



**AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT
ADDIS ABABA UNIVERSITY**



Determination and Spatial Mapping of the physicochemical and biological characteristics of Sewage of Feeding the Kaliti Wastewater Treatment Plant in Addis Ababa Ethiopia

By:

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Advisor:

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A Master's thesis submitted to the Africa Center of Excellence for Water Management, Addis Ababa University in partial fulfillment of the requirements for The Degree of Master of Science in Water Management (Water and Wastewater Technology)

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Addis Ababa, Ethiopia



Africa Center of Excellence for Water Management



Addis Ababa University

School of Graduate Studies

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Declaration

I, Zekarias Gelaye (GSR/9917/14), hereby declare that this MSc research thesis titled *“Determination and Spatial Mapping of the physicochemical and biological characteristics of Sewage of Feeding the Kaliti Wastewater Treatment Plant in Addis Ababa Ethiopia”* has been developed by me and has not been submitted to any other institution for award of any academic qualification. The content of the proposal has not been plagiarized and where works of other researchers have been used, they have been appropriately cited.

Candidate's Name**Signature****Date**

Zekarias Gelaye_____



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A MASTER'S THESIS SUBMITTED
TO
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APPROVED BY BOARD OF EXAMINERS

This is to certify that we have read this MSc thesis and that in our opinion; it is fully adequate, in scope and quality, as a Master's thesis for The Degree of Master of Science in Water Management (water and wastewater technology)

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ABSTRACT

Urban development in Addis Ababa usually exerts enormous pressure on the existing sewer network systems. The insufficiency in the performance of the sewer network has become one of the most critical issues in the sewer system sector that requires immediate action. Kaliti Catchment sewer system has problems related to sewer system coverage, manholes overflow, and capacity deficiency. The current study aims to evaluate the city's main wastewater infrastructure's performance and identify factors affecting the treatment efficiency of the plant, particularly the illegal discharge of toxic industrial waste, from exploring the characteristic nature of sewage within the Kaliti catchment area. Based on laboratory testing, geographic information systems, and statistical software applications, this study maps the physicochemical and biological properties of sewage at various sites. The characteristics of sewage were determined by considering 12 parameters at 20 stations (i.e., a total of 480 tastes were obtained). The laboratory analyses of the sewage samples were performed to determine the pH, temperature, electrical conductivity, total dissolved solids, chemical oxygen demand, biochemical oxygen demand, total coliforms and the concentrations of specific pollutants like phosphorus and nitrogen as well as the heavy metals. The findings were shows that municipal wastewater is organic in nature, having values of BOD of 505.30 ± 184.26 mg/l, COD of 1221.96 ± 401.97 mg/l, dissolved solids of 697 ± 155.95 mg/l, Electrical conductivity 1206.9 ± 326.44 μ s/cm, Temperature 21.88 ± 1.67 °C, PH 7.72 ± 0.17 , Total Nitrogen 69.97 ± 19.58 mg/l, Total phosphorus 14.08 ± 3.69 mg/l, Total coliform $24.68 \times 10^6 \pm 2.99 \times 10^6$ (per 100ml), Null Chromium mg/l, 0.39 ± 0.22 mg/l Manganese and 0.01 ± 0.02 mg/l Zinc. The spatial mapping was applied for detecting pollution hotspots and illegal sewer connections that could have compromised the city's main wastewater treatment system's efficiency. It is believed that such findings will inform the Addis Ababa Water and Sewerage Authority (AAWSA), which is mandated to both water supply and sanitation of the city, and other stakeholders about the current state of sewage characteristics, thereby facilitating the implementation of targeted mitigation measures.

Keywords: Characteristics of wastewater, Kaliti, Spatial Mapping, Pollution, Sewage

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List of Acronyms

AAU	Addis Ababa University
AAWSA	Addis Ababa Water and Sewerage Authority
APHA	American Public Health Association
BOD ₅	Biological Oxygen Demand (Five days)
COD	Chemical Oxygen Demand
Cr	Chromium Metal
CSS	Combined Sewer Systems
CSA	Central Statistics Agency
DO	Dissolved Oxygen
DOM	Dissolved Organic Matter
EC	Electric Conductivity
ECDSWCO	Ethiopian Construction Design & Supervision Works Corporation
EEPA	Ethiopian Environmental Protection Authority
GPS	Geographical Position System
GIS	Geographical Information System
Mn	Manganese Metal
SDSS	Spatial Decision Support System
TSS	Total Suspended Solids
TDS	Total Dissolved Solid
TN	Total Nitrogen
TP	Total Phosphorus
UASB	Up-flow Anaerobic Sludge Blanket
UN	United Nations
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WWTPs	Waste-water Treatment Plants
Zn	Zinc Metal

CHAPTER 1 INTRODUCTION

1.1. Background

Addis Ababa is the capital and largest city in Ethiopia. It is a grassland biome at an elevation of 2,355 meters and is located at 9° 1' 48" N, 38° 44' 24" E. The city lies at the foot of Mount Entoto and forms part of the watershed for the Awash River. The city is the seat for the government of Ethiopia and it is the country's financial, commercial, educational, and media center. The population of the city was estimated at 5.2 million in 2022, according to United Nations population projections. Sanitation provision in Addis Ababa is grossly deficient, as in most cities in sub-Saharan Africa: most people do not have access to a hygienic toilet; large amounts of fecal waste are discharged to the environment without adequate treatment; this is likely to have major impacts on the infectious disease burden and quality of life even worse to downstream communities (Hutton et al., 2007). Addis Ababa generates an estimate annual volume of 49 Mm³ of total wastewater, of which about 4 Mm³ is industrial wastewater (van Rooijen et al., 2010).

As a metropolitan setting, wastewater flows from businesses, residences, and runoff from precipitation, which are typically collected and transported for disposal. The wastewater system between the sources of wastewater generation and the wastewater treatment facility or, alternatively, the point of discharge into a nearby receiving water system is characterized as the sewer network. Inlets, manholes, drops, shafts, and pumps are a few of the installations and structures that make up a sewage system and are used to collect and transfer waste. A sewer system, according to the European definition, is a network of channels and ancillary workshops that transport wastewater from its source, such as a structure, roof drainage system, or paved area, to the point where it is discharged into a wastewater treatment factory or directly into the adjacent terrain (Rodriguez et al., 2009).

The suspended water phase, the biofilm, the sewer sediments, the sewer atmosphere, and the sewer walls are the five phases in which sewage processes take place in complicated systems. Additionally, chemicals are exchanged across interfaces. Other components of the urban system are impacted by processes that take place in the sewer system, such as the odorous compounds

that fill the urban environment. Additionally the pollutants that are dumped into the sewer, wastewater treatment facilities and nearby receiving waters also take in the byproducts of sewer activities (Tscheikner-Gratl et al., 2020).

Sewer network systems are considered an essential part of the urban water infrastructure, which have to be carefully operated and maintained in a rational, sustainable and scientifically based manner (Tscheikner-Gratl et al., 2020). But now, developing countries face additional challenges related to maintaining or improving the level of sanitation service in the face of aging wastewater infrastructure, new customers in need of sewer service, and increasingly strict environmental regulations as well as those illegal industrial discharges.

The unintended discharge into sewer lines would be considered "unlawful" because municipal sewer systems, which contain non-complexes wastewater in contrast to industrial wastewater treatment, are not designed and constructed to receive it. Ethiopia had no such guideline or standard for industrial wastewaters to be connected to municipal sewer systems so far whereby the several industries in the country have to treat in-situ and have to meet the environmental discharge limits already set by the environmental protection authority of the country or city. However, the Addis Ababa Water and Sewerage Authority (AAWSA) used to suffer to maintain its quality service provision such as in the proper fecal sludge and other wastewater management. This might have partly affected the treatment efficiency of its main and the centralized wastewater treatment facility; Kaliti wastewater treatment plant (KWWTP).

More importantly, the sanitation service hurdles are exacerbated by the poor monitoring and control system of AAWSA leading to illegal sewer connection and thereby negatively affecting the characteristic level of sewage in the sewer system of the city of Addis Ababa. Additionally, there are no such catchment wide studies performed locally to determine the status of such phenomena and the global context itself is also limited. The aim of this study is, therefore, to develop maps and techniques for detecting and possible avoiding illegal discharges through proper monitoring under local conditions and to provide guidance to municipalities whose task it is partly to control illegal sewer connection entries into the sewer network system towards quality service delivery.

1.2. Statement of the problem

The production of waste from human activities is unavoidable. A significant part of this waste will end up as wastewater. The quantity and quality of wastewater are determined by many factors. Not all humans or industries produce the same amount of waste. The amount and type of waste produced in households is influenced by the behavior, lifestyle, and standard of living of the inhabitants as well as the technical and legal framework by which they are surrounded. In households, most waste will end up as solid and liquid waste, and there are significant possibilities for changing the amounts and composition of the waste streams generated.

Relatively little research has been undertaken on determining the quality of wastewater discharges from domestic households as it goes along the sewerage system for its ultimate treatment in a designated facility. I developed a structured questionnaire and administered it to workers at a wastewater treatment plant to identify potential sources of illegal discharges. The findings revealed that such discharges originate from various sources, including construction materials; food waste; petroleum-based products such as oil, gasoline, grease, and fuel oil; paints, stains, resins, lacquers, and varnishes; heated water; animal carcasses; silt, sediment, concrete, cement, and gravel. The discharge of industrial wastewater into the municipal sanitation network may cause unexpected adverse effects on the performance of municipal waste-water treatment plants (WWTPs) (Purschke et al., 2020). Performance of WWTPs is routinely verified by assessing wastewater influents and effluents in terms of chemical and biochemical oxygen demand (COD and BOD, respectively), total nitrogen (TN), and phosphorous (TP) contents, among other current physicochemical parameters. These general wastewater quality parameters are normally required to oversee legal compliance and are used as the basis for the design of WWTPs. Nonetheless, those parameters are indicative and do not provide detailed information on the properties of specific components of dissolved organic matter (DOM), nor on the presence or identification of contaminants that reach the WWTP and that may impact the treatment performance, especially at the biological treatment stage (Ignatev & Tuhkanen, 2019). Thus, to ensure the proper operation of WWTPs, it is essential to check for the presence of (organic) micro contaminants and characterize DO throughout the sewage network, allowing the detection of specific hotspots and the implementation of preventive measures at their source. Most of the time in Addis Ababa, AAWSA discovers illegal connections to the water and sewer systems; at this time, AAWSA discovered some houses connecting ground water to our system and another, the beer company, connecting our system; and AAWSA also receives information from Kaliti wastewater treatment (KWWTP) about a high amount of oil,

grease, and scum. These influencing characteristics directly or indirectly affect the UASB treatment system. As a result, this paper is proposed to investigate the performance of wastewater infrastructure: spatial mapping of characteristic sewage levels in Addis Ababa and to propose potential mitigation measures.

1.3. Objectives of the study

1.3.1. General Objective

To determine and map the physico-chemical and biological property of sewage within the Kaliti catchment of Addis Ababa city and propose possible mitigation measures.

1.3.2. Specific Objective

- To determine the physico-chemical and biological level of wastewater in selected sewage systems of Kaliti catchment of Addis Ababa city.
- To visualize the features of sewage in a specific area using Geographic Information System (GIS) softer.
- To evaluate and propose possible mitigation mechanisms

1.4. Research Questions

- What are the characteristics of sewage in Addis Ababa at each site?
- Does the effluent come from different source have effect on the characteristics level?
- What are the biological, chemical and physical characteristics level of sewage?

1.5. Significance of the study

This study will assess and map the performance of wastewater structures in a kaliti catchment using GIS. The findings of this study will aid in determining whether the characteristics of a city's wastewater are suitable for anaerobic treatment (UASB). It will also be used by the environmental protection agency to help maintain the ecosystem and the surrounding community. Therefore, this study will serve as baseline information for further investigation of related studies in the future. Help identify sensitive areas of illegal sewer connections.

CHAPTER 2 LITERATURE REVIEW

2.1. Definition of wastewater

Wastewater refers to water that has been used in the home, in a business, or as part of an industrial process. It is generated after the use of freshwater, raw water, drinking water, or saline water in various deliberate applications or processes. Wastewater can be produced by a community of people and is commonly known as sewage or municipal wastewater (Pongrácz & Pohjola, 2004).

2.2. History of sewer line

Throughout history, the management and disposal of wastewater has been a persistent challenge for human settlements. The origin of sewer lines can be traced back thousands of years. In ancient Mesopotamia (modern-day Iraq), clay pipes were utilized to transport wastewater away from homes and public buildings. Similarly, the Indus Valley Civilization in present-day Pakistan and India developed sophisticated sanitary drainage systems as early as 2500 BCE, constructing brick-lined sewers for wastewater management (Vuorinen et al., 2007).

The Romans are well-known for their advancements in engineering and sanitation. Around 600 BCE, they constructed the Cloaca Maxima, a comprehensive sewer network in ancient Rome. This large covered system collected wastewater from both public and private structures and conveyed it to the Tiber River. The Romans employed stone, bricks, concrete, and various drainage and sewage management techniques, including sedimentation tanks and flushing toilets in affluent homes (Lofrano & Brown, 2010).

In the 20th century, sewer systems underwent standardization and enhancement. The introduction of new materials like cast iron, vitrified clay, and later plastic pipes significantly improved the durability and efficiency of sewer lines. Sewer systems became an integral component of urban planning, subject to stricter regulations and standards for wastewater management. Advanced treatment technologies, such as biological and chemical processes, were incorporated into sewage treatment plants to enhance the quality of treated wastewater before discharge (Fontecha et al., 2020).

In the present day, sewer systems continue to evolve due to technological advancements, environmental considerations, and a growing focus on sustainability and water conservation.

Efforts are being made to optimize systems, reduce energy consumption, and explore innovative approaches to wastewater management, including decentralized treatment and water reuse.

2.3. Types and performance of sewer networks

The design, materials used, and operation of sewer networks have a significant impact on sewer processes. Understanding sewer processes is crucial for designing and operating an effective sewer system. For example, the type of sewer plays a major role in determining whether aerobic or anaerobic processes dominate. Additionally, the flow regime in the water phase and the ventilation of the sewer atmosphere can influence the accumulation of odorous, corrosive, and toxic volatile substances produced by microbiological processes in the water (Schütze et al., 2004).

Sewers can be categorized in different ways, with three major classification criteria being: (1) the type of sewage collected, (2) the mode of transport applied, and (3) the size and function of the sewer. These categories result in different characteristics in terms of wastewater collection and transport within the sewer system. Considering these aspects is essential when examining sewer processes (Hvitved-Jacobsen T et al., 2013).

2.3.1. Transport Mode of Sewage Collected transport

There are four distinct types of wastewater collection systems: gravity sewers, vacuum sewers, pressure sewers, and small diameter gravity sewers (Choi, 2003). Conventional gravity sewers rely on the force of gravity to move wastewater from higher to lower areas, ensuring a continuous flow without causing manholes to overflow or requiring pipe pressurization. In Addis Ababa, gravity sewers are commonly used due to their ability to handle grit and sediment, their reduced formation of methane and hydrogen sulfide, and their suitability for installation in shallower and smaller excavations.

Vacuum sewers, on the other hand, employ a vacuum valve and a central vacuum station to extract wastewater from holding tanks (Islam, 2017). Pressure sewers function by utilizing pump pressure to transport wastewater from individual properties to a centralized location, eliminating the need for lift stations and manholes along the way (Saracevic et al., 2007). Lastly, small diameter gravity sewers not only transport wastewater but also carry out primary treatment at each connection point, separating the flow from grit and grease. This approach allows for the use of smaller pipes and less steeply inclined pipelines.

2.3.2. Size and Function of Sewer

A sewer system consists of a network through which sewage flows, starting from small collecting sewers in the upstream area of a catchment and gradually progressing to larger sewers until it reaches the wastewater treatment plant. Various terms are used to describe different types of sewers within this context. The smaller sewers in the upper part of the catchment are often referred to as lateral sewers. Multiple lateral sewers or secondary sewers typically discharge into a trunk sewer, which serves a larger catchment area. The intercepting sewer is the primary structure of the sewer network, receiving sewage from several trunk sewers and diverting it towards treatment and disposal (Moeini & Afshar, 2012).

2.3.3. Type of Sewage is Collected

The classification and characteristics of different types of sewers will be further explained and emphasized. Sanitary sewer networks, also known as separate sewers, are designed to collect and transport daily wastewater flow from residential, commercial, and industrial areas to a wastewater treatment plant. The wastewater in these sewers typically contains biodegradable organic matter and microorganisms, making it biologically active. It consists of a mixture of biomass, especially heterotrophic bacteria, and substrates that support this biomass (Hvitved-Jacobsen et al., 1998). The flow in sanitary sewers is controlled either by gravity or pressure exerted by pumps in pumping stations. In gravity sewers, where the sewer is partially filled, oxygen transfer through the air-water interface allows aerobic heterotrophic processes to occur (Zuo et al., 2023). Conversely, pressurized systems are full-flowing and lack reaeration, leading to the dominance of anaerobic processes in the wastewater (Mathioudakis & Aivasidis, 2009).

The residence time in a sewer network, influenced by catchment size, distance to the downstream treatment plant, and sewer characteristics like diameter and slope, affects the degree of wastewater transformation. Pressure sewers often have relatively high residence times, particularly during nighttime when wastewater flow is reduced (Kapo et al., 2017).

Storm sewer networks are designed for collecting and transporting storm water runoff from impervious or semi-pervious urban surfaces, such as streets, parking lots, and roofs. Inlets located in street gutters facilitate the entry of surface waters into these networks. Storm sewers operate during and after rainfall events, as well as snowmelt periods. Typically, storm sewers divert runoff water directly into nearby watercourses with limited or no chemical and biological treatment,

although the use of detention ponds or other facilities for runoff treatment is becoming more common (Savic et al., 2008).

Combined sewer networks are responsible for collecting, mixing, and transporting both municipal wastewater and urban runoff water. During periods of dry weather, these networks operate similarly to sanitary sewers. However, they are designed differently to accommodate runoff, incorporating overflow structures and detention basins to effectively manage large volumes of water during wet weather events. These additional components have an impact on various process details. Compared to sanitary sewers, combined sewer systems exhibit greater process variability due to frequent changes in flow conditions. The construction of combined sewer networks involves the use of gravity sewer lines, pressure pipes, or a combination of both (Arthur et al., 2015).

The size and function of a sewer have different effects on sewer processes. For instance, in larger-diameter sewers, the processes related to the water phase become more significant in comparison to surface-related processes like biofilm processes.

2.4. Composition of sewage in different cites

The sewage flow rate and composition vary considerably from place to place, basically depending on economic aspects, social behavior, type and number of industries located in the collection area, climatic Conditions, water consumption, type and conditions of the sewer system, and so forth (Seghezzo et al., 1998). Municipal wastewater is usually the main component of sewage, and is often used as a synonym. Table 2. 1 shows the most important constituents of raw sewage in three cities where anaerobic treatment plants are in operation (Seghezzo et al., 1998).

Table 2.1 composition of sewage in different cites (from van Haandel & Lettinga, 2004)

Constituent	Pedregal (Brazil)	Cali (Colombia)	Bennekom (The Netherlands)
Settle able solids	8.2	-	-
Suspended solids			
Total	429	215	-
Fixed	177	106	-
Volatile	252	107	-
BOD	368	95	231
COD	727	267	520
Nitrogen (as N)	44	24	45
Organic	10	7	-
Ammonia	34	17	-

Phosphorus			
Total	11	1.3	18
Orthophosphate	8	-	14
Organic	3	-	4
Escherichia coli (number in 100 ml)	4X10 ⁷	-	-
Sulphates	18	-	15
Chlorides	110	-	-
Alkalinity	388	120	350
Calcium	110	-	4
Magnesium	105	-	2
Temperature (°C)			
Maximum	26	27	20
Minimum	24	24	8

Fresh wastewater is a murky, turbid liquid with a neutral, earthy smell. In addition to contaminants in true solution, it also contains large floating and suspended solids (like feces, rags, plastic containers, and maize cobs), smaller suspended solids (like partially digested feces, paper, and vegetable peel), and very small solids in colloidal (non-settle able) suspension. Due to the large quantity of disease-causing (or "pathogenic") organisms it contains, it is offensive in appearance and dangerous in composition. Warm climates can cause wastewater to quickly lose its dissolved oxygen concentration and turn "septic" or "stale." The foul smell of septic wastewater is typically caused by hydrogen sulfide (Priyanga et al., 2023).

In simpler form, the composition of human feces and urine for wastewater. The organic fraction of both is composed principally of proteins, carbohydrates, and fats. These compounds, particularly the first two, form an excellent diet for bacteria, the microscopic organisms whose voracious appetite for food is exploited by public health engineers in the microbiological treatment of wastewater (Seghezzo et al., 1998).

2.5. Wastewater Constituents

The composition of wastewater can differ depending on its origin and the activities that produce it. It consists of various elements, including physical, chemical, and biological components. These aspects are interconnected, where temperature can impact gas levels and biological processes. When treating wastewater, important constituents to consider are substances that can be broken

down by microorganisms, solid particles in suspension, disease-causing organisms, essential nutrients, toxic metals, and substances of high environmental concern. If wastewater is intended for reuse, additional criteria may apply, such as the removal of persistent organic compounds, heavy metals, and dissolved inorganic substances (Drexler et al., 2013).

2.5.1. Physical Characteristics

The total solids content is the primary physical attribute of wastewater, encompassing floating matter, settle able matter, colloidal matter, and matter dissolved in the solution. Additionally, key physical properties include the distribution of particle sizes, turbidity, color, transmittance, temperature, conductivity, density, specific gravity, and specific weight. Odor, though often considered a physical factor, will be discussed in the subsequent section (Cavallini et al., 2013).

Total Suspended Solids (TSS): in wastewater refers to the concentration of solid particles that are suspended in the water and are generally visible to the naked eye. These solids can include a variety of materials such as organic matter, inorganic particles, debris, and microorganisms. TSS is an important parameter used to assess the overall quality and pollution level of wastewater. High TSS levels in wastewater can indicate pollution, inadequate treatment, or the presence of harmful substances. Monitoring and controlling TSS is crucial in wastewater treatment processes to ensure the removal of suspended solids before the treated water is discharged into the environment (Verma et al., 2013).

Total Dissolved Solids (TDS): in wastewater refers to the concentration of substances that are dissolved in the water. Unlike suspended solids, which can be seen and settle, dissolved solids are molecularly dispersed in the water and are not easily visible. TDS represents a collective measurement of different inorganic and organic substances that have dissolved in the wastewater, including salts, minerals, metals, organic compounds, and other dissolved substances.

These dissolved solids can come from various sources, such as industrial discharges, domestic wastewater, agricultural runoff, and natural processes. The level of TDS in wastewater is an important parameter used to evaluate the quality of water and determine its suitability for various purposes, such as irrigation, industrial processes, or environmental discharge (Peng et al., 2020).

Volatile solids and fixed solids: are two different types of substances present in wastewater. Volatile solids (VS) are materials that can be evaporated and burned off when exposed to temperatures around $500 \pm 50^{\circ}\text{C}$. Typically, volatile solids are considered to be organic matter, although not all organic matter can be burned, and some inorganic solids may also break down at high temperatures.

On the other hand, fixed solids (FS) are the residue that remains after a sample has been heated and ignited. Therefore, the total solids (TS), total suspended solids (TSS), and total dissolved solids (TDS) in wastewater comprise both fixed solids and volatile solids. The ratio of volatile solids to fixed solids is often used as an indicator of the organic matter content in the wastewater (Presti et al., 2021).

Turbidity: in wastewater refers to the cloudiness or opacity of the water due to the presence of suspended particles. These particles can consist of sediment, organic matter, inorganic substances, and microorganisms. Turbidity is a measure of how light is scattered and absorbed by these suspended particles. It is an important parameter used to evaluate the physical quality of water and wastewater. High levels of turbidity can indicate the presence of pollutants, such as sediment or suspended solids, and can be an indication of poor water quality. Additionally, it can interfere with the effectiveness of water treatment processes by impeding disinfection, filtration, and other treatment methods.

Turbidity is typically assessed using a turbid meter, which quantifies the amount of light scattered by the suspended particles in the water. The measurement is commonly expressed in nephelometric turbidity units (NTU) or formazan nephelometric units (FNU). Monitoring and managing turbidity in wastewater are crucial to ensure the efficiency of treatment processes and safeguard public health and the environment. Treatment techniques like sedimentation, filtration, and coagulation are frequently employed to decrease turbidity and remove suspended particles from wastewater (Kumar Mandal, 2014).

Color: The color of wastewater refers to how it visually appears, ranging from clear to various shades of yellow, brown, or other colors. It is influenced by the presence of dissolved and suspended substances, including organic matter, minerals, industrial dyes, and other pollutants.

The color of wastewater serves as an indicator of its quality and provides valuable information about the sources and types of contaminants present. For instance, a dark brown or black color may suggest the presence of organic matter or high concentrations of suspended solids.

A yellowish color can be associated with industrial dyes or specific chemical compounds. Moreover, the color of wastewater can be influenced by the presence of algae or other biological organisms.

Measuring and monitoring the color of wastewater is essential for water quality analysis. Colorimetric methods, such as using a spectrophotometer, are commonly utilized to quantify the intensity of color in wastewater samples. The results are typically reported in units like platinum-cobalt (Pt-Co) units or Hazen units.

Wastewater treatment processes often aim to reduce or eliminate undesired color, along with other contaminants. Techniques such as coagulation, sedimentation, filtration, and advanced oxidation processes may be employed to remove substances that cause color and enhance the visual appearance of the wastewater (Collivignarelli et al., 2019).

Temperature: The temperature of wastewater refers to the measurement of the heat energy contained within the water. It is a physical characteristic that indicates the thermal state of the wastewater. The temperature of wastewater can vary based on factors such as its source, environmental conditions, and any heat transfer that occurs during transportation or treatment. Typically, wastewater has a higher temperature than the local water supply due to the addition of warm water from households and industrial activities.

Temperature has various effects on chemical reactions, aquatic life, and the suitability of water for different purposes. Elevated temperatures can lead to changes in fish species within the receiving water body, particularly when surface water is used for cooling purposes in industrial facilities. Warm water has lower oxygen solubility, resulting in reduced dissolved oxygen levels during the summer months. Sudden temperature fluctuations can cause significant mortality rates among aquatic organisms and promote the growth of undesirable water plants and wastewater fungi.

Bacterial activity in wastewater is influenced by temperature, with optimum temperatures for bacterial activity falling between 25 and 35°C. Aerobic digestion and nitrification cease at 50°C, methane-producing bacteria become inactive at 15°C, and autotrophic-nitrifying bacteria practically stop functioning at 5°C (Ahsan et al., 2005).

Electrical conductivity (EC): in wastewater refers to the water's capacity to conduct an electric current. It quantifies the concentration of dissolved ions and salts in the water, influencing its ability to transmit electrical charges. EC is a crucial parameter used to evaluate the salinity or total dissolved solids (TDS) content in wastewater.

When wastewater contains dissolved ions and salts like sodium, chloride, calcium, or sulfate, it becomes conductive. The higher the concentration of dissolved ions, the greater the electrical conductivity of the wastewater. Electrical conductivity is typically measured in units such as Siemens per meter (S/m) or millisiemens per centimeter (mS/cm).

Monitoring the electrical conductivity of wastewater is vital for various applications and industries. It aids in assessing the overall water quality, determining its appropriateness for different uses (such as irrigation or industrial processes), and evaluating the efficiency of treatment processes. Elevated electrical conductivity levels in wastewater can indicate increased concentrations of dissolved salts, which may harm the environment or interfere with treatment processes.

Controlling and managing the electrical conductivity of wastewater may involve implementing appropriate treatment techniques, such as desalination or ion exchange, to reduce the concentration of dissolved ions. Additionally, monitoring changes in electrical conductivity over time can provide insights into the effectiveness of treatment processes and the impact of different sources of contamination on wastewater quality (de Sousa et al., 2014).

2.5.2. Inorganic Nonmetallic Constituents

Wastewater chemical constituents are classified as inorganic and organic, with inorganic components including nutrients, nonmetallic compounds, metals, and gases. Organic constituents are aggregate and individual, with aggregate organic constituents being crucial for treatment, disposal, and reuse. Inorganic nonmetallic and metallic constituents in wastewater come from background water supply levels, domestic use, highly mineralized water from private wells and groundwater, and industrial use. Inorganic nonmetallic constituents include pH, nitrogen, phosphorus, alkalinity, chlorides, Sulphur, gases, and Odors. pH is considered first due to its dependence on hydrogen ion concentration in solution (Sánchez Rojas & Bosch Ojeda, 2005).

PH

The pH of wastewater refers to its level of acidity or alkalinity. It is a measure of the concentration of hydrogen ions (H^+) in the water. Hydrogen-ion concentration is a crucial quality parameter in natural waters and wastewaters, expressed as pH. The range for biological life is typically 6–9, with extreme concentrations challenging to treat. The allowable pH range for treated effluents discharged into the environment is 6.5-8.5 (Kumar Mandal, 2014).

Chlorides

Chloride in wastewater refers to the presence of the chloride ion (Cl^-) in the water. It is an anion that occurs naturally and is commonly found in wastewater due to various sources, including domestic wastewater, industrial discharges, and runoff from the environment. Chloride is a matter of concern in wastewater due to its impact on applications involving water reuse. It is derived from sources such as natural water bodies, coastal areas, agricultural activities, industrial processes, and domestic wastewater. High chloride concentrations can also result from human excreta and the use of water softeners in homes.

Conventional methods of wastewater treatment typically do not significantly remove chloride, and the infiltration of groundwater into sewers near saltwater sources can contribute to elevated chloride concentrations (L. Zhang et al., 2021).

Alkalinity

Alkalinity in wastewater is primarily caused by the presence of hydroxides, carbonates, and bicarbonates of elements such as calcium, magnesium, sodium, potassium, and ammonia. These compounds help to resist changes in pH when acids are added. Alkalinity in wastewater is typically derived from water supply sources, groundwater, and domestic usage. It plays a critical role in chemical and biological treatment processes, nutrient removal, and the elimination of ammonia. Alkalinity levels can be determined by measuring molar quantities.

Monitoring alkalinity in wastewater is important to assess its stability and the potential for pH fluctuations that could adversely affect treatment processes and the environment. It provides valuable information for the design and optimization of treatment strategies. Alkalinity levels can vary depending on the sources of wastewater, including industrial discharges, domestic wastewater, and natural inputs.

There are various methods available to measure alkalinity, such as titration using acid-base indicators or automated analyzers. Alkalinity is typically reported in units like milligrams per liter (mg/L) or equivalents per liter (eq/L).

Controlling alkalinity in wastewater treatment processes is crucial to ensure optimal conditions for biological treatment, chemical reactions, and overall process efficiency. In certain cases, adjusting alkalinity levels through the addition of alkaline substances or implementing pH control measures may be necessary to maintain stability and support desired treatment outcomes (Zhao et al., 2020).

Nitrogen

Nitrogen is an essential element for the growth of microorganisms, plants, and animals, playing a vital role in protein synthesis. In wastewater treatment, nitrogen is necessary for biological processes, and insufficient nitrogen levels may require the addition of nitrogen. Nitrogen sources in wastewater include nitrogenous compounds from plant and animal sources, sodium nitrate, and atmospheric nitrogen. In soil and groundwater, the majority of nitrogen is of biological origin, as nitrogen fixation is a process mediated by living organisms. The chemistry of nitrogen is complex due to its various oxidation states and transformations caused by living organisms.

The most common forms of nitrogen found in wastewater include ammonia, ammonium, nitrogen gas, nitrite ion, and nitrate ion. Total nitrogen consists of organic nitrogen, ammonia, nitrite, and nitrate. The organic fraction of nitrogen is a complex mixture of amino acids, sugars, and proteins. Analytically, organic nitrogen is determined using the Kjeldahl method, which involves boiling the sample to release ammonia and digesting it for further analysis (Zhu et al., 2008).

Phosphorus

Phosphorus in wastewater refers to the presence of compounds containing phosphorus in the water. Phosphorus is an essential nutrient that occurs naturally and is commonly found in wastewater from various sources, including domestic sewage, industrial discharges, and runoff from agricultural activities. The control of phosphorus is crucial in surface waters to prevent harmful algal blooms caused by excessive algae growth.

Phosphorus in aqueous solutions can exist in different forms, including orthophosphate, polyphosphate, and organic phosphate. Orthophosphates are readily available for biological metabolism without further breakdown. Polyphosphates contain multiple phosphorus atoms and

oxygen atoms. Organic phosphates, although typically present in minor quantities in domestic wastewater, can be a significant component in industrial wastes and wastewater sludge (De-Bashan & Bashan, 2004).

Sulfur

Sulfur in wastewater is a naturally occurring element found in various forms, including sulfides, sulfates, and organic compounds. It can be sourced from industrial processes, domestic sewage, and agricultural runoff. Monitoring sulfur levels is crucial as high concentrations can cause environmental and human health issues. Treatment methods include chemical precipitation, biological treatment, and advanced processes. Regulatory standards may specify maximum sulfur limits for wastewater discharge. Sulfur also contributes to the production of hydrogen sulfide gas, causing odor issues (Lin et al., 2018).

Gases

Untreated wastewater contains common gases such as nitrogen, oxygen, carbon dioxide, hydrogen sulfide, ammonia, and methane. These gases are common in the atmosphere and pose health and safety concerns. Other gases like chlorine, ozone, and sulfur oxides are also present in wastewater. Environmental engineers must be familiar with these gases for disinfection, odor control, and combustion processes (Pichtel, 2016).

Hydrogen Sulfide: Hydrogen sulfide, a colorless, inflammable compound with a rotten egg odor, is formed from anaerobic decomposition of sulfur-containing organic matter or mineral sulfites and sulfates. It is toxic and can cause a false sense of security. High concentrations can lead to a loss of smell, and it can also cause blackening of wastewater and sludge. Other volatile compounds may cause more offensive odors (Yongsiri et al., 2005).

Methane: Methane gas, a colorless, odorless, and combustible hydrocarbon, is produced from the anaerobic decomposition of organic matter in wastewater. It is typically not found in untreated wastewater due to its toxic nature. However, it can be produced due to anaerobic decay in bottom deposits. Access ports and sewer junctions should be ventilated to prevent gas collection. Treatment plants should post warnings about explosion hazards and instruct employees on safety measures (Daelman et al., 2012).

Odors

Odors in domestic wastewater are caused by gases from organic matter decomposition or substances added. Fresh wastewater has a distinctive odor, while stale or septic wastewater has hydrogen sulfide. Odors are a major concern for public acceptance of wastewater treatment facilities. Control of odors is crucial in designing and operating facilities, as many projects are rejected due to their potential. Understanding the effects, detection, and measurement of odors is essential for effective wastewater management (Jiang et al., 2017).

Metallic Constituents

Small quantities of various metals, including cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc, are present in most water sources. Many of these metals are classified as priority pollutants. While these metals are essential for the growth of biological organisms, insufficient amounts can limit the growth of certain organisms, such as algae. However, excessive concentrations of these metals can be toxic and hinder the beneficial uses of water. Therefore, it is important to measure and regulate the concentrations of these substances to ensure water quality (Machado et al., 2016).

Metals play a critical role in the treatment, reuse, and disposal of treated effluents and bio solids. Living organisms require varying amounts of metallic elements for growth, but high concentrations can be toxic. As treated wastewater is commonly used for irrigation and landscape watering, it is crucial to determine the sodium adsorption ratio (SAR) and other metal concentrations. Trace metals in wastewater originate from residential discharges, groundwater infiltration, and industrial discharges. Heavy metals like cadmium, chromates, lead, and mercury should be removed at the industrial site to prevent their entry into the wastewater (Machado et al., 2016).

2.5.3. Aggregate Organic Constituents

Organic compounds found in wastewater primarily include proteins, carbohydrates, oils, fats, and a significant component known as urea. Additionally, wastewater contains small amounts of synthetic organic molecules, varying in complexity from simple to intricate structures. Several analytical methods have been developed to assess the organic content of wastewater, and these methods are categorized based on their ability to measure aggregate organic matter (Ghime & Ghosh, 2019).

Biochemical Oxygen Demand (BOD)

The 5-day BOD (Body of Oxygen) is the most widely used parameter for determining organic pollution in wastewater and surface water. It measures the dissolved oxygen used by microorganisms in biochemical oxidation of organic matter. Despite its limitations, BOD test results are used to determine oxygen requirements, waste treatment facility size, treatment process efficiency, and compliance with wastewater discharge permits. Understanding the test's details and limitations is crucial for its continued use (Penn et al., n.d.2012).

Total and Soluble Chemical Oxygen Demand (COD and SCOD)

Chemical Oxygen Demand (COD) is a measurement that quantifies the amount of oxygen required to chemically oxidize both organic and inorganic compounds present in wastewater. It serves as an indicator of the overall organic content and pollution load in the water. Total COD (TCOD) assesses the total oxygen demand of the wastewater, while Soluble COD (SCOD) specifically measures the oxygen demand attributed to the soluble fraction of organic compounds. Monitoring COD and SCOD is crucial for wastewater treatment plants to optimize processes and ensure compliance with regulations. Effective control of COD and SCOD helps manage the organic load, preventing negative impacts on water bodies and the environment (Elnakar & Buchanan, 2020).

The Total and Soluble Chemical Oxygen Demand (COD and SCOD) test determines the oxygen equivalent of organic material in wastewater that can be chemically oxidized using dichromate in an acid solution. The ultimate carbonaceous Biochemical Oxygen Demand (BOD) value is typically lower than the COD due to factors such as lignin oxidation, increased organic content, toxicity of certain organic substances, and high COD values resulting from inorganic substances. The COD test can be completed within 2.5 hours, whereas the BOD test takes five or more days. As biological treatment methods advance, the fractionation of COD into particulate and soluble fractions becomes increasingly important. These fractions include readily biodegradable soluble COD, slowly biodegradable colloidal and particulate COD, non-biodegradable soluble COD, and non-biodegradable colloidal and particulate COD (Elnakar & Buchanan, 2020).

Total and Dissolved Organic Carbon (TOC and DTOC)

Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC) are vital parameters in the management of wastewater. TOC measures all carbon-containing compounds present in the wastewater, including both dissolved and suspended forms. DOC specifically measures the carbon

content within the dissolved fraction of organic compounds. Distinguishing between TOC and DOC is important because not all organic carbon is in a dissolved state. Specialized instruments such as TOC analyzers are typically used for these measurements. Monitoring TOC and DOC enables wastewater treatment plants to optimize their processes, assess efficiency, and ensure compliance with regulatory standards, thereby minimizing the environmental impact of organic pollution (Imai et al., 2002).

The Total and Dissolved Organic Carbon (TOC and DOC) method is employed to determine the total amount of organic carbon in an aqueous sample. It converts organic carbon into carbon dioxide, which is then measured using an infrared analyzer. The TOC test is becoming increasingly popular due to its short completion time and its potential to provide insights related to BOD and COD values. Continuous on-line TOC analyzers have been developed to detect TOC concentrations in the parts per billion (ppb) range, enabling the monitoring of full-scale reverse osmosis (RO) units in purification projects. Fractionation of TOC into particulate and dissolved (soluble) fractions is also crucial for assessing treatability. Advanced methods have been developed to quantify the different groupings of dissolved and particulate TOC constituents (Imai et al., 2002).

UV-Absorbing Organic Constituents

UV absorption is a technique utilized to quantify organic compounds in wastewater by measuring their ability to absorb ultraviolet radiation. This method is particularly effective for substances like humic substances, lignin, tannins, and aromatic compounds. UV absorption measurements are typically conducted within the range of 200-400 nm, with 254 nm being the most commonly reported value. The results are expressed in units of cm^{-1} , pH, and UV wavelength. The SUVA (Specific Ultraviolet Absorbance) test is employed to differentiate between different water samples and evaluate the potential for trihalomethane (THM) formation (Gong et al., 2008).

Oil and Grease

Wastewater often contains oil and grease, which encompass substances like fats, oils, waxes, and other similar compounds. The oil and grease content in wastewater is typically determined by extracting a waste sample using trichloro-trifluoroethane. Oils and grease consist of alcohol or glycerol combined with fatty acids. Liquids containing fatty acids are referred to as oils, while

solid forms are known as grease. If not removed prior to discharge, grease can negatively impact aquatic life and create unsightly surface films in water bodies (Sanghamitra et al., 2021).

Fats and oils can be found in various sources such as butter, lard, margarine, vegetable fats, meats, cereal germinal areas, seeds, nuts, and certain fruits. When subjected to mineral acids, these substances can undergo reactions that result in the formation of glycerin and fatty acids, which can precipitate as soaps. Kerosene, lubricating oils, and road oils are derived from petroleum and coal tar and have the ability to float on wastewater, causing maintenance issues (Sanghamitra et al., 2021).

2.5.4. Biological Characteristics

The biological characteristics of wastewater pertain to the existence and activities of microorganisms and other biological entities within it. This section provides an overview of the biological aspects of wastewater, encompassing bacteria, fungi, algae, protozoa, plants, animals, and viruses. These microorganisms play a vital role in regulating the presence of disease-causing pathogens and facilitating the decomposition of organic matter in both natural environments and wastewater treatment facilities. The discussion includes the utilization of indicator organisms, methods for enumerating microorganisms, and the exploration of newly identified organisms (Chang et al., 2008).

Pathogenic Organisms

Pathogenic organisms in wastewater can be categorized into bacteria, protozoa, helminths, and viruses. These organisms can cause diseases like typhoid, dysentery, diarrhea, and cholera, which are highly infectious and cause thousands of deaths annually in areas with poor sanitation, especially in the tropics. Up to 4.5 billion people are infected with some parasites, with typical data on the quantity and concentration needed for an infectious dose (Son et al., 2022).

Bacteria

Domestic wastewater contains a diverse range of bacteria, both non-pathogenic and pathogenic. Examples of pathogenic bacteria found in domestic wastewater include species like Salmonella, Vibrio, Mycobacterium, Clostridium, Leptospira, and Yersinia. Among these, Salmonella typhi is the most prevalent bacterial pathogen in domestic wastewater and can lead to serious illnesses such as typhoid fever and salmonellosis. Shigella is another waterborne bacterium that causes bacillary dysentery or shigellosis. Other bacteria present in wastewater include Vibrio cholerae,

Mycobacterium tuberculosis, and certain types of waterborne gastroenteritis with unknown causes. These bacteria can pose a risk to newborns and contribute to outbreaks of gastrointestinal diseases, with waterborne transmission being the most common route of infection (Siripong & Rittmann, 2007).

2.6 UASB

One type of anaerobic biological technology for treating sewage is the up-flow anaerobic sludge bed or blanket. Professor Lettinga, who worked at the agricultural university in Wageningen, Netherlands, invented there. One of the most popular and effective anaerobic reactors is available. Given that treating high concentrations of organic wastewater has been so successful, treating low concentrations of organic wastewater with reactors has been one of the study's hottest issues. Low concentration sewage is often defined as having a COD concentration of less than 1000 mg/L. The feed water system, reaction district, gas-liquid-sludge separator, air chamber, and treated water discharge system are the key parts of a traditional UASB reactor (S. J. Zhang et al., 2013).

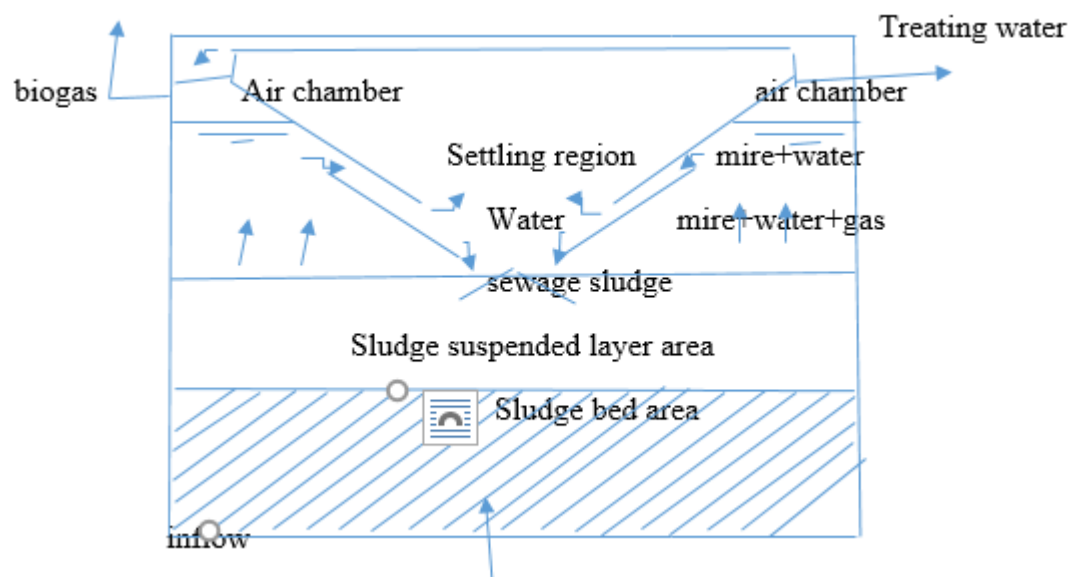


Figure 2.1 The working schematic of the UASB anaerobic bioreactor (S. J. Zhang et al., 2013)

The working principle of UASB biological reactor is the sewage bottom-up through the UASB. There is a high concentration and highly active sludge bed at the bottom of the reactor, where does the most of the organic pollutants in the sewage degrade to methane and carbon dioxide through anaerobic fermentation. Due to the agitation of the water and bubbles, there is a sludge suspension

layer above the sludge bed. There is a gas-liquid-sludge separator at the upside of the reactor, for the separation of the digestive gas, digestive liquid and sludge particles. The digestive gas has been exported from the top of the reactor; The sludge particles automatically fall to the sludge bed at the bottom of the reactor; The digestive water outflow from the clarification district, are shown in Fig2.1(S. J. Zhang et al., 2013).

About anaerobic treatment reaction mechanism, at present, the three stages and four flora doctrine are considered to be a more comprehensive description of the anaerobic biological treatment process in 1979, M. P. Bryant proposed a three-stages theory about anaerobic digestion, the three-stage theory include: The first stage is the hydrolysis fermentation stage. The second is the stage of hydrogen-producing and acetic acid. The third is the Methane production stage (S. J. Zhang et al., 2013).

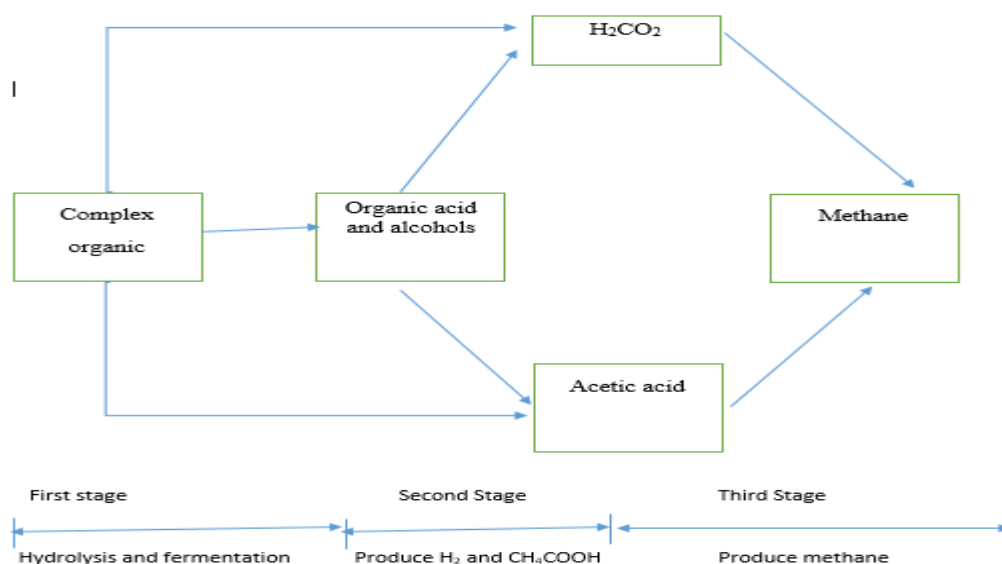


Figure 2.2 The diagram of the three-phase anaerobic digestion process(S. J. Zhang et al., 2013)

UASB reactor, the reactor used in this test has been added the anaerobic contact oxidation fill area on traditional UASB reactor, this method not only increases the attached area of anaerobic microorganisms, but also increases the contact between the anaerobic microorganisms and organic matter. Sewage bottom-up through the biofilm, the organic compounds adsorbed by the microorganisms and oxidation and decomposition, and make the sewage further purification. The inflow and effluent pH on the stability of the UASB reactor. The pH value is one of the most important factor of the anaerobic wastewater treatment. Many research and actual operating experience have shown that anaerobic digestion requires a relatively stable pH range, the pH range

of the anaerobic treatment refers to the pH of the reaction zone within the reactor, rather than the pH value of the inflow sewage.

The pH value of the inflow sewage would have been changed quickly by the biochemical processes and the dilution effects. The pH of the reactor's effluent wastewater is generally equal to or close to the pH within the reactor. The biggest factor of the pH changes is the acid, especially the formation of the acetic acid. Therefore, the sewage, which contain a large number of dissolved carbohydrates (such as sugar, starch), enter into the reactor, the pH will be reduced rapidly. For sewage containing a large number of proteins or amino acids, due to the formation of ammonia, the pH value has been increased slightly. (S. J. Zhang et al., 2013)

Anaerobic process, there is a large range of pH values for the hydrolytic bacteria and acidogenic bacteria, most of these bacteria can grow well in the range of pH 6.0-8.5. The suitable growth pH of the methane bacteria is 6.5-7.8, and the optimal pH is 6.8-7.2, this is the pH value range that the anaerobic treatment should be controlled. The reactor effluent pH is low for a long time, which will lead to the reactor acidification. So the effluent pH of the UASB reactor is an important indicator for the reactor's stability (S. J. Zhang et al., 2013).

Anaerobic biological wastewater treatment technologies generate high expectations in the field of environmental sanitation because, in addition to having the ability to treat a variety of wastewater strengths, they are more environmentally sustainable technologies than their aerobic counterparts. Anaerobic technologies could replace or complement aerobic-based treatment systems due to the advantages they provide, including biogas recovery, low excess sludge production, low construction, and operating costs, as well as low footprint and nutrient requirements. Thus, anaerobic technologies will be crucial to comply with goals 6 and 7 of the United Nations 2030 Sustainable Development Agenda (S. J. Zhang et al., 2013).

2.7. Previous Studies wastewater characteristics

The recent expansion of industries in Addis Ababa is causing additional environmental pollution through wastewater discharges; this is becoming a critical concern. To investigate whether conventional wastewater treatment works properly or not. Some studies that had been conducted in the characterization of wastewater in the Kaliti wastewater treatment plant in Addis Ababa showed that there was a different variance of constituents; some of them are reviewed in this

section.

Table 2.2 Removal of organic pollutants from municipal wastewater by Applying High-Rate Algal pond in Addis Ababa, Ethiopia by Keneni Alemu, Berhanu Assefa

Parameter (mg/l)	N	Average	Range	Standard deviation
pH	24	7.26	6.63–8.06	0.45
TDS	24	398.32	340–422	20.43
TSS	24	260.65	128–312	23.36
BOD5	24	266.49	246–285	11.55
COD	24	355.55	335–378	12.31

Table 2.3 Wastewater characteristics of Heineken Brewery(Agizew Nigussie et al., 2018)

Parameter	Units	Wastewater quantities and loads	
		Maximum	Average
Wastewater quantity	m ³ /d	1,900	-
COD-load	Kg/d	5,700	4,000
COD concentration	mg/l	3,000	2,100
BOD5	mg/l	1,800	1,300
TSS	mg/l	500	300
TN	mg/l	80	50
TP	mg/l	30	20
Temperature	°C	Range 25 - 38	

Table 2.4 Ethiopian Environmental Standard (mg/L) Effluent discharge limits

Parameter	Unit	Limit value
Temperature	°C	40
PH	-	6 – 9
BOD5 at 20 °C	mg/L	60
COD	mg/L	250
TSS	mg/L	50
Total ammonia (as N)	mg/L	20
Total N (as N)	mg/L	40
Total phosphorus (as P)	mg/L	5
Oil, fats and grease	mg/L	15
Mineral oil at the oil trap or interceptor	mg/L	20
T. Dissolved solid 105 °C	mg/L	3000

Table 2.5 Typical composition of raw municipal wastewater with minor contributions of industrial wastewater (Based on Henze, 2002)

Parameter	High	Medium	Low
COD total	1,200	750	500
COD soluble	480	300	200
COD suspended	720	450	300
BOD	560	350	230
VFA (as acetate)	80	30	10
N total	100	60	30
Ammonia-N	75	45	20
P total	25	15	6
Ortho-P	15	10	4
TSS	600	400	250
VSS	480	320	200

Table 2. 6 Typical content of metals in municipal wastewater with minor contributions of industrial wastewater (in mg/m³) (Henze, 2002)

Metal	High	Medium	Low
Aluminum	1000	600	350
Cadmium	4	2	1
Chromium	40	25	10
Copper	100	70	30
Lead	80	60	25
Mercury	3	2	1
Nickel	40	25	10
Silver	10	7	3
Zinc	300	200	100

CHAPTER 3 MATERIAL AND METHODS

3.1 Description of the Study Area

Location

Addis Ababa is located in the central part of Ethiopia, in the Ethiopian Highlands. It is situated at an elevation of approximately 2,400 meters above sea level. Geographically, it lies between the coordinates of approximately 9.0144° N latitude and 38.7468° E longitude. Addis Ababa serves as both the capital city and the political and economic center of Ethiopia (Moisa & Gameda, 2021).

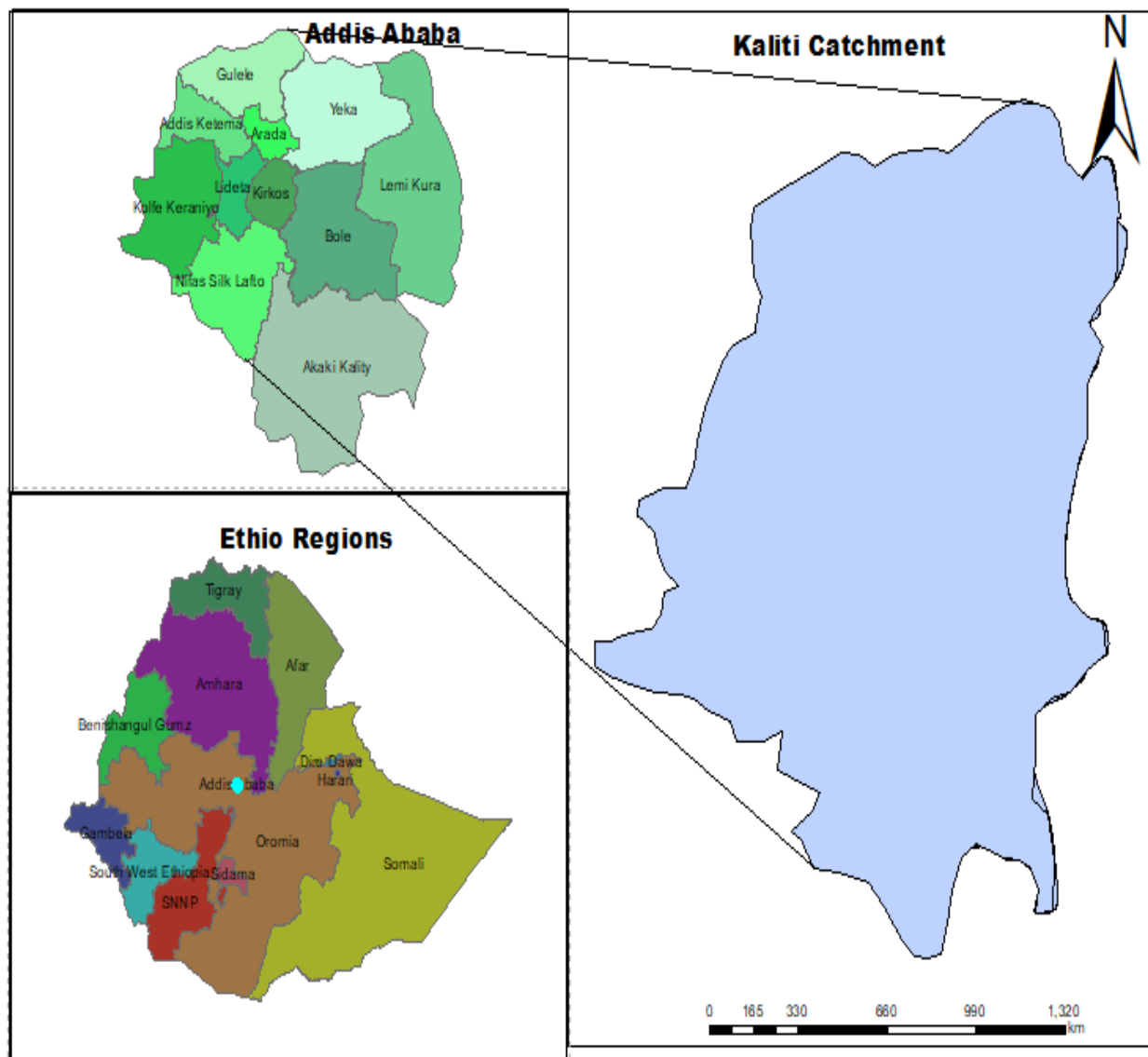


Figure 3.1 Location of study area

3.2 Wastewater flow catchment

The three wastewater flow catchments in Addis Ababa are Kaliti, Eastern, and Akaki (Figure 3.2). The Kaliti catchment is the subject of this investigation. The Kaliti wastewater watershed spans the central and northwest of the city and is made up of seven administrative sub-cities (Gulele, Kolfe-Keraniyo, Nifas-Silk-Lafto, Arada, Addis Ketema, Lideta, and Kirkos), as indicated in Figure 3.2. Addis Ababa is divided into eleven administrative sub-cities. Yeka, Bole and Lemikura are located in the Eastern catchment, and Akaki is located in the Akaki catchment. Approximately 80% of the city's wastewater is discharged through the Kaliti sewerage catchment, according to (Ali & Robele, 2023).

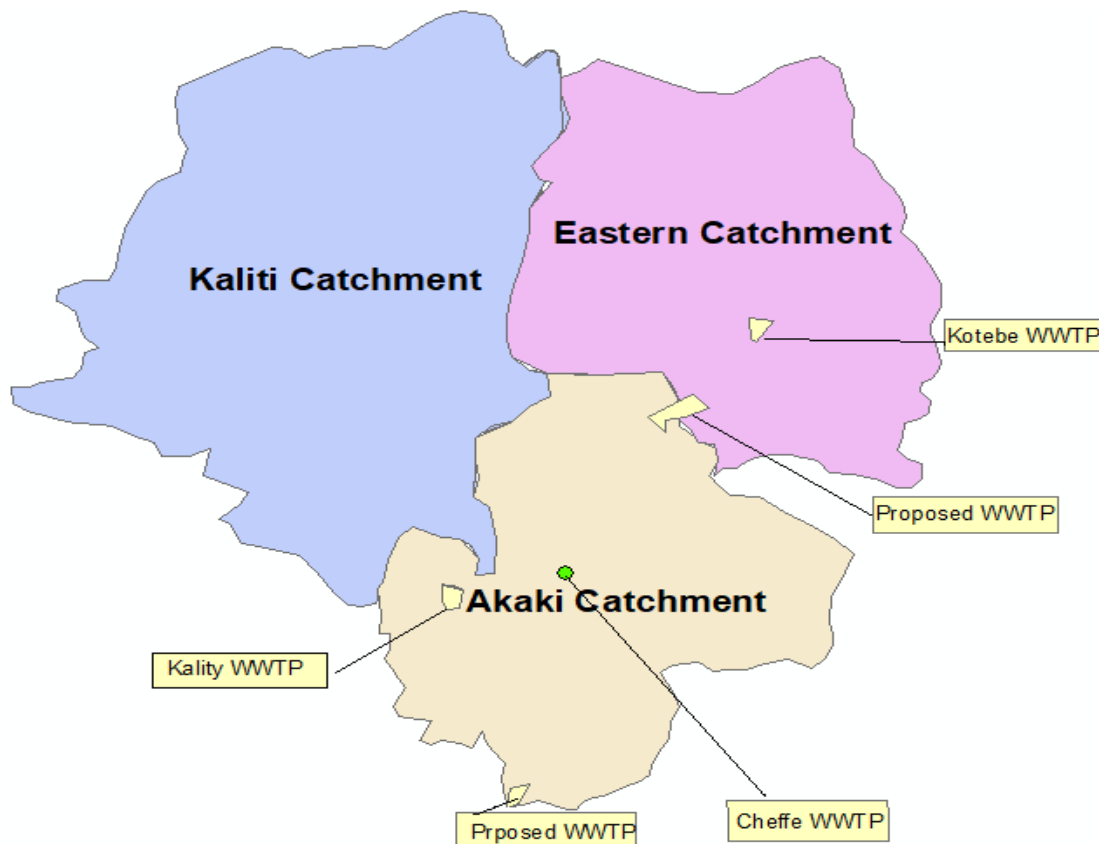


Figure 3.2 Location of study area—Kaliti Catchment

3.3 Existing sewerage system

There is only one centralized WWTP in the Kaliti watershed, and it has an installed capacity of 100,000 m³/d. The Kaliti treatment facility, which was put into service in 2018, is equipped with cutting-edge technologies, such as trickling filter units and an up flow anaerobic sludge blanket

(UASB). Due to the slower rate of connection to the sewage network, this plant has only been functioning at 75% of its potential (Ali & Robele, 2023). Additionally, 14 decentralized treatment facilities with a combined installed capacity of 60,240 m³/d (consisting of seven anaerobic baffled reactors, five membrane bioreactors, and two waste stabilization ponds) were built at various condominium housing sites. In the Kaliti catchment, a total of 1207 km of sewer lines—including trunk main, secondary line and tertiary lines—have been built. The trunk main (diameter 350-1500 mm), which covers 85 km of the 1207 km sewage line, is followed by the secondary sewer line (diameter 160-300 mm), which covers 927 km, and the tertiary sewer network (diameter less than 160 mm), which covers 195 km. Sewer lines are installed in more over 65% of some sub cities, including Bole, Kolfe-Keraniyo, and Nifas-Silk-Lafto. In the Kaliti catchment, there is a significant disparity between the amount of wastewater generated and the daily capacity for waste treatment (Ali & Robele, 2023).

3.4. Questionnaire the Impact of Municipal Wastewater on Kaliti Wastewater Treatment

To assess how municipal wastewater affects the Kaliti wastewater treatment process, the following questionnaire can be utilized. This questionnaire is designed to gather insights from various stakeholders, including wastewater treatment plant operators.

Section 1: General Information

1. Name:
2. Position/Title:
3. Organization:
4. Years of Experience in Wastewater Management:

Section 2: Characteristics of Municipal Wastewater

5. What are the primary sources of municipal wastewater in the Kaliti catchment area? (e.g., residential, industrial, commercial)
6. How do you characterize the composition of municipal wastewater entering the Kaliti treatment plant? (e.g., organic matter, nutrients, heavy metals)
7. Have there been any noticeable changes in the characteristics of municipal wastewater over the past few years? If yes, please specify.

Section 3: Treatment Process Evaluation

8. How effective do you find the current treatment processes (UASB reactors and trickling filters) in handling the municipal wastewater? Please rate on a scale of 1 to 5 (1 = Poor, 5 = Excellent).
9. What specific challenges does the Kaliti treatment plant face in treating municipal wastewater? (e.g., high pollutant loads, varying flow rates)
10. Have there been instances of treatment inefficiency linked to the characteristics of incoming municipal wastewater? Please provide examples.

Section 4: Impact of Illegal Discharges

11. How prevalent is the issue of illegal discharges of industrial wastewater into the municipal sewer system?
12. In your opinion, how do these illegal discharges affect the overall performance of the Kaliti wastewater treatment plant?
13. What measures are currently in place to monitor and control illegal discharges?

Section 5: Recommendations and Future Actions

14. What improvements do you suggest for the municipal wastewater management system to enhance the performance of the Kaliti treatment plant?
15. Are there any additional resources or support needed to address the challenges faced by the treatment plant?
16. How can community awareness and involvement be increased regarding the proper disposal of wastewater?

Section 6: Additional Comments

17. Please provide any additional comments or insights regarding the impact of municipal wastewater on the Kaliti wastewater treatment process.

This questionnaire aims to gather comprehensive data on the interplay between municipal wastewater characteristics and the operational efficiency of the Kaliti wastewater treatment plant, facilitating informed decision-making for improvements in wastewater management.

3.5. Sampling sites and sampling techniques

We collected samples from May 2023 to June 2023, respectively, because pollution impacts and the amount received vary by season. To ensure accurate and reliable analysis of the wastewater samples, the following protocols and procedures were followed:

Sampling Sites: The 20 sampling sites along the trunk sewer line were purposefully chosen by taking each stream of wastewater based on various factors such as land use characteristics, agricultural activities, population density, and potential sources of pollutants. This selection process will help capture a representative sample of the wastewater composition in the area.

Sampling Frequency: The sampling was conducted twice, covering the May and June months. This approach considers the seasonal variations in pollution levels, as different weather conditions can affect the amount and types of pollutants present in the wastewater.

Wastewater Sample Collection: At each sampling station, two types of samples were collected: physicochemical and trace metal analysis samples, and bacteriological analysis samples.

a. For physicochemical and trace metal analysis, 1 liter and 250 ml of wastewater samples were collected in pre-cleaned polyethylene bottles. The use of different volumes allowed for different types of analysis and ensured sufficient sample volume for accurate measurements.

b. For bacteriological analysis, sterilized bottles were used to collect the wastewater samples. This helped prevent contamination and ensured the integrity of microbial analysis.

Sample Preservation: After collection, all samples were stored in a refrigerator at a temperature of 4°C. This controlled storage environment helped maintain the stability and integrity of the samples until they were subjected to analysis.

Analysis Timeline: It was crucial to analyze the samples within 24 hours of collection to minimize any potential changes in the sample composition. Therefore, the analysis was carried out promptly to ensure accurate and reliable results.

By following these sampling and analysis procedures, the study aims to obtain comprehensive data on the physicochemical properties, trace metal concentrations, and microbial composition of the wastewater throughout the designated period and sampling locations. This information was contributed to a better understanding of pollution sources, variations, and potential impacts on the environment and public health.

3.6. Methods of Sample Analysis

3.6.1. In Situ Analysis

To measure pH, conductivity, TDS, and temperature using a HACH HQ440d multi-parameter portable meter, we followed these general steps:

Preparation: Ensure that the multi-parameter portable meter is calibrated and in good working condition. Check if the electrodes/probes for pH, conductivity, and temperature are clean and free from any debris or residue.

Calibration: Performed the necessary calibration for each parameter according to the manufacturer's instructions. Calibration solutions specific to each parameter are required. Typically, pH calibration involves using buffers of known pH values, while conductivity calibration involves using standard conductivity solutions.

pH Measurement:

- a. Rinse the pH electrode with distilled or deionized water to remove any residue.
- b. Immerse the pH electrode into the sample, ensuring that it was fully submerged and not touching the sides or bottom of the container.
- c. Allow the reading on the meter to stabilize. The pH value was displayed on the screen.

Conductivity Measurement:

- a. Rinse the conductivity probe with distilled or deionized water to remove any residue.
- b. Immerse the conductivity probe into the sample, ensuring that the probe's electrodes are fully submerged.
- c. Allow the reading on the meter to stabilize. The conductivity value was displayed on the screen.

TDS Measurement:

- a. Some multi-parameter meters have a separate mode for TDS measurement, while others calculate TDS based on the conductivity reading. Follow the meter's instructions for TDS measurement.
- b. If a separate TDS mode is available, select it on the meter.
- c. Immerse the conductivity probe into the sample, as described in the conductivity measurement step.
- d. Allow the reading on the meter to stabilize. The TDS value was displayed on the screen.

Temperature Measurement:

- a. Ensure that the temperature probe was clean and properly connected to the meter.
 - b. Immerse the temperature probe into the sample, ensuring that the sensing element was fully submerged.
 - c. Allow the reading on the meter to stabilize. The temperature value was displayed on the screen.
- Recording: Record the measured values of pH, conductivity, TDS, and temperature, along with any other relevant information such as sample identification, date, and time.

Cleaning: Rinse the electrodes/probes thoroughly with distilled or deionized water after each measurement to remove any sample residue. Follow the manufacturer's instructions for proper cleaning and storage of the electrodes/probes.

3.6.2. Laboratory Analysis

Municipal wastewater is used in the experiments. The characteristics of the samples such as pH, EC, TDS, Biological oxygen demand(BOD₅), Chemical oxygen demand (COD), Total solids(TS), Total Nitrogen (TN), Total Phosphorus (TP), Total Coliform and Heavy Metals are to be analyzed as shown in the table. 3.1. Experiments are conducted in AAU, AAWSA, ECDSWCO the main laboratories.

Table 3.1 Physico-chemical parameters and the methods adopted

No.	Parameters	Methods	Equipment's	Place of lab
1	pH	Multi-Parameter	Portable Meter	In situ
2	EC	Multi-Parameter	Portable Meter	In situ
3	TDS	Multi-Parameter	Portable Meter	In situ
4	BOD ₅	Manometric Method	BOD Incubator	AAWSA
5	COD	Open Reflux Method	Reflux Flash	AAWSA
6	TN	Macro-Kjeldah Method	Photometry	ECDSWCO
7	TP	Ascorbic Acid	Photometry	ECDSWCO
8	Total Coliform	Filtration Membrane	Filtration Membrane	ECDSWCO
9	Heavy Metals	ICP-OES	ICP-OES	AAU

We utilized the manometric method to quantify the biochemical oxygen demand (BOD) of sewage. This method involves collecting a representative sample, and performing a series of steps,

including dilution, and preparation of BOD bottles. The initial dissolved oxygen (DO) concentration is measured using a dissolved oxygen meter. The volume of the sample added to the BOD bottle is then sealed to prevent gas exchange. The bottles are subsequently incubated at a controlled temperature for 5 days, and the final DO concentration is measured after the incubation period. The BOD value is calculated using the formula $BOD (mg/L) = (Initial\ DO - Final\ DO) \times Dilution\ factor$. Finally, the BOD value is reported in units such as mg/L or ppm. To measure the chemical oxygen demand (COD) in wastewater, we employed the open reflux method. This technique encompasses several steps, which include sample collection, preservation, sample preparation, digestion, reflux, digestion period, cooling, calibration, and colorimetric measurement. The sample is collected from a location that accurately reflects the composition of the wastewater. If immediate testing is not feasible, a preservative is added to maintain sample integrity. The sample is then filtered to remove any suspended solids. A solution of potassium dichromate and sulfuric acid is prepared, and the sample is diluted. The reaction is maintained at a near-boiling temperature for 2 hours. Following digestion, the sample is cooled and further diluted. A calibration curve is established using standard solutions with known COD concentrations. The COD concentration is subsequently determined using the calibration curve and reported in units such as mg/L or ppm. The determination of total phosphorus is a widely used analytical chemistry method, in which we employed the use of ascorbic acid. This process entails sample preparation, calibration standards, reagent preparation, reaction vessel setup, acid digestion, addition of ascorbic acid, reaction time, color development, measurement, establishment of a calibration curve, phosphorus determination, and final reporting. The sample used can be water, soil extract, or any other suitable matrix. Calibration standards are prepared with known phosphorus concentrations, and appropriate reagents, including the ascorbic acid solution, are prepared. The reaction vessel is then transferred, and acid digestion is carried out to convert all forms of phosphorus into a single form suitable for quantification. The ascorbic acid solution reacts with the phosphorus in the sample, forming a colored complex, and the absorbance value is measured. Finally, the concentration of phosphorus is determined using the calibration curve and the absorbance value obtained. The phosphorus concentration is reported in the appropriate units. The macro-Kjeldahl method is a widely used analytical technique for determining nitrogen content in organic compounds. It involves series of steps, including weighing a representative sample, digestion with concentrated sulfuric acid, adding a catalyst, collecting the ammonia gas, titration with a standardized acid solution, and calculating the nitrogen content. The results are typically

reported as a percentage or in units of mass. It is important to adhere to recognized standards and guidelines to ensure accurate and comparable results, as the method provides a total nitrogen measurement, that includes both organic and inorganic forms. The Standard Total Coliform Membrane Filter Procedure is a method employed for the detection and quantification of total coliform bacteria in water samples. The procedure entails collecting a representative sample, preserving it using a preservative, setting up a filtration apparatus, transferring the sample to a suitable culture medium, incubating the plates, examining for coliform colonies, and calculating colony-forming units (CFUs) per volume of the water sample tested. Adherence to recognized standards and guidelines is crucial to ensure accurate and comparable results. Quality control measures are also implemented to maintain accuracy and reliability. ICP-OES is a technique utilized for determine heavy metals such as chromium, manganese, and zinc. The process involves various steps, including sample preparation, instrument calibration, instrument setup, nebulization and sample introduction, spectral acquisition, data acquisition and analysis, quality control, and data interpretation and reporting. Sample preparation requires digestion, dilution, filtration, and extraction. Instrument calibration entails utilizing calibration standards to prepare solutions with known concentrations of the target elements. Instrument setup involves following the manufacturer's instructions, introducing the sample into the instrument, and analyzing the emitted light. Data acquisition and analysis involve collecting emission spectra and comparing them to calibration standards. Quality control measures are incorporated to ensure accuracy and reliability. Data interpretation and reporting involve calculating concentrations based on calibration curves and measured intensities.

Table 3.2 Sample collection spots

FID	POINT X	POINT Y	LOCAL NAME(NEARBY)
MH-1	467914.262	994187.720	Alert Hospital Area
MH-2	466793.643	993444.283	Betel Area
MH-3	466527.913	992891.082	Ayer Tena Square Area
MH-4	469113.130	992646.819	watete bet Area
MH-5	472017.731	993162.757	Kera Beret Area
MH-6	470391.811	992313.760	Zoma Museum Area
MH-7	469017.218	991449.841	Tennis club Area
MH-8	470681.197	991407.264	Gofa Area
MH-9	472084.219	991532.942	Gofa Industry Area
MH-10	469519.772	989763.699	Jemo one Area
MH-11	472366.165	989815.558	Lafto River Area
MH-12	473584.721	990366.921	Gotera Mojo oil factory Area
MH-13	475396.855	993875.435	safaricom building Area
MH-14	475504.806	993769.072	Karamara Bridge Area
MH-15	474792.811	993284.883	Wollo sefer INSA Area
MH-16	473839.515	992188.713	Gotera Mamo River Area
MH-17	474411.811	989728.876	Sarise Addis Sefer Area
MH-18	473517.252	987580.985	kality Awash Leather factory Area
MH-19	473965.241	986937.577	Kality maseltgna Area
MH-20	473249.757	985691.856	Kality treatment Area

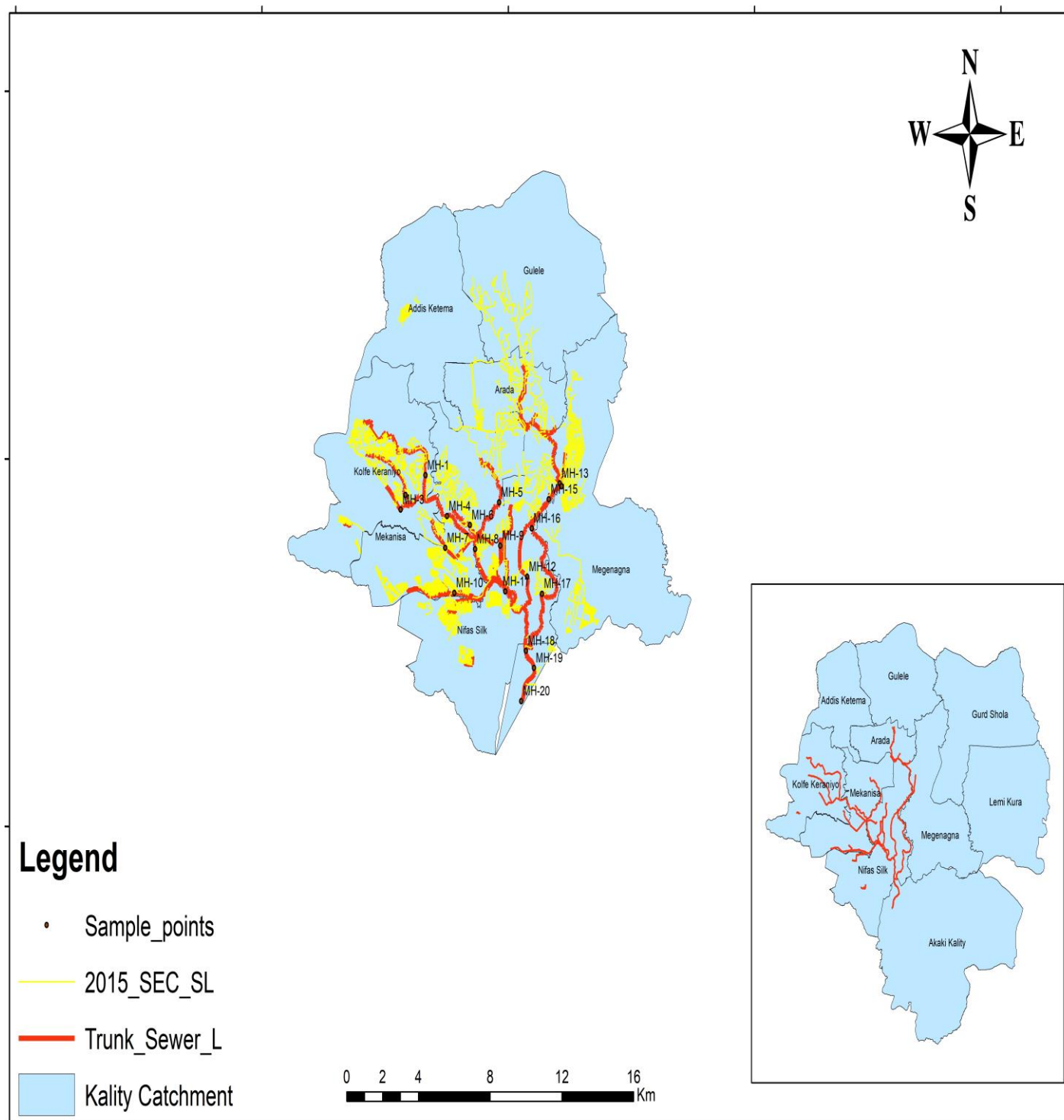


Figure3.3 Locations of Sampling stations within the Kaliti catchment

3.7 Models for Mapping

3.7.1 GIS as Decision Making Tool

Spatial mapping in GIS (Geographic Information System) The process begins by using a GPS device to take the x-y and elevation of twenty sampling points within the Kaliti catchment, then arranging them on Microsoft Excel sheets for each sampling point and giving the manhole name and x-y coordinate to ensure the map was accurate. Then we opened ARCGIS 10.7 softer by using menu options to import our prepared sheet, then the softer reads sample locations. After this, we added Addis Ababa Mosaic to integrate streets and topographic features; this was done by layer management options of softer. The map was analyzed to gain meaningful insights and to answer the questions for areas requiring more attention. Then cartographic representation: this was a map customized by using symbols and colors. This step makes the map easy to read and interpret the results. The finale step was map output to communicate public spatial information effectively.

The general principles outlined below

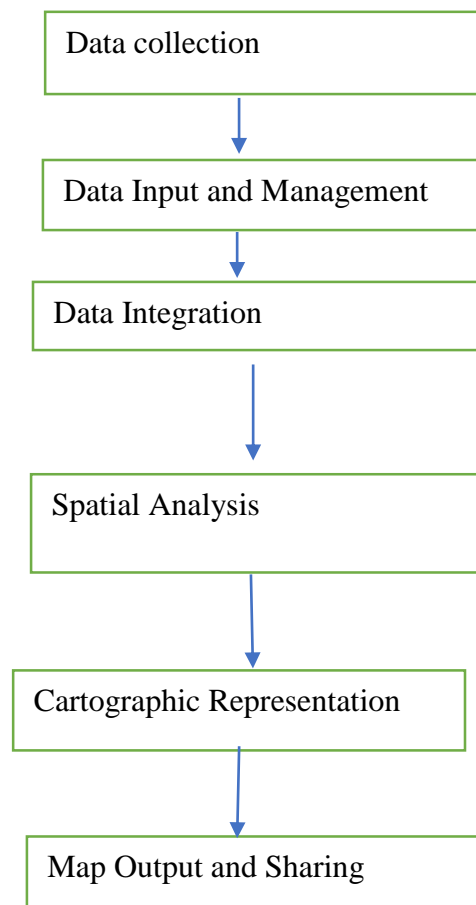


Figure3.5Techniques used in GIS for spatial mapping

CHAPTER 4 RESULT AND DISCUSSION

Concentrations of the analyzed parameters in the wastewater samples and the corresponding threshold limits are presented in Table 4.1. Manganese concentration was found to be 0.280 ± 0.215 mg/L in the rainy season and 0.390 ± 0.215 mg/L in the dry season, higher than the threshold limit of 0.02 mg/L. This because the corrosion of metal piping and fixtures, especially those composed of steel or galvanized iron, is the main cause of manganese in municipal wastewater. The other parameters are Zn, Cr, pH, EC, TDS, BOD₅, COD, TP, TN, temperature, and total coliform are below the threshold limits and are shown in the table below in detail.

Table 4.1 Characteristics and seasonal variability of the wastewater

Parameters	Season (month)		Permissible limits
	Dry season (May)	Rainy season (June)	
Mn (mg/L)	0.39 ± 0.22	0.28 ± 0.22	0.02
Zn (mg/L)	0.01 ± 0.02	0.01 ± 0.01	0.3
Cr (mg/L)	0	0	0.04
TDS (mg/L)	697.06 ± 155.95	345.03 ± 154.67	-
pH	7.72 ± 0.17	7.88 ± 0.21	8
EC ($\mu\text{s}/\text{cm}$)	1156.94 ± 282.16	968.59 ± 282.94	1200
Temperature($^{\circ}\text{c}$)	21.94 ± 1.67	21.88 ± 1.15	-
BOD ₅ (mg/L)	505.3 ± 184.26	428.35 ± 137.64	560
COD (mg/L)	1221.96 ± 401.97	1070.88 ± 344.10	1,200
TP (mg/L)	14.11 ± 3.71	11.52 ± 3.67	25
TN (mg/L)	69.97 ± 18.98	50.77 ± 19.06	100
Total Coliform(per 100ml) CFU	$24.68 * 10^6 \pm 2.99$	$21.28 * 10^6 \pm 2.99$	$5 * 10^8$

Mean (values are in mg/L otherwise stated) \pm standard deviation. Permissible limit for adapted from USEPA (2012) and WHO (2006).

4.1. Physico-chemical Parameters

4.1.1. Temperature

The samples were collected in the morning between 10 a.m. and 12 a.m. by considering the complete mixing of waste in the sewer system at all sampling sites. The spatial variation of temperature in the samples collected in the May and June months was not significant according to ANOVA analysis ($P = 0.887$). This might be due to stable influent wastewater characteristics,

sampling frequency, natural attenuation processes, and the uniform distribution of rainfall during the study period. Temperature all analysis result both months shows in Fig 4.1. The highest and lowest temperature values of wastewater were 24.1 °C and 19.2 °C in May and 23.6 °C and 19.5 °C in June, respectively. This was due to a variety of factors, such as the time of day, the number of people using the water, the season, and the climate. The average of May and June months temperatures was 21.94 and 21.875, respectively, which shows there is no variance in season. The temperature of all the wastewater samples is within the standard limit set by WHO and EEPA.

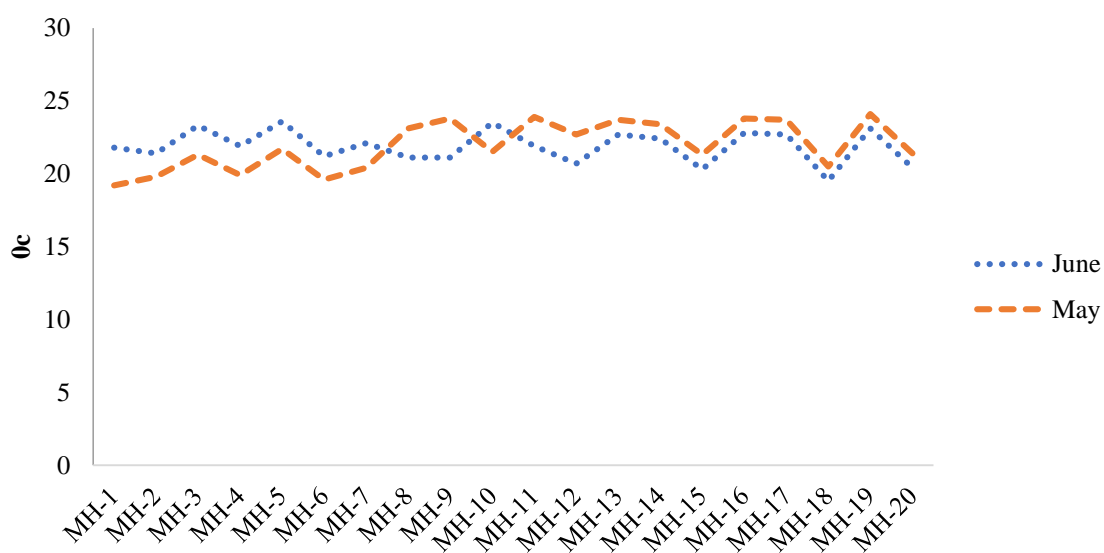


Figure 4.1 Temperature variation of the samples within the Kaliti catchment during May and June.

Table 4.2 ANOVA Table of Temperature

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.042	1	0.042	0.020	0.887
Within Groups	78.465	38	2.065		
Total	78.508	39			

4.1.2. pH

All analysis results for pH from May to June are shown in Fig 4.2. The spatial variation of pH in the samples collected in May and June months was significant according to ANOVA analysis ($P = 0.017$). This might be due to seasonal variation in rainfall and runoff, biological activity, wastewater composition changes, and changes in water usage and source. Typically, the pH of domestic wastewater ranges from around 6 to 9, according to the (EEPA, 2003). However, if the wastewater contains acids or bases, the pH can be lower or higher, respectively.

The physicochemical properties of the influent samples from three municipal sewage treatment plants in the Eastern Cape of South Africa were analyzed (Agoro et al., 2018). The pH range for WWTP-A was 7.02–8.65, for WWTP-B it was 7.01–8.77, and for WWTP-C it was 7.02–8.65. When comparing the pH values of these treatment plants to the results of this study, a similar trend is observed, as the pH of the influent in this study ranged from 7.43 to 8.06. It is the optimal pH range for an Up flow Anaerobic Sludge Blanket (UASB).

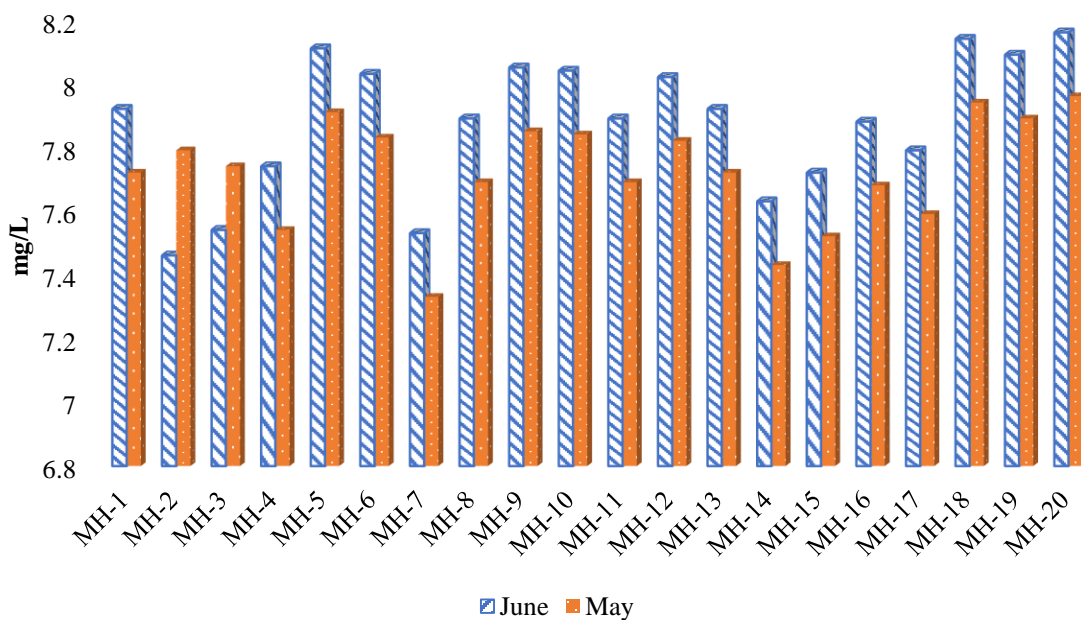


Figure 4.2 pH variation of the samples within Kaliti catchment during May and June.

Table 4.3 ANOVA Table of pH

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.236	1	0.236	6.255	0.017
Within Groups	1.431	38	0.038		
Total	1.667	39			

The pH variation was observed in the graph, prompting further investigation since the primary objective of this study is to characterize the mapping of sewage. To assess the spatial variation, developed a mapping using GIS software. The analysis revealed that the manholes MH-1, MH-2, MH-14, and MH-15, located upstream around the Aleert Hospital Area, Betel Area, Ayere Tena Square Area, Karamara Bridge Area, and Wollo Sefer INSA Area—regions with limited industrial activities—exhibited relatively lower pH values. In contrast, manholes located in the middle and downstream sections of the catchment showed higher pH levels, which are characteristic of industrial areas. This pattern suggests potential industrial intrusion into the sewage system in these regions.

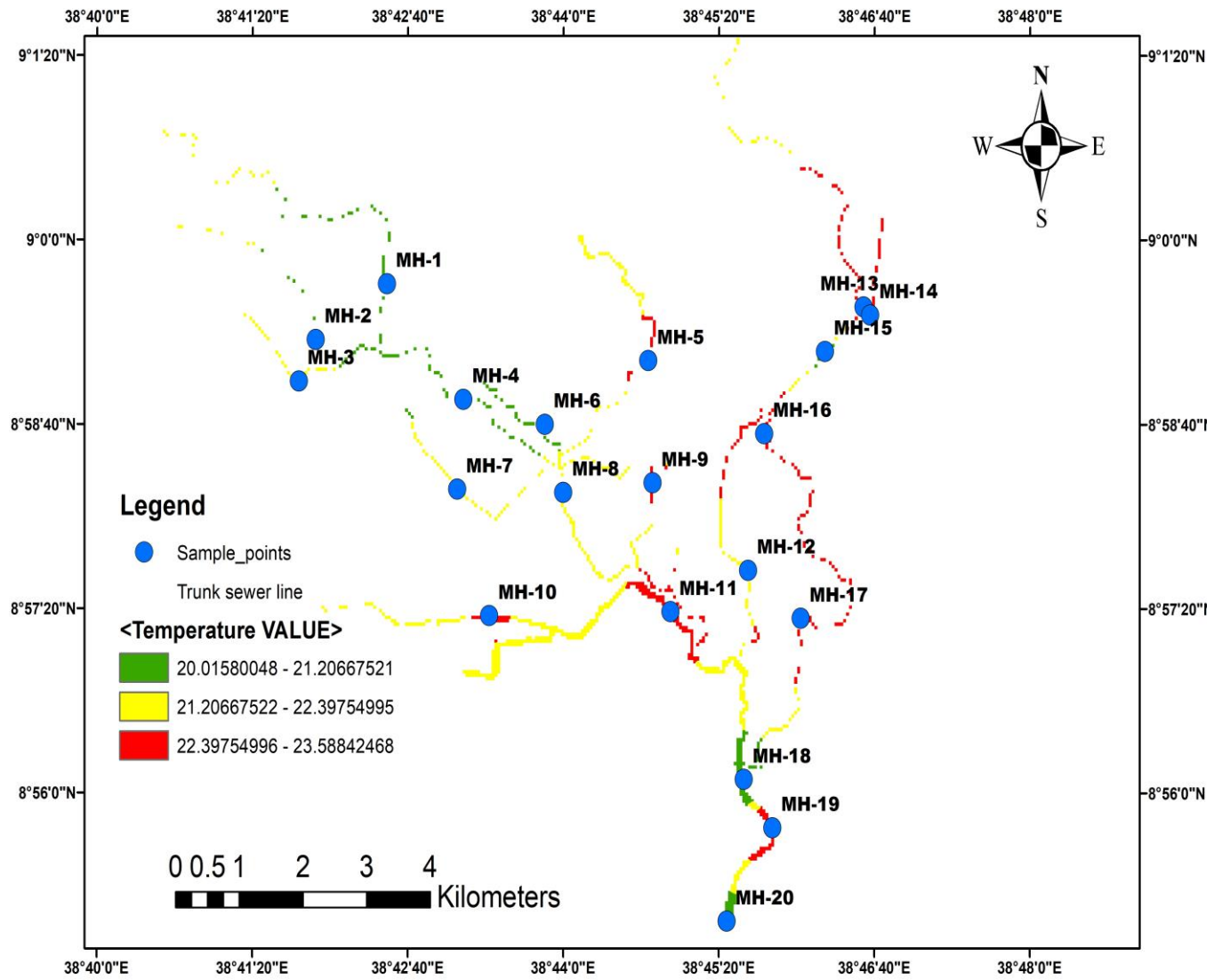


Figure 4.3 Spatial distribution of temperature of the samples along Kaliti catchment

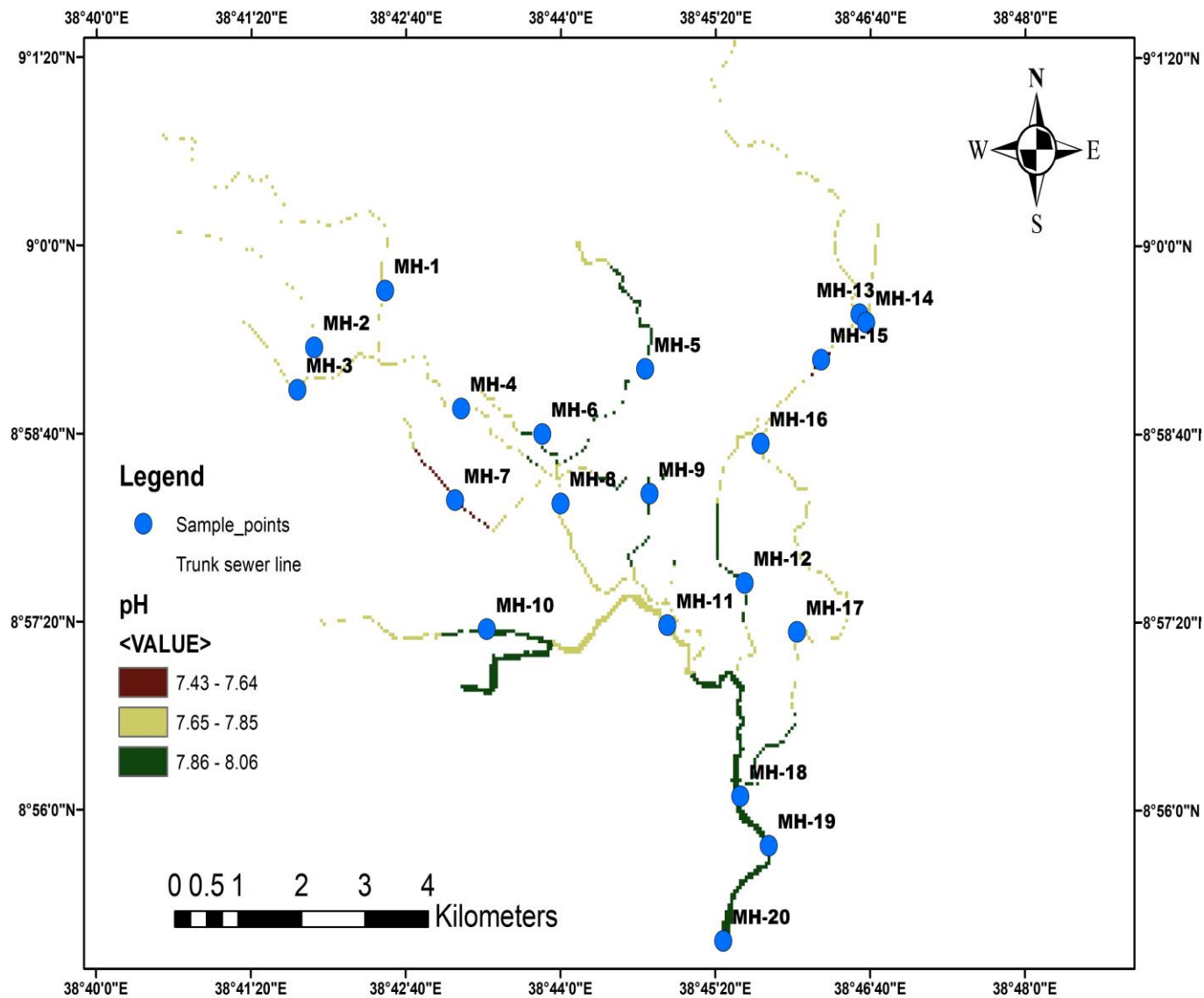


Figure 4.4 Spatial distribution of pH of the samples along Kaliti catchment

4.1.3. Electrical Conductivity (EC)

The measurements taken during each month of the study consistently appear in Fig 4.5. The spatial variation of Electrical conductivity (EC) in the samples collected in the May and June months was significant according to ANOVA analysis ($P = 0.042$). This might be due to variations in rainfall and runoff, changes in water usage, source of water supply. Differences in conductivity values, indicate that fluctuations in wastewater conductivity are ongoing and unpredictable. According to the IWA (Schultz, 2005) study, the EC ranged from 1200 to 1000 in municipal wastewater, which is medium. The mean value of EC obtained in this study falls within this range; the value is 1062.76. In the May month, the EC varies from 763.4 in manhole MH-14 to 1598 in manhole MH-7, and in the June month, the EC varies from 564.6 in manhole MH-14 to 1409 in manhole MH-7. Also, EC values decreased more in the June month than in the May month due to the concentration and type of dissolved solids and the presence of organic matter. Typically, the electrical conductivity of municipal wastewater ranges from about 50 to 1500 $\mu\text{S}/\text{cm}$ (micro Siemens per centimeter), according to EEPA, with an average value of around 500 $\mu\text{S}/\text{cm}$. However, these values can be significantly higher in areas with high levels of dissolved minerals or where industrial processes contribute to wastewater.

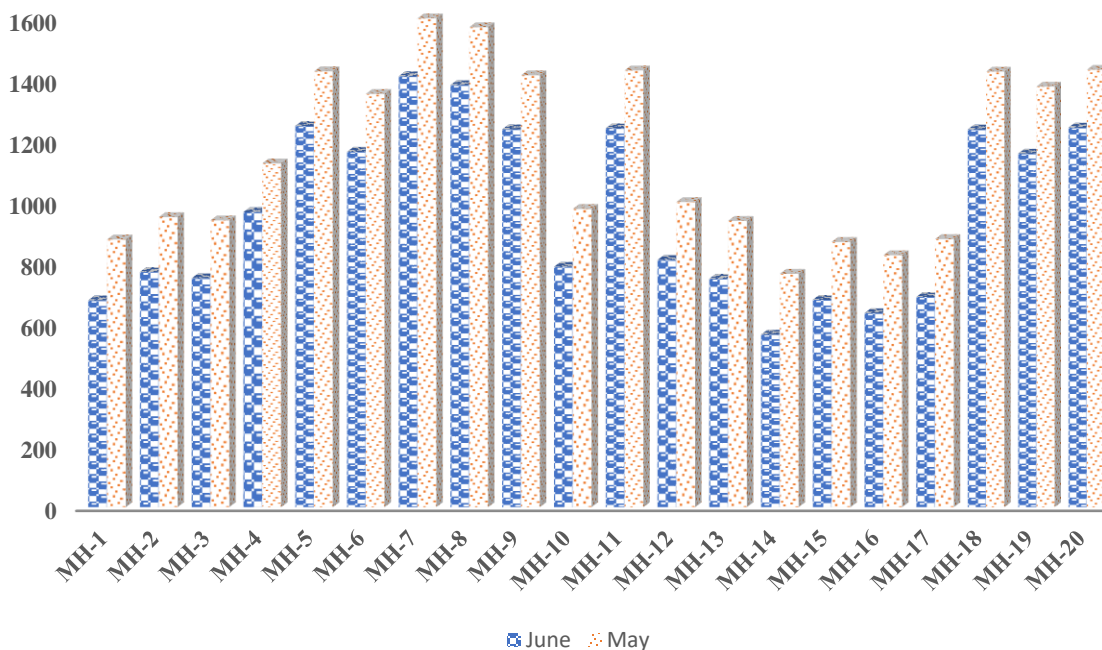


Figure 4.5 EC variation of the samples within Kaliti catchment during and May and June.

4.4. ANOVA Table of EC

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	354776.060	1	354776.060	4.444	0.042
Within Groups	3033622.434	38	79832.169		
Total	3388398.494	39			

Electrical conductivity (EC) variation was observed in the graphical analysis, which prompted further investigation, as the primary objective of this study is to characterize the mapping of sewage. To assess the spatial variation, I developed a mapping using GIS software. The results revealed that manholes MH-1, MH-2, MH-14, and MH-15, located upstream around the Aleert Hospital Area, Betel Area, Ayere Tena Square Area, Karamara Bridge Area, and Wollo Sefer INSA Area—regions with minimal industrial activity—exhibited relatively lower EC values. In contrast, manholes located in the middle and downstream sections of the catchment displayed higher EC levels, which are typically characteristic of industrial areas. This suggests the potential presence of industrial intrusions into the sewage system in those regions.

4.1.4. Total Dissolved Solids(TDS)

The seasonal variations of TDS (mg/L) values for the months of May and June are shown in Fig.4.6. The spatial variation of Total dissolved solids (TDS) in the samples collected during the May and June months was found to be significant according to ANOVA analysis ($P = 0.001$). This may be due to dilution and concentration effects, runoff composition, and the source of water supply. The TDS values of the sampled wastewater for all specified months in the dry season are twelve manholes exceeded the recommended limit set by APHA, However, in the rainy season, all TDS values were within the recommended limits. In general, the TDS level of municipal wastewater can range from around 200 to 600 milligrams per liter (mg/L).

All observed values are shown in the figure for the two months in the middle of the wastewater stream and at the end of the wastewater stream, where the TDS values are highest. The average highest and lowest detected TDS values of the sampled wastewater were 759.4 mg/L in MH-8 and 275.2 mg/L in MH-14, respectively. Furthermore, in the dry season, TDS values are higher than in the rainy season due to known dilution in the rainy season.

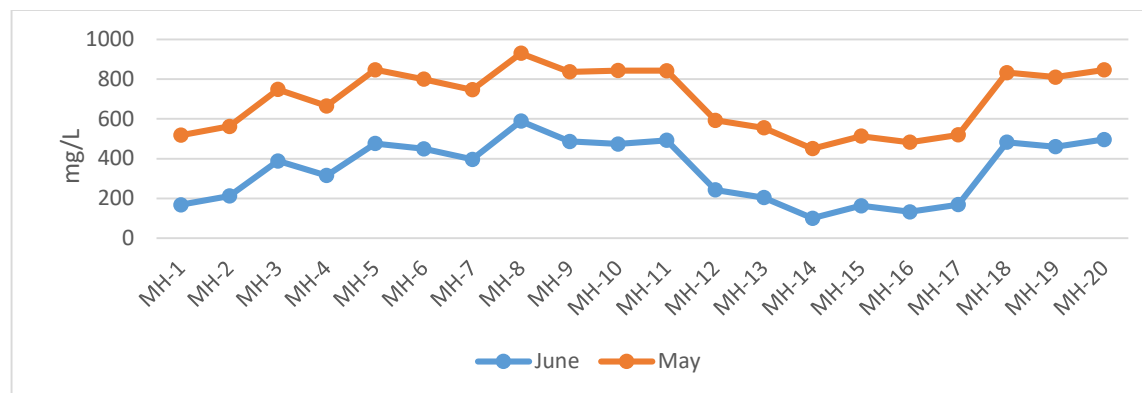


Figure 4.6 TDS variation of the samples within Kaliti catchment during and May and June.

4.5. ANOVA Table of TDS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1239251.209	1	1239251.209	51.374	0.000
Within Groups	916646.427	38	24122.274		
Total	2155897.636	39			

Total dissolved solids (TDS) variation was observed in the graphical analysis, which warranted further investigation due to the primary objective of this study being the characterization of sewage mapping. To assess the spatial variation of TDS, developed mapping using GIS software. The results revealed that manholes MH-1, MH-2, MH-14, and MH-15, located upstream around the Aleert Hospital Area, Betel Area, Ayere Tena Square Area, Karamara Bridge Area, and Wollo Sefer INSA Area—regions with no significant industrial activities—exhibited relatively lower TDS levels. In contrast, manholes located in the middle and downstream sections of the catchment showed higher TDS levels, which, along with elevated pH values, are characteristic of areas influenced by industrial activity. This pattern suggests the potential for industrial intrusion into the sewage system in these regions.

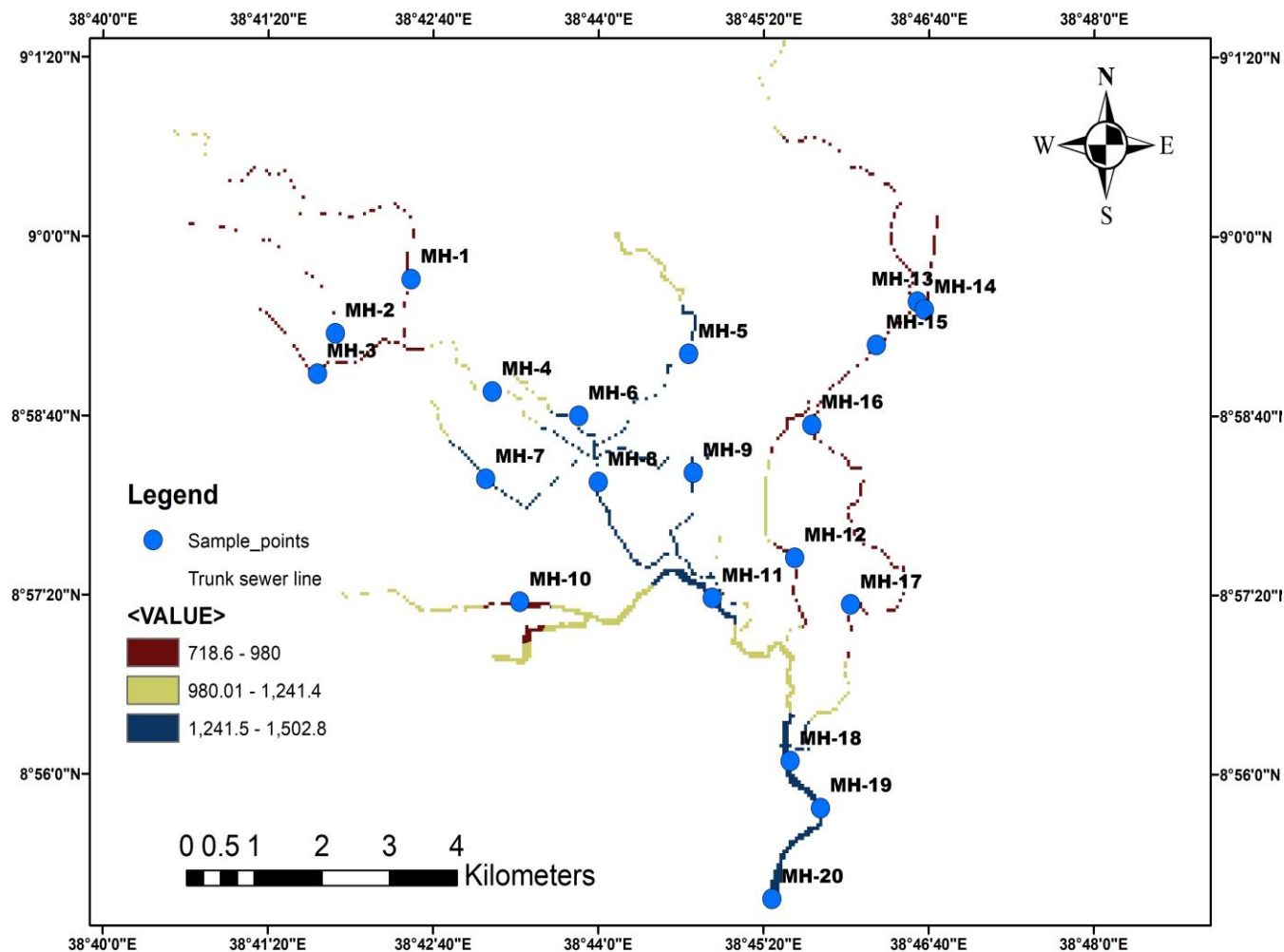


Figure 4.7 Spatial distribution of EC of the samples along Kaliti catchment

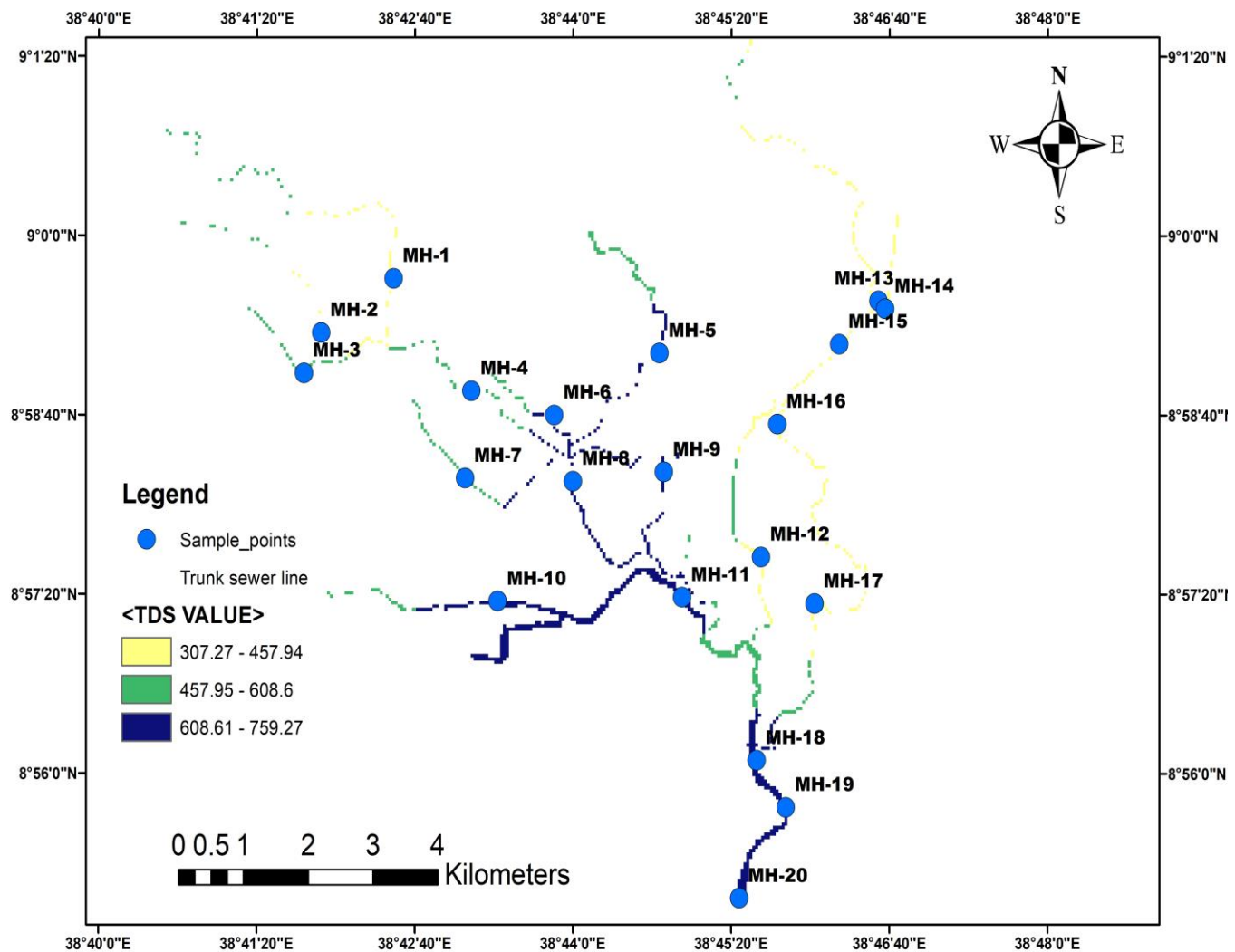


Figure 4.8 Spatial distribution of TDS of the samples along Kaliti catchment

4.1.5 Total Phosphorus (TP)

The measurements taken during May and June each month of the study consistently show in Fig. 4.9. The spatial variation of Total Phosphorus (TP) in the samples collected during the May and June months was found to be significant according to ANOVA analysis ($P = 0.028$). This may be due to seasonal biological activity, seasonal runoff and erosion, changes in water usage, and the variability of water supply source. According to the IWA (Schultz, 2005) study, the TP ranged from 6 to 15 raw municipal wastewater with minor contributions of industrial wastewater (in mg/L) in municipal wastewater, which is low. The mean value of TP obtained in this study lies within this range; the value is 12.74. In the dry season, TP varies from 7.12 in manhole MH-13 to 21.68 in manhole MH-20, and in the rainy season, TP varies from 4.62 in manhole MH-13 to 19.18 in manhole MH-20. Also, TP values decreased more in the rainy season than in the dry season because, during the rainy season, there was an increase in the volume of water entering the wastewater collection system.

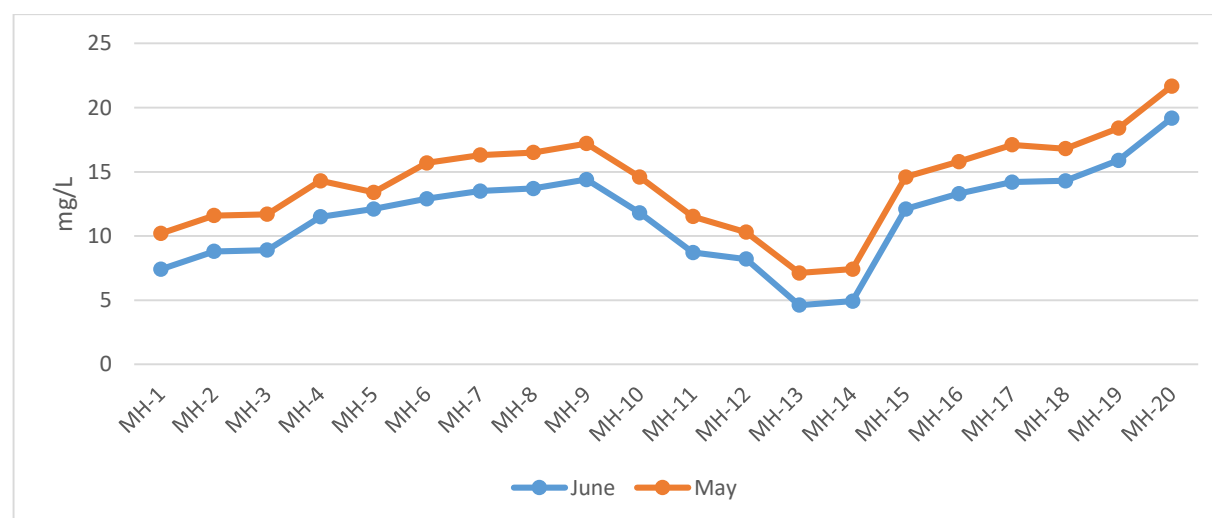


Figure 4.9 TP variation of the samples within Kaliti catchment during and May and June.

4.6. ANOVA Table of TP

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	71.824	1	71.824	5.236	0.028
Within Groups	521.269	38	13.718		
Total	593.093	39			

The TP variation was observed in the graph, prompting further investigation since the primary objective of this study is to characterize the mapping of sewage. To assess the spatial variation, developed a mapping using GIS software. Then see that MH-1, MH-2, MH-14, and MH-15, which are upstream around Aleert Hospital Area, Betel Area, Ayere Tena Square Area, Karamara Bridge Area, and Wollo Sefere INSA Araa, where there are no industrial activities, are relatively lower than those places in the middle of the stream and end of the stream manholes. Those showed a TP that is higher, which is characteristic of industrial areas. This somehow suggests that there will be potential industrial intrusions.

4.1.6 Total Nitrogen (TN)

The seasonal variation values of TN (mg/l) for the months of May and June are demonstrated in Fig.4.10. The spatial variation of Total Nitrogen (TN) in the samples collected during the dry and wet seasons was found to be significant according to ANOVA analysis ($P = 0.004$). This may be due to seasonal biological activity, seasonal runoff and erosion, changes in water usage, and the variability of water supply source. According to the IWA study (Schultz, 2005), the TN ranged from 60 to 100 in raw municipal wastewater with minor contributions of industrial wastewater (in mg/L) in municipal wastewater, which is medium. The mean value of TN obtained in this study lies within this range; the value is 60.56. In the dry season, the TN varies from 46.72 in manhole MH-3 to 113.68 in manhole MH-20, and in the rainy season, the TN varies from 27.52 in manhole MH-3 to 94.88 in manhole MH-20. Also, TN values decreased more in the June month than in the May month because, during the rainy season, there was an increase in the volume of water entering the wastewater collection system. The figure shows the highest total nitrogen found in the middle of the wastewater stream and at the end of the stream.

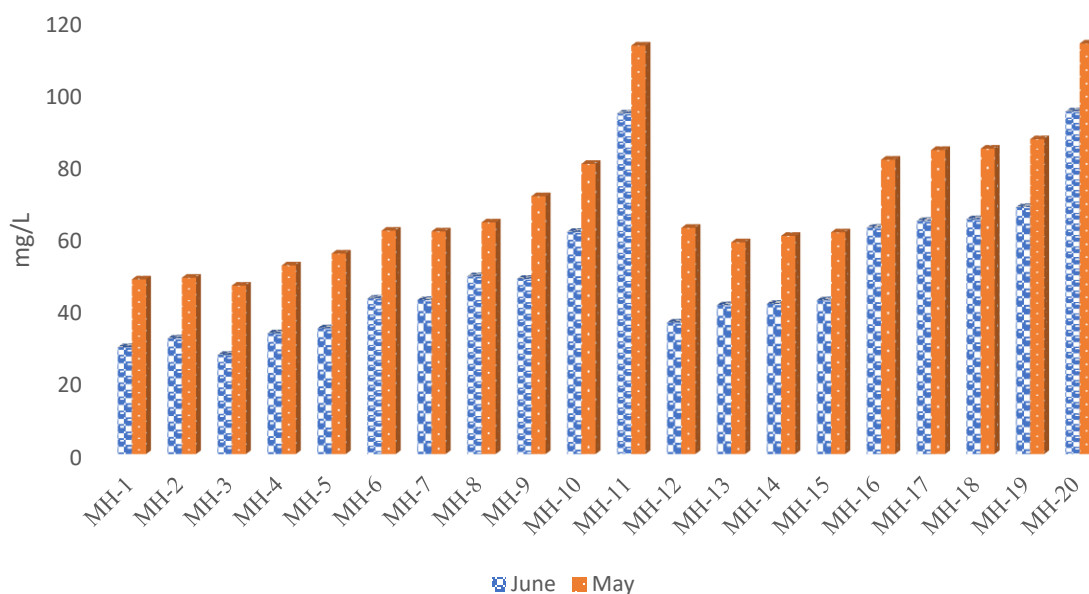


Figure 4.10 TN variation of the samples within Kaliti catchment during and May and June.

4.7.ANOVA Table of TN

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3541.924	1	3541.924	9.257	0.004
Within Groups	14540.284	38	382.639		
Total	18082.208	39			

Variation in total nitrogen (TN) levels was observed in the graphical analysis, prompting further investigation, as the main objective of this study is to characterize sewage mapping. To examine spatial variation in TN, mapping was developed using GIS software. The analysis revealed that manholes MH-1, MH-2, MH-14, and MH-15, located upstream in areas such as Aleert Hospital, Betel, Ayere Tena Square, Karamara Bridge, and Wollo Sefer INSA—regions with minimal industrial activity—exhibited relatively lower TN concentrations. In contrast, manholes located in the middle and downstream sections of the catchment showed higher TN levels, which, along with elevated pH values, are indicative of industrial areas. This suggests the possibility of industrial intrusions into the sewage TN system in these regions.

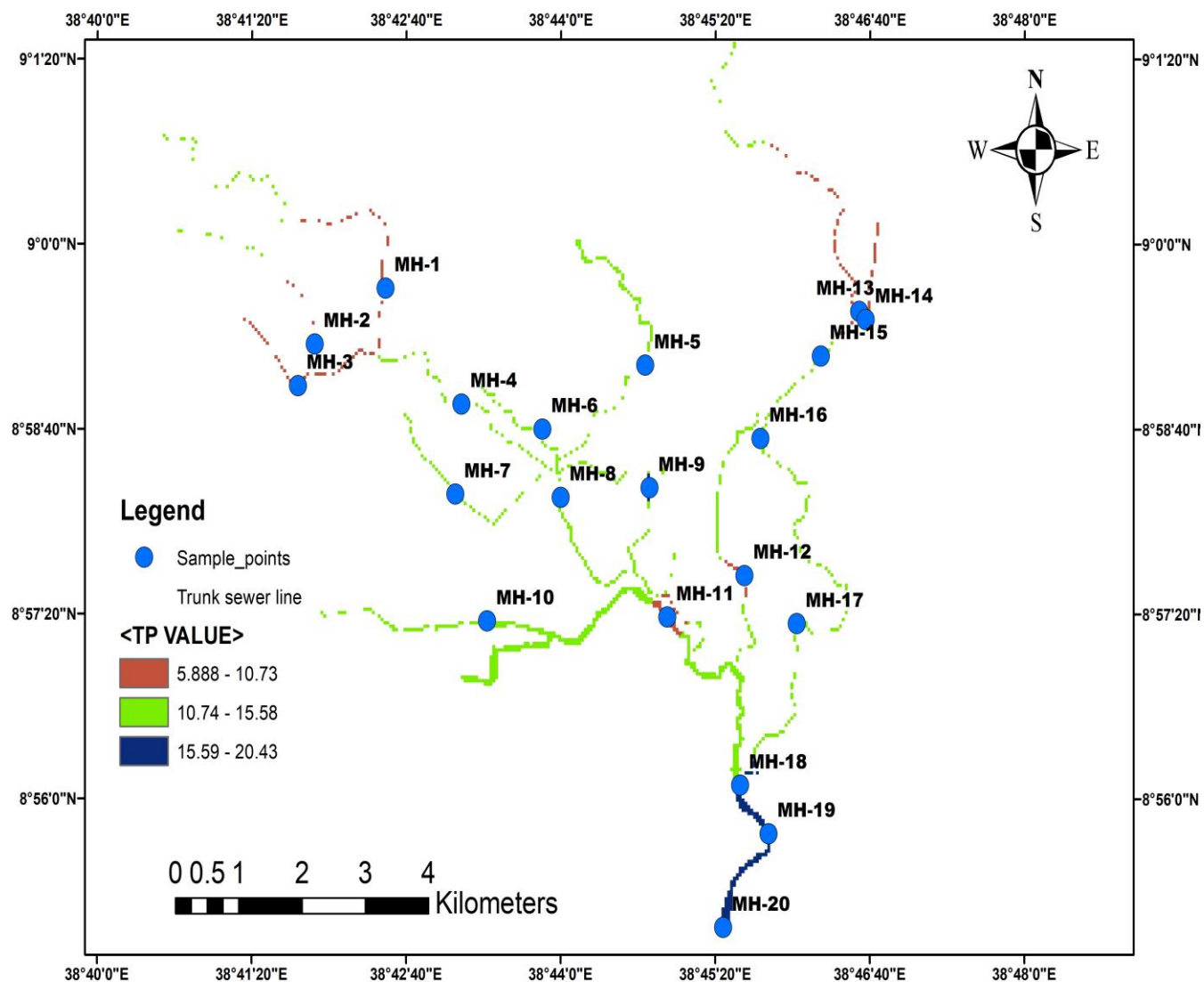


Figure 4.11 Spatial distribution of TP of the samples along Kaliti catchment

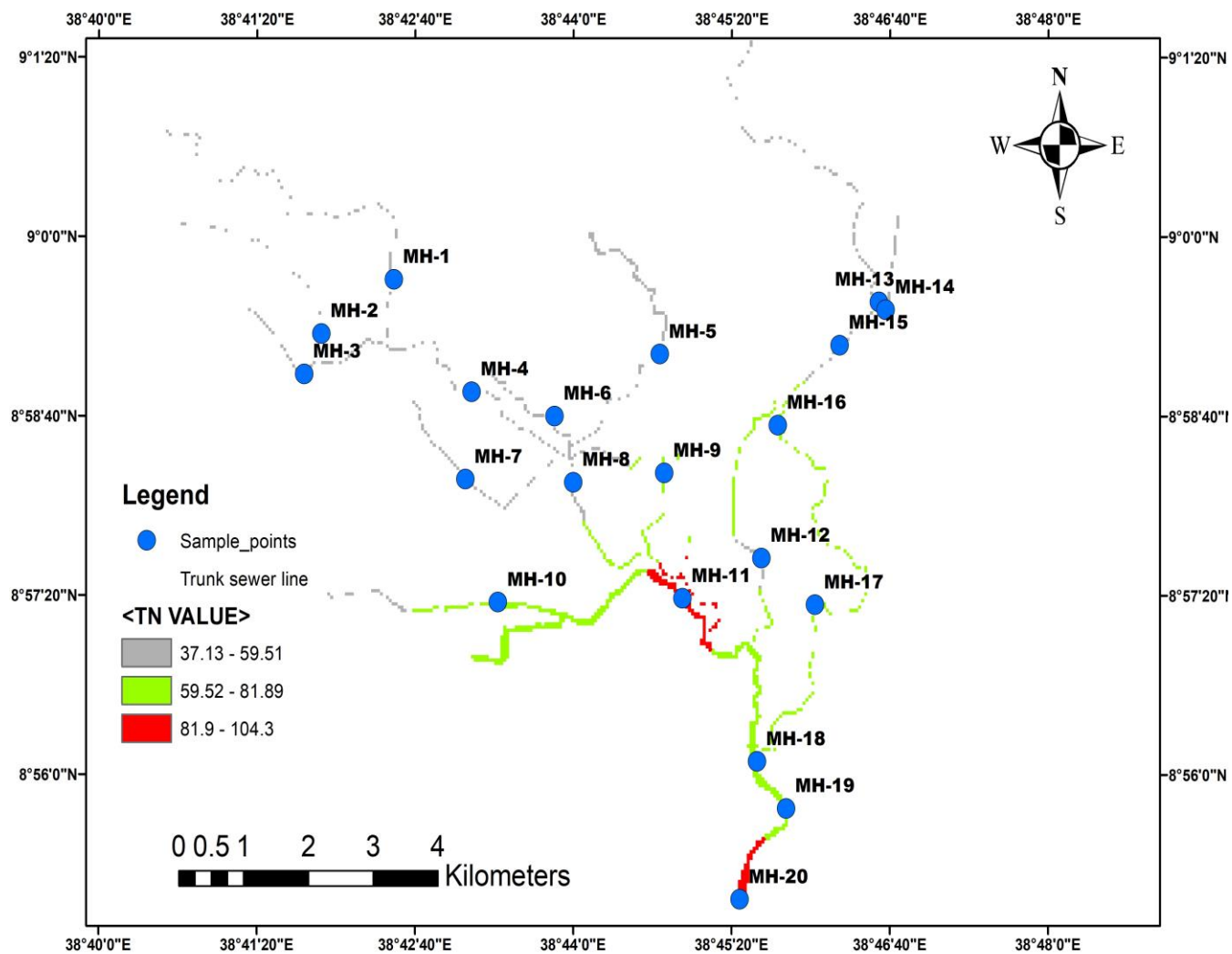


Figure 4.12 Spatial distribution of TN of the samples along Kaliti catchment

4.1.7 Chemical Oxygen Demand (COD)

The spatial variation of Chemical Oxygen Demand (COD) in the samples collected during the May and June months was not significant according to ANOVA analysis ($P = 0.209$). This may be due to effective mixing in the wastewater system, the homogeneity of wastewater sources, and the uniform distribution of rainfall during the study period, which contributes to the uniform distribution of COD throughout the study period. The average highest and lowest values observed for COD (mg/l) in the sampled wastewater were 1835 mg/l and 687.5 mg/l, respectively. The high value of COD) may be caused by urine, faces and organic food wastes generated from the kaliti catchment.

According to the IWA study (Schultz, 2005), the COD ranged from 750 to 1200 raw municipal wastewater with minor contributions of industrial wastewater (in mg/L) in municipal wastewater, which is considered medium. The mean value of COD obtained in this study falls within this range; the value is 1146.4. In the May month, the COD varies from 750 in manhole MH-1 to 1995 in manhole MH-20, and in the June month, the COD varies from 625 in manhole MH-1 to 1675 in manhole MH-20. Also, COD values decreased more during the June month than in the May month because, during the June month, there was an increase in the volume of water entering the wastewater collection system. The figure shows the highest total COD found in the middle and end of the wastewater streams MH-11, MH-12, MH-19, and MH-20.

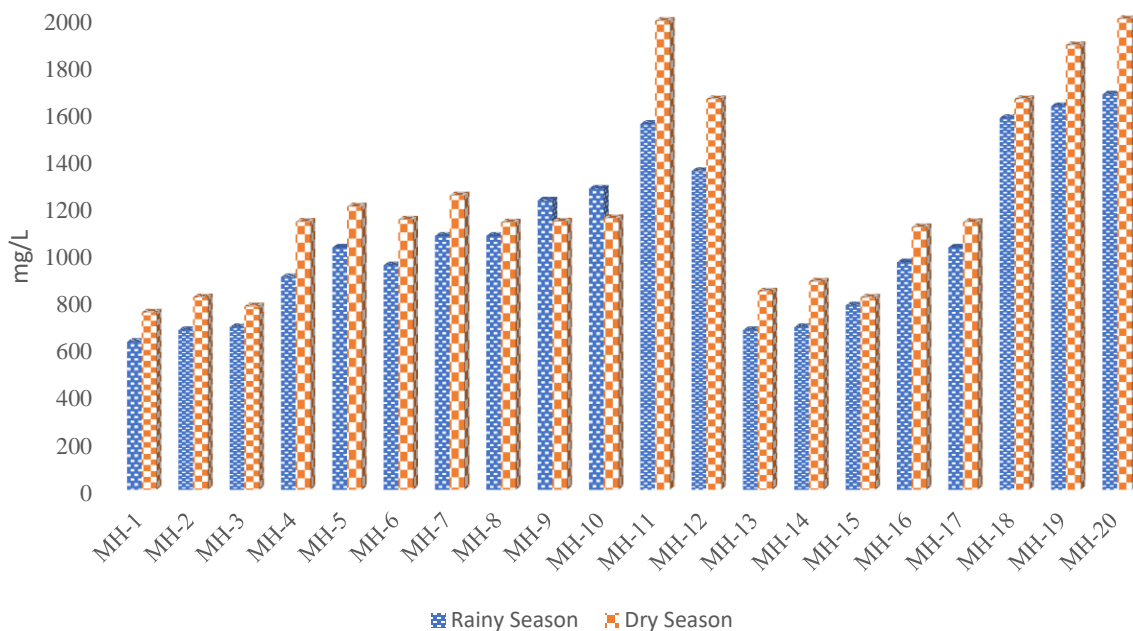


Figure 4.13 COD variation of the samples within Kaliti catchment during and May and June.

Chemical oxygen demand (COD) variation was observed in the graphical analysis, which prompted further investigation, as the purpose of this study is to characterize the spatial mapping of sewage. To assess spatial variation, developed a mapping using GIS software. The results indicated that manholes MH-1, MH-2, MH-14, and MH-15, located upstream around the Aleert Hospital Area, Betel Area, Ayere Tena Square Area, Karamara Bridge Area, and Wollo Sefer INSA Area—regions with minimal industrial activity—exhibited relatively lower COD levels. In contrast, manholes situated in the middle and downstream sections of the catchment demonstrated higher COD values, a characteristic often associated with industrial areas. This pattern suggests the potential for industrial intrusions into the sewage system in these regions.

4.1.8. Biochemical Oxygen Demand (BODs)

The seasonal variation values of BOD₅ (mg/L) for the months of May and June are demonstrated in Fig. 4.14. The spatial variation of Biological Oxygen Demand (BOD) in the samples collected during the May and June month was not significant, according to ANOVA analysis ($P = 0.143$). This might be due to effective mixing in the wastewater system, homogeneity of wastewater sources, and the uniform distribution of rainfall during the study period, which contributes to the uniform distribution of BOD throughout the study period.

According to the IWA study (Schultz, 2005), the BOD₅ ranged from 350 to 560 in raw municipal wastewater with minor contributions of industrial wastewater (in mg/L) in municipal wastewater, which is considered medium. The mean value of this study's BOD₅ obtained lies in this range; the value is 466.8 mg/L. In the May month, the BOD₅ varies from 300 mg/L in manhole MH-1 to 810 mg/L in manhole MH-20, and in the June month, the BOD₅ varies from 250 mg/L in manhole MH-1 to 670 mg/L in manhole MH-20. Additionally, BOD₅ values decreased more in the June month than in the May month because, during the June month, there was an increase in the volume of water entering the wastewater collection system. The figure shows the highest total BOD₅ found

in the middle and end of the wastewater streams MH-11, MH-12, MH-18, MH-19, and MH-20.

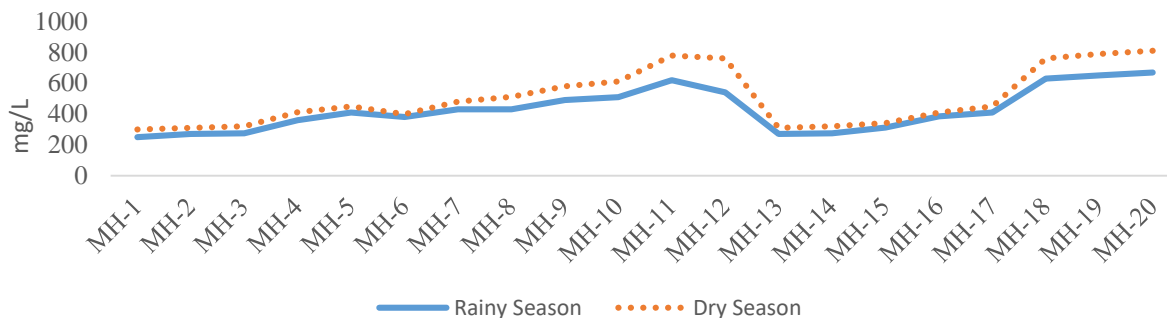


Figure 4.14 BOD variation of the samples within Kaliti catchment during and May and June.

4.9.ANOVA Table of BOD5

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	59213.025	1	59213.025	2.239	0.143
Within Groups	1005034.750	38	26448.283		
Total	1064247.775	39			

Biochemical oxygen demand over five days (BOD_5) variation was observed in the graphical analysis, leading to further investigation, as the primary objective of this study is to characterize the spatial mapping of sewage. To evaluate the spatial variation in BOD_5 , mapping was developed using GIS software. The analysis revealed that manholes MH-1, MH-2, MH-14, and MH-15, located upstream around the Aleert Hospital Area, Betel Area, Ayere Tena Square Area, Karamara Bridge Area, and Wollo Sefer INSA Area—regions with minimal industrial activity—exhibited relatively lower BOD_5 levels. In contrast, manholes located in the middle and downstream sections of the catchment showed higher BOD_5 values, which is characteristic of industrial areas. This suggests the possibility of industrial intrusions into the sewage system in these regions

4.1.9. Total Coliform

The seasonal variation values of total coliform (per 100 mL) for the May and June months are demonstrated in the table. According to the IWA (Schultz, 2005) study, the total coliform range found was 5×10^8 , which is high, and 1×10^6 , which is low, in raw municipal wastewater with minor contributions of industrial wastewater. This study's total coliform obtained lies in this range, which

is low. Bacteriological analysis of samples from the sites showed the minimum value was occurring at sample station MH-13, 18.4×10^6 CFU/100 ml, and the maximum value occurred at sample station MH-20, 27.4×10^6 , which is downstream of the sewer line system. Also, total coliform values decreased more in the rainy season than in the dry season because, during the rainy season, there was an increase in the volume of water entering the wastewater collection system.

Table 4.2 Seasonal variation of total coliform of the samples along Kaliti catchment

Manholes	Rainy Season	Dry Season
MH-1	17.7×10^6	21.1×10^6
MH-2	17×10^6	20.4×10^6
MH-3	19.1×10^6	22.5×10^6
MH-4	18.4×10^6	21.8×10^6
MH-5	18×10^6	21.4×10^6
MH-6	19.5×10^6	22.9×10^6
MH-7	20×10^6	23.4×10^6
MH-8	20.8×10^6	24.2×10^6
MH-9	19.1×10^6	22.5×10^6
MH-10	22.2×10^6	25.6×10^6
MH-11	22.8×10^6	26.2×10^6
MH-12	23×10^6	26.4×10^6
MH-13	16.7×10^6	20.1×10^6
MH-14	23×10^6	26.4×10^6
MH-15	23×10^6	26.4×10^6
MH-16	24.5×10^6	27.9×10^6
MH-17	24.7×10^6	28.1×10^6
MH-18	25×10^6	28.4×10^6
MH-19	25.3×10^6	28.7×10^6
MH-20	25.7×10^6	29.1×10^6

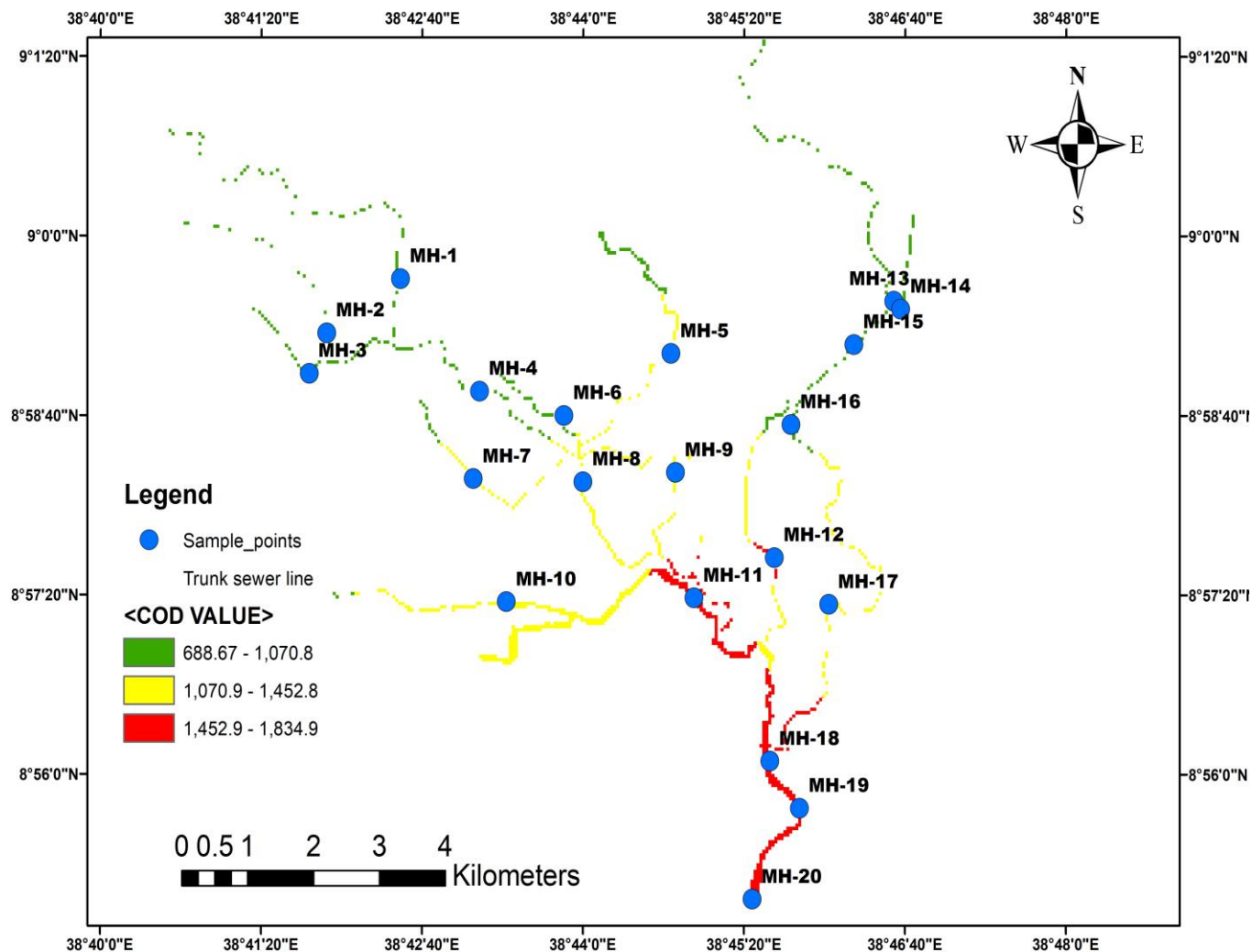


Figure 4.15 Spatial distribution of COD of the samples along Kaliti catchment

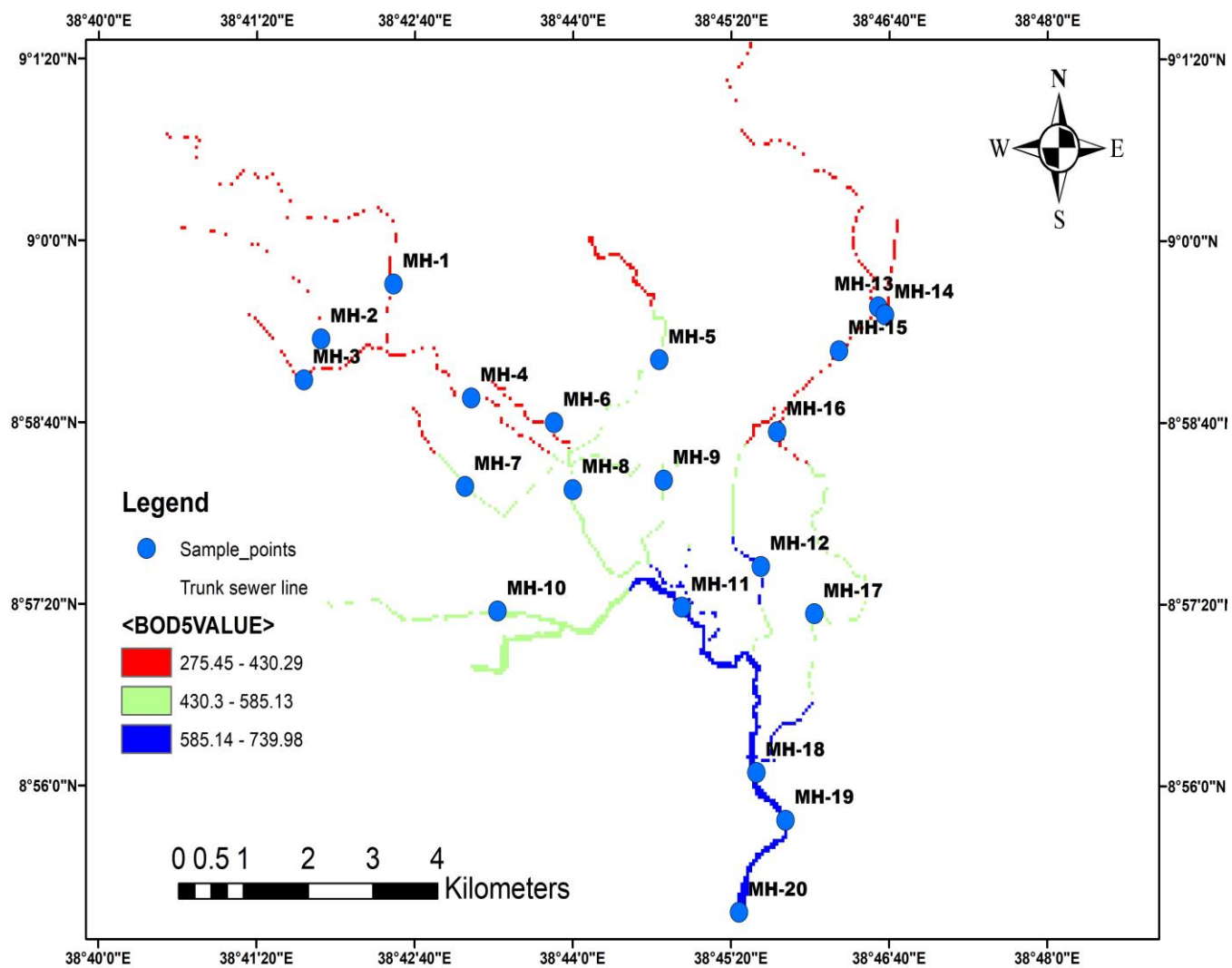


Figure 4.16 Spatial distribution of BOD5 of the samples along Kaliti catchment

4.1.10. Chromium

The measurements taken during May and June each month of the study consistently show in Fig.4.17 differences in total chromium values, according to the IWA (Schultz, 2005) study, the chromium ranged from 0.01 to 0.025 raw municipal wastewater with minor contributions of industrial wastewater (in mg/L) in municipal wastewater, which is low. The concentration of chromium in domestic wastewater can vary widely depending on the source and the level of treatment that the wastewater has undergone. In this study, the concentration of Chromium values is Nil t in all sampling sights except MH-11.

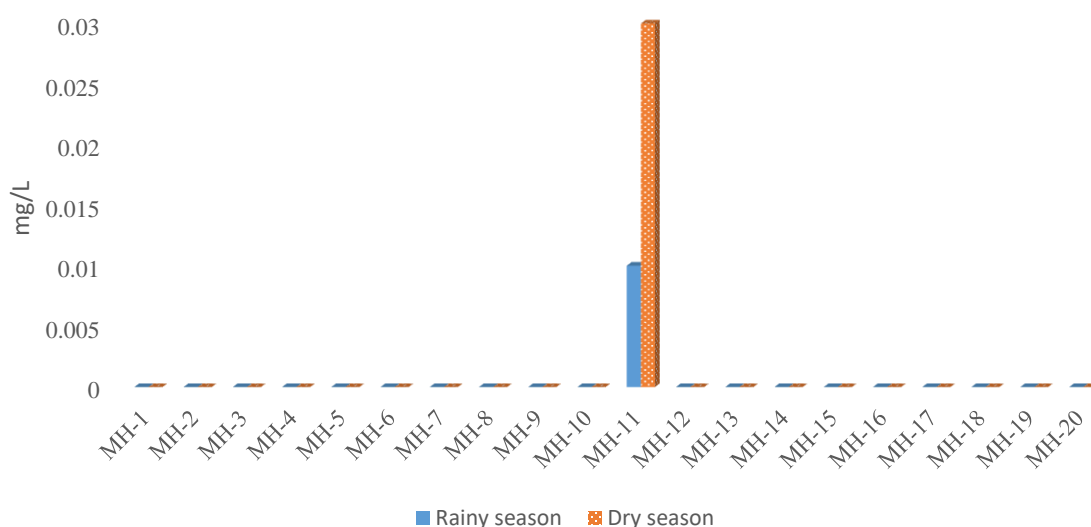


Figure 4.17 Cr variation of the samples within Kaliti catchment during and May and June.

4.1.11 Manganese

The seasonal variation values of concentrations of Manganese (mg/L) for the months of May and June are demonstrated in Fig.4.17. The spatial variation of Manganese (Mn) in the samples collected during the dry and wet seasons was not significant according to ANOVA analysis ($P = 0.114$). This might be due to effective mixing in the wastewater system, homogeneity of wastewater sources, and the uniform distribution of rainfall during the study period, which contributes to the uniform distribution of manganese throughout the study period. According to the IWA study (Schultz, 2005), the manganese levels greater than 0.2 mg/L in raw municipal wastewater with minor contributions from industrial wastewater, are considered high. The mean value of manganese obtained in this study falls within this range; the value is 0.33. In the dry season, manganese varies from 0.08 in manhole MH-7 to 0.87 in manhole MH-11, and in the rainy

season, manganese varies from 0 in manhole MH-3 to 0.76 in manhole MH-11. Additionally, manganese values decreased more during the rainy season than during the dry season because, during the rainy season, there was an increase in the volume of water entering the wastewater collection system. The figure shows the highest total manganese found at the start and middle of the wastewater streams MH-4, MH-5, MH-11 and MH-12.

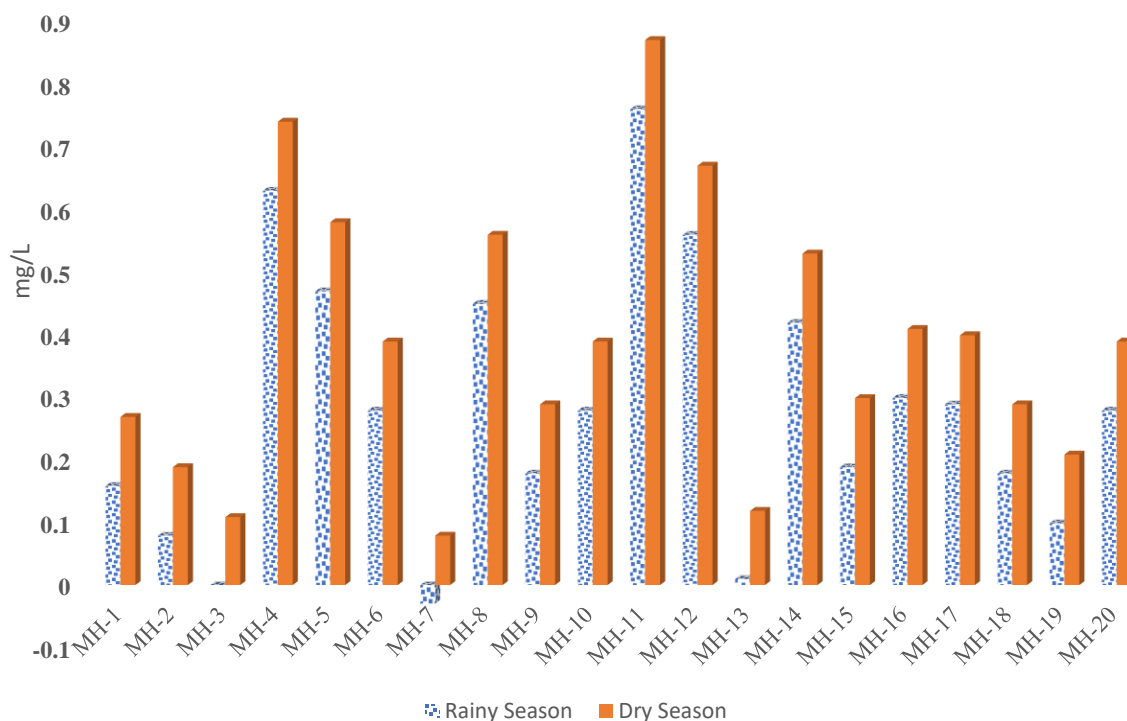


Figure 4.18 Mn variation of the samples within Kaliti catchment during and May and June.

4.1.12 Zinc

The seasonal variation values of zinc concentrations (mg/L) for the months of May and June are demonstrated in Fig. 4.18. The spatial variation of zinc (Zn) in the samples collected during the dry and wet seasons was not significant according to ANOVA analysis ($P = 0.418$). This might be due to effective mixing in the wastewater system, homogeneity of wastewater sources, and the uniform distribution of rainfall during the study period, which contributes to the uniform distribution of zinc throughout the study period. According to the IWA study (Schultz, 2005), the zinc concentration ranged from less than 0.1 in raw municipal wastewater to minor contributions of industrial wastewater (in mg/L) in municipal wastewater, which is low. The mean value of zinc

obtained in this study falls within in this range; the value is 0.008. In the dry season, zinc varies from zero in manholes MH-1, MH-2, MH-3, MH-4, MH-5, MH6, MH-7, and MH-8 to 0.1 in manholes MH-9. In the rainy season, zinc varies from zero to 0.05 in manholes. Also, zinc values decreased more in the rainy season than in the dry season because, during the rainy season, there was an increase in the volume of water entering the wastewater collection system. The figure shows the highest total manganese found in the middle of the wastewater streams MH-9 and MH-10.

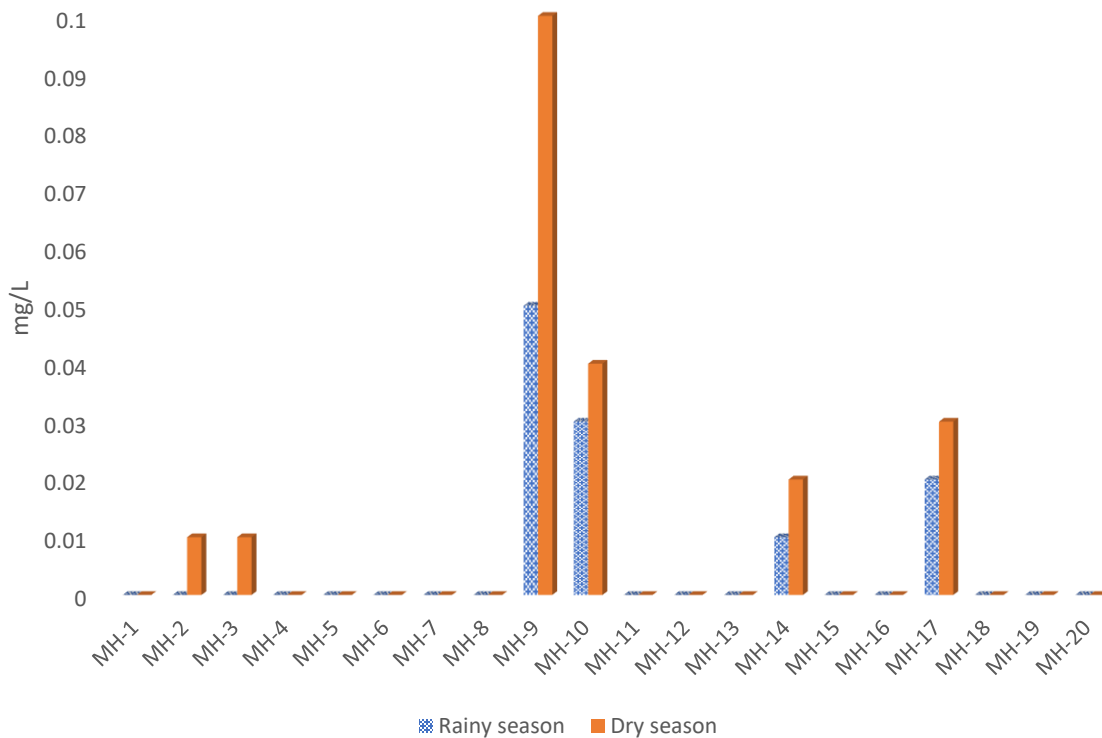


Figure 4.19 Zn variation of the samples within Kaliti catchment during and May and June.

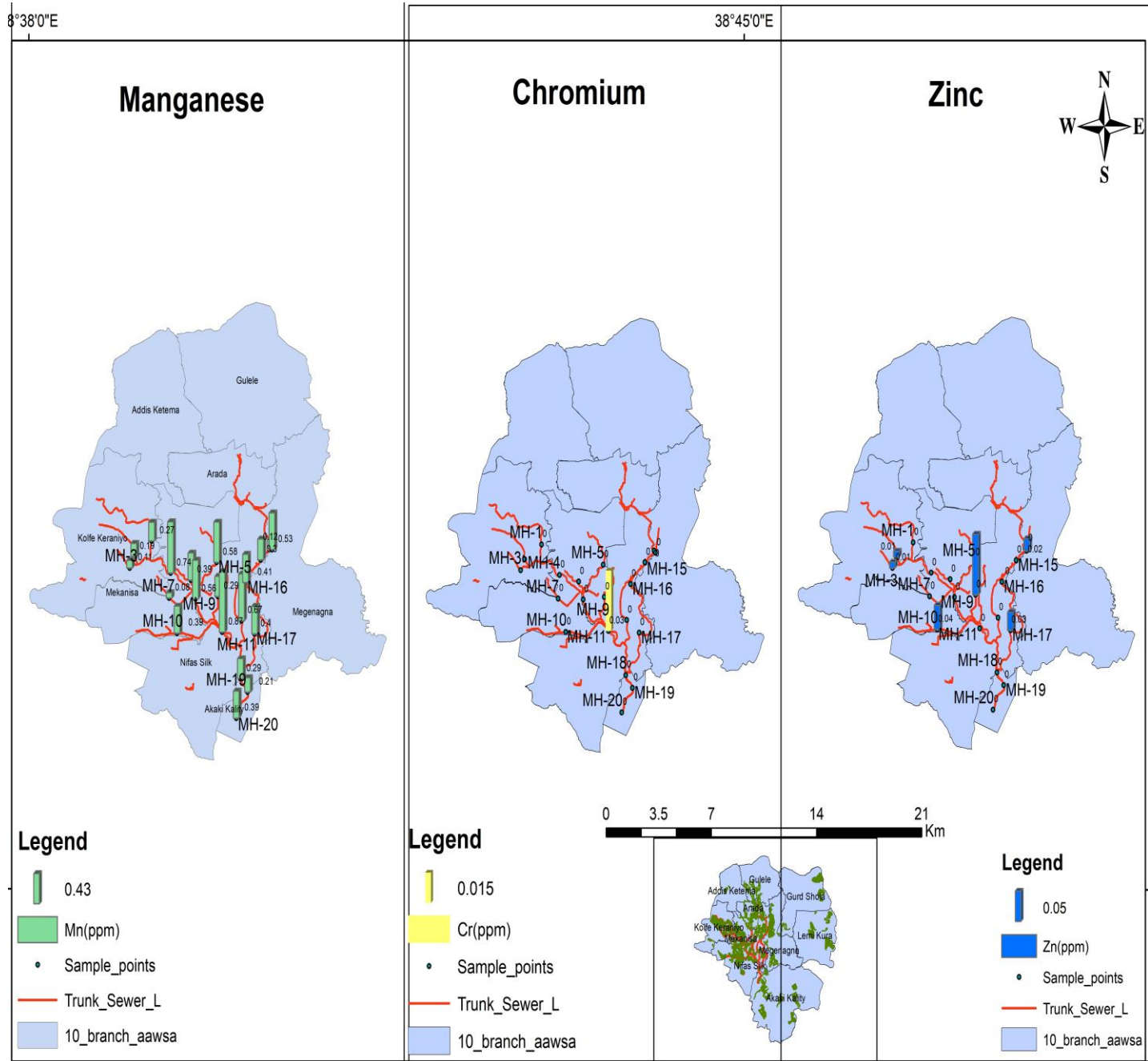


Figure 4. 20 Levels of Manganese, Chromium and Zinc in mg/l of the samples collected along Kaliti Catchment

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The results of the study were compared with available literature; in fact, heterogeneity exists among municipal wastewaters ascribed to contributing activities, climate, water supply conditions, and socioeconomic classes. The results obtained from this study showed that Zn, Cr, total coliform, and TP are low, in accordance with similar findings reported from previous research on IWA. The other waste water parameters BOD₅, COD, TN, EC, and pH are medium, and also Mn and TDS are high. From the data provided for different sample sites, we can conclude that the quality of wastewater varies across different sample sites, the Kaliti wastewater catchment, and seasons. The levels of total dissolved solids (TDS), pH, electrical conductivity (EC), total phosphorus (TP), and total nitrogen (TN) also vary significantly across different sample sites and seasons. However, the levels of biological oxygen demand (BOD₅), chemical oxygen demand (COD), temperature, manganese (Mn), and zinc (Zn) do not vary significantly across different sample sites and seasons. In general, the highest values for TDS, EC, BOD, COD, TN, TP, and Mn were observed in the dry season, followed by the rainy season. This could be due to reduced dilution, less water being used at the point of generation, considerable evaporation occurring during collection, and slower biological activity in the dry months. However, the concentration of pH is higher in the rainy season than in the dry season.

Finally, the study provides valuable insights into the quality and distribution of sewage characteristics in the Kaliti Catchment area. Through laboratory analysis and GIS tools, the study successfully mapped out the biological, chemical, and physical characteristics of sewage in Addis Ababa, shedding light on the sources and levels of pollution in the catchment. The proposed mitigation measures offer a pathway towards improving wastewater management practices and protecting the surrounding ecosystem and community. The findings of this research serve as a crucial baseline for future studies and interventions aimed at enhancing water quality and sustainable development in the region.

5.2 RECOMMENDATIONS

Based on the findings the following things need to recommend

- We recommended by implementing effective collection, treatment, and disposal strategies, municipal authorities can ensure the safe and sustainable management of wastewater, safeguarding public health, preserving water resources, and minimizing the impact on ecosystems.
- we recommended Continued investment in research, infrastructure upgrades, and regulatory frameworks is essential to address the evolving challenges associated with municipal wastewater and foster a more resilient and environmentally conscious future.
- In the downstream section of the sewer line, industrial activities have been found to make a minimal contribution to the overall damage. However, it is still crucial to conduct continuous assessments of the sewer line to minimize any potential harm. By regularly monitoring and evaluating the condition of the sewer line, potential issues or damages can be identified early on, allowing for prompt repairs and preventive measures. This proactive approach can help mitigate risks, prevent further damage, and ensure the smooth operation of the sewer system. Therefore, maintaining a consistent assessment schedule for the sewer line is essential to safeguarding its integrity and minimizing any potential adverse effects.

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sewer networks have a significant impact on sewer processes&f=false

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APPENDIX 1

Laboratory Result of Kaliti catchment wastewater

Test Report



Configuration

Sample Introduction	Agilent SPS 4	Drift Correction Argon Lines	False
AVS67 Enabled	False	Peak Lines Used	
AVS4 Enabled	False	QC Enabled	False
IsoMist Enabled	False	IEC Enabled	False
Oxygen Injection On	False	Custom Replicates Enabled	False

Elements

Element	Wavelength (nm)	Label	Type	Internal Standard	Background Correction	Pixels	Calibration Fit	Condition Set
Al	398.152	Al (398.152 nm)	Analyte		Fitted	2	Linear Weighted	1
Cd	228.502	Cd (228.502 nm)	Analyte		Fitted	2	Linear Weighted	1
Cr	267.716	Cr (267.716 nm)	Analyte		Fitted	2	Linear Weighted	1
Cu	324.754	Cu (324.754 nm)	Analyte		Fitted	2	Linear Weighted	1
Mn	257.610	Mn (257.610 nm)	Analyte		Fitted	2	Linear Weighted	1
Pd	340.458	Pd (340.458 nm)	Analyte		Fitted	2	Linear Weighted	1
Zn	206.200	Zn (206.200 nm)	Analyte		Fitted	2	Linear Weighted	1

Common Conditions

Replicate Count	3	Intelligent Rinse Enabled	False
Pump Speed (rpm)	12	AVS67 Enabled	False
Sample Uptake Time (s)	25	Uptake Delay (s)	
Sample Uptake Fast Pump	True	Uptake Rate (mL/min)	
Rinse Time (s)	30	Injection Rate (mL/min)	
Rinse Time Fast Pump	True	Bubble Injection Time (s)	
Rinse Port Position	1	Preemptive Rinse Time (s)	

Calibrations

Standard Concentrations By Element

Solution Label	Al (ppm)	Cd (ppm)	Cr (ppm)	Cu (ppm)	Mn (ppm)	Pd (ppm)	Zn (ppm)
Blank	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard 1	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Standard 2	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Standard 3	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Standard 4	20.00	20.00	20.00	20.00	20.00	20.00	20.00

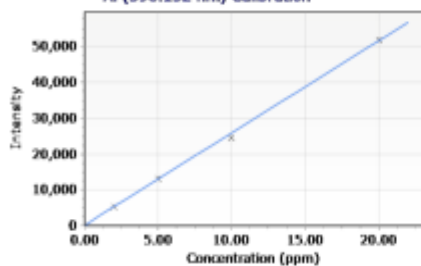
Label (Wavelength nm)	Calibration Fit	Minimum Concentration	Maximum Concentration	Calibration Error	Excess Curvature	Upward Curvature	%RSE Limit
Al (396.152 nm)	Linear Weighted	0.00 ppm	22.00 ppm	10 %			
Cd (226.502 nm)	Linear Weighted	0.00 ppm	22.00 ppm	15 %			
Cr (267.716 nm)	Linear Weighted	0.00 ppm	22.00 ppm	10 %			
Cu (324.754 nm)	Linear Weighted	0.00 ppm	22.00 ppm	10 %			
Mn (257.610 nm)	Linear Weighted	0.00 ppm	22.00 ppm	10 %			
Pd (340.458 nm)	Linear Weighted	0.00 ppm	22.00 ppm	25 %			
Zn (206.200 nm)	Linear Weighted	0.00 ppm	22.00 ppm	10 %			

Test Report



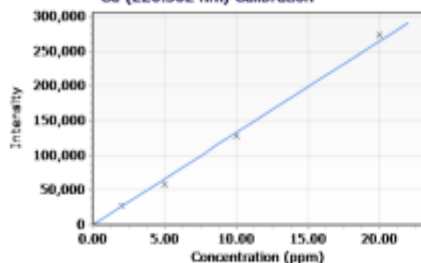
Agilent Technologies

Al (396.152 nm) Calibration



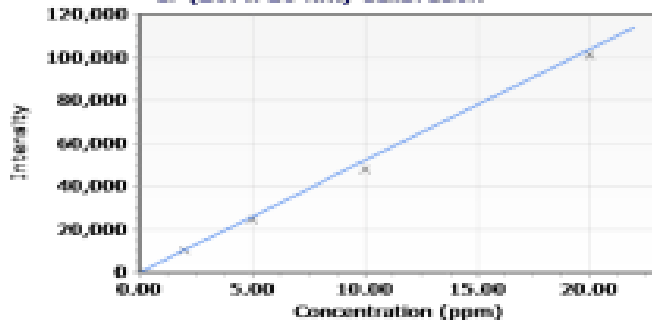
Intensity = 2580.14587913 * Concentration + 107.89654570
 Correlation coefficient: 0.99952
 %RSE:3.91228837

Cd (226.502 nm) Calibration



Intensity = 13225.52625986 * Concentration + 21.09211569
 Correlation coefficient: 0.99889
 %RSE:9.08712950

Cr (267.716 nm) Calibration

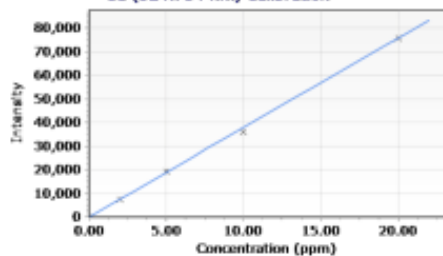


Intensity = 5202.43248373 * Concentration + 26.31295849
 Correlation coefficient: 0.99963
 %RSE:6.78558616

Test Report

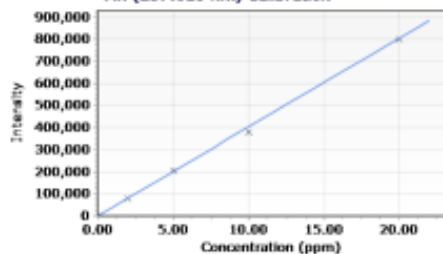


Cu (324.754 nm) Calibration



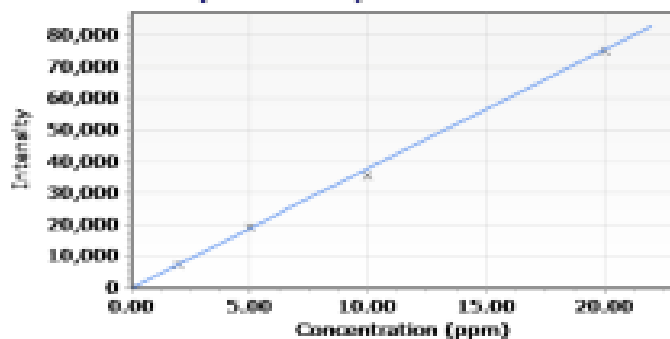
Intensity = 3794.38533680 * Concentration + 39.42751338
 Correlation coefficient: 0.99955
 %RSE:3.87212693

Mn (257.610 nm) Calibration



Intensity = 40257.40290548 * Concentration + 72.46689320
 Correlation coefficient: 0.99956
 %RSE:3.95950331

Zn (206.200 nm) Calibration



Intensity = 3775.04386764 * Concentration + 56.02450703
 Correlation coefficient: 0.99951
 %RSE:4.20765787

Results

Solution Label	Al (396.152 nm)	Cd (226.502 nm)	Cr (267.716 nm)	Cu (324.754 nm)	Mn (257.610 nm)	Pd (340.458 nm)	Zn (206.200 nm)
MH-1	0.01 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.27 (ppm)	Uncal (ppm)	0.00 u (ppm)
MH-2	0.01 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.19 (ppm)	Uncal (ppm)	0.01 (ppm)
MH-3	-0.01 !u (ppm)	0.00 !u (ppm)	0.00 !u (ppm)	0.00 ! (ppm)	0.11 ! (ppm)	Uncal (ppm)	0.01 ! (ppm)
MH-4	-0.01 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.74 (ppm)	Uncal (ppm)	0.00 u (ppm)
MH-5	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.00 (ppm)	0.58 (ppm)	Uncal (ppm)	0.00 u (ppm)
MH-6	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.39 (ppm)	Uncal (ppm)	0.00 u (ppm)
MH-7	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.08 (ppm)	Uncal (ppm)	0.00 (ppm)
MH-8	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.56 (ppm)	Uncal (ppm)	0.00 u (ppm)
MH-9	0.03 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.29 (ppm)	Uncal (ppm)	0.10 (ppm)
MH-10	0.04 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.39 (ppm)	Uncal (ppm)	0.04 (ppm)
MH-11	0.01 (ppm)	0.00 u (ppm)	0.03 (ppm)	0.00 (ppm)	0.87 (ppm)	Uncal (ppm)	0.00 (ppm)
MH-12	0.00 u (ppm)	0.00 (ppm)	0.00 u (ppm)	0.00 (ppm)	0.67 (ppm)	Uncal (ppm)	0.00 (ppm)
MH-13	-0.01 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.12 (ppm)	Uncal (ppm)	0.00 u (ppm)
MH-14	0.00 u (ppm)	0.00 (ppm)	0.00 u (ppm)	0.00 (ppm)	0.53 (ppm)	Uncal (ppm)	0.02 (ppm)
MH-15	-0.01 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.30 (ppm)	Uncal (ppm)	0.00 (ppm)
MH-16	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.41 (ppm)	Uncal (ppm)	0.00 u (ppm)
MH-17	-0.01 u (ppm)	0.00 (ppm)	0.00 (ppm)	0.00 (ppm)	0.40 (ppm)	Uncal (ppm)	0.03 (ppm)
MH-18	-0.01 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.29 (ppm)	Uncal (ppm)	0.00 u (ppm)
MH-19	-0.02 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.01 (ppm)	0.21 (ppm)	Uncal (ppm)	0.00 (ppm)