



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



**Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based
Sewage Treatment Process: The Case of Kality Centralized Sewage Treatment Plant, Addis
Ababa, Ethiopia**

By: Ashrake Hussen

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 Quality Management)

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School of Graduate Studies Addis Ababa University

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Declaration

I, Ashrake Hussen (GSR/7202/14), hereby declare that this MSc research thesis titled “*Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based Sewage Treatment Process: The Case of Kality Centralized Sewage Treatment Plant, Addis Ababa, Ethiopia*” has been developed by me and has not been submitted to any other university in order to receive a degree of any kind. Where help was requested, it was given. The perspectives of the MSc Examination Committee, the African Centre of Excellence for Water Management (ACEWM), or Addis Ababa University are not reflected in the findings, interpretations, or conclusions offered in this study.

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Abstract

Heavy metals pose a significant challenge to UASB and trickling filter-based sewage treatment plants due to retention, accumulation, limited solid-liquid separation, low sludge production, and anaerobic conditions, posing environmental risks like soil contamination and health issues due to impeded processes and inhibited microorganism activity. The study was aimed to investigating the Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based Sewage Treatment Process in Kality Centralized Sewage Treatment Plant, Addis Ababa. A study was conducted to measure the levels of heavy metals in effluents and sludge using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). The results found in the study showed that value of pH, BOD₅, COD and TSS were in the range from 6.75±0.04 - 7.54±0.13; 6±0.73 - 383.7±74.58 mg/l; 53±2.21 - 728.33±121.03 (mg/l) and 1.33±0.19 - 345.33±61.9 (mg/l), respectively. Similarly, NH₄-N 20.9±2.56 - 45.4±4.14 (mg/l); TN 52.17±4.24 - 58.2±3.79 (mg/l); TP 26.35±1.77 - 27.7±2.31(mg/l); SO₄⁻² 17.98±2.54 - 48.4±2.65 (mg/l); EC 591.83±31.21 - 855.33±43.7 (µs/cm), while for heavy metals; Pb Below Detectable Limits (BDL); Ag BDL - 63.5±13.5 mg/kg; Ba 60±4.47 µg/l - 1291±58.5 mg/kg; Fe 13.33±3.33 µg/l - 16538.5± 15192 mg/kg; Al BDL - 2358.5±662.5 mg/kg ; Cd 0 µg/l - 0.35±0.15 mg/kg; Cr 0 µg/l - 10.5±0.65 mg/kg; Cu 0 µg/l - 23.85±1.15 mg/kg; Zn 5.45±12.3 µg/l - 165±5.4, and Mn 165 ± 49.5 µg/l - 92.5±3.75 mg/kg. The treatment plant demonstrated exceptional efficacy in reducing physicochemical parameters and heavy metals, meeting the standards set by the Ethiopian Environmental Protection Authority and the World Health Organization, and the attainment of discharge limits for surface water bodies could be attributed to adsorption, precipitation, and bio-sorption processes. To optimize and improve future processes, ongoing data collection and monitoring of seasonal physicochemical parameters and heavy metal levels in the sewage treatment facility would be beneficial.

Key words: Fate of heavy metals, treatment performance, UASB, sewage treatment plant

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Acronyms

AAWSA	Addis Ababa Water and Sewerage Authority
ACEWM	Africa center of excellence in water
Ag NPs	Silver nanoparticles
ANN	Artificial Neural Networks
APHA	American Public Health Authority
BOD	Biological Oxygen Demand
CGGC	China Gezhouba Group Corporation
COD	Chemical Oxygen demand
DHS	Down flow hanging sponge
DWF	Dry Weather Flow
DWW	Domestic wastewater
EC	Electric Conductivity
EPA	Environmental Protection Agency
EPS	Extracellular polymeric substances
EQS	Environmental Quality Standard
EUWFD	European union water frame directive
HRT	Hydraulic retention time
IBM	International Business Machines Corporation
ICP-OES	Inductively Coupled Plasma optical emission spectroscopy
MLSS	Mixed liquid Suspended Solid
PH	Power of hydrogen
Ppb	parts per billion
Ppm	parts per million
SDGs	Sustainable development Goals
SRT	Sludge Retention Time
STP	Sewage treatment plant
TDS	Total dissolved solids
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total suspended solid

UASB	Up-flow anaerobic sludge Blanket
USEPA	United States Environmental Protection Agency
UWWTD	Urban Waste Water Treatment Directive
WFD	Water frame directive
WWTP	Wastewater treatment plant

Symbols

Pb	Lead
Zn	Zinc
Hg	Mercury
Mn	Manganese
Ag	Silver
Fe	Iron
Cd	Cadmium
Ba	Barium
Cu	Copper
Al	Aluminum

CHAPTER ONE

1. INTRODUCTION

1.1 Background and Justification

Our environment is replete with heavy metals such as cadmium, chromium, cobalt, copper, lead, and mercury. Large concentrations of these elements can be hazardous either acutely or over time, even if minimal levels are required for healthy health (Bakare & Adeyinka, 2022). Certain heavy metals, like iron, cobalt, copper, manganese, and zinc, are essential for a healthy life, with living organisms requiring varying amounts. On the other hand, certain heavy metals, like lead, plutonium, and mercury, are poisonous and can seriously harm organisms over time when they build up in them (R. Singh et al., 2011). Heavy metals can also exist in wastewater, posing significant challenges for wastewater treatment plants (WWTPs) due to their toxicity and impact on microorganisms, such as bacteria.

These heavy metals can enter wastewater treatment plants in various forms, including soluble, organically complexed, precipitated, and physically sorbed organic matter. They come from various sources, such as large manufacturing facilities, fertilizers, municipal waste, and the combustion of fossil fuels. Depending on the wastewater's origin and other factors, the amount of heavy metals in influent wastewater can change (Karvelas *et al.*, 2003). Water resources are at risk due to the rising discharge of household and municipal wastes that receive rare primary and secondary treatment, which hardly minimizes contamination (Abdelaal et al., 2022).

Among different wastewater treatment (WWT) methods, up-flow anaerobic sludge blanket (UASB)-based sewage treatment plants (STP) have gained popularity due to their low energy consumption, low sludge production, and high removal efficiency for organic pollutants. However, heavy metals can present a challenge for UASB-based systems due to their persistence, toxicity, and accumulation in sludge (Kaviyaran, 2014). Research has documented the presence of heavy metals in these systems (R. Singh et al., 2011) and emphasized the impact of several elements, including the types of heavy metals (R. Singh et al., 2011), treatment plant operating conditions, and sludge management techniques, on their fate (Bhat & Kumar, 2022; Matos & Correia, 2016). Because heavy metals have a tendency to bio-accumulate and bio-magnify in the environment, the discharge of household and municipal wastewater from ineffective primary and secondary

treatment poses a higher hazard to water resources (Abdelaal et al., 2022).

The heavy metals accumulation in sewage sludge can affect the treatment and final characteristics of the sludge. The treatment process can remove heavy metals by binding to sludge or passing through the treatment plant, thanks to advancements including high-rating UASB reactors and tertiary treatment that removes not only conventional parameters but also heavy metals (Karvelas *et al.*, 2003). However, the presence of heavy metals in wastewater and released effluents can cause major health risks to aquatic and human life and pose a serious environmental issue due to their toxicity, lack of biodegradability, bioaccumulation, and persistence (Adeyinka, 2022; Feng *et al.*, 2018; Sylwan & Thorin, 2021; Widziewicz *et al.*, 2015).

Effluent and sludge, the two major products created by WWTPs, can have significant environmental impacts. Effluent discharge can lead to water quality deterioration, biodiversity decline, and changes in ecosystem function due to the presence of toxins such as heavy metals. Sludge, while a useful resource for producing organic fertilizers due to its significant amounts of nutrients and organic carbon, can contain various contaminants, including heavy metals, which necessitate regulatory measures for its disposal (Duan *et al.*, 2017; Tytła *et al.*, 2015)

In order to address the issue of heavy metal contamination in WWT systems (R. Singh et al., 2011), several approaches have been proposed, including pre-treatment of wastewater, improving the effectiveness of heavy metal removal using advanced treatment techniques, optimizing operational conditions of the treatment plant, and adopting suitable sludge management practices (Chirila *et al.*, 2014; Sanz & Mill, 2021). These strategies are critical for achieving the Sustainable Development Goal 6 (SDG) by 2030, which aims to minimize untreated wastewater and provide clean, managed sanitation to everyone (World Bank, 2017).

Examples of these challenges can be seen in Ethiopia, where the only city with sewer connections, Addis Ababa, has been forced to treat industrial and hospital wastewater containing heavy metals, despite being designed for organic pollutants (BEKELE, 2021). The efficacy of the existing STP in Ethiopia can be impacted by co-treatment, as there is an absence of systematic data and understanding regarding the emergence and destiny of Hazardous Materials (heavy metals). This lack of information accounts for a major knowledge void. Addressing this issue through careful study could inform policies concerning human and environmental health and contribute to the

literature review database and knowledge.

1.2 Statement of the Problem

Hazardous materials (heavy metals) can be removed, along with carbonaceous material, using the UASB system. UASB systems are popular STPs for household and industrial wastewater, and effectively reduce biodegradable carbon, nitrogen, phosphorus, and some heavy metals. However, it's important to note that heavy metals can accumulate in the UASB reactor sludge and may be released into the environment through sludge disposal or effluent discharge. Because heavy metals can enter the food chain and have negative health effects on humans, their pollution and toxicity in treated effluent and sludge provide significant environmental and social challenges. In fact, the discharge of thousands of contaminants into the receiving water with WWTP effluent creates a complex mixture exposure scenario and leads to various ecological consequences, such as water quality deterioration, decline in biodiversity, and changes in ecosystem function (Huizhen,*et al.*, 2022). Poisonous water could be produced if heavy metals are not removed during WWT treatment process (Huizhen,*et al.*, 2022). Therefore, understanding the metal composition of sewage sludge is crucial for agricultural applications and addressing contamination and toxicity.

The Kality centralized sewage treatment plant in Addis Ababa, Ethiopia, is responsible for treating wastes from the central part of the city. The treated effluent is discharged into the Little Akaki River, while the sludge is transferred to drying beds and managed there. However, the illegal discharge of chemicals into the sewage network from an industrial plant (Butte & Zu, 2020), substantial difficulties have been presented by both the direct release of hospital effluents without pretreatment (BEKELE, 2021). Addis Ababa, Ethiopia is facing a challenge regarding the presence of heavy metals in wastewater treatment effluent and its impact on soil used for agriculture, irrigation, and other purposes as a result of rapid expansion of cities and population growth. This leads to potential health hazards for farmers and consumers, reduced crop productivity and quality, and disruption of aquatic ecosystems, making it crucial to study the Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based Sewage Treatment Process of Kality Centralized Sewage Treatment Plant. Therefore, this study highlights the importance of investigating Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based Sewage Treatment Process, and highlights the necessity of adhering to environmental

regulations for the purpose of controlling pollution caused by domestic waste and safeguarding both human health and the environment.

1.3 Research Questions

A, Does the concentration of selected physiochemical parameters (pH, BOD₅, COD, TSS, SO₄²⁻, NH₄-N, TN, TP, and EC) and heavy metals (Cd, Pb, Ba, Mn, Cu, Zn, Cr, Fe, Al, and Ag) in the Kality UASB and trickling filter-based sewage treatment plants exceed the EPPA discharge limit to a surface water body?

B, To what extent do the heavy metal concentrations vary among treatment units and sampling periods in a UASB and trickling filter -based sewage treatment plant?

C, What is the extent of heavy metal transformation, removal, and/or accumulation during the anaerobic digestion process in UASB reactors(UASBr)?

D, Is there association between the amounts of selected heavy metals and physicochemical parameters in a UASB-based sewage treatment plant?

E. What is the efficacy of the treatment plant in removing the selected heavy metals and physicochemical parameters?

1.4 Objectives of the Study

1.4.1 General Objective of the Study

The research's goal was to Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based Sewage Treatment Process in Kality Centralized Sewage Treatment Plant

1.5.2 Specific Objectives

- ✚ To determine the concentration of heavy metals, physicochemical parameters in the influent, effluent of the UASB reactor and trickling filter, and sludge from the UASB reactor, returned activated sludge from secondary clarifier and dewatered sludge from the drying bed and characteristics removal efficiency of the treatment plant.
- ✚ To examine the variations in heavy metal concentrations and physicochemical characteristics across different treatment units and sampling periods in the sewage treatment plant.
- ✚ To evaluate the Pearson correlation between heavy metals and physicochemical parameters in the treatment plant.

1.5 Significance of the Study

This research finding is significant as it paves the way for periodic monitoring of the concentration of heavy metals and other parameters in the effluent and sludge before their discharge into the environment. This monitoring would ensure that the effluent remains within the carrying capacity of the receiving water bodies, thus safeguarding aquatic life. The results of this research will assist the Addis Ababa Authority for Water and Sewerage (AAWSA), policymakers, and managers in effectively treating and managing effluents to prevent the accumulation of toxic pollutants in the environment, which poses a health hazard to the population. Monitoring the heavy metals and physicochemical parameters to assess the treatment plant's performance plays a crucial role in ensuring public health and environmental well-being.

From an academic perspective, the research findings will identify research gaps and recommend areas for further investigation into environmental heavy metals. This will contribute to the development of strategies for controlling the release of pollutants into the environment. Furthermore, the research findings will aid the local standards governing body in effectively monitoring and enforcing laws with relation to heavy metals and formulating standards for effluent discharge. Adverse health effects on humans and aquatic life, as well as the emergence of resistant bacteria in the environment, underscore the importance of such monitoring. Monitoring the characteristics of influent, effluent, and sludge is essential for developing new treatment technologies, achieving effective wastewater treatment, and finding solutions for sludge management.

1.6. Scope of the Study

Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based Sewage Treatment Process of Kality Centralized Sewage Treatment Plant (STP) were investigated in Addis Ababa, Ethiopia. Samples of wastewater were taken from the influent, effluent, and sludge from units of the treatment plant. Additionally, dried sludge samples were collected from the drying bed of the treatment plant. The study aimed to comprehensively investigate Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based Sewage Treatment throughout the entire treatment process, emphasizing the need for a detailed examination of heavy metals in the Kality centralized STP.

The experimental investigation of heavy metals was conducted using ICP-OES at the ACEWM core laboratory of Addis Ababa University, under the College of Natural and Computational Science. Furthermore, the physicochemical characterization of wastewater samples from different units of the treatment plant was carried out at Kality China Gezhouba Group Corporation (CGGC) physicochemical laboratory.

1.7 Limitation of the Work

This study focuses only on common physicochemical parameters and heavy metals, which might not represent all physicochemical parameters and heavy metals found STP. The study only considered a two-day sampling period in April, May, and June respectively, which may not accurately represent the long-term Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based Sewage Treatment Process of Kality STP. The study did not account for potential seasonal variations in heavy metals concentrations, which could influence their Treatment Performance and Fate of Heavy Metals in a UASB and Trickling Filter Based Sewage Treatment Process of Kality Centralized STP. The study focused on a specific sewage treatment plant, limiting generalizability to other plants with different configurations or operational conditions.

1.8 Thesis Organization

The thesis is divided into 5 chapters, each with a specific purpose:

Chapter 1 provides background information on the study, including the problem being addressed, objectives, significance, scope and limitations.

Chapter 2 is a comprehensive literature review covering topics such as definitions of hazardous materials and heavy metals, the composition and sources of wastewater and sludge, how heavy metals occur and behave in wastewater treatment plants, and relevant regulations.

Chapter 3 focuses on the materials and methods used in the study, detailing the procedures and techniques for collecting and analyzing data/samples to ensure scientific rigor.

Chapter 4 presents the results and discussion of the findings, providing an in-depth examination and interpretation of how heavy metals occurred and behaved in the WWTP under examination.

Chapter 5 summarizes the study's conclusions and recommendations for policymakers based on results. It also identifies possible directions for this field's future investigation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Heavy metal: sources, toxicity and environmental impacts

2.1.1 Definition heavy metal

The term "heavy metal" is frequently utilized in studies of pollution and environmental impacts, but has faced controversy over precise definitions and calls to stop using it altogether (Ali *et al.*, 2019; Kinuthia *et al.*, 2020). When discussing about transition metals like copper, lead, and zinc, we usually characterize the heavy metals as those with high relative atomic mass or high density, which is usually above 3.5–5 g/cm³ (Ali *et al.*, 2019; Kinuthia *et al.*, 2020). Some definitions specify an atomic number between 21-92, encompassing metals from scandium to uranium. More recently, the term has broadened to include any naturally occurring element above atomic number 20, regardless of density or mass (Ali *et al.*, 2019). While characteristics like high density, atomic mass and atomic number are commonly used to describe heavy metal, the designation is also frequently based on known toxicity of certain elements like arsenic, cadmium, chromium, lead and mercury rather than physical properties. Despite controversy over precise definitions and calls to stop using the term "heavy metal," its use continues to increase in scientific literature related to pollution and environmental impacts.

2.1.2 Composition of municipal wastewater and sludge

Wastewater generated by a community includes: a) residential wastewater from kitchens, bathrooms, and other sources; b) raw or treated industrial wastewater that is released into the sewer system; and occasionally c) runoff from urban areas and rainwater. Sewage mostly consists of domestic wastewater, which is sometimes used interchangeably with the term sewage. The composition of sewage varies greatly from location to location, contingent upon various factors such as water consumption, sewer system design, social behavior, economic issues, and the kind and quantity of industries present.

Sewage has a range of chemicals that can be found in it, including heavy metals, trace elements, detergents, solvents, pesticides, and other uncommon substances like hormones, antibiotics, and medications. Metals like copper, mercury, cadmium, lead, zinc, nickel, and chromium often occur in municipal wastewater from human activities and exceed prescribed limits (Du *et al.*, 2017;

Gopal, 2020). Therefore, Characterizing wastewater is essential to design appropriate treatment systems and protect receiving waters (Daud *et al.*, 2018). Overall, wastewater composition depends on many locale-specific factors and contains a complex mixture of organic and inorganic compounds, including heavy metals that require treatment prior to discharge.

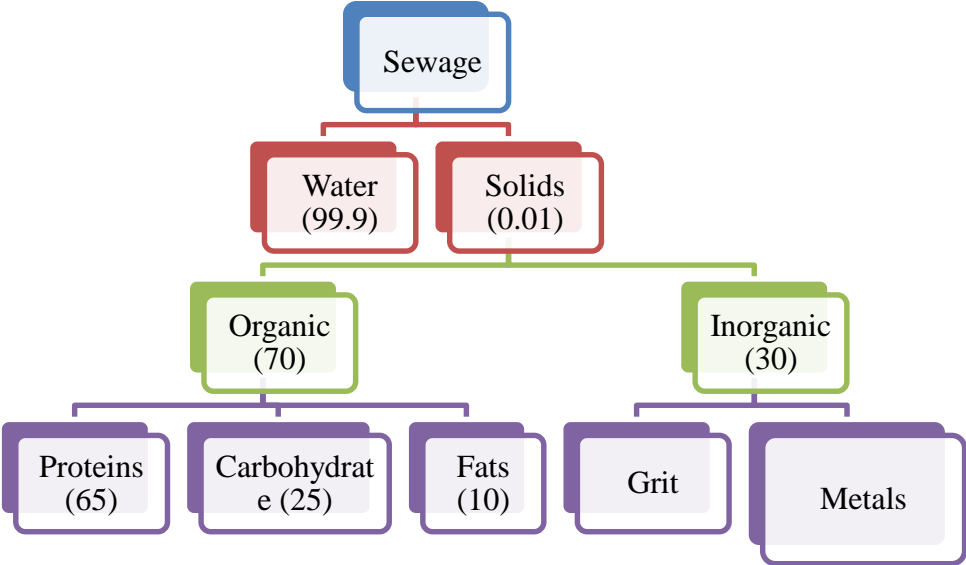


Figure 1 composition of municipal sewage

2.1.3 Source of heavy metals in municipal wastewater and sludge

Municipal wastewater contains heavy metals from diverse sources including residential, commercial, industrial, and urban runoff discharges (Karvelas *et al.*, 2003). Domestic activities like food preparation, cleaning, personal care, and human waste contribute significantly to metals like chromium (Abel *et al.*, 2022). Commercial sources including restaurants, car washes, photography studios, and medical facilities also contribute these metals (Abel *et al.*, 2022). Corrosion of lead, copper, and galvanized pipes releases metals into drinking water and wastewater (Santos-Echeandia, 2016).

Urban runoff transports atmospheric deposition of metals from roofs, streets, and other impervious surfaces to WWTPs, especially in combined sewers (Santos-Echeandia, 2016). Diffuse emissions from corrosion, runoff, and streets make up a major portion of metals Table 1. Food, dental amalgam, fertilizers, landfill leachate, and flame retardants also add metals like cadmium, zinc, mercury, and antimony (Hargreaves *et al.*, 2016; Sylwan & Thorin, 2021). Based on Table 1 heavy

metals emanate from different sources (point and nonpoint) mainly anthropogenic activities that greatly contribute to treatment plants for municipal wastewater.

Table 1 Possible heavy metal sources in municipal wastewater treatment plants (MWWTPs)

No	Heavy metals	Sources of heavy metals	Reference
1	Pb	Cleaning, personal care products, food products, mechanical and car washes, pipe corrosion, old paint pigments, various varnishes, roofing, cable covering, traffic, runoff	(Abel <i>et al.</i> , 2022; Hargreaves <i>et al.</i> , 2018; Matos & Correia, 2016; Ziolko <i>et al.</i> , 2011)
2	Cu	Cleaning, personal care products, and food products, mechanical and car washes, pipe corrosion, leaching from pipes and taps, rainwater, flooring factory, drinking water	(Hargreaves <i>et al.</i> , 2018; Matos & Correia, 2016; Ziolko <i>et al.</i> , 2011)
3	Zn	Galvanized PVC pipes, Commercial activities, domestic activities, carwashes, food	(Abel <i>et al.</i> , 2022; Agoro <i>et al.</i> , 2020; Matos & Correia, 2016; Ziolko <i>et al.</i> , 2011)
4	Cr	Commercial activities, industrial activities, service activities, domestic sources, chromium salt, products, oils and lubricants, paints and pigments, alloys, pesticides, and gardening products,	(Abel <i>et al.</i> , 2022; Geng <i>et al.</i> , 2021)
5	Hg	Dental amalgam, mercury chloride, pesticide, old paints and pigments, wood preservatives, glass mirrors, agricultural chemicals, and landfill leachate	(Geng <i>et al.</i> , 2021; Hargreaves <i>et al.</i> , 2018)
6	Cd	Car washes, Ni-Cd batteries, paints and photography, processing of food, detergents, body care products, and storm waters,	(Matos & Correia, 2016; Ziolko <i>et al.</i> , 2011).
7	Ni	Drinking water, alloys used in sanitary equipment, inappropriate disposal of used Ni-Cd batteries and paints, household stainless steel products	(Hargreaves <i>et al.</i> , 2018; Matos & Correia, 2016; Ziolko <i>et al.</i> , 2011)

2.1.4 Wastewater and sludge related legislation and regulation and its impact on the heavy metal sources

The ongoing evolution of legislation worldwide seeks to continually refine the requirements related to pollutant removal from domestic sewage. The standards for effluent, or treated wastewater, differ based on the receiving water environment and the age of the WWTP design. In many towns that use combined sewers for inflow, achieving these legislative limits can be challenging (Drozdova et al., 2019). Urban wastewater and sewage sludge contain environmental contaminants like heavy metals, pharmaceuticals, and personal care products (PPCPs), requiring proper treatment according to Urban Waste Water Treatment Directive (UWWTD) in Europe and the Clean Water Act (CWA) Within the United States (Hargreaves *et al.*, 2018; Karvelas *et al.*, 2003). In Ethiopia, the Public Health Proclamation No. 200/2000, the Water Resources Proclamation, and other national policies are in place to protect water resources and ensure that sewage and industrial effluents do not harm water resources for human usage. The nation's hazardous waste management laws were established by the 103 Hazardous Waste Management and Disposal Proclamation No. 1090/2018. This legislation regulates the management of hazardous waste to prevent harm to human health and the environment and places responsibilities on waste generators to minimize waste generation and properly contain, label, and transport waste.

The Minamata Convention treaty, agreed by the United Nations Environment Program (UNEP) in 2013, states that progress must be made to reduce the use of mercury in dentistry, encouraging the use of non-mercury-containing alternatives (Hargreaves *et al.*, 2016). The treatment and disposal of waste, and particularly heavy metals, are further complicated due to the reality that standards are lower in developing countries where wastewater treatment technology is less advanced. The reuse of sludge in Europe is partly limited by regulations, especially stricter standards in some countries.

Time-trend analyses of metals in sewage sludge show decreased levels due to regulatory actions. For instance, the metal content that sewage sludge contains (Cd, Cr, Cu, Hg, Ni, Pb, and Zn) decreased in the 1970s and has stabilized since the 1980s in Stockholm (Sörme & Lagerkvist, 2002). This suggests that environmental legislation and regulations can effectively reduce the release of hazardous substances into the environment. However, long-term strategies to reduce metal emissions to WWTPs must focus on dispersed and diffuse emissions, as well as a better

understanding of urban erosion processes (Idowu, 2022). For instance, currently, producers use metals like Pb, As, Cd, Co, Sb, Hg, Ni, and Cr above WHO limits in cosmetics.

2.1.5 The silent killer: heavy metals impact on human health, environment, and micro-organism

The harmful effects of heavy metals on humans, animals, and plants have been extensively studied in scientific literature (Ali & Eren, 2019; Wang *et al.*, 2021). Among these metals, lead, nickel, zinc, copper, iron, chromium, and cadmium are frequently found impurities (Wang *et al.*, 2021). Due to their expanding use in many industries, human exposure has increased, creating serious problems for the environment and public health (Tchounwou *et al.*, 2012).

The toxicity of these metals, particularly mercury, cadmium, and lead, has been a focal point of research due to their potential to cause severe health effects, such as autoimmune conditions, diabetes, hypertension, kidney damage, and nervous system disorders (Ali & Eren, 2019; Kinuthia *et al.*, 2020; Shikuku *et al.*, 2017). Additionally, arsenic, though a semi-metal, is considered extremely carcinogenic, causing skin lesions indicative of chronic arsenic toxicity (Lawal *et al.*, 2021).

Mercury is a common pollution that has been connected to a number of health problems, including harm to the growing fetus, kidneys, lungs, and brain (Kinuthia *et al.*, 2020; Tchounwou *et al.*, 2012). Dental amalgams and fish intake are two forms of exposure, with fish consumption being a serious risk because of the bioaccumulation of mercury in aquatic habitats (Tchounwou *et al.*, 2012). Cadmium, as another heavy metals of concern, is primarily associated with cigarette smoke, certain industries, and contaminated food sources (Tchounwou *et al.*, 2012). Chronic exposure can lead to damage in several body systems and increase cancer risk (Du *et al.*, 2017; Kinuthia *et al.*, 2020). Likewise, lead exposure, often from deteriorating paint and contaminated food and water, can accumulate in the body and cause neurological, hematological, and kidney disorders, with children being particularly vulnerable (Tchounwou *et al.*, 2012). Copper, though an essential nutrient, can cause gastrointestinal distress and aesthetic issues when present in high concentrations in drinking water. When taken in excess, zinc—another crucial trace element—can lead to weight loss, weakened immunity, and nausea (Lawal *et al.*, 2021).

These heavy metals, when present in wastewater and soil, can disrupt biological processes and pose significant risks to aquatic organisms, humans, and the environment (Duan *et al.*, 2017). For instance, heavy metals in high concentrations can inhibit nitrification and denitrification during wastewater treatment, leading to the release of inadequately treated effluent and metal-contaminated sludge, which can contaminate soils and groundwater (Maal-bared, 2020; Wang *et al.*, 2021).

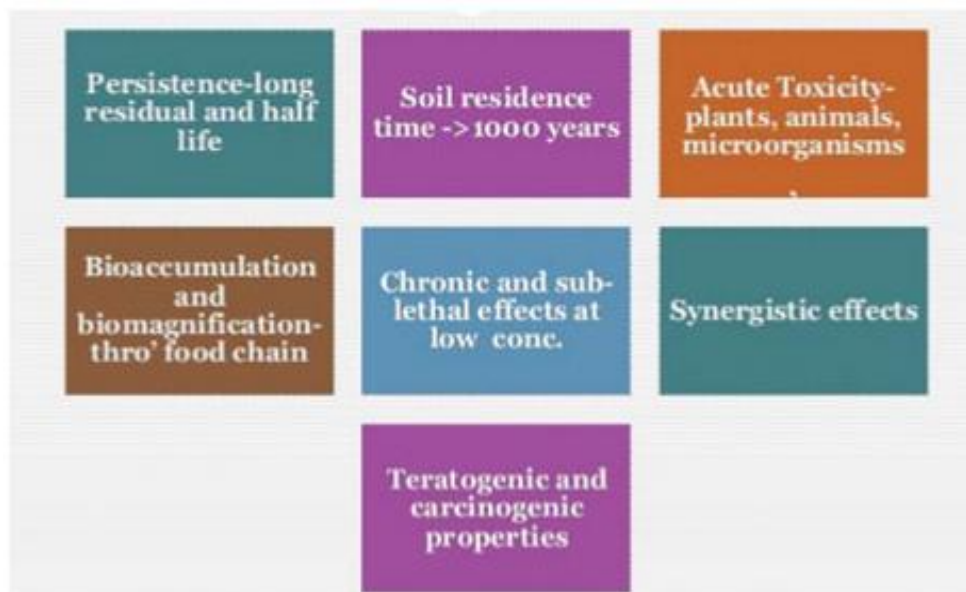


Figure The toxicity of heavy metals in the environment (Czikkely & Fogarassy, 2018).

2.1.5.1 Effects of heavy metals biological wastewater Treatment

The heavy metals can inhibit microbial metabolism and activity in biological wastewater treatment processes. Chromium disrupts microbial metabolism by competing with oxygen as an electron acceptor. Heavy metals inhibit nitrification and denitrification steps by impairing autotrophic and heterotrophic bacteria (Wang *et al.*, 2021). They disrupt microbial populations, diversity, species composition, and reproduction (Sa, 2010).

Sudden toxic shocks from metals can reduce microbial activity, lowering treatment capacity and efficiency(Chipasa & Ali, 2003). Modeling studies reveal metals like copper and cadmium reduce heterotrophic bacteria, although effluent quality may remain acceptable (Buaisa *et al.*, 2020). Different metals have varying toxicity effects – copper inhibits hydrolysis, nickel affects methanogen activity, while cadmium and copper are most toxic to volatile fatty acid consumers (Kadam *et al.*, 2022).

2.2 Overview of the occurrence, fate, and removal of heavy metals in the sewage treatment plant

The process of biological wastewater treatment breaks down organic waste in water by means of microorganisms. Anaerobic and aerobic processes are the two categories into which the process is separated (Sysop, 2020). There is oxygen during the aerobic process and none during the anaerobic process. The method uses the regular biological processes of bacteria, nematodes, or other tiny organisms to break down organic wastes (Sysop, 2020). A wide variety of organic materials, including trash, wastes, and partially digested food, are commonly found in wastewater. Toxins, heavy metals, and pathogenic organisms might also be present. Establishing a method that makes it simple to gather the byproducts of decomposition for appropriate disposal is the aim of biological wastewater treatment.

Aerobic wastewater treatment methods include septic tanks, oxidation ditches, surface and spray aeration, activated sludge, trickling filters, pond and lagoon-based treatments, and aerobic digestion (Sysop, 2020). Biological treatment methods include wetlands and filtration, with activated sludge being a popular secondary treatment for wastewater from pulp and paper mills, food processing, municipal sewage, and industrial waste streams (Sysop, 2020).

Anaerobic wastewater treatment processes, including filters, ponds, and lagoons, effectively remove up to 90% of organic matter from industrial and municipal wastewater. UASB reactors are a prominent anaerobic wastewater treatment technology known for their simplicity, low cost, and energy production via biogas (Daud *et al.*, 2018). UASB reactors work by retaining anaerobic sludge that facilitates high-rate treatment and granule formation (Zhang, 2016). The heavy metals can inhibit the metabolic activity of anaerobes and reduce biogas production. UASB reactors reduce metal concentrations through mechanisms like precipitation, sorption, and complexation but overcoming inhibition remains a key challenge (Kadam *et al.*, 2022).

Trickling filter (TFs) is an attached growth process used to treat wastewater. It involves dripping wastewater over a bed of media like rocks or crushed stone where microorganisms grow in a biofilm (Hargreaves, 2017; Ziolkó *et al.*, 2011). The microbes produce extracellular polymeric substances (EPS) that can bind metals in the wastewater, though the exact metal removal

mechanisms are still unclear. TFs are followed by clarifiers to settle out washed off microbes. Overall, trickling filters are a simple, low energy, and cost-effective biological treatment method commonly used in small and medium wastewater treatment plants, despite uncertainties around metal removal processes. Although the biofilm makes organic removal more effective, additional investigation is required into how it interacts with metals.

According to a study by Liu *et al.*, (2019), heavy metals accumulated in the sludge of a UASB reactor that was used to treat home wastewater; the concentrations of these metals were highest in the sludge bed's bottom layers. The investigation discovered that the lowest layer of the sludge bed contained the highest quantity of copper (Cu), followed by zinc (Zn) and lead (Pb). Abdel-Shafy *et al.*, (1995) found that an anaerobic digester improved wastewater quality by reducing pollutants and removing chromium and other metals. They recommended chromium recovery for environmental protection.

Olujimi O. *et al.*, (2013) determined that certain elements exceeded discharge limits and needed to be optimized for both environmental and health reasons when heavy and trace metal levels in South African WWTP effluents were examined. Olofsson *et al.*, (2010) found a Swedish WWTP effectively removed most substances but some remained in sludge. Dalel Belhaja, *et al.*, (2013) found 22-43% of heavy metals accumulated in activated sludge, requiring management.

Bakare & Adeyinka, (2022) found most heavy metals in South African WWTPs exceeded recommended levels. Hargreaves *et al.*, (2018) found that activated sludge poorly removed dissolved metals; enhanced colloidal removal could increase removal. Bio-sorption occurs through extracellular/cell accumulation and precipitation (Laurent *et al.*, 2011). Return flows from dewatering constitute significant heavy metals entering treatment (Santos-Echeandia, 2016; Yoshida *et al.*, 2015).

Feng *et al.*, (2018) found Shanghai WWTPs significantly treated some heavy metals but risks to aquatic organisms and consumption. Oliveira *et al.*, (2007) found 61.5% Hg to 10.4% Mn removal in Brazil, within standards; sludge usable with monitoring. Nyamukamba *et al.*, (2019) found most metals in the treatment of wastewater are within limits in South Africa but some WWTPs had high TSS, TN, TP, Cu, Pb, Zn; recommend treatment and monitoring. (Tytła, 2019) found

some risk and contamination in Polish WWTP sludge but within standards; while Zn, Ni, and Cd are mobile, the majority of heavy metals are not.

2.2.1 Metal size distribution within the sewage treatment plant

The distribution of heavy metals in UASB-based STP is influenced by various factors, including the characteristics of the wastewater, operation conditions, and the type and concentration of heavy metals. Rather of altering the dispersion of heavy metals among phases, treatment plants should concentrate on lowering the total amount of heavy metals in wastewater. According to Chipasa, (2003), the study aimed to compare heavy metals components of the wastewater influent and effluent and examine the heavy metals contents in the sludge before and after anaerobic digestion. The study found that Cu and Zn had more significant changes in the heavy metals content than Cd and Pb, with insignificant reductions at 0.02 and 0.05 mg/l, respectively.

Gardner *et al.*, (2013) detected high levels of aluminum and iron in United Kingdom (UK) WWTPs, with only a small proportion in the dissolved phase. Cu and Ni were observed to occur in the dissolved phase, which may affect their removal during treatment. Since lead was mostly found in solids, primary sedimentation is when it should be eliminated. The concentration of influent metals has no bearing on the distribution of heavy metals between the liquid and solid phases. The presence of functional groups and dissolved organic carbon affects the distribution of heavy metals in the soluble fraction.

2.2.2 Spatiotemporal heavy metal distribution at the sewage treatment plant

A study conducted in India by Singh *et al.*, (2018) evaluated the spatial and temporal variation of heavy metals within an UASB-based STP. According to the study, there were considerable variations in the concentrations of heavy metals at each stage of the treatment process, with the influent having the highest concentrations and the effluent having the lowest. Similarly, Vriens *et al.*, (2017) discovered the geographical distribution of several components connected to anthropogenic or geogenic sources in the Swiss STP, and Shamuyarira & Gumbo, (2014) showed that the amounts of heavy metals in sewage sludge varied among South African municipalities.

Seasonal fluctuations in influent characteristics, operating condition changes, and diurnal patterns

of wastewater generation and release are some other factors that might cause temporal variations in heavy metals concentrations. The behavior of heavy metals in sewer systems, as observed during Dry Weather Flow (DWF) and Wet Weather Flow (WWF), can also affect water quality in watercourses (Drozdova *et al.*, 2015). Studies have found that during wet weather periods, an increase in the concentrations of As, Cr, Cd, Pb, Mn, and Fe occurs in the sewer system, while Zn, Cu, and Ni concentrations decrease. Moreover, the proportion of heavy metals within household wastewater varies, as shown in a study by (Drozdova *et al.*, 2019).

Studies have found seasonal fluctuations in elements like Cu, Zn, Pb, and Cd at WWTPs, with higher values often occurring in summer and autumn (Douglas *et al.*, 2022; Drozdova *et al.*, 2019; Joel *et al.*, 2017). While treatment efficiency remains stable, physicochemical parameters like COD, TSS, and conductivity show seasonal patterns, generally with lower values in wet seasons in light of dilution effects (Alsulaili *et al.*, 2020). Seasonal variations in rainfall and temperature also impact WWTPs, as shown in studies conducted in South Africa (Makuwa *et al.*, 2022) and Kuwait (Alsulaili *et al.*, 2020).

Seasonal variations in weather, sources of contamination, and patterns of household water consumption influence the quantities of minor components in wastewater. The peak usage times of the day and rainy weather, when storm water adds more pollution, are typically when the levels of heavy metals are highest (Penradee Chanpiwat *et al.*, 2010). Overall, wastewater heavy metals concentrations vary spatially and temporally based on source inputs and treatment, accumulating in sludge and requiring careful management to prevent environmental contamination (Du *et al.*, 2017; Guo *et al.*, 2023). Therefore, it is essential to comprehend the spatiotemporal fluctuations of heavy metals in UASB-based STP in order to optimize the treatment procedure and guarantee the successful removal of heavy metal from wastewater.

2.2.3 Heavy metals removal in primary, secondary, and tertiary sewage treatment

Adsorption and precipitation are the two main mechanisms responsible for the removal of heavy metals during initial treatment (Hargreaves *et al.*, 2016). Various techniques, such as coagulation/flocculation and sorption technologies, can further enhance heavy metals removal throughout the treatment process (Sylwan & Thorin, 2021). The addition of a sorbent during or

directly following primary treatment can mainly enhance the removal of dissolved heavy metals. The removal of heavy metals in traditional treatment varies because of physicochemical variables and operational characteristics (Hargreaves *et al.*, 2017).

In Sewage Treatment Works (STWs), primary sedimentation is essential for the removal of heavy metals because it lessens the load of heavy metals on following biological treatment processes, which lowers the possibility of metal toxicity to microorganisms (Ziolko *et al.*, 2011). Factors that influence heavy metals removal during primary sedimentation include metal speciation, suspended solids (SS) removal, partitioning, and operational parameters like pH, temperature, particle size, metal concentration, and EPS concentration (Hargreaves *et al.*, 2017). During primary sedimentation, influence-suspended solids concentration plays a critical role in regulating the removal of dissolved and particulate heavy metals (Ziolko *et al.*, 2011).

Metals like copper (Cu) and zinc (Zn) behave differently during secondary treatment; Cu removal is a reflection of Cu's affinity for organic material (Gardner *et al.*, 2013). The biological treatment removes solid metals through settling and dissolved metals through sorption to the biological matrix. Extracellular polymers may increase dissolved metal concentrations, like copper, which is resistant unless dilute (Ziolko *et al.*, 2011). Additionally, because it controls the amount of biomass used in the process, the concentration of biodegradable COD in the influent wastewater also indirectly influences the capacity to remove heavy metals (Sylwan & Thorin, 2021). While chromium removal efficiency rises with MLSS and sludge age as fewer microorganisms are wasted and heavy metals discharged in final effluents are either sorbed to suspended solids or associated with dissolved organic matter, copper, nickel, and zinc removal rates are highest with the lowest COD (Ziolko *et al.*, 2011).

The tertiary treatment introduces additional removal of pollutants not eliminated in primary and secondary treatment. This includes heavy metals, organic matter, nutrients, and pathogens (Matos & Correia, 2016). Tertiary methods include coagulation/flocculation to precipitate dissolved metals, adsorption using activated carbon to accumulate pollutants, and increasing pH to reduce metal solubility (Karnib *et al.*, 2014). Microalgae offers tertiary treatment through the bio-sorption of nutrients and metals (Chan *et al.*, 2019). Heavy metals were removed 70–80% by chemical precipitation with lime and iron salts, and the residual metals were removed by adsorption on

activated carbon (Gulas *et al.*, 2015). Sand filtration can also contribute to treatment through adsorption and biodegradation (El *et al.*, 2018).

Microbial enhanced heavy metal removal is a promising approach for wastewater treatment plants. In recent years, microbiological treatment to remediate contamination by heavy metals has aroused public attention as such pollution has seriously threatens ecosystems and human health and impedes sustainable development (S. Wang *et al.*, 2021). In particular, the exploration of the combination of microbiological approaches with chemical methods or phytoextraction are scrutinized in this review relative to real waste heavy metal remediation. The technical field of microbial remediation includes bio-sorption, bioleaching, bio-minerization, etc (S. Wang *et al.*, 2021). A 300 L aerated packed reactor was designed to effectively leach heavy metals from electroplating sludge within a few hours using the mixed microbial stock solution.

In bioremediation, most microorganisms follow two common mechanisms: metal sequestering or immobilization and enhancement of solubility properties of the metal, other organisms oxidize or reduce the heavy metals to a less toxic form (Abo-Alkasem *et al.*, 2023). Bio-augmentation is the application of outsourcing microbial strains that occur naturally or are genetically engineered to decontaminate polluted soil or water (Abo-Alkasem *et al.*, 2023). It is a bioremediation method that involves adding archaea or bacterial cultures to a bioreactor to treat sewage or other contaminated materials (Daphtary & Daphtary, 2023). It increases the level of active microbes and microorganisms, transforming contaminants into less harmful compounds (Daphtary & Daphtary, 2023). Bio-augmentation is commonly used in municipal wastewater treatment and advances microbial ecology, biology, immobilization, and bioreactor design (Daphtary & Daphtary, 2023).

2.2.4 Heavy metal removal during sludge treatment

Sewage sludge is the byproduct of wastewater treatment containing concentrated heavy metals and pollutants. (Jaroslaw Gawdzik, Joanna Dlugosz, 2015). Common sludge treatment processes include thickening, digestion, conditioning, dewatering, and stabilization (Jaroslaw Gawdzik, Joanna Dlugosz, 2015). Additional sludge handling like stabilization, dewatering, and drying further reduces volume before disposal (Geng *et al.*, 2021). Managing wastewater sludge with concentrated levels of heavy metals and other pollutants is made easier by these integrated technologies for volume reduction and water removal. Land application is limited by potential

heavy metals accumulation and toxicity. Monitoring total metal content is essential to guarantee adherence to rules, especially for agricultural reuse (Du *et al.*, 2017; Jaroslaw Gawdzik, Joanna Dlugosz, 2015). An integrated approach considering influent, treatment process, and end use is crucial for optimal heavy metals management in sludge.

Sludge treatment is a critical component of wastewater treatment that handles the concentrated solids removed from liquid effluent. This sludge contains high levels of heavy metals along with other pollutants and requires effective treatment before final disposal. Anaerobic digestion reduces overall sludge mass through the conversion of organic matter to gases, while some volatile and soluble metals are released in the liquid fraction (Chipasa, 2003). Additional investigation is required to understand fundamental removal mechanisms, optimize the selective removal of key toxic metals like Hg and Cd, and minimize residual metal content through integrated sludge handling processes (Chipasa, 2003).

2.2.5 Heavy metal removal mechanism used in sewage treatment

During treatment procedures, the heavy metals are extracted from wastewater using a variety of physical, chemical, and biological mechanisms (Hammoudani , 2021). Key removal mechanisms include bio sorption, bioaccumulation, precipitation, and adsorption to sludge particles and extracellular polymers (Azizi et al., 2016; Chipasa & Ali, 2003; Feng et al., 2018). Adsorption, where metals are attracted to the suspended solid's surface (Hargreaves et al., 2016), and precipitation, are significant for metals like copper and chromium (Ziolko et al., 2011). Other crucial processes that involve the attachment of heavy metals to sludge particles or microorganisms are adsorption and bio-sorption.

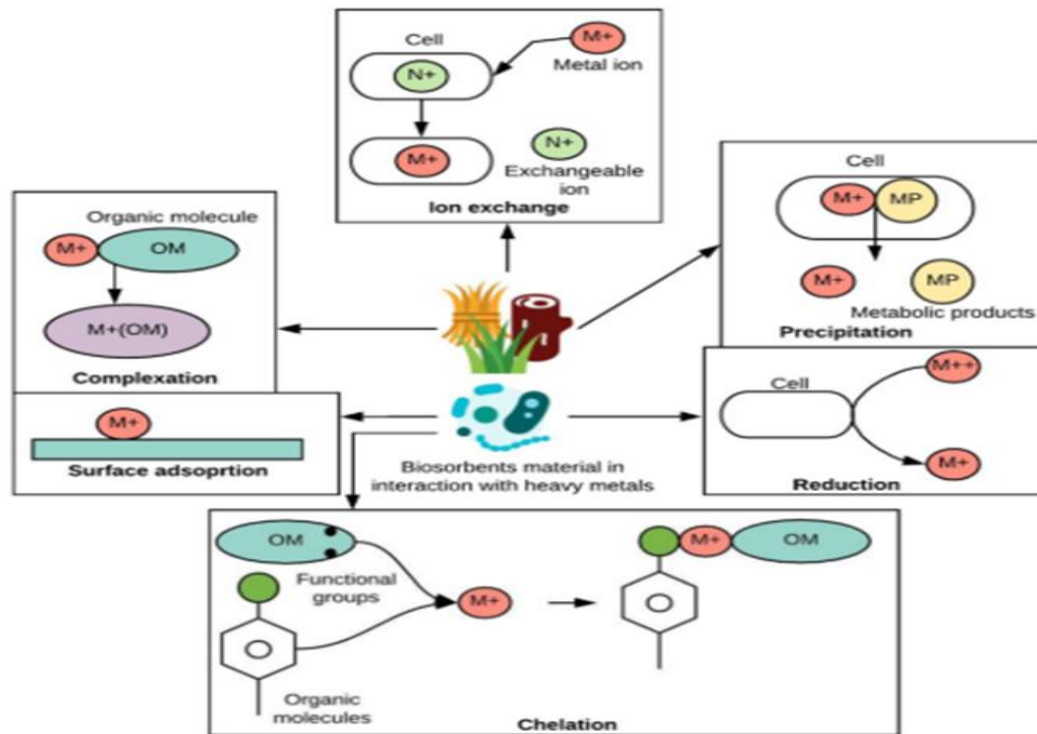


Figure 2 General schematic diagram for the bio-sorption of microorganisms adapted from (Calderón, 2020)

Bio sorption and bioaccumulation occur primarily during secondary treatment by microorganisms in activated sludge systems (Azizi *et al.*, 2016; Jun *et al.*, 2015). It can remove iron and copper, while coagulants remove chromium, cadmium, and lead (Li *et al.*, 2021). Bio sorption involves passive binding to microbial cell walls allowing heavy metals to be absorbed onto phosphate and other cell surfaces, while bioaccumulation is active transport into cell (Feng *et al.*, 2018). The binding of sorbate to the bio-sorbent is a complicated step in the bio-sorption mechanism. Chemical and functional groups that have the ability to bind and sequester metal ions include amine, amide, imidazole, thioether, sulfonate, carbonyl, sulfhydryl, carboxyl, phosphodiester, phenolic, imine, and phosphate groups. Complexation, chelation, reduction, precipitation, and ion exchange are some of the bio-sorption mechanisms (Calderón, 2020) Figure 2.

Complexation is the process by which an organic or inorganic ligand binds to a metal ion to generate a complex molecule (Narayanan & Narayan, 2019). Between the metal ion and the ligands, mononuclear (mono-dentate) complexes are created in which the metal atom is positioned in the center (Kanamarpudi *et al.*, 2018). Depending on the number of binding ligands involved, a poly-nuclear (multi-dentate) complex with multiple metal ions in the center can have a metal

atom with a positive, negative, or neutral charge (Kanamarlapudi et al., 2018). Complexation has an effect on the solubility and bioavailability of heavy metals in biological wastewater treatment, which can reduce the effectiveness of microbial remediation. The efficiency of microbial remediation for the removal of heavy metals can be diminished by complexing agents found in wastewater. For example, *Pseudomonas aeruginosa*'s ability to remove copper from wastewater may be hindered by the presence of humic acid.

Chelation is the process of forming a complex compound by the binding of a metal ion with an organic or inorganic ligand (Renu et al., 2017). Chelation is a technique that can be used in biological wastewater treatment to extract heavy metals from wastewater (Xu & Xu, 2008). Wastewater can be treated using chelating chemicals to create stable complexes with heavy metals that can be subsequently extracted by adsorption or precipitation (Xu & Xu, 2008). High selectivity, low cost, and convenience of application are just a few benefits of using chelating agents to remove heavy metals. Nevertheless, there are certain disadvantages to using chelating agents, including the possibility of harmful byproduct development and chelating agent interference with the biological treatment procedure (Xu & Xu, 2008).

Transferring electrons from one molecule to another is the process of reduction (Mpongwana et al., 2022). Reduction is a technique used in biological wastewater treatment to extract heavy metals from wastewater. Through the process of anaerobic respiration, microorganisms can consume heavy metals as electron acceptors, reducing them to less hazardous forms (Hammoudani et al., 2021). *Desulfovibrio* bacteria, for instance, have the ability to convert sulfate to sulfide, which can subsequently be utilized to reduce heavy metals like mercury and cadmium (Hammoudani et al., 2021).

All weak electrostatic interactions, such as hydrogen bonds, Van Der Waals, and the dipole-dipole interactions between the sorbent and sorbate, which usually range from 0.2 to 4 kJ/mol, are described by the adsorption type known as physio-sorption (Ayob *et al.*, 2021). These bonds are thought to be the weakest since they are easily broken. The process of chemisorption involves the sorbate and sorbent exchanging or sharing electrons to form an ionic or covalent connection (Ayob *et al.*, 2021). Because of its greater adsorption capability and stronger interactions with heavy metals, it is more widely used in the removal of heavy metals (Ayob *et al.*, 2021).

Precipitation of dissolved metals into insoluble compounds happens through aeration and bacterial oxidation in secondary treatment, followed by sedimentation and filtration (Agoro *et al.*, 2020). For some metals, removal through volatilization may occur to some degree as Yoshida *et al.*, (2015) documented likely volatilization of the semi-metal Sb (44%) and heavy metal Hg (6%) during sludge digestion.

The dissolved metals copper and zinc show different behaviors in the secondary treatment process, with copper being removed due to its affinity for organic material (Gardner *et al.*, 2013). During biological treatment, metals associated with solids are removed through settling with sludge flocs, and dissolved metals through sorption to the biological matrix. Extracellular polymers, on the other hand, have a great affinity for organic ligands, which means that when they are released from the cells, they may raise the concentration of some dissolved metals, especially copper (Ziolko *et al.*, 2011). Heavy metals removal during primary sedimentation can limit the chance of these processes being hampered by metal toxicity to the microorganisms in the succeeding biological treatment.

During sludge treatment, the main methods for removing heavy metals are partitioning into dried sludge solids, precipitation as insoluble salts, volatilization or solubilization into liquid fractions, and sequestration by chelating agents. The main way that metals end up in excess sludge is through sorption to particles and biopolymers (Hammoudani *et al.*, 2021). Precipitation as sulfides or hydroxides is a key pathway for decreasing metal solubility and bioavailability in sludge (Maharaj *et al.*, 2019).

2.2.6 Physicochemical and Operating parameters influencing heavy metals removal STP

2.2.6.1 Influence hydraulic retention time

The hydraulic retention time (HRT) in wastewater treatment systems is a key operating parameter influencing heavy metals removal. Longer HRTs in primary settling tanks allow more time for SS to settle out, increasing metal removal through sedimentation (Liew *et al.*, 2021). In biological treatment processes like UASBr, overly long or short HRTs are detrimental to performance (Hargreaves *et al.*, 2017). Increased HRTs in trickling filters improve the elimination of organics and solids, likely enhancing associated heavy metal removal (Hargreaves *et al.*, 2017). More specifically, longer HRTs increase the amount of interaction between wastewater and biomass,

which enhances heavy metal biosorption and bioaccumulation (Sutherland & Ralph, 2021). Optimum HRTs for biological reactors range from 2-12 hours depending on the (Azizi *et al.*, 2016; Feng *et al.*, 2018). In general, longer hydraulic retention durations improve heavy metal removal by giving crucial adsorption and precipitation processes more time to take place.

2.2.6.2 Influence of return flows

Heavy metals from sludge treatment return flows can be a major source of these elements for primary settlers (Sylwan & Thorin, 2021). By increasing suspended solids concentrations, they can either boost or decrease the removal of heavy metals by adding metals linked to fine particles (Sylwan & Thorin, 2021). Ferric salts in return may aid coagulation and replace heavy metals ions in complexes (Ziolko *et al.*, 2011). Return flows increased soluble copper removal despite increasing copper concentrations by raising suspended solids (Sylwan & Thorin, 2021). However, the accumulation of HMs in bio solids can reduce secondary treatment removal (Hargreaves *et al.*, 2016).

2.2.6.3 Sludge retention time (SRT) and concentration

Longer sludge ages result in higher removal efficiency, and SRT is a key factor in the removal of heavy metals from UASB systems (Gulyas *et al.*, 2015). Sludge age regulates microbial community composition, with older sludge ages generating smaller, denser flocs that settle better, enhancing metal removal (Ziolko *et al.*, 2011). However, after reaching a certain sludge age, the accumulating heavy metals can inhibit biological treatment. Biological metal removal is influenced by sludge age, physical trapping in flocs, and cellular accumulation (Kumar *et al.*, 2020). MLSS often found at older sludge ages also increase metal removal efficiency (Azizi *et al.*, 2016; Ziolko *et al.*, 2011). Sludge concentration impacts removal through bio-sorption and bioaccumulation (Hammoudani *et al.*, 2021). Metal removal increased with sludge concentration until saturation of binding sites was reached. Optimum sludge concentration varies based on wastewater composition and treatment conditions.

2.2.6.4 Physicochemical parameters

Sewage treatment plants' pH balance is greatly influenced by microbes. When organic matter is broken down by bacteria in UASB (upflow anaerobic sludge blanket) reactors without oxygen,

biogas is produced and the pH of the effluent is lowered (Bressani-Ribeiro et al., 2018a) . Trickling filters (TFs) are a popular choice for UASB reactor post-treatment. Compared to alternative post-treatment methods, they are more affordable, have lower operating costs, and require less maintenance (Bressani-Ribeiro et al., 2018a).

Generally speaking, the pH of the wastewater from TFs is alkaline whereas the pH of the wastewater from UASB reactors is acidic (Bressani-Ribeiro et al., 2018a). The UASB reactor's effluent typically has a pH of 6.5 to 7.5, whereas the TF's effluent typically has a pH of 7.5 to 8.5 (Bressani-Ribeiro et al., 2018a). An alkaline solution, such lime, can be added to the UASB reactor to change the pH of the effluent (Bressani-Ribeiro et al., 2018a). One way to modify the pH of the TF effluent is to introduce an acidic solution, like sulfuric acid, into the reactor (Bressani-Ribeiro et al., 2018).

Pipi *et al.*, (2018) assessed heavy metals removal efficiency at two STP in Bauru, São Paulo, Brazil. The study analyzed 66 samples for seven metals and seven physicochemical parameters. Findings demonstrated effective heavy metal removal and enhanced effluent quality. High heavy metals concentrations can affect pH, COD, and dissolved oxygen in aquatic environments. pH is negatively correlated with sludge heavy metals activity, while high pH is favorable for its stability (Xiao *et al.*, 2023).

Koju *et al.*, (2022) assessed physicochemical parameters and heavy metals concentrations in industrial effluents from Kathmandu Valley, Nepal. Most parameters were within permissible limits, with heavy metals concentrations varying among industries. Significant positive connections between heavy metals and physicochemical characteristics were discovered by the investigation. The study recommends WWTP and strict environmental laws for industries.

2.3 Efficiency of heavy metal removal in the sewage treatment plant (STPs)

The effectiveness of WWTPs in eliminating heavy metal pollutants from wastewater has been the subject of numerous research. Depending on the kind of metal, the removal efficiency can differ significantly; some metals, like Cu and Cr, can be removed at rates more than 70%, while other metals, such As, Cd, and Hg, have lower removal rates (Onchoke *et al.*, 2015). A number of variables, including metal concentration, speciation, water content, temperature, solubility, SS,

and effluent makeup, affect overall removal efficiency.

Secondary treatment methods (e.g. activated sludge) can remove some heavy metals through biological and physicochemical processes, but are less effective for metals that are poorly adsorbed like B, Li, and Mo (Choubert *et al.*, 2011). Highly adsorbable metals like Fe, Al, and Pb are removed more efficiently (30-80%) than poorly adsorbable metals like Co, Ni, and Sb (<30%) (Choubert *et al.*, 2011). Overall, the literature shows metals exhibit complex behavior in WWTPs, with removal efficiency depending on multiple factors. While some metals are removed efficiently, others may solubilize or desorb during treatment resulting in negative removal efficiencies (Rashid, 2020). Edokpayi *et al.*, (2015) stated that consistent removal efficiencies for Al, Fe, and Zn were observed in the heavy metals removed from the Thohoyandou WWTPs. Azizi *et al.*, (2016) reported that WWTPs have high removal efficiencies for As, Cd, Cr, and Cu. At 8 and 40 mg/l of composite heavy metals, the outlet clearance efficiency for Cd concentration was 71.01% and 11.78%, respectively. This was found to be lower than the amounts for the other heavy metals under investigation.

Salihoglu, (2013) revealed that while no discernible removal of heavy metals was shown for As, Cd, Pb, Sb, and Sn, heavy metal removal efficiencies of 75% were attained for Tot. Cr, Tot. Fe, Al, and Cu. Study by Ali & Eren, (2019) found that the removal percentages for Ag, Sb, and As were 11%, 19.35%, and 27.87%, respectively, while the removal efficiency for Ag, Al, Fe, and Ni was 100%, 100%, 99%, and 99.5%. Feng *et al.*, (2018) investigated removal efficiencies for As, Cd, Cr, and Cu were 39.70%, 14.79%, 14.92%, 50.100%, 10.72%, 16.44%, 6.97%, and 43.93%, respectively, in a study on full-scale WWTPs. Compared to other heavy metals (Pb, Zn, Cd, Cr, As, and Hg), As, Cd, and Hg showed lower removal efficiencies, with Cu and Cr having a 70% efficiency (Onchoke *et al.*, 2015). The trace element content decreases in the following order: Zn > Mn > Ba > Ni > Cu > Pb > As > Co > Cd > Cr > Mo > B, according to the percentage of heavy metals removed from the effluent (Onchoke *et al.*, 2015). The quantities of metal influent, operating parameters, physicochemical and biological factors, the biological sludge process, dissolved organic matter, and pH all affect how well heavy metals are removed in biological WWTPs (Xiao *et al.*, 2023; Jun *et al.*, 2015).

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Description of the Study Area

Addis Ababa, the capital and largest city of Ethiopia, is an important center for the country and Africa. The city's population was estimated at 4.4 million in 2017 (Butte & Zu, 2020). The Kality Catchment is the only area in Addis Ababa with a centralized sewage treatment system. The Kality centralized sewage treatment plant was built in the 1970s and expanded in 2018 with World Bank funding. It is located in Addis Ababa's Kality neighborhood on the east side of the Tinsu Akaki Wenz river with coordinates 8°54'52"N 38°45'18"E. The plant was designed to treat 7,600 cubic meters of wastewater per day, but it runs under its designed capacity. Sewage from about 1,800 connections to the 120- kilometer pipe sewer network and from other sources is transported to the Kality centralized sewage treatment plant. The sewer system was designed for 200,000 house hold but only serves about 13,000 households. Additional sanitation relies on septic tanks and pit latrines. Sludge is disposed of via drying beds, landfills, sewer injection, and land application (Butte & Zu, 2020).

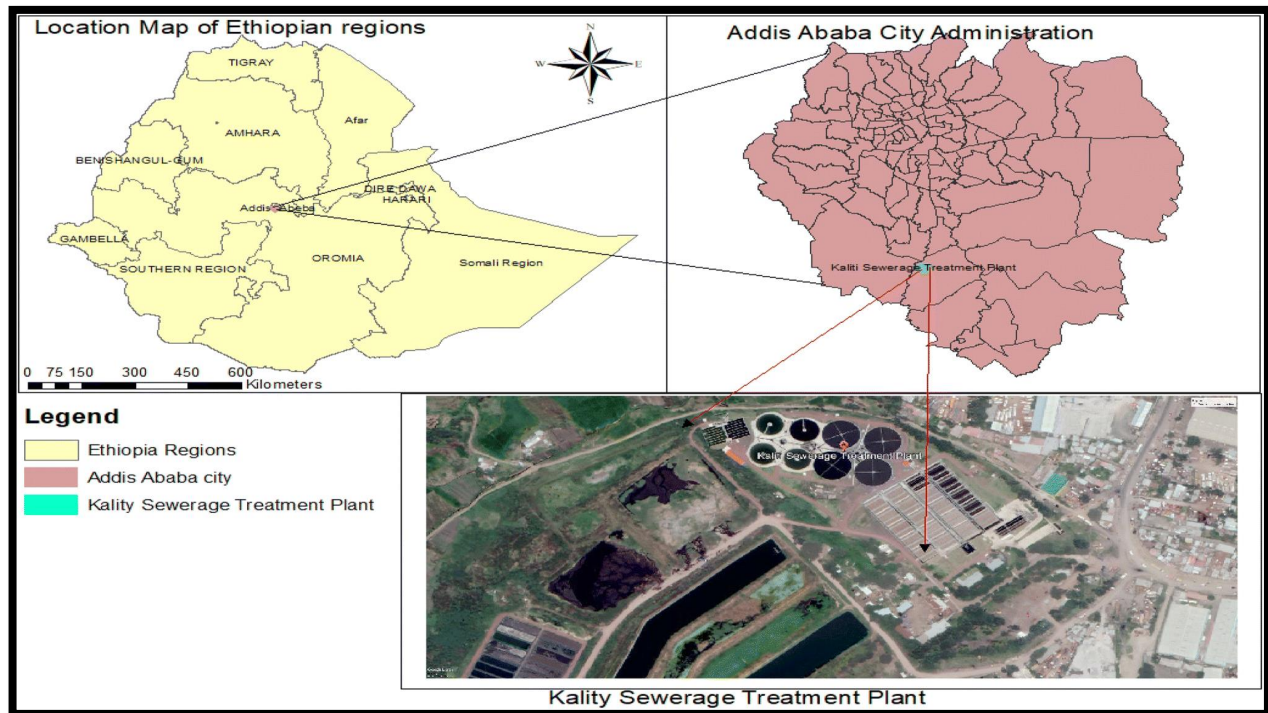


Figure 3 Kality centralized sewage treatment plant

3.2 Description of Kality centralized sewage treatment process (System)

The treatment scheme of Kality centralized sewage treatment plant consists of the preliminary treatment of sewage (screening, de-gritting, and degreasing units), the biological treatment (UASB reactors and trickling filters), and the disinfection process (chlorination, de-chlorination (Figure 4). Additionally, there is a sludge treatment line, which includes the pretreatment of latrine sludge and the dewatering of all sludge produced by sludge drying beds.

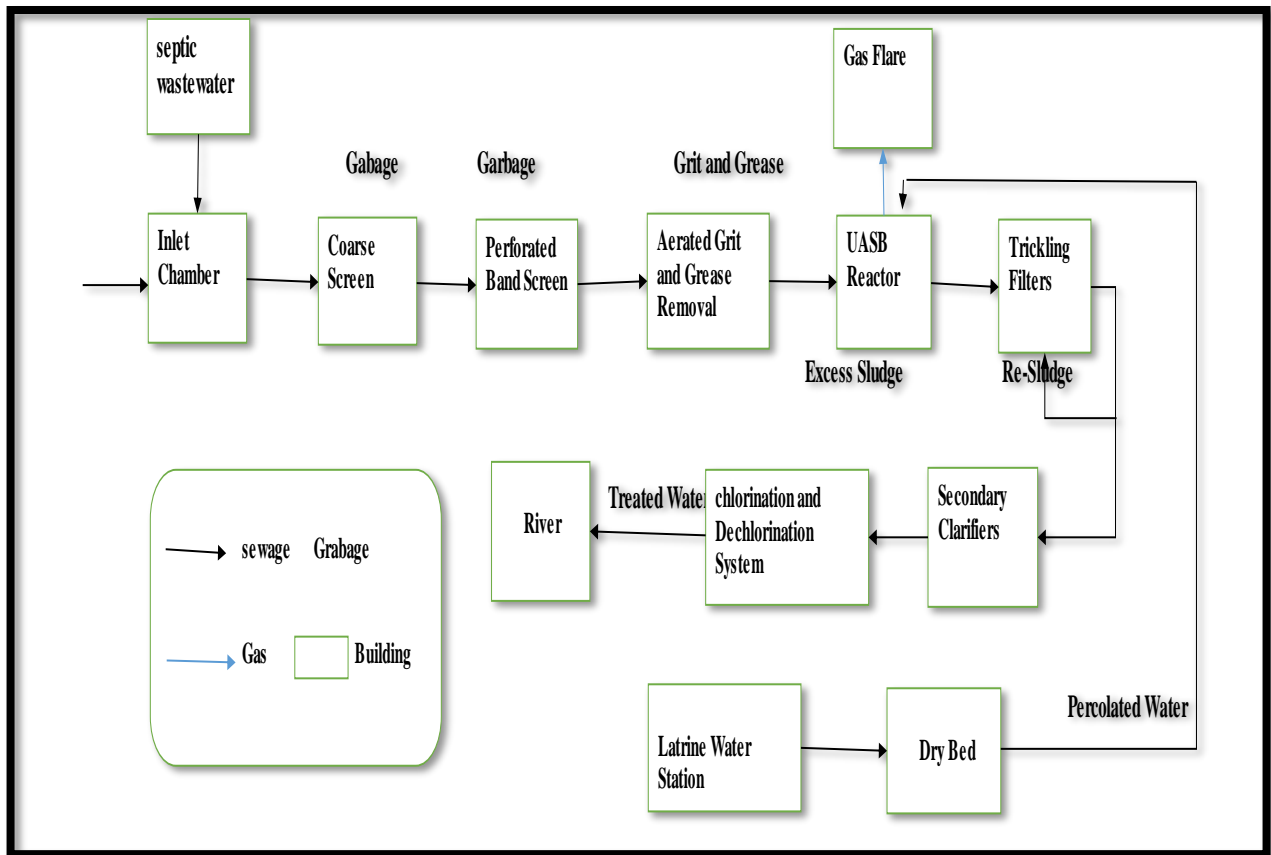


Figure 4 Kality sewage treatment plant process flow diagram

3.2.1 Preliminary Treatment system

The preliminary treatment system consists of a trash rack and coarse and fine screen. The trash rack is made of rectangular steel bars arranged in parallel with an opening of 70 mm in width. It includes screening to remove large materials like rags, cans, bottles, and wood that could clog subsequent processes (AKTOR, 2017). Coarse bar screens with 20-mm slots are installed

downstream of the septic waste receiving station. Each of the four screens has a capacity of 0.29 m³/s to handle peak flows if one screen is nonoperational. Downstream of the coarse screens are four perforated band screens with 3 mm openings in each channel, also designed for 0.29 m³/s capacity each. These fine screens provide further protection from materials disturbing downstream treatment units (AKTOR, 2017).



Figure 5 coarse and fine screen of preliminary treatment system

3.2.2 Primary treatment system

Downstream of the screening, there are two aerated grit and grease removal systems, each with a longitudinal aerated grit chamber and adjacent grease settling tank, to facilitate some BOD₅ reduction before the wastewater proceeds to the next treatment phase. The primary treatment stage helps separate suspended solids, grease, and heavy inorganic solids, reducing BOD by 15-30% (AKTOR, 2017). The tanks have dimensions of 35m length by 3.25 m in width for grit and 2.5 m for grease. Settled grit is collected by a traveling scraper bridge and pumped into a grit classifier. Pre-treated wastewater overflows via weirs to the next UASB treatment stage (AKTOR, 2017).

3.2.3 Secondary Treatment system (UASB Reactor)

The UASB treatment stage consists of 20 UASB reactor cells in four lines of five cells each (AKTOR, 2017). Each line is fed via overflows from a distribution chamber through four main

distribution channels with a width of 2.9 m each. Each UASB reactor is loaded through two feeding channels with a width of 0.7 m each, with two isolation penstocks. Each UASB reactor contains ten three-phase separators (settlers) covering the full length and width. The GRP (glass fiber reinforced plastic) settlers maintain the anaerobic sludge inside the reactor by separating the gas, liquid, and solid phases (AKTOR, 2017). The gas is removed in the gas hood, while solids settle out in the sedimentation compartments before returning to the digestion compartment. Kality centralized sewage treatment plant has a design hydraulic retention time (HRT) of 12.2 hours, volumetric hydraulic loading (VHL) of $1.97 \text{ m}^3/\text{m}^3/\text{d}$, organic loading rate (OLR) of $2.29 \text{ kg COD}/\text{m}^3.\text{d}$, and solid retention time (SRT) of 38 d. The treated effluent from the UASB reactors flows to the next treatment stage in trickling filter distribution chambers (AKTOR, 2017). The UASB reactors facilitate anaerobic digestion using settlers to retain sludge, remove gas, and settle out solids, pretreating the wastewater before it proceeds to trickle filters. The UASBr has estimated removal efficiencies for BOD₅, COD, and TSS of 55%, 55%, and 70%, respectively (AKTOR, 2017).



Figure 6 UASB reactor of Kality sewage Treatment Plant (Abewaw, 2021)

Trickling Filters with Recirculating Pumping Station

The TF stage consists of four reinforced concrete filters with UV-resistant plastic media, under drainage, and a ventilation system (AKTOR, 2017). The filters have a diameter of 40.5 m and a

4.88 m filter depth, avoiding pumping between inlet and secondary clarifiers. Influent flows by gravity to a distribution tower, evenly distributing flow to the filters. Each filter has 25,131 m³ of media and can be taken offline. A rotary distributor delivers wastewater evenly over the media surface, allowing uniform hydraulic loading over the design flow range. The filters and distributors are designed for flows above 3,500 m³/h without recirculation.



Figure 7 Trickling filter and its distribution system

3.2.4 Secondary Clarifiers with Return Sludge Pumping Station

The TF stage consists of four reinforced concrete filters with UV-resistant plastic media, drainage, and a ventilation system (AKTOR, 2017). The filters have a diameter of 40.5 m and a filter depth of 4.88 m, avoiding pumping between the inlet and secondary clarifiers. Influent flows by gravity to a distribution tower, evenly distributing flow to the filters. Each filter has 25,131 m³ of media and can be taken offline. A rotary distributor delivers wastewater evenly over the media surface, allowing uniform hydraulic loading over the design flow range. The filters and distributors are designed for flows above 3,500 m³/h without recirculation.



Figure 8 secondary clarifier, and distribution chamber

3.2.5 Tertiary Treatment system

The closed culvert that collects the effluent from the last sedimentation tanks is used to cleanse the water before it is released into the river or irrigation system (AKTOR, 2017). Penstocks allow the isolation of each chlorination tank and the bypass of disinfection. Disinfection uses sodium hypochlorite (12% active chlorine), and de-chlorination uses sodium metal-bisulfite (30–40%) (AKTOR, 2017). At the outlet, treated effluent can be directed via penstocks either to the river for discharge or to irrigation systems for reuse (AKTOR, 2017). The final stage of treatment disinfects the secondary treated effluent using chlorination and de-chlorination chemicals. Flow measurement and control valves allow for both river discharge and irrigation reuse of the treated wastewater. This final process ensures effluent meets quality standards before being released from the plant.

3.2.6 Sludge treatment system

A pumping station directs the stabilized excess sludge from UASB reactors toward the gravity beds. The daily sludge volume from the UASB reactors is calculated to be 360 m³/d at 5%. Depending on the initial concentration and the meteorological circumstances, the predicted drying period is one to two weeks. Sludge can be removed at a lower solid concentration of 18–20%, while the predicted maximum dried concentration can be as high as 35%. The treatment plant had 12,000 m² with 26 beds for the UASB sludge. In the Kality plant, the sludge drying beds have been designed based on a sludge layer of 30cm for UASB sludge and 40cm for latrine sludge.

3.3 Methodology for wastewater and sludge sample collection

3.3.1 Types of sample collected and their sampling location

The Standard Procedures for the Examination of Water and Wastewater were followed in the study's collection of samples of raw sewage, processed effluents, and sludge from the various wastewater system units (APHA, 2017). The wet season (June) and the dry season (April and May) were when the samples were gathered. Two days in a row were used to gather the samples. Furthermore, throughout the course of the 24-hour period, composite samples of the influent (raw wastewater) and final effluent were regularly taken. The treatment system's effluent and sludge

(0.2 m height) from the UASBr, effluent from the trickling filter, returned activated sludge from the secondary clarifier, and dried sludge from the drying bed were the units from which grab samples were taken Table 2. Flow-proportional composite sampling collects small volumes during high flows, preventing biased over- and under-sampling and ensuring accurate composites across all flow conditions.

Table 2 Description of Sampling Points of Sewage Treatment Plant

No	Collected samples	Co-ordinates	Description
1	Influent	38° 45' 26.2973" E 8° 55' 8.5046" S	Composite samples were taken immediately after the screening
2	UASB Effluent	38° 45' 25.3766" E 8° 55' 8.7031" S	Grab effluent samples were collected in the effluent of UASBr.
3	UASB Sludge	38° 45' 22.1732" E 8° 55' 10.8706" S	Each UASBr has five sludge sample ports that measure 2.7, 2.1, 1.4, 0.85, and 0.2 meters in length. However, in this study grab samples were collected at 0.2 meters, with the sample being continuously mixed to obtain an average.
4	Trickling Filter effluent	38° 45' 20.1074" E 8° 55' 11.52936" S	Before the wastewater entered the secondary clarifier, samples were taken from the trickling filter's outflow.
5	Returned activated Sludge samples	38° 45' 17.9017" E 8° 55' 12.74933" S	Samples of grab sludge were taken from the secondary clarifier and then put back into the UASB reactor.
6	Final effluent samples	38° 45' 15.9665" E 8° 55' 12.19728" S	Composite samples from the final effluents were collected before entering to disinfection chamber.
7	Dry sludge samples	38° 45' 10.0924" E 8° 55' 1.194168" S	Grab sludge samples were taken from several sludge drying beds and combined to create a representative sample.



Figure 9 pH and conductivity measuring device

3.3.4 Sample Handling

Two distinct polyethylene bottles that had previously been acid-washed with analytical-grade nitric acid for physicochemical and heavy metals analysis were used to collect samples in order to prevent contamination. Samples for physicochemical characteristics were taken in the Kality centralized sewage treatment plant's CGGC laboratory on the same day of sampling. As for samples of heavy metals, samples were brought to the lab the same day and kept chilled at 4°C until analysis. Before lab analysis, clean sample bottles and use rapid refrigeration to retain the chemical speciation and prevent losses or contamination.

3.4 Instruments, Apparatus, and chemical reagents

multi-probe and temperature measuring device (Hana), Polyethylene bottles, buffer solutions, Ice-box, Conductivity meter model (DDS-11A), spectrophotometer (DR 5000), filter paper (45µm), test tube, ICP-OES (5000X), microwave digester (MARS6240/50), Analytical balance, High-grade AAS 250-ml standard solution of Al, Zn, Cr, Fe, Cu, Mn, Pb, Ba, and Cd, Analytical grade 65% Nitric Acid, Reagent grade hydrogen peroxide, 37% HCl, Phosphate (PhosVer®), Powder Pillow (Nitriver®, Reagent Powder Pillow Sulfa ver® 4), Potassium hydroxide pellet, Desiccator, Oven, Mineral Stabilizer, Polyvinyl Alcohol, and Nessier reagent.

3.5, Analyzing for physicochemical parameters and heavy metals in the sewage treatment plant

The collected wastewater samples from influent, UASBr effluent, TF effluent, final UASBr effluent and sludge, and secondary clarifier underwent analytical tests for a variety of parameters using standard techniques for water and wastewater analysis (APHA,2017). The measurement of physicochemical parameters such as pH and electrical conductivity was carried out at the site since these values might change when transported to the laboratory. They were measured on-site using Hana portable PH and conductivity meters (Figure 9), providing actual conditions and context for understanding sample properties and matrix effects. Chemical Oxygen Demand (COD) (chromium-sulphoric acid oxidation Hach Lange), Biological Oxygen Demand (BOD) (Manometric BOD₅ Measurement Hach Method), Electrical Conductivity (EC) (Method APHA 2510 B), Total Suspended Solids (TSS) (APHA 2540 D), Ammonium-Nitrogen (NH₄-N) (Indo-phenol blue Hach Lange), and Sulfate (SO₄²⁻) (Barium Sulfate Hach Lange), Total Nitrogen (TN) (Digestion with Peroxo-di-sulfate Hach Lange), and Total Phosphate (TP) (Phosphor Molybdenum Blue Hach Lange). All the physicochemical parameter tests were conducted at the Kality centralized STP CGGC laboratories.

All sludge and sewage samples were gathered in accordance with the accepted practices for water and wastewater analysis (APHA 2017). The total heavy metal content of the well mix of the filtered samples was directly examined in the Addis Abeba University core water laboratory of the ACEWM. Preserved samples of sewage (influent, UASBr effluent, trickling filter effluent, returned activated sludge from secondary clarifier, and final effluent) were filtered through 0.45 µm nitrate-cellulose filters (Schleicher &Schuell). Filtration is needed in relation to heavy metals in ICP-OES to remove any particulate matter that may interfere with the analysis. Particulate matter can cause blockages in the nebulizer and spray chamber, leading to reduced sensitivity and accuracy of the analysis. Samples of sludge from the UASBr were digested by EPA Method 3051A (Microwave Digestion with HNO₃) (Nham & Monitoring, 2006). The target heavy metals were Al, Ba, Cd, Pb, Mn, Cu, Zn, Cr, Fe, and Ni based on toxicity, availability and recoverable potential.

3.6 Quality Control for Heavy metals and Physicochemical parameters

All tests were carried out in standardized, calibrated, and triplicate to ensure consistent procedures

across experiments, accurate measurements, and precision and reproducibility, respectively, for both physicochemical and heavy metals analyses. All of the test tubes were rinsed with 10% HNO₃ (v/v) followed by deionized water before being used in the experiments. To guarantee accurate identification, each sample bottle was meticulously labeled with a unique sample number, creating a record of every sample that was taken. Every grab sample was taken below the sewage flow's surface and well mixed.

Analytical-grade HNO₃ and hydrogen peroxide for microwave digestion were used in this study to achieve the compatibility of the isolation of metals in the sample. By using microwave digestion with HNO₃ and H₂O₂, metals can be isolated from the sample matrix more efficiently and directly, allowing for more accurate and precise determination of metal concentrations. In order to verify the sensitivity status of the ICP-OES, an instrument calibration was carried out utilizing all of the samples and the chosen heavy metals (each requiring five points of calibration). To ensure accurate results, detect contamination, and quantify random errors, quality assurance measures included the use of duplicate samples, reagent blanks, and matrix-matched calibration curves.

3.7 Data conversion and analysis

Removal efficiency among the heavy metals were calculated by using the equation:

$$RE \% = \frac{C_{in} - C_{out}}{C_{in}} * 100\% \quad \text{Equation 1}$$

Where C_{in} and C_{out} are the levels of heavy metals determined in the inlet and outlet wastewater, respectively.

The heavy metals analysis from dried sludge was determined by the following: -

$$\text{Metal (mg/kg)} = [\text{conc of metals (mg/L)} \times \text{volume of sample (mL)}] / [\text{sample weight (kg)} \times 1000]$$

Equation 2

The experimental output from the research was analyzed using the statistical software program IBM SPSS Statistics 23, and Excel was used for data visualization and manipulation. The study employed IBM SPSS to examine the spatiotemporal variation and connection between heavy metals and physicochemical parameters over a two-day period and along the treatment unit. A one-way analysis of variance (ANOVA) was performed to compare the physicochemical characteristics and heavy metal levels in the various treatment units. This statistical test is employed to examine how the mean concentrations of the groups differ from one another. In the

event that notable differences were noticed in the datasets, a Tukey's post hoc analysis was carried out for multiple comparisons. When evaluating the results, a significance level of 0.05 or below was deemed to be statistically significant. Tables and graphs that gave an overview of the data were used to present the study's descriptive results. Furthermore, the association between the concentration of heavy metals and physicochemical characteristics was evaluated using the Pearson correlation test.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Physicochemical characteristics of sewage

The physical and chemical properties of wastewater samples from raw wastewater (influent), effluent from (UASB and trickling filter), sludge's from (UASB and secondary clarifier) and final effluent are displayed in Table 3

4.1.1 Inflow Characteristics

Figure 10 below shows the characteristics of the inflow into the research area during the study period. Over the course of two consecutive sampling days in April, the treatment plant's flow characteristics show an increasing tendency that continues gradually until the first sample days of June. This pattern could be attributed to the unseasonal distribution of rainfall during April and May, as these months are typically considered dry. Overall, the flow distribution throughout the study period displays a left-skewed (-0.465) and platykurtic nature, indicating a lower occurrence of extreme outliers compared to a normal distribution (-1.589). The distribution shows a flatter peak and thinner tails than a normal distribution.

The sanitary sewer system may see an increase in sewage flow rates as a result of connections from residential, commercial, and industrial areas causing inflows and infiltration. Storm water inflows happen when it gets into sewers through unfit connections, like sump pumps, downspouts, roof drains, or storm drains. Significant amounts of precipitation-related runoff can enter the sewer system during storms and other periods of precipitation. Heavy metals and other physicochemical factors, which are influenced by treatment flow, can have an impact on the effectiveness of sewage treatment. It is noteworthy that a major determinant of treatment efficiency is the flow rate. Flow characteristics, including temperature, pH, electrical conductivity (EC), sulfate (SO_4^{2-}), chemical oxygen demand (COD), biological oxygen demand (BOD_5), and phosphate (PO_4^{3-}), are particularly susceptible to the effects of treatment flow, as per (Somerset, 2020).

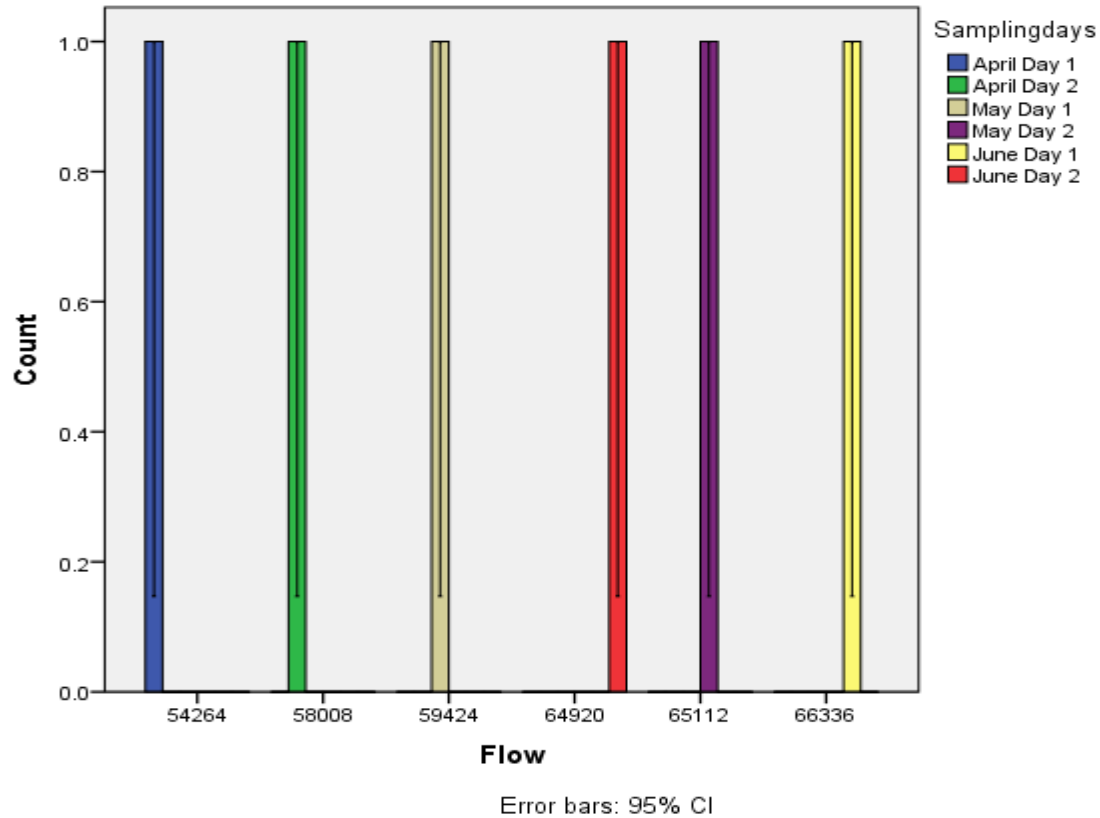


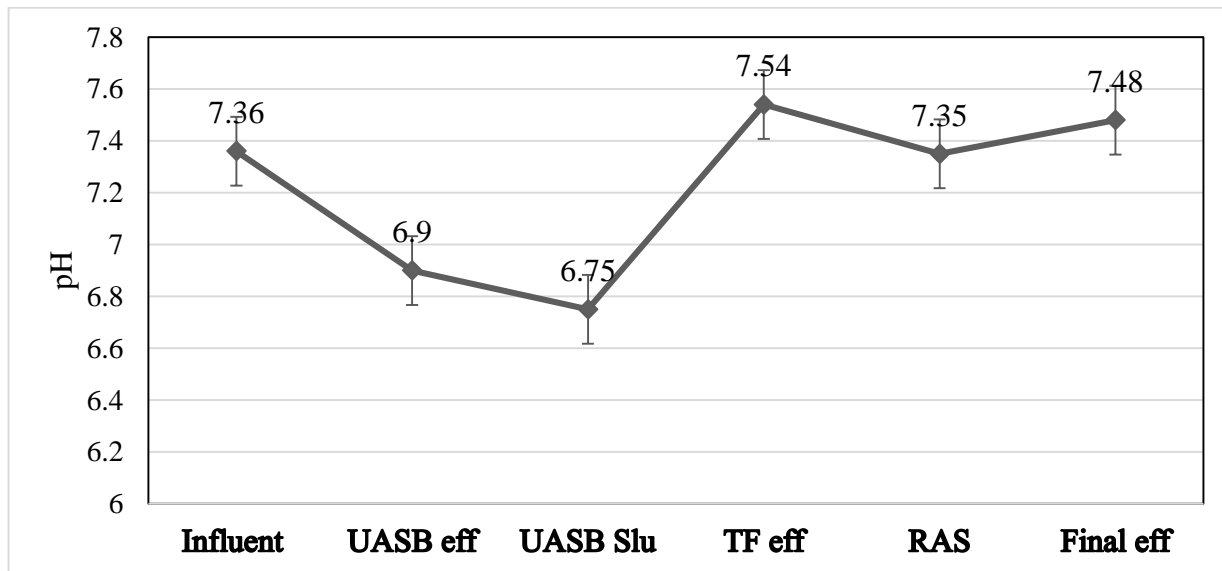
Figure 10 Daily variation of inflow during study period in kality centralized sewage treatment plant

4.1.1 pH profile in the treatment systems

The range of pH values found in sewage samples taken from various treatment units was 6.75 ± 0.04 (UASBr sludge) to 7.54 ± 0.13 (TF effluent). The sewage treatment plant's UASB sludge had the lowest mean pH (6.75), whereas trickling filter effluent had the highest mean pH (7.54). The sewage treatment plant's UASB sludge was found to have a pH of 6.75, which is mildly acidic. This can result from the anaerobic digestion process' generation of organic acids (Chernicharo et al., 2015). However, the trickling filter effluent's pH was found to be 7.54, which is somewhat alkaline. Bicarbonates produced during aerobic digestion may be the cause of this (Chernicharo et al., 2015). This was in agreement with the pH value (5.85–7.55) observed in WWTPs in Cape Town, South Africa (Somerset, 2020). The pH value varies from 6 to 9 in the final treated effluent while the mean pH was below the discharge limit of EEPA (2003), (Table 3).

The pattern of domestic influent discharge that the value of pH was significantly differs across sewage treatment units ($P < 0.05$). All daily and monthly results of the samples gathered from final effluents were within the discharged limits of effluents to water bodies (EPA, (2003) as shown in Table 3. It is crucial to maintain the pH of the effluent within the ideal range, which can be achieved by adding chemicals like sulfuric acid or lime (Chernicharo et al., 2015). The pH of the effluent is important because it affects the quality of the treated water. If the pH is too low or too high, it can cause problems like scaling, corrosion of pipes, and damage to aquatic life (Chernicharo et al., 2015).

A study carried out by Velusamy and Kannan, (2016) supports the investigation of seasonal variation in the physicochemical and microbiological characteristics of STP by analyzing the variation of pH across different sampling points and months. However, based on the variation of pH in the sample collected in two consecutive days and months (April, May, and June) was not significantly different ($p = 0.783$). The observed results in STP contradict the results obtained by Somerset (2020), with most of the pH values recorded within the sampling period in WWTP being around neutral ($pH = 7$), but they are significantly different from one another.



* UASB eff = UASB Effluent; *UASB slu = UASB Sludge; *TF eff=Trickling filter effluent; *RAS= Returned Activated Sludge, Final eff = Final treated effluent

Figure 11 The mean pH values along sewage treatment units

Table 3 physicochemical characteristics sewage in Kality centralized STP (Concentrations are in mg/l except for pH, and conductivity ($\mu\text{s}/\text{cm}$) mean value \pm standard error (M \pm S.E)

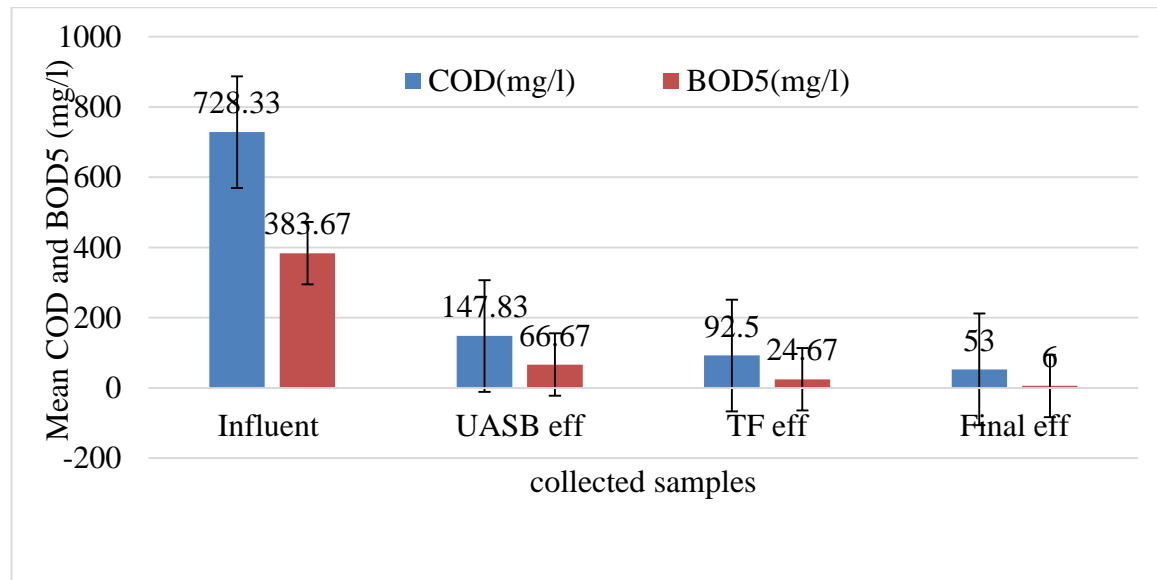
parameters	Influent	UASB eff	UASB slud	TF eff	RAS	Final eff	(EPA, 2003)
pH	7.34 \pm 0.1	6.9 \pm 0.1	6.75 \pm 0.04	7.54 \pm 0.13	7.35 \pm 0.07	7.48 \pm 0.08	6-9
BOD ₅	383.7 \pm 7 4.58	66.67 \pm 10. 67		24.67 \pm 4.8		6 \pm 0.73	80
COD	728.33 \pm 121.03	147.83 \pm 7. 9		92.5 \pm 12.3 6		53 \pm 2.21	250
TSS	345.33 \pm 61.9	45 \pm 3.3	43.74 \pm .49	57.83 \pm 9.8 1	1.33 \pm 0.1 9	11.5 \pm 1.1	100
SO ₄ ²⁻	17.98 \pm 2. 54	17.9 \pm 1.61				48.4 \pm 2.65	250
NH ₄ -N	38.12 \pm 5. 89	45.4 \pm 4.14				20.9 \pm 2.56	30
EC	748.33 \pm 43.53	855.33 \pm 43 .7				591.83 \pm 31 .21	1000
TN	58.2 \pm 3.7 9					52.17 \pm 4.2 4	80
TP	26.35 \pm 1. 77					27.7 \pm 2.31	10

* UASB eff = UASB Effluent; *UASB slud = UASB Sludge; *TF eff=Trickling filter effluent; *RAS= Returned Activated Sludge, Final eff = Final treated effluent

A similar study conducted by Maurya and Srivastava (2019) to assess seasonal variation physicochemical characteristics in the Jaganpur STP in India in summer (mid-March to mid-July) found that the pH of effluent samples varied significantly along different sampling sites and ranged from 8.5 to 9, which is alkaline in nature. The pH of the treated final effluent water varies from 7.45 to 8.33 from a STP in Bhopal (India) (Kushwah *et al.*, 2011). Hammoudani *et al.*, (2021) reported that inlet (raw wastewater) pH ranges from 7.89 ± 0.078 while effluent ranges from 7.35 ± 0.05 . The overall mean distribution of pH along the sewage treatment unit follows the following trend: The effluent from trickling filter (7.54 ± 0.13) was greater than the final effluent (7.48 ± 0.08), returned activated sludge (7.35 ± 0.07), influent (7.34 ± 0.1), UASB effluent (6.9 ± 0.1) and UASB sludge (6.75 ± 0.04) Figure 11.

4.1.2 Biochemical Oxygen Demand (BOD₅) profile in treatment systems

The mean concentration of BOD₅ in the influent was 383.7 ± 74.58 mg/l, and it ranged from 210 to 740 mg/l. In the meantime, BOD₅ in the final effluent had a mean concentration of 6 ± 0.73 mg/l and was in the range of 4 to 8 mg/l, which is consistent with the values from the literature shown in Table 4.



* UASB eff = UASB Effluent; *TF eff=Trickling filter effluent, Final eff = Final treated effluent

Figure 12 Mean values of BOD₅ and COD (mg/l) along sewage treatment unit

The highest BOD₅ concentration (383.7 ± 74.58 mg/l) was recorded at the influent, while the lowest concentration (6 ± 0.73 mg/l) was noted in the final effluent. It indicates that following the treatment

procedure, the amount of organic pollutants was much reduced. This shows that the wastewater treatment plant was successful in eliminating organic debris that decomposes bio-degradably and enhancing the water quality.

Table 4 : Features of sewage in many cities across the world.

Parameters	Pakistan(Rizvi, 2010)		Palestine Al Bireh (Mahmoud, 2002)	Brazil Pedrega (van Haandel & Lettinga, 1995)	Colombia Cali(van Haandel & Lettinga, 1995)	Netherland Bennekom (van Haandel & Lettinga, 1995)
	Karachi	Lahore				
BOD	220–475	200–215		368	95	231
COD	200–1400	580–803	1586	727	267	520
Sulfate	50–200	-	-	18	-	15
NH ₄ +-N	-	-	80	34	17	-
TN	-	-	104	44	24	-
TP	-	-	13	11	13	18
TSS	250–900	106–176	736	492	215	-

The high BOD₅ level at the influent might be due to the high organic matter content in raw sewage that flows into the treatment plant or heavy discharge of industrial effluents and domestic sewage, which requires high levels of oxygen for decomposition. There was a significant difference in the BOD₅ levels was significantly varied in the samples collected from different unit ($p < 0.05$) while it was not significant in the samples collected on two consecutive days from the same treatment unit ($p = 0.922$). The temporal variation of BOD₅ concentration in different study periods did not show statistical significance this might be due to a similar pattern of rainfall distribution throughout the study period.

The BOD₅ level in the final effluent was within the EEPA recommended effluent discharge Limit into the surface water body (80 mg/L), (EEPA, 2003). Metcalf and Eddy (2003) classified wastewater into weak (110 mg/l), medium (220 mg/l), and strong (400 mg/l) categories based on its BOD₅. Based on this classification, the wastewater treated in Kality centralized sewage treatment plant is characterized as strong wastewater, which indicates high organic matter content

in the raw sewage that flows to the treatment plant, requiring high levels of oxygen to be decomposed. The sewage treatment plant's results aligned with Bhave's (2020) research on the fluctuations in BOD₅ during the sampling period in domestic sewage treatment in India. The mean overall spatiotemporal distribution of BOD₅ in the STP follows the trend influent (383.7 ± 74.58 mg/l) > UASB effluent (66.67 ± 10.67 mg/l) > effluent from TF (24.67 ± 4.8 mg/l) > final treated effluent (6 ± 0.73 mg/l), as displayed in Figure 12.

4.1.3 Chemical oxygen Demand (COD) profile in treatment systems

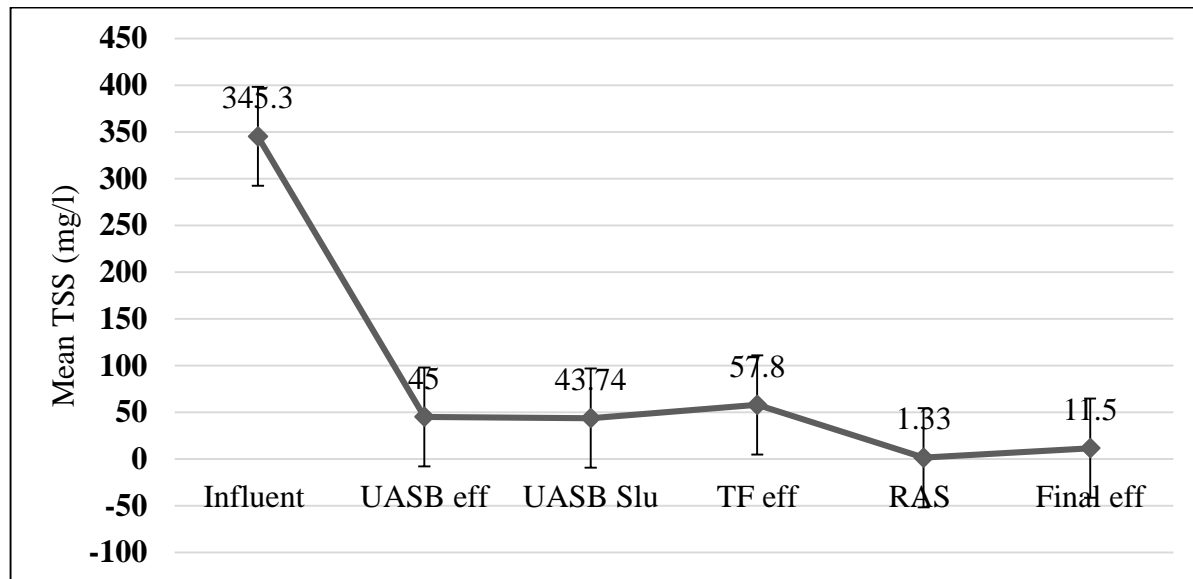
The COD concentrations in the sewage received by the sewage treatment plant range from on a daily basis to a mean of 728.3 ± 121.03 mg/L, which is in line with the value found in Table 4 of the literature. The highest COD concentration was recorded at the influent (L), and the lowest value was recorded at the final treated effluent (53 ± 2.21 mg/L). The final treated effluent's COD content ranged from 45 mg/L to 59 mg/L, whereas the influent's COD concentration was adjusted between 362 mg/L and 1145 mg/L.

The influent had the largest variance in COD concentration (728.3 ± 121.03 mg/L), while the final effluent had a mean value of 53 ± 2.21 mg/L. Bhave (2020) found that untreated wastewater had COD levels between 188 and 684.6 mg/L, while treated wastewater had COD of 15 to 112.8 mg/L. The influent wastewater's COD concentration can range from 200 to 500 mg/L, while the effluent wastewater's concentration can be as low as 20 to 30 mg/L (Phanwilai et al., 2020). There was a significant variation in COD concentration among the different treatment units ($P = 0.000$), whereas the variation was not significant between samples collected on two consecutive days ($p = 0.937$).

The treated sewage effluent's COD content was less than the 250 mg/L EEPA (2003) limit for water body discharge Table 3. According to Hammoudani *et al.*, (2021), the input and output of COD range from 844.28 ± 69.66 and 36.92 ± 5.36 , respectively. The overall mean distribution of COD along the sewage treatment units follows the trend: Influent (728.33 ± 121.03 mg/L) > UASB effluent (147.83 ± 7.9 mg/L) > Effluent from trickling filter (92.5 ± 12.36 mg/L) > final treated effluent (53 ± 2.21 mg/L).

4.1.4 Total suspended solids (TSS) profile in the treatment system

The TSS concentrations was in the range from 135 to 547 mg/l with a mean of 345.3 ± 61.9 mg/l in the influent whereas it was varied in the range from, 8.0 to 16.0 mg/l in the final treated effluent with a mean concentration of 11.5 ± 1.1 mg/l. This results are consistent with that of Bhave (2020), who discovered that TSS concentrations in treated wastewater vary from 10 to 48 mg/l across different test sites, while untreated wastewater can have concentrations ranging from 38 to 500 mg/l.



UASB eff = Effluent treated with UASBR; UASB slu = Sludge from UASBR; TF eff = Effluent treated with Trickling filter; RAS= returned activated sludge from secondary clarifier

Figure 13 The mean values of TSS in sewage treatment plant across the treatment unit

The maximum TSS concentration in the Kality centralized sewage treatment plant was recorded in the influent (345.33 ± 61.9 mg/l), whereas the minimum was recorded at returned activated sludge (1.33 ± 0.19 mg/l). The minimum concentration in returned activated sludge might be due to the sampling type and the daily rainfall effect. Table 3 shows that the amount of TSS significantly varied across the treatment units ($P = 0.000$). However, the TSS in the samples collected on two consecutive days was not significantly varied ($p = 0.955$). This might be due to extended, similar rainfall conditions that have a significant effect on TSS concentration in STP. The effluent of the sewage treatment plant had a mean TSS concentration of 11.5 ± 1.1 mg/l, which is below the provisional EEPA (2003) discharge limits into water bodies

The overall mean distribution of TSS in the sewage treatment plant follows the trend: influent (345.33 ± 61.9 mg/l) > effluent from trickling filter (57.83 ± 9.81 mg/l) > UASB effluent (45 ± 3.3 mg/l) > UASB sludge (43.74 ± 4.9) > Treated final effluent (11.5 ± 1.1 mg/l) > returned activated sludge from secondary clarifiers (1.33 ± 0.19 mg/l), as shown in Table 3.

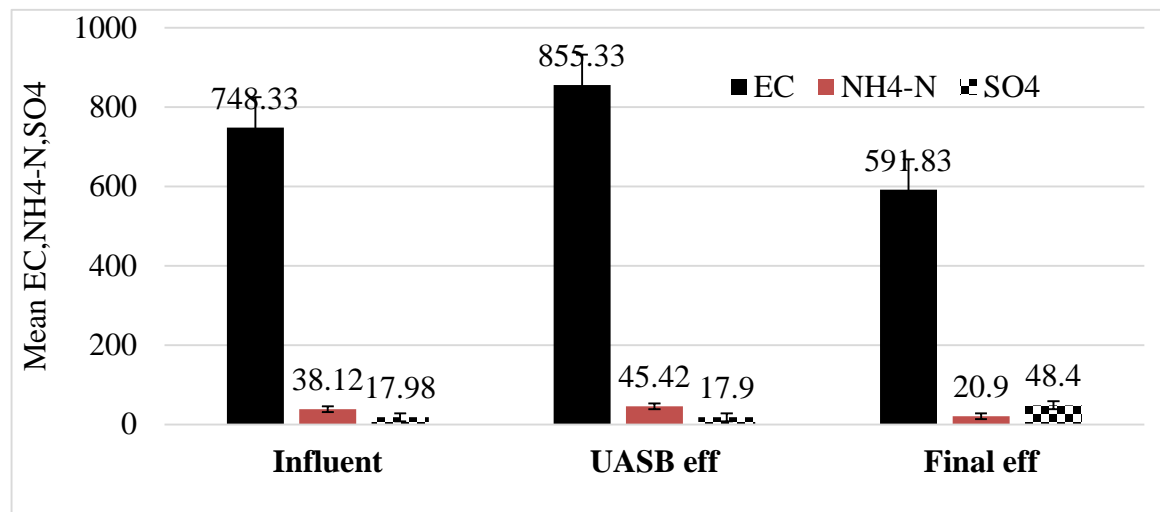
4.1.5 Electrical Conductivity (EC) profile in the treatment system

The EC value in the treatment system is displayed in Table 3. The EC value in the treated effluent and UASB effluent was between 591.8 ± 31.21 and 855.3 ± 43.7 $\mu\text{S}/\text{cm}$, respectively, and this value is consistent with the literature value in Table 4. The reason for the lower EC value in the treated effluent compared to the UASB effluent is that the trickling filter reduces the dissolved salts and minerals by biological oxidation and nitrification. The implication of this is that the treated effluent has a better water quality and can be reused for irrigation or other purposes. However, the lower EC value also means that the treated effluent has a lower buffering capacity and may be more susceptible to pH changes.

The mean concentration of EC varied significantly between treatment units ($p < 0.005$), but there was no significant difference between samples taken on two different days ($p > 0.005$). It could be caused by variations in the kind and amount of inorganic materials, such as sulfides, carbonate compounds, and chlorides, and dissolved solids, during various stages of the treatment unit (Bressani-Ribeiro et al., 2018). The consistent operation of the treatment plant and stable effluent quality over time, despite significant variation between samples collected in two consecutive days, is crucial for regulatory compliance, environmental protection, and public health, requiring regular monitoring. Depending on the kind of wastewater being processed, the treatment technique used, and the efficiency of the plant, the EC concentration in sewage treatment plants might change. It is noteworthy, therefore, that the average sewage treatment effluent concentration (591.83 ± 31.21 mg/l) was below the admissible range for the EEPA, 2003-established preliminary discharge limits into aquatic bodies (Table 3).

In a similar study conducted by Maurya and Srivastava (2019) to evaluate the seasonal variation physicochemical characteristics in the Jaganpur sewage treatment plant in India, the EC of effluent samples fluctuated from 200 to 250 $\mu\text{S}/\text{cm}$ across different sampling sites during the summer (mid-March to mid-July), ranging, with the lowest levels recorded in the winter (mid-November

to mid-March). During rainy periods, higher EC levels are likely caused by increased water consumption leading to higher domestic wastewater discharge, higher flow rates from water bodies and lower flow rates of STP effluent. Conversely, reduced EC concentrations in the winter are due to low overflow runoff from sewage treatment plant and improved treatment of ions. High EC values indicate that the water has a high mineral content, ion exchange, and solubilization.



* UASB eff = UASB Effluent, Final eff = Final treated effluent

Figure 14 The average values of EC, NH₄⁺-N and SO₄²⁻ across in sewage treatment units

A study carried out in the Delhi region reported an average EC concentration of 2,169 μS/cm at the inlet sampling site, while the mean concentration after treatment was 2,161.43 μS/cm (Gautam *et al.*, 2013). Hammoudani *et al.*, (2021) reported an average concentration of 2,729.04 ± 252.36 mg/l at the inlet and 2,240 ± 187.71 mg/l in the effluent. In general, the mean distribution of EC in sewage treatment plants followed the trend of influent (748.33±43.53 μS/cm) > UASB effluent (855.33±43.7 μS/cm) > treated effluent (591.83±31.21 μS/cm).

4.1.6 Concentration and profile of Sulfate (SO₄²⁻) in treatment system

The treatment plant receives waste with a sulfate concentration ranging from 11.3 to 26.1 mg/l on a daily basis, with a mean concentration of 17.98 ± 2.54 mg/l, which is consistent with literature values Table 4. The concentration of sulfate in the final treated effluent of the sewage treatment plant was 48.4 ± 2.65 mg/l, and this directly discharges into the small Akaki River. The minimum and maximum sulfate concentrations in the sewage treatment plant were 17.9 ± 1.61 mg/l, which

was recorded in UASB effluent, and 48.4 ± 2.65 mg/l in the final effluent. The reason for the increase of sulfate concentration in UASB and trickling filter based sewage treatment plant is mainly due to the oxidation of sulfide produced by anaerobic degradation of organic matter in the UASB reactor. The sulfide is stripped from the UASB effluent and reacts with oxygen in the air or in the trickling filter, forming sulfate. The implication of this phenomenon is that it can cause odour problems, corrosion of pipes and equipment, and toxicity to aquatic life in the final effluent.

The concentration of sulfate increases across the treatment unit, which contributes to a significant variation in concentration among treatment units ($P = 0.000$). The concentration of sulfate found in the effluent can increase due to several reasons, such as the use of sulfate-containing chemicals in industrial processes or the presence of sulfate found in the environment (Xia *et al.*, 2020). There was no significant variation in concentration among the samples collected over two consecutive days ($P = 0.972$). The mean sulfate concentration in the outlet (48.4 ± 2.65 mg/l) was below the EEPA provisional discharge limit in water bodies (EEPA, 2003). The overall mean variation of sulfate in sewage treatment plants follows the trend of final treated effluent (48.4 ± 2.65 mg/l) > influent (17.98 ± 2.54 mg/l) > UASB effluent (17.9 ± 1.61 mg/l) Figure 14.

4.1.7 Concentration and profile of Ammonium-Nitrogen (NH₄-N) in the treatment systems

Table 3 shows that the final treated effluent and UASB effluent at the sewage treatment plant had average daily concentrations of NH₄⁺-N ranging from 20.9 ± 2.56 mg/l to 45.42 ± 4.14 mg/l, respectively. These values are consistent with the literature value shown in Table 4. The finding also aligns with Nelson *et al.*, (2005) finding that the ammonium nitrogen concentration (NH₄-N) in sewage water ranges from 20 to 40 mg/l which indicates a greater fecal matter content, which is produced through metabolic processes in plants, animals, and humans. Saha *et al.*, (1970) conducted a similar study and found that ammoniacal nitrogen ranged from 5.24 to 61.94 mg/l, with significant ($p < 0.05$) variations among different treatment units.

The average amount of NH₄⁺-N in the treatment plant varied significantly ($P = 0.000$) across treatment units but not over two consecutive days during the sampling campaign ($P = 0.771$). The UASB effluent recorded the highest mean concentration of ammonium nitrogen (45.4 ± 4.14 mg/l), while the final treated effluent recorded the lowest. The mean concentration of NH₄⁺-N in UASB effluent exceeded that of the influent (38.12 ± 5.89 mg/l) and final treated effluent (20.9 ± 2.56

mg/l), which might be due to the lysis and death of microbial cells in the UASB reactor. The main reason for the high concentration of $\text{NH}_4\text{-N}$ in UASB effluent is the conversion of organic nitrogen to ammonia during the anaerobic digestion process. This means that the UASB reactor does not remove nitrogen from the wastewater, but rather transforms it into a more soluble and mobile form. a post-treatment step is needed to reduce the $\text{NH}_4\text{-N}$ concentration and prevent eutrophication and toxicity problems in the receiving water bodies. One possible post-treatment option is the trickling filter, which is a type of aerobic biological filter that can oxidize ammonia to nitrate and nitrite, and possibly achieve partial denitrification. That is why it is lower in final treated effluent of the sewage treatment plant.

The overall mean concentration of ammonium nitrogen in the sewage treatment plant followed the trend; UASB effluent (45.4 ± 4.14 mg/l) > influent (38.12 ± 5.89 mg/l) > final treated effluent (20.9 ± 2.56 mg/l), as indicated in Figure 14. However, the mean treated effluent concentration of ammonium nitrogen (20.9 ± 2.56 mg/l) was below the acceptable discharge limit into water bodies (EEPA, 2003). The conversion of ammonia to nitrate in the nitrification process is reduces ammonia nitrogen levels, and microbes present in the treatment processes will assimilate ammonia nitrogen and incorporate it into cell mass. UASB operate under anaerobic conditions, which means they lack oxygen for nitrification. As a result, the ammonia concentration in UASB effluent is typically high and dependent on multiple factors such as influent ammonia concentration, hydraulic retention time, temperature, and reactor pH.

4.1.8 Concentration profile of Total Nitrogen (TN) and Phosphorus (TP) in the treatment system

Considering the information provided in Table 3 it was found that the average concentration of TN in a sewage treatment plant varied from 58.17 ± 3.79 mg/L at the influent to 52.17 ± 4.24 mg/L at the treated final effluent, which is lower than the literature (104 mg/l) value in Palestine Al Bireh (Mahmoud, 2002) whereas greater than the literature value in Brazil and Colombia Table 4. A sewage treatment plant's influent to effluent TN concentration decreases because some of the nitrogen is eliminated by biological processes like nitrification and denitrification. The TP value of sewage treatment plant ranges from 26.35 ± 1.77 mg/L at the influent to 27.7 ± 2.31 mg/L at the treated effluent, respectively, which was lower than the literature value in Palestine, Brazil, and Colombia Table 4. This indicates that the wastewater does not undergo significant phosphorus removal throughout the biological treatment process, and the effluent still surpasses the limit of

less than 1 mg/L for TP value (Sekandari, 2019). This indicates that the wastewater still surpasses the limit of less than 1 mg/L for TP value and that the biological treatment procedure does not significantly remove phosphorus from the wastewater. This suggests that in order to lower the phosphorus level, the sewage treatment plant should implement other techniques such as membrane filtering, chemical precipitation, or biological phosphorus removal. If not, the receiving water bodies may be at risk of eutrophication and deterioration of water quality due to the high TP value of the effluent. There was no discernible difference between the treatment units, according to the statistical analysis (ANOVA) of the mean concentrations of TN and TP in the sewage treatment plant ($P > 0.05$, respectively). However, TN showed significant variation ($P = 0.028$) among two consecutive days of sampling, whereas TP showed no significant variation ($P = 0.172$). TUKY-HSD tests revealed that whereas TN varied significantly over the two subsequent days, there were no statistically significant variations in TP or TN between treatment units or between days. The small number of sample units used for analysis may be the cause of the insignificant fluctuation of TN and TP.

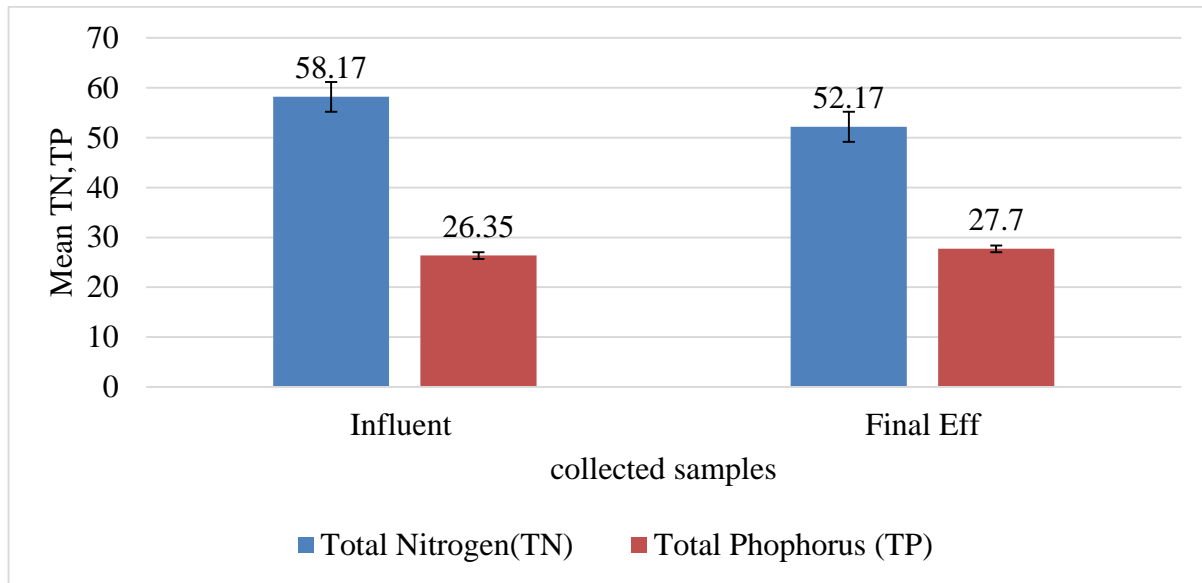


Figure 15 The average TN and TP values in sewage treatment unit

It is noteworthy that the mean concentration of TP increased from 26.35 ± 1.77 mg/L at the influent to 27.7 ± 2.31 mg/L at the treated effluent, which was not consistent with the national recommendation value of the EEPA (10 mg/l) permissible discharge limit into water bodies. The

release of phosphorus from the anaerobic sludge in the UASB reactor is the primary cause of the increase in TP content in the effluent (Chai et al., 2019). The bacteria in the sludge retain extra phosphorus when exposed to aerobic conditions and release it when exposed to anaerobic ones (Młyński et al., 2020). This behavior is known as luxury uptake (Młyński et al., 2020). The increment of TP might be because of UASB process can generate sludge with high phosphorus content due to the anaerobic conditions favoring phosphorus release from biomass. If the settling and separation of these phosphorus-rich solids are not efficient, they can contribute to higher phosphorus concentrations in the effluent or it might be due frequent runoff that hinders biological uptake, which may not be effectively facilitated by the short hydraulic retention times associated with these treatment methods. Even though the mean concentration of the final treated effluent of STP (52.17 ± 4.24 mg/L) was below the (80 mg/l) EEPA (2003) provisional discharge standard limit into water bodies regular monitoring is important since the excess phosphorus may cause eutrophication in the receiving water bodies, which can lead to algal blooms, oxygen depletion, and ecological imbalance.

Hammoudani *et al.*, (2021) reported that the TP inlet was 8.94 ± 0.35 and 4.74 ± 0.57 in the effluent, and the TN was 85.18 ± 7.85 at the inlet and 4.77 ± 0.54 at the outlet. Elevated phosphate and nitrate concentrations in effluents can lead to eutrophication, blocking sunlight from entering the water and disrupting treatment (Po well *et al.*, 2008). Different methods, such as adding oxygen or nitrate to the reactor, coupling UASB with aerobic or anoxic reactors, membrane bioreactors, or constructed wetlands, have been proposed for reducing nitrogen and phosphorus concentrations in UASB-based treatment plants. High phosphate-P values can also be caused by runoff from domestic, municipal, and agricultural waste or riverside detergents (Kushwah *et al.*, 2011).

4.1.9 Removal efficiency of the sewage treatment plant for physicochemical parameters

According to the data presented in Figure 16, the effectiveness of sewage treatment plant varies when it comes to removing pollutants. The removal efficiency ranges from a negative 62.8% for sulfate to a positive 98.4% for BOD₅. A study conducted in Iran found that the removal efficiency of BOD₅ was up to 75.3%, while the removal efficiency of COD was up to 56.5%. The Bahirdar WWTP's BOD₅ removal efficiency was approximately 92.07%, surpassing the EEPA's recommended criteria (Haile, 2018).

In this study, the COD removal efficiency of the treatment plant ranged from 86.74% to 95.2%, with a mean removal efficiency of 92.72% Figure 16. This suggests a significant decrease in the average COD concentration from influent to the treated effluent. The Bahirdar Dar WWTP had a COD removal efficiency of approximately 62.27%, which is below the guidelines set by the EEPA (Haile, 2018). Nevertheless, the Kality WWTP showed a COD removal capacity of approximately 73%, which is within the limits allowed by the EEPA (Abebaw, 2021). Over the course of the investigation, the BOD5 removal efficiency of the Kality centralized sewage treatment facility ranged from 97.5 to 99.46%, with no discernible variations.

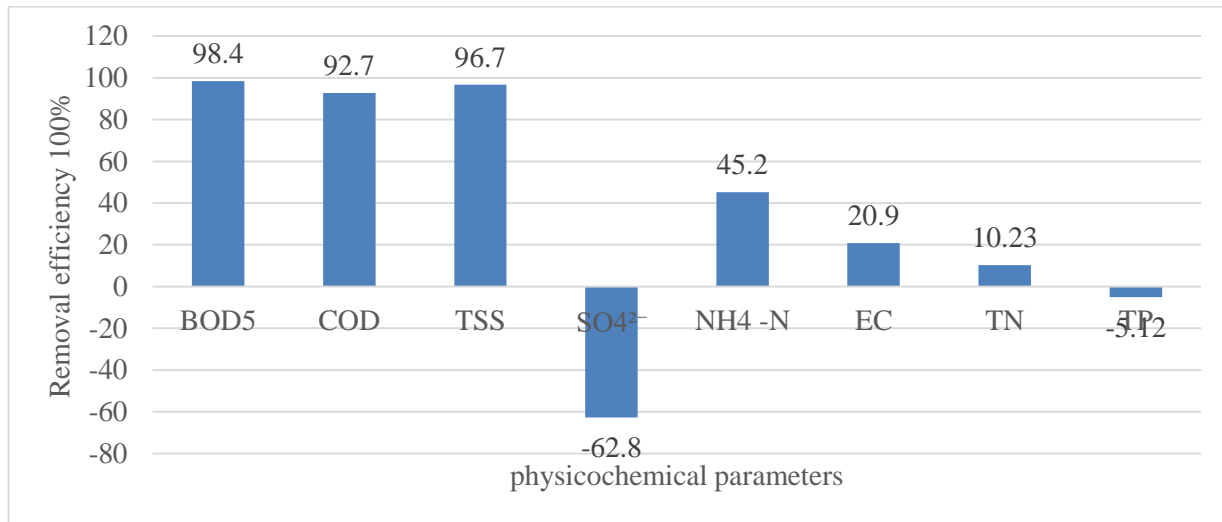


Figure 16 Removal Efficiency of Physicochemical Parameters in a Sewage Treatment Plant

Additionally, the treatment plant's TSS removal effectiveness ranged from 92.38% to 98.22%, with a mean of 96.67%. During the dry season, the Kality central sewage treatment plant showed a TSS reduction efficiency of 64%, which is regarded as good (Abebaw, 2021). A similar study conducted by Bhawe (2020) on domestic sewage treatment plant found the maximum and minimum removal efficiency of TSS at 97.62% and 89.47%, respectively. The Bahirdar textile WWTP achieved an impressive TSS reduction efficiency of 71.96% (Haile, 2018).

The Kality centralized sewage treatment plant had a removal efficiency of ammonium nitrogen of 45.2%, which was below the designed performance. The effectiveness of removing ammoniacal nitrogen from wastewater is determined by the treatment process and initial concentration of ammoniacal nitrogen (Xiang *et al.*, 2020). The Kality centralized sewage treatment plant removal efficiency for TP is negative 5%, indicating a greater TP concentration in the treated effluent than

in the influent. The mean concentration of TN decreased from the influent to the treated effluent with a 10.23% removal efficiency, although the decrease was not significant.

The removal efficiency of sewage treatment plant for sulfate was the worst at negative 62.8%. Because sulfate ions are highly soluble and stable in aqueous solutions, removing them from effluents is a challenging task (Mohammadi *et al.*, 2019). For wastewater, biological treatment methods like activated sludge are ineffective at eliminating sulfate (Xia *et al.*, 2020). However, sulfate can be removed from wastewater using chemical precipitation processes such as lime precipitation or barium precipitation (Fang *et al.*, 2018). Overall, the performance of sewage treatment plants for physicochemical parameters during the study period follows the trend of $BOD_5 > TSS > COD > NH_4^+-N > EC > TN > TP > SO_4^{2-}$.

4.2 Heavy metal Concentration in the treatment systems

The metals that were analyzed in the gathered samples are:- Aluminum (Al), Zinc (Zn), Cadmium (Cd), Chromium (Cr), Barium (Ba), Silver (Ag), Iron (Fe), Lead (Pb), Manganese (Mn), and Copper (Cu). Most of the metals except lead (Pb) was detected in the collected wastewater and sludge samples.

4.2.1 Silver (Ag) concentration profile in the treatment systems

Silver (Ag) was not detected (was below the detection of the instrument used for analysis both influents and effluents across the treatment units. This could be because lower production or consumption of Silver Nano plastic(AgNP)-containing products during the summer, which leads to increased dilution of AgNPs in the receiving water due to rain or runoff and lower AgNP stability and solubility in the influent, resulting in aggregation, precipitation, or transformation due to higher temperature, pH, or salinity. However, Gagnon *et al.*(2021) reported total Ag concentrations in the range of 0.15 to 0.40 $\mu\text{g/L}$ in influent samples (before treatment) and from 0.003 to 0.025 $\mu\text{g/L}$ in the treated effluent, and the highest (0.025 $\mu\text{g/L}$) was recorded from the sample collected in the aerated lagoon. In addition, Kuhre *et al.*, (2018) found that the influx of a STP contained total silver concentrations (non-nano-specific) up to 105 $\mu\text{g/L}$.

4.2.2 Lead (Pb) concentration profile in treatment system

The laboratory analysis of lead revealed a concentration below the detection limit (BDL), indicating that no significant amount of lead was found at any of the sampling points along the sewage treatment plant unit. This could be because reduced input of lead from industrial or domestic sources throughout the time spent studying or to decreased production or consumption of products containing lead. The finding is consistent with the results reported by Carletti *et al.*,(2008) in large-scale WWTP that handled municipal and industrial wastewater.

4.2.3 Barium (Ba) concentration profile in the treatment system

Table 5 Levels of Heavy Metals in Raw Wastewater and Treated Effluents (Mean \pm SE)

Heavy metals	Influent	UASB eff	TF eff	Final eff	(EEPA, 2003) in ppb	Rem eff %
Ag (ppb)	BDL	BDL	BDL	BDL	10	-
Ba (ppb)	70 \pm 2.58	86.67 \pm 2.1	60 \pm 4.47	60 \pm 4.47	100	14.29
Fe (ppb)	118.33 \pm 22.71 8	63.48 \pm 25. 92	13.33 \pm 3.33	36.67 \pm 26.79	1000	69.01
Al (ppb)	8 \pm 2	5 \pm 2.89	0	BDL	200	100
Cd (ppb)	13.33 \pm 4.22	0	0	0	10	100
Cr (Ppm)	9.33 \pm 3.7	0	0	0	100	100
Cu (ppb)	3.33 \pm 2.1	0	0	0	200	100
Mn (ppb)	395 \pm 13.1	635 \pm 61.85	368.33 \pm 85.18	165 \pm 49.5	200	58.23
Zn (ppb)	20 \pm 12.38	5.45 \pm 12.3	10 \pm 2.58	22 \pm 7.85	30-500	-10
Pb(ppb)	BDL	BDL	BDL	BDL	1.00	-

UASB eff = Effluent treated with UASBR; UASB slu = Sludge from UASBR; TF eff = Effluent treated with Trickling filter; RAS= returned activated sludge from secondary clarifier Rem eff = removal efficiency

The concentration of barium in water can vary depending on various factors, including the source of water, industrial activities, and treatment methods (He and Xu, 2016). The concentration of barium showed significant variation between different treatment units ($P = 0.000$). The mean concentration of barium was found to be $70 \pm 2.58 \mu\text{g/l}$ at the influent, $86.67 \pm 2.10 \mu\text{g/l}$ at effluent from UASB, $3185 \pm 1301.83 \mu\text{g/l}$ at UASB sludge, $60 \pm 4.47 \mu\text{g/l}$ at the effluent from trickling filter, $76.67 \pm 9.89 \mu\text{g/l}$ at returned activated sludge from secondary clarifier, $60 \pm 4.47 \mu\text{g/l}$ at the treated final effluent, and $25.817 \pm 1.173 \text{ mg/l}$ in dry sludge. The results found in the study revealed that barium has a greater tendency to occur in sludge (dry sludge, $1291 \pm 58.5 \text{ mg/kg}$) and UASB effluent ($1.158 \pm 1.072 \text{ mg/l}$).

Barium levels in Kality centralized sewage treatment plant were not significantly different over two consecutive days ($P = 0.794$) or during the sampling period ($P = 0.901$). This might be due to may be stable due to a consistent and homogeneous source and composition of wastewater, which contains heavy metals or due to the uniform pattern of rainfall during the study period at the sewage treatment plant, which was significant with the test of homogeneity of variance ($P = 0.072$).

The implication of having high or constant barium levels in the effluent is that it may pose a risk to the environment and human health. Barium is not very soluble and is removed consistently, so its concentration stays stable, even when it's raining heavily in sewage systems. The concentration of barium in sewage sludge is higher than in wastewater due to physical and chemical treatment processes that produce a semisolid, nutrient-rich product known as bio-solids. Barium is not very soluble or mobile in the environment and tends to bind strongly to particles in wastewater and sewage sludge.

4.2.4 Iron (Fe) concentration profile in the treatment systems

The concentration iron content of the influent was $118.33 \pm 22.718 \mu\text{g/l}$ while in the UASB treated effluent and in the Sludge from UASBr were $63.48 \pm 25.92 \mu\text{g/l}$ and $275.2 \pm 119.26 \text{ mg/l}$, respectively. Granular sludge is used in the UASB reactor, a type of anaerobic treatment system, to eliminate organic debris from wastewater (Jie Wang et al., 2018). The sludge has the ability to precipitate or adsorb iron from the wastewater, lowering the iron concentration in the effluent (Shingleton et al., 2023). Sludge with a high iron concentration may be more difficult to dewater, reuse, or dispose of because of its increased volume and metal content (Shingleton et al., 2023).

The iron concentration was also 13.33 ± 3.33 $\mu\text{g/l}$ in effluent from trickling filter, 66.67 ± 49.24 $\mu\text{g/l}$ in returned activated sludge from secondary clarifier and 36.67 ± 26.79 $\mu\text{g/l}$ in final effluent. Elevated iron levels in wastewater can lead to toxicity, corrosion, and coloring issues in the water bodies that receive it (Shingleton et al., 2023).

Dry sludge had the highest Fe concentration (16538.5 ± 15192 mg/kg), followed by UASB sludge, while the lowest concentration was observed at the trickling filter. In aerobic environments, like the trickling filter, the iron in the sludge can also oxidize to form insoluble hydroxides or sulfides. There will be less iron in the trickling filter effluent as a result of these compounds settling with the sludge or being eliminated by the clarifier (Shingleton et al., 2023). The treated effluent of the sewage treatment plant, with 36.67 ± 26.79 $\mu\text{g/l}$, was below the EEPA discharge limit to a surface water body (1000 $\mu\text{g/l}$). Agoro et al. (2020) reported elevated levels of Fe in influent (6.588 mg/L) and effluent (0.636 mg/L) samples from the Eastern Cape, South Africa.

The iron concentrations exhibited significant variation across different units of the treatment plant ($P = 0.000$). The temporal variation of Fe concentration in the samples collected in between two consecutive days and months was not significant ($P = 0.703$ and $P = 0.637$) respectively, indicating that the concentration was uniformly distributed throughout the study period. The high concentrations of iron might be due to dissolution of iron from old and obsolete pipelines (Pipi *et al.*, 2018). Previous research has shown that high Fe concentrations in wastewater could lead to soil acidification and the loss of available phosphorus and molybdenum when applied to the soil (Adeyinka, 2022).

4.2.5 Aluminum (Al) concentration profile in the treatment systems

The highest average concentration of Al was recorded in dry sludge (2358.5 ± 662.5 mg/kg) followed in the sludge from UASB (5.042 ± 2.224 mg/l), whereas the lowest mean concentration was recorded at the final treated effluent (<0.00 mg/l). Al may be transported to the wastewater stream and introduced into the UASB reactor, where the sludge may precipitate or adsorb it (Kaviyaran, 2014). After drying and dewatering the UASB reactor sludge, a greater concentration of Al will be found in the dry sludge (Kaviyaran, 2014). Through biological oxidation and filtration, the trickling filter, a post-treatment procedure, can further remove Al from

the effluent. As a result, the final treated effluent has the lowest Al concentration (Zhao et al., 2021).

The concentration of Al varies significant in the different treatment units ($P < 0.05$). This might be due to difference in sources and characteristics of wastewater, treatment process, precipitation nature, and retention time in different treatment units. The temporal variation of Al concentration in the samples collected in consecutive days and months was not statistically significant ($P = 0.682$ and $P = 0.525$), respectively. The insignificance of temporal variation might be due sampling frequency, stable influent characteristics and steady treatment performance during study period. The sewage treatment plant has a neutral pH that might support the non-occurrence of aluminum in treated effluent. The mean concentration in treated effluent was below the EEPA and WHO (200 ppb) discharge limits for surface water bodies. High Al concentrations in dry sludge can increase volume and metal content, making disposal and reuse difficult (Kaviyarasan, 2014). This affects biogas production and anaerobic digestion, necessitating optimized treatment processes and Al concentration management.

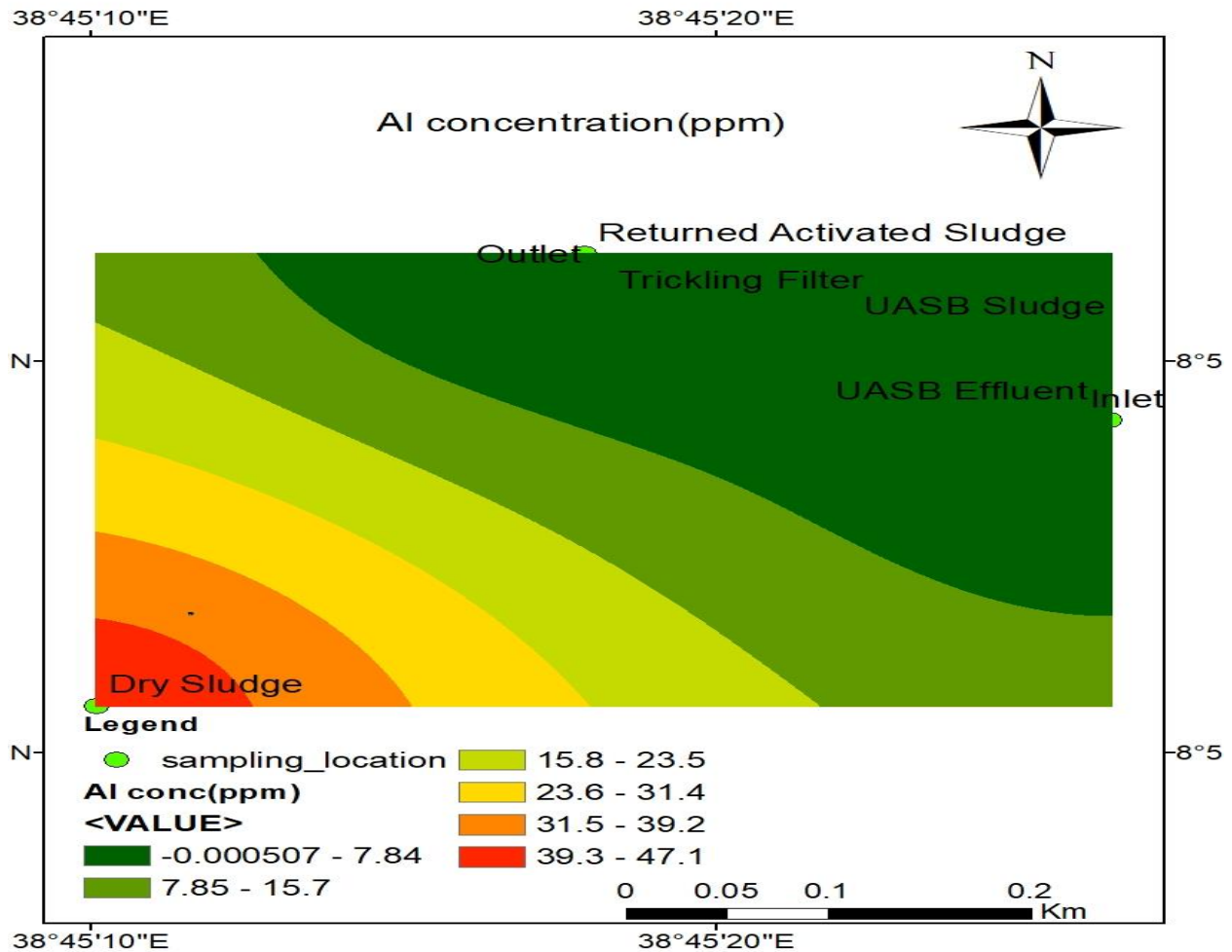


Figure 17 Mean Concentration of Aluminum (Al) Along the Sewage Treatment Unit

4.2.6 Cadmium (Cd) Concentration profile in the treatment systems

The sewage treatment plant at Kality received sewage with a Cd concentration ranging from 0 to 30 $\mu\text{g/l}$ with a mean concentration of $13.33 \pm 4.22 \mu\text{g/l}$. The Cd concentration in final treated effluent was below 0.00 $\mu\text{g/L}$. The quantity of lead that is still present in the water after it has undergone treatment is known as the final treated effluent's concentration of lead. A reading of less than 0.00 $\mu\text{g/l}$ indicates that the wastewater treatment procedure is highly successful in eliminating Cd. The sources and activities that produce the effluent have an impact on the content of Cd in it. The sewage is moderately polluted by Cd, as indicated by the mean value of $13.33 \pm 4.22 \mu\text{g/l}$ (El-Hameed et al., 2021).

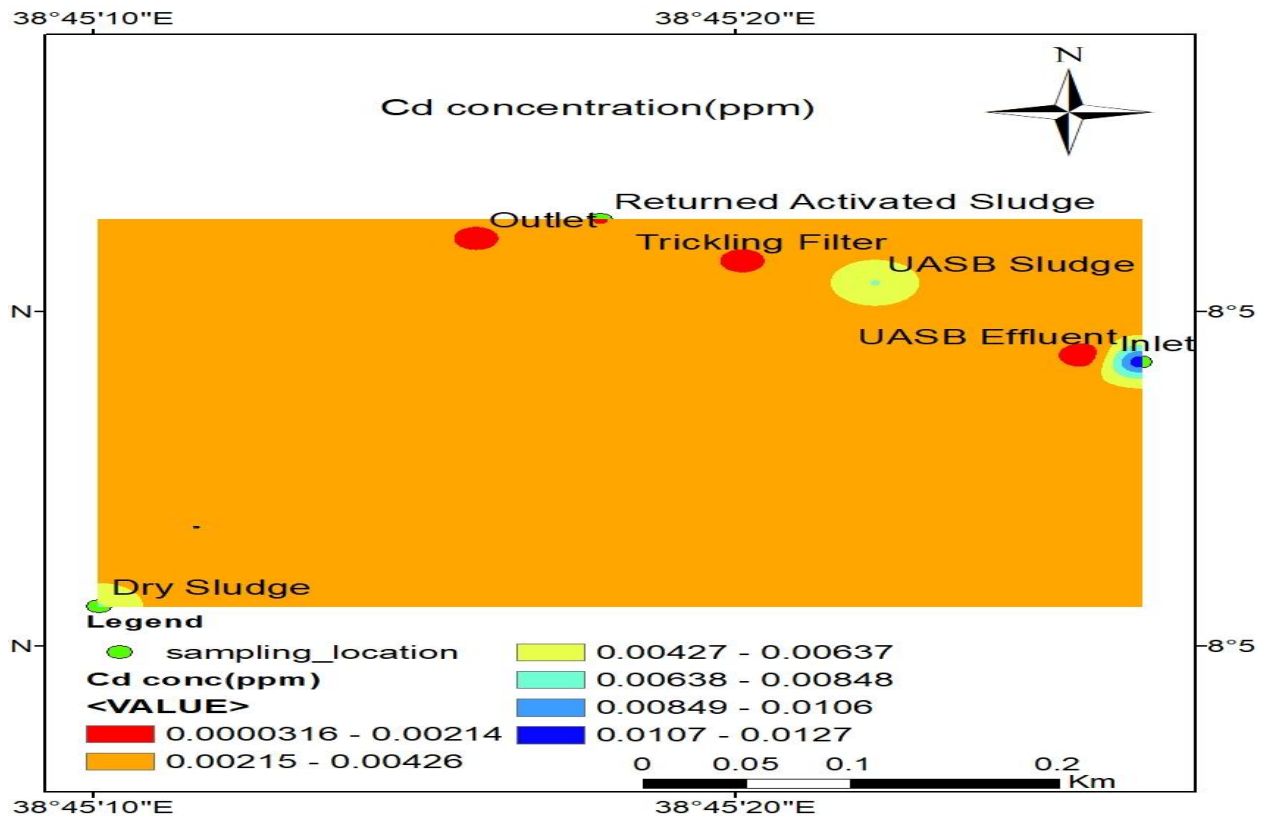


Figure 18 Mean Concentration of Cadmium (Cd) in Treatment Systems Across Treatment Units

In contrast, Olujimi O. *et al.* (2013) reported an influent Cd concentration of 1.85 to 8.88 $\mu\text{g/L}$, and an effluent Cd concentration of 1.25 to 2.29 $\mu\text{g/L}$ in Kraaifontein WWTP. Agoro *et al.* (2020) reported Cd concentration in the range from 0.11–0.12 mg/L in effluent from wastewater treatment plants in the Eastern Cape, South Africa. The concentration of cadmium in sewage treatment plant varies depending on the source of the wastewater. The highest concentration of cadmium was recorded at the influent sample ($13.33 \pm 4.22 \mu\text{g/l}$), which is the raw wastewater entering the plant. This indicates that cadmium is present in the domestic and industrial sources of wastewater.

This indicates that cadmium is present in the domestic and industrial sources of wastewater. The lowest concentration of cadmium was recorded at the treated final effluent and UASB effluent ($0 \mu\text{g/l}$), which are the treated wastewater leaving the plant and the effluent from the anaerobic reactor, respectively. This shows that the wastewater treatment process was effective in removing cadmium from the water. The concentration of cadmium was highest in the influent (13.33 ± 4.22

$\mu\text{g/l}$ and in sludge from UASB ($6.67 \pm 4.94 \mu\text{g/l}$) followed by dry sludge ($0.35 \pm 0.15 \text{ mg/kg}$) and returned activated sludge from secondary clarifiers ($1.67 \pm 1.67 \mu\text{g/l}$).

The amount of Cd in the treatment plant varied spatially at different treatment units, which was significant according to ANOVA analysis ($P = 0.01$). This is because of the difference in source and characteristics of wastewater, treatment process, retention time. The temporal variation of cadmium concentration in the samples collected consecutive days and months was not significant ($P = 0.272$) and ($P = 0.198$), respectively. This might be due to stable influent wastewater characteristics, sampling frequency, steady fast performance of treatment process, and uniform distribution of rainfall during the study period, which contributes to the uniform distribution of Cd throughout the study period. The final treated effluent of sewage treatment plant ($0 \mu\text{g/l}$) was below the EEPA ($5 \mu\text{g/l}$) and WHO ($0.0030 \mu\text{g/l}$) discharge limits for a surface water body. This suggests that the treated wastewater can be reused for agricultural purposes without posing a risk of cadmium contamination.

4.2.7 Chromium (Cr) concentration profile in the treatment systems

At the kality centralized sewage treatment plant, the levels of Cr in sewage influent was in the range from 0 to $20 \mu\text{g/l}$, with mean concentration of $9.33 \pm 3.7 \mu\text{g/l}$. However, in the final treated effluent Cr concentration was reduced level of $0 \mu\text{g/l}$. It indicates that the Cr concentration in the sewage influent was relatively low, compared to other studies that reported higher levels of Cr in wastewater from industrial sources (*World Bank Group, 2023*). It's important to note that the mean concentration of Cr varies significantly ($P < 0.05$) between treatment units, with the dry sludge having the greatest concentration ($10.5 \pm 0.65 \text{ mg/kg}$). Conversely, the concentration of chromium in the UASB effluent sample, trickling filter effluent, activated sludge that was returned from the secondary clarifier, and final treated effluent was found to be less than $0.000 \mu\text{g/l}$.

The average concentration of Cr along the treatment units follows this sequence: dry sludge ($10.5 \pm 0.65 \text{ mg/kg}$) > UASB sludge ($26.67 \pm 9.55 \mu\text{g/l}$) > influent ($9.33 \pm 3.7 \mu\text{g/l}$). Because of the concentration effect and water loss, the dry sludge has a greater Cr concentration than the wet sludge (Niu et al., 2023). However, chromium concentration was no significant varied in the samples collected consecutive a two-day or over a month's ($P = 0.756$ and $P = 0.9$), respectively. The treated effluent concentration from sewage treatment plant was below the discharge limit to

the surface water bodies of EEPA (50 µg/l) and WHO (100 µg/l). Given that Cr is a metal that causes cancer and mutations, it can lessen the chance that it will be harmful to the environment and public health.

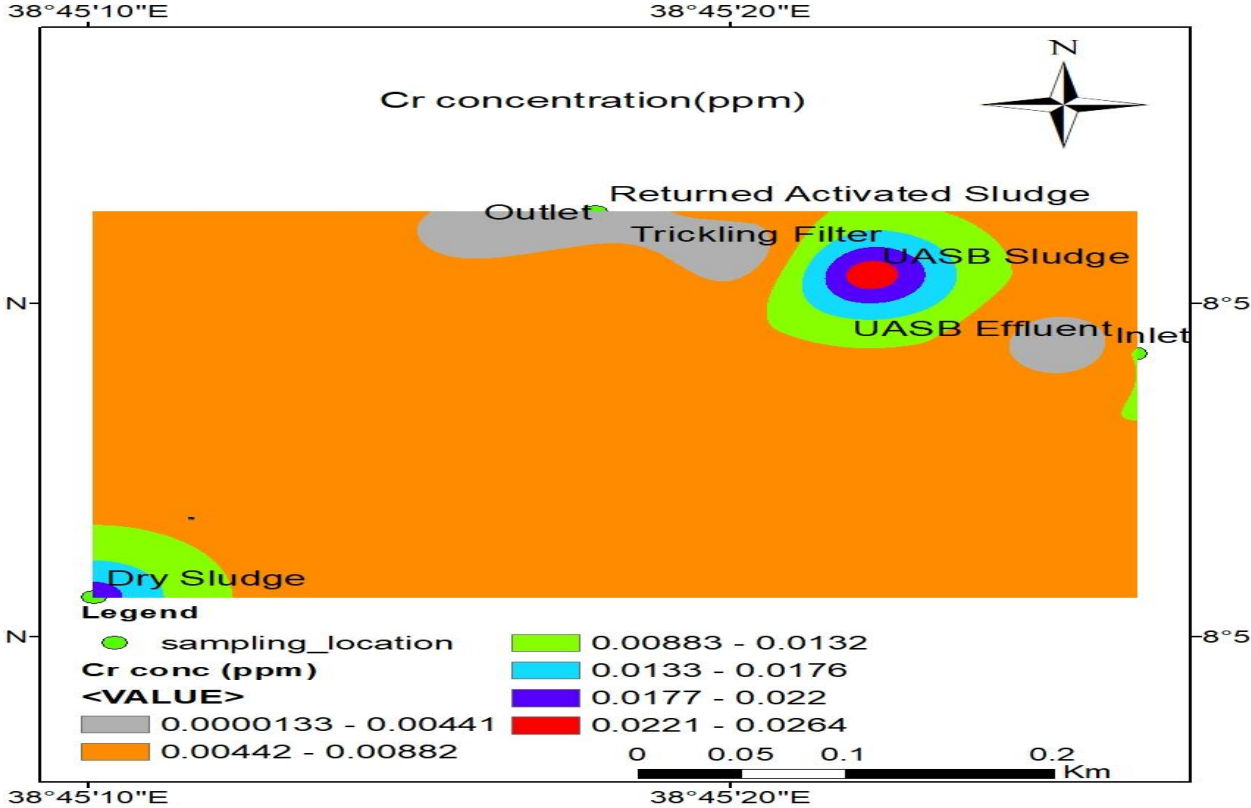


Figure 19 Spatiotemporal Variation of Mean Chromium (Cr) Concentration Along Treatment Units

4.2.8 Copper (Cu) Concentration profile in treatment systems

The average concentrations of copper were in the ranging of 0 to 10 µg/l, with a mean concentration of 3.33±2.1 µg/l. In contrast, Olujimi, *et al.* (2013) reported copper concentrations that vary between 96.56 and 135.76 µg/L at the Kraaifontein WWTP while final effluent concentrations was ranging from 7.66 to 25.16 µg/L. <0.05). The highest mean copper concentration (476.67 ± 23.33 µg/l) was recorded in dry sludge, while the lowest concentrations were observed in the treated UASB and trickling filter effluents. The reason for this could be attributed to the fact that copper is a heavy metal that can accumulate in sludge over time (Thawornchaisit *et al.*, 2019). Because copper tends to adsorb onto solid particles or precipitate as

solid compounds, it can build in the sludge throughout the wastewater treatment process. The observed greater mean copper content can be attributed to the ability of dry sludge, which has a high solids concentration, to hold more copper.

The average copper concentration was highest in dry sludge (23.85 ± 1.15 mg/kg) followed by UASB sludge (60 ± 24.22 µg/l). The copper concentration in the influent (93.33 ± 2.1 µg/l) and in all the other sample was very low. There was no significant temporal variation in copper concentration between two consecutive days ($P = 0.272$) or over a three-month sampling period ($P > 0.05$). The mean concentration of the final treated effluent (0 µg/l) was below the EEPA (1000 µg/l) discharge limit for a surface water body.

4.2.9 Manganese (Mn) Concentration profile in the treatment systems

The STP of kality receives sewage with varying Mn concentrations, ranging from 360 to 440 µg/l on a daily basis, with a mean concentration of 395 ± 13.10 µg/l. The treated discharged from the treatment facility contains Mn concentrations ranging from 10 to 370 µg/l, with a mean concentration of 165 ± 49.5 µg/l. The mean concentration of manganese in the STP varies spatially along different treatment units ($P = 0.000$). The maximum concentration of manganese was recorded in dry sludge (1850 ± 75.06 µg/l) while the minimum concentration was in the final treated effluent (165 ± 49.5 µg/l). The general spatial distribution of Manganese follows the trend dry sludge (92.5 ± 3.75 mg/kg) > returned activated sludge (1566.67 ± 224.71 µg/l) > UASB effluent (635 ± 61.85 µg/l) > influent (395 ± 13.10 µg/l) > UASB Sludge (381.67 ± 104.48 µg/l) > effluent from TF (368.33 ± 85.18 µg/l) > final treated effluent (165 ± 49.5 µg/l).

The temporal variation of copper concentration among two consecutive days and month-based sampling periods was not significant at ($P = 0.272$) and ($P = 0.198$), respectively. Mn concentrations in STP remained steady over two days of sampling, suggesting an even discharge of wastewater through the sewage pipeline. The average concentration of Mn in treated effluent (165 ± 49.5 µg/l) was below both EEPA (300 ppb) and WHO (500 ppb) for surface water bodies. The levels of Mn in wastewater samples may substantially increase as the Mn concentration in iron-containing materials increases. Mn can cause an iron shortage in aquatic organisms, including blue-green algae, and can also prevent the synthesis of chlorophyll (Adeyinka, 2022).

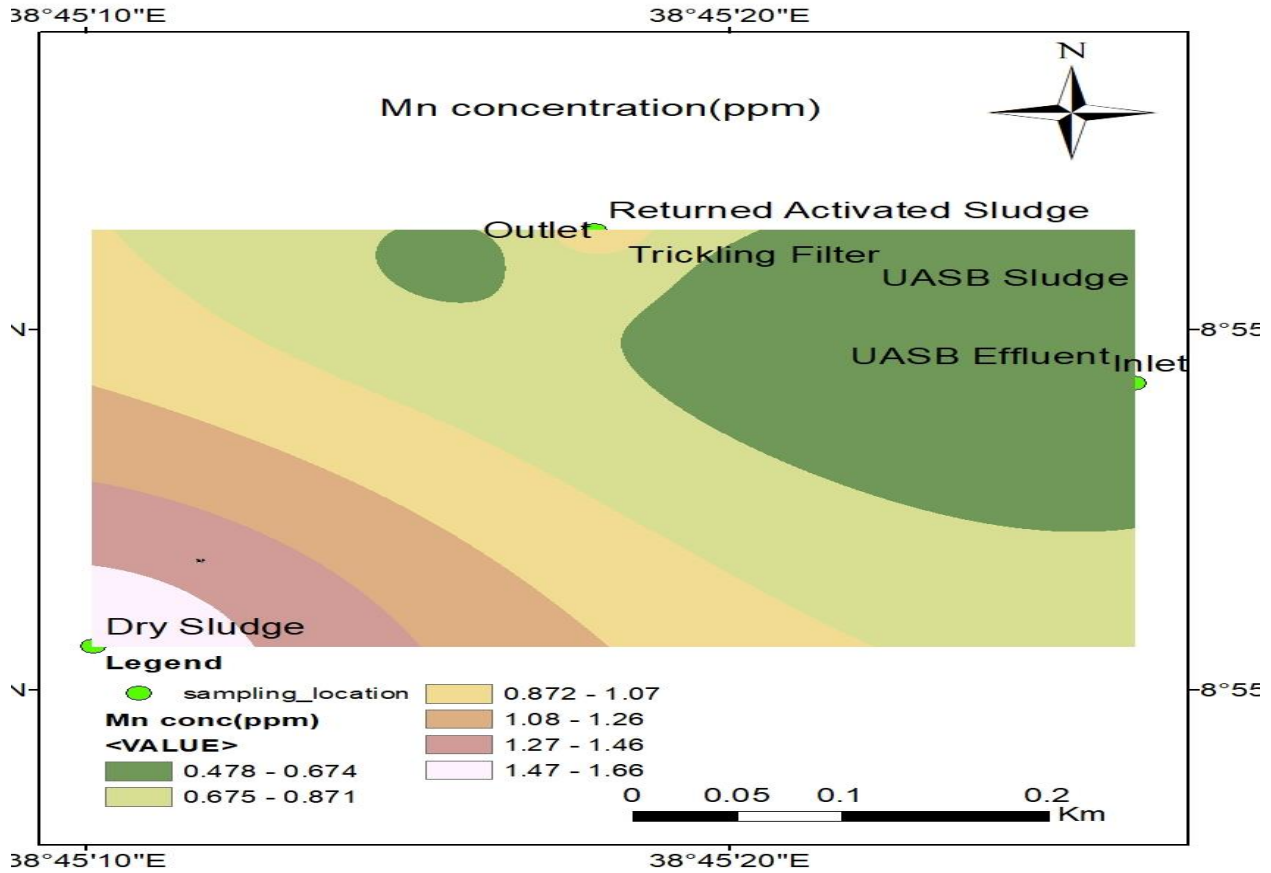


Figure 20 The Mean Concentration of Manganese (Mn) in Treatment Plant Systems Across Treatment Units

4.2.10 Zinc (Zn) concentration profile in the treatment systems

At the Kaliti centralized sewage treatment plant, the incoming sewage contains zinc concentrations ranging from 0 to 80 $\mu\text{g/l}$, with a mean concentration of $20 \pm 12.38 \mu\text{g/l}$. Zinc concentrations in the treatment plant's outlet discharge range from BDL to 50 $\mu\text{g/l}$, with an average of $22 \pm 7.85 \mu\text{g/l}$. The average concentration of Zn varies significantly across different treatment units ($P = 0.000$). The highest mean concentration of zinc was recorded at dry sludge ($3300 \pm 108.24 \mu\text{g/l}$), while the lowest mean concentration was at UASB effluent ($5.45 \pm 12.3 \mu\text{g/l}$). The zinc concentration increases in the following order: dry sludge ($165 \pm 5.4 \text{ mg/kg}$) > UASB sludge ($420 \pm 148.96 \mu\text{g/l}$) > returned activated sludge ($26.67 \pm 6.67 \mu\text{g/l}$) > final treated effluent ($22 \pm 7.85 \mu\text{g/l}$) > effluent from trickling filter ($10 \pm 2.58 \mu\text{g/l}$) > UASB effluent ($5.45 \pm 12.3 \mu\text{g/l}$). The average concentration of effluent released by the treatment plant ($22 \pm 7.85 \mu\text{g/l}$) was lower than the EEPA discharge limit of 30-500 ppb in the water body.

4.2.11 Concentration of heavy metals in the treatment units

Extensive research was conducted to assess the levels of various heavy metals in the WWTP's influent. Zinc, chromium, cadmium, iron, barium, and copper were all detected with 100% accuracy, while aluminum showed an 83.33% detection rate. None of the samples contained lead or silver. The influent samples had an average concentration of heavy metals ranging from BDL for Ag and Pb to $395 \pm 13.10 \mu\text{g/L}$ for Mn. Several studies have yielded similar results, with no lead found in the influents of WWTP (Gulyás *et al.*, 2015). According to Adeyinka's research (2022), iron had the highest concentration of all heavy metals, with a mean value ranging from 0.122 to 1.808 mg/L in the influent samples.

The amount of heavy metals varied widely in the samples collected over a three-month, indicating diverse sources of metals that contributing to the sewage treatment plant. The variation of cadmium content in the influent was lower than that of other metals (Chipasa and Ali, 2003). Except for manganese, which was greater than literature values, the influent of the Kality centralized sewage treatment facility had lower concentrations of most metals than those reported in previous studies. The higher concentration of manganese in Kality sewage treatment because of domestic activities and natural sources. Meanwhile, the lowest level of lead (<0.001) indicates reduced contribution of industrial discharge in the study period. The result indicates a lower contribution of anthropogenic sources of metals to the treatment plant or dilution effect of extended rainfall during study period. The maximum average concentration of heavy metals found in the Kality centralized sewage treatment plant was manganese, with a concentration of $395 \pm 13.10 \mu\text{g/l}$, while the lowest concentration was copper, with a concentration of $3.33 \pm 2.1 \mu\text{g/l}$. The general pattern of the metal distribution in the influent of the sewage treatment plant follows $\text{Mn} > \text{Fe} > \text{Ba} > \text{Zn} > \text{Cd} > \text{Cr} > \text{Al} > \text{Cu}$.

The amount of heavy metals in UASB effluent did not show any significant variation over the sampling periods ($P = 0.338$). The average concentration of heavy metals in the UASB effluent of the treatment plant ranged from BDL for Ag, and Pb to $1158.33 \pm 1072.34 \mu\text{g/L}$ for Ba. The overall metal distribution in the UASB effluent follows this sequence: $\text{Ba} (1158.33 \pm 1072.34 \mu\text{g/L}) > \text{Mn} (635 \pm 61.85 \mu\text{g/L}) > \text{Fe} (63.48 \pm 25.92 \mu\text{g/L}) > \text{Zn} (5.45 \pm 12.3 \mu\text{g/L}) > \text{Al} (5 \pm 2.89 \mu\text{g/L}) > \text{Cd} = \text{Cu} = \text{Cr} > \text{Ag} = \text{Pb}$ Figure 21.

The amounts of heavy metals in kaliti centralized sewage treatment plant effluent from trickling filter varied between BDL (Ag and Pb) and $368.33 \pm 85.18 \mu\text{g/L}$ (Mn) over sampling periods ($P = 0.000$). Mn was the highest ($368.33 \pm 85.18 \mu\text{g/L}$), followed by Ba ($60 \pm 4.47 \mu\text{g/L}$), Fe ($13.33 \pm 3.33 \mu\text{g/L}$), Zn ($10 \pm 2.58 \mu\text{g/L}$), then Al, Cr, Cd, and Cu, and lastly Ag and Pb. The highest concentration of Mn in the trickling filter's effluent may be the result of operational factors like pH and oxidation-reduction as well as a greater concentration of Mn in the WWTP's influent.

The treatment plant treated effluent displayed a 100% detection rate for Mn, Cu, Fe, Ba, and Cd, 83.33% for Zn, and 0% for Al, Ag, and Pb. The concentration and existence of these heavy metals are crucial because, if released into the environment untreated, they could cause ecotoxicity. Over the sampling period, the amount of heavy metals in the outlet varied significantly ($P = 0.000$), with manganese being the dominant metal, while Cr, Cu, and Cd exhibited the lowest concentrations. The higher concentration of Mn in treated effluent might be due the influence of the concentration of Mn in influent of WWTP and the increment operational parameters like pH influence manganese speciation, favoring its dissolution. According to the homogeneity of variance test ($P = 0.000$), the amount of heavy metals-treated effluent did not vary significantly, indicating that the treatment plant is highly efficient. It should be mentioned, though, that greater amounts of Ba ($60 \mu\text{g/L}$), Fe ($36.667 \mu\text{g/L}$), Mn ($165 \mu\text{g/L}$), and Zn ($22 \mu\text{g/L}$) were found in the treated effluent after treatment. Metals in treated effluent increase metal contents in soil irrigated by this water and transferred to plant and animals through food chain. On average, the treated effluent concentrations of heavy metals were significantly lower than the levels set by EEPA for surface water discharge Table 5.

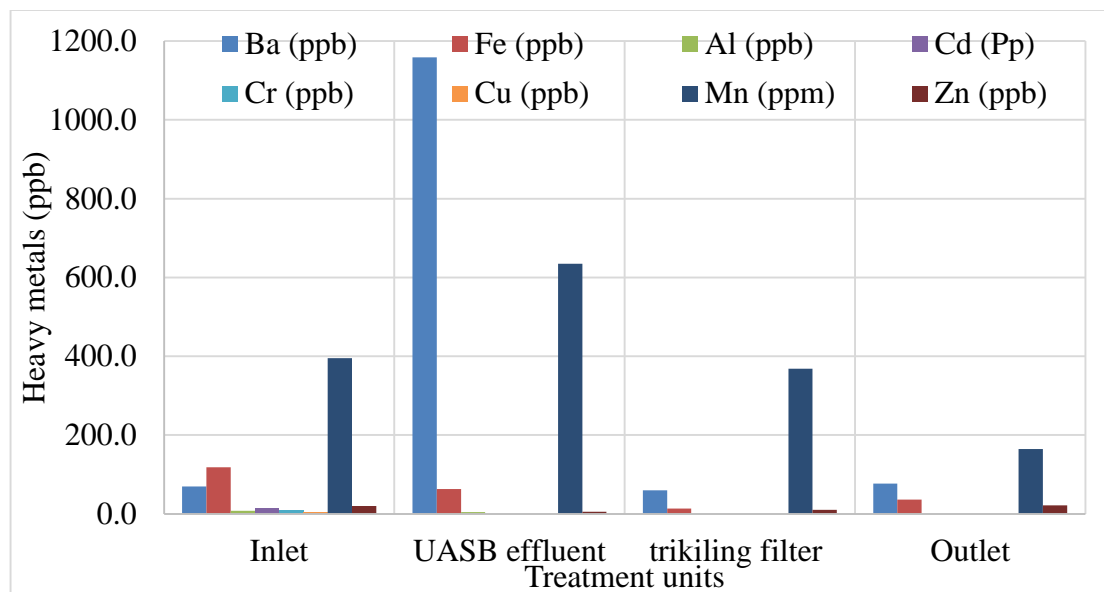


Figure 21 Mean Concentration of Heavy Metals in the Treatment Unit

4.2.12 The Concentration of Heavy metals in the sewage sludge

Of all the metals in the system, 77.8% were found in the sludge UASB reactor and were distributed throughout the system. The mean concentration UASB sludge of STP was dominated by concentration Fe (275.2 ± 119.26 mg/l) and Cd (0.0067 ± 0.0049 mg /L) took the lowest concentration. The concentration of Fe in UASB sludge might be due to corrosion of pipes and addition of iron due to biological process such as the breakdown of organic matter by iron-reducing bacteria whereas the lowest concentration of Cd might be the nature of Cd in the natural system enables to exist in lowest concentration. The high concentration of iron in the UASB sludge may indicate that iron is being effectively removed from the wastewater during the treatment process whereas lowest concentration of cadmium in the UASB sludge is a positive outcome, indicating successful removal or minimal input of cadmium in the wastewater treatment process. The overall distribution of metals in UASB sludge was $Fe > Ba > Zn > Mn > Cu > Cr > Cd$ Table 6.

The occurrence and distribution of heavy metal in returned activated sludge from secondary clarifiers accounted 77.8 % of the total heavy metal distribution in the system. Manganese concentration (1.567 ± 0.225 mg /l) was dominant in returned activated sludge whereas Cr and Cu took the lowest mean concentration in the sludge. Manganese is a heavy metal that can have adverse effects on the microbial ecology of activated sludge (Maal-Bared, 2020). A study suggests that heavy metals like Manganese can impact the biological nutrient removal process by

affecting the microbial community's metabolic activity (Maal-Bared, 2020). The study also highlights the importance of monitoring heavy metal concentrations in influent wastewater to support decision-making at the wastewater utility level (Maal-Bared, 2020). The general distribution trend of metals in returned activated sludge was in the Mn > Ba > Fe > Zn > Cr = Cu (Table 6).

Table 6 Mean ± Standard Error Values of Heavy Metals in Sludge Samples and Comparison with International Standard Values for Agricultural Application

Heavy metals	Influent (µg/l)	UASB Sludge in mg/l	Returned sludge in mg/l	Dry Sludge in mg/kg	USEPA (mg/kg)	Final eff (µg/l)	(EEPA, 2003) mg/kg
Ag	BDL	BDL	BDL	63.5± 13.5		BDL	
Ba	70 ± 2.58	3.185 ± 1.302	0.0767±0.0099	1291± 58.5		60 ± 4.47	
Fe	118.33±22.718	275.202±119.264	0.067 ± 0.049	16538.5±15192		36.67±26.79	
Al	8± 2	5.042± 2.224	0.03	2358.5± 662.5		BDL	
Cd	13.33±4.22	0.0067±0.0049	0.00016	0.35± 0.15	85	0	0.5
Cr	9.33± 3.7	0.0267±0.0096	0	10.5± 0.65	3000	0	500
Cu	3.33± 2.1	0.06± 0.0242	0	23.85± 1.15	4300	0	500
Mn	395±13.1	0.382 ± 0.105	1.567 ± 0.225	92.5± 3.75		165 ± 49.5	
Zn	20±12.38	0.42 ± 0.149	0.0267±0.0067	165± 5.4	7500	22 ± 7.85	500
Pb	BDL	BDL	BDL	BDL		BDL	

The occurrence and distribution of heavy metal in dry sludge accounts 90% of the heavy metal

distribution. This indicated that the heavy metals are accumulated in sludge. Iron (16538.5 ± 15192 mg/kg) dominated in the dry sludge whereas cadmium (0.35 ± 0.15 mg/kg) took the lowest concentration (Table 6). The higher concentration of Fe in the dry sludge might be due the higher concentration of Fe in UASBr which results from different sources in the city. The result was consist with Duan *et al.*, (2017) reported that Cd has the lowest mean concentration in sewage sludge from Municipal WWTPs in Shanxi, China.

The general distribution of heavy metals in dry sludge $Fe(16538.5 \pm 15192 \text{ mg/kg}) > Al (2358.5 \pm 662.5 \text{ mg/kg}) > Ba (1291 \pm 58.5 \text{ mg/kg}) > Zn (165 \pm 5.4 \text{ mg/kg}) > Mn (92.5 \pm 3.75 \text{ mg/kg}) > Ag (63.5 \pm 13.5 \text{ mg/kg}) > Cu (23.85 \pm 1.15 \text{ mg/kg}) > Cr(10.5 \pm 0.65 \text{ mg/kg}) > Cd (0.35 \pm 0.15 \text{ mg/k})$ (Table 6). The study revealed that the heavy metals in dry sludge from sewage treatment plant was below the standards of USEPA and EEPA required for agricultural application Table 6. In the kality centralized sewage treatment plant, heavy metals, which are absent in the treated effluent, tend to accumulate in sludge, whereas metals that are low concentration but high effluents tend to attract to liquid. The concentrations of Ba, Fe, Zn, Mn, Cd, Cr, Cu, and Ag are relatively low in liquid part of the sewage but reasonably high in sludge. It indicates that these heavy metals precipitate in the prevailing conditions in sewage and concentrate in the sludge.

4.2.13 Heavy metal removal efficiency

As depicted in Figure 22, the treatment process was effective in significantly lowering the concentrations of barium (Ba), cadmium (Cd), chromium (Cr), cupper (Cu), zinc (Zn), Manganese (Mn), iron (Fe), and aluminum (Al). The treatment plant was highly effective in removing aluminum (Al), cadmium (Cd), chromium (Cr) and cupper (Cu) with a 100% removal efficiency for these metals. Despite not being specifically designed for metal removal, the sewage treatment plant still managed to achieve significant removal efficiencies for these metals (Figure 22). Considering the effluent concentration and removal efficiency for Mn, and Fe, the relatively high discharge of may result from the high initial concentration while the relatively high discharge of Ba and Zn may result from poor efficiency of the treatment (Table 5 and Figure 22). However, the removal efficiency for barium (Ba) was quite low, at 14.286, indicating that the treatment process was not effective in removing this metal from the wastewater.

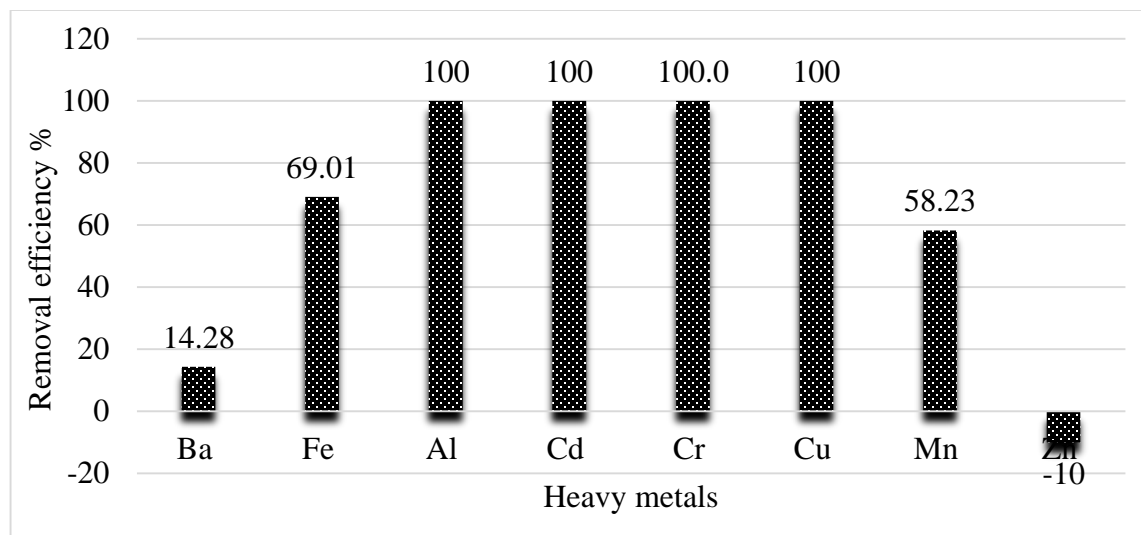


Figure 22 Comparison of Heavy Metal Removal Efficiencies in the Kality Centralized Sewage Treatment Plant

The results copper (88.88%) and chromium (91.98%) found in this study was higher than the results reported , respectively) of this study with others by Feng *et al.*, (2018). Surprisingly, the Kality centralized sewage treatment plant exhibited negative removal efficiencies (-10%) when it came to removing zinc, indicating its ineffectiveness in addressing this particular contaminant. The treatment plant also removed Fe and Mn from the wastewater with removal efficiencies of 69.01% and 58.23%, respectively. In general, the removal efficiency for heavy metals in sewage treatment follows the order Al = Cd = Cu = Cr > Fe > Mn > Ba > Zn. During the studied period, it was observed that the removal efficiency of the sewage treatment plant was ineffective, as it removed less than 50% of the total influx of Ba (14.28) from the influent. It is worth noting that Zhou *et al.*, (2019) reported negative removal efficiency for Zn, Pb, Cd, and Ni in a China WWTP. Meanwhile, Xiao *et al.*, (2013) found that a full-scale hybrid constructed wetland receiving municipal sewage had average removal efficiencies of 46.5%, -7.3%, -25.6%, and 13.8% for Cu, Pb, Cr, and Zn, respectively.

4.3 Pearson correlation between physicochemical and heavy metals

The correlations between physico-chemical parameters and heavy metals are presented in Table 7. In this study, it was found that $\text{NH}_4\text{-N}$ had a positive correlation with BOD_5 (0.924**) and COD (0.817*), while EC had a positive correlation with BOD_5 (0.968**), $\text{NH}_4\text{-N}$ (0.962**), and COD

(0.812*). This correlation suggests that organic pollution might contribute for NH_4^+ -N pollution in the wastewater. Monitoring and controlling the levels of NH_4^+ -N in the wastewater can potentially reduce the organic pollution and improve water quality.

In this study, a strong and significant positive Pearson correlation was observed between TSS and COD (0.964**), but no correlations were found between TSS and heavy metals. The findings of this study reveal a noteworthy and affirmative connection between TSS and COD during wastewater treatment, indicating a strong association between them. However, there is no indication of any links between TSS and the concentration of heavy metals, which suggests that other factors may be responsible for the presence of heavy metals in wastewater. The presence of organic matter and suspended solids are typical factors that impact both TSS and COD, which explains the robust correlation between them. In contrast, the concentration of heavy metals may be influenced by various factors not related to TSS, resulting in an absence of correlation. It's also plausible that WWTPs have effective methods for eliminating heavy metals, which reduces their concentration and limits the potential for correlation with TSS. This is different from Koju et al., (2022) who found a positive relationship between TSS and the concentration of heavy metals specifically iron (Fe), Copper (Cu), Manganese (Mn), Zinc (Zn), Lead (Pb) and Arsenic (As).

In this study observed correlations between physicochemical parameters and heavy metals in sewage were poor. Pearson correlation analysis for heavy metals concentration revealed significant positive and negative correlations ($p < 0.05$ and $P < 0.01$) between heavy metals and physicochemical parameters. Aluminum had a strong negative correlation with TN (-0.914*) it had a strong positive correlation with Fe (0.838*). Cadmium (Cd) showed a significant strong negative correlation with TP (-0.914*). It has been observed that treatment plants exhibit a significant negative correlation between Aluminum and TN. This is believed to be caused by Aluminum ions hindering the availability of nitrogen compounds, thereby impeding the assimilation process for microorganisms and the formation of complex compounds. Furthermore, the strong positive correlation between Aluminum and iron (Fe) can be attributed to their mutual presence in industrial processes and co-precipitation in similar forms. It is also worth noting that certain ligands could increase their adsorption onto solid particles.

Table 7 Correlation Analysis of Physicochemical Parameters and Heavy Metals in the Kality

Centralized Sewage Treatment Plant

	pH	BOD5	COD	NH ₄ -N	TSS	EC	SO ₄ ²⁻	TP	TN	Inflow	Ba	Fe	Al	Cd	Mn	Zn	Cr
pH	1																
BOD	-0.75	1															
COD	-0.157	0.73	1														
NH ₄ ⁺ .N	-0.576	.924**	.817*	1													
TSS	-0.144	0.678	.964**	0.708	1												
EC	-0.691	.968**	.812*	.962**	0.746	1											
SO ₄ ²⁻	0.513	-0.661	-0.599	-0.556	-0.559	-0.721	1										
TP	0.066	0.478	0.51	0.54	0.363	0.397	-0.112	1									
TN	-0.324	0.466	0.05	0.277	0.031	0.242	0.059	0.664	1								
Inflow	-0.659	0.409	-0.232	0.173	-0.184	0.205	0.137	0.119	0.781	1							
Ba	0.014	-0.19	-0.455	-0.331	-0.323	-0.374	0.722	-0.036	0.545	0.697	1						
Fe	-0.045	-0.255	-0.171	-0.05	-0.277	-0.057	-0.146	-0.516	-0.801	-0.514	-0.625	1					
Al	0.404	-0.705	-0.41	-0.517	-0.423	-0.525	0.202	-0.686	-.914*	-0.671	-0.378	.838*	1				
Cd	-0.408	-0.027	-0.212	-0.258	-0.026	-0.01	-0.32	-.817*	-0.341	0.131	0	0.186	0.231	1			
Mn	-0.546	0.549	0.12	0.247	0.242	0.35	-0.123	0.218	0.789	.838*	0.591	-0.79	-.857*	0.241	1		
Zn	0.302	0.127	0.632	0.169	0.638	0.256	-0.639	0.13	-0.396	-0.733	-0.732	0.078	0.111	0.06	-0.288	1	
Cr	-0.173	0.613	0.682	0.708	0.488	0.663	-0.672	0.712	0.177	-0.239	-0.696	0.061	-0.315	-0.483	-0.123	0.516	1

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

* . Correlation is significant at the 0.05 level (2-tailed).

Agoro et al., (2020) observed that Cd exhibited a negative correlation with Fe ($r = -0.86$, at $p < 0.01$) and a positive relationship with copper ($r = -0.94$ at $p < 0.01$). Mn had a strong (negative) correlation with Al (-0.857^*) and a positive correlation with inflow (838^*) Table 7. The strong negative correlation with Al might be due competition for adsorption sites on the surfaces of solids in the treatment plant and chemical reactions. The strong correlation between two heavy metals indicates strong dependence of both metals on the same causal factor (Maurya & Srivastava, 2019).

However, a study by Koju et al., (2022) found that pH and EC had little effect on heavy metals concentration.

Conversely, a study conducted Papi et al., (2018) found a negative correlation between pH and metal concentration, supporting the hypothesis that metals are directly related to organic matter. For instance, a study conducted by Papi et al. in Brazil found that high concentrations of metals in the aquatic environment can significantly affect the pH, chemical oxygen demand, and dissolved oxygen of the treated water (Lin et al., 2022). The study also found that the abundance of heavy metals such as Ba, Mn, Zn, Cu, Se, Fe, and Al in the samples was correlated with the physicochemical parameters of the treated water (Lin et al., 2022). Another study conducted by Wang et al. in China found that the concentration of heavy metals in sewage sludge was positively correlated with the pH, electrical conductivity, and organic matter content of the sludge (Lin et al., 2022).

CHAPTER FIVE

5. CONCLUSION AND RECOMNDATION

5.1 Conclusion

In conclusion, With the exception of TP, which exceeded the limit, the physicochemical characteristics of the treatment plant effluent were found to be below the EEPA discharge limit on the surface water body. There was significant variation in the concentration of physico-chemical parameters among different units, as it was observed that the higher concentration was recorded in influent except pH, SO_4^{2-} , and TP, which tend to increase toward effluent during the study period. However, there was no significant variation in the concentration of physicochemical parameters between the sampling days and months. The majority of physicochemical parameters (BOD_5 , COD, TSS, $\text{NH}_4\text{-N}$, TN, and EC) were successfully reduced by the treatment plant, with the exception of SO_4^{2-} and TP, which perform poorly for them.

The sewage effluent and sludge from the treatment plant have heavy metals concentrations below EEPA and WHO discharge limits and meet USEPA standards for land application and surface disposal. The concentration of heavy metals varied significantly ($p < 0.05$) between the various treatment plant units; however, there was no significant fluctuation ($p > 0.05$) between the sample days and months. The analyzed concentrations of heavy metals Ba, Fe, Zn, Mn, Cd, Cr, Cu, and Ag in sewage are low in liquid but high in sludge, suggesting precipitation and concentration of heavy metals in sludge. Despite not being specifically designed for metal removal, the treatment plant was highly effective in removing Al, Cd, Cu, and Cr, with a 100% removal efficiency, but ineffective at removing Ba and Zn. The study also found strong, significant positive correlations between BOD_5 and COD, COD and TSS, and heavy metals concentrations in the treatment plant, while negative correlations were observed between parameters TN and Al, TP and Cd, and Al and Manganese.

5.2 Recommendations

- The study recommends conducting regular analysis of heavy metals in treatment plants during the dry season to understand their spatiotemporal variation and dilution effect.
- The study also suggests investigating the inefficiency of removing sulfate and TP during the dry season and implementing regular monitoring to ensure compliance with regulatory standards and prevent environmental pollution.
- The study recommends optimizing the increment of sulfate by Optimizing the hydraulic retention time (HRT) and organic loading rate (OLR) of the UASB reactor, Enhancing the nitrification in the trickling filter by increasing the dissolved oxygen concentration, the surface area of the media, and the recirculation ratio and Using bio-filters to treat the off-gas from the UASB reactor and the trickling filter.
- The study also recommends identifying major sources of heavy metal discharge and conducting a speciation analysis.
- The study proposes an intriguing recommendation to assess the levels of Arsenic and mercury in sewage treatment plants, as their exclusion from this study was attributed to the absence of established standards.
- The study strongly recommends conducting research on emerging contaminants and human neuroendocrine-disrupting chemicals in sewage treatment plants.
- The study also recommends exploring novel approaches for unlocking the potential of sludge management and nutrient/resource recovery from sewage treatment plant sludge.

REFERENCE

- Abdel-Shafy, H. I., Hegemann, W., & Genschow, E. (1995). Fate of heavy metals in the leather tanning industrial wastewater using an anaerobic process. *Environmental Management and Health*, 6(2), 28–33. <https://doi.org/10.1108/09566169510085135>
- Abdelaal, A., Abdelkader, A. I., Alshehri, F., Elatiar, A., & Almadani, S. A. (2022). Assessment and Spatiotemporal Variability of Heavy Metals Pollution in Water and Sediments of a Coastal Landscape at the Nile Delta. *Water (Switzerland)*, 14(23). <https://doi.org/10.3390/w14233981>
- Abeba, A. (2021). *Performance Evaluation and Optimization of Kality Wastewater Treatment Plant , Addis Ababa , Ethiopia.*
- Abel, J., Guillen, E., Beatriz, M., & Malpartida, A. (2022). Ecological risk assessment and identification of sources of heavy metals contamination in sewage sludge from municipal wastewater treatment plants in the Metropolitan Area of Lima - Callao , Peru. *Environment, Development and Sustainability*, 0123456789, 1–32. <https://doi.org/10.1007/s10668-022-02774-w>
- Abo-Alkasem, M. I., Hassan, N. H., & Abo Elsoud, M. M. (2023). Microbial bioremediation as a tool for the removal of heavy metals. *Bulletin of the National Research Centre*, 47(1). <https://doi.org/10.1186/s42269-023-01006-z>
- Adeyinka, B. F. B. and G. C. (2022). Evaluating the Potential Health Risks of Selected Heavy Metals across Four Wastewater Treatment Water Works in Durban ,. *Toxics*, 10(20 June), 1–17.
- Agoro, M. A., Adeniji, A. O., Adefisoye, M. A., & Okoh, O. O. (2020). Heavy metals in wastewater and sewage sludge from selected municipal treatment plants in eastern cape province, south africa. *Water (Switzerland)*, 12(10). <https://doi.org/10.3390/w12102746>
- AKTOR. (2017). *Kaliti Wastewater Treatment Plant - Civil and Electromechanical Works - Design Supply and Built.VOLUME 1 OPERATION & MAINTENANCE MANUALS SECTION A - DESCRIPTION OF THE PLANT.*
- Ali, H., Khan, E., & Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, 2019(Cd). <https://doi.org/10.1155/2019/6730305>

- Ali, S. F., & Eren, A. E. (2019). OCCURRENCE , SEASONAL CHANGES AND REMOVAL EFFICIENCY ASSESSMENT OF HEAVY METALS IN URBAN WASTEWATER TREATMENT PLANT. *Journal of Asian Scientific Research*, 9(6), 48–55.
<https://doi.org/10.18488/journal.2.2019.96.48.55>
- Alsulaili, A., Al-Buloushi, B. Y., & Hamoda, M. F. (2020). Seasonal variation pattern of physicochemical and microbial parameters in a wastewater treatment plant. *Desalination and Water Treatment*, 208, 244–260. <https://doi.org/10.5004/dwt.2020.26461>
- APHA. (2017). *Wastewater, Standard Methods for examination water and wastewater*.
- Ayob, S., Othman, N., Ali, W., Altowayti, H., Sheikh, F., Bakar, N. A., Tahir, M., & Soedjono, E. S. (2021). A Review on Adsorption of Heavy Metals from Wood-Industrial Wastewater by Oil Palm Waste. *Journal of Ecological Engineering*, 22(3), 249–265.
- Azizi, S., Kamika, I., & Tekere, M. (2016). Evaluation of Heavy Metal Removal from Wastewater in a Modified Packed Bed Biofilm Reactor. *PLOS ONE*, 5(May 17), 1–13.
<https://doi.org/10.1371/journal.pone.0155462>
- Bakare, B. F., & Adeyinka, G. C. (2022). Evaluating the Potential Health Risks of Selected Heavy Metals across Four Wastewater Treatment Water Works in Durban , South Africa Evaluating the Potential Health Risks of Selected Heavy Metals across Four Wastewater Treatment Water Works in Durban , So. *Toxics*, 10(June), 340.
<https://doi.org/10.3390/toxics10060340>
- BEKELE, B. (2021). *Assessment of Effluent Characteristics and Wastewater Management practices in selected Hospitals of Addis Ababa, Ethiopia* (Issue September).
- Bhat, U. Q. S. U., & Kumar, I. A. A. (2022). Assessment of potential risks of heavy metals from wastewater treatment plants of Srinagar city , Kashmir. *International Journal of Environmental Science and Technology*, 19(9), 9027–9046. <https://doi.org/10.1007/s13762-021-03612-8>
- Bhave, P. P. (2020). Performance Evaluation of Wastewater Treatment Plant. *Water Conservation Science and Engineering*, 5(6 Feb), 23–29.
- Bressani-Ribeiro, T., Almeida, P. G. S., Volcke, E. I. P., & Chernicharo, C. A. L. (2018). Trickling filters following anaerobic sewage treatment: state of the art and perspectives. *Environmental Science: Water Research and Technology*, 4(11), 1721–1738.
<https://doi.org/10.1039/c8ew00330k>

- Buaisha, M., Balku, S., & Özalp, Ş. (2020). Heavy Metal Removal Investigation in Conventional Activated Sludge Systems. *Civil Engineering Journal*, 6(3), 470–477.
- Butte, G., & Zu, T. (2020). *Kaliti wastewater treatment plant field trip* (Issue March).
- Calderón, O. A. R. (2020). Current Updates and Perspectives of Biosorption Technology : an Alternative for the Removal of Heavy Metals from Wastewater. *BIOLOGY AND POLLUTION*, 6(29 January), 8–27.
- Carletti, G., Fatone, F., Bolzonella, D., & Cecchi, F. (2008). Occurrence and fate of heavy metals in large wastewater treatment plants treating municipal and industrial wastewaters. *Water Science & Technology*, 1329–1336. <https://doi.org/10.2166/wst.2008.230>
- Chai, W., Guo, L., Li, X., & Tang, J. (2019). Interval Prediction of Effluent TP for Wastewater Treatment Plants. *2019 IEEE Conference on Control Technology and Applications (CCTA)*, 511–516. <https://doi.org/10.1109/CCTA.2019.8920639>
- Chan, A., Salsali, H., & Mcbean, E. (2019). Heavy Metal Removal (Copper and Zinc) in Secondary Effluent from Wastewater Treatment Plants by Microalgae. *Acs Sustainable Chemistry and Energy*, November 2013, 1–9. <https://doi.org/10.1021/sc400289z>
- Chernicharo, C. A. L., van Lier, J. B., Noyola, A., & Bressani Ribeiro, T. (2015). Anaerobic sewage treatment: state of the art, constraints and challenges. *Reviews in Environmental Science and Bio/Technology*, 14(4), 649–679. <https://doi.org/10.1007/s11157-015-9377-3>
- Chipasa, K., & Ali, S. (2003). Accumulation and fate of selected heavy metals in a biological wastewater treatment system. *Waste Management*, 23(May), 135–143.
- Chirila, E., Draghici, C., & Brasov, U. T. (2014). Total and dissolved metals occurrence in municipal wastewater treatment plant effluents TOTAL AND DISSOLVED METALS OCCURRENCE. *Environmental Engineering and Management Journal*, 13(September), 2211–2218. <https://doi.org/10.30638/eemj.2014.246>
- Choubert, J., Pomiès, M., Ruel, S. M., & Coquery, M. (2011). In fl uent concentrations and removal performances of metals through municipal wastewater treatment processes. *Water Science & Technology*, 63, 1967–1973. <https://doi.org/10.2166/wst.2011.126>
- Czikkely, M., & Fogarassy, C. (2018). Urban Wastewater M anagement in Focus of Heavy Metal Contamination. *YBL JOURNAL OF BUILT ENVIRONMENT*, 6(January), 103–113.
- Dalel Belhaja, Ikram Jaabiria, Nesrine Turkia, Habib Ayadib, M. K. (2013). Occurrence and fate of heavy metals in activated sludge wastewater treatment plant. *ResearchGate*, February

2015. <https://doi.org/10.13140/2.1.1721.4246>

Dandan Xiao , He Li ., Yizhuo Wang, G. W. and C. W. (2023). Distribution Characteristics of Typical Heavy Metals in Sludge Potential Risks. *Water*, 15(11 Januray), 1–13.

Daphtary, N., & Daphtary, N. (2023). *What is bioaugmentation, and how does it work?*

<https://chemtech-us.com/articles/what-is-bioaugmentation-and-how-does-it-work/>

Daud, M. K., Rizvi, H., Akram, M. F., Ali, S., Rizwan, M., Nafees, M., & Jin, Z. S. (2018).

Review of Upflow Anaerobic Sludge Blanket Reactor Technology : Effect of Different Parameters and Developments for Domestic Wastewater Treatment. *Journal of Chemistry*, 2018(21 January 2018), 1–13.

Dewil, R., Baeyens, J., & Goutvrind, R. (2006). Ultrasonic treatment of waste activated sludge.

Environmental Progress, 25(2), 121–128. <https://doi.org/10.1002/ep.10130>

Douglas, R., Albert, G., Reuben, O., Paul, O., Hellen, N., & Boniface, G. (2022). Assessment of Heavy Metal Concentrations (Cu , Cd , Pb , and Zn) in Wastewater from Gusii Treatment Plant in Kisii. *Pan Africa Journal of Sciences*, 01(February).

<https://doi.org/10.47787/pasj.v1i02.12>

Drozdova, J., Raclavska, H., Raclavsky, K., & Skrobankova, H. (2019). Heavy metals in

domestic wastewater with respect to urban population in Ostrava , Czech Republic. *Water and Environment Journal*, 33, 77–85. <https://doi.org/10.1111/wej.12371>

Drozdova, J., Raclavska, H., & Skrobankova, H. (2015). A survey of heavy metals in municipal wastewater in combined sewer systems during wet and dry weather periods. *Urban Water Journal*, 12(2), 131–144.

Du, P., Zhang, L., Ma, Y., Li, X., Wang, Z., & Mao, K. (2017). Occurrence and Fate of Heavy Metals in Municipal Wastewater in Heilongjiang Province, China: A Monthly

Reconnaissance from 2015 to 2017. *Water Article, Cd*, 1–16.

Duan, B., Zhang, W., Zheng, H., Wu, C., & Zhang, Q. (2017). Disposal Situation of Sewage

Sludge from Municipal Wastewater Treatment Plants (WWTPs) and Assessment of the Ecological Risk of Heavy Metals for Its Land Use in Shanxi , China. *Environmental Research and Public Healt*, 14(21 July), 823. <https://doi.org/10.3390/ijerph14070823>

Edokpayi, J. N., Odiyo, J. O., Msagati, T. A. M., & Popoola, E. O. (2015). Removal Efficiency of Faecal Indicator Organisms , Nutrients and Heavy Metals from a Peri-Urban Wastewater Treatment Plant in Thohoyandou , Limpopo Province , South Africa. *Int. J. Environ. Res.*

- Public Health* 2015, 12(3), 7300–7320. <https://doi.org/10.3390/ijerph120707300>
- EEPA. (2003). *AMBIENT ENVIRONMENT STANDARDS FOR* (Issue August).
- El-Hameed, M. M. A., Abuarab, M. E., Al-Ansari, N., Mottaleb, S. A., Bakeer, G. A., Gyasi-Agyei, Y., & Mokhtar, A. (2021). Phycoremediation of contaminated water by cadmium (Cd) using two cyanobacterial strains (*Trichormus variabilis* and *Nostoc muscorum*). *Environmental Sciences Europe*, 33(1). <https://doi.org/10.1186/s12302-021-00573-0>
- El, R., Zakaria, H., Said, A., Taleb, E., Benafqir, M., Lhanafi, S., & El, N. (2018). Removal of heavy metals and organic pollutants by a sand rich in iron oxide. *Euro-Mediterranean Journal for Environmental Integration*, 17(20 February 2018), 1–11. <https://doi.org/10.1007/s41207-018-0058-9>
- Fang, P., Tang, Z. J., Chen, X. B., Huang, J. H., Tang, Z. X., & Cen, C. P. (2018). Removal of High-Concentration Sulfate Ions from the Sodium Alkali FGD Wastewater Using Ettringite Precipitation Method: Factor Assessment, Feasibility, and Prospect. *Journal of Chemistry*, 2018. <https://doi.org/10.1155/2018/1265168>
- Feng, J., Chen, X., Jia, L., Liu, Q., Chen, X., Han, D., & Cheng, J. (2018). Effluent concentration and removal efficiency of nine heavy metals in secondary treatment plants in Shanghai , China. *Environmental Science and Pollution Research*, 25(10 April 2018), 17058–17065.
- Gagnon, C., Turcotte, P., Gagné, F., & Smyth, S. A. (2021). Occurrence and size distribution of silver nanoparticles in wastewater effluents from various treatment processes in Canada. *Environmental Science and Pollution Research*, 28(46), 65952–65959. <https://doi.org/10.1007/s11356-021-15486-x>
- Gardner, M., Jones, V., Comber, S., Scrimshaw, M. D., Coello-Garcia, T., Cartmell, E., Lester, J., & Ellor, B. (2013). Performance of UK wastewater treatment works with respect to trace contaminants. *Science of the Total Environment*, 456–457, 359–369. <https://doi.org/10.1016/j.scitotenv.2013.03.088>
- Gautam, S. K., Sharma, D., Tripathi, J. K., Ahirwar, S., & Singh, S. K. (2013). A study of the effectiveness of sewage treatment plants in Delhi region. *Applied Water Science*, 3(1), 57–65. <https://doi.org/10.1007/s13201-012-0059-9>
- Geng, Y., Zhang, C., Zhang, Y., Huang, D., Yan, S., Sun, T., & Wang, J. (2021). Heavy metal (loid) s in sewage sludge in China : concentrations and spatial-temporal variations. *Environmental Science and Pollution Research*, 28(7 February 2021), 29146–29156.

- Gopal, V. (2020). Physico-Chemical Characteristics of Different Types of Waste Waters in Thiruvananthapuram District , South India. *Journal of Aquatic Biology & Fisheries* /, 8(30-10–2020), 88–96.
- Group, W. B. (2023). *Cleaner Cities, Brighter Futures: Ethiopia's journey in urban sanitation*. <https://www.worldbank.org/en/news/feature/2023/11/17/cleaner-cities-brighter-futures-ethiopia-s-journey-in-urban-sanitation>
- GULYÁS, G., VIKTÓRIA PITÁS, BENCE FAZEKAS, A. Á. K., & Department. (2015). Heavy Metal balance in a communal Wastewater Treatment plant. *HUNGARIAN JOURNAL OF INDUSTRY AND CHEMISTRY*, 43(1), 1–5. <https://doi.org/10.1515/hjic-2015-0001>
- Guo, S., Nkinahamira, F., Adyari, B., Zhang, Y., & Hu, A. (2023). Fate and Spatial – Temporal Variation of 23 Elements at 7 Wastewater Treatment Plants in Southeast City of China. *Water Article*, 15(21 March), 1–12.
- Haile, Y. T. (2018). *Institute of Water and Energy Science (Including Climate Change) Master Dissertation Submitted in partial fulfillment of the requirements for the Master degree in Water Engineering Presented by.*
- Hammoudani, Y. E. L., Dimane, F., & Ouarghi, H. El. (2021). Removal efficiency of heavy metals by a biological wastewater treatment plant and their potential risks to human health. *Environmental Engineering and Management Journal*, 20(6), 995–1002.
- Hargreaves, Andrew J, Constantino, C., Dotro, G., Cartmell, E., Hargreaves, A. J., Constantino, C., Dotro, G., & Cartmell, E. (2018). Fate and removal of metals in municipal wastewater treatment : a review. *Environmental Technology Reviews*, 7(1), 1–18. <https://doi.org/10.1080/21622515.2017.1423398>
- Hargreaves, Andrew J, Vale, P., Whelan, J., Constantino, C., Dotro, G., Campo, P., & Cartmell, E. (2017). Distribution of trace metals (Cu , Pb , Ni , Zn) between particulate , colloidal and truly dissolved fractions in wastewater treatment. *Chemosphere*, 175(7 February), 239–246. <https://doi.org/10.1016/j.chemosphere.2017.02.034>
- Hargreaves, Andrew Joseph. (2017). *Developing a Treatment Technology for the Removal of Trace Metals from Municipal Wastewater* (Issue October).
- Hargreaves, Vale, P., Whelan, J., Constantino, C., Dotro, G., & Cartmell, E. (2016). Mercury and antimony in wastewater : fate and treatment. *Water Air Soil Pollu*, 23 February 2016, 227: 89. <https://doi.org/10.1007/s11270-016-2756-8>

- He, S., & Xu, Y. J. (2016). Spatiotemporal distributions of Sr and Ba along an estuarine river with a large salinity gradient to the Gulf of Mexico. *Water (Switzerland)*, 8(8).
<https://doi.org/10.3390/w8080323>
- Idowu, G. A. (2022). Heavy metals research in Nigeria : a review of studies and prioritization of research needs. *Environmental Science and Pollution Research*, 29(27 July), 65940–65961.
<https://doi.org/10.1007/s11356-022-22174-x>
- Jaroslawn Gawdzik, Joanna Dlugosz, M. U. (2015). GENERAL CHARACTERISTICS OF THE QUANTITY AND QUALITY OF SEWAGE SLUDGE FROM SELECTED WASTEWATER TREATMENT PLANTS. *Environment Protection Engineering*, 41(2), 107–117. <https://doi.org/10.5277/epe150209>
- Joel, C., Ezekiel, K., & Mwamburi, L. A. (2017). Effect of Seasonal Variation on Performance of Conventional Wastewater Treatment System. *Journal of Applied & Environmental Microbiology*, 5(January), 1–7. <https://doi.org/10.12691/jaem-5-1-1>
- Juliastuti, S. R., Baeyens, J., & Creemers, C. (2003). Inhibition of nitrification by heavy metals and organic compounds: The ISO 9509 test. *Environmental Engineering Science*, 20(2), 79–90. <https://doi.org/10.1089/109287503763336511>
- Jun, Y., Ding, G. A. O., Tong-bin, C., & Mei, L. E. I. (2015). Comparison of heavy metal removal efficiencies in four activated sludge processes. *J. Cent. South Univ.*, 22(march 14), 3788–3794. <https://doi.org/10.1007/s11771-015-2923-x>
- Kadam, R., Khanthong, K., Jang, H., Lee, J., & Park, J. (2022). *Occurrence , Fate , and Implications of Heavy Metals during Anaerobic Digestion : A Review*.
- Kality Wastewater Treatment Plant - Wikimapia*. (2023.). <http://wikimapia.org/24716583/Kality-Wastewater-Treatment-Plant>
- Kanamarlapudi, S. L. R. K., KumarChintalpudi, V., & Muddada, S. (2018). Application of Biosorption for Removal of Heavy Metals from Wastewater. In *InTech eBooks*.
<https://doi.org/10.5772/intechopen.77315>
- Karnib, M., Kabbani, A., Holail, H., & Olama, Z. (2014). Heavy Metals Removal Using Activated Carbon , Silica and Silica Activated Carbon Composite. *Energy Procedia*, 50, 113–120. <https://doi.org/10.1016/j.egypro.2014.06.014>
- Karvelas, M., Katsoyiannis, A., & Samara, C. (2003). Occurrence and fate of heavy metals in the wastewater treatment process. *Chemosphere*, 53(10 June), 1201–1210.

[https://doi.org/10.1016/S0045-6535\(03\)00591-5](https://doi.org/10.1016/S0045-6535(03)00591-5)

- Kaviyarasan, K. (2014). Application of UASB Reactor in Industrial Wastewater Treatment—A Review. *International Journal of Scientific & Engineering Research*, 5(1), 584–589.
<http://www.ijser.org/researchpaper/Application-of-UASB-Reactor-in-Industrial-Wastewater-Treatment.pdf>
- Kinuthia, G. K., Ngure, V., Beti, D., Lugalia, R., Wangila, A., & Kamau, L. (2020). Levels of heavy metals in wastewater and soil samples from open drainage channels in Nairobi, Kenya: community health implication. *Sci Rep*, 10(1), 8434.
<https://doi.org/10.1038/s41598-020-65359-5>
- Koju, N. K., Sherpa, C. D., & Koju, N. P. (2022). Assessment of Physico-Chemical Parameters Along with the Concentration of Heavy Metals in the Effluents Released from Different Industries in Kathmandu Valley. *Water, Air, and Soil Pollution*, 233(5).
<https://doi.org/10.1007/s11270-022-05645-2>
- Kumar, M., Gogoi, A., & Mukherjee, S. (2020). Metal removal, partitioning and phase distributions in the wastewater and sludge: Performance evaluation of conventional, upflow anaerobic sludge blanket and downflow hanging sponge treatment systems. *Journal of Cleaner Production*, 249, 119426. <https://doi.org/10.1016/j.jclepro.2019.119426>
- Kushwah, R. K., Bajpaia, A., Malik, S., & Singh, A. (2011). Seasonal variation of physicochemical parameters of waste water from a sewage treatment plant, Bhopal (India). *International Journal of Chemical Sciences*, 9(3), 1545–1552.
- Laurent, J., Casellas, M., Carrère, H., & Dagot, C. (2011). Effects of thermal hydrolysis on activated sludge solubilization, surface properties and heavy metals biosorption. *Chemical Engineering Journal*, 166(3), 841–849. <https://doi.org/10.1016/j.cej.2010.11.054>
- Lawal, K. K., Ekeleme, I. K., Onuigbo, C. M., & Ikpeazu, V. O. (2021). A review on the public health implications of heavy metals. *World Journal of Advanced Research and Reivew*, 10(11 June), 255–265.
- Li Huizhen, Li Weizong, Liu Yuan, Y. J. (2022). Research Advances in Evaluating Occurrence and Toxicity of Contaminants in Wastewater Treatment Plant Effluents and Receiving Waterways. *Asian Journal of Ecotoxicology*, 17(4), 489–502.
<https://doi.org/10.7524/AJE.1673>
- Li, L., He, J., Gan, Z., & Yang, P. (2021). Occurrence and fate of antibiotics and heavy metals in

- sewage treatment plants and risk assessment of reclaimed water in Chengdu, China. *Chemosphere*, 272, 129730. <https://doi.org/10.1016/J.CHEMOSPHERE.2021.129730>
- Liew, C., Kiatkittipong, W., Lim, J., & Lam, M. (2021). Stabilization of heavy metals loaded sewage sludge : Reviewing conventional to state-of-the-art thermal treatments in achieving energy sustainability. *Chemosphere*, 277, 130310. <https://doi.org/10.1016/j.chemosphere.2021.130310>
- Lin, G., Wang, K., He, X., Yang, Z., & Wang, L. (2022). Characterization of physicochemical parameters and bioavailable heavy metals and their interactions with microbial community in arsenic-contaminated soils and sediments. *Environmental Science and Pollution Research*, 29(33), 49672–49683. <https://doi.org/10.1007/s11356-022-19395-5>
- Maal-Bared, R. (2020). Operational impacts of heavy metals on activated sludge systems: the need for improved monitoring. *Environmental Monitoring and Assessment*, 192(9), 560. <https://doi.org/10.1007/s10661-020-08529-2>
- Mahmoud, N. J. A. (2002). *Anaerobic Pre-treatment of Sewage Under Low Temperature (15 °C) Conditions in an Integrated UASB-Digester System.*
- Matos, P. C. M., & Correia, M. A. T. M. M. (2016). Behaviour and fate of metals in urban wastewater treatment plants : a review. *International Journal of Environmental Science and Technology*, 13(1), 359–386. <https://doi.org/10.1007/s13762-015-0887-x>
- Maurya, C., & Srivastava, J. N. (2019). Current Seasonal Variations in Physicochemical and Heavy Metals Parameters of Sewage Treatment Plant Effluent and Suitability for Irrigation. *Journal of Water Resource and Protection*, 11(07), 852–865. <https://doi.org/10.4236/jwarp.2019.117052>
- Metcalf and Eddy, I. (2003). *Wastewater EngbyMecalfandEddy2003.pdf.*
- Młyński, D., Młyńska, A., Chmielowski, K., & Pawelek, J. (2020). Investigation of the wastewater treatment plant processes efficiency using statistical tools. *Sustainability (Switzerland)*, 12(24), 1–16. <https://doi.org/10.3390/su122410522>
- Mohammadi, M., Mowla, D., Esmaeilzadeh, F., & Ghasemi, Y. (2019). Enhancement of sulfate removal from the power plant wastewater using cultivation of indigenous microalgae: Stage-wise operation. *Journal of Environmental Chemical Engineering*, 7(1), 102870. <https://doi.org/10.1016/j.jece.2018.102870>
- Mpongwana, N., Rathilal, S., & Tetteh, E. K. (2022). Recovery Strategies for Heavy Metal-

- Inhibited Biological Nitrogen Removal from Wastewater Treatment Plants: A Review. *Microorganisms*, 10(9). <https://doi.org/10.3390/microorganisms10091834>
- Narayanan, C. M., & Narayan, V. (2019). Biological wastewater treatment and bioreactor design: A review. *Sustainable Environment Research*, 1(1), 1–17. <https://doi.org/10.1186/s42834-019-0036-1>
- Nelson, M. J., Nakhla, *et al.* (2005). Nitrification (Ammonia Oxidation) In Wastewater Treatment Plants. In *Engineering* (Vol. 3, Issue 1). https://www.bioscienceinc.com/wp-content/uploads/2016/03/Nitrification-Ammonia-Oxidation-in-Wastewater-Treatment-Plants1.pdf%0Ahttp://www.wis.pk.edu.pl/media/file/konferencje/Jingjing_Yang.pdf%0Ahttp://www.loc.gov/catdir/enhancements/fy0647/98037263-d.htm
- Nham, T. T., & Monitoring. (2006). Monitoring Heavy Metals by ICP- OES for Compliance with RoHS and. *Agilent Technology Application Note*, 2003.
- Niu, L., Sun, S., Yu, F., Zhang, X., Fan, S., Sun, Y., Lin, W., Wang, B., & Zhang, X. (2023). Performance of Sludge in the UASB Reactor for Treating Sulfate Wastewater: Sulfate Removal and Changes in the Community Structure Before and After Reaction. *Water, Air, & Soil Pollution*, 234(4), 246. <https://doi.org/10.1007/s11270-023-06267-y>
- Nyamukamba, P., Moloto, M. J., Tavengwa, N., & Ejidike, I. P. (2019). Evaluating Physicochemical Parameters , Heavy Metals , and Antibiotics in the Influent and Final Effluents of South African Wastewater Treatment Plants. *Pol. J. Environ. Stud*, 28(February), 1305–1312. <https://doi.org/10.15244/pjoes/85122>
- Oliveira, A. D. S., Bodo, A., Beltramini Trevilato, T. M., Magosso Takayanagui, A. M., Domingo, J. L., & Segura-Muñoz, S. I. (2007). Heavy metals in untreated/treated urban effluent and sludge from a biological wastewater treatment plant. *Environmental Science and Pollution Research*, 14(7), 483–489. <https://doi.org/10.1065/espr2006.10.355>
- Olofsson, U., Lundstedt, S., & Haglund, P. (2010). Behavior and fate of anthropogenic substances at a Swedish sewage treatment plant. *Water Science and Technology*, 62(12), 2880–2888. <https://doi.org/10.2166/wst.2010.987>
- Olujimi O. O., Fatok O. S., Odendaal J. P., D. A. P. and O. O. U. (2013). Variation in levels and removal efficiency of heavy and trace metals from wastewater treatment plant effluents in Cape Town and Stellenbosch , South Africa. *African Journal of Biotechnology Full*, 15(September), 1101–1135. <https://doi.org/10.5897/AJB12.1723>

- Onchoke, K. K., Janusa, M. A., & Sasu, S. A. (2015). Evaluation of the performance of a rural municipal wastewater treatment plant in Nacogdoches , East Texas (USA). *Chemistry and Ecology*, 31(September 2015), 567–582. <https://doi.org/10.1080/02757540.2015.1029463>
- Penradee Chanpiwat, Suthipong Sthiannopkao, K.-W. K. (2010). Metal content variation in wastewater and biosludge from Bangkok ’ s central wastewater treatment plants. *Microchemical Journal*, 95(February), 326–332. <https://doi.org/10.1016/j.microc.2010.01.013>
- Phanwilai, S., Noophan, P., Li, C. W., & Choo, K. H. (2020). Effect of COD:N ratio on biological nitrogen removal using full-scale step-feed in municipal wastewater treatment plants. *Sustainable Environment Research*, 30(1). <https://doi.org/10.1186/s42834-020-00064-6>
- Pipi, A. R. F., Magdalena, A. G., Giafferis, G. P., da Silva, G. H. R., & Piacenti-Silva, M. (2018). Evaluation of metal removal efficiency and its influence in the physicochemical parameters at two sewage treatment plants. *Environmental Monitoring and Assessment*, 190(5). <https://doi.org/10.1007/s10661-018-6633-3>
- Powell, N., Shilton, A. N., Pratt, S., & Chisti, Y. (2008). Factors influencing luxury uptake of phosphorus by microalgae in waste stabilization ponds. *Environmental Science and Technology*, 42(16), 5958–5962. <https://doi.org/10.1021/es703118s>
- Rashid, S. S. (2020). *Investigation on Life Cycle Assessment of Centralised Wastewater Treatment, and its Upgrading using LCA*.
- Renu, Agarwal, M., & Singh, K. (2017). Heavy metal removal from wastewater using various adsorbents: A review. *Journal of Water Reuse and Desalination*, 7(4), 387–419. <https://doi.org/10.2166/wrd.2016.104>
- Rizvi, H. C. B. S. T. B. A. U. A. S. B. R. (U.) U. S. C. B. (2010). *Sewage Treatment By an Upflow Anaerobic Sludge Blanket Reactor (Uasb) Under Subtropical Conditions*. 107.
- S Makuwa, M Tlou, E Fosso-Kankeu, & E Green. (2022). The effects of dry versus wet season on the performance of a wastewater treatment plant in North West Province, South Africa. *Water SA*, 48(1 January), 40–49. <https://doi.org/10.17159/wsa/2022.v48.i1.3897>
- Sa, M. (2010). Experimental studies on effect of Heavy Metals presence in Industrial Wastewater on Biological Treatment. *International Journal of Environmental Sciences*, 1(4), 666–676.
- Saha, M. L., Alam, A., Khan, M. R., & Hoque, S. (1970). Bacteriological, Physical And

- Chemical Properties Of The Pagla Sewage Treatment Plant's Water. *Dhaka University Journal of Biological Sciences*, 21(1), 1–8. <https://doi.org/10.3329/dujbs.v21i1.9739>
- Salihoglu, N. K. (2013). Assessment of Urban Source Metal Levels in Influent , Effluent , and Sludge of Two Municipal Biological Nutrient Removal Wastewater Treatment Plants of Bursa , an Industrial City in Turkey. *Clean – Soil, Air, Water*, 41(February), 153–165. <https://doi.org/10.1002/clen.201100518>
- Santos-Echeandia, J. (2016). The fate and transport of trace metals through sewage treatment plant processes. *Sewage Treatment: Processes and Impact, January 2009*, 1–7.
- Sanz, M. R., & Mill, V. (2021). Inputs of Total and Labile Dissolved Metals from Six Facilities Continuously Discharging Treated Wastewaters to the Marine Environment of Gran Canaria Island (Canary Islands , Spain). *Environmental Research and Public Health*, 18(November), 11582.
- Sekandari, A. W. (2019). Cost Comparison Analysis of Wastewater Treatment Plants. *IJSTE- International Journal of Science Technology & Engineering |*, 6(1), 65–72. www.ijste.org
- Shamuyarira, K. K., & Gumbo, J. R. (2014). Assessment of Heavy Metals in Municipal Sewage Sludge : A Case Study of Limpopo Province , South Africa. *Environmental Research and Public Health*, 11(February), 2569–2579. <https://doi.org/10.3390/ijerph110302569>
- Shikuku, V. O., Achieng, G. O., Ng, E., Okowa, G. M., Masitsa, G. A., & Owuor, J. J. (2017). activated sludge at a municipal wastewater treatment plant in Kisumu City , Kenya. *Research Journal of Chemical Sciences*, 7(8), 19–25.
- Shingleton, C. E., Shingleton, C., & Virginia, W. (2023). *Concentrated Wastewater Treatment Using a Ferric Iron-dosed Anaerobic Upflow Sludge Blanket Reactor for Recovery of Phosphorus and Ammonium Concentrated Wastewater Treatment Using a Ferric Iron-dosed Anaerobic Upflow Sludge Blanket Reactor for Recovery of.*
- Singh, A., Kamble, S. J., Sawant, M., Chakravarthy, Y., Kazmi, A., Aymerich, E., Starkl, M., Ghangrekar, M., & Philip, L. (2018). Technical , hygiene , economic , and life cycle assessment of full-scale moving bed biofilm reactors for wastewater treatment in India. *Environ Sci Pollut Res*, 25(10 Nov), 2552–2569.
- Singh, R., Gautam, N., Mishra, A., & Gupta, R. (2011). Heavy metals and living systems: An overview. *Indian Journal of Pharmacology*, 43(3), 246–253. <https://doi.org/10.4103/0253-7613.81505>

- Somerset, G. S. O. O. F. O. V. S. (2020). Physicochemical properties of wastewater effluent from two selected wastewater treatment plants (Cape Town) for water quality improvement. *International Journal of Environmental Science and Technology*, 0123456789. <https://doi.org/10.1007/s13762-020-02788-9>
- Sörme, L., & Lagerkvist, R. (2002). Sources of heavy metals in urban wastewater in Stockholm. *Science of the Total Environment*, 298(1–3), 131–145.
- Sutherland, D. L., & Ralph, P. J. (2021). Shortening hydraulic retention time through effluent recycling : impacts on wastewater treatment and biomass production in microalgal treatment systems. *Journal of Applied Phycology*, 0123456789. <https://doi.org/10.1007/s10811-021-02573-2>
- Sylwan, I., & Thorin, E. (2021). Removal of Heavy Metals during Primary Treatment of Municipal Wastewater and Possibilities of Enhanced Removal : A Review. *Water*, 13(April), 1–26.
- Sysop. (2020). *What Is Biological Wastewater Treatment?* <https://www.fluencecorp.com/what-is-biological-wastewater-treatment/>
- Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012a). Molecular, Clinical and Environmental Toxicology. In A. Luch (Ed.), *Molecular, Clinical and Environmental Toxicology* (Vol. 101). Springer Basel. <https://doi.org/10.1007/978-3-7643-8340-4>
- Tchounwou, Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012b). *Experientia Supplementum Volume 101*. <http://www.springer.com/series/4822>
- Thawornchaisit, U., Juthaisong, K., Parsongjeen, K., & Phoengchan, P. (2019). Optimizing acid leaching of copper from the wastewater treatment sludge of a printed circuit board industry using factorial experimental design. *Journal of Material Cycles and Waste Management*, 21(6), 1291–1299. <https://doi.org/10.1007/s10163-019-00882-w>
- Tytła, M. (2019). Assessment of Heavy Metal Pollution and Potential Ecological Risk in Sewage Sludge from Municipal Wastewater Treatment Plant Located in the Most Industrialized Region in Poland — Case Study. *Environmental Research and Public Health*, 16(July), 1–16.
- Tytła, M., Widziewicz, K., & Zielewicz, E. (2015). Heavy metals and its chemical speciation in sewage sludge at different stages of processing. *Environmental Technology*, 2016, 32(August 2015), 899–908. <https://doi.org/10.1080/09593330.2015.1090482>

- van Haandel, A. C., & Lettinga, G. (1995). *Anaerobic Sewage Treatment: A Practical Guide for Regions with a Hot Climate*. <https://api.semanticscholar.org/CorpusID:129756196>
- Velusamy, K., & Kannan, J. (2016). Seasonal Variation in Physico-Chemical and Microbiological Characteristics of Sewage Water from Sewage Treatment Plants. *Current World Environment*, *11*(3), 791–799. <https://doi.org/10.12944/cwe.11.3.14>
- Vriens, B., Voegelin, A., Hug, S. J., Kaegi, R., Winkel, L. H. E., Buser, A. M., & Berg, M. (2017). Quantification of Element Fluxes in Wastewaters: A Nationwide Survey in Switzerland. *Environmental Science and Technology*, *51*(19), 10943–10953. <https://doi.org/10.1021/acs.est.7b01731>
- Wang, Jianmin, Huang, C. P., & Allen, H. E. (2003). *Modeling heavy metal uptake by sludge particulates in the presence of dissolved organic matter*. *37*, 4835–4842. <https://doi.org/10.1016/j.watres.2003.08.021>
- Wang, Jie, Fang, H., Jia, H., Yang, G., Gao, F., & Liu, W. (2018). Effect of zero-valent iron and trivalent iron on UASB rapid start-up. *Environmental Science and Pollution Research*, *25*(1), 749–757. <https://doi.org/10.1007/s11356-017-0457-5>
- Wang, M., Chen, C., Ju, Y., Tsai, M., Chen, C., & Dong, C. (2021). Toxic / Hazardous Substances and Environmental Engineering Distribution and environmental risk assessment of trace metals in sludge from multiple sources in Taiwan. *Journal of Environmental Science and Health, Part A*, *56*(4), 481–491. <https://doi.org/10.1080/10934529.2021.1887687>
- Wang, S., Liu, T., Xiao, X., & Luo, S. (2021). *Advances in microbial remediation for heavy metal treatment : a mini review*.
- Widziewicz, K., Tytła, M., Widziewicz, K., & Zielewicz, E. (2015). Heavy metals and its chemical speciation in sewage sludge at different stages Heavy metals and its chemical speciation in sewage sludge at different stages of processing. *Environmental Technology*, *37*(September), 899–908. <https://doi.org/10.1080/09593330.2015.1090482>
- Worldbank. (2017). *INTERNATIONAL DEVELOPMENT ASSOCIATION PROJECT APPRAISAL DOCUMENT ON A PROPOSED CREDIT*.
- Xia, X., Zhu, F., Li, J., Yang, H., Wei, L., Li, Q., Jiang, J., Zhang, G., & Zhao, Q. (2020). A Review Study on Sulfate-Radical-Based Advanced Oxidation Processes for Domestic/Industrial Wastewater Treatment: Degradation, Efficiency, and Mechanism.

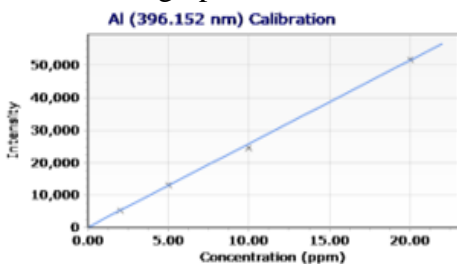
- Frontiers in Chemistry*, 8(November). <https://doi.org/10.3389/fchem.2020.592056>
- Xiang, S., Liu, Y., Zhang, G., Ruan, R., Wang, Y., Wu, X., Zheng, H., Zhang, Q., & Cao, L. (2020). New progress of ammonia recovery during ammonia nitrogen removal from various wastewaters. *World Journal of Microbiology and Biotechnology*, 36(10), 1–20. <https://doi.org/10.1007/s11274-020-02921-3>
- Xiao, H., Zhang, S., Zhai, J., He, Q., Mels, A., Ning, K., & Liu, J. (2013). Retention and distribution of Cu, Pb, Cr, and Zn in a full-scale hybrid constructed wetland receiving municipal sewage. *Water Science and Technology*, 67(10), 2257–2264. <https://doi.org/10.2166/wst.2013.121>
- Xu, Y., & Xu, T. (2008). Heavy Metal Complexes Wastewater Treatment with Chelation Precipitation. *2008 2nd International Conference on Bioinformatics and Biomedical Engineering*, 2789–2793. <https://doi.org/10.1109/ICBBE.2008.1029>
- Yahya El Hammoudani *, F. D. (2021). Occurrence and fate of micropollutants during sludge treatment : Case of Al-Hoceima WWTP, Morocco. *Environmental Challenges*, 5(August), 100321. <https://doi.org/10.1016/j.envc.2021.100321>
- Yoshida, H., Christensen, T. H., Guildal, T., & Scheutz, C. (2015). A comprehensive substance flow analysis of a municipal wastewater and sludge treatment plant. *Chemosphere*, 138, 874–882.
- Zhang, L. (2016). *Anaerobic Treatment of Municipal Wastewater in a UASB-Digester System*.
- Zhao, W., Xie, H., Li, J., Zhang, L., & Zhao, Y. (2021). Application of alum sludge in wastewater treatment processes: “Science” of reuse and reclamation pathways. *Processes*, 9(4), 1–12. <https://doi.org/10.3390/pr9040612>
- Ziolko, D., Martin, O. V., Scrimshaw, M. D., & Lester, J. N. (2011). *An evaluation of metal removal during wastewater treatment: The potential to achieve more stringent final effluent standards*. 41(8), 733–769. <https://doi.org/10.1080/10643380903140299>

APPENDICES

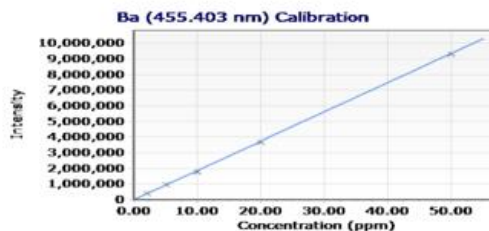
1.ICP-OES result of heavy metal concentration in kaliti centralized wastewater treatment plant over two consecutive days of April, May, and June (2023)

sampling Date	Solution Label	Ag (338.289 nm)	Ba (455.403 nm)	Fe (238.204 nm)	Al (396.152 nm)	Cd (226.502 nm)	Cr (267.716 nm)	Cu (324.754 nm)	Mn (257.610 nm)	Zn (206.200 nm)
12/4/2023	Inlet	BDL	0.06 (ppm)	0.15 (ppm)	0.01 (ppm)	0.01 u (ppm)	0.02 u (ppm)	0.01 u (ppm)	0.36 (ppm)	0.01 (ppm)
12/4/2023	UASB effluent	BDL	0.08 (ppm)	0.14 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.71 (ppm)	0.00 u (ppm)
12/4/2023	UASB Sludge	BDL	0.63 (ppm)	10.89 (ppm)	0.19 (ppm)	0.00 (ppm)	0.00 u (ppm)	0.01 (ppm)	0.18 (ppm)	0.05 (ppm)
12/4/2023	trikiling filter	BDL	0.05 (ppm)	0.01 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.18 u (ppm)	0.01 u (ppm)
12/4/2023	Returned sludge	BDL	0.07 (ppm)	0.04 (ppm)	BDL	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	2.37 (ppm)	0.02 (ppm)
12/4/2023	Outlet	BDL	0.05 (ppm)	0.01 (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.13 (ppm)	0.05 (ppm)
12/4/2023	Dry Sludge	BDL	23.58 (ppm)	938.45 (ppm)	20.83 (ppm)	0.00 (ppm)	0.18 (ppm)	0.47 (ppm)	1.72 (ppm)	3.24 (ppm)
13/04/2023	Inlet	BDL	0.07 (ppm)	0.15 (ppm)	0.01 (ppm)	0.00 u (ppm)	0.01 u (ppm)	0.01 u (ppm)	0.36 (ppm)	0.00 (ppm)
13/04/2023	UASB effluent	BDL	0.08 u (ppm)	0.15 u (ppm)	BDL	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.33 (ppm)	BDL
13/04/2023	UASB Sludge	BDL	0.13 (ppm)	0.37 (ppm)	0.02 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.77 (ppm)	0.00 (ppm)
13/04/2023	trikiling filter	BDL	0.05 u (ppm)	0.01 u (ppm)	BDL	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.12 (ppm)	0.00 u (ppm)
13/04/2023	Returned sludge	BDL	0.12 u (ppm)	0.31 u (ppm)	0.03 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	1.17 (ppm)	0.01 (ppm)
13/04/2023	Outlet	BDL	0.08 (ppm)	0.17 (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.22 (ppm)	0.01 (ppm)
24/05/2023	Inlet	BDL	0.07 (ppm)	0.13 (ppm)	0.01 (ppm)	0.03 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.40 (ppm)	0.01 (ppm)
24/05/2023	UASB effluent	BDL	0.09 (ppm)	0.02 (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.71 (ppm)	0.01 (ppm)
24/05/2023	UASB Sludge	BDL	6.84 (ppm)	610.02 (ppm)	11.81 (ppm)	0.01 (ppm)	0.05 (ppm)	0.11 (ppm)	0.46 (ppm)	0.81 (ppm)
24/05/2023	trikiling filter	BDL	0.08 (ppm)	0.03 (ppm)	0.00 u (ppm)	0.00 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.70 (ppm)	0.01 (ppm)
24/05/2023	Returned sludge	BDL	0.09 (ppm)	0.04 (ppm)	BDL	0.01 (ppm)	0.00 u (ppm)	0.00 u (ppm)	2.15 (ppm)	0.05 (ppm)
24/05/2023	Outlet	BDL	0.06 (ppm)	0.01 u (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 (ppm)	0.37 (ppm)	0.03 (ppm)
24/05/2023	Dry Sludge	1.00 (ppm)	27.55 (ppm)	2838.38 o (ppm)	63.45 o (ppm)	0.01 (ppm)	0.24 (ppm)	0.52 (ppm)	1.98 (ppm)	3.59 (ppm)
25/05/2023	Inlet	BDL	0.07 (ppm)	0.18 (ppm)	0.01 (ppm)	0.02 (ppm)	0.006u (ppm)	0.00 (ppm)	0.39 (ppm)	0.02 (ppm)
25/05/2023	UASB Sludge	BDL	6.52 (ppm)	545.31 (ppm)	8.38 (ppm)	0.00 (ppm)	0.05 (ppm)	0.13 (ppm)	0.46 (ppm)	0.84 (ppm)
25/05/2023	UASB effluent	BDL	0.09 (ppm)	0.01 (ppm)	BDL	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.65 (ppm)	0.01 (ppm)
25/05/2023	trikiling filter	BDL	0.06 (ppm)	0.01 u (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 (ppm)	0.36 (ppm)	0.01 (ppm)
25/05/2023	Returned sludge	BDL	0.06 (ppm)	0.00 (ppm)	BDL	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	1.25 (ppm)	0.01 u (ppm)
25/05/2023	Outlet	BDL	0.05 (ppm)	0.02 u (ppm)	BDL	0.00 u (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.01 (ppm)	BDL
13/06/2023	Inlet	BDL	0.07 (ppm)	0.06 (ppm)	BDL	0.01 u (ppm)	0.02u (ppm)	0.00 (ppm)	0.44 (ppm)	0.00 u (ppm)
13/06/2023	UASB effluent	BDL	0.09 (ppm)	0.05 (ppm)	BDL	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.72 (ppm)	0.00 (ppm)
13/06/2023	UASB Sludge	BDL	0.31 (ppm)	25.40 (ppm)	0.31 (ppm)	0.03 (ppm)	0.02 (ppm)	0.01 (ppm)	0.03 (ppm)	0.13 (ppm)
13/06/2023	trikiling filter	BDL	0.06 ! (ppm)	0.01 !u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.47 (ppm)	0.01 (ppm)
13/06/2023	Returned sludge	BDL	0.06 (ppm)	0.00 (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 u (ppm)	1.38 (ppm)	0.04 (ppm)
13/06/2023	Outlet	BDL	0.06 (ppm)	0.01 u (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 (ppm)	0.11 (ppm)	0.02 (ppm)
13/06/2023	Dry Sludge	1.54 (ppm)	26.32 (ppm)	2726.82 o ppm	56.92 o (ppm)	0.01 (ppm)	0.21 (ppm)	0.44 (ppm)	1.85 (ppm)	3.07 (ppm)
14/06/2023	Inlet	BDL	0.08 (ppm)	0.04 (ppm)	0.00 u (ppm)	0.01 (ppm)	0.00 u (ppm)	0.00 (ppm)	0.42 (ppm)	0.08 (ppm)
14/06/2023	UASB effluent	BDL	0.09 (ppm)	0.02 (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.69 (ppm)	0.01 (ppm)
14/06/2023	UASB Sludge	BDL	4.68 (ppm)	459.22 (ppm)	9.54 (ppm)	0.00 (ppm)	0.04 (ppm)	0.10 (ppm)	0.39 (ppm)	0.69 (ppm)
14/06/2023	trikiling filter	BDL	0.06 (ppm)	0.01 (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 u (ppm)	0.38 (ppm)	0.02 (ppm)
14/06/2023	Returned sludge	BDL	0.06 (ppm)	0.01 (ppm)	BDL	0.00 (ppm)	0.00 u (ppm)	0.00 (ppm)	1.08 (ppm)	0.03 (ppm)
14/06/2023	Outlet	BDL	0.06 (ppm)	0.00 (ppm)	BDL	0.00 u (ppm)	0.00 u (ppm)	0.00 (ppm)	0.15 (ppm)	0.00 (ppm)

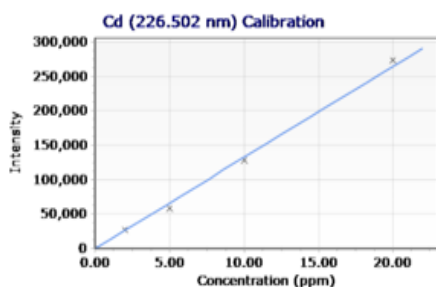
2, Calibration graph of ICP-OES result for heavy metal analysis



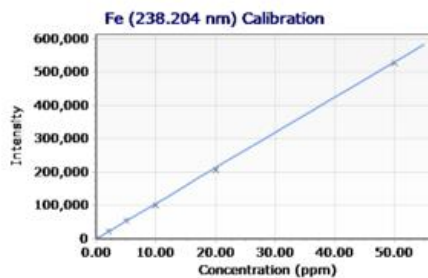
Intensity = 2580.14587913 * Concentration + 107.89654570
 Correlation coefficient: 0.99952
 %RSE:3.9122883



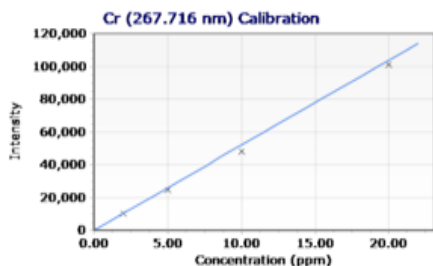
Intensity = 187294.28322375 * Concentration + 260.13094366
 Correlation coefficient: 0.99992
 %RSE:5.01731596



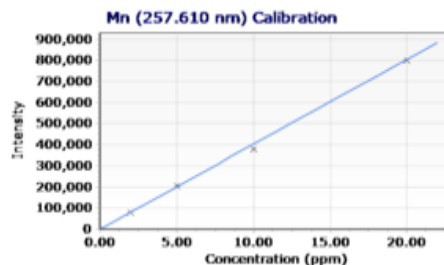
Intensity = 13225.52625986 * Concentration + 21.09211569
 Correlation coefficient: 0.99889
 %RSE:9.08712950



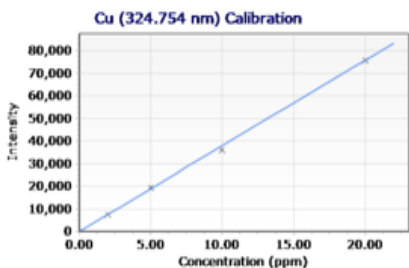
Intensity = 10606.39175628 * Concentration + 468.39170362
 Correlation coefficient: 0.99986
 %RSE:4.72577124



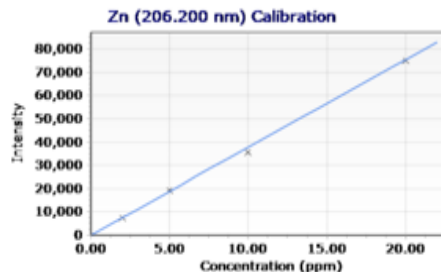
Intensity = 5202.43248373 * Concentration + 26.31295849
 Correlation coefficient: 0.99963
 %RSE:6.78558616



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



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



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