HEAVY METALS CONCENTRATION IN SEDIMENTS AND CHARACTERIZATION OF HYDROCHEMICAL FACIES IN THE SURFACE WATER IN LOKICHAR BASIN, TURKANA COUNTY, KENYA

BY

ELIZABETH LUSWETI (BSc. Earth Science)

Reg No: I56/38139/2017

A Thesis Submitted to the Department of Geography in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science Hydrology in the School of Pure and Applied Sciences, Kenyatta University.

June 2025

DECLARATION

This thesis is my original work and has not been presented for a degree or any other award from the university.

Signature……………………... Date……..... /………..../2025

Elizabeth Lusweti (I56/38139/2017)

Department of Geography

SUPERVISORS

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

Dr. Mary Makokha

Department of Geography

Kenyatta University

Signature……………………... Date………. /…….... /2025

Dr Jackson Musau

Department of Geography

Kenyatta University

Signature……………………. Date………. /………. /2025

DEDICATION

I dedicate this thesis to my dear parents and Siblings.

ACKNOWLEDGEMENT

I would wish to acknowledge the following for their instrumental role in my study. First, my supervisors: are Prof. Joy Obando, Dr. Mary Makokha and Dr Jackson Musau. Second, family and friends for the continuous support throughout the study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

LIST OF ABBREVIATIONS

As	Arsenic
BOD	Biological Oxygen Demand
Cd	Cadmium
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
Fe	Iron
KEBS	Kenya Bureau of Standards
KNBS	Kenya National Bureau of Statistics
NTU	Nephelometric Turbidity Units
Pb	Lead
SW	Surface Water
USEPA	US Environmental Protection Agency
WHO	World Health Organization
Zn	Zinc

ABSTRACT

Surface water contamination due to heavy metals has become a great concern to the health of human beings. Thus the research examined the concentration of heavy metals in water sediments and the characterization of the hydro-chemical facies of the surface water in the Lokichar basin. The key objectives included the investigation of the selected physical and chemical properties in surface water, determination of the level of concentration of selected heavy metals in sediments and characterization of the hydro-chemical facies of surface water in the Lokichar basin. Water and sediment samples were collected by the typical method, processed and analyzed. The parameters which were sampled insitu are Temperature, pH, Turbidity and Electrical Conductivity while BOD,COD, D.O, pH, Sulphate, Nitrate, Magnesium, Chloride, Potassium, Sodium, Calcium, Zinc, Iron, Cadmium, Arsenic and Lead were sampled and analysed in the laboratory. ANOVA was used to determine the variations between water quality parameters. Piper and Durov diagrams were used to determine the hydro-chemical facies of water. Finally, samples of sediments were analysed using geo –accumulation (Igeo) and contamination factor (CF) to determine the heavy metal concentration and sources. The results showed that there was no significant difference in each site ($p > 0.05$) in all physical-chemical water quality parameters in different sampling sites. The hydro-chemical analysis revealed the water types in the region as; 40 % $Ca^{2+-}Mg^{2+-}Cl^{-}SO_4^{2-}$ type, 40% $Ca^{2+}Mg^{2+}$-HCO_{3-}, 20 % Na+-K+-$HCO_{3-,}$ with no Na^{+}-K^{+}-Cl^{-}-SO_4^{2-} water type in 50 % of the sample. Durov and Piper diagrams illustrated that a simple mineral dissolution or mixing process is mainly responsible for variation in the hydro-geochemistry of surface water in the study area. Igeo revealed that Lokichar Basin was practically uncontaminated with anthropogenic sources with values ranging between 0-1. The CF indicated that the pollution intensity ranged from low to moderate in Lokichar Basin. Overall, it can be concluded that oil exploration has not interfered with the quality of the surface water resources in the Lokichar Basin.The study recommends continuous monitoring of surface water resources in Lokichar Basin,

CHAPTER ONE: INTRODUCTION

This chapter introduces the background of the study the rationale behind it and also the the objective and the scope of the study.

1.1 Background of the Study

Oil and gas industries act as a key player in the economies of nations that are significant oil producers, yet they also pose a considerable risk of causing severe environmental catastrophes. As highlighted by Johnston, Lim, and Roh (2019), the global count of oil fields stands at approximately 40,000, and around 6 million individuals reside or labor in their vicinity. Many countries endowed with substantial petroleum resources depend on the revenue generated from their sales, contributing to their economic well-being. The production and processing of oil and gas, on the other hand, have negative impacts on human health and the environment; soil, water and air (Plänitz & Kuzu, 2015). Russia, the United States of America (USA), Saudi Arabia, and China are the world's top oil producers (Al-Ghouti, Al-Kaabi, Ashfaq, & Da'na, 2019).

There are sixteen oil-producing and exporting countries in Africa, including Nigeria, Libya, Angola, and Algeria (ADB., 2009). Uganda was the first country in East Africa to discover oil in 2006. Prior to it, agriculture formed the backbone of the majority of the region's economies. Commercial oil drilling in Kenya began in the Lokichar Basin in Turkana County in 1960 and has continued ever since (Heya, 2011; Purcell, 2014). Later in December 2017, 38 wells at the Tertiary Rift Valley Oil Block 13T South Lokichar Basin were drilled (TullowPLC, 2018). The oil exploration process creates a significant amount of waste (Fakhru'l-Razi et al., 2009).

The primary waste output linked to oil and gas extraction is known as produced water, which contains organic compounds, salts, metals, and radioactive substances(Azetsu-Scott et al., 2007). The key components found within produced water encompass factors such as salinity levels (quantified as salt content), total dissolved solids (TDS), electrical conductivity, oil and grease content, polyaromatic hydrocarbons (PAHs), as well as benzene, toluene, ethylbenzene, and xylenes (collectively referred to as BTEX), phenols, organic acids, and naturally occurring organic and inorganic compounds that contribute to water hardness and scaling (Al-Ghouti et al., 2019).

The discharge of this wastewater into the freshwater environment affects agricultural resources and destroys aquatic life. Silambarasan, Senthilkumaar, and Velmurugan (2012) demonstrated that a significant worry pertains to the presence of heavy metal pollution within surface water, particularly in rivers, given their role as pathways for the conveyance of metallic substances (Mohiuddin, Zakir, Otomo, Sharmin, & Shikazono, 2010). In the past, there was a common belief that rivers and lakes in developing nations were least affected by pollution. However, this perception has gradually shifted due to the rise in industrial development over time Kenya follows this pattern as well. In the country, oil mining was identified in Turkanal County, specifically within the Lokichar basin, which is a dry region with limited water resources and encounters annual episodes of sudden floods (Bett, 2018). Even though surface water supplies are limited and sporadic in Lokichar, they play a crucial role in supporting agricultural, industrial, domestic, and environmental needs. Consequently, they are essential for fostering economic growth and development (Elsawwaf, Feyen, Batelaan, & Bakr, 2014). The outcomes generated throughout the process of oil mining can be classified into two groups: solids (drilling mud and cuttings) and produced water (Erakhrumen, 2015). The noxious composites, manifested as heavy metals and hydrocarbons, are believed to be responsible for causing harm to the environment (Padhan, P. P., R., & Padhi, 2021). Previous studies from Lokichar basin have highlighted that produced water mudpits have been observed near oil the oil block 13T posing a contamination risk to surface water resources through runoff and infiltration(Mugendi, 2020).Furthermore, health concerns stemming from the contamination of water and air could contribute to security challenges arising from the scarcity of resources.

Considering the risk of pollution resulting from improper disposal and inadequate treatment of waste generated by oil mining, which could be exacerbated by heavy rainfall runoff, it becomes imperative to exercise vigilant waste management practices (Kuwayama, Olmstead, & Krupnick, 2015). As WHO (1997) outlined, water pollution ranks as a significant issue, followed by air quality metrics are susceptible to spatial and temporal variations. As a result, it's crucial to discern whether these changes stem from natural occurrences or human-related factors (Zarei & Bilondi, 2013). Inherent factors encompass runoff, erosion, and weathering, while human-driven factors involve industrial, urban, and agricultural activities that generate waste, leading to the introduction of heavy metals into rivers, water pans, and dams (Gautam, Sharma, Ahirwar, & Singh, 2013; Sheela et al., 2012).

The region has gained significance due to the potential benefits of oil mining for both Kenya and the global economy. While oil mining in this region could bring substantial positive outcomes, it's crucial to acknowledge the associated risks. Consequently, there are concerns about the enduring effects on the basin in terms of the environment, social, and economy due to oil mining.Prior to commercial oil exploration Seasonal hydrology, aeolian deposition, and rock weathering were the main natural processes that impacted the hydrochemistry of the area. According, to Agaya (2021) before oil exploration water resources in Lokichar showed low levels of heavy metals with the main source being geogenic inputs.

This research focused on evaluating the presence of heavy metals in water and sediment, as well as characterizing the hydro-chemical composition of surface water resources in Lokichar. Anticipated oil mining activities in Lokichar are expected to open up new opportunities in the northern frontier, likely leading to the growth of industries and population. This growth, in turn, might result in increased waste production. Therefore, comprehending the ential impact of oil mining on the quality of surface water within the watershed is essential for creating efficient waste management strategies.

1.2 Statement of the Problem

The Lokichar basin has witnessed population growth and infrastructure enhancements as a result of the ongoing oil mining activities in the area (Mugendi, 2020). The increase in regional demographic and the progression of development endeavors has resulted in escalated water requirements for agriculture,domestic and industril use, thereby exerting pressure on surface water resources. This situation necessitates the implementation of effective water management strategies to address the demand (F. Opiyo, Wasonga, Nyangito, Schilling, & Munang, 2015).

The area is characterized by arid and semi-arid conditions, leading to the intermittent nature of the majority of surface water sources (Bett, 2018). Consequently, oil mining might impact the quality of surface water, the availability of water supply, and the deterioration of the aquatic ecosystem. This may stem from various factors including oil spills, the discharge of radioactive waste, drilling waste fluids and mud, sewage and greywater, cooling water, as well as engine and waste oil (Kappel, Williams, & Szabo, 2013).Since Lokichar experiences flash floods yearly the runoff originating from these oil fields, particularly from mud pits containing additives, has the potential to result in water pollution in adjacent water sources like streams and rivers (Cooley, Donnelly, Ross, & Luu, 2012). Hence, the study being proposed aimed to examine the presence of heavy metals in water and sediments, as well as to characterize the hydro-chemical composition of surface water resources within the Lokichar basin.

1.3 Objectives

The general objective of this study is to ascertain the concentration of heavy metals in sediments and to characterize the hydro-chemical composition of surface water within the Lokichar basin, located in Turkana County.

1.3.1 The specific objectives

i. To investigate the selected physical and chemical properties of surface water in the Lokichar basin.

ii. To determine the concentration of heavy metals Pb ,Zn and Cd present in the sediments in the Lokichar basin.

iii. To characterize the hydro-chemical facies of surface water in the Lokichar basin.

1.4 Research questions

The following research questions will be answered.

I. What is the physico- chemical status of rivers in the surface water?

II. Are there significant differences in Physio-chemical parameters concentrations across sampling sites in the Lokichar Basin?

III. Are there significant differences in heavy metal concentrations across sampling sites in the Lokichar Basin?

IV. What is the spatial variation of Pb Cd and Zn in the sediments ?

V. Which water type governs the surface water in Lokichar ?

1.5 Justification and Significance of the Study

The study examined heavy metals in both water and sediments within surface water resulting from oil mining activities. More specifically, this entailed analyzing the impact of these compounds, originating from oil mining, on the well-being of the community. The findings of this study would enhance our comprehension of the levels of toxic pollutants within surface water resources. Additionally, the results would add to the existing knowledge base, influencing discussions on policies for managing water quality.

The outcome of this research aims to heighten environmental awareness and concern about the relatively nascent stage of oil mining. Furthermore, the information gathered from this study holds the potential to aid in evaluating the efficiency of disposal methods, treatment approaches, and monitoring protocols for surface water resources. The assessment could yield effective strategies for water governance and a clearer grasp of the interconnections between the quality of surface water and oil extraction.

1. 6 Scope and Limitations

The research was conducted within Turkana County's Lokichar Basin. Its primary focus encompassed the evaluation of heavy metal concentrations within sediments and the characterization of hydro-chemical traits in surface water. As a result of the expansive nature of the basin, not every surface water resource could be sampled. The study was also limited by a small sample size and a single -season data collection.

Furthermore, the research operates under the assumption that the deterioration in water quality is attributed to the oil industry; however, this presupposition might not entirely align with reality since geological factors specific to the region could influence the levels of heavy metals.

CHAPTER TWO: LITERATURE REVIEW

This chapter reviews similar research done on this study highlighting the findings and the gaps which this study is addressing..

2.1 Empirical Research

The rise in developmental activities and the push for industrial progress have exerted pressure on the surface water reserves present in the area. Hydrologists are increasingly alarmed by the patterns and conditions of these surface waters. Consequently, the decreasing quality of water in these habitats jeopardizes their long-term viability, sparking significant apprehension. As a result, comprehending the impact of oil mining on the surface water within the Lokichar basin emerges as pivotal for effective water resource management, encompassing both its volume and quality aspects (Ashun, 2014). Water contamination stands as a major driver of water shortage and reduced availability for diverse applications like agriculture (Reuben, 2014).

According to Bakke, Klungsøyr, and Sanni (2013) produced water is the primary waste generated during oil extraction and it consists of a blend of injected water, natural formation water, chemicals used in hydraulic fracturing, and hydrocarbons. The composition of the produced water can differ between different geographical areas due to its interaction with formations containing hydrocarbons (Igunnu & Chen, 2014). As stated by Isehunwa and Onovae (2011), approximately one billion barrels of produced water are released annually during oil and gas extraction activities in Nigeria.

The ongoing generation of such significant volumes of produced water discharges is projected to rise, as the proportion of water to oil increases with the aging of production wells (Da Silva, Chiavone-Filho, de Barros Neto, & Foletto, 2015).

During periods of heavy rainfall, the freshwater environment is at risk of contamination from petroleum hydrocarbons and associated chemical wastes if they manage to enter the water, which could potentially lead to water pollution. Frequently, the water extracted during offshore drilling is released into the nearby aquatic environment (Durell, Neff, A., Garpestad, & Gruner, 2000). As Obire and Amusan (2003) pointed out, the toxic potential of organic and inorganic compounds within produced water is often greater than that of crude oil. Additionally, they highlighted that produced water generally contains higher salinity levels than certain seawater, which has the potential to harm freshwater resources. Neff and DeBlois (2011) further emphasized the environmental pollution risks posed by heavy metals and naturally occurring radioactive materials found in produced water. The discharge of inorganic ions like sodium, potassium, calcium, and chloride is a significant concern, particularly when released onto land, into surface waters, or brackish environments (Neff & DeBlois, 2011).

Within the river basin of Western Siberia, where more than 112 oil fields are situated, surface water exhibited considerable levels of chloride and increased salinity. These findings imply the potential discharge of wastewater associated with oil activities, likely attributed to leaks and intentional disposal. In a majority of produced waters, sodium stands as a prominent dissolved component. This may lead to substantial decline in soil quality by altering the composition of clays and soil textures, ultimately leading to erosion.

Elevated sodium concentrations can additionally contribute to compromised soil structure and hinder the efficient infiltration of water into the soil (Guerra, Dahm, & Dundorf, 2011). Erakhrumen (2015) conducted a study focused on assessing the levels of heavy metals within untreated produced water. The aim of the study was to enhance awareness among pertinent stakeholders regarding the impacts of untreated produced water and potential mitigation approaches. The author acknowledges that one of the byproducts of unrefined petroleum extraction is produced water, which includes varying quantities of hydrocarbons and toxic metals. The heavy metals identified in the untreated produced water included elements such as iron, copper, manganese, cadmium, lead, nickel, and chromium. The author also notes that as a result of non-decomposable characteristic and tendency of heavy metals to accumulate, their presence might be detected at considerable distances from the discharge point, particularly within surface waters.

However, solely analyzing the levels of heavy metals in untreated produced water is inadequate for effectively informing stakeholders about the repercussions of releasing untreated produced water. The reason for this is the accumulation of heavy metals influences the acute toxic impacts on the ecosystem. Gaagai, Boudoukha, Boumezbeur, and Benaabidate (2017) explore the hydrochemical classification of surface water through the application of environmental statistical techniques and time series analysis.

The main goal of the research was to define the chemical composition of the surface water within the Babar watershed and identify the origins of the chemical elements found using advanced numerical methods and time series analysis. Across the research three stations, water temperature remained consistent and was primarily influenced by the regional climate.

The Piper Diagram visually represented the chemical composition of the surface water, depicting two types: Alkaline water that exhibits temporary hardness because of carbonate substances. Saline water that has temporary hardness as well originating from prevalent gypsum and halite. The academic paper underscored the significance of employing statistical analysis involving multiple variables in hydrochemistry to enha nce comprehension of water resource ecology and quality enhancement. However, some notable shortcomings in the paper are apparent. The deterioration of stored water quality due to various forms of contamination, including the leaching of diverse toxic elements, wasn't assessed through sampling for their concentration levels. Consequently, the precise sources of these chemical elements remained unclear.

H. Singh, Pandey, Singh, and Shukla (2017) systematically examined sediment pollution by heavy metals. The study's focus was on seven specific heavy metals: cobalt, copper, nickel, cadmium, zinc, lead, and chromium. The study's summary highlighted a limited portion of riverbed sediment being tainted by these harmful metals, yet the sediment's quality is projected to deteriorate in the near future. The authors recognized that seasonal variations in physicochemical water characteristics are attributed to the influx of toxic pollutants from industries. However, the study overlooked the relationship between the identified heavy metals in water and sediments, neglecting a crucial aspect. Moreover, the evaluation of physicochemical parameters in water is pivotal, as the presence of heavy metals in sediments isn't the sole indicator of water contamination.

Mwangi (2014) evaluated the bacteriological and physicochemical quality of water intended for domestic use. The primary goal of the study was to evaluate the water quality in the Kiamumbi catchment.

Physical indicators of water quality included pH, electrical conductivity (EC), dissolved solids, and turbidity. The study also examined various heavy metals such as zinc, chromium, copper, calcium, magnesium, manganese, cadmium, nickel, lead, and ions like chloride, sulfate, and phosphate. Bacterial analysis focused on total coliform bacteria. The study's findings revealed that the catchment area was contaminated by pollutants from multiple sources, leading to the conclusion that the water distributed to homes within the watershed was unsuitable for use.

The research however does not provide the degree of contamination such as moderately polluted to strongly polluted. In addition, the author does not specifically state the different causes of pollution in the catchment this complicates the ability to monitor and treat the condition of water quality within the watershed . Table.2.1 depicts the summary of the literature as per the authors finding and the gaps that the research addressed.

Table2.1; Summary of the key literature

AUTHOR	FINDINGS	GAPS
Bakke et al. (2013)	Produced water is the main by-product in oil exploration and contains heavy metals which pose as a risk to surface water quality when discharged to the environment.	The author does not test the heavy metals present in the surface water to determine the source of pollution.
Erakhrumen (2015)	The author found that untreated produced water contains heavy metals which accumulate and their levels can be identified at a considerable distance from the point of release in the surface water.	The author just examined heavy metals' concentration in water, not sediments.
Gaagai, Boudoukha, Boumezbeur, and Benaabidate (2017)	The author examined the hydro-chemical classification of surface water employing environmetric methods. A Piper diagram was used to determine the surface water type in the catchment	The author however did not consider the deterioration of water quality due to various forms of pollution. As a result, the source of the pollution was not explicitly mentioned.
H. Singh, Pandey, Singh, and Shukla (2017)	The author methodically analysed sediment pollution by heavy metals in a river. It was discovered that a minor section of the riverbed was contaminated.	However, the author did not investigate the physic-chemical analysis in water because heavy metal presence in sediments is not the sole indicator of water contamination
Mwangi (2014)	The author assessed the bacteriological and physico-chemical quality of household water sourced from surface water in the Kiamumbi catchment was analyzed. The research found that the watershed is contaminated by pollutants from various points, hence unsuitable for consumption.	The author does not provide the level of contamination and the clearly state the source of pollution

Source: Author 2023

2.2 Physical water quality parameters

These physical water parameters respond to sensory perceptions of taste and odor, aiding in the assessment of water pollution levels (Makokha, 2017).

2.2.1 Temperature

Temperature indicates the degree of warmth or coldness present. The commonly utilized temperature scales include Celsius (°C), Fahrenheit (°F), and Kelvin (K).

Temperature plays a role in affecting the solubility and breakdown of substances in water, such as PAHs (WHO, 2008a). Factors that can lead to fluctuations in water temperature within aquatic environments encompass alterations in weather conditions as well as the release of industrial effluents into rivers (M. Kumar & Kumar, 2013).

2.2.2 Turbidity

Turbidity signifies the level of transparency within water, quantified in nephelometric turbidity units (NTU). It is impacted by suspended or dissolved particles that disperse light and lead to a cloudy appearance of the water. Factors such as the discharge of waste, the proliferation of algae, and runoff from urban areas influence turbidity. For drinking water, the recommended turbidity level should not exceed 5 NTU, ideally remaining below 1 NTU, as stipulated by (USEPA., 2009).

2.2.3 Electrical Conductivity

It represents the extent of its ability to carry an electric current. The SI unit is Siemens per meter (S/m). It plays a crucial role in detecting the existence of minerals within the water.

Conductivity in water bodies like streams and rivers is primarily influenced by the geological composition of the region through which the water flows (Gupta & Paul, 2013).

2.2.4 Colour

The term colour means the factual colour of the water from which turbidity has been removed. The seeming colour is because of the suspended matter as well as due to the substance on the solution removed by filtration. The amount of colour is founded on a platinum cobalt scale.

The visual comparison method will be used. Colour in drinking water may be a result of the presence of coloured organic matter and metals such as iron and manganese(WHO, 2006)

2.2.5 Taste and Odour

Odours in water are consequently of the major presence of an organic substance, others may be suggestive of increased biological activity or pollution(WHO, 2006).

Commonly the taste buds in the oral cavity detect the inorganic compounds of metals such as magnesium, calcium sodium, copper iron and zinc.

2.3Chemical parameters

P. Kumar, Meena, and Mahajan (2019), state that chemical parameters encompass chemical elements that readily dissolve in water, thus shaping water quality by reflecting the characteristics of the climate, geochemistry, and pollution status.

2.3.1 Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) signifies the volume of oxygen necessary for the oxidation and decomposition of organic or inorganic substances present in water. Sosale, Varsha, and Raju (2020) establish that elevated COD levels indicate the existence of organic pollution. When evaluating optimal waste management strategies, one of the pivotal factors assessed is oxygen demand, as organic compounds are inherently unstable and require chemical and biological oxidation for stabilization.

The determination of chemical oxygen demand involves measuring the amount of consumed oxygen through titrimetric and photometric methods. This test employs dichromate in an acidic solution, which is heated to convert organic carbon into carbon (II) oxide and water. The test outcomes are obtainable within 1.5 to 3 hours, contingent on the pace of water quality assessment and the testing procedure.

2.3..2 Dissolved Oxygen

It denotes the quantity of oxygen gas that has dissolved within water. When conducting the dissolved oxygen examination, samples should be promptly collected and analyzed. Consequently, it's an on-site assessment. The level of dissolved oxygen in water must not exceed 110 percent, as this could pose risks to aquatic ecosystems. The dissolved oxygen concentration hinges on factors like ion activity, surrounding temperature, and atmospheric pressure. It is emphasized that water quality and the restoration of rivers rely significantly on the presence of dissolved oxygen. The presence of oxygen in water is a positive sign of good water quality, while the absence of oxygen is an indicator of severe poll. (Al-Heety, M., & M., 2011).

2.3.3 pH

The pH indicates the concentration of hydrogen ions within a solution. Both KEBS and WHO suggest that, in water systems, the pH value should be within the range of 6.5 to 8.5 (USEPA., 2005; WHO, 2008a). The pH levels govern the degradation of hydrocarbons. Depending on the specific chemical properties of the hydrocarbon, the pH of the water, and the duration of their interaction, the degradation process can unfold relatively swiftly. When water registers a pH ranging from eight to nine, hydrolysis can occur rapidly, often leading to a substantial decrease or complete loss of the chemical's reactivity.

2.3. Sulphates

Sulfates are naturally present in potable water. Concerns related to health regarding sulfates in drinking water have been focused on diarrhea, which might be associated with the consumption of water containing elevated sulfate concentrations. Drinking water standards have established a lower maximum allowable level of 250 mg L^{-1} for sulfate, based on sensory aspects like taste. The presence of sulfate in drinking water can also result in noticeable flavor changes and could potentially contribute to the corrosion of the distribution system (USEPA, 2012; WHO, 2008b).

2.3.5Nitrates and Nitrite

Nitrates and nitrites are chemical compounds composed of nitrogen and oxygen, found in a variety of organic and inorganic substances. Nitrates (NO_3) serve as an important nitrogen (N) source for plant growth. The presence of nitrates in water serves as an indicator of overall water quality.

Elevated nitrate levels could indicate the potential presence of other substances, including disease-causing bacteria from sewage, pesticides, or various inorganic and organic compounds that might pose health risks. Moreover, elevated nitrate concentrations have been associated with stomach cancer and adverse reproductive effects (Rife, Funk, & Weller, 2017).

The occurrence of nitrite in water can result from the oxidation of ammonium compounds or the reduction of nitrate.

The presence of nitrite suggests that the organic material in the water hasn't undergone complete oxidation. There should be no detectable level of nitrite in drinking water (APHA, 1992).

2.3.6Chloride

Chloride is naturally present in all types of water. In natural freshwater bodies, its uptake is limited and lower compared to sulfate and bicarbonates. As a result, chloride levels serve as an indicator of potential contamination. Hoque, Panda, and Ali (2018) demonstrate that industrial discharges contain elevated chloride levels, so the discharge of these waste materials could raise chloride concentrations in freshwater. The World Health Organization (WHO) in 2004 suggests a maximum allowable limit of 200 mg L^{-1} for chloride in water. The presence of chloride in water may be due to the suspension of salt deposits, discharge of effluents, oil well operations and sewage discharges

2.3.7 Calcium and Magnesium

The presence of calcium plays a crucial role in various bodily functions, and its occurrence in water is necessary in appropriate amounts. An investigation conducted in Pakistan regarding water pollution and its implications for public health unveiled that elevated levels of these ions could render water unsuitable for living organisms. Hence, an excessive concentration of calcium might result in adverse effects such as hypercalciuria, the formation of urinary tract stones, deposition in soft tissues like kidneys and arteries, and inhibition of bone remodeling (Azizullah, Khattak, Richter, & Häder, 2011).

Magnesium ions may occur naturally from rock-bearing granitic soil which contains a high concentration of magnesium ions(M. Kumar & Kumar, 2013). Presence of magnesium ions in water is directly related to hardness(Murhekar 2011). The appropriate limit of the ions in water is recommended by KEBS (2010) to be 100mg/l.

2.3.8 Manganese

Manganese holds a vital role for numerous organisms, including humans. Elemental and inorganic variations of manganese could be found suspended within the atmosphere. In bodies of water, manganese is present in both dissolved and suspended states. Anaerobic groundwater commonly contains elevated levels of dissolved manganese. Within most water, the divalent form is prominent within a pH range of 4 to 7, but more oxidized variations might emerge at higher pH values or due to microbial oxidation. Manganese has the ability to adhere to soil to varying degrees, influenced by the organic content and cation exchange capacity. While it can accumulate in lower organisms, its bio-magnification within food chains isn't particularly significant (Adepoju-Bello & Alabi, 2005)**.**

Manganese levels found in lakes and rivers worldwide span from 0.001 to approximately 0.6 mg/l. Elevated concentrations in well-oxygenated waters are typically linked to industrial contamination. Groundwater and specific lakes and reservoirs with reduced oxygen levels can foster heightened concentrations, reaching up to 1.3 mg/l in neutral water and 9.6 mg/l in acidic conditions (Adepoju-Bello & Alabi, 2005).

In a health investigation conducted in Japan, detrimental outcomes were observed in individuals who consumed manganese dissolved in their drinking water.

The manganese originated from 400 dry-cell batteries that were buried close to a well used for potarble water supply. A total of sixteen instances of poisoning were documented, manifesting symptoms such as fatigue, heightened muscle tension, tremors, and disruptions in neural functions. The most severe repercussions were evident among elderly individuals, whereas only minor effects were observed in children (APHA, 1992).

2.3.9. Total hardness

It is the total of calcium and Magnesium concentrations measured as calcium carbonate in mg/l. It is divided into two categories carbonate hardness and non-carbonate hardness. Hard water prevents lather formation with soap (M. Kumar & Kumar, 2013). Temporary hardness occurs when the existing anion is carbonate and can be eliminated through boiling. Anions such as chlorides sulphate and nitrates cause permanent hardness. Sources of hardness include sewage and run-off from sediments particularly limestone and magnesium-containing materials (Olumuyiwa, Fred, & Ochieng, 2012).

2.3.10 Fluoride

Fluoride has dual importance in water, high levels of fluoride cause dental fluorosis and a concentration of <0.8 mg/l can lead to dental cavities. It is important to keep up the fluoride levels in drinking water between 0.8mg/l-1.0mg/l. Sources of fluoride include weathering rocks, phosphatic fertilizers and leaching untreated sewage (M. Kumar & Kumar, 2013). Human induced origin of fluoride include the application of phosphate fertilizer as pesticides

2.4 Heavy metals

Heavy metals refer to metallic elements with a relatively high density, typically exceeding 4 g/cm³. Heavy metals contamination in water holds significant implications for living organisms; however, concentrations surpassing the limits set by WHO and KEBS can lead to health disorders. These excessive levels may stem from either natural sources or human activities. Natural sources include interactions at the water-soil and water-rock interfaces, as well as the wet and dry deposition of atmospheric salts. Human induced sources involve rapid urbanization and industrialization.

The heavy metals examined in the study include Arsenic (As), Lead (Pb), Cadmium (Cd), Zinc (Zn), and Iron (Fe). Zinc, while essential for human health in moderate amounts due to its role as a catalyst in enzymatic activities, can pose health concerns when its concentrations rise. WHO establishes acceptable concentrations for drinking water, while KEBS imposes an upper limit of 5 mg/L for zinc content.

According to(Githaiga, Njuguna, Gituru, & Yan, 2021) the cadmium levels in water pans in Turkana averages at 0.012 mg/L, above WHO limits."

Zinc is a necessary element for humans, albeit at lower levels, as it plays a role in enzyme activity and accumulates in muscles and the liver. Prolonged exposure to elevated zinc levels can result in conditions such as cancer, congenital abnormalities, organ damage, nervous system disorders, and impaired immune function (WHO, 2003).

Iron is commonly found in water due to industrial effluents, sewage, and landfill leachate. It holds an important part in the life of living organisms. The recommended acceptable concentration by both WHO and KEBS is 0.3 mg/l. Iron builds up in muscles and the liver, elevated iron levels can have a negative impact on the brain and central nervous system.

Cadmium enters water systems through industrial discharges, corrosion of galvanized pipes, and its inclusion in phosphate fertilizers, acting as a source of water pollution. KEBS establishes a 0.005 mg/l maximum allowable limit for cadmium. Classified as a toxic metal, it tends to accumulate with age, disrupting kidney and bone function, potentially leading to cardiovascular issues, cancer, and renal diseases. Cadmium might also hinder metallothionein, a protein that binds excess essential metals for removal, consequently raising urinary zinc levels.

Lead is among the common heavy metals. In aquatic environments, it stems from aerosol deposition from activities like coal combustion, cement production, and the use of petrol additives. Beyond acceptable limits, lead becomes a metabolic toxin and enzyme inhibitor. WHO and KEBS recommend levels not exceeding 0.05 mg/l. Excessive lead exposure can impair the nervous system and result in blood and brain disorders (WHO, 2004): (KEBS, 2007). Apart from this, lead's biological impacts involve interference with hemoglobin synthesis, leading to damage within the blood system. In its solid form, arsenic is very dangerous and a naturally occurring element of the Earth's crust.Nonferrous mining, mineral extraction, burning trash and fossil fuels, and pesticide use are some of the sources of arsenic.KEBS suggests a maximum of 0.05 mg/L of arsenic, however WHO's tentative recommendation value is 10 μg/L. The immediate effects of high arsenic levels include acute arsenic poisoning, which manifests as diarrhea, vomiting, and abdominal pain. These signs can escalate to numbness, muscle spasms, and even death in severe instances. The initial signs of prolonged exposure through drinking water and food often manifest as changes in skin coloration, skin lesions, and hyperkeratosis—hardened areas on the palms and soles of the feet (Maria, *et al.,* 2017).

2.5 Hydro-geochemistry of surface water

The earth's survival and the existence of all living beings, including humans, hinge on the essential natural resources of land and water (Shanmugam, Selvakumar, & Yeh, 2014). The chemical composition of water arises from the hydrogeochemical processes involving the dissolution or precipitation of minerals in the soil, the reduction and oxidation of compounds, the release or absorption of gases, the sorption or exchange of ions, pollution from various sources, the leaching of fertilizers or organic matter, and the blending of diverse water sources (Anazawa & Ohmori, 2005**.** The mechanism relies on interactions between water and rocks, input from the atmosphere, chemical contributions due to human actions, precipitation, geological formations, and the mineral composition of aquifers (Murugesan, Krishnaraj, Kannusamy, Selvaraj, & Subramanya, 2011).

Geochemical models were employed to evaluate how contaminants behave in a specific geological setting, gauging their accessibility and movement. These models predict contaminant behavior by considering the chemical and physical attributes of the surrounding soil sediments and solutions (Bricker, 1999; Di Bonito, Breward, Crout, Smith, & Young, 2008). We can assess surface water's suitability for residential and agricultural uses by comprehending its chemistry. Good soil and water management techniques can produce better crops if surface water quality is high. Factors like the quality of water, soil type, salt tolerance characteristics of plants, climate and drainage decides the suitability of irrigation water in the agriculture sector (Glover, Reganold, & Andrews, 2000; Oliver, Bramley, Riches, Porter, & Edwards, 2013).

Piper trilinear diagram (Piper, 1944) was used evaluate the evolution of the river water and the relationship between rock types and water composition while the Durov diagram is advantageous over the Piper diagram in revealing some geochemical processes that could affect groundwater genesis (Lloyd and Heathcoat, 1985). Both diagrams reveal similarities and differences among water samples because those with similar qualities will tend to plot together as groups (Todd, 2001).

2.6 Geochemist workbench

Bethke and Yeakel (2016) explain that the Geochemist Workbench functions as a computer-based model employed to study the chemical processes that impact geological structures. This model can mimic a variety of processes, such as mineral dissolution, sorption, and ion exchange.The tool comprises six main components: file management, editing data, graphing, analysis, and help resources. Analyte entry into spreadsheets, computation of physical and chemical parameters not first observed in the field, consideration of fluid components, mineral saturation, and species concentrations are all made possible by the data section.

The model also generates diverse graphs, such as Durov diagrams depicting relationships between multiple ions within hydrochemical samples. The Piper diagram, on the other hand, classifies cations and anions, grouping them into hydrochemical facies.

By comparing duplicate samples from different sources, cross-referencing with standards, checking regulatory limits, and mixing samples, the model analyzes data. Additionally, it offers users essential guides, modeling references, command explanations, a comprehensive manual, and updates to support their interactions with the tool.

Carrillo-Chavez et al. (2014), determined the mineralogy and geochemistry of mine waste material from the Xichú mining area, Guanajuato state using the Geo-chemist workbench. The study concluded that geochemical dynamics are controlled by precipitation and dissolution. Therefore, the Geo-chemist workbench program plays a crucial role in figuring out how dissolution-precipitation interactions regulate the movement of heavy metals into the environment.

2.7 Determination of the Level of Concentration of Selected Heavy Metals in the Sediments

Examining the trends in heavy metal levels within soil studies permits the retrospective tracking of industrialisation's progression and the utilization of fertilizers over recent decades.The concentration measurements were established through the application of a contamination factor (Hakanson, 1980) and Geo-accumulation (Müller, 1969). The arrangement of heavy metals throughout the soil profile can offer insights into their source (Chen, Teng, Lu, Wang, & Wang, 2015; Pejman, Bidhendi, Ardestani, Saeedi, & Baghvand, 2015; Sołek-Podwika, Ciarkowska, & Kaleta, 2016). The accumulation of heavy metals in soil might mirror past human actions (Mazurek et al., 2017; Shu & Zhai, 2014; Sołek-Podwika et al., 2016; Tang, Li, & Xu, 2015). Conversely, contemporary human-induced pollution sources like transportation, industrial activities, and agriculture unquestionably impact the buildup of heavy metals within the soil (Gao & Chen, 2012; Ogunkunle & Fatoba, 2013; Sayadi, Shabani, & Ahmadpour, 2015). Emissions of heavy metals may come from adjacent or distant sources, which could result in on-site deposition.

Their tendency to attach to dust particles also enables them to be carried across extensive distances (Mazurek et al., 2017; Mohamed, Mohamed, Rabeiy, & Ghandour, 2014; Ripin, Hasan, Kamal, & Hashim, 2014)

Given their significant presence in the Earth's crust, heavy metals can be influenced by the characteristics of the parent material and the soil formation process, which can either promote or hinder their accumulation (Grzebisz, Ciesla, Komisarek, & Potarzycki, 2002; Hawkes & Webb, 1963; Shuguang, Kefa, Yao, Jinlin, & Jianli, 2015; Teng et al., 2004). Moreover, the natural process of parent material weathering plays a role in determining the quantity of heavy metals present in the soil (Chen et al., 2015; Kierczak, Pędziwiatr, Waroszewski, & Modelska, 2016)Hence, it becomes imperative to utilize precise and reliable instruments for the identification of soil degradation and, whenever feasible, to implement measures to halt its advancement (Qingjie, Jun, Yunchuan, Qingfei, & Liqiang, 2008)

2.8 Pollution Indices

The effectiveness of evaluating soil contamination from heavy metals hinges on the utilization of pollution indices. One of the initial indices was the Geo-accumulation index developed by Muller (1969) and the Contamination factorlater by Hakanson (1980). These pollution indices serve as a valuable tool and reference for conducting a comprehensive geochemical evaluation of the soil environment (Caeiro et al., 2005; Dung, Cappuyns, Swennen, & Phung, 2013; Kowalska et al., 2016; Mazurek et al., 2017).

The comprehensive aspect of evaluating soil quality using indices is further exemplified by its capability to estimate both environmental risk and the extent of soil degradation. (Adamu & Nganje, 2010; Caeiro et al., 2005).

The indices aid in distinguishing whether the buildup of heavy metals stemmed from natural processes or resulted from human activities (Caeiro et al., 2005; Elias & Gbadegesin, 2011; Qingjie et al., 2008; Sutherland, 2000).

Moreover, pollution indices hold significant value in the surveillance of soil quality and the assurance of future sustainability, particularly when it comes to agroecosystems (Kelepertzis, 2014; Ogunkunle & Fatoba, 2013; Ripin et al., 2014). Calculating indices of soil pollution necessitates the evaluation of the geochemical baseline (GB).

This concept was introduced to differentiate between the natural levels of heavy metals in the soil and the anomalous concentrations (Reimann & Garrett, 2005). There have been several definitions used to describe the geochemical background (GB). Hawkes and Webb (1963) defined GB as 'the typical abundance of an element in unproductive earth material.' Matschullat, Ottenstein, and Reimann (2000) described GB as involving 'spatiotemporal variations of heavy metal content that are distinctive for a particular soil type or region' and that 'demonstrate the natural distribution of heavy metals.'

Another perspective on GB, given by Matschullat et al. (2000), is that it serves as a 'relative measure to differentiate between naturally occurring element or compound concentrations and those influenced by human activity in actual sample collections.' Karim, Qureshi, and Mumtaz (2015) determined that in a given environmental sample, GB “is a relative measure to distinguish between naturally occurring element or compound concentrations and those influenced by human activity”.

'Reimann and Garrett (2005) described GB as 'typical element concentrations in a defined area' and 'the concentration of a substance in a sample material at a distance from a source where the substance's concentration can no longer be definitively traced back to this source.'

Gałuszka (2007) explained GB as a 'theoretical natural concentration range of a substance in a specific environmental sample (or medium), considering its spatial and temporal variabilityGałuszka and Migaszewski (2011) proposed two approaches. Their first approach centers on distinguishing between normal and abnormal heavy metal contents in soil, water, etc., encompassing the definition: 'GB represents the standard concentration of a specific element in the material under investigation, such as rock, soil, plants, and water' (Bates & Jackson, 1984), which aligns with Haris et al.'s (2017) definition. Kowalska et al. (2016) differentiated between two types of GB, reference and local (natural). The reference geochemical background might be the average heavy metal content published in the literature, which can vary significantly depending on soil types and localization

2.8.1 Contamination Factor

Hakanson (1980) introduced this equation. This approach relies on computing the contamination factor (Cf) for each pollutant (as outlined in table 2). The purpose behind calculating the contamination factor is to offer an assessment of the extent of contamination across a sampled location. However, the Cf necessitates averaging a least of five sediment samples from the surface to get an average pollutant concentration, which is then contrasted with an initial reference level considered pristine.

The formula is presented as follows:

$$C_f = \frac{C_{m\ \text{sample}}}{C_{m\ \text{background}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

where 'C_m sample' refers to the metal content in the sediment and 'C_m background' is the metal content from a natural reference, such as those reported in (Alshahri, 2017; Wedepohl, 1995)**Table1~~2~~.2: Summary of the contamination le**

Contamination Factor	**Level**	**Contamination Summary**
1	$C_f < 1$	Low
2	C_f; $1 \leq C_f < 3$	Moderate
3	C_f; $3 \leq C_f < 6$	Considerable
4	$C_f \geq 6$	Very high

2.8.2 Geo-Accumulation Index

(Müller, 1969) established the geo-accumulation index, a quantitative measure for the degree of heavy metal pollution in aquatic sediments. This is calculated by the following equation.

$$I_{geo} = \log_2 \frac{Cn}{1.5\,Bn} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

Cn is the metal concentration in the sediment, Bn is the background concentration of the element and 1.5 is the factor compensating background data as result of the lithogenic effect. The classifications into 7 pollution levels are summarized in table 3.

Table 2.3: Summary of the Geo-accumulation index levels

Igeo level	Level	Contamination summary
1	$I_{geo < 0}$	Practically unpolluted
2	0 <Igeo< 1	Unpolluted to moderately polluted
3	1 <Igeo< 2	Moderately polluted
4	2 <Igeo< 3	Moderately to strongly polluted
5	3 <Igeo< 4	Strongly polluted
6	4 <Igeo< 5	Strongly to extremely polluted
7	5 <Igeo	Extremely polluted

2.9 Conceptual Framework

This study adopts and adjusts a conceptual framework originally proposed by Kristensen (2004) to investigate the impacts of oil exploration and inadequate waste disposal on the quality of surface water. The research is centered on the repercussions arising from the presence of the oil mining industry and subpar waste disposal practices. The framework illustrates how the process of oil mining can potentially influence both water and sediment quality. This model clarifies the specific parameters under examination, aligning with the study's objectives and research inquiries. Additionally, the framework demonstrates the consequences of these parameters exceeding permissible levels, and outlines the potential responses, including water demand management, policy development, and water quality monitoring. Figure 1 visually represents the influence of oil mining and improper waste disposal on the quality of water and sediment in surface water resources

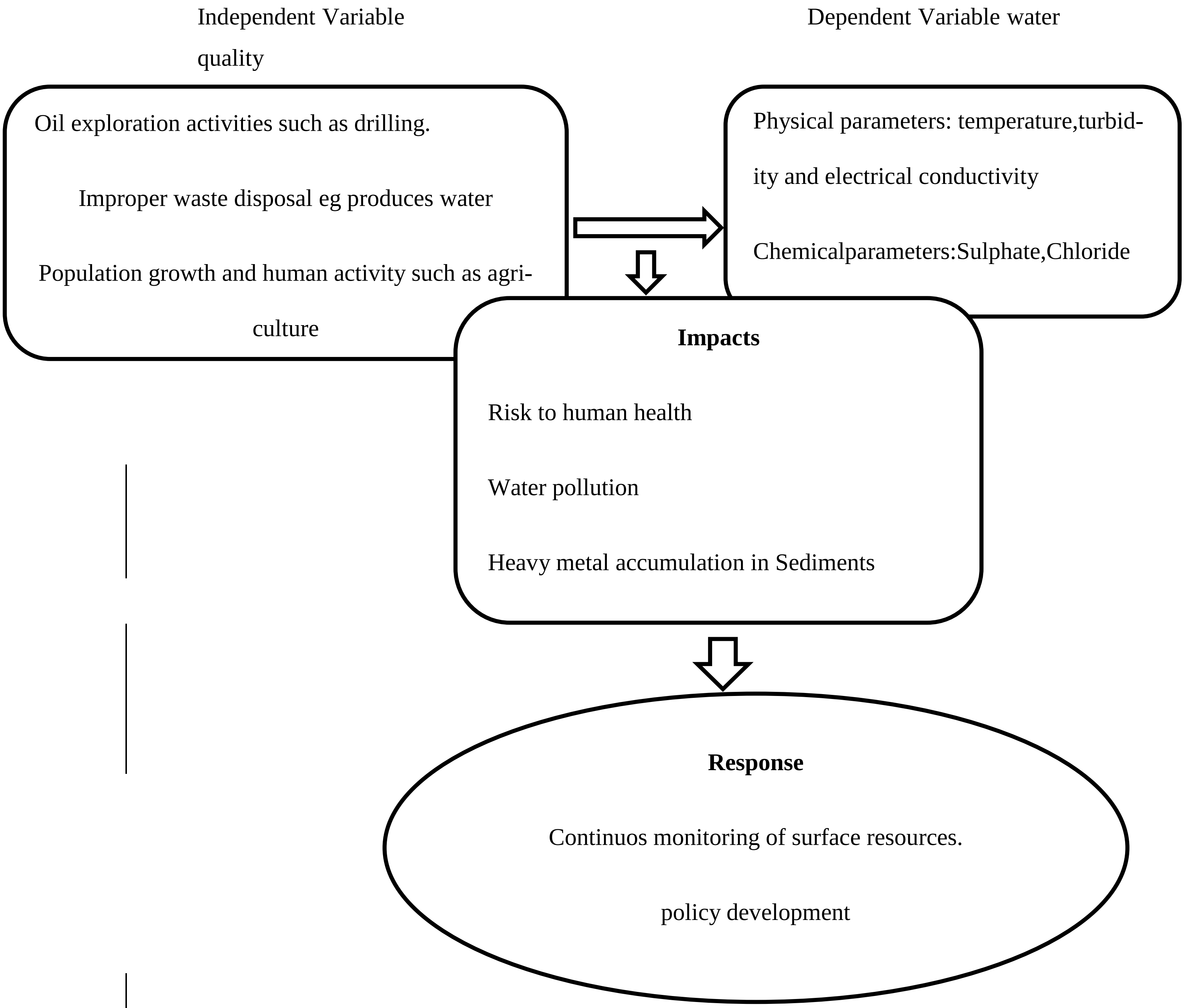

Figure 2.1: Conceptual framework

Source: Adopted and modified from Kristen, 2004.

CHAPTER THREE: METHODOLOGY

3.1 INTRODUCTION

This section covers the resources and methods applied in the research. It includes a description of the study location, research structure, methods for gathering field data, and the analysis process. This involves conducting laboratory tests for physical and chemical properties and performing statistical analysis using tools like Excel as well as software such as Geochemist Work Bench. Table 4 highlights the detailed organization of materials and methods employed by this study while Table 5 summarizes each method of analysis.

3.2 Study area characteristics

The research site was located in Turkana County, a key region for oil exploration. The Lokichar basin is positioned to the southwest of Turkana and is about 550 km north of Nairobi, roughly at coordinates 2° 22′ 48″ N, 35° 39′ 0″ E. The basin spans around 80 km in length, with a width of 25 km and a depth exceeding 7 km. Figure 3.1 shows the location of the Lokichar Basin in detail. The region ismarked byextreme weather conditions, experiencing two distinct seasons: dry periods (June-September and December-March) and rainy periods (March-May and October-November). Rainfall could be sporadic and uneven, sometimes happening beyond the usual rainy season (Government, 2016).The socio-economic activities in the area include agriculture,pastoralism and fishing(Mugendi, 2020)

In the region, the typical temperature span is 24 – 38 °C. During the dry seasons, temperatures vary between 26 – 40°C, while in the wet seasons, the range is 20 – 25 °C.

The coldest months tend to be November and December, while the hottest periods occur in January, March, and August, sometimes reaching above 37 °C (F. E. Opiyo, 2014). According to F. E. Opiyo (2014), potential evapotranspiration is higher than precipitation, with yearly estimates of roughly 2,148–2,249 mm

In terms of geography, the region is distinguished by an elongated elevation running in a general north-south direction. The middle areas are surrounded by man-made accumulations that overlay the natural contours of the land (RSK, 2014). The lack of significant vegetation and the arid, warm climate have influenced the development of soils that share similarities with desert conditions. These soils tend to have elevated pH levels, limited drainage capabilities, minimal organic material, and a low clay content (RSK, 2014).

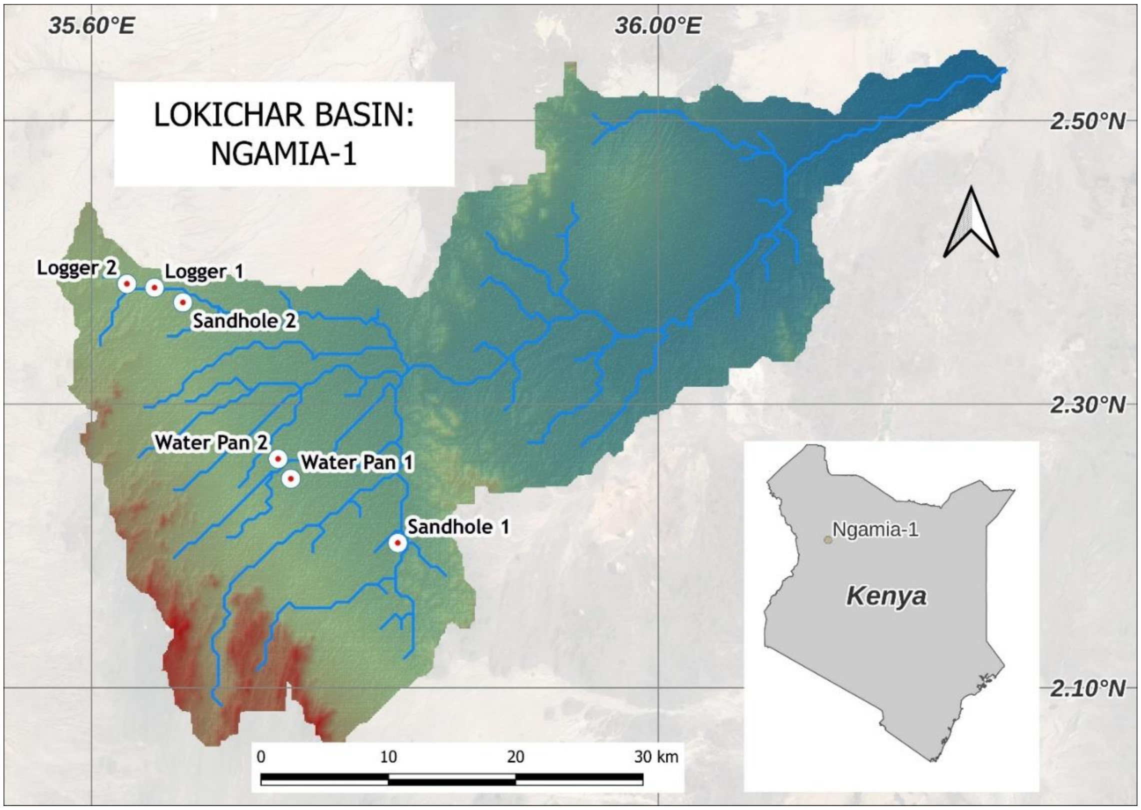

Figure 3.1: Lokichar Basin Map

Source: Satellite map of the Turkana area

3.3 Research design

The study employed an experimental research approach, which included the collection of physical-chemical data from surface water sources within the Lokichar Basin.

The selection of sampling locations took into account their proximity to mining sites, as well as their distance from these sites to enable meaningful comparisons.The sampling locations with proximity near the oil mines were within 1-5km whereas the ones far from the mining site were within 5-10 km

3.4 Sampling techniques

A random sampling technique was used to select the sampling site for the study. The study was between October-November 2020 which was the rainy season(Mugendi, 2020). Water and sediments were sampled from water pans, sand wells and lagger near and far off the mining points and the GPS points were recorded. A total of 12 samples were collected during the study,6 water samples and 6 sediment samples.The sampling points were selected based on the proximity to the oil mines, availability of surface water resources which are intermittent ensuring spatial representation across the basin(USEPA, 2012).

The water samples were gathered using 500 ml plastic containers. Before collecting the samples, the containers underwent cleaning with detergent that doesn't contain phosphate determined by verifying the manufacturer product label to confirm absence of phospate . Subsequently, they were rinsed with tap water followed by a solution of nitric acid and water in a 1:1 ratio, and ultimately rinsed with deionized water. To prevent cross-contamination between different locations, the containers were rinsed three times during the sampling process. Then the water sampling points were stirred allowed to settle then sampled collected.Each sample container was labeled, recorded in a field notebook, and stored in a chilled container until transportation to the laboratory for analysis.

For sediment collection, impermeable polythene sacks weighing 500 gm were used for each site. A bed material sampler facilitated the collection process, with the sediments being stored for analysis in the laboratory.

The collection was done at a depth of 1-5 cm, where the disturbance of sediments is minimal. The water samples were preserved at a temperature of -20˚C or lower in a cool box using dry ice and then transported to the laboratory for subsequent analysis.

The multi-parameter Aquaread AP-7000 instrument from the United Kingdom was utilized to measure various variables including temperature, turbidity, electrical conductivity, pH, and dissolved oxygen. The instrument was powered on, and its electrode was immersed in a beaker containing the water sample for the specific variable being measured.

3.5 Sample analysis

The parameters underwent analysis following the established procedures outlined in the guidelines by Rice, Bridgewater, and the Association (2012). Distilled water was employed to create solutions and clean equipment after assessing each individual sample. Prior to analysis, all equipment was calibrated in accordance with the manufacturer's instructions. To prepare sediment samples, they were dried for a period of 72 hours, subsequently crushed using a mortar and pestle, and then sifted to obtain sediment particles of a size equal to or less than 63 micrometers. Standardization was conducted before each weighing. For the determination of three heavy metals within each 2-gram sediment sample, a comprehensive digestion method was applied (A. Singh, Sharma, Agrawal, & Marshall, 2010). The specimens were gently heated within a Teflon container at a temperature of 80˚C, combined with 20ml of a mixture composed of three acids (HNO_3, H_2SO_4, and $HClO_4$) in a ratio of 5:1:1. This procedure was maintained until the sediment was fully dissolved, yielding a clear solution.

After this, the acquired solution was allowed to cool to ambient temperature and subsequently strained using Whatman filter paper no. 42, with the filtrate collected in a 100ml volumetric flask.

The examination of the solution was performed using an Atomic Absorption Spectrophotometer (AAS).

This device is extensively utilized in environmental assessments due to its dependable nature and user-friendly operation. It identifies the existence and levels of elements by studying the spectrum generated when an element is vaporized and absorbs specific frequencies of light. The accuracy of the analysis was controlled by using reagent blanks in duplicate samples. The physical parameters that were measured in situ included the following parameters pH, electrical conductivity, temperature, turbidity and dissolved oxygen using a multi-parameter. Colour, taste and odour were determined through visualization. Magnesium (Mg^{2+}),Calcium(Ca^{2+}),Nitrate($NO^{-2}{}_{3}$), Sulphate ($SO^{-2}{}_{4}$), Chloride (CI^{-}),Nitrite($NO^{-}{}_{2}$),(Fluoride(F), Manganese(Mn^{2+})and COD were analyzed from the KEWI laboratory.

3.5 .1 Fluoride

Fluoride was analyzed using the potentiometric method by ionometer WT model pH/ION340i by Labstuff.eu England. Sulphate nitrate, chloride iron manganese was analyzed using the photometric method, photometer WTW, model photo flex Turb set by labstore in the United Kingdom

3.5.2 Chloride

Chloride was analyzed by the argentometric method in a natural or slightly alkaline solution by titration with standard silver nitrate, using potassium chromate as an indicator. Silver chloride is quantitatively precipitated before red silver chromate is formed.

$$c\text{hloride}\,\frac{\text{mg}}{\text{l}} = \frac{\text{A}-\text{B}\times\text{N}\times 35.45\times 1000}{\text{MI sample}} \qquad 3.1$$

Where A=ml $AgNO_3$ required sample

B=ml Ag NO_3 required for blank

N= normality of $AgNO_3$ used

3.5.3 Nitrate

Nitrate was analyzed using the spectrophotometric method following the Beers law upto 11mg/l as N, 1ml of 1N HCI per 50ml was added to the sample absorbance was read at 220nm and 275nm and 0 absorbances was set with distilled water.

3.5.4 Nitrite

The test is carried out by adding a tablet to the sample water. Nitric acid reacts with sulphanilic acid the diazo compound together with N-(1-naphthyl) ethylene diamine forms a reddish dye. The tablet is crushed and mixed with the sample to dissolve. An allowance of 10 minutes is given to permit colour change and a wavelength of 520 nm on the photometer is chosen to take readings.

3.5.5 Sulphate

Sulphate was determined by the spectrophotometric method .it should be noted that sulfate ions are precipitated as $BASO_4$ in acidic media (HCI) with Barium Chloride $BACI^-$. The absorption of light by this precipitated suspension is measured by a spectro-photometer at 420mm.

Calculations

$$\frac{\mathrm{Mg}}{\mathrm{L}}\mathrm{SO} = \frac{\mathrm{mg\ SO4}}{\mathrm{ml\ sample}} \qquad 3.2$$

3.5.6 Magnesium

For the assessment of magnesium hardness, 1.5 ml of a Mg^{2+} buffer was introduced to a 50 ml sample within a beaker. A small amount of magnesium indicator was included, and the mixture was titrated using 0.01N EDTA solution until a purple hue appeared. To ascertain calcium hardness, 1.5 ml of a Ca^{2+} buffer was combined with a 50 ml sample in a beaker. A pinch of calcium indicator was added, and titration was performed using 0.01N EDTA solution until the color changed to purple. Titration occurred promptly after the indicator's addition due to its instability in alkaline conditions.

$$Ca^{2+} = (\mathrm{Titre}\ \times 8 \times \mathrm{D.F})$$

$$\mathrm{Mg}^{2+} = (\mathrm{Titre} \times 0.67 \times \mathrm{D.F}) \qquad 3.3$$

3.5.7 Total Hardness

About 1 ml of a buffer solution ($NH_4CI^-NH_4OH$) was introduced to a 50 ml sample. A small amount of the total hardness indicator was incorporated into the solution and subjected to titration using the 0.01N EDTA solution. The transition of color from blue to pink indicated the endpoint. The resulting titration value was noted and then multiplied by a dilution factor of 20.

Calculation

$$\text{Total hardness} = (\text{titre} \times 20 \times \text{D. F}). \text{Calcium and Magnesium hardness} \ldots\ldots\ldots\ldots\ldots 3.4$$

3.5.8 Manganese

The common manganese-bearing minerals are oxides, hydroxides, carbonates and silicates manganese. Manganese was analyzed using the palintest photometric method the test measures manganese over the range of 0-0.030mg/l. the sample was filled in a test tube of 10ml.1 manganese tablet was crushed and mixed to dissolve. Another 2 mangnese tablet was crushed and added to the mix. The test was swirled to aid the dissolvent of the tablet a cap was placed on the tube. The tube was placed in the palintest Automatic wavelength selection photometer and the results were displayed in mg/l.

3.5.9 Chemical Oxygen Demand

This is a measurement of pollution in wastewater and natural waters. Test tubes for various samples are added to a rack with two more blank samples. potassium dichromate 1.5 ml is added to the test tube and 2.5 ml of distilled water is also added into the tubes for standard and blanks. The samples are to be kept separately. Conditional on the strength of the pollution 1.5ml is taken for samples less polluted and 0.001ml for samples highly polluted coupled with distilled water of 2.5 ml. For the standard samples, 3.5 ml of concentrated sulphuric acid is added and sealed immediately. Measure 3.5 ml of sulphuric acid with silver nitrate to both the blank samples and all other samples. The test tubes should be then sealed and placed in a digester for 2 hours at 148 degrees except for the blank samples. After 2 hours the samples should be cooled and titrated with ferrous Ammonium sulphate (FAS) using a COD indicator.

Calculations

Molarity of ferrous Ammonium sulphate solution

$$\text{Volume } 0.0167\mathrm{K}_2\ Cr_2O_7 = \frac{solution\ titrated\ ml \times 0.1}{The\ volume\ of\ FAS\ used\ in\ the\ titration\ ml} \qquad 3.5$$

Hence to calculate the

$$COD\ level\,\frac{MgO_2}{l} = \frac{A - B \times M \times 8000}{The\ volume\ of\ the\ sample\ in\ ml} \qquad 3.6$$

Where:

A= ml FAS used for blank

B= ml FAS used for sample

M= molarity of FAS

Waterborne heavy metals were assessed through the application of atomic absorption spectroscopy. The utilization of this apparatus was selected due to its simplicity, reliability, and high sensitivity. It identifies, quantifies, and examines the emission of particles stemming from atoms or ions of the specific element under investigation (McMahon, 2008).

All samples were cross validated by use of blank and duplicates,no missing data was recorded and outliers were checked and retained within quality assurance limits(Rice, Bridgewater, & Association, 2012)

Table .1: Summary of the Methodology (Rice et al., 2012).

Name of the parameter	METHOD OF ANALYSIS	INSTRUMENT
Turbidity	A nephelometric method in situ	Multi-parameter WTWmodel photoflex turbset
Temperature	In situ	Conductivity meter aqualitic,model AL20CON
Dissolved oxygen	In situ	DO meter HACH sension 6
Ph	In situ	pH meter(Orion 4 star)
Iron	Photometric method	Photometer
Calcium	titrimetrically using standard EDTA	Photometer
Magnesium	titrimetrically using standard EDTA	Photometer
Total hardness	Photometric method	Photometer
Chloride	Argentometric method	Silver nitrate as titrant
Nitrate	spectrophotometric method	Spectrometer HACH DR/2000
Nitrite	Palintest photometer	Palintest photometer 7100
Fluoride	potentiometric method	Photometer
Manganese	Palintest photometer method	Palintest photometer 7100
Ec		Conductivity meter sension 5
Sulphate	spectrophotometric method	spectrometer HACH DR/2000
COD	Open reflux method	

3.6 Data analysis

The collected data was organized in an Excel spreadsheet and then transferred to the student edition version 12 of Geochemist Workbench, which includes a data sheet. Table 3.2 presents a condensed overview of the data analysis in accordance with the study's objectives. The data for various physical and chemical parameters were examined by comparing them against established standards and by comparing duplicates from different sampling locations.

Correlation analysis was primarily employed to forecast patterns or demonstrate the absence of patterns. It serves as a dimensionless measure of the connection between two variables, ranging from -1 to +1 (Kothari, 2004). Karl Pearson's correlation coefficient (r) remains unaffected by alterations in scale or shifts in position. A value of r nearing +1 (-1) indicates a robust positive (negative) correlation. In this research, correlation analysis was applied to ascertain if connections existed among specific essential water quality variables being studied. It was also employed to evaluate the associations between the chosen water quality parameters.

Table 3.2: Summary of the objectives data and tool analysis

Objective	Variables	Source of data	Data analysis
To investigate the physical and chemical properties of water from River Lokichar.	Temperature, turbidity, Electrical conductivity and pH will be measured in situ while, COD, D.O, Sulphate nitrate calcium chloride and heavy metals will be analyzed from the laboratory.	Direct sampling	Excel and Geo-chemist Workbench
To determine the level of concentration of selected heavy metals present in the sediments	Sediments	Direct sampling	The contamination factor will be employed to assess the extent of heavy metal presence within sediments. An enrichment factor index will also be utilized to ascertain the origin of heavy metals in the sediments.
To characterize the hydrochemistry of water from River Lokichar	Ca^{2+} $Mg^{2+,}$ Na^{+} k^{+} SO^{2-}_{4} HCO^{-}_{3} CI^{-} $NO^{-}{}_{3}$values	Direct sampling	Geo-Chemist workbench

Source: Author 2023.

Pearson's correlation coefficient was computed between the water quality parameters of the two sampling sites using excel to find the relationship between parameters. The value of Pearson's correlation which shows the strength of the relationship between two variables ranges from -1.00 to + 1.00 (Kibena, Nhapi, & Gumindoga, 2014).

Analysis of Variance (ANOVA) was employed to assess disparities in the means of the population by evaluating the extent of variability within each sample compared to the variability between the samples (Kothari and Garg, 2014). A two-way ANOVA was carried out to establish the correlation between water quality parameters at the two sampling locations.

The concentration of heavy metals in water was assessed using standard deviations, with mean concentrations of heavy metals calculated. The data was then represented through graphical visualization. For heavy metals in sediments, the contamination factor (CF) was employed, calculated by dividing the concentration of each metal in the sediment by a reference value. The resulting values were summed and categorized based on contamination factor values. Furthermore, to discern whether heavy metals in sediments originated from human activities or geological sources, the Geo-accumulation index (I geo) was applied, determined using equation 2.2. In order to classify cations and anions and group them into distinct water types, hydro-chemical facies were identified through the Piper and Durov diagrams (Tiwari, 2011). The Geo-chemist workbench community edition software version 15.0 was used to plot the piper and durov diagrams.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

This part divulges the outcomes and examines the finding from water quality analysis, sediment analysis and characterization of the facies of water. The results from statistical analysis, Geo-chemist Workbench software and contamination factor/index of enrichment factor were used to comprehensively examine the impact of oil mining on surface water resources in Lokichar Basin. The various hydro-chemical processes influencing the surface water quality in the region and the water types are demonstrated by the Durov plots and piper diagram.

4.1 Selected Physical and Chemical Properties of Water

The minimum, average, standard deviation and maximum of the physiochemical properties are shown in table 4.1.

Table 4.1: The physio-chemical properties of surface water. Values indicate mean ± standard deviation.

Parameter	Areas further from oil wells	Proximity to oil wells	Overall	KEBS STANDARDS
Turbidity (NTU)	0.93±0.55	4.17±3.02	2.55 ±2.63	5
Temperature(˚C)	25.87±0.91	26.70±0.98	26.28 ±0.96	35
D.O	6.85±0.24	6.81±1.33	6.83 ±0.85	4
E.C(uS/cm)	447.9±144.6	483.1±114.2	465.5 ±118.1	1000
Ph	6.43±0.55	7.13±0.93	6.78 ±0.78	8.5
Fe^{-} $^{(}$mg/L)	26.07±17.76	18.50±5.77	22.28 ±12.52	0.3
CA $^{2+}$ (mg/L)	129.37±47.35	45.33±12.22	87.35 ±55.45	250
Mg $^{2+}$ (mg/L)	100.98±75.89	32.91±47.42	66.95 ±67.78	100
Hardness (mg/L)	738.67±419.12	248.67±217.72	493.67 ±401.57	500
CI- (mg/L)	516.67±76.38	366.67±30.55	441.67 ±97.25	250
NO^{-3} (mg/L)	1.22±0.74	0.59±0.20	0.90 ±0.60	10
NO^{-2} $^{(}$ mg/L)	0.05±0.04	0.03±0.04	0.04 ±0.04	10
F (mg/L)	1.13±0.17	1.11±0.09	1.12 ±0.12	1.5
MN $^{2+}$ (mg/L)	0.01±0.01	0.00±0.00	0.00 ±0.01	0.1
SO_{-4} (mg/L)	9980.00±1935.36	101313.33±685.95	10146.67 ±1311.41	400
COD (mg/L)	317.95±47.01	348.72±216.12	333.34 ±140.89	50

There was a decrease in the mean values of nearly all the parameters of the surface water away from the oil mines in comparison to areas around the oil mines aside for turbidity, electrical conductivity, temperature, pH, chloride, sulphate and COD. (Table 4.1).

The mean values of turbidity increased from 0.93mg/l to 4.17mg/l, Temperature from 25.87 ˚C to 26.70 ˚C, electrical conductivity from 447.9 uS/cm to 483.1 uS/cm to, chloride from 316.67mgl to366.67mg/l, sulphate from to 9980mg/l to 10313.33 mg/l and COD 317.95 mg/l to348.72mgl away and around oil mines respectively in the rainy season.

The mean values of D.O 6.83 ±0.85, iron 22.28 ±12.52, sulphate10146.67 ±1311.41, chloride 441.67 ±97.25 and COD 333.34 ±140.89 surpassed the KEBS recommended levels (Table 6). When the levels of physicochemical parameters in water exceed the guidelines established by KEBS (2010), it results in water contamination, rendering it unsuitable for consumption (Mbura, 2018; Onwughara, Ajiwe, & Nnabuenyi, 2013).

It should be noted that turbidity influences other parameters such as colour which affect the water quality (F. A. O. Otieno, Olumuyiwa, & Ochieng, 2012). Turbidity in water is due to the occurrence of suspended matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms (Walakira, 2012). Also, this is an indication of excessive human activities besides water resources (Abdalla, 2009; Yisa & Tijani, 2010).Unique sources of turbidity in water include waste discharges from industries and domestic, breakdown of aquatic plants leading to decay thus producing humus acid(Rueben, 2014). This explains the increase in turbidity of water from the area around the oil mines in the rainy season. The discrepancies in the temperature values were due to weather changes (Kumar et al. 2013).

The increase of chloride ions in water is due to the prolonged water/rock interaction (Abdalla, 2009).

Elevated chloride levels in water are typically considered an indication of pollution and are often used as an indicator of groundwater contamination (Environ Monit Asses, 2016). This can also be attributed to the properties of produced water which contains high level of chloride ions(D Mbugua, MK Makokha, & Shisanya., 2022).

The electrical conductivity increase can be clarified by the geology of the area (Gupta &Paul 2013). The presence of chloride, phosphate and nitrate raises the conductivity whereas an oil spill lowers the conductivity(American Public Health Association, 1992; Bhateria & Jain, 2016). Surface water resources that run via clay soil tend to have high conductivity values (Bhateria & Jain, 2016). A higher level of electrical conductivity indicates a large number of dissolved solids ionized in nature as cations and anions this is due to the type of soil and the geology of the area(Prasad, Kumar, Shilpa, & Yelamaggad, 2014) . Electrical conductivity is a convenient indicator of water mineralization (Jain & Vaid, 2018).

The pH values varied during the study due to waste entering the water and the decomposition of organic matter. Dissolved carbon dioxide and soil type can also cause acidic water (Vaikosen, Ebeshi, & Airhihen, 2014). An increase in pH is caused by organic pollution and household waste entering the water surface. The natural pH level of surface water is predicted to be 7.0 (O Akoto, T.N. Bruce, & Darko., 2008). Differences in concentration can be due to carbonates and bicarbonates dissolved in the water, which can disturb the pH of most surface waters. (O Akoto et al., 2008; A. Otieno, Kitur, & Gathuru, 2017). The pH value can be used to accurately indicate fluctuations in water quality, indicating the suitability of water for intended uses(Yang, Pan, Blyth, & Lowe, 2008).

Low pH levels increase the solubility of heavy metal compounds, resulting in higher concentrations of heavy metals in water (Nkambule, 2016).

According to Bradl (2005), the most important sources of sulfate are volcanoes caused by rock weathering and human activities such as mine tailings and fossil fuel burning hence the increase in sulphate. COD is useful for the determination of wastewater quality requirements discharged into receiving waters to limit their impact(Nkambule, 2016). The increase in COD levels could be attributed to the presence of produced water since COD concentration in produced water ranges between 2600 mg/l and 120,000 mg/l(Al-Ghouti et al., 2019).

The increased levels of iron could have also been attributed to the presence of produced water in surface water (D Mbugua et al., 2022). Iron is one of the parameters that are components of the produced water.

4.2 Relationship among water quality parameters

There exists a significant positive correlation between EC and Mg (0.90), TH (0.83), Nitrite (0.94) fluoride (0.91) and sulphate (0.99). Table 4.2 shows the relationship of parameters. Which is positive with most parameters this signifies the importance of electrical conductivity in the determination of water quality (Howladar et al., 2021). Chlorides are positively correlated with temperature, indicating severe corrosion in water pipe systems and should be treated as follows. The strong correlation between sulphate and electrical conductivity suggests that the increase in salinity is largely due to the dissolution of sulphate ions(Tredoux, Van Der Merwe, & Peters, 2009).

The conductive ions originate from dissolved salts and inorganic substances like alkalis, chlorides, sulfides, and carbonates. Substances that dissociate into ions are referred to as electrolytes. A greater number of ions results in increased water conductivity. This explains the strong correlation between electrical conductivity with magnesium, total hardness nitrite fluoride and sulphate (Swain, Sahoo, & Taloor, 2022). The weathering caused by alternative wet and dry conditions of the arid, and semi-arid climate is responsible for the leaching of fluoride from the minerals in the soils and rocks (Narsimha & Sudarshan, 2017). This is because groundwater sources of fluoride include the dissolution of fluorite-bearing rocks, leachate from untreated sewage, and phosphate-bearing fertilizers, so the use of phosphate fertilizers or Possibly due to the use of rocks containing stones (Kumar& Kumar, 2013). Total water hardness can be described as a combination of temporary and permanent cations such as Calcium, Magnesium, Iron, Manganese, Barium, and Sulfate. Therefore, there exists a significant relationship between total hardness and manganese sulphate and nitrate. Manganese has a strong correlation with total hardness since it contains multivalent cations which contribute to the measure of the hardness of water (Pande, Sinha, & Agrawal, 2015).

Table 4.2: Correlation analysis

	TURBIDITY	*TEMP*	*DO*	*EC*	*pH*	*Fe^{2+}*	*Ca^{2+}*	*Ma^{2+}*	*TOTAL HARDNESS*	*Cl^{-}*	*NO^{-}_{3}*	*NO^{-}_{2}*	*F^{-}*	*Mn^{2+}*	*SO^{2-}_{4}*	*COD*
TURBIDITY	1.00															
TEMP	-0.85	1.00														
DO	-0.45	0.86	1.00													
EC	-0.39	-0.15	-0.64	1.00												
pH	0.79	-0.34	0.20	-0.88	1.00											
IRON	-0.90	0.52	0.01	0.76	-0.98	1.00										
CALCIUM	0.54	-0.91	-0.99	0.56	-0.09	-0.11	1.00									
MAGNESIUM	0.05	-0.57	-0.91	0.90	-0.58	0.40	0.87	1.00								
TOTAL HARDNESS	0.19	-0.68	-0.96	0.83	-0.46	0.26	0.93	0.99	1.00							
CHLORIDE	-0.97	0.95	0.65	0.16	-0.61	0.76	-0.73	-0.29	-0.42	1.00						
NITRATE	0.67	-0.96	-0.96	0.42	0.07	-0.27	0.99	0.78	0.86	-0.83	1.00					
NITRITES	-0.68	0.19	-0.35	0.94	-0.99	0.93	0.25	0.70	0.59	0.48	0.09	1.00				
FLUORIDE	-0.73	0.26	-0.28	0.91	-1.00	0.96	0.18	0.64	0.53	0.55	0.02	1.00	1.00			
MANGANESE	0.71	-0.98	-0.95	0.37	0.12	-0.33	0.98	0.74	0.83	-0.86	1.00	0.03	-0.04	1.00		
SULPHATE	-0.25	-0.30	-0.75	0.99	-0.80	0.66	0.68	0.95	0.90	0.01	0.55	0.88	0.84	0.50	1.00	
COD	-0.91	0.55	0.04	0.74	-0.97	1.00	-0.15	0.37	0.23	0.79	-0.30	0.92	0.95	-0.36	0.63	1.00

4.3 Spatial Variation in Water Quality

The ANOVA indicated that there was not any significant distinction in each site ($p > 0.05$) for all physical-chemical water quality parameters in different sampling sites. This would be due to the geology of the research area since the samples were gathered in the same area just in different locations.

The ANOVA two-replication factor was used to determine both the control points (sites far away from the mining) which were downstream and the site near the mining area (downstream. The analysis demonstrated that there was not any significant difference in each site ($p > 0.05$) in all physical-chemical water quality parameters in different sampling sites.

4.4: Characterization of Hydro-Chemical Facies of Surface Water

4.4 1 Classification of Water based on Piper Diagram

From the piper trilinear diagram (Figure 4.1), 40% of the samples (region IV) belong to the $CaHCO_3$ water type which is strongly associated with weathering (Sappa, Iacurto, Ferranti, & De Filippi, 2019). The water type characterized as $Ca^{-}HCO_3$ signifies the potential presence of freshwater or recharging. This phenomenon is linked to the interaction between atmospheric water and carbon dioxide, leading to the creation of carbonic acid. When rainwater descends onto the land, it reacts with the aquifer's underlying material ($CaCO_3$), causing an excess of Ca^{2+} and HCO_{3-} ions to emerge. Consequently, during the recharging process, a substantial amount of Ca^{2+} and HCO_{3-} ions are introduced into the groundwater (Hussien & Faiyad, 2016; Peter, 2020).

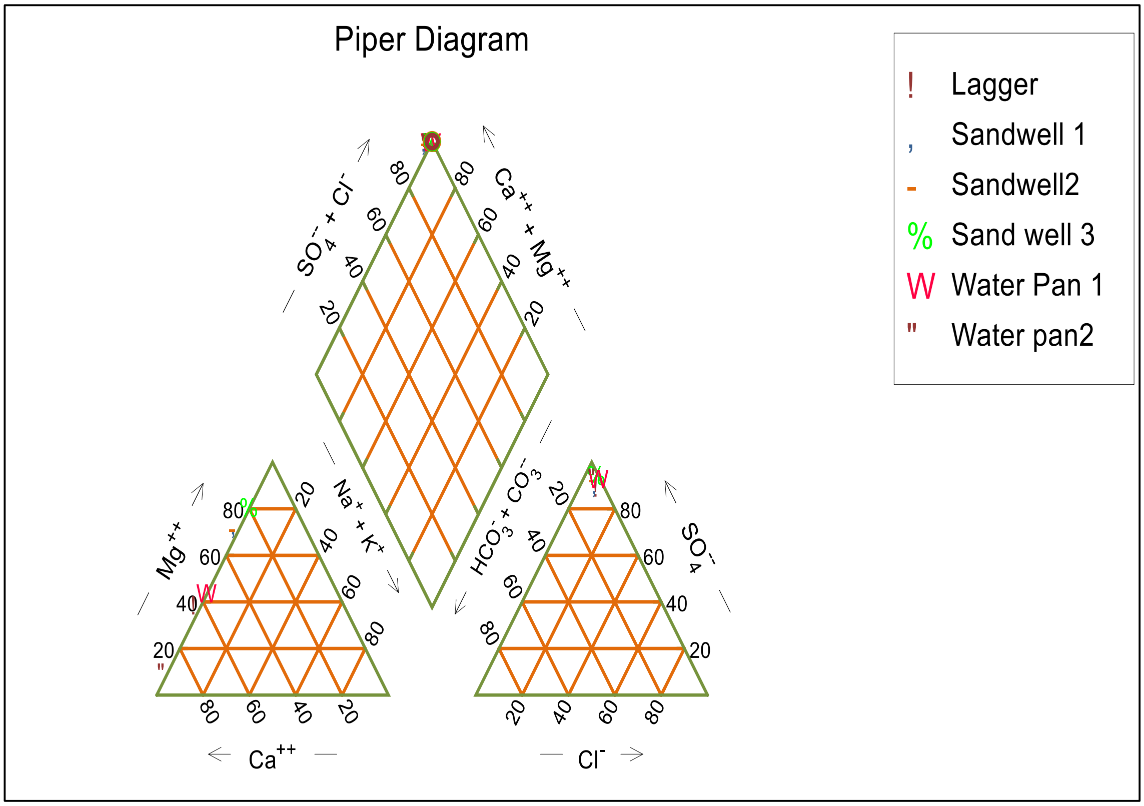

Figure 4.1: Plotted Piper Diagram for lokichar basin

The samples belonged to the mixed water type which is caused by the mixing of waters or water-rock interactions (Nematollahi, Ebrahimi, Razmara, & Ghasemi, 2016). Therefore, it can be suggested that the composition of water resources is shaped by the interplay between water and rocks as well as human-induced pollution. No samples were observed to be represented in region II (Na-Cl water type) implying that there is no likelihood of seawater (sea salt) intrusion, atmospheric precipitation or industrial waste.In addition, the Lokichar Basin is found originally in sediments accumulated in a large freshwater lake similar to some modern rift lakes hence the existence of freshwater (Talbot et al., 2004).

4.4.2 Classification of Water Based on the Durov Diagram

The Durov diagram was used to understand the hydro-chemical process controlling surface water system.Isehunwa and Onovae (2011). It was observed in Figure 4.2 that In the Durov diagram, 50.0% of the samples fall on the mixing line. This trend was attributed to water exhibiting simple dissolution or mixing with no dominant major anion (Aghazadeh, Chitsazan & Golestan. 2017). Furthermore, around 30% of the samples exhibit a prevailing presence of SO_4^{2-} or anionic dominance, accompanied by a prevalence of Na+. This water type is relatively infrequent and suggests potential mixing or unusual influences related to dissolution (Ravikumar et al., 2015).

Additionally, it was noted that within the remaining 20% of the samples, there is a prevalence of $SO_4{}^{2-}$ or anionic dominance along with a prevalence of $Ca^{2+.}$ This combination, often indicating recharge water within lava and gypsiferous deposits, might otherwise suggest mixed water or water displaying straightforward dissolution processes (Ravikumar et al.,2015). This validates the connection between water and rock, which is consistent with findings by Ziani, Abderrahmane, Boumazbeur, and Benaabidate (2017). Such patterns often suggest recharging within lava and gypsiferous formations, while alternatively, they could signify mixed water or water undergoing uncomplicated dissolution, as indicated by Ravikumar et al. (2015).

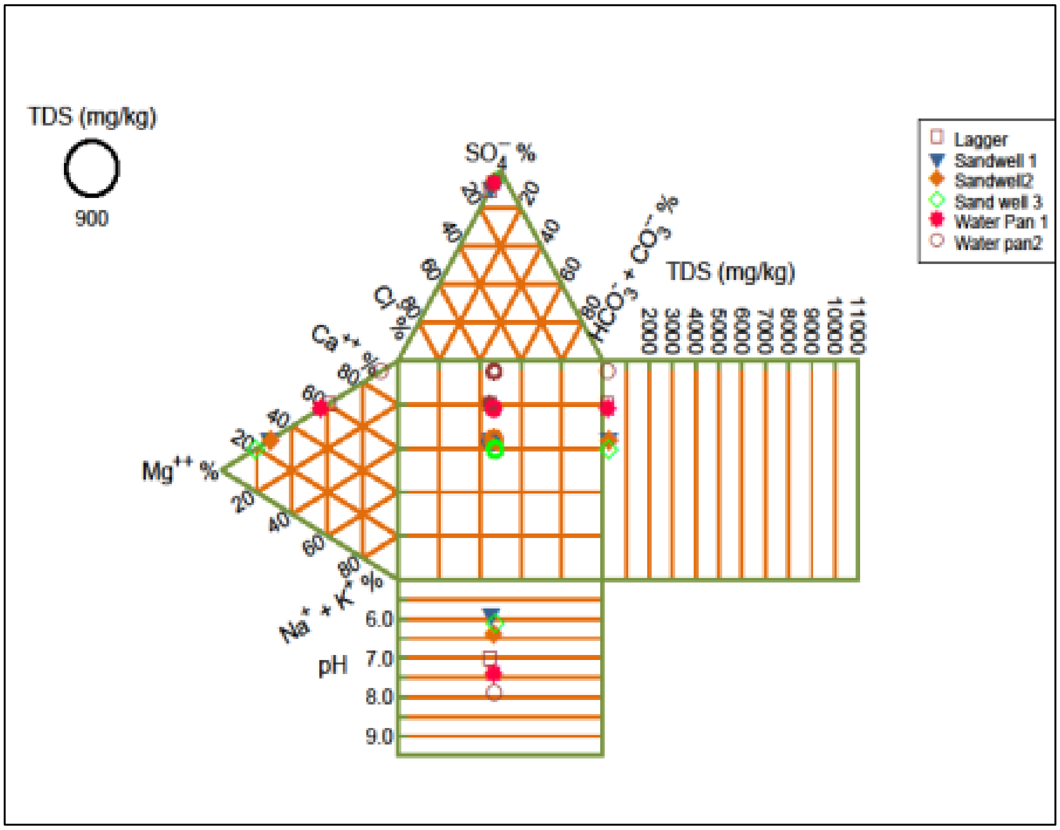

Figure 14.2: Durov Plot for surface water in lokichar basin

4.5 Level of Concentration of Selected Heavy Metals in the Sediment

Descriptive statistics were employed to condense the heavy metal parameters of the collected sediment samples, outlining their minimum, maximum, standard deviation, and coefficient of variance for each parameter (Table 4.3). The mean, standard deviation (SD), and coefficient of variance (CV) analyses were crucial to illustrate the precision and accuracy of each measured parameter. Most of the CV assessments showed positive values, indicating substantial similarity among the sampling stations. This likeness stemmed from uniform environmental conditions and sediment attributes across the Lokichar Basin.

In general, it was observed that the range of lead (Pb) concentrations (1.76–2.70 mg/kg) in the sediment exceeded those of zinc (Zn) (0.12–0.30 mg/kg) and cadmium (Cd) (-0.04 to -0.03 mg/kg).

The Pb was high due to the location of the sampling point near a major road which was under construction where construction vehicles were being parked. Hence anthropogenic sources of Pb could have been from spillage of leaded petrol from the vehicles (Haris et al., 2017).Abugu et al. (2024) notes that in the Niger Delta in Nigeria Pb and Cd are

often 2-4 times due to proximity to infrastructural activities.

Table 4.3: heavy metal concentration

Heavy metal	Unit	Min	Max	Mean ± SD
Pb	mg/kg	1.7585	2.7037	2.316 ± 0.363
Zn	mg/kg	0.1187	0.3042	0.191 ± 0.066
Cd	mg/kg	-0.0352	-0.0299	-0.033 ± 0.002

Analysis of variance (ANOVA) was used to determine whether the differences in variables between the stations were significant. The outcome indicated no substantial differences ($p > 0.05$) in any of the variables between the sampling stations for the heavy metals Zn and lead Pb. This was due uniform geological formation which similar to the findings from Awash River in Ethiopia where heavy metals like Zinc did not exhibit spatial variation among sampling sites (Eliku & Leta, 2018)

Whereas for Cd there was a there was a statistically significant difference in Cadmium (Cd) concentrations between sampling sites ($p < 0.05$).. Cd was high in the control site in the study due to little practices of vegetable planting near the banks of the river(Haris et al., 2017). WHO (2017),notes that even moderate levels of Cd and Pb in water can lead to kidney damage and aquatic death therefore continuos monitoring is important .

4.5.1 Geo-accumulation Index (Igeo)

Table 4.4 shows the Igeo value for Zn, Pb Cd in the Lokichar basin for areas around the oil exploration.

The geo-accumulation index (Igeo) for Zn in Lokichar basin sediment varied from 0.72 from 0.5, Pb (0.45 to 0.67) and Cd (0.46-0.53). All stations were in class 0-1(unpolluted). This suggests that the Lokichar Basin had minimal contamination from human-induced origins of zinc (Zn), lead (Pb), and cadmium (Cd). The presence of these heavy metals in the sediment primarily originated from natural processes like the breakdown of soil and rocks due to weathering (Haris et al., 2017).

Table 4.4: Geo-accumulation pollution classification for sediments

Parameter	Sandwell 3	Water Pan 1	Water Pan 2	Classification
Zinc	0.71	0.28	0.5	Unpolluted
Lead	0.45	0.67	0.57	Unpolluted
Cadminium	0.5	0.53	0.46	Unpolluted

4.5. 3Contamination Factor

Table 4.5 shows the Cf values of Pb, Zn and Cd at each sampling site. The contamination level of zinc (Zn) in the majority of sampling locations exhibited a contamination factor (Cf) of less than 1, indicating low contamination.

However, at water pan 1, the calculated contamination factor placed the sediment in a category of moderate contamination, with a Cf value falling between 1 and 3. The high concentration of Zn in water pan is because of heavy metals' affinity to silt soil found in the pan (Amadi & Nwankwoala, 2013).

Table4.5: Contamination factor for sediments in Lokichar basin

Parameter	Sandwell 3	Water Pan 1	Water Pan 2	Classification
Zinc	0.64	1.64	0.91	Moderately polluted
Lead	1.01	0.7	0.79	Moderately polluted
Cadmium	0.91	0.86	0.98	Moderately polluted

Increased concentrations of these metals in soil profiles pose a major risk to groundwater and surface water. (Ololade, 2014). High concentrations of zinc in soil cause phytotoxicity. The values for Pb showed low pollution intensity for most of the sampling site with exception of sandwell 1 which indicated moderate pollution. All the sampling sites for Cd fell under low pollution intensity of contamination factor. The low concentration was due to the Arid and semi-arid nature of the land in Lokichar basin,Cadmium is found in soil through inorganic fertilizers and hence leached to the surrounding soil (Amadi & Nwankwoala, 2013).

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.0 Conclusion

1. The levels of physicochemical parameters of surface water were determined. It was found that all the sampling sites had high Dissolved Oxygen, Iron, chloride, sulphate and COD levels according to the KEBS standards. When the remaining chemical characteristics were examined in the lab, it was found that the dominant cations were in the order; Ca^{2+}> Na^{+} >Mg^{2+}> Fe^{2+} while the order of dominant anions was HCO_3>Cl^->SO_4^{2-}>NO_{3-}>F^-
2. The heavy metal analysis of sediments revealed that the Coefficient of Variance (CV) analyses were positive for most samples which show high similarity between the stations. The similarities resulted from the Lokichar Basin's similar geological conditions and sedimentary features. The concentration of Lead was leading among stations (1.76–2.70 mg/kg). The findings showed that there were no significant differences ($p<0.05$) in any of the variables between the Zn and Pb heavy metal sample station. Whereas for Cd there was a significant difference between sampling sites due to the anthropogenic sources of mining and sewage sludge (Sidhu, Singh, Batish, & Kohli, 2017). Igeo offers a precise assessment of the movement and distribution of metals stemming from human-induced origins.

The geo-accumulation index (Igeo) for zinc (Zn) in the sediment of the Lokichar Basin ranged from -1.72 to 0.21, for lead (Pb) it spanned from 0.45 to 0.67, and for cadmium (Cd) it fell between 0.46 and 0.53. Across all stations, the values were within the range of class 0-1, indicating unpolluted conditions. This suggests that the Lokichar Basin experienced minimal contamination from human-induced sources of Zn, Pb, and Cd. The contamination factor (Cf) was also computed to determine the sediment's contamination status. The Cf values for Pb, Zn, and Cd were assessed at each sampling site. Zn pollution intensity mostly showed a Cf value below 1, indicating low contamination, except for water pan 1, which fell within the moderate contamination range with Cf between 1 and 3. The values for Pb showed low pollution intensity for most of the sampling sites with the exception of Sandwell 1 which indicated moderate pollution. All the sampling sites for Cd fell under low pollution intensity of contamination factor < 1.

The hydro-geochemical facies showed that the main mechanisms governing the chemistry of the groundwater in the region were ion exchange, mixing of the fluids, atmospheric precipitation, and the dissolving of salt deposits inside the vadose zones.

3. They further revealed the water types in the region as; 40 % Ca^{2+}-$Mg^{2+-}Cl^{-}$-SO_4^{2-} type, 40% Ca^{2+}-Mg^{2+}-HCO_{3-}, 20 % Na^{+}-K^{+}-HCO_{3-} with no Na^{+}-K^{+}-Cl^{-}-SO_4^{2-} water type. The research area's predominant hydro-chemical facies, according to the hydrochemistry results, is Mixed Type. Variations in the hydrogeochemistry of groundwater in the research region are primarily caused by simple mineral breakdown or blending processes, according to surface water types evaluated and opposed to using Durov and Piper diagrams.

5.1 Recommendation

1. WaterResources Autnority(WRA) should ensure constant monitoring of the water parameters in all the surface water to take precautionary measures in case parameters change to ensure that water in the study area meets the required standards for domestic use.
2. Water Resources Authority (WRA) should periodically test for heavy metals in sediment since the sediments act as the bed material for heavy metals in rivers.
3. A hydro-chemical characterization should be done periodically by Water Resources Authorityto determine the source of pollution as this may change over time as a result of continued oil mining.

5.2 Recommendation for Further Research

I. More research is to be done on the health implications of surface water contamination on the inhabitants of the area since parameters such as Sulphate and chloride were found to be high during the study which has serious health implications for humans.

II. Analysis of microbiological factors that affect the local area surface water condition. It was observed during the study that most surface water resource were shared for drinking by humans and animals.

III. Determination of seasonal variability of hydro-geochemical parameters in surface water,.

REFERENCES

Abdalla, O. A. (2009). Groundwater recharge/discharge in semi-arid regions interpreted from isotope and chloride concentrations in north White Nile Rift, Sudan. *Hydrogeology Journal, 17*(3), 679-692.

Abugu, H. O., Egbueri, J. C., Agbasi, J. C., Ezugwu, A. L., Omeka, M. E., Ucheana, I. A., & Aralu, C. C. (2024). Hydrochemical characterization of ground and surface water for irrigation application in Nigeria: A review of progress. *Chemistry Africa, 7*(6), 3011-3036.

Adamu, C. I., & Nganje, T. N. (2010). Heavy metal contamination of surface soil in relationship to land use patterns: A case study of Benue State, Nigeria. *Materials Sciences and Applications, 1*(03), 127.

ADB. (2009). *Oil and Gas in Africa.* Abidjan, Côte d'Ivoire: African Development Bank.

Adepoju-Bello, A. A., & Alabi, O. (2005). Heavy metals: A review. *The Nig. J. Pharm, 37,* 41-45.

Agaya, B. M. (2021). Technology innovations for mitigating environmental and social impacts of oil and gas production in Kenya *Environment and Sustainable Development* (pp. 262-282): Routledge India.

Al-Ghouti, M. A., Al-Kaabi, M. A., Ashfaq, M. Y., & Da'na, D. A. (2019). Produced water characteristics, treatment and reuse: A review. *Journal of Water Process Engineering, 28,* 222-239.

Al-Heety, A., M., A., & M., E. (2011). Physico-chemical assessment of euphrates river between Heet and Ramadi Cities, Iraq. *Journal of Water Resource and Protection,, 3*(11).

Alshahri, F. (2017). Heavy metal contamination in sand and sediments near to disposal site of reject brine from desalination plant, Arabian Gulf: Assessment of environmental pollution. *Environmental Science and Pollution Research, 24*(2), 1821-1831.

Amadi, A. N., & Nwankwoala, H. (2013). Evaluation of heavy metal in soils from Enyimba dumpsite in Aba, southeastern Nigeria using contamination factor and geo-accumulation index.

American Public Health Association, A. (1992). *Standard Methods For the examination of Water and Waste water*. Washington D.C.

Anazawa, K., & Ohmori, H. (2005). The hydrochemistry of surface waters in Andesitic Volcanic area, Norikura volcano, central Japan. *Chemosphere, 59*(5), 605-615.

APHA. (1992). *Standard methods for examination of water and wastewater.* Washington, DC: American Public Health Association.

Ashun, E. (2014). *Assessment, and Mapping of Groundwater Quality in the Thiririka Sub-catchment Kiambu County, Kenya.* (MSC), Kenyatta University, Nairobi.

Azetsu-Scott, K., Y., P., , Wohlgeschaffen, G., , D., J., , Niven, S., & Lee, K. (2007). Precipitation of heavy metals in produced water: Influence on contaminant transport and toxicity. *Marine Environmental Research, 63*(2), 146-167.

Azizullah, A., Khattak, M. N. K., Richter, P., & Häder, D.-P. (2011). Water pollution in Pakistan and its impact on public health—a review. *Environment international, 37*(2), 479-497.

Bakke, T., Klungsøyr, J., & Sanni, S. (2013). Environmental impacts of produced water and drilling waste discharges from the Norwegian offshore petroleum industry. .*Marine environmental research,, 92*, 154-169.

Bett, G. K. (2018). *Geochemical Evaluation Of The Hydrocarbon Potential Of Source Rocks In The Anza Basin*. University of Nairobi.

Bhateria, R., & Jain, D. (2016). Water quality assessment of lake water: a review. *Sustainable Water Resources Management, 2*, 161-173.

Bradl, H. (2005). Sources and origins of heavy metals *Interface science and technology* (Vol. 6, pp. 1-27): Elsevier.

Bricker, O. P. (1999). An overview of the factors involved in evaluating the geochemical effects of highway runoff on the environment.

Caeiro, S., Costa, M. H., Ramos, T., Fernandes, F., Silveira, N., Coimbra, A., . . . Painho, M. (2005). Assessing heavy metal contamination in Sado Estuary sediment: an index analysis approach. *Ecological indicators, 5*(2), 151-169.

Carrillo-Chavez, A., Salas-Megchun, E., Levresse, G., Munoz-Torres, C., Perez-Arvizu, O., & Gerke, T. (2014). Geochemistry and mineralogy of mine-waste material from a “skarn-type” deposit in central Mexico: Modeling geochemical controls of metals in the surface environment. *Journal of Geochemical Exploration, 144*, 28-36.

Chen, H., Teng, Y., Lu, S., Wang, Y., & Wang, J. (2015). Contamination features and health risk of soil heavy metals in China. *Science of the Total Environment, 512*, 143-153.

Cooley, H., Donnelly, K., Ross, N., & Luu, P. (2012). Hydraulic fracturing and water resources: separating the frack from the fiction. *Pacific Institute, Oakland*.

D Mbugua, MK Makokha, & Shisanya., C. (2022). Assessment of Physicochemical Properties of Groundwater near Oil Well Pads in Lokichar Basin, Turkana County, Kenya. *Open Access Library Journal*.

Da Silva, S. S., Chiavone-Filho, O., de Barros Neto, E. L., & Foletto, E. L. (2015). Oil removal from produced water by conjugation of flotation and photo-Fenton processes. *Journal of Environmental Management Health,, 147*, 257-263.

Di Bonito, M., Breward, N., Crout, N., Smith, B., & Young, S. (2008). Overview of selected soil pore water extraction methods for the determination of potentially toxic elements in contaminated soils: operational and technical aspects *Environmental geochemistry* (pp. 213-249): Elsevier.

Dung, T. T. T., Cappuyns, V., Swennen, R., & Phung, N. K. (2013). From geochemical background determination to pollution assessment of heavy metals in sediments and soils. *Reviews in Environmental Science and Bio/Technology, 12*(4), 335-353.

Durell, G., Neff, J., Melbye,, A., J., S., , Garpestad, E., & Gruner, H. (2000). *Monitoring and assessment of produced water originating contaminants in the Ekofisk Region of the North Sea*. SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production.

Elias, P., & Gbadegesin, A. (2011). Spatial relationships of urban land use. *Soils and Heavy*.

Eliku, T., & Leta, S. (2018). Spatial and seasonal variation in physicochemical parameters and heavy metals in Awash River, Ethiopia. *Applied Water Science, 8*, 1-13.

Elsawwaf, M., Feyen, J., Batelaan, O., & Bakr, M. (2014). Groundwater-surface water interaction in Lake Nasser, Southern Egypt. Hydrological Processes. 414-430.

Erakhrumen, A. A. (2015). Concentrations of heavy metals in untreated produced water from a crude oil production platform in Niger-delta, Nigeria. *Research in Forestry, Wildlife and Environment*(7(1)), 89-101.

Fakhru'l-Razi, A., P., A., A., L. C., B., D. R. A., M., & S. S., A., Z. Z. . (2009). Review of technologies for oil and gas produced water treatment. *Journal of hazardous materials, 170(2-3*, 530-551.

Gaagai, A., Boudoukha, A., Boumezbeur, A., & Benaabidate, L. (2017). Hydrochemical characterization of surface water in the Babar watershed (Algeria) using environmetric techniques and time series analysis. . *International Journal of River Basin Management,, 15*(3), 361-372.

Gao, X., & Chen, C.-T. A. (2012). Heavy metal pollution status in surface sediments of the coastal Bohai Bay. *Water research, 46*(6), 1901-1911.

Gautam, S. K., Sharma, D. T., 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.

Githaiga, K. B., Njuguna, S. M., Gituru, R. W., & Yan, X. (2021). Water quality assessment, multivariate analysis and human health risks of heavy metals in eight major lakes in Kenya. *Journal of Environmental Management, 297*, 113410.

Glover, J. D., Reganold, J. P., & Andrews, P. K. (2000). Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington State. *Agriculture, ecosystems & environment, 80*(1-2), 29-45.

Government, T. C. (2016). *The Turkana County Water and Sewerage Services Sector Policy*. Lodwar.

Grzebisz, W., Ciesla, L., Komisarek, J., & Potarzycki, J. (2002). Geochemical assessment of the heavy metals pollution of urban soils. *Polish Journal of Environmental Studies, 11*(5), 493-500.

Guerra, K., Dahm, K., & Dundorf, S. (2011). *Oil and gas produced water management and beneficial use in the Western United States*. Washington, DC:.

Gupta, T., & Paul, M. (2013). The seasonal variation in ionic composition of pond water of Lumding, Assam, India. *Current World Environment, 8*(1), 127-131.

Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. *Water research, 14*(8), 975-1001.

Haris, H., Looi, L. J., Aris, A. Z., Mokhtar, N. F., Ayob, N. A. A., Yusoff, F. M., . . . Praveena, S. M. (2017). Geo-accumulation index and contamination factors of heavy metals (Zn and Pb) in urban river sediment. *Environmental geochemistry and health, 39*, 1259-1271.

Hawkes, H. E., & Webb, J. S. (1963). Geochemistry in mineral exploration. *Soil Science, 95*(4), 283.

Heya, M. (2011). Overview of Petroleum Exploration in Kenya.

Howladar, M. F., Chakma, E., Koley, N. J., Islam, S., Al Numanbakth, M. A., Ahmed, Z., . . . Akter, S. (2021). The water quality and pollution sources assessment of Surma river, Bangladesh using, hydrochemical, multivariate statistical and water quality index methods. *Groundwater for sustainable development, 12*, 100523.

Hussien, B. M., & Faiyad, A. S. (2016). Modeling the hydrogeochemical processes and source of ions in the groundwater of aquifers within Kasra-Nukhaib region (West Iraq). *International Journal of Geosciences, 7*(10), 1156-1181.

Igunnu, E. T., & Chen, G. Z. (2014). Produced water treatment technologies. *International Journal of Low-Carbon Technologies, 9*(3), 157-711.

Isehunwa, S., & Onovae, S. (2011). Evaluation of produced water discharge in the Niger-Delta.

Jain, C., & Vaid, U. (2018). Assessment of groundwater quality for drinking and irrigation purposes using hydrochemical studies in Nalbari district of Assam, India. *Environmental Earth Sciences, 77*, 1-14.

Kappel, W. M., Williams, J. H., & Szabo, Z. (2013). *Water resources and shale gas/oil production in the Appalachian Basin: critical issues and evolving developments*: US Department of the Interior, US Geological Survey Washington, DC, USA.

KEBS. (2007). Drinking Water Specification *The Requirement for Drinking Water* (Vol. 3rdEdition). Nairobi,Kenya.

Kelepertzis, E. (2014). Accumulation of heavy metals in agricultural soils of Mediterranean: insights from Argolida basin, Peloponnese, Greece. *Geoderma, 221*, 82-90.

Kibena, J., Nhapi, I., & Gumindoga, W. (2014). Assessing the relationship between water quality parameters and changes in landuse patterns in the Upper Manyame River, Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C, 67*, 153-163.

Kierczak, J., Pędziwiatr, A., Waroszewski, J., & Modelska, M. (2016). Mobility of Ni, Cr and Co in serpentine soils derived on various ultrabasic bedrocks under temperate climate. *Geoderma, 268*, 78-91.

Kothari, C. R. (2004). *Research methodology: Methods and techniques*: New Age International.

Kowalska, J., Mazurek, R., Gąsiorek, M., Setlak, M., Zaleski, T., & Waroszewski, J. (2016). Soil pollution indices conditioned by medieval metallurgical activity–A case study from Krakow (Poland). *Environmental pollution, 218*, 1023-1036.

Kumar, M., & Kumar, R. (2013). Assessment of physico-chemical properties of ground water in granite mining areas in Goramachia, Jhansi, UP, India. *International Research Journal of Environment Sciences, 2*(1), 19-24.

Kumar, P., Meena, N. K., & Mahajan, A. K. (2019). Major ion chemistry, catchment weathering and water quality of Renuka Lake, north-west Himalaya, India. *Environmental Earth Sciences, 78*, 1-16.

Kuwayama, Y., Olmstead, S., & Krupnick, A. (2015). Water quality and quantity impacts of hydraulic fracturing. *Current Sustainable/Renewable Energy Reports, 2*(1), 17-24.

Makokha, K. J. (2017). *Analysis of groundwater quality and identification of abstraction points in Kahawa Wendani, Kiambu County.* (MSC), Nairobi Univerity.

Mazurek, R., Kowalska, J., Gąsiorek, M., Zadrożny, P., Józefowska, A., Zaleski, T., . . . Orłowska, K. (2017). Assessment of heavy metals contamination in surface layers of Roztocze National Park forest soils (SE Poland) by indices of pollution. *Chemosphere, 168*, 839-850.

Mbura, K. S. (2018). Assessment of selected physico-chemical parameters of ground water in Tharaka Nithi County, Kenya. *Masters Degree Thesis. Kenyatta University, Kenya*.

McMahon, G. (2008). *Analytical instrumentation: a guide to laboratory, portable and miniaturized instruments*: John Wiley & Sons.

Mohamed, T. A., Mohamed, M. A. K., Rabeiy, R., & Ghandour, M. A. (2014). Application of pollution indices for evaluation of heavy metals in soil close to phosphate fertilizer plant, Assiut, Egypt. *Assiut Univ Bull Environ Res, 17*(1), 45-55.

Mohiuddin, K., Zakir, H., Otomo, K., Sharmin, S., & Shikazono, N. (2010). Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. *International Journal of Environmental Science & Technology, 7*(1), 17-28.

Mugendi, K. D. (2020). Oil and gas Exploration and Sustainable Environmental Management in oil Block 13t South Lokichar Basin, Turkana County, Kenya. PhD. *PhD*.

Müller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. *Geojournal*(2), 108-118.

Murhekar , G. H. (2011). Assessment of physico-chemical status of ground water samples in Akot city. *Research Journal of Chemical Sciences, 1*(4), 117-124.

Murugesan, V., Krishnaraj, S., Kannusamy, V., Selvaraj, G., & Subramanya, S. (2011). Groundwater potential zoning in Thirumanimuttar sub-basin Tamilnadu, India—A GIS and remote sensing approach. *Geo-spatial Information Science, 14*(1), 17-26.

Mwangi , W. J. (2014). *Assessment of Bacteriological and Physico-Chemical Quality of Water for Domestic uses in Kiamumbi Catchment, Kiambu County Kenya.* (Msc), Jomo

Kenyatta University of Agriculture and Technology

Narsimha, A., & Sudarshan, V. (2017). Contamination of fluoride in groundwater and its effect on human health: a case study in hard rock aquifers of Siddipet, Telangana State, India. *Applied Water Science, 7*, 2501-2512.

Neff, J., Lee, K., , & DeBlois, E. M. (2011). Produced water: overview of composition, fates, and effects. *Produced water,*, 3-54.

Nematollahi, M., Ebrahimi, P., Razmara, M., & Ghasemi, A. (2016). Hydrogeochemical investigations and groundwater quality assessment of Torbat-Zaveh plain, Khorasan Razavi, Iran. *Environmental Monitoring and Assessment, 188*, 1-21.

Nkambule, T. S. (2016). Evaluation of the status of water quality of the Great Usuthu River, Swaziland.

O Akoto, T.N. Bruce, & Darko., D. (2008). Heavy metals pollution profiles in streams serving the Owabi reservoir. *African Journal of Environmental Science and Technology, 2 No 11*.

Ogunkunle, C. O., & Fatoba, P. O. (2013). Pollution Loads and the Ecological Risk Assessment of Soil Heavy Metals around a Mega Cement Factory in Southwest Nigeria. *Polish Journal of Environmental Studies, 22*(2).

Oliver, D., Bramley, R., Riches, D., Porter, I., & Edwards, J. (2013). soil physical and chemical properties as indicators of soil quality in A ustralian viticulture. *Australian Journal of Grape and Wine Research, 19*(2), 129-139.

Ololade, I. A. (2014). An assessment of heavy-metal contamination in soils within auto-mechanic workshops using enrichment and contamination factors with geoaccumulation indexes. *Journal of Environmental protection, 2014*.

Olumuyiwa, L., Fred, A., & Ochieng, M. (2012). Characteristics, qualities, pollutions and treatments of water in Durban, South Africa. *International Journal of Water Resources and Environmental Engineering, 4*(6), 162-170.

Onwughara, N., Ajiwe, V., & Nnabuenyi, H. (2013). Physicochemical studies of water from selected boreholes in Umuahia North Local Government Area. *Abia State, Nigeria. International Journal of Pure & Applied Bioscience, 1*(3), 34-44.

Opiyo, F., Wasonga, O., Nyangito, M., Schilling, J., & Munang, R. (2015). Drought adaptation and coping strategies among the Turkana pastoralists of northern Kenya. *International Journal of Disaster Risk Science, 6*, 295-309.

Opiyo, F. E. (2014). *Climate variability and change on vulnerability and adaptation among Turkana pastoralists in north-western Kenya.* University of Nairobi.

Otieno, A., Kitur, E., & Gathuru, G. (2017). Physico-Chemical Properties of River Kisat, Lake Victoria Catchment, Kisumu County, Kenya. *Environ. Pollut. Climate Change, 1*(4), 1-4.

Otieno, F. A. O., Olumuyiwa, I. O., & Ochieng, G. M. (2012). Groundwater: Characteristics, qualities, pollutions and treatments: An overview. *African journal of agricultural research*.

Padhan, D., Rout,, P. P., K., R., A., S.,, & Padhi, P. P. (2021). Bioremediation of heavy metals and other toxic substances by microorganisms. . *Soil bioremediation: an approach towards sustainable technology*, 285-329.

Pande, G., Sinha, A., & Agrawal, S. (2015). Impacts of leachate percolation on ground water quality: A case study of Dhanbad city. *Global Nest J, 17*(1), 162-174.

Pejman, A., Bidhendi, G. N., Ardestani, M., Saeedi, M., & Baghvand, A. (2015). A new index for assessing heavy metals contamination in sediments: A case study. *Ecological indicators, 58*, 365-373.

Peter, S. K. (2020). *Hydrochemical Analysis and Modelling of Ground Water in Mbeere South Sub-County, Embu County, Kenya.*, SCHOOL OF PURE AND APPLIED SCIENCES, KENYATTA UNIVERSITY.

Plänitz, E., & Kuzu, D. (2015). Oil production and the transformation of livelihoods of communities in Ghana.

Prasad, S. K., Kumar, M. V., Shilpa, T., & Yelamaggad, C. (2014). Enhancement of electrical conductivity, dielectric anisotropy and director relaxation frequency in composites of gold nanoparticle and a weakly polar nematic liquid crystal. *RSC Advances, 4*(9), 4453-4462.

Purcell, P. (2014). Oil and gas exploration in East Africa: A brief history. *AAPG Search and Discovery Article, 30388*, 14-17.

Qingjie, G., Jun, D., Yunchuan, X., Qingfei, W., & Liqiang, Y. (2008). Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. *Journal of China university of geosciences, 19*(3), 230-241.

Reimann, C., & Garrett, R. G. (2005). Geochemical background—concept and reality. *Science of the total environment, 350*(1-3), 12-27.

Reuben, G. (2014). *ASSESSMENT OF THE IMPACT OF EFFLUENTS FROM BONITE BOTTLERS AND CHINA PAPER INDUSTRIESON THE WATER QUALITY IN KARANGA RIVER, TANZANIA* (MSC), Kenyatta University.

Rice, E. W., Bridgewater, L., & Association, A. P. H. (2012). *Standard methods for the examination of water and wastewater* (Vol. 10): American public health association Washington, DC.

Rife, D. M., Funk, M., & Weller, M. (2017). The Johns Hopkins Center for a Livable Future Bloomberg School of Public Health 615 North Wolfe Street, W7010 Baltimore, MD 21205 June 1, 2017.

Ripin, S. N. M., Hasan, S., Kamal, M. L., & Hashim, N. (2014). Analysis and pollution assessment of heavy metal in soil, Perlis. *The Malaysian Journal of Analytical Sciences, 18*(1), 155-161.

RSK. (2014). Lake Turkana Development Plan *Strategic Environmental Assessment. Scoping Report (Final).*

Rueben, G. (2014). *Assesment of the impact of effluents from bonite bottlers and China paper industrieson the water quality in Karaga River ,Tanzania.*, Kenyatta University.

Sappa, G., Iacurto, S., Ferranti, F., & De Filippi, F. M. (2019). Groundwater quality assessment in a karst coastal region of the West Aurunci Mountains (Central Italy). *Geofluids, 2019*.

Sayadi, M. H., Shabani, M., & Ahmadpour, N. (2015). Pollution index and ecological risk of heavy metals in the surface soils of Amir-Abad Area in Birjand City, Iran. *Health Scope, 4*(1).

Shanmugam, V., Selvakumar, S., & Yeh, C.-S. (2014). Near-infrared light-responsive nanomaterials in cancer therapeutics. *Chemical Society Reviews, 43*(17), 6254-6287.

Sheela, A., Letha, J., Joseph, S., Chacko, M., Sanal Kumar, S., & Thomas, J. (2012). Water quality assessment of a tropical coastal lake system using multivariate cluster, principal component and factor analysis. *Lakes & Reservoirs: Research & Management, 17*(2), 143-159.

Shu, Y., & Zhai, S. (2014). Study on soil heavy metals contamination of a lead refinery. *Chinese Journal of Geochemistry, 33*(4), 393-397.

Shuguang, Z., Kefa, Z., Yao, C., Jinlin, W., & Jianli, D. (2015). Exploratory data analysis and singularity mapping in geochemical anomaly identification in Karamay, Xinjiang, China. *Journal of Geochemical Exploration, 154*, 171-179.

Sidhu, G. P. S., Singh, H. P., Batish, D. R., & Kohli, R. K. (2017). Tolerance and hyperaccumulation of cadmium by a wild, unpalatable herb Coronopus didymus (L.) Sm.(Brassicaceae). *Ecotoxicology and environmental safety, 135*, 209-215.

Singh, A., Sharma, R. K., Agrawal, M., & Marshall, F. M. (2010). Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. *Food and chemical toxicology, 48*(2), 611-619.

Singh, H., Pandey, R., Singh, S. K., & Shukla, D. (2017). Assessment of heavy metal contamination in the sediment of the River Ghaghara, a major tributary of the River Ganga in Northern India. *Applied Water Science, 7*(7), 4133-4149.

Sołek-Podwika, K., Ciarkowska, K., & Kaleta, D. (2016). Assessment of the risk of pollution by sulfur compounds and heavy metals in soils located in the proximity of a disused for 20 years sulfur mine (SE Poland). *Journal of Environmental Management, 180*, 450-458.

Sutherland, R. (2000). Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. *Environmental geology, 39*(6), 611-627.

Swain, S., Sahoo, S., & Taloor, A. K. (2022). Groundwater quality assessment using geospatial and statistical approaches over Faridabad and Gurgaon districts of National Capital Region, India. *Applied Water Science, 12*(4), 75.

Talbot, M., Morley, C., Tiercelin, J.-J., Le Hérissé, A., Potdevin, J.-L., & Le Gall, B. (2004). Hydrocarbon potential of the Meso-Cenozoic Turkana Depression, northern Kenya. II. Source rocks: quality, maturation, depositional environments and structural control. *Marine and Petroleum Geology, 21*(1), 63-78.

Tang, Q., Li, Y., & Xu, Y. (2015). Land suitability assessment for post-earthquake reconstruction: A case study of Lushan in Sichuan, China. *Journal of Geographical Sciences, 25*(7), 865-878.

Teng, F.-Z., McDonough, W., Rudnick, R., Dalpé, C., Tomascak, P., Chappell, B., & Gao, S. (2004). Lithium isotopic composition and concentration of the upper continental crust. *Geochimica et Cosmochimica Acta, 68*(20), 4167-4178.

Tiwari, R. (2011). Assessment of groundwater quality and pollution potential of Jawa block Rewa district, Madhya Pradesh, India. *Proceedings of the international academy of ecology and environmental sciences, 1*(3-4), 202.

Tredoux, G., Van Der Merwe, B., & Peters, I. (2009). Artificial recharge of the Windhoek aquifer, Namibia: Water quality considerations. *Boletín geológico y minero, 120*(2), 269-278.

TullowPLC. (2018). *Tullow Oil OPerations in East Africa Kenya.* Nairobi: Government press.

USEPA. (2012). *Ground water and drinking water*.

USEPA. (2005). *National Management Measures to Control Nonpoint Source Pollution from Urban Areas*. (EPA 841-B-05-004).

USEPA. (2009). A set of Scientific Issues Being Considered by the Environmental Protection Agency Regarding: Selected Issues Associated with the Risk Assessment Process for Pesticides with Persistent, Bioaccumulative, and Toxic Characteristics. (pp. 28-31,): USEPA.

Vaikosen, E. N., Ebeshi, B. U., & Airhihen, B. (2014). Bioaccumulation of Heavy Metals and Hydrocarbons in Hemichromis Fasciatus Exposed to Surface Water in Borrow Pits Located Within Onshore Oil Exploration and Production Area *Environment and Pollution, 3*(3), 38-55.

Wedepohl, K. H. (1995). The composition of the continentalcrust. . *Geochimica et Cosmochimica, 59*(7). doi: doi:10.1016/0016-7037(95)00038-2

WHO. (2003). *Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva: World Health Organisation.

WHO. (2004). *Guidelines for Drinking Water Quality*

WHO. (2006). Guideline for Drinking Water Quality. *A.I.T.B.S*

Publishers and Distributors. (Redg). Deh, Volume 1(3rd Edition).

WHO. (2008a). *Guidelines for Drinking-Water Quality*. Geneva, Switzerland.

WHO. (2008b). Guidelines for Drinking-Water Quality. Geneva, Switzerland.

WHO. (2017). Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines.

Yang, X., Pan, X., Blyth, J., & Lowe, C. R. (2008). Towards the real-time monitoring of glucose in tear fluid: Holographic glucose sensors with reduced interference from lactate and pH. *Biosensors and Bioelectronics, 23*(6), 899-905.

Yisa, J., & Tijani, J. O. (2010). Analytical studies on water quality index of river Landzu.

Zarei, H., & Bilondi, M. P. (2013). Factor analysis of chemical composition in the Karoon River basin, southwest of Iran. *Applied Water Science, 3*(4), 753-761.

APPENDIX

Appendix 1:Two -factor without replication for control site

SUMMARY	Count	Sum	Average	Variance
1.2	15	9359.36432	623.9576213	3944668.5
0.3	15	13221.8963	881.4597533	7497721.3
1.3	15	14316.114	954.4076	8485345.8
TEMP	3	77.6	25.86666667	0.8233333
DO	3	20.55	6.85	0.0559
EC	3	1343.6	447.8666667	20899.363
pH	3	19.3	6.433333333	0.3033333
IRON	3	78.2	26.06666667	315.52333
CALCIUM	3	388.1	129.3666667	2242.4033
MAGNESIUM	3	302.95	100.9833333	5759.623
TOTAL HARDNESS	3	2216	738.6666667	175665.33
CHLORIDE	3	1550	516.6666667	5833.3333
NITRATE	3	3.6518	1.217266667	0.550572
NITRITES	3	0.15382	0.051273333	0.0013238
FLUORIDE	3	3.4	1.133333333	0.0294333
MANGANESE	3	0.019	0.006333333	7.233E-05
SULPHATE	3	29940	9980	3745600
COD	3	953.85	317.95	2209.6963

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	904129.6236	2	452064.8118	1.8049267	0.18310394	3.340386
Columns	271975373.4	14	19426812.39	77.564039	1.3518E-18	2.063541
Error	7012924.456	28	250461.5877			
Total	279892427.5	44				

Appendix 2:Two factor without replication for mining site

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1.2	15	9359.36432	623.9576	3944668.5
0.3	15	13221.8963	881.4598	7497721.3
1.3	15	14316.114	954.4076	8485345.8
TEMP	3	77.6	25.86667	0.8233333
DO	3	20.55	6.85	0.0559
EC	3	1343.6	447.8667	20899.363
pH	3	19.3	6.433333	0.3033333
IRON	3	78.2	26.06667	315.52333
CALCIUM	3	388.1	129.3667	2242.4033
MAGNESIUM	3	302.95	100.9833	5759.623
TOTAL HARDNESS	3	2216	738.6667	175665.33
CHLORIDE	3	1550	516.6667	5833.3333
NITRATE	3	3.6518	1.217267	0.550572
NITRITES	3	0.15382	0.051273	0.0013238
FLUORIDE	3	3.4	1.133333	0.0294333
MANGANESE	3	0.019	0.006333	7.233E-05
SULPHATE	3	29940	9980	3745600
COD	3	953.85	317.95	2209.6963

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	904129.6236	2	452064.8	1.8049267	0.183104	3.340386
Columns	271975373.4	14	19426812	77.564039	1.35E-18	2.063541
Error	7012924.456	28	250461.6			
Total	279892427.5	44				

Appendix 3: Anova Analysis for Lead

SUMMARY

Groups	Count	Sum	Average	Variance
2.4957	2	5.0903	2.54515	0.050276
2.5566	2	3.7516	1.8758	0.027378

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.448029	1	0.448029	11.53909	0.07681	18.51282
Within Groups	0.077654	2	0.038827			
Total	0.525684	3				

Appendix 4: Anova analysis for Cadmium

SUMMARY

Groups	Count	Sum	Average	Variance
-0.0352	2	-0.0693	-0.03465	6.05E-07
-0.0315	2	-0.064	-0.032	8.82E-06

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit

Groups *Count* *Sum* *Ave*

Between Groups	7.0225E-06	1	7.02E-06	1.490186	0.346575	18.51282
Within Groups	0.000009425	2	4.71E-06			
Total	1.64475E-05	3				

far	3	0.5568	0.
near	3	0.5915	0.19

ANOVA

Source of Variation	*SS*	*df*	*M*
Between Groups	0.000201	1	0.00
Within Groups	0.021615	4	0.00
Total	0.021816	5	

Appendix 5:Instrumental Analysis for Zinc

Zn(213.9nm)	**Location**	**Date**	**operational condition**	**concentration(ppm)**	**correlation coefficient**	**Recovery**
	lagger 1	10-08-20	A-Ac	0.1692	1.00	61.26
	sandwell2	10-08-20	A-Ac	0.2311	1.00	76.73
	sandwell 1	11-08-20	A-Ac	0.1565	1.00	53.7
	sandwell3	12-08-20	A-Ac	0.1187	1.00	37.83
	waterpan1	13-08-20	A-Ac	0.3042	1.00	73.43
	waterpan 2	14-08-20	A-Ac	0.1686	1.00	62.65

Appendix 6:Instrumental Analysis for Lead

Pb(283.3nm)	Location	Date	operational condition	concentration(ppm)	correlation coefficient	Recovery
	lagger 1	10-08-20	A-Ac	2.4957	1.00	18.06
	sandwell2	10-08-20	A-Ac	2.3866	1.00	27.87
	sandwell 1	11-08-20	A-Ac	2.7037	1.00	28.35
	sandwell3	12-08-20	A-Ac	2.5566	1.00	7.09
	waterpan1	13-08-20	A-Ac	1.7588	1.00	11.57
	waterpan 2	14-08-20	A-Ac	1.9928	1.00	4.2

Appendix 7:Instrumental Analysis For Cadminum

Cd(228.8nm)	Location	Date	operational condition	concentration(ppm)	correlation coefficient	Recovery
	lagger 1	17/08/2020	A-Ac	-0.0352	1.000000	3.03
	sandwell2	17/08/2020	A-Ac	-0.0352	1.000000	3.52
	sandwell 1	17/08/2020	A-Ac	-0.0341	1.000000	1.81
	sandwell3	17/08/2020	A-Ac	-0.0315	1.000000	12.22
	waterpan1	17/08/2020	A-Ac	-0.0299	1.000000	17.03
	waterpan 2	17/08/2020	A-Ac	-0.0341	1.000000	4.13