltration and root development, ultimately reducing crop yields. Additionally, sodium can compete with essential nutrients like calcium and magnesium, causing imbalances in the soil's nutrient composition.

Similarly, calcium concentration values from the laboratory tests for the river exceeded allowable limits, rendering it unsuitable for irrigation according to standards. Furthermore, sulfate values for the Atebela River during the study ranged between 1 and 86 mg/l. Stations S-08, S-04, S-09, S-10, S-16, and S-17 recorded values above the standard limit, while the remaining stations were within the acceptable range for irrigation (65% compliance). The highest sulfate value observed at Atebela, near municipal waste, industrial zones, and agricultural activities

The study highlights concern about sodium, calcium, and sulfate levels in the river, with implications for the suitability of the water for irrigation purposes. The findings underscore the importance of adhering to established standards to ensure sustainable agricultural practices and prevent adverse effects on soil and crop health.

Based on the information provided, it can be concluded that the Atebela River is unsuitable for irrigation purposes. Several factors contribute to this determination: **Electrical Conductivity (EC):** Downstream of industrial effluent release points (Station S-08), the EC value is 3.39 dS/m, exceeding the prescribed limit established by the Food and Agriculture Organization (FAO). Elevated EC levels reduce the availability of water to plants, leading to a diminished yield potential. **Sodium Concentrations**: Sodium concentrations in the river ranged from 19.5 to 1440 mg/l. Most sample stations, including Station S-08 associated with agricultural activities and industrial processes, recorded sodium concentrations that exceeded FAO standards. Elevated sodium levels in irrigation water can have detrimental effects on soil structure, plant health, water infiltration, root development, and overall crop yields. **Calcium Concentrations:** Calcium concentration values from laboratory tests exceeded allowable limits, rendering the river unsuitable for irrigation according to standards. **Sulphate Concentrations**: Sulphate values for the Atebela River ranged between 1 and 86 mg/l. Several stations, including S-08, S-04, S-09, S-10, S-16, and S-17, recorded sulfate values above the standard limit. High sulfate levels near municipal waste, industrial zones, and agricultural activities raise concerns about the river's suitability for irrigation.

In summary, the study consistently highlights concerns about elevated levels of salinity, sodium, calcium, and sulfate in the Atebela River, indicating that the water is not suitable for irrigation purposes. Adhering to established standards is emphasized to ensure sustainable agricultural practices and prevent adverse effects on soil and crop health.

Table 4.4. Table 4.5. The test result of irrigation purpose

	S-01	S-02	S-03	S-04	S-05	S-06	S-07	S-08	S-09	S-10	S-11	S-12	S-13	S-14	S-15	S-16	S-17	FAO limit
EC	0.9	0.86	0.52	0.73	0.502	0.621	0.422	3.39	2.801	1.003	0.67	0.59	0.388	0.26	0.86	1.001	1.031	3
TDS	448	432	260	363	251	310.5	211	1695	900.5	1502	337	179	194	129	432	500.5	515.5	2000
Sodium	43	87	49	59	48.5	87	47.5	1440	440	87.5	55	26	31	19.5	59	152.5	81	40
Calcium	67.2	39.2	75.2	72	60	20	22.4	32	39.2	72	68	40	50.4	24	32	64	80	20
magnesium Mg	1.2	0.3	1.3	1.3	0.8	0.5	24.96	16.8	19.7	7.2	21.6	21.6	20.16	19.2	24	8.4	14.4	5
sulphate	35	4	1	21	4	1	1	1	43	7	1	4	4	1	2	86	23	20
SAR	10.40	27.69	11.20	13.78	12.44	38.43	13.80	412.27	114.66	19.66	11.62	6.63	7.38	5.93	15.77	35.85	16.67	15

This irrigation water quality index calculated based on this popular irrigation water quality assessment method using the most important variable that influences the water quality for irrigation use was evaluated according to irrigation water quality index values given by different researchers (Table.). However, the irrigation water quality classes were different for different irrigation water quality assessment methods (Table).

Table: Irrigation water classes according to irrigation water quality index value ((Adeyemi *et al.*, 2019; Yousif and Chabuk, 2023).

Table 4.6. Irrigation water quality index. (*2008)*

S/No	Irrigation water quality index	Suitability class of irrigation water
	SAR less than 10	Excellent
1. SAR value	10 < SAR < 18	Good
	18 < SAR < 26	Fair poor
	SAR greater than 26	Unsuitable
2. KI value	KI < 1	Good
	KI > 1	Unsuitable
3. SSP Value	SSP < 20	Excellent
	20 < SSP < 40	Good
	40 < SSP < 60	Fair
	60 < SSP < 80	Fair poor
	SSP > 80	Unsuitable
4. PI value	PI > 25% 25% < PI < 75%	Suitable Moderately suitable
	PI < 25%	unsuitable
5. RSC value	RSC < 1.25 1.25 < RSC < 2.50	Suitable Fair poor
	RSC > 2.5	Unsuitable

4.3. Developed water quality index

The Water Quality Index is most frequently used for assessing the suitability of water for drinking and irrigation purposes. The value of this index is established by comparing present water parameters with drinking and irrigation water quality standards. Based on the assessment that has been carried out, some researchers have classified the quality of drinking water into five grades.

This grading provides water quality indices (WQI) with the following general description of the CCME WQI Index the CCME WQI relies on measures of the scope; frequency and amplitude of excursions from guidelines. Once the CCME WQI value has been calculated, water quality is classified into one of the following categories: Excellent: (CCME WQI

Value 95-100) – water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. Good: (CCME WQI Value 80-94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels. Fair: (CCME WQI Value 65-79) – water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels. Marginal: (CCME WQI Value 45-64) – water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels. Poor: (CCME WQI Value 0-44) – water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels. The assignment of CCME WQI values to these categories is a critical, but somewhat subjective, process. The categorization is based on the best available information, expert judgment, and the general public's expectations of water quality. The outcome of the assessment in this study points out the relationship between WQI and WPI that is statistically significant polluted for both water quality. Drinking Water Quality Characterization and the Use of the Water Quality Index (WQI) Surface water quality has to be evaluated for acceptability for drinking purposes, and the Water Quality Index (WQI) is an effective tool for doing so. WQI is a quantitative evaluation that measures water quality using an index, providing an in-depth evaluation of individual water quality metrics and their aggregate impact on overall water quality in a given area. The idea of WQI was designed with the consumption of humans in consideration, providing decision-makers with a simple and understandable metric of water quality and prospective uses. The Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI) is a well-established approach for assigning mathematical values to many water quality criteria, ensuring that they contribute equally to the overall quality index. To maintain worldwide standards, comparisons are conducted to criteria established by respected organizations such as the World Health Organization (WHO). The CCME WQI particularly measures 19 water quality indicators, including temperature, turbidity, pH, total hardness, alkalinity, total dissolved solids, boron, magnesium, chromium, iron, potassium, and phosphate.

Table 4.7. Range of Water Quality for CCME, 2014

Station	S01	S02	S03	S04	S05	S06	S07	S08	S-09	S-10	S-11	S-12	S-13	S-14	S-15	S-16	S-17
CCME WQI	46.6	45.6	49.1	47.8	47.5	42.9	47.2	44.2	31.24	31.8	37.4	54.3	78.6	51.9	37.4	47.9	52.63
0-44	Poor: (CCME WQI Value 0-44) – water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels																
45-64	Marginal: (CCME WQI Value 45-64) – water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.																
65-79	Fair: (CCME WQI Value 65-79) – water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.																
80-94	Good: (CCME WQI Value 80-94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.																
95-100	Excellent: (CCME WQI Value 95-100) – water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.																

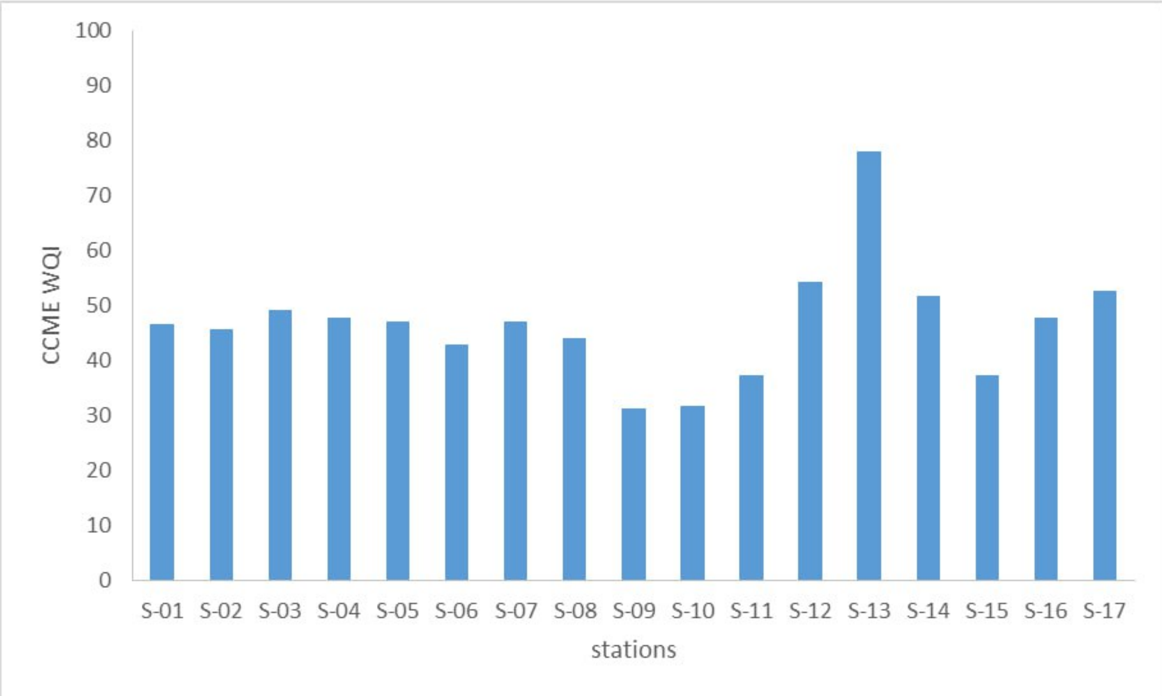

Figure 4.14 Spatial & season variation of WQI values of Atebala River

The visual representation in Figure 4.14 illustrates the Inclusive CCME WQI across a system of 17 distinct stations, each designated as S-01 to S-17. Among these stations, station S-13 stands out prominently, displaying a notably elevated WQI in comparison to all other stations. The observed point in WQI at station S-13 is attributed to a lower influent at this particular station. This implies that the reduced influx of contaminants or pollutants into the water system at station S-13 has positively impacted its water quality, showcasing the importance of influent levels in determining and understanding variations in water quality across different monitoring stations.

The x-axis of the graph describes the stations under examination, each denoting a distinct sampling point. Meanwhile, the y-axis illustrates the Comprehensive Canadian Water Quality Index (CCME WQI), spanning from 0 to 100. This index serves as a complete metric, summarizing various water quality parameters to provide a holistic assessment of environmental conditions across the sampled stations. Each bar on the graph shows the CCME WQI value of a specific station, and the majority of bars cluster within the 40-50 range, classified as Marginal according to the classification by Paun et al. in 2016. Particularly, Station S-13 distinguishes itself by exhibiting a CCME WQI value ranging from 80 to 90. This range signifies a substantial improvement in water quality in comparison to other stations and falls under the category of good WQI, as defined by Paun et al. in 2016. Generally, the examination or testing of the water quality in the Atebela River at 17 designated stations yielded a calculated value of 16.24 using the water quality index equation (eq 3.7). This classification categorizes the river as having poor quality.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The broad analysis of the Atebela River's water quality reveals a concerning level of pollution arising from various industrial, municipal, medical, and agricultural activities in the surrounding area. The study identified key sources of pollution, including industrial waste from diverse sectors such as textiles, food processing, metalworks, and more. Municipal waste, medical waste, and agricultural runoff were also significant contributors, releasing a variety of pollutants into the river, ranging from heavy metals and chemicals to organic compounds.

The examination of specific chemical constituents and physiochemical properties at different sampling sites highlighted the extent of contamination. Parameters such as electrical conductivity (EC), total dissolved solids (TDS), and bicarbonate (HCO3-) exceeded WHO water quality standards at several locations, indicating a substantial impact on water quality. The identified industries, such as the paint factory and textile operations, were notably responsible for elevated levels of these parameters.

The physico-chemical characterization of the Atebela River's surface water demonstrated variations in temperature, pH, electrical conductivity, total dissolved solids, total suspended solids, total alkalinity, phosphate, potassium, ammonium, total hardness, fluoride, COD, BOD5, and various heavy metals. These findings underscore the diverse nature of pollutants present in the river, with some locations exhibiting concentrations that exceed established drinking water standards.

The suitability for drinking, the study found that while the temperature and pH levels generally fell within acceptable ranges, other parameters such as electrical conductivity, total dissolved solids, and bicarbonate posed significant challenges. Elevated levels of these constituents, particularly at industrial discharge points, emphasized the need for stringent pollution control measures and water quality management strategies.

The evaluation of water quality for irrigation purposes raised additional concerns, particularly regarding salinity, sodium, calcium, and sulfate levels. The high electrical conductivity downstream of industrial effluent release points, as well as the elevated sodium concentrations at multiple sites, rendered the Atebela River unsuitable for sustainable irrigation practices. The potential negative impacts on soil structure and plant health further emphasized the urgency of adhering to recommended salinity limits.

The developed irrigation water quality index corroborated these findings, indicating that the Atebela River's water is unsuitable for irrigation purposes. The index considered parameters such as sodium absorption ratio (SAR), Kelly's index (KI), sodium percentage (SSP), permeability index (PI), and residual sodium carbonate (RSC). The results consistently categorized the water as either fair-poor or unsuitable for irrigation across various assessment methods.

The Atebela River poses a significant threat to its water quality and ecosystem health due to pollution from a multitude of human activities. The results emphasize the critical need for immediate and effective pollution control measures, wastewater treatment facilities, and sustainable practices in industrial, municipal, medical, and agricultural sectors. Mitigating the pollution sources and implementing water quality management strategies are essential to preserve the Atebela River's ecological integrity and ensure the well-being of downstream communities. Continued monitoring and periodic assessments are crucial for tracking changes in water quality and guiding ongoing efforts toward the restoration and protection of this vital water resource.

5.2. Recommendation

Addressing the water quality concerns in Sebeta Town necessitates a comprehensive and collaborative effort from diverse authorities and stakeholders, highlighting the significance of community engagement. Mandatory actions should focus on in-depth investigations into industry responsibilities and enhancing local community awareness.

To alleviate pollution issues and foster sustainable development, the following measures are recommended:

- The water quality of the Atebela River has declined to poor and marginal levels, making it unsuitable for drinking and irrigation.
- Ensure that both point and non-point pollution sources are effectively controlled to manage potential pollutants and maintain physicochemical parameters within acceptable limits.
- Continuous monitoring of water quality parameters throughout the year is imperative.
- Manufacturing facilities and companies must be held responsible for their environmental impact.
- Raising public awareness about the adverse effects of pollution can empower citizens to exert pressure on businesses, encouraging owners to treat their effluents responsibly.
- For the sustainable management of this water resource, environmental protection agencies at various levels and other relevant administrative or non-governmental bodies should enforce stringent as well as technical measures.

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ANNEX.1. WHO WATER QUALITY STANDARDS

S.No	Description of item		WHO Guideline	
		Unit	Guide line Value	Acceptable Value
1	Power of Hydrogen (pH)	mg/L	6.5- 8.5	6.5- 8.5
2	Ammonia (NH_3)	mg/L	5	1.5
3	Electrical Conductivity	mg/L	2000	
4	Turbidity (NTU)	NTU	20	1.5
5	Total Hardness	mg/L	300	500
6	Magnesium	mg/L	50	50
7	Alkalinity	mg/L	200	200
8	Calcium	mg/L	200	
9	Total Iron	mg/L	0.3	0.1
10	Manganese	mg/L	0.1	0.1
11	Nitrate (NO3-N)	mg/L	5	
12	T. Dissolved Solid (TDS)	mg/L	1000	1000
13	bicarbonate	mg/L	75	75
14	CO_3	mg/L		
15	NH_4	mg/L	5	30
16	NO_2	mg/L	300	300
17	NO_3	mg/L	50	50
18	SO_4	mg/L	250	250
19	Sodium	Mg/L	200	200
20	Potassium	Mg/L	5	
21	Chloride	Mg/L	1000	250
22	Sulphate	Mg/L	250	250
23	Aluminium	Mg/L	0.2	0.2
24	Zinc	Mg/L	0.1	4
25	Nitrate	Mg/L	50	
26	Nitrite	Mg/L	3	
27	Fluoride	Mg/L	20	1.5
28	Boron	Mg/L	2.4	2.4
29	Barium	Mg/L	0.1	0.7
30	Copper	Mg/L	2	2
31	Chromium	Mg/L	0.05	0.05
32	Total Coliform (100ml)	Mg/L	Undetectable	Undetectable
33	E-Coli (100ml)	Mg/L	Undetectable	Undetectable

ANNEX.2. TANNING AND LEATHER VALUES FOR DISCHARGES.

Parameter	Limit Value
Temperature	40 C
pH	6 – 9
BOD_5 at 20^0C	90% removal or 200 mg/l, whichever
COD	500 mg/l
Suspended solids	50 mg/l
Total ammonia (as N)	30 mg/l
Total nitrogen (as N)	80% removal or 60 mg/l, whichever is less
Total phosphorus (as P)	80% removal or 10 mg/l, whichever is less
Oils, fats, and grease	15 mg/l
Mineral oils at oil trap or interceptors	20 mg/l
Chromium (as total Cr)	2 mg/l
Chromium (as Cr VI)	0.1 mg/l
Chlorides (as Cl)	1000 mg/l
Sulfides (as S)	1 mg/l
Phenols	1 mg/l
Total nitrogen (as N)	80% removal or 40 mg/l, whichever is less
COD (mg O_2 /l)	80% removal or 150 mg/l, whichever is less
Total phosphorus (as P)	80% removal or 10 mg/l, whichever is less
Suspended solids	30
Total ammonia (as N)	20
Oils, fats & grease	20
Phenols	1
Mercury (as Hg)	0.001
Nickel (as Ni)	2
Cobalt (as Co)	1
Lead (as Pb)	0.5
Antimony (as Sb)	2
Tin (as Sn)	5
Chromium (as Cr VI) Chromium (as total Cr)	0.1 1
Arsenic (as As)	0.25
Cadmium (as Cd)	1
Zinc (as Zn)	5
Copper (as Cu)	2
Mineral oils (Interceptors)	20
Benzene, toluene & xylene (combined)	1

ANNEX 3: SAMPLING SITE FIGURES