REPUBLIC OF TÜRKİYE
HARRAN UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

THE EFFECT OF SOME REFINERY AND INDUSTRIAL WASTEWATER DISCHARGES LOCATED NORTHWEST OF ERBIL CITY ON THE WATER QUALITY OF THE GREAT ZAB RIVER

HAREM ALI ABDULHAQ

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

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Şanlıurfa
2024

TEZ ÖNERİSİ VE TEZ YAZMA YÖNERGESİNE UYGUNLUK BEYANI

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İmza

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ABSTRACT

MASTER THESIS

THE EFFECT OF SOME REFINERY AND INDUSTRIAL WASTEWATER DISCHARGES LOCATED NORTHWEST OF ERBIL CITY ON THE WATER QUALITY OF THE GREAT ZAB RIVER

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Utilizing the Water Quality Index (WQI), this research evaluates the water quality across the Great Zab River in different sampling areas and the overall water quality. The investigation helps shed light on the possible sources of pollution. The whole picture, including both underlying natural conditions as well as human activities, is depicted by the combined effects represented by the WQI values. Results showed different water qualities from moderate to poor, on and off rising values of which are blamed on pollution arising from industrial plants and mixing with river water. The medium gradation of WQI in the upper part of the River Great Zab, 57.48, is consistent with the moderately good water quality and the lower value of WQI or rather the equal good water quality at the downstream part of the river where it is 56.00. In contrast, the Cola North Iraq plant and its confluence with the river have combined WQI values of 43.32 and 44.97, and therefore they represent unacceptable water quality. Nevertheless, the statistician shows that the locations of the refinery, the factory, and the power plant noticeably affect the water quality of the river at their blending points. The thesis results sharply remind us of the necessity to close our eyes strictly in an ecological way, establish environmental regulations, and make use of sustainable technologies to protect the nature of the river. Measures that are concise to eliminating pollutant sources and giving a boost to the environmental consciousness of communities must be integral in the conservation of the Great Zab River and the preservation of the surrounding ecosystems.

KEYWORDS: Water Quality Index (WQI), Iraq, Geographic Information Systems (GIS), River Pollution, Industrial Wastewater, Python Script

ÖZET

YÜKSEK LİSANS TEZİ

ERBİL ŞEHRİNİN KUZEYBATISI'NDA BULUNAN BAZI RAFİNERİ VE ENDÜSTRİYEL ATIKSU DEŞARJLARININ BÜYÜK ZAP NEHRİ SU KALİTESİNE ETKİSİ

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Bu çalışmada, Su Kalitesi İndeksini (WQI) kullanarak Büyük Zap Nehri'ninfarklı örnekleme alanlarındaki su kalitesinindeğerlendirilmesi amaçlanmıştır. Araştırma, olası kirlilik kaynaklarına ışık tutmaya yardımcı olmaktadır. Genel bir bakış açısı ile hem altta yatan doğal koşulları hem de antropojenik etkilerin sebep olduğu koşullarınWQI değerleri tarafından temsil edilen birleşik etkilerle tasvir edilmektedir. Sonuçlar, sanayi tesislerinden kaynaklanan ve nehir suyuna karışan kirlilikten sorumlu tutulan, orta dereceden kötü dereceye kadar farklı su kaliteleri göstermiştir. Büyük Zap Nehri'nin üst kısmında 57.48 olan orta dereceli WQI değeri, orta derecede iyi su kalitesi ve 56.00 olan nehrin aşağı kısmında daha düşük WQI değeri veya eşit derecede iyi su kalitesi ile tutarlıdır. Buna karşılık, Kuzey Irak Colatesisi deşarjınınnehirle karıştığınokta 43.32 ve 44.97'lik birleşik WQI değerlerine sahiptir ve bu nedenle kabul edilebilir limitlerin dışında bir sukalitesini temsil etmektedir. Bununla birlikte, istatistiksel değerlendirmelerrafineri, fabrika ve enerji santralinin konumlarının nehrin su kalitesini karışım noktalarında belirgin bir şekilde etkilediğini göstermektedir. Tez sonuçları, nehrin doğasını korumak için gözlerimizi kesinlikle ekolojik bir şekilde bakmamız, çevresel düzenlemeler oluşturmamız ve sürdürülebilir teknolojilerden yararlanmamız gerektiğini keskin bir şekilde hatırlatmaktadır.Kirletici kaynakların ortadan kaldırılmasına ve toplumların çevre bilincinin artırılmasına yönelik tedbirler, Büyük Zap Nehri'nin ve çevresindeki ekosistemlerin korunmasının ayrılmaz bir parçası olmalıdır.

ANAHTAR KELİMELER: Su Kalitesi İndeksi (WQI), Irak, Coğrafi Bilgi Sistemleri (CBS), Nehir Kirliliği, Endüstriyel Atıksu, Python Komut Dosyası

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SYMBOLS

&: and

C : Celsius

g : Gram

L : Litre

m: metre

º : Degree

ABBREVIATIONS

AWQI : Australian Water Quality Index

BCWQI : British Columbia Water Quality Index

BOD5 : Biological oxygen demand

CCME : Canadian Council of Ministers of the Environment

Cd : Cadmium

Cl2 : Chlorine

Cn : Cyanides

COD : Chemical oxygen demand

Cr : Chromium

Cu : Copper

DO : Dissolved oxygen

EC : Electrical Conductivity

F2 : Flouride

FC/FS : Fecal Coliform/Fecal Streptococcus

Fe : Iron

GIS : Geographical Information System

GPS : Global Positional System

IGRWD : Iraqi Groundwater for Drinking

mg : miligram

Ni : Nickel

NO2 : Nitrite

NO3 : Nitrate

nse : Normalized sum of excursions

NSF WQI : National Sanitation Foundation Water Quality Index

NWQI : Indian National Water Quality Index

Pb : Lead

pH : Hydrogen ion concentration

PO4 : Phosphate

S : Sulfide

TDS : Total dissolved solids

TSS : Total suspended solid

UNECE : The United Nations Economic Commission for Europe

WHO : World Health Organization

WQ : Water Quality

WQI : Water Quality Index

Zn : Zinc

1. INTRODUCTION

Industrial and refinery effluent on disposal can cause water quality in the Upper Great Zab River in Northern Iraq to get worse. The profitable and ecologically significant river that borders three industrial factories accumulates industrial waste daily, carrying it on the flow. This is the source of many concerns about water quality but also of aquatic organisms. Forming the core of the problem is the establishment of whether the river's quality is still whole or has been contaminated by nearby industrial activities. In it, the discharges are not to dirtify or greatly change the composition of water either. Nevertheless, the risks associated with discharge of discolored water are very high as revealed by (Wei et al., 2019).

The addition to an already complex picture are the deadly chemicals from refinery and plant operators which are released into wastewater. The contents of these discharges consist of a wide range of substances, for example, heavy metals, hydrocarbons, and solvents, which can cause a number of health issues for humans and aquatic organisms (Singh and Shikha, 2018). Fish and water-born creatures when consumed by humans can retain heavy metals such as mercury and lead in their muscle tissue and cause neurological and reproductive disorders. One of the effects of water pollution is that exposure to such pollutants can lead to cancer, birth defects, and diseases for individuals who use the rivers as their drinking water or for relational purposes (Khatoon and Malik, 2021).

The apprehension is whether low-level wastewater, which might carry potentially dangerous wastes, can cause toxicity in the river's water quality. Water quality is the seed from which everything depends on the ecological balance of the river. A poorer quality of water reduces the chances of different species living in the river as it potentially damages biodiversity and the harmony of the natural system (Zou et al., 2021). Consequently, there is an urgent need now for a thoughtful, comprehensive, and enduring plan to confirm and improve the quality and availability of the Great Zab River water for generations to come.

Industries such as refineries and factories are responsible for the majority of pollutants that are introduced to the river which include heavy metals, organic compounds, and other deadly substances. The contamination of the Great Zab River by high loads of effluents contained in the discharged water alters the water quality and ecological balance to a great extent and it poses threats to both waterborne life and the people who depend on the river for drinking water as well as for agricultural practices (Zegait and Remini, 2019). To understand the complex nature of these environmental consequences adequately, we need to dig deeper into the multidimensional factors such as the industries as well as their links.

Freshwater rivers heavily burdened with effluent from refinery and factory discharges tend to have lower levels of oxygen (Banerjee et al., 2019). This is because of the decomposition of organic stuff in it like sewage and plant dead matter. The lack of dissolved oxygen is therefore the main reason for asphyxiation of aquatic species through this mechanism. Apart from that, low oxygen levels can be advantageous toward toxic algae and bacteria expansion. These algae and bacteria may secrete poisonous toxins that are dangerous to human beings and animals(Eldos et al., 2022).

The effluents from the refineries and factories which warm the water can have bad effects on the aquatic ecosystem. For example, when the water temperature climbs above the fish's comfort zone, they will get stressed and will definitely be prone to sickness and death. Disruption of temperature ranges can further lead to the reproductive behavior of aquatic life and migration of birds being affected and this in turn cascades into a greater ecosystem disruption (Bashir et al., 2020).

The effects of the refinery and industry emissions on rivers can be seen also in the water itself. They create a tendency towards soil and plant failure on the riverbank, which greatly benefits the local ecology. As an illustration, when the soil gets contaminated with hazardous agents, it can actually impede the growth of the vegetation around and consequently cause erosion, thus leading to loss of habitat to those animals that rely on it for food and protection (Trujillo-González et al., 2017).

The Great Zab River, a source of living and vitality for many urban centers and natural environments is as a matter of fact among the environmental problems in recent decades caused by intense industrialization and urbanization in the adjacent regions. Due to this, the discharge of pollutants coming out from diversified sources such as flyovers, factories, and refineries into the Great Zab River has become aggravated. The agglomerate effect of discharges has driven up a lot of environmental questions, therefore, there is a need for an in-depth study of the long-term sustainability of the river ecosystem(Aziz and Fakhrey, 2016).

The main purpose of this research is to explore the question of the inflow of industrial and refinery wastewater into the Great Zab River in northern Iraq. This research is to be viewed as a qualitative evaluation sheet which defines Great Zab River water quality, as to how it is influenced by industrial activities in the area. A need to check whether the wastewater from such industrial sites is toxic and causes damage to a river and diseases to the biodiversity it supports comes underneath (Wei et al., 2019).

Additionally, this experiment aims to yield new findings on the ecological consequences of the discharge of process waters used in the manufacturing sector. This evaluation along with the results will show how many pollutants (if any at all) pose a threat to water quality for the Great Zab River and their severity. Moreover, we want to consider how water quality fluctuates in different seasons, which is of great concern when you know that seasonal changes usually occur in industrial production and environmental conditions (Wei et al., 2019).

Actually, what we are interested in is findings that can be used to develop new and more effective policies and recommendations on industrial wastewater disposal which will be beneficial not only for the Great Zab but also for many other rivers that are located in industrial sites. We expect that the results of the research will create awareness around sustainability and safekeeping of the waters as well as develop practices that ensure the health of water bodies and the ecosystems for good.

This study covers the consequences of industrial wastewater discharge as well as refinery effluents on the Great Zab River water quality from the perspective of a number of interrelated research questions. Specifically, we aspire to measure the amount to which industrial wastewater discharge into the Great Zab River affects the water quality. Does the discharge of effluents from the adjoining industries downgrade the quality of the water in the river and if so, to what extent? What is the given water sample information on the specific pollutants in the river that are linked directly to the industrial wastewater discharges? What influence does the pollution have in addition to the total wellness of the river or which the river can sustain the life below water?

A third crucial research aspect is the seasonal water quality trends identification. Would there be any changes noticed in the river’s water quality through different seasons? Whether the pollution of the industrial wastewater on the river’s water quality changes in its quality with the seasonal fluctuation of industrial production and environmental conditions (Xu et al., 2019).

Finally, it seeks to address the potential for negative impacts on water quality resulting from the Great Zab River by investigating mitigating measures that can be done. How changes implemented in the current industrial wastewater management strategies can be made to reduce the chance of causing environmental damage to the Great Zab River? With such application in mind, how could the results cover policy developments and strategies for management all around this indispensable resource (Al-Ansari, 2013)? By means of these research questions, this thesis aims to present the environmental problem and to show the possible ways of its resolution by virtue of the sustainable way of doing it.

The low level of waste management and the crisis of dangerous dumping of trash which are generated by human being activities in developing countries are major problems. Among all other natural resources, freshwater reservoirs are those that have the highest rate of contamination due to pollution, which often turns them into unfit places where people can live or where water can be used for drinking. Industries are the most important sources of pollution in all eco-systems and their discharge effluents to water bodies can change the physical, chemical, and biological composition, causing heavy public health and environmental problems Industrial wastewater is all about chemical, inorganic, and toxic components that might collect in receiving bodies of water rendering them not usable for drinking and irrigation causing dysfunction of the aquatic life. (Siddiqua et al., 2022).

The issue of industrial and refinery wastewater discharge into the river system is having a serious impact on the Great Zab River basin in Northern Iraq and worldwide. The thesis is thus two sides of the coin; on a positive note, it enlarges the understanding of industrial pollution and environmental effects through investigation of its extent and influence. The above measures include determining the intensity of wastewater discharge on the river water quality and the relationship of this water quality to that of the aquatic ecosystem, which serves as objective evidence of industrial wastewater disposal impact (Brion et al., 2015).

Oil is an instrumental pollution contributor to water if it is discharged there, oil can lead to an ecological disaster. In addition, it brings a major environmental risk in terms of the presence of by-products of heavy metals and poisons in predischarge waters. Overly, sustainable ways of waste management and disposal matter a lot in the aim of preserving and protecting the environment as well as public health (Toma et al., 2018).

Pollutants discarded by refineries and factories include organics and inorganics as well as heavy metals. Those pollutants into the Great Zab River. The manifestation of harmful substances such as benzene, toluene, and xylene which are lethal to aquatic organisms in refinery effluents is a major environmental concern. Unlike organic chemicals, inorganic chemicals such as cadmium, lead, and mercury are also predominant in refinery and manufacturing effluents, being capable of combing with sediment and bio accumulating into aquatic organisms. Nitrogen and phosphorous are also present in factory and oil refinery wastes that are discharged into the river, which can initiate the eutrophication process and create thick algal blooms (Hassan and Ali, 2016).

The contents of heavy metals such as cadmium, chromium, copper, and zinc in the Great Zab River surpass WHO and the Iraqi drinking water permitted levels, (WHO) (2006) and IGRWD respectively. The key cause of the discharge of metal into the river happened because of the waste that comes from refineries and manufacturing plants (Shekha, 2016).

The Great Zab River is also heavily contaminated by the polycyclic aromatic hydrocarbons (PAHs) which are known to be present in the effluents coming from the refineries. PAHs are non-specific carcinogens that play a role in human ailments, as well as the lives of aquatic organisms (Raghad et al., 2023).

If we look at pollutants from refineries, factories, and other sources which have a great impact on the Great Zab River ecosystem. The discharge of organic and inorganic compounds in effluents causes acute and chronic intoxication in aquatic animals, resulting in species death or low reproduction and growth rate. Toxic metals have a tendency to accumulate in the sediments impairing aquatic organisms that live along the bottom and hence affecting the overall ecosystem structure. In addition to this, excessive nutrients in the effluents can lead to eutrophication, and depletion in dissolved oxygen causing harm to aquatic life. For instance, there are algal blooms that can lead to anoxic conditions in the river, and subsequent fish and other aquatic fauna deaths (Raghad et al., 2023).

The Great Zab River was polluted by the refinery and industrial wastewater which in turn resulted in a number of diseases among the people. Organic compounds are released which pollute the waters used for drinking and other human activities. By being exposed to these chemicals you can develop several health issues including cancer, neurosis, and development problems (Aziz and Fakhrey, 2016).

In addition to the above-mentioned heavy toxic metals like lead, cadmium, and mercury also can cause health damage for humans. These metals can build up, in fish and other aquatic lives which are essential foods of this community. In particular, exposure to these metals has resulted in neurological, developmental, and reproductive abnormalities (Aziz and Maulood, 2015).

Toxic release into the waters of the Great Zab River basin from refineries and factories have contaminated drinking water sources; the concentrations of heavy metals within the drinking water sources have gone beyond the (WHO) (2006) and the Iraqi Standards for Drinking Water permissibility limits and pose a serious health risk to the inhabitants that consume fish and other water organisms (Aziz and Fakhrey, 2016).

Following that, the study may be of paramount importance in establishing the regulations for public policy and the industry regarding wastewater disposal. Given the far-ranging and deep observations that this project aims to point to, it can serve as a key source of information for designing and implementing more practical, eco-friendly approaches to industrial wastewater disposal. This may be caused by regulations that prohibit discharges that cause harm and even require methods of cleaning waste, which in turn advances the quality of water and guarantees the ecological well-being of the Great Zab River (Kareem, 2016).

Finally, by using the results of this particular study, we can suggest a plan of work for other industrial areas, where rivers might be exposed to the same kind of ecological threats due to the drainage of untreated wastewater. As a result, this dissertation could be virtually limitless with its scope by shaping greener industrial practices, and possible policies for the management of water resources, which is the fundamental issue toward keeping the health of global rivers up and running.

Here, 'water quality' is associated with the physical, chemical, and biological constituents of the water that is found in the Great Zab River. Factors like pH, temperature, dissolved oxygen, and the levels of pollution are the constituents of this procedure. The expression 'industrial and refinery wastewater' means the water that is pumped away from industrial plants and refineries following its use. This waste contains different levels of pollutants depending on the industry that generated it and its waste treatment practices (Singh and Shikha, 2018).

The 'discharge' is a process employing which the effluent water is discharged into the river. This could be a steady or seasonal flow. Therefore, this thesis focuses on the hydrologic contribution of the discharge into the Great Zab River water quality in periods or time seasons (Singh and Shikha, 2018).

Based on this research, we propose to define the 'impact' as any alteration caused in a river water quality, which can be traced to the sewage directly from an industry or a refinery. This implies a transformation of the chemical components, the level of pollutants in the water, and any resultant damage to the life of aquatic creatures inhabiting the river system. The 'impact' is estimated by taking samples at the discharge points and at different time intervals to identify any seasonal trends (Radelyuk et al., 2021).

The intention is to develop a careful, data-oriented correlation between the discharges and any existing changes in the water-related variables, hence characterizing their 'effect' on the condition of the water in River Great Zab. This thesis aims to give a full and robust account of the pollution concerns associated with surplus wastewater discharge in the river systems much like the Great Zab River.

This thesis makes several key assumptions while investigating the impact of industrial and refinery wastewater discharges on the water quality of the Great Zab River. One primary assumption is that the specific parameters selected to define 'water quality,' such as pH, temperature, dissolved oxygen, and concentration of certain pollutants, are representative indicators of the overall health and viability of the river's ecosystem. This implies that changes in these parameters, caused by wastewater discharges, directly correspond to changes in the river's health (Albek et al., 2019).

The second basic premise is that any 'industrial wastewater from the refinery' is considered to be a source of pollution that degrades the quality of water in the river (Singh and Shikha, 2018). This thesis recognizes the better identification of local discharge sources as the major sources of possible environmental pollution by such industrial emitters and refineries.

The dissertation attributes the "impact" to the "discharge." The emphasis is on the fact that the water quality parameters driven downriver from the discharge points considerably differ from those driven upstream, thus, the causative factor is the load of industrial and refinery wastewater. This thesis took for granted that water quality changes were not predominantly due to other external factors (Schliemann et al., 2020).

It is believed that data gathered in a low-flow condition is indicative of variation in water quality during different seasons and provides a reliable understanding of the water quality deterioration by wastewater discharge (Schliemann et al., 2020). The research on hand is hinged on those implied precepts; which are utilized to put into context the research problems as well as interpreting the results.

This thesis is deeply structured in a way that enables me to deal with the subject matter in a thorough and comprehensible way by presenting my research questions in a systematic manner. The structure of this thesis has been composed in a way that it provides us with an idea of how we are going to progress through the research problem and each section does so in an absolute manner towards answering the research questions.

Objective of the study:

1- The aim of this research is to assess the impact of industrial wastewater pollution on aquatic environments in the Great Zab River.

2- The objective of the present study was to identify the shore-based pollution sources of the Great Zab river and to collect water and sediment samples from the major outfalls of canals and drains for laboratory analysis to assess the effects of pollutants, particularly oil and grease and other pollutants on the riverine and estuarine ecosystem.

3- The attention of this scientific-study institutes and planning and designing organizations must be directed not only towards the way to reduce the polluting and poisoning action of industrial discharges on the environment but primarily towards preventing or diminishing the discharges of the refineries.

4- After analyzing samples from upstream of this factory, power plant, refinery, and downstream of each of them we detected which discharge streams are most affected and polluted the river.

5- Using the water quality index for interpretation of the quality of the sample points and making a water quality map.

2. PREVIOUS STUDIES

The Great Zab River is the fundamental natural element of the ecological sustainability and socio-economic growth of Erbil province in the northern part of Iraq. Moreover, the relentless industrialization and urban development in the vicinity have brought up questions regarding the distress to the water quality of the river due to the discharges of refineries and industrial wastewater in the area. The aim of this study is to review the pieces of literature regarding the effects of these releases on the water quality of the River Great Zab. The study to be examined in this review was conducted by studying the relevant studies, research articles, and reports. This study seeks to know what pollutants surround these discharges, assess their effects on the river ecosystem, and evaluate the associated risk factors that are applicable to human health.

The Great Zab River, spanning Turkey and Iraq for 400 kilometers (250 miles), makes it a key water resource for both countries. It originates in Lake Van in Turkey and joins the Tigris River south of Mosul (Iraq). Lake Zebord would be the one that lives on the territory of the Great Zab draining basin with an area of around 40,300 km2 (250,041 square miles). The river is fed by numerous tributaries during its long course. Here the river and its tributaries generally receive little or no support from rocks melting so the discharge varies a lot from year to year. The Great Zab River is a lifeline for agricultural activity and also serves as drinking water for livestock and a huge population of people living in Dohuk City. However, elevating the pollution levels from the industrial releases makes the water body unviable. Equally, the wellbeing of the community is placed at risk. (Abbas et al., 2017)

The Great Zab River is the main water source in Northern Iraq from where household, agricultural, and industrial water demand is being fulfilled. Nevertheless, the increase in pollution levels by refinery pipelines and factory wastewater endangers the functions of rivers and the health of those who are dependent on them. Pollutants, in the shape including organic and inorganic chemicals, heavy metals, and nutrients can have the effect of being a source of acute and chronic toxicity in aquatic bodies, a method of river eutrophication, and serious health consequences for human beings (Bashir et al., 2020).

In the ecological context, the environment is a system, where all living organisms exist and interact. It can be described as the combination of the physical, chemical, and biological factors that make it feasible for life to exist and survive. So, keeping the environment clean is the key to protecting the health of and preventing the scales of pollution from local to global. In the context of water pollution, oil fields and refineries pose quite a challenge to the locals Furthermore, the presence of invasive species is another major threat to coral reefs. Introduction: Through the ages, the beautiful coral reefs have faced incessant threats from human activities that have impeded their growth and survival. Coral reefs are vital to marine biodiversity and Texting requires measures that are scientifically justifiable and studies should be comprehensive (Chu and Karr, 2017).

It is worth mentioning that from the year 2003, the oil industry became of great prominence in Northern Iraq. Hence, careful investigation and enforcement of pollution areas are essential to face the environmental challenges emerging from unexpected causes (Hashim et al., 2020).

In another Erbil waterway study by Lak (2007), water samples from 20 sites were taken along the water channel. The results showed that the water sample from the untreated polluted water had a considerable degradation effect on the water quality of the Great Zab River. Lak (2007) saw that the variations in DO levels proved to be the leading cause of fluctuation in both BOD5 and COD.

Shekha (1994) made microbial density research in the Erbil wastewater channel included in the water system. He asserted that both greywater and blackwater from human activities as well as primary sources that are hard to spot like runoff could be the cause of the highest levels of microorganisms. Aziz et al. (2001) presented a complete wastewater profile at the wastewater channel of the Erbil water treatment plant; this report considered many physicochemical and biological parameters such as total bacteria count, coliforms, streptococci, staphylococci, and fungi. The research results illustrated that fecal contamination at the first four sites was mostly from human sources because the FC/FS (Fecal Coliform/Fecal Streptococcus) ratio was high, whereas in the next three it looked more like cattle caused it.

The case example of Lak (2007) mentioned that the densities of coliform and faecal coliform showed a progressively decreasing trend and shifted from the low-water period to the high-water period. Nonetheless, there are inadequate detailed studies to give microbial separation of untreated wastewater, as well as the linked health risks of the plants to which such water is applied for irrigation in the zone. So, the present study can function as basic groundwork for later research with a focus on both ecological and epidemiological sides.

Oil Pollution:

Oil pollution outcome is normally studied in line with oil penetration and seepage in the oilfields or during fuel transfer from the old pipelines at oil refineries. However, while the distribution of oil in rivers during the transportation of petroleum products is not the same as in road accidents or fuel dripping from trucks, it is responsible for the pollution of waterways in cities. Such a conventional scheme of delivery is usually the prevalent means of working on the majority of projects. A similar process implicates the refineries' waterway the inability of the oily wastewater, especially the concentrates effluent, to pass through the purification treatment. Such environmentally harmful compounds undergo rigorous investigation at this point. Use our AI to write for you about Global Warming. It is fast and easy to use! Let our AI writing tool help you save time and effort while improving the quality of your content. This year, the evaluation of Kawergosek refinery wastewater impact on surrounding sources was made by Aziz and Fakhrey (2016). Evidence as such derived from a test of refinery effluent contaminants. The main source of this pollution was at the confluence of the Great Zab River, and only the groundwater had a small impact. The focus of this paper is water pollution from the discharge of petroleum and industrial wastes.

Refinery Overview:

Erbil Kawergosk oil refinery is the sole refinery of Northern Iraq, being located in the western part of Erbil City at a distance of some 50 kilometers. It is respectable as one of the largest refineries in Iraq and also represents the private sector's big investment in Northern Iraq. The operations of the refinery were kick-started in 2009. The main purpose of this refinery is to provide energy, especially for the people in the region as well as to improve their economy.

Nevertheless, generating produced water inside the Kawergosk refinery plant poses environmental issues as it is a large amount of produced water. The wastewater comprised of these compounds possesses crude oil wastes, greasy lie, polycyclic and aromatic hydrocarbons, phenols, sulfides, and naphthenic acids, among others, as reported by Aziz and Ali (2017). Effective water treatments and appropriate actions are necessary to prevent the pollution of water resources, and this was highlighted by Aziz and Fakhrey (2016).

The oil refinery in Kawergosk has implemented a whole suite of oil effluent removal and separation measures. This is a point without a doubt because water quality downstream should be the main point of concern for making sure treatment of the effluent is not a problem for water resources and the natural environment surrounding the refinery. The oil factory has developed a group of strategies and techniques used for the treatment of the complex oily waste flow and compliance with environmental legislation (Aziz and Fakhrey, 2016).

In their article, Aziz and Fakhrey (2016) noticed that if the Kawergosk oil refinery is to be successful there must be a number of different stages targeted at different kinds of contaminants. These stages can encompass a combination of physical, chemical, or biological processes so as to achieve the best results. The refinery using these modern devices and approaches follows these treatment methods completely and appropriately.

The removal of solid particles and oil drops is one of the crucial steps among physical separation techniques applied by the refinery. This process is usually accomplished through the use of settling tanks or clarifiers wherein the pollution allows its heavier components and oil to settle at the bottom. The solid residues and the oil can be processed or disposed of in an eco-friendly way (Aziz and Fakhrey, 2016).

The wastewater treatment continues with a subsequent series of operations that major on the remaining dissolved contaminants. Chemical coagulants and flocculants can be usefully employed to facilitate the aggregation of fine particles, which in turn assists with their separation from the water. Such chemicals in turn induce the development of larger flocks which are simple to be removed through methods like sedimentation or filtration (Amoatey and Baawain, 2019).

Sometimes the technology of such types of treatment is modified in order to upgrade leading to the removal of specific or some contaminants. An instance of that would be the implementation of induced air flotation (IAF) or dissolved air flotation (DAF) to address oily wastes in wastewater. These oil spill control systems induce the production of fine air bubbles into the water and collect the droplets of oil with the bubbles and they both float to the surface, while the oil is being taken out from there. Such a method has been able to give hope in terms of the use of oily effluent as a source of energy (Muñoz-Alegría et al., 2021).

Furthermore, the refinery acknowledges the vital role biological treatment techniques play in taking out organic pollutants in the wastewater. In this way, microorganisms are deployed in biological processes, like those of the activated sludge systems and biofilm reactors, to provide the removal of organic compounds and their further metabolization. Natural wastewater treatment techniques named biotic systems have as their main purpose to minimize levels of organic contaminant and improve water quality in general as it was studied by (Aziz and Ali, 2017).

In order to achieve the desired efficacy of gas separation and removal, the refinery monitors and possibly tunes the operating conditions. This entails routine sampling and testing of the treated water for the purpose of ascertaining the effectiveness of the treatment methods utilized. The treatment process would be closely looked after and changes are to be anticipated if necessary so that the optimum removal of pollutants can be achieved and regulatory implementation can be done.

Industrial Wastewater:

To many, the consequences of industrial wastewater on the water quality of the Great Zab River as a potential source of environmental and health risks is a matter of great concern. Industrial activities, most of them livelihoods, such as refineries, lead to huge wastewater ejecting that most of the time contains heavy metals, organic compounds, nutrients, and other contaminants. These pollutants can create a severe deterioration of the water quality of the river and place the organisms within the river and communities that depend on the river for various needs at risk (Genanaw et al., 2021).

In the work of Shekha (2016) PhD thesis physical and chemical investigations have been conducted to estimate the quality of water in the Great Zab River waterway. The main targets were to investigate the sources of the pollutants and apply the Iraqi standard for drinking water to check the suitability of the water supply for drinking consumption and irrigation purposes. This research employed a multivariate statistical method, which allowed the analysis of the multiple physical and chemical indicators present in the river. The goal of this was to suggest the most significant factors that lead to water degradation and to gain a system understanding of them. Finally, the scientist compared the data obtained with the validated standards to establish whether the water was suitable for drinking and the purposes of irrigation. The findings of the study explore the degree of parameters of physico-chemical, pollutant sources, water quality evaluation, and its suitable use for both human consumption and agricultural practices in the Great Zab River region, thus contributing to the body of knowledge of the issue.

The issue of refilling the Great Zab River with highly toxic chemicals from factories is one of the major issues. A prime example of these is the heavy metals (lead, mercury, cadmium, and chromium) that are abundant in industrial wastewater and can have very strong adverse effects on aquatic creatures (Bilotta and Brazier, 2008). These pollutants can be seen as the fish eat them at different levels in the ecosystem, this, in turn, is known as bioaccumulation and biomagnification which might affect fish population and other aquatic organisms. Furthermore, these poisonous substances can cause lasting problems to human health if they end up in a water supply and are consumed by the local people (Arantes et al., 2016).

The activities of the Cola North Iraq plant operation in Erbil might have both negative and positive influences on the water quality of the Great Zab River. Water consumption for making beverages and possible wastewater discharge together with the presence of chemical additives all add up to adverse environmental impacts. Although for complete modern manufacturing facilities set-up wastewater treatment systems are often put in place, leaks, poor handle or limited treatment may cause the emissions of untreated & partially treated wastewater, polluting the environment. The management of water resources well, the adoption of effective treatment methods and compliance with environmental control measures become necessary for the industrial sectors to reduce their environmental footprint. The joint effort of the industry, regulating authorities, and local community that are in charge of taking good care of the water resources and performing various sustainable acts is inevitable (Duan, 2022).

The Thermal power plant in Erbil, which is located near the Great Zab River also stands out in the context of the deterioration of the water quality of the river. Through the process of heat removal by using water for cooling, the plant itself is the principal source that supports new energy production. It is therefore worth mentioning that the discharge from the plant is quite problematic as it contains pollutants and thermal effluents that ultimately flow into the Great Zab River. These pollutants of which the heavy metals and chemicals are included have led to the reduction and level of the health of the river due to the poor water quality. The increase in the pollution level and a temperature rise in the water body have caused effects on the whole ecosystem around it. These have led to species decline and the development of harmful algae blooms. Besides, the deterioration of water quality is a doubly negative factor as it affects the adequacy of water reserved for drinking and irrigating the local populated areas (Idowu et al., 2020).

Amongst organic compounds, petroleum hydrocarbons, solvents, and other industrial chemicals are also some major components of industrial wastewater. Incorporated into the Great Zab River, these chemicals can pollute the water resources and harm the river ecosystem. Such pollutants may cause an array of woes like lowering dissolved oxygen levels, interfering with the photosynthesis of aquatic plants, and disrupting the process of reproduction among the fishes and other species. Alongside the issue of these organic toxins, eutrophication contributes to the development of hazardous algal blooms- which in turn result in poorer water conditions and could endanger the creatures that live in it (Amoatey and Baawain, 2019).

Human wastewater in turn is a secondary source of these materials. These nutrients, once discharged into the waters of the Great Zab River, may cause eutrophication, which refers to an abundance of algae during the process of fertilization. The excessive growth of algae due to oxygen utilization consequently may lead to oxygen depletion and death of fish and other aquatic organisms in water. Eutrophication not only brings about the river ecosystem change but also these changes could have some effects on the whole biodiversity and ecological functions of the river (Madden et al., 2013).

Rasul et al. (2023) examined the occurrence of heavy metals in edibles and their associated health risks, Although heavy metals play key roles in the metabolic processes of plants and humans, nobody would want them in excess because heavy exposure may cause adverse reactions. The study employed a research design where the researchers measured three edible plants (Eruca sativa Mill., Apium graveolens L., and Lactuca sativa L.) for essential and non-essential metals (Pb, Zn, Cd, Cu, Mn, and Ni) first by having the root and shoot parts analyzed using ICP-MS. The soil samples revealed enrichment of these metals in A. graveolens, especially in roots where Pb concentration reached 46.58 mg Pb/kg mean value, Zn - 49.85 mg Zn/kg mean value, Mn - 71 mg Mn/kg mean value and Cd 5.06 mg Cd/kg mean value (in shoots). Root of L. sativum revealed 42 mg Copper/kg root and 14.85 mg Nickel/kg root. Ultimately, the irrigation by wastewater, which is a metal-rich source of contamination, caused the inedible status of these plants in the area we have focused on. the study underscores the necessity of checking and controlling heavy metal concentrations in food plants in order to prevent the risk of food contamination.

It should be taken into account that discharging industrial wastewater into the Great Zab River leads to its water quality deterioration even if ecological matters aside. The river plays a key role in the irrigation of the surrounding areas towns and districts as well. One of the major dangers that the presence of pollutants in water can cause is a huge threat to public health. When water used as a source of drinking water or irrigation for farming is contaminated, the quality of crops and yield may be compromised bringing economic burdens to local farmers (Hamdan et al., 2018).

Combating the chances of industrial wastewater pollution in the Great Zab River should be a comprehensive problem. The industrial effluents of the factories should be decently treated by modern treatment processes and the government should establish some severe rules to make them follow. Wastewater management standards can be improved through the use of advanced methods, including the implementation of an effective treatment system and the creation of monitoring programs; this may reduce significantly water pollution resulting from industrial activities (Fan et al., 2021).

Additionally, promoting sustainable industrial practices that prioritize pollution prevention, resource conservation, and the use of environmentally friendly alternatives can help minimize the generation of harmful wastewater. Encouraging industries to adopt cleaner production techniques, improve waste management practices, and implement water reuse and recycling initiatives can contribute to the reduction of pollutant discharges into the Great Zab River (Fan et al., 2021).

Erbil Wastewater Channel

Numerous studies have been done which came up with a results of how effluent wastewater may have an influence on water pollution in Iraqi inland water bodies. For example, Kanber (1973) published an article about Mosul wastewater contamination of the Tiger River in 1973 and was mainly focused on the self-purification process. Mohammed (1980) carried out a hydrological study of the Tigris River to investigate its health in a polluted channel in the Baghdad area and how this influenced the total water quality of the Tigris River. Khamees (1979) assessed the detrimental impacts of Sulaimania`s sewage water and sugar factory flows to the Tanjaro River from the Kiliasan River. Maulood (1980) reported the

Sulaimaniya sugar mill's effusion became responsible for the oxygen deficiency and fish's suffocating characteristics in Kiliasan River.

The Erbil sewage channel operates as the terminal point for the treated wastewater and stormwater from Erbil City. Shekha (1994) carried out seasonal ecological research on the Erbil wastewater way and established very low dissolved oxygen levels (either non-detection or very low) from Apr till Sept that time was correspondent to higher amounts of microbes concentrations during the same months. Aziz et al. (2001) noted that the ammonia-oxidizing bacteria responsible for this nitrification was existent downstream in the Erbil wastewater channel. They noticed an increased occurrence of algal flora that are resistant to pollutants in the first 5 sites as compared to those in the last 3 sites studied. Should a facultative pond be constructed at Erbil wastewater source for irrigation instead of duplicating the aerated lagoon system according to Mustafa and Sabir (2001) study. In Ali (2002) algae taxa were identified, while the water physic-chemical properties (such as dissolved oxygen and BOD5 levels) were assessed.

With regard to physical and chemical properties, Aziz (2004), based on investigating the characteristics of Erbil wastewater at Tooraq village, has recommended the establishment of a wastewater treatment unit in order to utilize the water for agriculture purposes. Bapeer (2004) sampled a total of 57 different waterbodies in the Erbil province, including those along the Arab-Kand section of the sewage-based channel, and conducted various BOD5 tests which indicated values ranging up to 38 mg/l, whereas dissolved oxygen content ranged from an undetectable level to 3.45 mg/l. Researchers Lak (2007) found that the environment of the Erbil wastewater channel was the prime cause of pollution in the water of the Great Zab River as the polluted water had harmful effects on its quality. Lak also observed fluctuations between dissolved oxygen and both BOD_5 and COD values on which the water quality was deficient and classified as weak wastewater.

Many investigations have been done on how to use wastewater for agricultural purposes. They (Aziz and Amin, 2005) estimated electrical conductivity, total dissolved salts and sodium contents of the wastewater, and of course the coliform bacteria. They classified it as excellent to good quality based on the above parameters. They however advised against using it in industrial and fodder crops due to its high coliform bacteria content. Integrating the experience of Ganjo et al. (2006), Typha angustifolia L. was used to biologically remove Erbil’s wastewater and subsequently, it was applied for irrigation. The authors used the data from the implementation of reclaimed water for sampling to characterize cation and anion streftinals for several water qualities. Another similar example is Trajani (2006) study in which he applied the processes of sieving and coagulation to the Erbil wastewater channel and succeeded in increasing its efficiency in treating the biological wastewater. It has been demonstrated that discharge of treated effluent has resulted in the decline of total suspended salts, COD, BOD_5, NO_3, PO_4, and micro-organism population.

For a long time, the agriculture sector has been utilizing wastewater as part of its operations in different countries. On the other hand, this entails exposing crop workers, handlers, and consumers to pathogens that can result in health complications for human beings. Guidelines minimizing the quantities of bacteria as well as water-borne pathogens that can be contained in wastewater utilized for irrigation have been developed to guard farmers and crop consumers. Reported issues regarding microorganisms which are common in India Pakistan, Jordan, and Syria, include threats of the same nature.

The research studies for bacteria pollution in the Tigris River in Baghdad have been done in Iraq. Mutlak (1980) determined the level of bacteria in water at four sites of the river by the river. In the study conducted by El-Dohlob and Ali (1981) among the 55 species of fungi reported, 24 species were not previously found in such an environment of sewage and polluted waters of Shatt Al-Arab creeks. Sewage farming's success in Iraq was verified by Mutlak (1985) through the determination of total bacteria, coliforms, streptococci, and salmonella sp. in the communities with close wastewater treatment plants, contaminated soil, and produce crops irrigated with it. Al-Hilo (2006) found that the densest microbial number was in the activated sludge of the wastewater treatment in the south of Baghdad city, Rustomya, during the summer season.

In the case of Northern Iraq, the primary evaluation of water sources has been conducted on clean groundwater. Scant studies have been done regarding bacteria isolation, the threat of untreated effluents, and the diseases that can be spread by watering plants with diluted wastewater in the Erbil area. Thus, the current study represents a stepping stone for further research activities not only in the field of ecology but even epidemiology.

Surface Water Quality

Because surface water quality is closely related to ecosystem health and therefore human health as well, it makes perfect sense that water quality is given equal or greater priority than water quantity. It means the physical and ecological properties of water-bodies including lakes, rivers, oceans, and streams. Consider the chemicals, biological, and physical properties inherent in the water, and whether there are pollutants and contaminants there that may render the water unable to be used for purposes such as drinking water, supporting aquatic life, recreation, and irrigation jobs (M. Shareef and G. Muhamad, 2008).

The quality of surface water can be influenced by a mix of natural processes, human actions, and the neighboring environment. Some natural features like climate, geology, or plant cover can have a major effect on how good or bad the water will be. For example, torrential rainfall can be responsible for runoff that carries silt and other contaminants into adjacent water areas. Geological formations tend to alter the composition of minerals in water which consequently influence chemical properties. Vegetation is an indispensable component of water quality preservation by functioning as a natural purifier, providing nutrients and pollution absorption, decreasing erosion, and providing a home to several organisms (Khatri and Tyagi, 2015).

On the other hand, human activities that generate pollution of surface water quality contribute more than natural processes to the impairment of this resource. Pollution of water is caused by industrial operations, poor agricultural practices, urbanization, and improper waste disposal. The industries, as well as power plants, discharge a number of dyes and compounds, heavy metals, and organic pollutants into the water source. Farming methods, particularly the application of chemical fertilizers and pesticides, contribute to the runoff of nutrients and other substances that enter these streams and lakes, causing eutrophication. In urban communities where there is not adequate waste management system sewage discharge and other waste materials are released into water bodies due to which human health and aquatic life are also at risk (Khatri and Tyagi, 2015).

Evaluation of the quality of surface water relies on the collection and measurement of different parameters which are aimed at having an overarching picture of the water condition and suitability of its use for different purposes. All of these variables include temperature, pH, DO content, turbidity, nutrients (i.e. nitrogen and phosphorus), heavy metals, pesticides, pathogens, and other contaminants. The temperature determines the speed of metabolism of water creatures and the speed of chemical reactions in water. pH of water is a measure of the acid or alkaline content, which decides the solubility of nutrients and the activity of metals. Dissolved oxygen being very important for aquatic organisms is also an important indicator of the overall health level of the aquatic environment. Turbidity is a reflection of the water quantity in a body of water and its level of transparency. This transparency depends on the presence of suspended particles and sediment. Nutrients are vital for plant growth, but if applied in excess eutrophication will take place thereby disrupting aquatic systems and ecosystems. In aquifers, pharmaceutical drugs and other dangerous chemicals may be present at toxic levels which could be harmful to aquatic life forms and also for humans. An additional health concern is pathogens, including bacteria and viruses that need close monitoring as they can pose risks to human health. The presence of E-coli bacteria (as a usable index) gives evidence of water pollution (Zainurin et al., 2022).

The standards and guidelines for water quality differ across countries and regions; however, they are commonly made to protect human health, preserve the ecosystem, and make water suitable for multiple purposes. The entities of the government and regulating agencies design rules or programs that help in managing and improving the surface water quality whole process. Among these efforts are pollution control protocols that probably will result in reduced levels of pollutants discharges, wastewater treatment facilities that will remove pollutants from domestic and industrial wastewater, land use planning strategies that will help to reduce the pollutant runoff and conservation activities are vital for water quality improvement as they primarily include riparian zones and wetlands protection (Zainurin et al., 2022).

Water quality monitoring and maintenance become very integral when thinking of sustainable water resource management where public health is safeguarded, conservation of biodiversity is ensured, and freshwater is made available for all uses. Through watershed-based monitoring programs, we can continuously collect data on indicators of water quality and gather information on the overall trend. This information is critical in ensuring that appropriate decisions are made regarding water resource management, pollution prevention, and conservation efforts including water quality management, water resource allocation and development, water pollution prevention and control, and water conservation. Surface water quality is one of the natural resources that everyone is responsible for its preservation. Therefore, if stakeholders want to fulfill this responsibility, they must understand the forces that lead to water quality and how to fix them (Banda and

Kumarasamy, 2020).

Surface water quality is influenced by natural processes, human activities, and the surrounding environment. Monitoring and assessment of water quality parameters provide insights into the health and suitability of water bodies for various uses. Governments and regulatory agencies implement measures to manage and improve water quality, aiming to protect human health and ecological balance. Monitoring and maintaining surface water quality is vital for sustainable water resource management and the availability of clean water for different purposes. By addressing the factors that contribute to water pollution and implementing appropriate measures, we can ensure the long-term health and sustainability of surface water resources (Majed and Islam, 2022).

Water Quality Index (WQI)

The study showed the vital role of the water quality index by Hernández-Romero et al. (2004) which is used as a criterion for the classification of surface waters. The WQI stands as an appertaining measure that uses complex data and converts it into a simple value, which is easier to understand and compare. This simplification brings the stakeholders, decision-makers, and the general public closer together so that all can understand and interpret water quality conditions correctly.

In the research by Pandey and Sundaram (2002), the water quality of the Ganga River in India was assessed by means of the water quality index. The researchers considered five key parameters: dissolved oxygen (DO), biochemical oxygen demand (BOD_5), temperature, pH, and fecal coliform. Using these parameters, they were able to get the WQI, which is a highly accurate evaluation of river water quality. The information derived from this assessment not only showed possible problems but also assisted in shaping water management initiatives.

In the same manner, Raczynska (2000) carried out a review of the Tywa and Rurzyca rivers in Poland. The researchers examined various crucial water indicators, such as dissolved oxygen, biochemical oxygen demand, phosphate (PO_4) concentration, dissolved substances, ammonium-nitrogen NH_4-N, and nitrite-nitrogen NO_2-N. They then immediately calculated the WQI for both rivers and classified the water as good. This categorization facilitated a better understanding of the overall health status of the rivers and consequently informed about the decision-making for their conservation and protection.

One more experiment by Sánchez et al. (2007)concentrated upon the La Rozas watershed that lies in the Northwest of Madrid, Spain. For the water quality index, they used the data for two rivers, Guadarrama and Manzanar, as well as the ponds of Paris Park. The computed WQI values were found to be 70, 65, and 55 subsequent. These values referred to classifications which then were divided into good and medium-quality categories. With the WQI, the scientists could monitor the water quality in all the locations sampled and identify the sites that needed more effort for water management and conservation.

These researches confirmed the precious role of the Water Quality Index in the examination and categorizing of the surface water body. WQI aggregates many water quality parameters into one final score that gives a holistic, concise assessment of the current water quality. Simplification makes decision-making effective for policymakers, researchers, and water resource managers as it provides an understanding of the status of water quality and allows the identification of possible problems or concerns (Sánchez et al., 2007).

There are also a few drawbacks to the water quality index as an evaluation tool. One limitation, however, is the difference in regulations and standards between jurisdictions and regions around the world. Setting parameters like quality standards and threshold values may differ from one another which can lead to a question of index interpretation and application. The alignment of the water index with the existing regulatory framework of the region studied cannot be ignored to maintain its significance and reliability (Fawkes and Sansom, 2021).

Nevertheless, the third challenge is involved with the parameters that are taken in to consider when calculating the water quality index. The selection of factors for consideration should be determined by their relationship with the body of water being conserved and its intended purpose. Nevertheless, the introduction of extra parameters which such indices may comprise can lead to complexity as you may struggle to overtake and use the index. This should be done by weighing the significance of the related parameters against making the index simple and accessible (Fawkes and Sansom, 2021).

Another thing that needs to be taken into account is the matter of appropriate parameter weights. The chosen parameters have their relative weights to evaluate their overall water quality. On the other hand, weighting may rely on experts' estimates and might depend on the views of the stakeholders. Transparency and uniformity of weights assigning must be maintained and these parameters will contribute to the credibility and precision of the index (Sutadian et al., 2015).

The water quality index is a term that defines the specific time and location where the water quality is sampled. It also disregards the time and place differences within a water body. Monitoring and assessment must be conducted on a frequent basis to portray changes in the condition of water in their duration and to also allow for acknowledging the variance that different places have within the water body (Ahmed et al., 2020).

The water quality index is a valuable tool for assessing and categorizing surface water quality. It simplifies complex water quality data into a single numerical value, providing a representative measure of overall water quality. The index facilitates better understanding, communication, and decision-making related to water resource management and conservation efforts. However, it is important to consider the limitations of the index, such as variations in regulations, parameter selection, weighting, and its snapshot nature. By acknowledging these limitations and using the index appropriately, stakeholders can make informed decisions to protect and manage water resources effectively(Ewaid et al., 2020).

Water Quality Regulations

One of the apprehensions and drawbacks of Index WQI is the existence of regulations and restrictions. These provisions and standards are set up this way so as to ensure that any record of events or the atmosphere, for instance, would help in the interpretation, as well as the correct representation of the occurrences and the effectiveness of decision-making based on the index. Here are some key aspects to consider:

Regulatory Variations: The degree of water quality regulations and standards may diverge due to economic development and cultural differences among countries and areas. It is very imperaceble to consider the WQI you are applying with the specific regulatory framework of the area where it is used. Making sure that the index includes water quality indicators and limits adopted by the local agencies guarantees that the index is relevant to the local area, like what Lukhabi et al. (2023) observed.

Parameter Selection: Parameter selection for the WQI education should be based on the scientific understanding of the relationship between the water body, its purpose, and its relevance to each respective water body. It is also crucial to have different parameters that will capture changes in key characteristics of your water quality such as dissolved oxygen, pH, nutrients, bacteria, and phytoplankton. Nevertheless, factors becoming too excess or irrelevant can result in the creation of a more complex and nevertheless impractical index (Tripathi and Singal, 2019).

Parameter Weighting: It is vital that each parameter gets an appropriate weight so that it can be weighed significantly compared to the rest of the methods in the index calculation. The assignations should be proportional to the paramountcy of each element considering to the specific water object under investigation and the objectives of the scrutiny. The limitation in the subjectivity of giving weight to the analysis process can be the case when it depends on the judge or opinion of stakeholders (Sutadian et al., 2017).

Index Calculation Methodology: The methodology to be followed in the calculation of the WQI should be transparent, consistent, and scientifically grounded. The parameters and arithmetic operations used to come up with an index value which is normally based on sound scientific principles will need to be subjected to strong checks and validation. The procedure to obtain every parameter has to be described properly so that the results can be clear. Otherwise, the transparance of the index will be questionable and hard to understand (Environment-IRAQ, 2012).

Simplification and Generalization: WQI is a simplification of water quality parameters distilled into a single numerical value. While it carries a couple of positive sides to it, such as simplified communication and decision-making, it is also true that it is not without limitations. The WQI may miss some complexity of water quality dynamics, and it may not cover the range of specific pollutant sources, localized effects and etc. Therefore, it is imperative that this be incorporated with detailed product-specific parameters as well as additional tests if required (Banda and Kumarasamy, 2020).

Temporal and Spatial Considerations: The WQI represents bottlenecked water quality at a certain period and location. It does not take into account inlet-outlet variations or spacial homogeneity within a water body. The index is, therefore, the best method for water quality monitoring and evaluating the water quality over the sewage system. However, the index gives only the overall reports for the water quality over long periods of time and within big water catchment-release areas so it is vital to correctly interpret the reports and the decisions that should be made based on localized information (Namugize and Jewitt, 2018).

Data Availability and Monitoring Frequency: The precision and stability of the WQI come into play with limited and high-quality data available for the picked parameters. The right monitoring frequency, along with good data collection efforts, become key factors as this guarantees the required updated and representational information for the index calculation process (Namugize and Jewitt, 2018).

The Water Quality Index which is to be regulated and limited strives to assure it is correctly used, is reliable, and matches the objectives of assessing and managing the level of water quality. Compliance with the existing regulatory structure, key indicators as a selection, calculation method selection, limitation to some extent, and supplementary data to the index make the Water Quality Index more effective and convenient for policy making (Ochungo et al., 2019).

2.1. Effects Of Industrial Wastewater Discharge On Surface Water Quality:

Industrialization has been the hallmark of human progress, driving economic growth, technological advancements, and improved living standards. However, alongside these achievements, industrial activities have left an indelible mark on the environment, particularly concerning water resources. One of the most significant challenges posed by industrialization is the discharge of wastewater into surface water bodies. Industrial wastewater contains a diverse array of pollutants, and when released without adequate treatment, it can severely degrade the quality of surface water (Singh et al., 2023). This chapter investigates the multifaceted effects of industrial wastewater discharge on surface water quality, exploring the sources and composition of pollutants, the physical, chemical, and biological consequences, the associated human health concerns, the economic implications, and the role of environmental regulations in mitigating this pressing environmental issue.

Industrial wastewater arises from a broad spectrum of industrial processes, spanning various sectors such as manufacturing, mining, chemical production, food processing, textiles, and energy generation. The composition of industrial wastewater is highly heterogeneous, dependent on the type of industry and the specific processes involved. Typically, it encompasses organic and inorganic pollutants, heavy metals, suspended solids, nutrients, and other contaminants (Osman, 2014).

Organic compounds present in industrial wastewater encompass a range of substances, including solvents, oils, greases, and various chemicals utilized in industrial processes. Many of these organic compounds are toxic, persistent, and pose significant challenges for water treatment. Heavy metals, such as lead, mercury, cadmium, and chromium, are common pollutants in industrial effluents and are notorious for their toxicity and ability to bioaccumulate in aquatic ecosystems. Suspended solids, comprising sediments and organic matter, can cloud the water and adversely affect aquatic life by reducing light penetration and hindering photosynthesis. Nutrients, primarily nitrogen and phosphorus, are often present in excess and can lead to eutrophication, a process in which excessive plant growth depletes oxygen levels, leading to negative impacts on aquatic organisms (Singh and Shikha, 2018).

The discharge of industrial wastewater can result in immediate physical impacts on surface water bodies. When large volumes of untreated or inadequately treated wastewater are released, it can disrupt the natural flow of rivers and streams, causing erosion and sedimentation. Consequently, the sudden influx of water can lead to flash floods and alter the habitats of aquatic organisms (Lemessa et al., 2023).

Furthermore, the elevated temperature of industrial wastewater due to cooling processes used in various industries can result in thermal pollution. Thermal pollution can negatively affect aquatic life, especially species adapted to specific temperature ranges, and may lead to reduced dissolved oxygen levels, further stressing aquatic ecosystems (Brion et al., 2015).

Chemical pollutants present in industrial wastewater are of major concern for surface water quality. Heavy metals, notorious for their toxicity and persistence, can have serious implications for aquatic life and human health. These pollutants can accumulate in the tissues of organisms, leading to biomagnification up the food chain (Singh and Shikha, 2018).

Organic compounds in industrial wastewater, such as pesticides, solvents, and petroleum byproducts, can also be highly toxic and challenging to degrade. Some of these compounds can undergo transformation into more harmful forms, compounding their environmental impact (Radelyuk et al., 2021).

Moreover, changes in pH levels can occur due to the discharge of acidic or alkaline industrial wastewater. Altered pH levels can disrupt the life cycles of aquatic organisms, leading to declines in populations of sensitive species (Kareem, 2016).

The biological impacts of industrial wastewater discharge on surface water quality are extensive and can cause significant disruptions to aquatic ecosystems. Aquatic organisms, including fish, invertebrates, and aquatic plants, are highly sensitive to changes in water quality. The presence of pollutants can lead to direct exposure to toxic pollutants that can cause fish kills and harm other aquatic organisms, leading to declines in populations of sensitive species and pollutants can interfere with the reproductive processes of aquatic organisms, reducing fertility and successful spawning also pollutants can accumulate in the tissues of aquatic organisms and magnify up the food chain, affecting higher trophic levels, including humans, some species may be more tolerant of pollution, leading to shifts in the composition of aquatic communities and disrupting ecological balance, however, aquatic organisms may change their behavior, such as feeding and migration patterns, in response to chemical pollutants (Brion et al., 2015).

The effects of industrial wastewater discharge on surface water quality are widespread and profound. The pollutants present in industrial effluents can disrupt physical, chemical, and biological processes, leading to imbalances in aquatic ecosystems and adverse impacts on human health and socio-economic wellbeing (Kareem, 2016).

2.1.1. Effect of the Drinking Industry on Surface Water Quality

The beverage industry has witnessed substantial growth in recent years. While these companies have brought us an array of refreshing drinks, concerns have been raised regarding their impact on the environment, particularly on surface water quality (Almeida et al., 2018).

The production of the drinking industry requires vast amounts of water for processing and cleaning. Companies draw water from local sources, which can place immense pressure on already stressed water bodies. Over-extraction can lead to reduced water levels in streams, rivers, and underground aquifers, adversely affecting aquatic ecosystems and biodiversity (Brion et al., 2015).

The manufacturing process generates substantial wastewater, often laden with pollutants such as organic matter, sugars, and chemicals. If not adequately treated, these effluents find their way into nearby surface waters, contaminating them. High levels of organic materials and nutrients can lead to eutrophication, causing harmful algal blooms and depleting oxygen levels, harming aquatic life (Schliemann et al., 2020).

Another Factor is plastic bottles and packaging used in the drinking industry are a significant contributor to plastic pollution in surface water bodies. Plastic debris adversely affects marine and freshwater environments, posing risks to wildlife and human health through ingestion and contamination (Xu et al., 2019).

Drinking production involves the use of various additives like preservatives, flavors, and colorants. Some of these chemicals, when not managed responsibly, can leach into surface water through improper disposal or runoff, leading to water quality degradation and potential health hazards (Xu et al., 2019).

The drinking industry has an undeniable impact on surface water quality. Water consumption, wastewater discharge, plastic pollution, and chemical additives are significant contributors to water degradation.

2.1.2. Effect of the Thermal Power Plant on Surface Water Quality

Thermal power plants are a cornerstone of modern electricity generation, providing a substantial portion of the world's energy needs. However, their reliance on water for cooling purposes and subsequent discharge of heated effluents into surface water bodies can have significant implications for water quality. This essay explores the effects of thermal power plants on surface water quality, highlighting the various pollutants and environmental consequences associated with their operation (Madden et al., 2013).

One of the most evident impacts of thermal power plants on surface water quality is the alteration of water temperatures. These plants draw massive volumes of water from nearby water sources, such as rivers or lakes, to cool their systems and dissipate excess heat. The discharged water is typically warmer than the natural temperature of the receiving water body. Such abrupt changes in temperature can be detrimental to aquatic ecosystems (Madden et al., 2013).

Coldwater species, in particular, are vulnerable to these thermal fluctuations. Increased water temperatures can disrupt their metabolic rates, reproductive cycles, and overall behavior. In some cases, these temperature changes can force cold water species to migrate or seek refuge in areas with more stable conditions, leading to shifts in species distribution and potential declines in biodiversity (Fullerton et al., 2018).

The release of heated water into surface water bodies can lead to reduced levels of dissolved oxygen. As water temperature rises, its ability to hold dissolved gases, including oxygen, decreases. Consequently, the warm water discharged from thermal power plants can be depleted of oxygen, creating hypoxic conditions in the vicinity of the discharge point (Madden et al., 2013).

Low dissolved oxygen levels pose a severe threat to aquatic life, as many organisms, such as fish and invertebrates, depend on oxygen to survive. In areas with diminished oxygen concentrations, fish kills may occur, and sensitive species may struggle to thrive. The disruption of the natural oxygen balance can cascade through the food web, affecting the overall health and functioning of the aquatic ecosystem (O'Boyle, 2020).

Thermal power plants use a range of chemicals for water treatment and to prevent corrosion and scaling in their cooling systems. These chemicals can find their way into the discharged water, leading to chemical pollution. Additionally, the combustion of fossil fuels in the power generation process can release heavy metals and other harmful pollutants that may be carried into the surface water (Rajaković-Ognjanović et al., 2011).

Chemical pollution can have detrimental effects on aquatic life. Some chemicals may be toxic to fish, invertebrates, and aquatic plants, leading to reduced reproductive success and overall population decline. Persistent pollutants can bioaccumulate in the food chain, posing risks to both aquatic organisms and humans who consume contaminated fish or water (Lehtonen et al., 2017).

Thermal power plant discharges are often nutrient-rich due to the water's contact with various chemicals and substances during the cooling process. This nutrient enrichment, combined with elevated temperatures, creates favorable conditions for algal growth. Consequently, algal blooms can occur, leading to eutrophication.

Excessive algal growth can disrupt the balance of the aquatic ecosystem. As algae die and decompose, they consume dissolved oxygen during decomposition, leading to further oxygen depletion in the water. This can create dead zones, where aquatic life cannot survive, and severely impact fisheries, recreational activities, and overall water quality (Madden et al., 2013).

The intake and discharge of water in thermal power plants can alter natural water flow patterns, leading to habitat disturbances in the affected water bodies. Dredging and construction activities during the establishment of power plants may physically damage aquatic habitats, leading to habitat loss for various plant and animal species (de Lima et al., 2022).

The disruption of habitats can have cascading effects on the entire ecosystem. Many aquatic species rely on specific habitats for shelter, breeding, and feeding, and any disturbances to these areas can lead to population declines and changes in community composition (Lehtonen et al., 2017).

Thermal power plants have undoubtedly played a pivotal role in meeting the world's energy demands. However, their impact on surface water quality cannot be overlooked. The alteration of water temperatures, reduced dissolved oxygen levels, chemical pollutants, algal blooms, and habitat disturbance are some of the significant consequences of their operation.

2.1.3. The Effects of Oil Refineries on the Surface Water Quality

Oil refineries are essential industrial facilities responsible for processing crude oil into various refined products, including gasoline, diesel, jet fuel, and other petroleum-based products. While these refineries are crucial for meeting our energy demands, their operations can have significant effects on surface water quality (Rahi et al., 2021).

One of the most immediate and visible impacts of oil refineries on surface water quality is the risk of oil spills and leaks. Accidents during the transportation, storage, or refining process can result in large quantities of oil being released into nearby water bodies. Oil spills can coat the water surface, leading to immediate harm to aquatic life and birds, as well as disrupting the natural ecosystem balance Lusweti et al. (2022), the spilled oil can also contaminate sediments and persist in the environment for an extended period, causing long-term damage to water quality and habitats.

Oil refineries generate substantial volumes of wastewater during their processes. This wastewater, known as refinery effluent, contains various pollutants, including heavy metals, organic compounds, and other toxic substances. If not adequately treated, the discharge of untreated or poorly treated refinery effluents into surface water bodies can severely degrade water quality. The presence of these pollutants can harm aquatic life, contaminate drinking water sources, and impair the recreational and ecological value of the water body (Singh and Shikha, 2018).

Oil refineries require vast amounts of water for cooling their equipment and processes. This cooling water absorbs heat from the refining operations and is subsequently discharged back into nearby water bodies. The thermal discharge can raise the temperature of the receiving water, leading to thermal pollution. Elevated water temperatures can negatively impact aquatic ecosystems, disrupt breeding patterns, and reduce the dissolved oxygen content, threatening the survival of aquatic organisms (Lusweti et al., 2022).

Besides the direct discharges, oil refineries can contribute to surface water contamination indirectly through runoff. Rainwater can pick up oil and petroleum-based substances from various surfaces within the refinery, such as storage tanks, pipelines, and machinery, and transport these pollutants into nearby water bodies. Runoff can introduce a steady stream of low-level pollution, leading to cumulative negative impacts on water quality over time (Radelyuk et al., 2021).

The refining process involves the use of various chemicals, additives, and catalysts to modify the properties of crude oil and produce specific petroleum products. Some of these chemicals can find their way into the water streams through spills, leaks, or improper disposal practices. Additionally, byproducts and waste from the refining process may contain harmful substances that can contaminate surface water if not adequately managed (Amin Al Manmi et al., 2019).

Oil refineries are essential components of our modern energy infrastructure, but they pose significant challenges to surface water quality. Oil spills and leaks, wastewater discharge, cooling water discharge, oil discharge through runoff, and chemical additives are some of the primary factors contributing to the negative impact on water bodies (Amin Al Manmi et al., 2019).

2.2. Surface Water Quality

Surface water quality refers to the chemical, physical, and biological characteristics of water bodies such as rivers, lakes, and streams that are exposed to the atmosphere. It is crucial to assess and monitor surface water quality to protect human health, support aquatic ecosystems, and ensure the sustainability of water resources. Various factors influence surface water quality, including human activities such as industrial discharge, agriculture, urban runoff, and waste disposal. Additionally, natural factors like weather patterns, geological processes, and nutrient cycling can also affect surface water quality. Monitoring surface water quality helps identify pollution sources, track changes over time, and implement effective management strategies to improve and maintain the health of these vital water bodies (Chapman et al., 2019).

The assessment of surface water quality involves measuring various parameters, including temperature, pH, dissolved oxygen, turbidity, nutrient levels (such as nitrogen and phosphorus), heavy metals, and the presence of pathogens and pollutants. Monitoring programs collect data at different points in water bodies to provide a comprehensive understanding of water quality across various locations and seasons. Regulatory agencies often establish water quality standards and guidelines to define acceptable limits for these parameters, ensuring that surface water remains safe for drinking, recreation, and sustaining aquatic life. By comparing the measured values with established standards, authorities can take necessary actions to address pollution sources and implement measures for water quality improvement (Al-Obaidy et al., 2015).

Preserving and enhancing surface water quality is a collaborative effort that involves governments, industries, communities, and individuals. Environmental regulations and best practices aim to reduce the discharge of pollutants and contaminants into surface water bodies. Sustainable land use practices, proper waste management, and the use of eco-friendly technologies contribute to maintaining water quality. Additionally, protecting riparian zones, which are the areas along the water's edge, helps prevent sediment runoff and pollution from adjacent lands. Public awareness and education about the importance of surface water quality and responsible water use are vital in encouraging collective action to safeguard these precious resources (Chapman et al., 2019). Through ongoing monitoring, proactive measures, and collective commitment, we can ensure the continued health and resilience of surface water ecosystems for future generations.

2.2.1. Surface Water Quality Parameters

Surface water quality parameters are essential indicators used to assess the health and condition of water bodies such as rivers, lakes, and streams. These parameters provide valuable information about the chemical, physical, and biological characteristics of surface water, helping us understand its suitability for various uses, including drinking water, recreation, and supporting aquatic life. Monitoring these parameters is crucial to identify potential pollution sources, track changes over time, and implement effective management strategies to protect and preserve surface water resources. In this comprehensive analysis, we will explore the most common surface water quality parameters and their significance in ensuring the health and sustainability of our water bodies (Vasistha and Ganguly, 2020).

Physical Parameters

a) Temperature: Water temperature is a fundamental physical parameter that influences the biological processes in aquatic ecosystems. It is affected by various factors, including air temperature, solar radiation, and the flow of water. Temperature fluctuations can affect the metabolic rates of aquatic organisms, alter dissolved oxygen levels, and impact the distribution and behavior of aquatic species. High temperatures can lead to thermal pollution, negatively affecting sensitive aquatic species, and causing oxygen depletion (Hester and Doyle, 2011).

b) Turbidity: Turbidity measures the cloudiness or haziness of water caused by suspended particles such as sediment, silt, and organic matter. High turbidity levels can reduce light penetration into the water, affecting aquatic plant growth and photosynthesis. It can also hinder feeding and reproduction in aquatic organisms and create challenges for water treatment processes, making it difficult to produce clear drinking water (Davies-Colley and Smith, 2001).

Chemical Parameters

a) Dissolved Oxygen (DO): DO is a critical chemical parameter that measures the amount of oxygen available in water for aquatic organisms. Aquatic plants and animals rely on dissolved oxygen to survive and carry out essential biological processes. Low DO levels can lead to hypoxic conditions, causing fish kills and affecting the overall health of aquatic ecosystems (Banerjee et al., 2019).

b) Nutrients (Nitrogen and Phosphorus): Nutrients, particularly nitrogen and phosphorus, are essential for the growth of aquatic plants and algae. However, excessive nutrient levels, often caused by agricultural runoff or wastewater discharge, can lead to eutrophication. This process results in algal blooms, oxygen depletion, and habitat degradation, negatively impacting aquatic biodiversity (Mishra, 2023).

c) Heavy Metals: Heavy metals such as lead, mercury, cadmium, and arsenic can be toxic to aquatic organisms and humans at high concentrations. These metals often enter water bodies through industrial discharges, stormwater runoff, and natural processes. Accumulation of heavy metals in the food chain can lead to bioaccumulation and pose risks to human health through fish consumption (Beniah Obinna and Ebere, 2019).

d) Organic Compounds: Organic compounds, including pesticides, herbicides, and industrial chemicals, can enter surface water through runoff and point-source pollution. Some organic compounds are persistent and can bioaccumulate in aquatic organisms, leading to adverse effects on wildlife and human health (Kumar et al., 2022).

e) pH: The pH level measures the acidity or alkalinity of water. The pH scale ranges from 0 to 14, with 7 being neutral. Values below 7 indicate acidity, while values above 7 indicate alkalinity. pH influences the availability of nutrients and the toxicity of certain substances in the water. Drastic changes in pH can harm aquatic life, especially species that are sensitive to acidity or alkalinity(Boyd et al., 2011).

Biological Parameters

a) Bioindicators: Biological parameters are used to assess the health of water bodies based on the presence or absence of specific species or groups of organisms. Certain organisms, known as bioindicators, are highly sensitive to pollution and environmental changes. Their presence or absence can indicate the overall ecological health of the water body (Burger, 2006).

b) Bacteria and Pathogens: Monitoring the presence of bacteria and pathogens in surface water is crucial for assessing its suitability for human contact, recreation, and drinking water sources. Elevated levels of bacteria can pose risks to public health, causing waterborne diseases and infections (Burger, 2006).

Surface water quality parameters play a crucial role in assessing and maintaining the health and sustainability of water bodies. By monitoring physical, chemical, and biological indicators, we can identify pollution sources, track changes over time, and implement effective management strategies to protect and preserve surface water resources. As the global population grows and water resources face increasing pressures from human activities, it becomes ever more vital to prioritize the protection of our surface water quality. Through proactive monitoring, responsible management, and public awareness, we can ensure the availability of clean and safe surface water for current and future generations (Ahmed et al., 2020).

2.3. Water Quality Index (WQI)

Water quality assessment is a critical aspect of understanding the condition of surface water bodies. The evaluation of water quality involves analyzing various parameters that provide insights into the physical, chemical, and biological characteristics of the water. One widely used tool for assessing water quality is the water quality index (WQI). The WQI converts extensive datasets into a single numerical value, making it easier to interpret and communicate overall water quality information (Syeed et al., 2023).

The Water Quality Index (WQI) is a numerical rating system used to assess and communicate the overall health or suitability of water for various purposes. It is a valuable tool for evaluating the quality of water bodies, such as rivers, lakes, streams, and groundwater sources. The index combines multiple water quality parameters into a single score, making it easier for policymakers, scientists, and the general public to understand and compare water quality across different locations and time periods (Kannel et al., 2007).

The final WQI value usually ranges from 0 to 100 or 0 to 10, with higher values indicating better water quality. The index is typically divided into different categories, such as excellent, good, fair, poor, and very poor, to provide an easy-to-understand assessment of water quality (Lumb et al., 2006).

2.3.1. Water Quality Index Parameters

The Water Quality Index (WQI) is a comprehensive tool utilized to assess and communicate the overall quality of surface water. It employs a multidimensional approach by incorporating multiple parameters into a single numerical value, providing a concise representation of water quality. Although the specific parameters considered in the calculation of the WQI may vary depending on the region and purpose of the assessment, several key parameters are commonly included (Hamdan et al., 2018).

Dissolved Oxygen (DO) is a crucial parameter that measures the amount of oxygen present in water. Aquatic organisms rely on dissolved oxygen for survival, making it a critical indicator of water quality. Insufficient levels of dissolved oxygen can indicate pollution or an excess of organic matter in the water, which can be harmful to aquatic life (Banerjee et al., 2019).

Conductivity is a significant parameter used in water quality assessments and is an essential component of the Water Quality Index (WQI). It measures the ability of water to conduct electrical current, which is directly related to the concentration of dissolved salts and ions present in the water. Since different pollutants and dissolved substances, such as chloride, sulfate, and nitrate, increase the conductivity of water, it serves as an indicator of overall water quality and pollution levels. High conductivity values may signify the presence of industrial discharges, agricultural runoff, or wastewater inputs, indicating potential contamination. On the other hand, low conductivity may be an indicator of clean water with minimal dissolved solids. By incorporating conductivity into the WQI, authorities and researchers gain valuable insights into the salinity and pollution levels of water bodies, enabling them to implement appropriate measures for maintaining and improving water quality (Chidiac et al., 2023).

Total Dissolved Solids (TDS) is an essential parameter used in water quality assessments and plays a crucial role in determining the overall health of water bodies within the Water Quality Index (WQI) framework. TDS refers to the total concentration of inorganic and organic substances that are dissolved in water, including minerals, salts, metals, and organic compounds. High TDS levels are often associated with pollution, as they can originate from agricultural runoff, industrial discharges, urban stormwater, and natural sources. Excessive TDS in water can adversely affect aquatic life and disrupt ecosystems by altering osmoregulation in freshwater organisms. Additionally, high TDS may lead to undesirable taste and odor in drinking water, impacting its potability. On the other hand, low TDS levels can indicate a lack of essential minerals and nutrients in water, which may also have adverse effects on aquatic life (Chidiac et al., 2023).

Residual Chlorine (Cl2) is a critical parameter considered in water quality assessments and is an integral part of the Water Quality Index (WQI) due to its significant role in disinfection and public health protection. Residual chlorine refers to the concentration of chlorine remaining in water after the disinfection process. Chlorination is a common method used by water treatment facilities to kill harmful microorganisms and make water safe for human consumption. The presence of residual chlorine indicates that the water has been effectively disinfected, reducing the risk of waterborne diseases. However, maintaining an appropriate level of residual chlorine is essential, as excessive amounts can lead to taste and odor issues and the formation of disinfection byproducts, which can be harmful to health. On the other hand, insufficient residual chlorine levels may result in inadequate disinfection and the persistence of pathogens in the water supply. Regular monitoring of residual chlorine levels helps ensure that water remains safe and potable throughout the distribution system. Including residual chlorine as part of the WQI allows water authorities to assess the efficacy of the disinfection process and take corrective actions to maintain optimal chlorine levels for safeguarding public health (Ochungo et al., 2019).

Fluoride (F2) is an important parameter considered in water quality assessments, and its inclusion in the Water Quality Index (WQI) is crucial due to its impact on dental health and overall water safety. Fluoride occurs naturally in many water sources and is also added to public water supplies to prevent tooth decay. While fluoride is beneficial in appropriate concentrations, excessive levels can lead to dental fluorosis and other health issues. Dental fluorosis is a condition that affects tooth enamel, causing discoloration and weakening of the teeth (Aoun et al., 2018).

Total Phosphate (PO4-3) is a significant parameter considered in water quality assessments and an essential component of the Water Quality Index (WQI) due to its impact on aquatic ecosystems. Phosphates are essential nutrients for plant growth, and they play a crucial role in supporting the growth of algae and aquatic vegetation. However, excessive levels of phosphate in water bodies can lead to eutrophication, a process where there is an overabundance of nutrients that cause rapid algal growth. The excess algae can deplete dissolved oxygen in the water when they decompose, leading to hypoxic or anoxic conditions, which are harmful to aquatic life. Additionally, the proliferation of harmful algal blooms can produce toxins that threaten public health and the well-being of aquatic organisms.

Monitoring total phosphate levels is vital to detect nutrient imbalances and potential pollution sources, such as agricultural runoff and wastewater discharges. By including total phosphate as a parameter in the WQI, authorities can assess the nutrient status of water bodies, identify areas of concern, and implement appropriate measures to mitigate eutrophication and preserve the ecological balance of aquatic environments. Managing phosphate levels in water contributes to maintaining the health and sustainability of aquatic ecosystems and the quality of water resources for various uses (Chidiac et al., 2023).

Sulfides (S-2) are a critical parameter considered in water quality assessments and an important component of the Water Quality Index (WQI) due to their potentially harmful effects on aquatic ecosystems and human health. Sulfides are formed through the decomposition of organic matter in anaerobic conditions, such as in sediment or stagnant water bodies. High concentrations of sulfides in water can indicate the presence of pollution sources, such as untreated sewage or industrial discharges. Sulfides are toxic to aquatic life, particularly to fish and other sensitive organisms. They can interfere with the respiration process in aquatic organisms, leading to decreased oxygen uptake and even mortality in extreme cases. Moreover, the presence of sulfides in water can result in foul odors and unpleasant taste, making the water unsuitable for human consumption and recreational activities (Amoatey and Baawain, 2019).

Cyanides, specifically Total Free Cyanides (Cn), are a critical parameter considered in water quality assessments and a significant component of the Water Quality Index (WQI) due to their extreme toxicity and potential for severe environmental and human health impacts. Cyanides can enter water bodies through industrial processes, mining activities, and accidental spills. Even at very low concentrations, cyanides can be lethal to aquatic organisms, disrupting their respiratory systems and causing rapid mortality. Moreover, cyanides can persist in the environment for extended periods, making their impact on ecosystems long-lasting. In addition to their acute toxicity to aquatic life, cyanides can pose a serious risk to human health, especially if contaminated water is used for drinking or agriculture. Cyanides interfere with cellular respiration, and exposure to elevated levels can lead to severe health consequences, including neurological disorders and even death ((WHO), 2006).

Total Iron (TFe) is an important parameter considered in water quality assessments and a key component of the Water Quality Index (WQI) due to its influence on water aesthetics, aquatic life, and human health. Iron can naturally occur in water sources, or it may enter water bodies through industrial discharges, agricultural runoff, or corroded pipes. Elevated levels of total iron in water can lead to aesthetic issues, such as reddish-brown discoloration, which is commonly known as "iron staining" or "rusty water." While iron itself is not generally toxic to aquatic life, high concentrations can create unfavorable conditions for certain species, disturb the balance of aquatic ecosystems, and impact water clarity. Additionally, excessive iron in drinking water may cause undesirable tastes and odors and promote the growth of iron bacteria, which can clog water supply systems. Monitoring total iron levels is crucial to identify potential contamination and ensure compliance with water quality standards. By incorporating total iron as a parameter in the WQI, authorities can assess its presence in water sources, implement appropriate treatment measures to maintain acceptable levels and safeguard both the environment and public health from the adverse effects of iron contamination (Chidiac et al., 2023).

Total Chromium (Cr) is an essential parameter considered in water quality assessments and a significant component of the Water Quality Index (WQI) due to its potential toxicity and environmental impact. Chromium is a naturally occurring element that exists in several different forms, including trivalent (Cr(III)) and hexavalent (Cr(VI)) chromium. While trivalent chromium is generally less toxic and occurs naturally in the environment, hexavalent chromium is highly toxic and primarily originates from industrial processes and certain human activities. Elevated levels of total chromium in water can result from industrial discharges, mining activities, and improper disposal of waste. Hexavalent chromium, in particular, poses significant health risks to both aquatic life and humans. It is a known human carcinogen and can cause respiratory problems, skin irritation, and other adverse health effects (Sharma et al., 2022).

Nickel (Ni) is an important parameter considered in water quality assessments and a significant component of the Water Quality Index (WQI) due to its potential environmental and health impacts. Nickel occurs naturally in the Earth's crust, but human activities, such as industrial processes, mining, and urban runoff, can contribute to elevated nickel levels in water bodies. Nickel is toxic to aquatic life, and exposure to high concentrations can lead to adverse effects on fish, invertebrates, and other aquatic organisms. Additionally, nickel can bioaccumulate in aquatic food chains, further amplifying its impact on ecosystems. In terms of human health, exposure to nickel through drinking water or consumption of contaminated aquatic products can cause allergic reactions, respiratory problems, and long-term health issues (Genchi et al., 2020).

Copper (Cu) is a crucial parameter considered in water quality assessments and an essential component of the Water Quality Index (WQI) due to its significance in both natural and anthropogenic sources. Copper occurs naturally in the environment and can also enter water bodies through industrial discharges, agricultural runoff, and corrosion of copper-containing pipes and fittings. While copper is an essential micronutrient for some aquatic organisms, elevated levels can be toxic to many aquatic species, including fish and invertebrates. Copper toxicity can impair reproduction, growth, and behavior, ultimately disrupting aquatic ecosystems. Additionally, copper can adsorb to sediment particles and persist in the environment for extended periods, leading to potential long-term effects on aquatic life. In terms of human health, high levels of copper in drinking water can cause gastrointestinal problems and other health issues, particularly for individuals with certain sensitivities (Manne et al., 2022).

Zinc (Zn) is a critical parameter considered in water quality assessments and an important component of the Water Quality Index (WQI) due to its widespread occurrence and potential impact on aquatic ecosystems and human health. Zinc enters water bodies through natural sources, such as the weathering of rocks and soils, as well as human activities like industrial discharges, agricultural runoff, and urban stormwater. In small amounts, zinc is an essential micronutrient for aquatic organisms and plays a role in various biochemical processes. However, elevated zinc levels can be toxic to aquatic life, particularly to fish and invertebrates. Zinc toxicity can impair growth, reproduction, and behavior, leading to disruptions in aquatic food chains and overall ecosystem health (Li et al., 2018).

Cadmium (Cd) is a crucial parameter in water quality assessments and a significant component of the Water Quality Index (WQI) due to its high toxicity and potential for severe environmental and health impacts. Cadmium enters water bodies primarily through industrial discharges, agricultural runoff, and improper waste disposal. Even at low concentrations, cadmium can be highly toxic to aquatic life, and its bioaccumulation in aquatic food chains can magnify its harmful effects. Cadmium exposure can lead to various health issues in humans, such as kidney damage, respiratory problems, and bone disorders. Moreover, long-term exposure to cadmium is a known human carcinogen, increasing the risk of certain cancers (Kubier et al., 2019).

Lead (Pb) is a fundamental parameter in water quality assessments and holds significant importance as a key component of the Water Quality Index (WQI) due to its notable toxicity and potential health implications. This heavy metal can enter water bodies through various anthropogenic and natural sources, including industrial discharges, corrosion of plumbing systems, and atmospheric deposition. Even at low concentrations, lead poses a substantial risk to both aquatic biota and human health. In aquatic ecosystems, lead can disrupt biological processes, impede growth, and negatively impact reproductive success in aquatic organisms. For human populations, exposure to lead-contaminated water can lead to severe health consequences, particularly in vulnerable groups such as children and pregnant women. The ingestion of lead-contaminated water can result in neurodevelopmental impairments, cognitive deficits, and other chronic health disorders. The monitoring of lead levels in water is imperative to identify potential sources of contamination and ensure adherence to water quality standards. By incorporating lead as a parameter in the WQI, authorities can effectively assess water quality, develop targeted remediation strategies, and safeguard both the environment and human well-being from the deleterious effects of lead exposure (Chidiac et al., 2023).

Oil & Grease is a crucial parameter in water quality assessments and an important component of the Water Quality Index (WQI) due to its potential environmental and ecological impacts. Oil and grease in water primarily originate from various human activities, such as industrial discharges, urban runoff, and oil spills. They can also enter water bodies through natural sources, such as seepage from underground petroleum deposits. Oil and grease can form a thin film on the water surface, reducing oxygen exchange and light penetration, which can harm aquatic organisms and disrupt aquatic ecosystems. Moreover, oil and grease can serve as carriers for other toxic substances, leading to further ecological damage. Additionally, the presence of oil and grease in water bodies can negatively impact recreational activities and aesthetics, deterring visitors and tourists (Eljaiek-Urzola et al., 2019).

Nitrates (NO2- and NO3-) are essential parameters in water quality assessments and significant components of the Water Quality Index (WQI) due to their widespread occurrence and potential impact on both aquatic ecosystems and human health. Nitrates are a natural part of the nitrogen cycle, but their levels in water can be influenced by human activities, such as agricultural runoff, wastewater discharge, and excessive use of fertilizers. High nitrate concentrations in water can lead to eutrophication, a process where excessive nutrient levels stimulate the growth of algae and aquatic plants, depleting oxygen levels and causing harm to aquatic organisms (Mousavi et al., 2013).

Chemical Oxygen Demand (COD) is a vital parameter in water quality assessments and a significant component of the Water Quality Index (WQI) due to its role in quantifying the organic pollution present in water. COD represents the amount of oxygen required to chemically oxidize organic substances in water, including both biodegradable and non-biodegradable compounds. High COD levels indicate the presence of pollutants from various sources such as industrial discharges, sewage, and agricultural runoff. When water with elevated COD is discharged into aquatic systems, it can lead to a decrease in dissolved oxygen levels, causing harm to aquatic life and potentially creating dead zones (Li et al., 2018).

Biological Oxygen Demand (BOD5) measures the amount of oxygen consumed by microorganisms as they decompose organic matter in the water. Elevated BOD5 levels suggest the presence of pollutants, such as sewage or industrial wastewater, which can deplete oxygen levels and negatively impact aquatic organisms (Latif and Dickert, 2015).

pH, an indicator of the acidity or alkalinity of water, plays a significant role in water quality. It affects the solubility and availability of nutrients and metals, as well as the survival of aquatic organisms. A pH value of 7 is considered neutral, while values below 7 indicate acidity and values above 7 indicate alkalinity (Boyd et al., 2011).

Turbidity refers to the cloudiness or clarity of water caused by suspended particles. High turbidity can reduce the penetration of light into the water, impacting photosynthesis and the health of aquatic plants. Furthermore, it can interfere with the respiration and feeding of aquatic organisms (Davies-Colley and Smith, 2001).

Total Suspended Solids (TSS) is a measure of the concentration of suspended particles, including organic matter, sediment, and pollutants, in water. Elevated TSS levels can reduce water clarity, clog fish gills, and have detrimental effects on aquatic ecosystems (Bilotta and Brazier, 2008).

Nitrate and phosphate are nutrients essential for plant growth. However, excessive levels of these nutrients, often resulting from agricultural runoff or wastewater discharges, can lead to a phenomenon called eutrophication.

Eutrophication occurs when an excess of nutrients stimulates the growth of algae and aquatic plants, subsequently depleting oxygen levels and negatively impacting aquatic life (Khan and Mohammad, 2014).

Total Coliform and Fecal Coliform are indicators of bacterial contamination and the presence of fecal matter in water. Elevated levels of coliform bacteria may suggest the potential presence of harmful pathogens, posing risks to human health if the water is used for drinking or recreational purposes (Niyoyitungiye et al., 2020).

These parameters, along with other specific variables relevant to the region or water body being assessed, are typically measured and integrated using a standardized formula to calculate the Water Quality Index. The resulting index value offers an overall assessment of water quality and aids in making informed decisions regarding water resource management and protection. By considering multiple parameters, the Water Quality Index provides a comprehensive and reliable measure of the health and suitability of surface water for various purposes, ensuring the preservation of ecosystems and the well-being of human populations.

2.3.2. Water Quality Index Types

Water Quality Index (WQI) types refer to the various approaches and methodologies used to calculate and interpret water quality index values. Different WQI types have been developed to suit specific regional or local conditions, regulatory frameworks, and intended applications. Here are a few commonly used types of water quality indices:

Canadian Council of Ministers of the Environment (CCME) Water Quality Index: The CCME WQI is a widely adopted index in Canada. It incorporates nine parameters, including dissolved oxygen, pH, total suspended solids, total coliforms, and others. It assigns weights to each parameter and calculates an overall index value, ranging from 0 to 100, which is classified into five water quality categories (Munna et al., 2013).

National Sanitation Foundation Water Quality Index (NSF WQI): The NSF WQI is an index developed in the United States. It considers ten parameters, including total coliform, turbidity, pH, and others. The index provides a single value ranging from 0 to 100, and it offers interpretive categories to determine the water quality status (Said et al., 2004).

Oregon Water Quality Index: The Oregon Water Quality Index is specifically tailored for water bodies in the state of Oregon, USA. It incorporates ten parameters, such as pH, temperature, dissolved oxygen, and various nutrient concentrations. The index provides a single value between 0 and 100, and it includes classifications indicating water quality conditions (Cude, 2001).

Australian Water Quality Index (AWQI): The AWQI is designed for water bodies in Australia. It considers nine parameters, including pH, electrical conductivity, turbidity, and nutrient concentrations. The index calculates a single value on a scale of 0 to 100, with interpretive classes indicating water quality conditions (Jahan and Strezov, 2017).

Indian National Water Quality Index (NWQI): The NWQI is a composite index developed for water quality assessment in India. It incorporates 28 water quality parameters, including physical, chemical, and bacteriological parameters. The index calculates a single value ranging from 0 to 100 and provides classifications to assess water quality status (Cude, 2001).

British Columbia Water Quality Index (BCWQI) is a comprehensive water quality assessment tool, it is designed to provide a standardized and scientifically sound approach to evaluating the overall health of water bodies in British Columbia. The BCWQI takes into account multiple water quality parameters, such as physical, chemical, and biological indicators, to assess the condition of water resources. Some of the key parameters considered in the index include temperature, dissolved oxygen, pH, turbidity, nutrient concentrations (nitrogen and phosphorus), total suspended solids, and various metals and organic substances. Additionally, the presence of certain indicator bacteria, such as E. coli, is considered for freshwater quality assessment (Ewaid et al., 2020).

The index uses a scale from 0 to 100, with higher values indicating better water quality. The index values are then categorized into different classes to describe the overall condition of the water (Asadollahfardi, 2015):

Excellent (90-100): Water quality is excellent, and the water is suitable for all uses.

Good (80-89): Water quality is good, and the water is suitable for most uses.

Fair (70-79): Water quality is fair, and the water may be suitable for some uses with additional treatment or precautions.

Marginal (50-69): Water quality is marginal, and the water may not be suitable for certain uses or requires significant treatment.

Poor (0-49): Water quality is poor, and the water is not suitable for most uses.

The BCWQI is a valuable tool for environmental managers, policymakers, and researchers to monitor and assess the health of water bodies across British Columbia. By tracking changes in water quality over time, authorities can identify potential pollution sources, implement targeted remediation measures, and protect the health of aquatic ecosystems and the well-being of the communities that rely on these water resources (Ewaid et al., 2020).

These are just a few examples of water quality index types that are commonly used. It's important to note that specific regions or organizations may develop their own custom water quality indices to address local conditions, specific regulations, or unique water quality concerns. The choice of water quality index type depends on the context and objectives of the assessment, and it should align with the parameters and criteria considered important for evaluating water quality in a given region or jurisdiction.

2.3.3. Water Quality Regulations

Water quality regulations are a crucial aspect of environmental protection and public health management. These regulations are established by governmental and environmental agencies at various levels to set standards and guidelines for the quality of water resources. The primary objective of water quality regulations is to ensure that water bodies, such as rivers, lakes, streams, and groundwater, meet specific quality criteria for various uses, including drinking water, recreation, agriculture, and supporting aquatic ecosystems. In this comprehensive discussion, we will delve into the significance of water quality regulations, their development, implementation, and their role in safeguarding our most precious resource - water.

The need for water quality regulations arose due to the detrimental impacts of industrialization, urbanization, and agricultural practices on water bodies. During the

19th and early 20th centuries, rapid industrial growth and urban expansion led to severe pollution of waterways, often resulting in waterborne diseases and ecological degradation. In response to these challenges, the first water quality regulations were introduced to control industrial discharges and protect public health (Hayes, 2022).

All countries and regions developed their water quality regulations, often building upon international agreements and conventions, water quality regulations encompass several essential components that collectively ensure the protection and sustainable management of water resources (Rieu-Clarke, 2020). These components include:

a) Water Quality Standards: Water quality standards define the acceptable levels of various physical, chemical, and biological parameters in water bodies. These standards are based on scientific research and risk assessments, and they vary depending on the intended use of the water. For example, drinking water standards are more stringent than recreational water quality standards (CFR, 1983).

b) Monitoring and Assessment: Water quality regulations require regular monitoring and assessment of water bodies to evaluate compliance with established standards. Monitoring programs collect data on key parameters and assess the overall health of water bodies. This information is crucial for identifying pollution sources, implementing remedial actions, and making informed decisions for water resource management (CFR, 1983).

c) Point and Non-Point Source Pollution Control: Water quality regulations address both point-source and non-point source pollution. Point-source pollution originates from specific discharge points, such as industrial outfalls or wastewater treatment plants. Non-point source pollution, on the other hand, is diffuse and comes from various sources, such as agricultural runoff or stormwater. Regulations aim to control and reduce both types of pollution through best management practices and pollution prevention measures (POLLUTION, 2024).

d) Waste Discharge Permits: Industries, municipalities, and other entities that discharge pollutants into water bodies typically require permits. Waste discharge permits specify the allowable levels of pollutants and set conditions for monitoring and reporting. These permits are an essential tool for regulating discharges and ensuring compliance with water quality standards (CFR, 1979).

e) Source Water Protection: Water quality regulations often include provisions for protecting the sources of drinking water. Source water protection measures aim to prevent pollution and contamination of water bodies before they enter drinking water treatment systems (Fawkes and Sansom, 2021).

f) Public Awareness and Education: Water quality regulations often involve public awareness and education programs to inform the public about the importance of water quality, conservation, and responsible water use. Empowering communities with knowledge fosters public participation in water resource protection efforts (Fawkes and Sansom, 2021).

Water quality regulations often transcend national boundaries, especially for transboundary water bodies. Several international agreements and conventions address water quality and transboundary water management. One prominent example is the United Nations' 2030 Agenda for Sustainable Development, which includes Sustainable Development Goal 6 (SDG 6) - Clean Water and Sanitation. SDG 6 aims to ensure the availability and sustainable management of water and sanitation for all, focusing on water quality improvement and equitable access to safe drinking water (CDC, n.d).

The United Nations Economic Commission for Europe (UNECE) Water Convention is another critical international instrument that promotes transboundary cooperation on water quality and quantity issues. The convention encourages countries to prevent, control, and reduce transboundary water pollution and foster sustainable water management.

While water quality regulations have made significant strides in improving the condition of water bodies, several challenges persist. Some of the key challenges include (Kumar et al., 2022):

a) Emerging Contaminants: The presence of emerging contaminants, such as pharmaceuticals, microplastics, and endocrine-disrupting substances, poses new challenges to water quality regulation. Addressing these contaminants requires ongoing research and continuous updates to regulatory frameworks (Kumar et al., 2022).

b) Non-Point Source Pollution: Non-point source pollution remains challenging to control due to its diffuse nature. Effective implementation of agricultural best management practices and stormwater management measures are essential for mitigating non-point source pollution.

c) Climate Change: Climate change impacts, including rising temperatures, altered precipitation patterns, and extreme weather events, can exacerbate water quality issues. Water quality regulations need to be adaptive and resilient to address these changing conditions.

d) Integrated Approaches: Integrated water resource management approaches that consider the interconnectedness of water bodies, groundwater, and ecosystems are vital for comprehensive water quality regulation.

Water quality regulations play a vital role in protecting our most precious resource - water. They set standards and guidelines for water quality, facilitate pollution control, and support sustainable water management practices. By monitoring water bodies, regulating discharges, and fostering public awareness, water quality regulations ensure that our water resources remain safe, clean, and available for various uses. International agreements and conventions further enhance cooperation on transboundary water issues, emphasizing the global importance of water quality protection. As we face new challenges, such as emerging contaminants and climate change, continuous innovation, and adaptive approaches will be essential to safeguarding water quality for current and future generations (Sanderson and Solomon, 2009).

3. MATERIALS AND METHODS

This is a critical part of a thesis as it explains the research design and methods used in the study. The chapter provides a detailed explanation of how the research was conducted, including the research approach, research strategy, and research method. It also describes the size of the study and the sampling technique used to select the sample. In addition, the chapter discusses the data collection methods and tools used in the study, such as physicochemical analysis, water quality index (WQI), GIS software, and Python Script. The ethical considerations of the study, such as informed consent, confidentiality, and privacy, are also addressed in this chapter. Furthermore, the chapter presents the data analysis methods used in the study, such as statistical analysis and spatial analysis.

3.1. Study Area

The study will cover eight main points along the Great Zab River, including upstream and downstream of the river, and six contaminating sources.

The study site for this research is located in Erbil, which is a large and ancient city located in northern Iraq. The study area is located between the latitudes of 36.16◦ and 36.21◦ and longitudes of 43.40◦ and 43.46◦, as shown in Figure 1. The site of study section provides a detailed description of the location where the study was conducted, including information on geography, climate, social infrastructure, vegetation, and other relevant factors.

The topography of the study area is characterized by a mix of flat and hilly terrain, with the city surrounded by mountains.

The climate is hot and dry in the summer, with temperatures reaching up to 50°C, and cold and rainy in the winter, with temperatures dropping to below freezing:

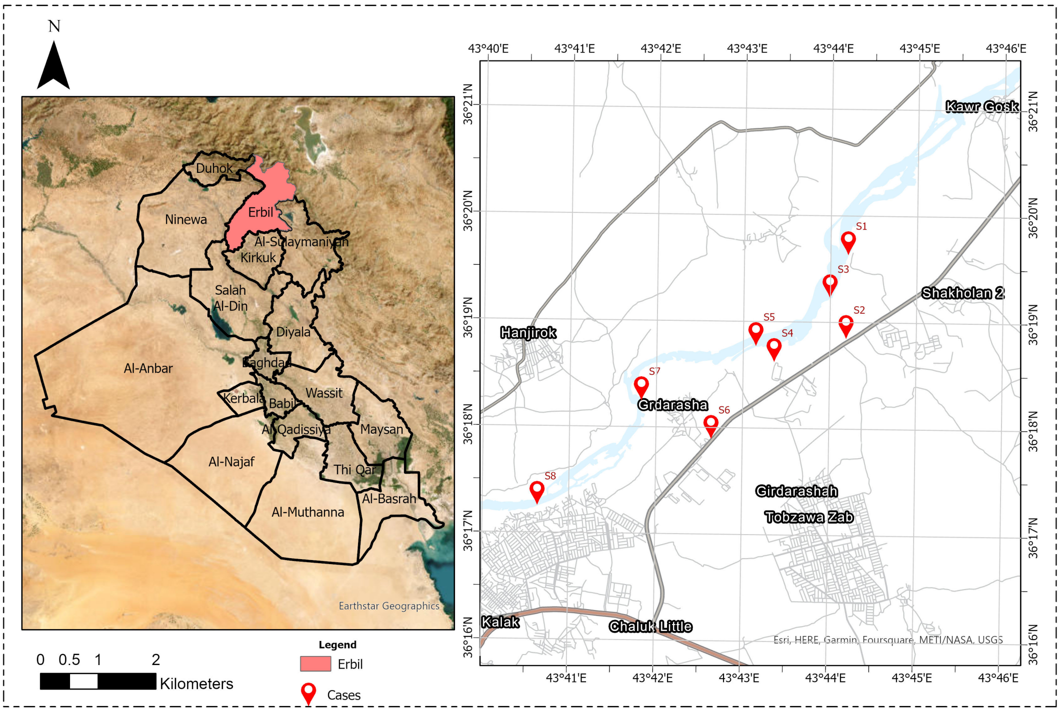

Figure 3.1. Study Area and Sampling Points

As figured in the Site location there are some important points that are important for the study and were used to take samples at those points that are shown below in Table 3.1.

Table 3.1. Site Basic Sampling Locations

Sample location	*Name*	*Latitude*	*Longitude*
Upstream Great Zab River	S1	36.327206” N	43.736709” E
Erbil refinery discharge	S2	36.314103” N	43.73646” E
Erbil Refinery mixing point	S3	36.3204167° N	43.7332806° E
Cola North Iraq plant discharge	S4	36.183729” N	43.432150” E
Cola North Iraq plant discharge mixing point	S5	36.3128194° N	43.719089° E
Thermal power plant discharge	S6	36.298209” N	43.710651” E
Thermal power plant discharge mixing point	S7	36.304114° N	43.697128° E
Downstream Great Zab River	S8	36.287541” N	43.677271” E

In this study, there are eight main points that are crucial to the research. One point is located upstream of the Great Zab River, and the other point is located downstream of the river. The purpose of these two points is to determine the water quality of the river before and after contamination. The other six points are located at each contaminating source and their mixing point with the river. The objective of these six points is to check the effectiveness of each source in contaminating the river. The sampling and analyzing were done through the four seasons of the year 2023, every season sampling was done in one day, the Spring sampling was taken on March 27th, the Summer sampling on July 18th, the Fall sampling on October 10th, and the winter Sampling on December 5th.

It is important to note that the sampling technique used in this study should follow general principles and guidelines to ensure that the samples collected are representative of the water body and that the analytical results are accurate. The Site of Study section of the research should provide a detailed description of the location where the study was conducted, including information on geography, climate, social infrastructure, vegetation, and other relevant factors. In this study, the three contaminating sources are considered point sources of pollution. The geostatistical method has been applied to identify contaminant sources in river pollution problems.

In summary, the eight main points in this study are located in Northern Iraq, specifically in Erbil, and along the Great Zab River. The sampling technique used should follow general principles and guidelines to ensure that the samples collected are representative of the water body and that the analytical results are accurate. The Site of Study section of the research paper should provide a detailed description of the location where the study was conducted, including information on geography, climate, social infrastructure, vegetation, and other relevant factors. The three contaminating sources in this study are considered point sources of pollution, and the geostatistical method has been applied to identify contaminant sources in river pollution problems.

3.2. Water Sampling and Laboratory Analyzing Method

The sampling technique used in this study will follow general principles and guidelines to ensure that the samples collected are representative of the water body and that the analytical results are accurate. Proper labeling, observation, collection, storage, transportation, and analysis of the samples will be essential to ensure the accuracy and reliability of the results.

When taking samples of water from a river to the laboratory(all the samples were analyzed in Kar Erbil Wastewater laboratory in Erbil), it is important to follow proper procedures to ensure that the samples are representative of the water body and that the analytical results are accurate and it's necessary to consider:

Label the samples: Filling out the sample labels with the name, the date, time, and the site location

Observe: Once arriving at the site, walk around and find the best way to access the water. If possible, and have waders, it may want to go into the stream and collect a sample from a safe location in the water.

Collect the sample: Use clean sampling equipment and containers to collect the water sample

Collecting the sample at the same location for both bacteriological and chemical analyses

Store and transport the samples: The samples should be properly labeled, stored, and transported to the laboratory for analysis.

The storage and transportation conditions should be appropriate for the water quality parameters of interest

In summary, when taking samples of water from a river and discharges to the laboratory, it is important to follow proper procedures to ensure that the samples are representative of the water body and that the analytical results are accurate. Proper labeling, observation, collection, storage, transportation, and analysis of the samples are essential to ensure the accuracy and reliability of the results.

During the study samples were transferred to the lab and many tests were done on the samples using different instruments and devices, some of these devices were multifunctional and used for getting more than one parameter, these instruments included:

The WTW™ inoLab™ 7110 Conductivity Meter The inoLab® Cond 7110 seems to be an instrument designed to handle conductivity measurements in the laboratory with the highest accuracy and reliability(Figure 3.2). The screen size and the broad array of functions represented in the product suggest it is designed for everyday use and accurate measurements. The capability to measure factors like salinity, specific resistance and total dissolved solids (TDS) covers a wide range of values, which makes it suitable for the application of a variety of purposes. Moreover, the ability to connect individual special measuring cells in a way that makes it possible to measure from pure water to highly concentrated solutions range is also possible. However, the main impression is that this device is designed for convenient and effective work with measurements of the conductivity in laboratory (Said et al., 2004).

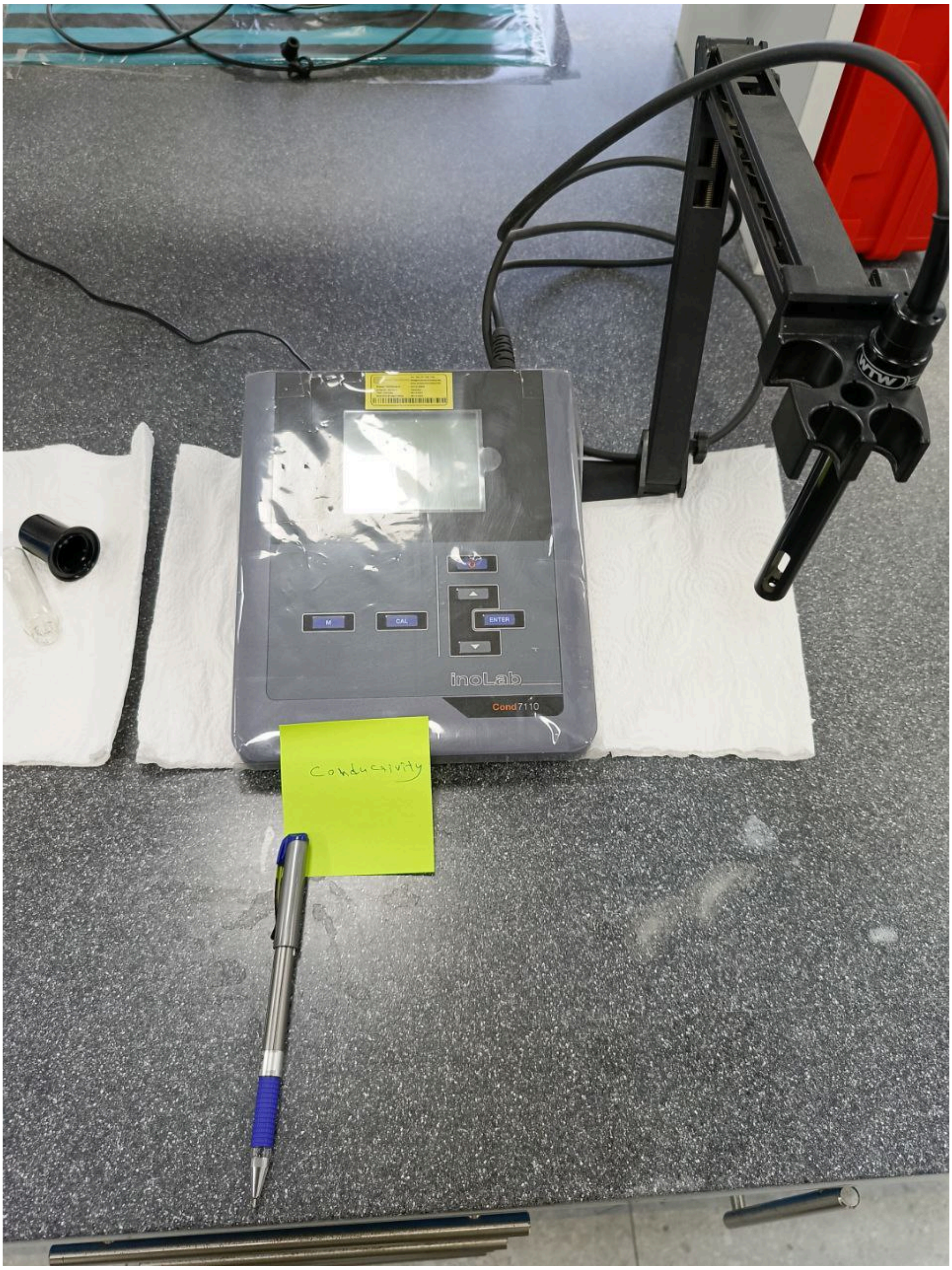

Figure 3.2. WTW™ inoLab™ 7110 Conductivity Meter

The Hach HQ411D Laboratory pH-Meter is an advanced digital meter designed for water quality experts (Figure 3.3). It is a reliable and easy-to-use device that takes the guesswork out of pH measurements. Overall, the Hach HQ411D Laboratory pH-Meter is a reliable and easy-to-use device for routine pH measurements in the lab. The procedure for using the device involves calibrating the meter with buffer solutions and then measuring the pH of the sample to be tested.

The device is also suitable for measuring mV/RedOx/ORP in addition to pH. (Sørensen et al., 2020).

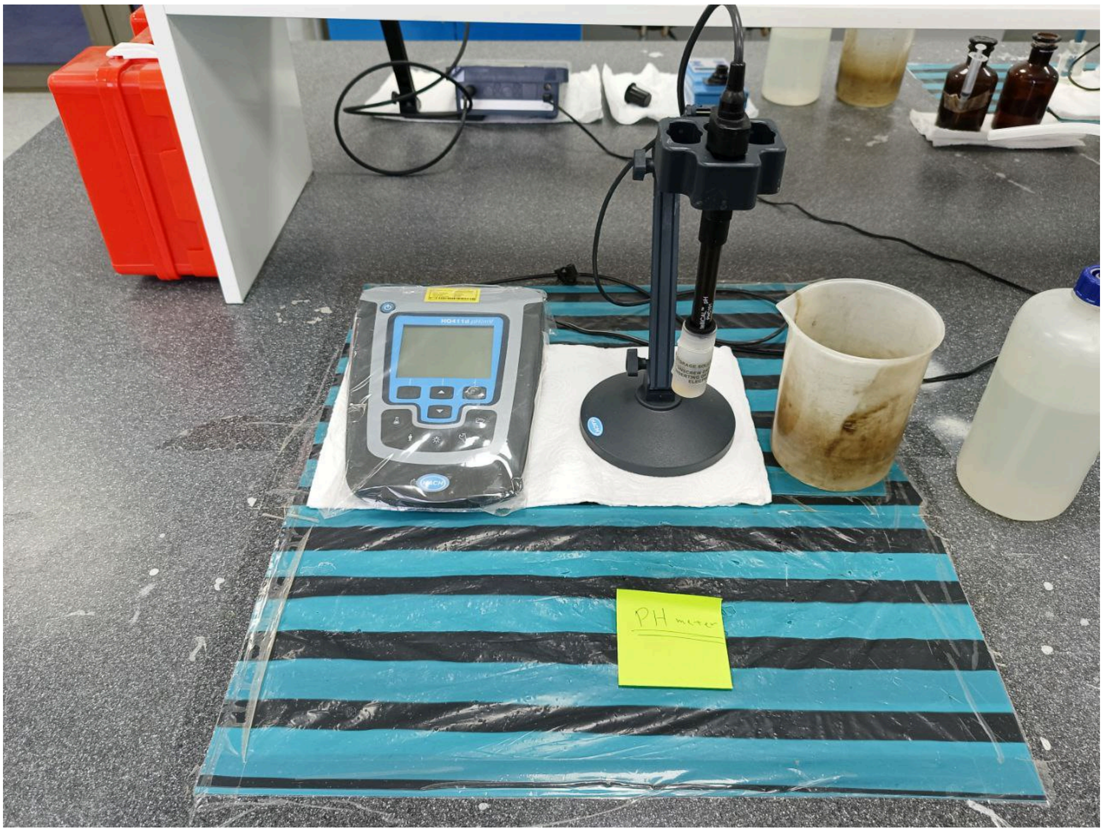

Figure 3.3. Hach HQ411D Laboratory pH-Meter

The Hach DR3900 Laboratory VIS Spectrophotometer is a benchtop visible spectrum (320-1100 nm) split beam spectrophotometer designed for laboratory water analysis. Here are some parameters that it can measure:

Ammonium

Chemical Oxygen Demand (COD)

Phosphate

Nitrate

And many others

The DR3900 is optimized for safe processes and accurate results daily (Figure 3.4). It simplifies water analysis by providing step-by-step guides, and it is optimized for consistent, quick, and accurate water analysis results (Liu et al., 2019).

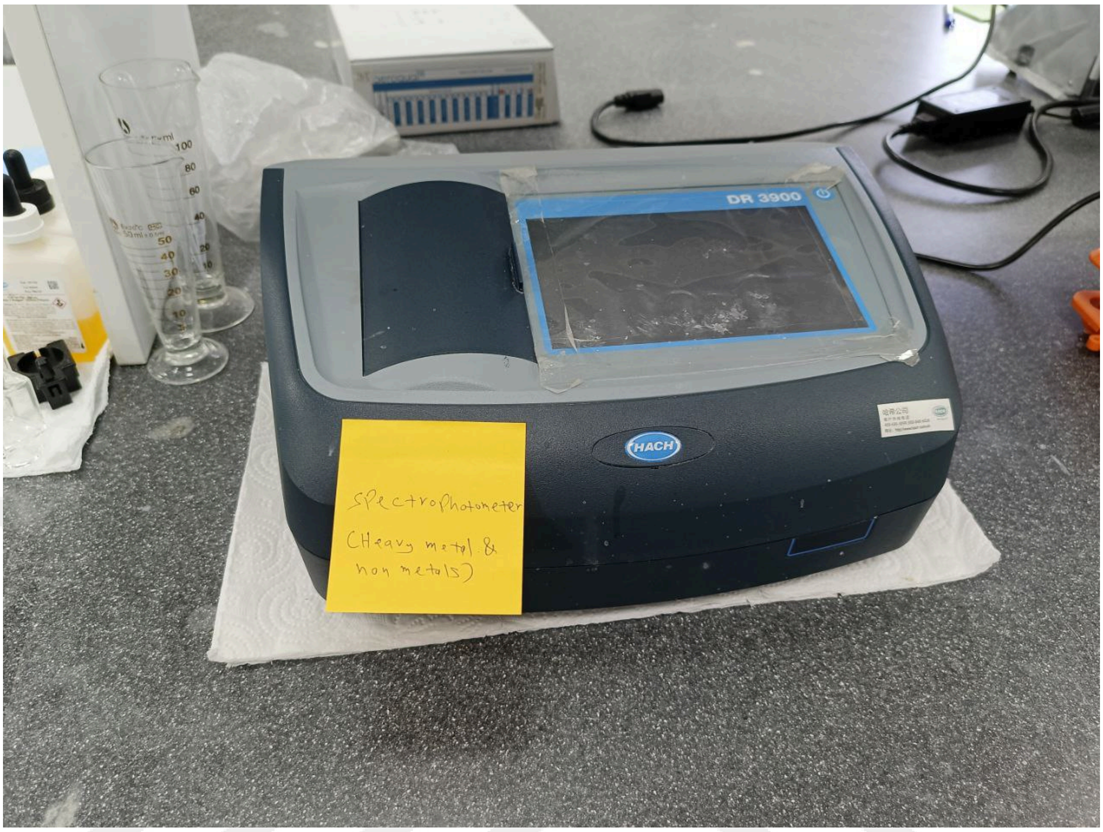

Figure 3.4. Hach DR3900 Laboratory VIS Spectrophotometer

The BODTrak II machine is a respirometric Biochemical Oxygen Demand (BOD5) apparatus designed for measuring the amount of oxygen consumed by microorganisms while decomposing organic matter in a sample (Figure 3.5). Here are some parameters that it can measure:

-Biochemical Oxygen Demand (BOD5)

-Total test time

-Oxygen consumption by microorganisms

The BODTrak II machine is easy to set up and allows for quick sample preparation for BOD5 analysis

It simplifies BOD5 analysis by providing results comparable to the dilution method in only two to three days (Majed and Islam, 2022).

Figure 3.5. BODTrak II Machine

A rotary vacuum pump is a type of positive displacement pump that moves fluids and gases with vanes mounted to a rotor(Figure 3.6). It is commonly used in various industries, including the food and beverage industry, automobile manufacturing, and laboratory testing. In river water tests, a rotary vacuum pump is important for creating a vacuum in the testing equipment, especially for the TSS test (Spano et al., 2023).

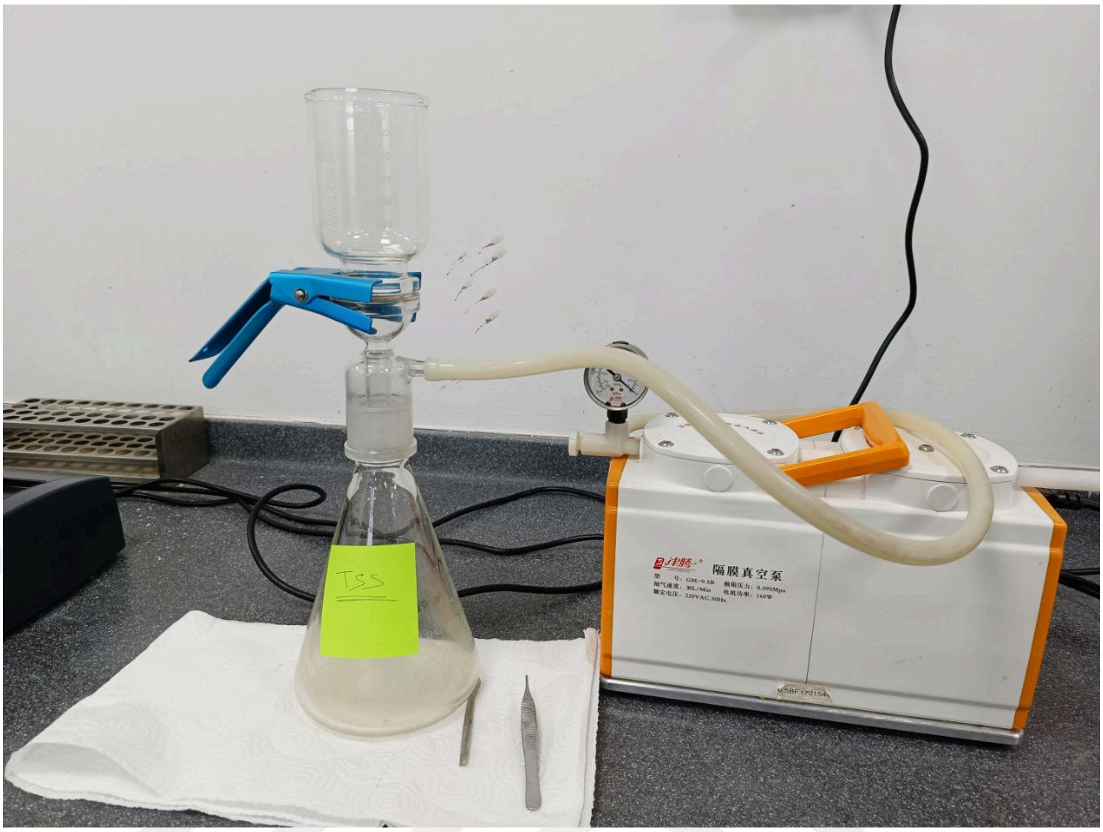

Figure 3.6. TSS Test

The Hach DRB200 Dry Thermostat Reactor is a versatile and easy-to-use device used for digestion for metals analysis, digestion for nutrients analysis, or culture biological samples (Figure 3.7). It features independent heating blocks that enable cuvettes and reaction vessels to be digested at identical or different temperatures and times. The DRB200 thermostat ideally complements the Hach reagents (COD, TOC), Overall, the Hach DRB200 Dry Thermostat Reactor is an important tool for water quality tests. The DRB200 is used for digestions for metals analysis, digestions for nutrients analysis, or culture biological samples (Majed and Islam, 2022).

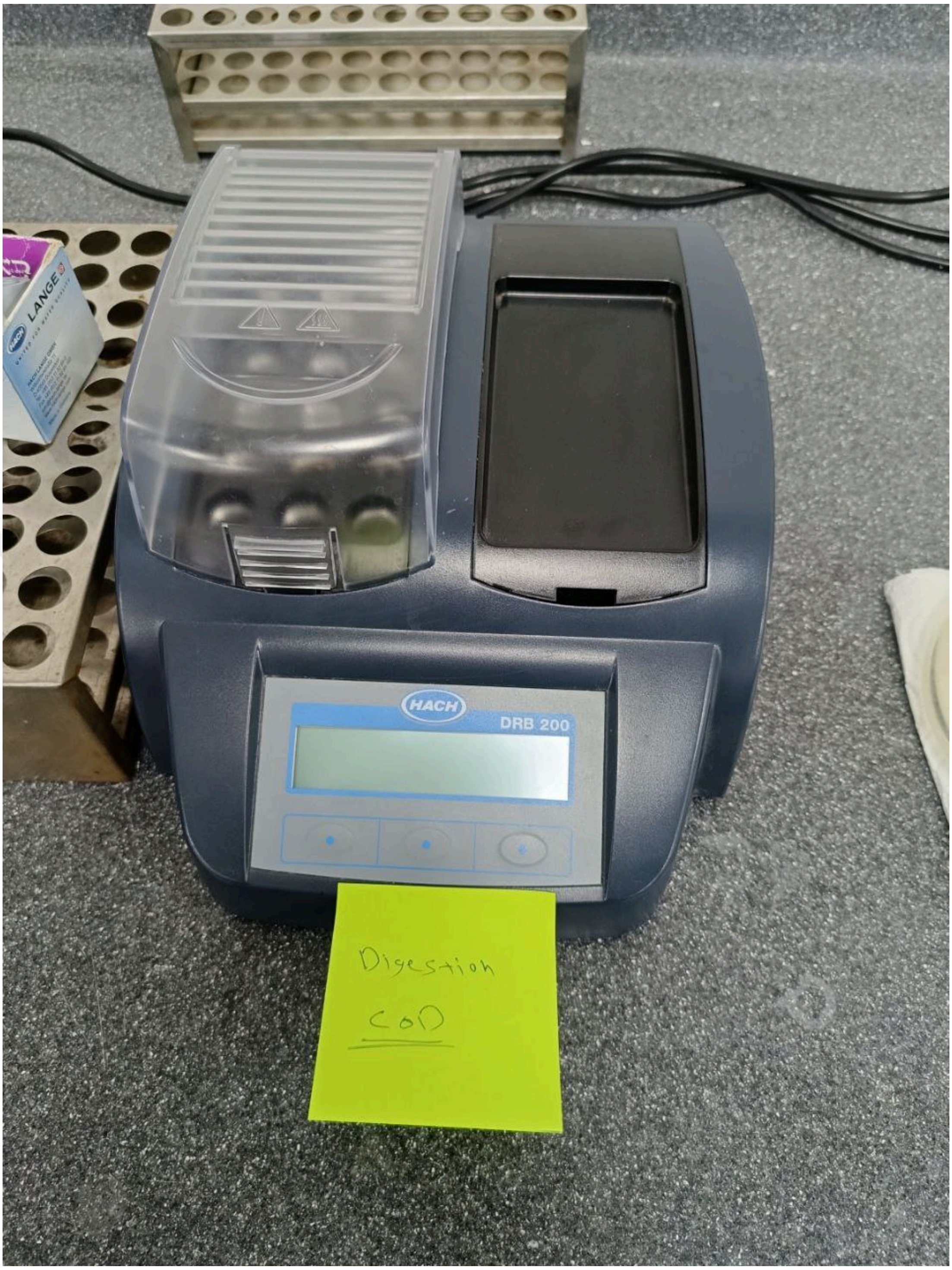

Figure 3.7. Hach DRB200 Dry Thermostat Reactor

The Hach HT200S High-Temperature Thermostat is an important tool for testing water quality (Figure 3.8). Here are some reasons why:

-The HT200S can be used for a range of Hach Lange LCK cuvette tests to increase the speed of digestion

-The high-speed digestion (HSD) technology of the HT200S meets the need for fast, effective digestion in municipal, industrial, and service laboratories

-The special construction of the high-temperature thermostat allows fast heating and cooling times for up to twelve cuvettes or reaction vessels

-The HT200S is a block heater that can be used with Hach reagents (COD, TOC, Test 'N' tube) to complement the DRB200 reactor for digestions for metals analysis, digestions for nutrients analysis, or culture biological -samples (Arkoh et al., 2021).

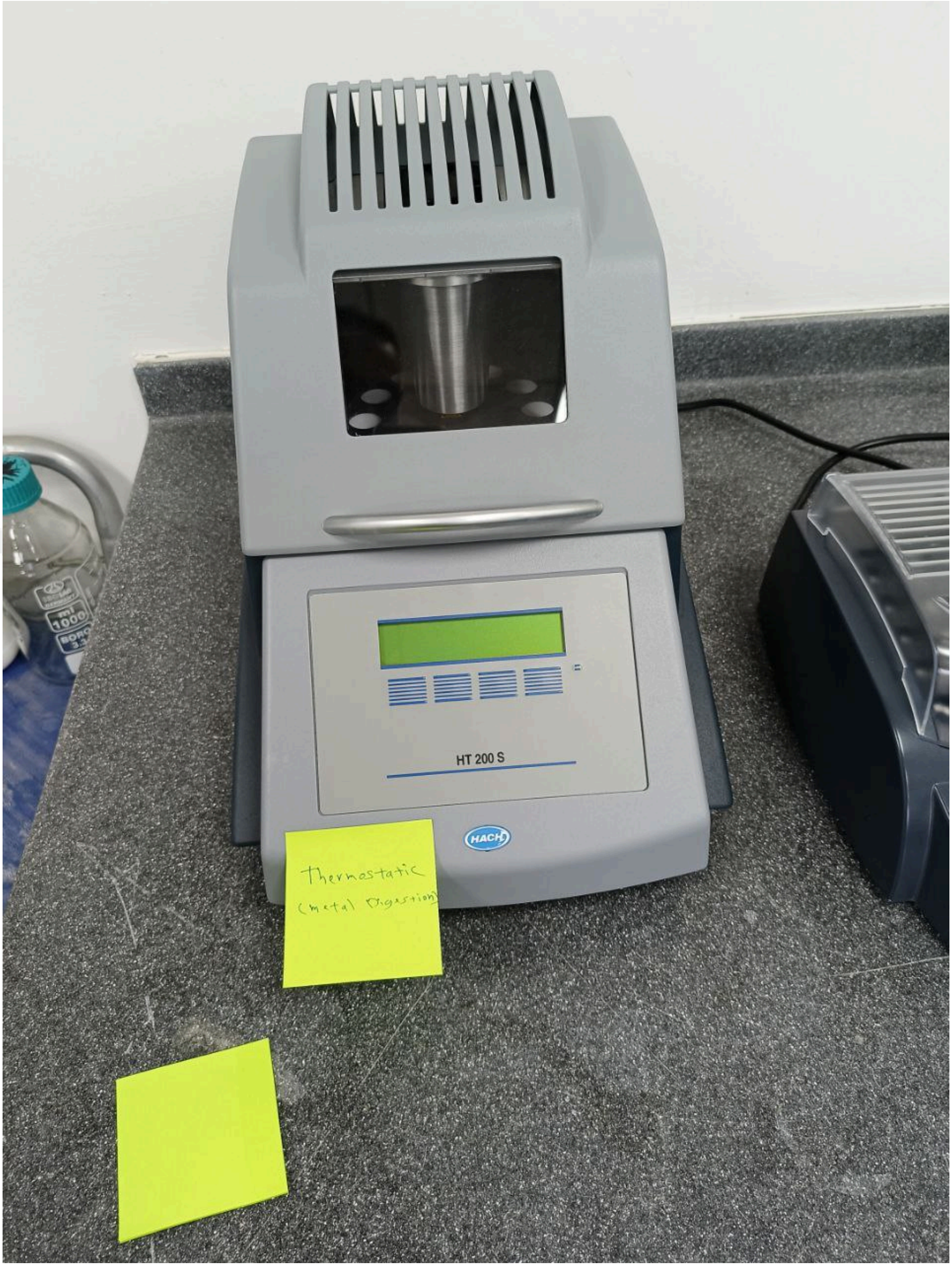

Figure 3.8. The Hach HT200S High-Temperature Thermostat

The Hach HQ30D Flexi device is a portable meter designed for water quality applications to measure dissolved oxygen (DO). The HQ30D Flexi device is a rugged portable meter that can be used in the field and plant (Figure 3.9). The device is designed to measure DO using the LDO101 optical dissolved oxygen probe or the field luminescent DO sensor with a 5 m cable. The device has a one-channel advanced handheld meter that can be used to measure DO, pH, conductivity, and temperature. The device has a large, easy-to-read color display that shows measurement results and calibration status (Wei et al., 2019).

In summary, the Hach HQ30D Flexi device is a portable meter designed for water quality applications to measure dissolved oxygen. It is a versatile and user-friendly device that can be used in the field and plant to provide accurate and reliable measurements of DO, pH, conductivity, and temperature. The device is durable, has a long battery life, and is ideal for environmental monitoring applications.

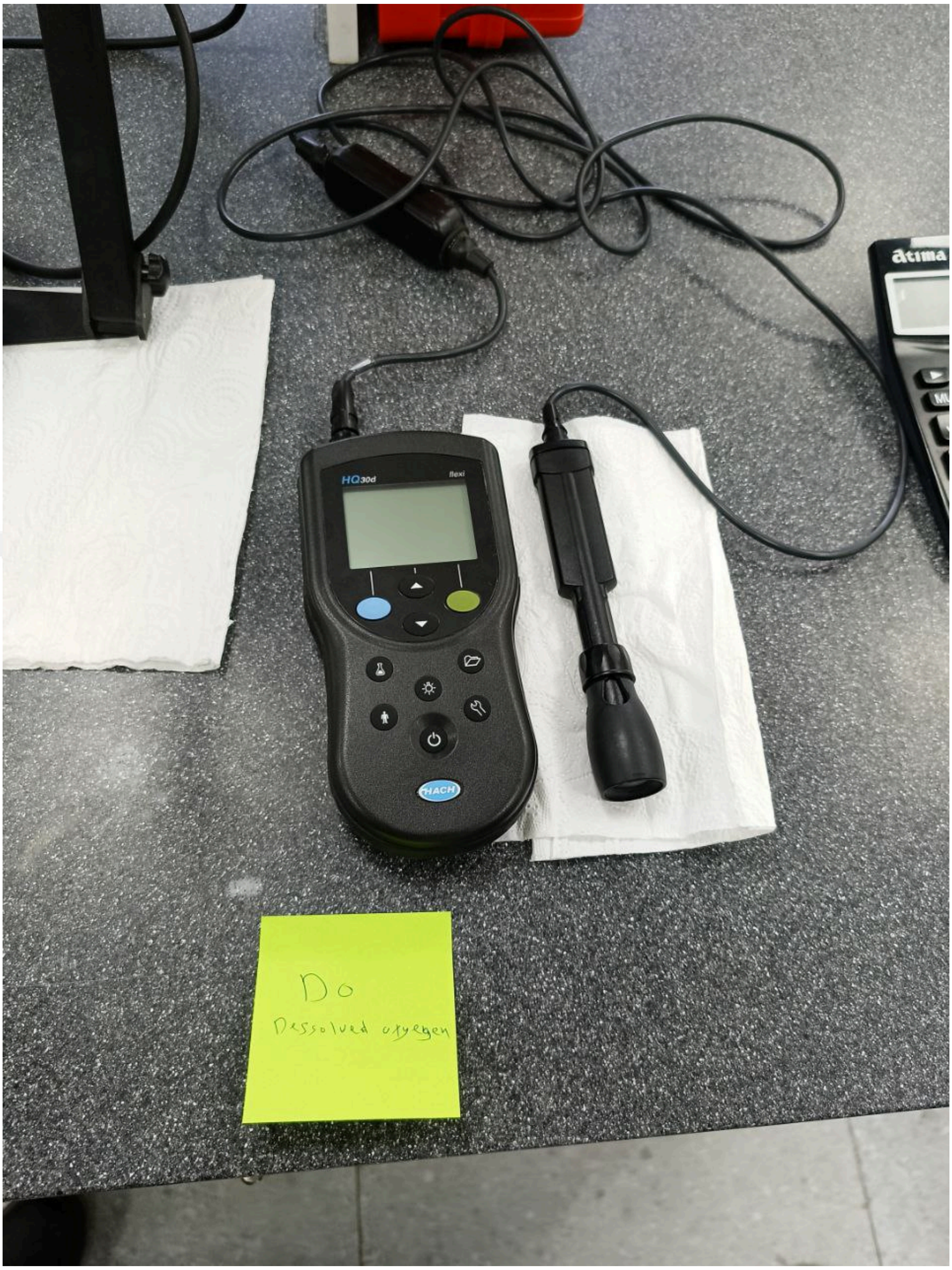

Figure 3.9. Hach HQ30D Flexi

3.3. Water Analyzing Method

In this section, the comprehensive approach employed to analyze water samples in the context of the thesis will be detailed. Water analysis is a critical component of understanding water quality, assessing environmental impacts, and ensuring the safety of water for various applications. The methodology outlined here is crucial for providing accurate, reliable, and reproducible results that underpin the findings and conclusions of the study.

The water analysis methodology comprises several key steps, each of which will be described in detail:

Data collection method: The data collection methods and tools used in this study will include physicochemical analysis, water quality index (WQI), and GIS software. These methods will be used to assess the effects of pollutants, particularly physical, chemical, and biological parameters that affect the water quality of the river.

Sample Preservation: Sample preservation is a critical step in water analysis to maintain the integrity of collected water samples. It involves the immediate application of techniques or chemicals to prevent alterations in the sample's chemical composition or microbial content. Preservation methods may include acidification to maintain pH levels, refrigeration to slow biological activity, or the addition of specific chemicals to inhibit microbial growth. Proper sample preservation is essential for ensuring the accuracy and reliability of subsequent analyses, preserving the quality of data throughout the study(Said et al., 2004).

Physical Parameters: Physical parameters in water analysis encompass measurable attributes that provide insights into the physical characteristics of a water sample. Key parameters include temperature, turbidity, and electrical conductivity. Temperature affects various chemical and biological processes, influences the water's acidity or alkalinity, turbidity measures clarity, and conductivity indicates the water's ability to conduct electrical current. Monitoring these parameters is fundamental for assessing water quality, environmental conditions, and suitability for diverse applications(Trujillo-González et al., 2017).

Chemical Analysis: Chemical analysis in water assessment involves the investigation of a water sample's chemical constituents. This encompasses the determination of pH, elements, ions, heavy metals, organic compounds, and nutrients present in the water. Various methods such as spectrophotometry, chromatography, and titration are used to quantify these substances. Accurate chemical analysis is crucial for identifying pollutants, evaluating water quality, and ensuring compliance with safety standards. It plays a pivotal role in understanding water's composition and its suitability for specific uses(Li et al., 2018).

Data Interpretation: Data interpretation in water analysis is the process of making sense of the collected information, drawing conclusions, and extracting meaningful insights from the data. This step involves applying statistical and analytical methods to identify trends, correlations, and patterns. It helps researchers understand the implications of water quality measurements and their significance in relation to the study's objectives. Proper data interpretation is essential for making informed decisions, identifying trends or anomalies, and ultimately informing policy or action related to water quality and safety(de Lima et al., 2022).

Statistical Analysis: Statistical analysis is a crucial component of water research, involving the application of mathematical and statistical methods to interpret water quality data. It aids in uncovering trends, relationships, and patterns within the dataset. Tools like SPSS can handle regression analysis, hypothesis testing, and correlation to help researchers draw meaningful conclusions, identify significance, and assess the reliability of results. Statistical analysis plays a fundamental role in guiding informed decisions, policy formulation, and understanding the impact of various factors on water quality parameters.

3.4. Water Quality Index (WQI)

The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) is a comprehensive tool designed for the convenient summarization and communication of complex water quality data to both environmental managers and the general public. Developed for the Water Quality Index Technical Subcommittee of the CCME Water Quality Guidelines Task Group, this index offers a numerical representation of water quality, ranging from 0 (indicating the worst water quality) to 100 (reflecting the best water quality). The index is divided into five descriptive categories Excellent, Good, Fair, Marginal, and Poor, each associated with specific index value ranges. (Lumb et al., 2006) as shown in the table 3.2.

Table 3.2. CCME WQI Categories

CCME WQI	Rating
0-44	Poor
45-64	Marginal

65-79	Fair
80-94	Good
95-100	Excellent

The development of CCME WQI involved a formula originally created by the British Columbia Ministry of Environment, Lands and Parks, with subsequent modifications by Alberta Environment. The index incorporates three key elements: scope, frequency, and amplitude. Scope represents the number of variables not meeting water quality objectives (Eq. 3.1), frequency denotes how often these objectives are not met (Eq. 3.2), and amplitude measures the extent by which the objectives are not achieved (Eq.3.6), but before this we have to calculate the excursion that as shown in (Eq. 3.3), (Eq. 3.4), and the collective amount by which individual tests in nse as shown in (Eq.3.5).

To calculate the CCME WQI (Eq. 3.7), a minimum of four variables sampled at least four times is recommended, allowing flexibility for local conditions. The index can be applied to track changes at a specific site over time or to compare different sites, provided that the same variables and objectives are employed for valid comparisons.

One notable feature is the flexibility of the CCME WQI, accommodating various water quality variables, testing periods, and types of water bodies. The categorization process, determining whether water quality falls into the Excellent, Good, Fair, Marginal, or Poor range, involves a subjective assessment based on expert judgment and public expectations.

A few calculations are necessary for calculating CCME WQI as shown below:

Firstly, F1(scope) is the percentage of variables that do not meet their objective at least one time during the period and should be determined as below:

$$F1 = \left(\frac{\text{Number of failed variables}}{\text{total number of variables}}\right) \times 100 \tag{3.1}$$

then, F2 (frequency) is the percentage of each test that doesn't meet objectives and should be determined as below:

$$F2 = \left(\frac{\text{Number of failed tests}}{\text{total number of tests}}\right) \times 100 \tag{3.2}$$

For calculating F3 should excursion$_i$ be founded as following:

$$\text{excursion}_i = \left(\frac{\text{Failed Test Value}_i}{\text{Objective}_i}\right) - 1 \tag{3.3}$$

this if the failed test value was greater than the objective, but in case the objective was greater than the failed test value the equation changes to this:

$$\text{excursion}_i = \left(\frac{\text{Objective}_i}{\text{Failed Test Value}_i}\right) - 1 \tag{3.4}$$

then nse (Normalized sum of excursion):

$$\text{nse} = \left(\frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{number of tests}}\right) \tag{3.5}$$

then F3(amplitude) is the amount of every failed test value that does not meet their objective that can be calculated after finding (nse) and excursion as shown below:

$$\text{F3} = \left(\frac{\text{nse}}{0.01\text{nse} + 0.01}\right) \tag{3.6}$$

After these steps, CCME WQI can be calculated as below:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right) \tag{3.7}$$

3.5. Water Quality Index Map

In this thesis, the Water Quality Index (WQI) map serves as a critical visual representation, encapsulating the spatial distribution of water quality throughout the study area. It incorporates data from diverse monitoring sites, encompassing numerous water quality parameters. By employing color-coded or shaded regions, the map categorizes areas based on their respective WQI values. This visual tool provides a comprehensive overview, making complex water quality data easily interpretable. The WQI map aids in identifying regions with varying degrees of water quality, pinpointing trends, assessing environmental impacts, and comparing water quality across different areas or timeframes. It offers an invaluable reference point for readers, enhancing the comprehensibility and impact of the thesis, here it utilized ArcGIS's kriging interpolation technique to create a spatial representation of the water quality index (WQI) across the study area, and manually the interpolation was edited because there is no such action for interpolating flowing rivers. Kriging is a geostatistical interpolation method that estimates values at unsampled locations based on the spatial correlation between sampled points. By inputting the WQI data collected at various sampling points, ArcGIS's kriging tool generated a continuous surface map depicting the distribution of water quality index values throughout the region. This map provides valuable insights into the spatial variation of water quality across the study area, enabling better understanding and management of water resources.

3.6. Concentration Maps Made By Python Script:

A map was created to visualize the river distribution data for each water quality parameter. Initially, river-related data is extrapolated and stored in a Google Sheet to create a realistic representation of river distribution. The script, written in Python, starts by authenticating the user to provide secure access to this data using Google's authentication services.

After successful authentication, the script accesses the Google Sheet, retrieves the river distribution data, and loads it into a DataFrame. This data is then transformed into a GeoDataFrame, enabling geographic operations in the Python environment. The coordinates in the DataFrame are used to create points, which are then joined into a polygon representing the path and boundaries of the river.

To detail water quality parameters, the script extracts these data from the designated worksheet, converting them into numeric formats suitable for analysis. The core of the visualization process involves spatial interpolation, specifically using Inverse Distance Weighting (IDW). This technique estimates parameter values across a predefined grid overlaying the river polygon, emphasizing data from closer points to enhance accuracy.

The interpolated data is then visually represented in a series of maps. These maps display diverse biochemical concentrations along the river using a color gradient scale to depict varying levels of concentration. Each map is annotated with relevant geographic markers, scales, and legends, offering a comprehensive visual analysis of the environmental conditions affecting the river.

4. FINDINGS

The study delves into a comprehensive analysis of the Great Zab River, scrutinizing various water quality parameters impacted by industrial discharges and seasonal variations. The investigation focuses on pH levels, Biochemical Oxygen Demand (BOD_5), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), residual chlorine, oil and grease, fluoride, phosphate, lead, copper, zinc, and cadmium concentrations at different sampling points along the river. Notably, the pH values exhibit seasonal trends, with winter and fall registering the highest values, while summer records the lowest. Biochemical Oxygen Demand (BOD_5) levels showcase disparities between upstream and downstream sites, influenced by industrial discharges from the Cola North Iraq plant and thermal power plant, with the Erbil refinery demonstrating lower BOD_5 levels. Dissolved Oxygen (DO) levels reveal a dynamic relationship between natural processes, industrial activities, and dilution effects, emphasizing the complexity of maintaining water quality, all these parameters compared with Iraqi water quality standard regulations for dual irrigation (Environment-IRAQ, 2012) (Iraqi water quality standard regulations for dual irrigation, 2012), as well it used as standard regulations to find CCME WQI.

The analysis extends to Total Dissolved Solids (TDS), where seasonal and industrial site variations are evident. Conductivity levels display substantial fluctuations, emphasizing potential industrial impacts. TSS concentrations highlight the significance of industrial activities in determining suspended solids, necessitating ongoing monitoring for water quality conservation. Nitrate and nitrite levels exhibit unique trends, indicating potential industrial contributions, while residual chlorine concentrations and oil and grease concentrations underscore the impact of both natural occurrences and human activities on the river's ecosystem. Fluoride and phosphate levels display intricate interactions between natural factors and industrial impacts, emphasizing the need for continued surveillance. Lastly, lead, copper, zinc, and cadmium concentrations exhibit seasonal and site-specific variations, necessitating thorough monitoring for effective water quality management in the Great Zab River. The comprehensive examination presented in this study underscores the importance of understanding the complex interplay between natural processes and industrial inputs to develop targeted pollution control strategies and ensure the conservation of the river's ecosystem.

Water Quality Index:

The Water Quality Index (WQI) is a useful measure for evaluating and conveying the overall condition of the Great Zab River at different sampling locations. The WQI value reflects the combined effect of many water quality parameters, offering a full overview of the environmental circumstances. Here will examine the analysis of WQI values at each specific sampling location and present it as a Water Quality Map as shown in Figure 4.1.

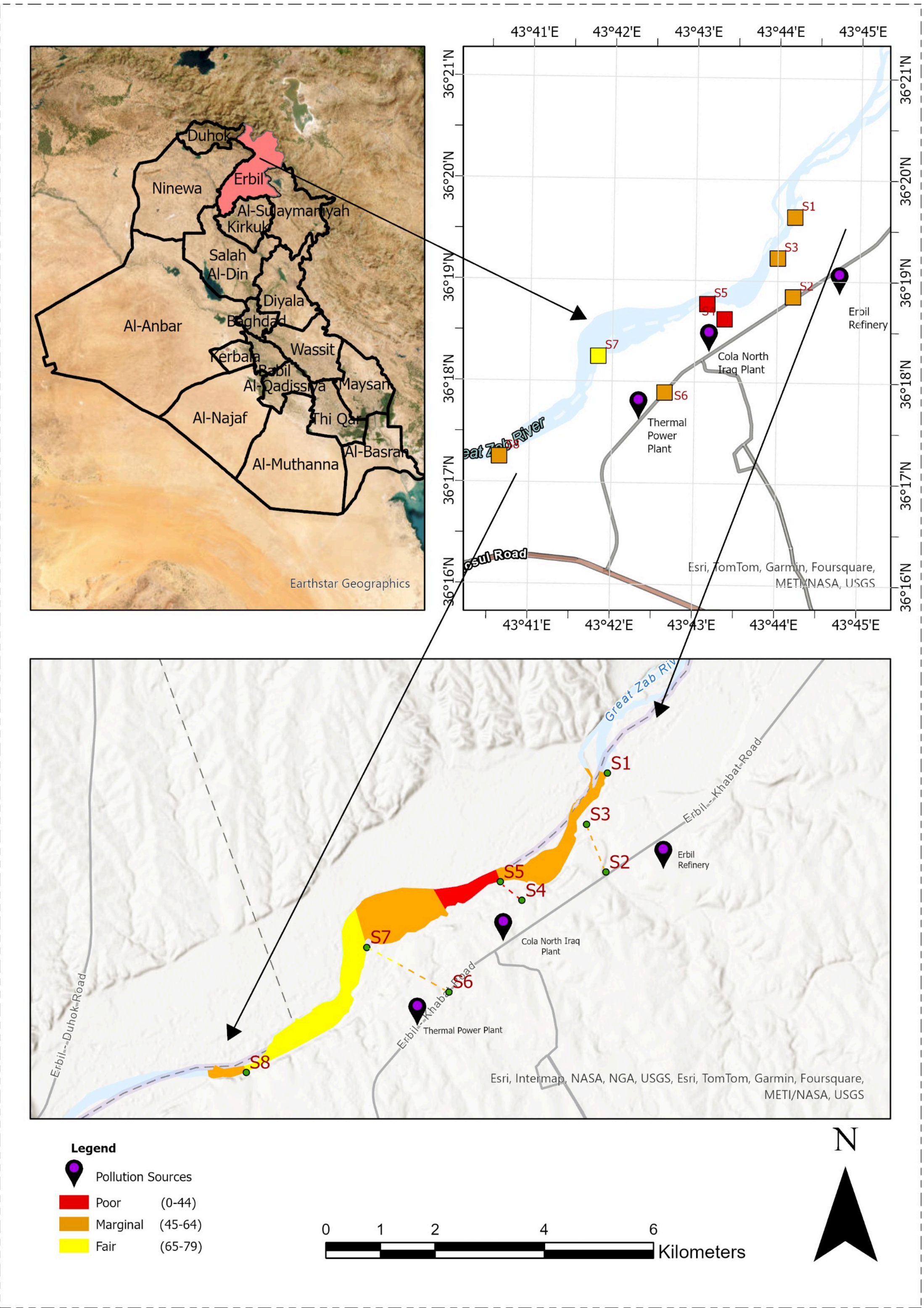

Figure 4.1. Water Quality Map

Great Zab River Upstream

The upstream portion of the Great Zab River has a moderate water quality level, indicated by a Water Quality Index (WQI) of 57.48. This suggests a fairly even distribution of water quality criteria. Although the water quality is deemed satisfactory, it is possible that there are effects from natural processes or minimal human activity in the upstream area, The temperature varies across seasons, with cooler temperatures in winter at 12.2°C and warmer temperatures in summer at 26.9°C as shown in Table 4.1. These fluctuations primarily result from natural seasonal changes influenced by weather patterns and water flow dynamics.

Table 4.1. Great Zab River Upstream (S1)

Parameters (mg/L)	SPRING	SUMMER	FALL	WINTER	St. Value (Environment-IRAQ 2012)
BOD_5	78	12	18	15	40
DO	7.88	7.2	5.1	7.9	-
PH(No Unite)	7.9	6.9	6.8	8.6	6.4-8
*EC(*µS/cm)	353	394	482	1082	-
TDS	226	256	313	687	2500
TSS	78	38	57.6	77	40
NO_2	0.001	0.008	0.009	0.014	-
CL_2	0.02	0.01	0.01	0.08	0.5
COD	102	12	48	31	100
OIL & GREASE	3.6	5.2	4.9	5.1	-
F_2	0.411	0.2	0.3	0.4	1
NO_3	0.993	0.792	5.1	7.4	50
PO_4	0.29	1	0.89	3.6	25
Pb	0.114	0.077	0.077	0.102	0.1
Cu	0.56	0.04	0.04	0.48	0.2
Zn	0.005	0.035	0.035	0.089	2
Cd	0.025	0.16	0.083	0.097	0.01
Ni	0.092	0.1	0.3	0.5	0.2

Cn	0.011	0.009	0.009	0.081	-
S	0.03	0.02	0.02	0.21	-
Cr	0.02	0.05	0.06	0.14	0.1
Fe	0.51	0.48	0.48	0.57	5
T°C	15.3	26.9	18.2	12.2	-
WQI	57.48				

The Erbil Refinery

The Water Quality Index (WQI) of 63.13 for the Erbil Refinery signifies a moderate level of water quality. The refinery's industrial activities could cause localized consequences, which might contribute to the variance in water quality metrics. Frequent surveillance is essential for comprehending and alleviating any detrimental impacts on the aquatic ecology, this sampling point experiences temperature changes reflective of both seasonal variations and industrial activities. Winter temperatures around 14.3°C are slightly higher due to the refinery's heat emissions, while summer temperatures was 27.1°C remain warmer but follow a similar pattern to the natural climate (Table 4.2).

Table 4.2. Erbil Refinery (S2)

Parameters(mg/L)	SPRING	SUMMER	FALL	WINTER	St. Value (Environment-IRAQ 2012)
BOD_5	40	18	14	17	40
DO	4.9	5.4	4.9	5.2	-
PH(No Unite)	7.2	5.5	6.2	7.3	6.4-8
*EC(*µS/cm)	2220	2120	2416	1896	-
TDS	1421	1357	1381	1284	2500
TSS	1421	4	37	41	40
NO_2	0.129	0.029	0.041	0.041	-

CL_2	0.01	0.07	0.068	0.054	0.5
COD	82	56	71	84	100
OIL	5.8	5	5.98	9.6	-
F_2	0.403	0.081	0.077	0.071	1
NO_3	0.328	0.238	0.428	2.6	50
PO_4	1.7	1.7	1.7	3.6	25
Pb	0.07	0.081	0.094	0.108	0.1
Cu	0.06	0.1	0.1	0.21	0.2
Zn	0.006	0.063	0.07	0.074	2
Cd	0.016	0.15	0.19	0.2	0.01
Ni	0.055	0.054	0.06	0.063	0.2
Cu	0.006	0.014	0.018	0.024	-
S	0.09	0.02	0.023	0.047	-
Cr	0.01	0.03	0.037	0.043	0.1
Fe	0.25	1.04	1.3	1	5
T°C	17.2	27.1	19	14.3	-
WQI	63.13				

The Erbil Refinery Discharging into the River:

Upon the combination of the refinery effluent with the river water, the Water Quality Index (WQI) experiences a marginal increase to 63.28, indicating a persistent state of satisfactory water quality. The process of mixing may lead to the dispersion of pollutants, thereby slightly enhancing the overall water quality in comparison to the refinery alone, after mixing with the river, temperatures slightly decrease, particularly noticeable in winter temperature of 13.1°C, indicating the river's cooling effect on the industrial discharge as shown in Table 4.3.

Table 4.3. Erbil Refinery Mixing With The River (S3)

Parameters(	SPRING	SUMMER	FALL	WINTER	St. Value (

mg/L)					Environment-IRAQ 2012)
BOD_5	25.3	17.8	20.7	19.8	40
DO	8.9	6.2	5.7	5.9	-
PH(No Unite)	7.8	6.41	6.91	8	6.4-8
*EC(*µS/cm)	1023	1108	1208	1102	-
TDS	620	720.2	785.2	801	2500
TSS	620	61	49	62	40
NO_2	0.21	0.2	0.28	0.21	-
CL_2	0.04	0.05	0.062	0.09	0.5
COD	62	41	58	66	100
OIL & GREASE	5.3	6.8	7.04	4.6	-
F_2	0.15	0.17	0.214	0.43	1
NO_3	2.41	1.2	7.6	5.3	50
PO_4	2.67	1.51	1.84	3.89	25
Pb	0.091	0.082	0.097	0.088	0.1
Cu	0.152	0.084	0.176	0.27	0.2
Zn	0.64	0.53	0.502	0.071	2
Cd	0.21	0.16	0.128	0.054	0.01
Ni	0.84	0.71	0.817	0.51	0.2
Cn	0.011	0.012	0.017	0.074	-
S	0.037	0.024	0.021	0.38	-
Cr	0.029	0.034	0.035	0.035	0.1
Fe	0.84	0.76	0.824	0.049	5
T°C	15.9	27	18.7	13.1	-
WQI	63.28				

Cola North Iraq Plant:

The Cola North Iraq plant sampling location has a Water Quality Index (WQI) of 43.32, which suggests that the water quality is poor. The particular procedures or components associated with the production of the Cola North Iraq plant can impact the factors that determine the quality of water. Additional examination of these variables is vital to guarantee the implementation of sustainable methods and mitigate ecological repercussions, Temperature variations here follow a similar pattern to the upstream river, with cooler temperatures in winter is 13.8°C and warmer temperatures in summer is 28.2°C. The influence of industrial processes may contribute to slightly higher temperatures across seasons as shown in Table 4.4.

Table 4.4. Cola North Iraq Plant (S4)

Parameters(mg/L)	SPRING	SUMMER	FALL	WINTER	St. Value (Environment_IRAQ 2012)
BOD_5	82	107	93	90.2	40
DO	9.02	6.9	5.2	6	-
PH(No Unite)	7.2	7.1	6.9	7.1	6.4-8
*EC(*µS/cm)	639	1551	1671	1751	-
TDS	409	993	992	1021	2500
TSS	14	47	34	41	40
NO_2	0.193	0.04	0.0502	0.061	-
CL_2	0.01	0.06	0.02	0.097	0.5
COD	150	167	181	174	100
OIL & GREASE	16.5	24	19.8	21.35	-
F_2	2.16	1.86	1.86	2	1
NO_3	2.44	3.82	4.02	5.01	50
PO_4	8.44	12.5	14.3	15.3	25
Pb	0.086	0.086	0.081	0.087	0.1

Cu	2.33	1.88	0.91	0.84	0.2
Zn	1.14	0.384	0.402	0.346	2
Cd	0.303	0.589	0.627	0.482	0.01
Ni	0.159	0.235	0.426	0.514	0.2
Cn	0.017	0.038	0.048	0.056	-
S	0.17	0.03	0.041	0.34	-
Cr	0.01	0.02	0.02	0.037	0.1
Fe	0.44	0.04	0.04	0.051	5
T°C	16.3	28.2	19.1	13.8	-
WQI	43.32				

Cola North Iraq Plant mixing with the River

When Cola North Iraq plant wastewater is combined with river water, the resulting Water Quality Index (WQI) is 44.97, indicating a poor level of water quality. The process of mixing may have a mitigating impact, resulting in a slightly enhanced Water Quality Index (WQI) as compared to the Cola North Iraq plant on its own, upon mixing with the river, temperatures decrease slightly, reflecting the river's cooling effect on the industrial discharge, with winter temperatures of 13.3°C being lower compared to summer 27.4°C (Table 4.5).

Table 4.5. Cola North Iraq plant Mixing With The River (S5)

Parameters(mg/L)	SPRING	SUMMER	FALL	WINTER	St. Value (Environment_IRAQ 2012)
BOD_5	67	83	88.3	67	40
DO	8.4	6.7	5.8	6.1	-
PH(No Unite)	7.02	6.82	6.98	8	6.4-8
*EC(*µS/cm)	1198	1271	1409	1090	-

TDS	802	826	915	691	2500
TSS	55.3	61	51.6	69.5	40
NO_2	0.018	0.024	0.049	0.097	-
CL_2	0.043	0.053	0.051	0.087	0.5
COD	88	94	102	91	100
OIL & GREASE	11.06	14.6	16.03	6	-
F_2	1.08	1.21	1.57	1.48	1
NO_3	3.18	2.41	3.57	5.3	50
PO_4	5.6	5.6	7.98	5.7	25
Pb	0.09	0.0945	0.0991	0.021	0.1
Cu	0.871	0.971	0.902	0.38	0.2
Zn	0.22	0.29	0.33	0.31	2
Cd	0.357	0.4775	0.401	0.09	0.01
Ni	0.22	0.26	0.371	0.42	0.2
Cn	0.02	0.024	0.03	0.074	-
S	0.021	0.025	0.038	0.024	-
Cr	0.024	0.03	0.038	0.27	0.1
Fe	0.351	0.37	0.386	0.491	5
T°C	15.4	27.4	18.4	13.3	-
WQI	44.97				

The Thermal Power Plant

The sampling station of the Thermal Power Plant has a Water Quality Index (WQI) of 61.29, indicating a moderate overall water quality. The observed water quality metrics may be influenced by industrial discharges and cooling operations. Consistent surveillance and strict compliance with environmental standards are vital for the sustainable functioning of an operation, this point consistently maintains higher temperatures throughout the year due to the operational heat output of the power plant. Winter temperatures of 23.1°C are relatively warmer compared to other sampling points (Table 4.6).

Table 4.6. The Thermal Power Plant (S6)

Parameters (mg/L)	SPRING	SUMMER	FALL	WINTER	St. Value (Environment-IRAQ 2012)
BOD_5	94	80	76	81	40
DO	6.13	6.5	6.3	5.4	-
PH(No Unite)	7.4	7.4	7.5	7.6	6.4-8
EC(µS/cm)	1035	2270	2370	2072	-
TDS	662	2270	1468	1684	2500
TSS	61	7	7.3	6.2	40
NO_2	0.02	0.047	0.033	0.084	-
CL_2	0.04	0.03	0.03	0.037	0.5
COD	232	174	151	108	100
OIL & GREASE	19	6.2	5.8	7.2	-
F_2	0.025	1.28	1.28	2	1
NO_3	3.55	4.45	5.21	6.8	50
PO_4	1.39	2.58	2.58	4.7	25
Pb	0.088	0.087	0.08	0.091	0.1
Cu	0.21	0.08	0.077	0.094	0.2
Zn	0.127	0.051	0.055	0.072	2
Cd	0.044	0.114	0.104	0.087	0.01
Ni	0.136	0.3	0.37	0.49	0.2
Cn	0.015	0.063	0.06	0.05	-
S	0.09	0.01	0.01	0.058	-
Cr	0.01	0.02	0.021	0.054	0.1

Fe	0.99	0.21	0.28	0.34	5
T°C	24	30.6	25.1	23.1	-
WQI	61.29				

The Thermal Power Plant is being mixed with the river

When the discharge from the thermal power plant is combined with the river water, the Water Quality Index (WQI) experiences a substantial boost to 67.99, which signifies a fair level of water quality. The process of mixing seems to have a beneficial effect on the dilution and dispersion of pollutants, hence enhancing the overall quality of water (Table 4.7).

Wastewater from the Thermal Power Plant goes through a significant transformation after it is mixed in the Great Zab River and therefore has a relatively good WQI (Water Quality Index) with a score of 67.99, which refers to the weak water quality level. This process originates from the natural filter of the wetland close to the mixing point, which purges lower levels of heavy metals such as lead, copper, zinc, cadmium, nickel, chromium, as well as iron. The wetland aids in the outflow of pollutants, dissipating them over a large territory and hence diminishing the industrial waste from the power station. Thus, the diverting of industrial effluents along the watercourse stream proves the prospects for environmental recovery and the creation of sustainable water systems management in the territory as a whole. The key step is constant monitoring and observation of water quality indicators along with the enforcement of environmental regulations to allow the aquatic environment to become a healthy ecosystem, after mixing with the river, temperatures decrease noticeably, especially in winter at 16.1°C, showcasing the river's cooling effect on the thermal discharge

Table 4.7. The Thermal Power Plant Is Being Mixed With The River (S7)

Parameters(mg/L)	SPRING	SUMMER	FALL	WINTER	St. Value (Iraqi Regulations)
BOD_5	21	19	15.8	18.5	40

DO	8.6	6.5	5	5.5	-
PH	7.8	7.2	7	8.1	6.4-8
*EC(*µS/cm)	1102	1023	1221	1118	-
TDS	678	664.9	793	824	2500
TSS	91	78	38.6	81	40
NO_2	0.048	0.036	0.046	0.024	-
CL_2	0.057	0.05	0.043	0.096	0.5
COD	58	71	41	49	100
OIL & GREASE	4.618	7.36	6.08	6.1	-
F_2	0.92	1.2	1.03	1.09	1
NO_3	3.25	2.38	5.07	7.8	50
PO_4	1.89	2.62	2.97	4.2	25
Pb	0.0746	0.0819	0.091	0.095	0.1
Cu	0.084	0.05	0.071	0.039	0.2
Zn	0.045	0.037	0.042	0.097	2
Cd	0.12	0.146	0.075	0.07	0.01
Ni	0.28	0.2	0.4	0.4	0.2
Cn	0.0027	0.0036	0.0038	0.061	-
S	0.041	0.03	0.04	0.21	-
Cr	0.039	0.027	0.041	0.017	0.1
Fe	1.2	0.41	0.46	0.041	5
T°C	18.1	28.5	22.2	16.1	-
WQI	67.99				

The Great Zab River downstream

The WQI (Water Quality Index) of the downstream portion of the river is 56.00, indicating a reasonable level of water quality. This phenomenon could be influenced by the combined impact of inputs from upstream sources and natural processes. Regular monitoring is crucial for evaluating any patterns or changes in water quality over a while, Similar to the upstream point, temperatures vary seasonally, with cooler temperatures in winter at 12.6°C and warmer temperatures in summer at 26.8°C, reflecting natural climate patterns and water flow dynamics (Table 4.8).

Table 4.8. The Great Zab River Downstream (S8)

Parameters(mg/L)	SPRING	SUMMER	FALL	WINTER	St. Value (Environment-IRAQ 2012)
BOD_5	130	17	22	20	40
DO	6.9	6.9	5.8	7.2	-
PH(No Unite)	7.2	6.7	7	8.2	6.4-8
*EC(*µS/cm)	394	402	647	892	-
TDS	231	257	420	502	2500
TSS	231	70	91.3	88.7	40
NO_2	0.025	0.008	0.006	0.089	-
CL_2	0.07	0.01	0.04	0.08	0.5
COD	154	17	71	58	100
OIL & GREASE	8.2	8.4	11.1	8.7	-
F_2	0.587	0.2	0.3	0.4	1
NO_3	0.867	0.864	1.052	6.5	50
PO_4	0.44	1.26	1.04	1.52	25
Pb	0.148	0.083	0.158	0.113	0.1
Cu	0.43	0.04	0.05	0.18	0.2
Zn	0.153	0.035	0.052	0.092	2
Cd	0.127	0.166	0.184	0.047	0.01
Ni	0.268	0.1	0.3	0.6	0.2
Cn	0.016	0.009	0.009	0.041	-

S	0.12	0.02	0.03	0.23	-
Cr	0.06	0.05	0.06	0.07	0.1
Fe	3.23	0.48	0.58	0.91	5
T°C	15.1	26.8	18.5	12.6	-
WQI	56.00				

To summarize, the WQI values offer a thorough assessment of the total water quality of the Great Zab River . While certain regions display satisfactory or moderate conditions, others demonstrate enhanced water quality through the process of mixing. The WQI values emphasize the significance of continuous monitoring, adherence to regulations, and sustainable practices to protect the environmental integrity of the Great Zab River.

The Water Quality Index (WQI) is a valuable tool for assessing the overall condition of water bodies by considering multiple water quality parameters. The WQI values provide a comprehensive overview of the environmental circumstances, aiding in the evaluation of the Great Zab River's water quality at various sampling locations. The WQI values at specific sampling locations indicate the overall water quality and the potential impacts of human activities and natural processes on the river.

The upstream portion of the Great Zab River exhibits a moderate water quality level, with a WQI of 57.48, suggesting satisfactory water quality with potential influences from natural processes or minimal human activity (Sutadian et al., 2015). Similarly, the Erbil Refinery and the Thermal Power Plant show moderate water quality levels, with WQI values of 63.13 and 61.29, respectively. These moderate levels may be attributed to industrial activities, emphasizing the need for continuous monitoring and adherence to environmental standards (Tabrez et al., 2022).

Conversely, the Cola North Iraq plant sampling location and its mixing with the river display poor water quality, with WQI values of 43.32 and 44.97, respectively. This indicates the potential impact of Cola North Iraq plant production processes on water quality, necessitating further examination and sustainable practices to mitigate ecological repercussions (Tabrez et al., 2022)

The WQI values highlight the significance of continuous monitoring, adherence to regulations, and sustainable practices to protect the environmental integrity of the Great Zab River. The process of mixing, such as the combination of refinery effluent with river water, may lead to the dispersion of pollutants, affecting the overall water quality. Additionally, the mixing of the Thermal Power Plant discharge with the river water results in a substantial boost in WQI, signifying enhanced water quality through the dilution and dispersion of pollutants(Sutadian et al., 2015).

The WQI values offer a comprehensive assessment of the total water quality of the Great Zab Riveras as representatively shown in Figure 4.2, emphasizing the need for sustainable practices, continuous monitoring, and adherence to environmental standards to protect the river's environmental integrity. The WQI values at specific sampling locations reflect the combined effects of natural processes, industrial activities, and mixing processes on the overall water quality of the Great Zab River.

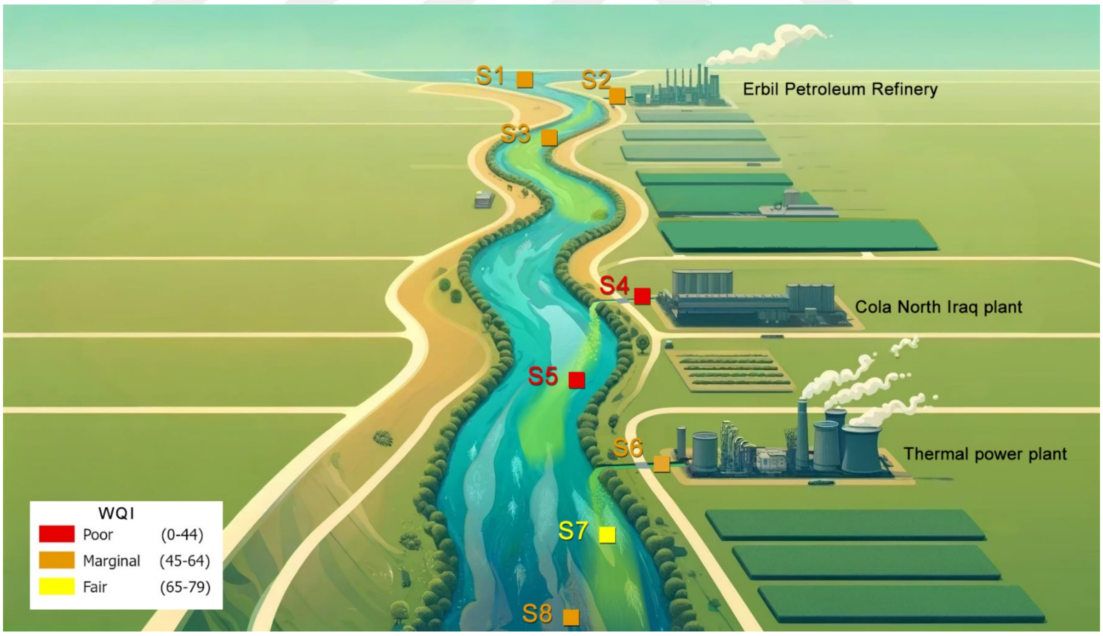

Figure 4.2. Study Area and Water Quality Results

Flow Rate:

The table provides a comprehensive overview of the average discharge (flow rate) of the Great Zab River across different months and years, from 2017 to 2023 (Table 5.3). By examining the data, we can identify patterns of increase and decrease in flow rate for each year.

The analysis of the flow rate data from 2017 to 2023 reveals varying patterns of increase and decrease influenced by factors such as precipitation, snowmelt, and seasonal variations (Jansson et al., 2003). In 2017, the flow rate gradually increased from January to April, with the most significant rise occurring between February and March, attributed to snowmelt and increased precipitation during the winter and early spring months. However, from April onwards, the flow rate experienced a gradual decline, reaching its lowest point in October before stabilizing towards the end of the year). Similarly, in 2018, the flow rate followed a similar pattern of increase and decrease, with a considerable spike in flow rate from February to March, but a more pronounced decline after April compared to 2017. In contrast, 2019 demonstrated a remarkable increase in flow rate across almost all months compared to the preceding years, particularly during March and April, attributed to exceptional precipitation or snowmelt events during this period (Jansson et al., 2003).

The flow rate remained relatively high throughout the year, indicating sustained hydrological activity. Moving to 2020, the flow rate displayed fluctuations throughout the year, with notable peaks in April and May, but the increase in flow rate was less pronounced and sustained compared to 2019, with fluctuations observed in subsequent months. In 2021, the flow rate experienced a general decrease compared to the previous years, with fewer instances of significant increases, although there were still notable fluctuations throughout the year, particularly in March and April. In 2022, the flow rate showed a mixed pattern, with some months experiencing increases while others demonstrated decreases, including a substantial rise from January to April, followed by a gradual decline in the latter part of the year. Finally, in 2023, the flow rate exhibited a significant decrease compared to the preceding years, particularly in the first half of the year, with fewer instances of notable increases, showing an overall downward trajectory (Jansson et al., 2003).

These fluctuations highlight the dynamic nature of the hydrological system and underscore the importance of continuous monitoring and analysis for effective water resource management. The varying patterns of increase and decrease in flow rate for each year emphasize the complex interplay of factors such as precipitation, snowmelt, and seasonal variations, which contribute to the dynamic nature of the hydrological system (Jansson et al., 2003).

The flow rate of each plant according to their official data Erbil Refinery discharges about 100 m3/h of wastewater, the Cola North Iraq Plant discharges about 90 m3/h of wastewater, and the Thermal Power Plant produces 77 m3/h of industrial wastewater.

Table 4.9. Average Discharge of Great Zab River

	Average Discharge (m^3/sec.), from Directorate of Irrigation-Erbil											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2017	164	176	325	578	483	292	200	155	141	140	158	166
2018	185	298	369	376	433	267	179	141	131	167	177	516
2019	405	396	541	827	812	551	290	190	152	142	138	155
2020	182	274	458	731	602	327	204	131	108	105	118	115
2021	152	240	290	341	280	153	102	84	73	73	78	99
2022	143	163	248	417	345	253	109	79	68	67	77	83
2023	63	117	163	335	252	174	101	76	70	77	132	206

5. DISCUSSION

5.1. Effects of pH

The pH value in upstream of the Great Zab River that not affected by the wastewater discharges of the three sites was ranged between 6.8-8.6 as shown in (Figure 5.1), the highest value was 8.6 during the winter season (December 2023) in the direct effect of weathering of carbonate rocks in the catchment area by rainfall, the lowest was 6.8 at fall season of 2023, these results are almost near of Aziz and Fakhrey (2016) research in Iraq, Erbil, which results ranged between 6.5 to 8.5.

The downstream from the study area of the Great Zab River pH value ranged between 6.7-8.2, the highest value was recorded at 8.2 in the winter season of 2023, while the lowest value was recorded in the summer season of 2023 these results were similar to Aziz and Fakhrey (2016) research in Iraq, Erbil, which results ranged between 6.5 to 8.5.

All three discharge and mixing points with the river pH value ranged between 5.5-8.1, the highest value 8.1 was recorded in the mixing point of the Thermal power plant during the winter season of 2023, the lowest value 5.5 was recorded in the Erbil refinery discharge at summer season of 2023, Cola wastewater discharge have most stable value 6.9-7.2, these results aligned with Rahi et al. (2021) in Iraq refineries which was about 6.8, there was no significant change during seasonal changes. Generally, the highest pH value was recorded during the winter season, and the lowest values were recorded during the summer season in all sample points during the study time, however, all the values are aligned in their research. The fluctuations in pH levels throughout the seasons result from the weathering of carbonate rock and are further influenced by a decrease during summer, primarily due to the direct impact of evaporation.

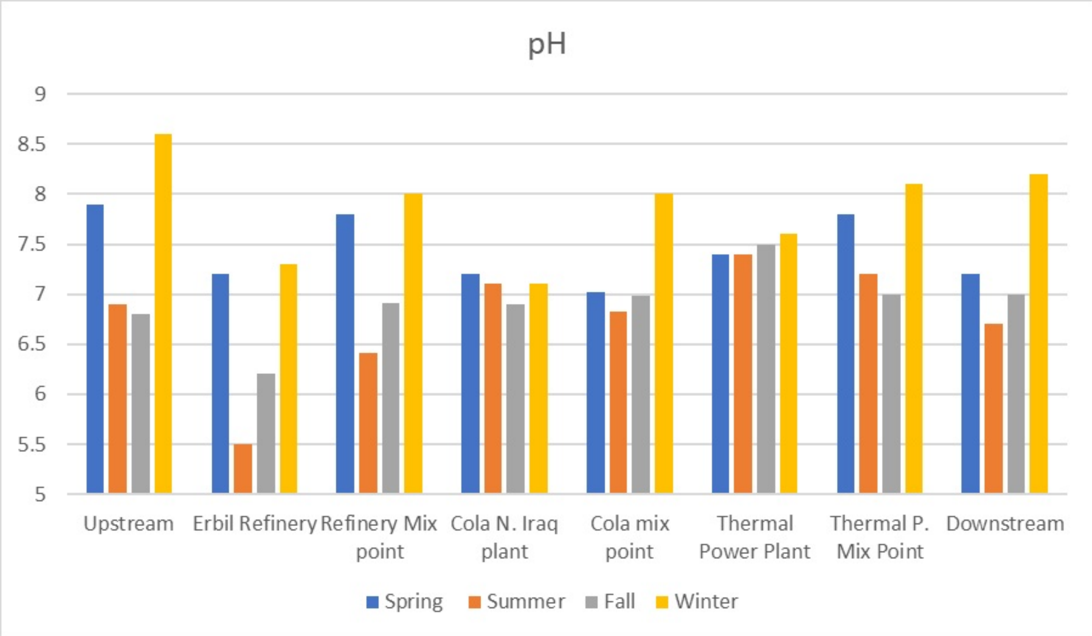

Figure 5.1. Change of pH of sample points

The pH values in the upstream and downstream of the Great Zab River, as well as at the discharge and mixing points with the river, exhibit significant variations. In the upstream, the pH ranged between 6.8 and 8.6, with the highest value recorded during the winter season and the lowest during the fall season of 2023. Conversely, the downstream pH ranged between 6.7 and 8.2, with the highest value recorded during the winter season and the lowest during the summer season of 2023, this is how Toma et al. (2018) reported in their research in Iraq, which ranged between 6.6 to 7.3.

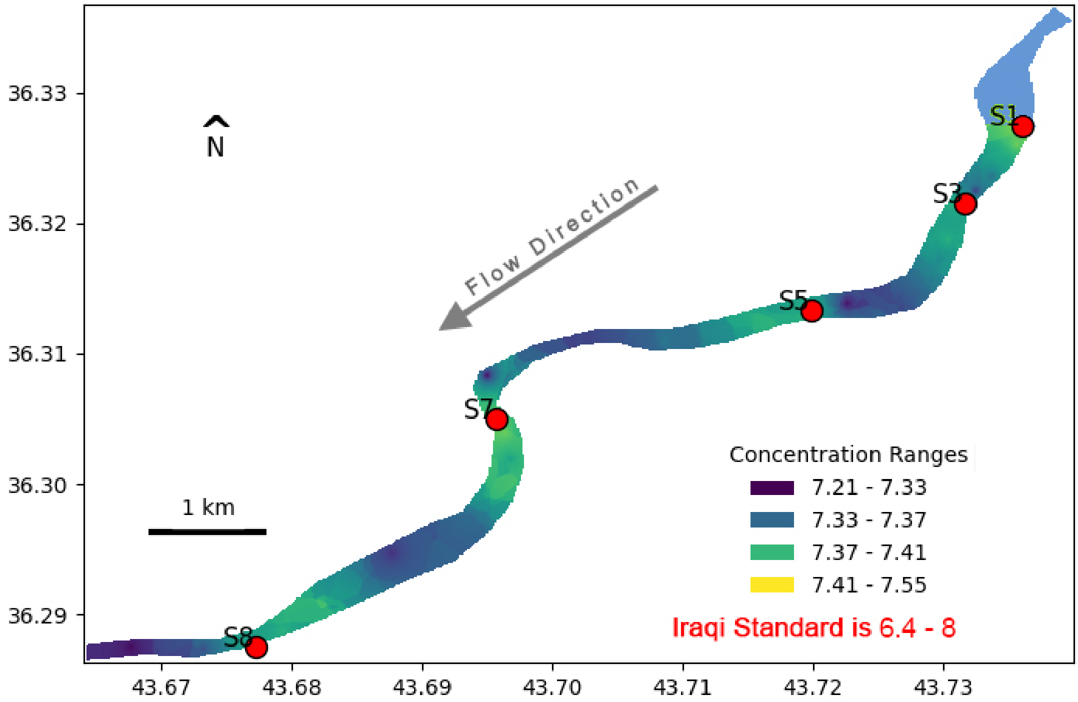

Figure 5.2. Water Quality Map of pH level

The variations in pH values at different points along the Great Zab River are indicative of potential impacts from industrial activities and seasonal changes. The pH values are crucial indicators of water quality and can be influenced by various factors, including industrial wastewater discharges (Lokhande et al., 2012). The observed fluctuations in pH at the discharge and mixing points with the river underscore the potential impact of industrial effluents on the river's water quality (Sun et al., 2019). Additionally, the stability of pH values in the Cola wastewater discharge suggests a consistent effluent composition, which may be attributed to specific treatment processes employed by the company (Bouchareb et al., 2021).

The presence of minerals like calcium, magnesium, and bicarbonates can affect pH, with alkaline minerals tending to raise pH and acidic minerals lowering it, also decomposing organic matter can release acids, reducing pH, also pH can vary with temperature, although this effect is more pronounced in pure water rather than water with dissolved substances (Zainurin et al., 2022).

The potential influence of industrial wastewater discharges on the pH values of the Great Zab River is further supported by studies on the physico-chemical parameters of industrial effluents. These studies have highlighted the impact of industrial effluents on nearby water bodies, affecting vegetation, aquatic life, and overall water quality (Lokhande et al., 2012). Furthermore, the environmental impact of wastewater discharge with multi-pollutants from the iron and steel industry emphasizes the need to assess the impact of industrial activities on water quality, including pH variations (Sun et al., 2019).

5.2. Effects Biochemical Oxygen demand:

Many variables can influence water's Biochemical Oxygen Demand (BOD_5), besides just the amount of organic matter in the water. According to Lak (2007), Temperature is the main determinant; higher temperatures increase the rate of microbial activity thus the BOD_5 increases. pH levels as well as BOD vary, mostly as a result of the large amount of waste, resulting in the death of microorganisms. Nutrient concentrations, especially nitrogen and phosphorus have a profound effect on the growth of microbes which in turn leads to BOD_5. Moreover, a decrease in dissolved oxygen concentration is proportional to the increase in BOD_5 because the process of BOD_5 leads to the depletion of oxygen in water. In addition, the existence of inhibitors or toxic substances may lead the microbial processes to change which in turn will affect the readings of BOD_5. In this case, the full BOD_5 picture is only complete when the complex environmental aspects are taken into account (Ali, 2002).

The BOD_5 value in upstream of the Great Zab River ranged between 12-78 mg/L, the highest level of 78 mg/L was recorded in the spring season of 2023, and the lowest value of 12 mg/L was recorded, results were near Hamdan et al. (2018) results in Iraq ranged between 3 to 123 mg/L in Shatt Al-Arab river, which is the lowest record of BOD_5 from the whole study as shown in Figure 5.3.

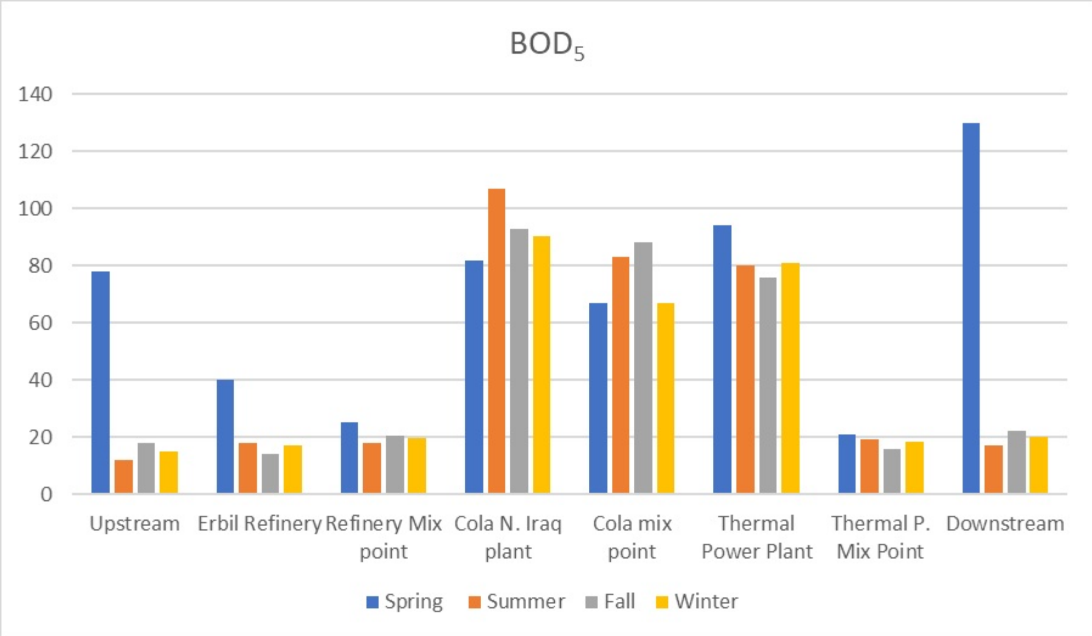

Figure 5.3. Change of BOD5 Concentrations

The downstream of the Great Zab from the study area ranged between 17-130 mg/L during the study year, but the highest value at all from the study was recorded downstream of the Great Zab River during the spring season the value was 130 mg/L the result coming accordance with Hamdan et al. (2018) in Shatt Al-Arab in Iraq, while the value of BOD_5 was lowest at summer during the study year, which most affected season after all discharges in the lowest point of the study area.

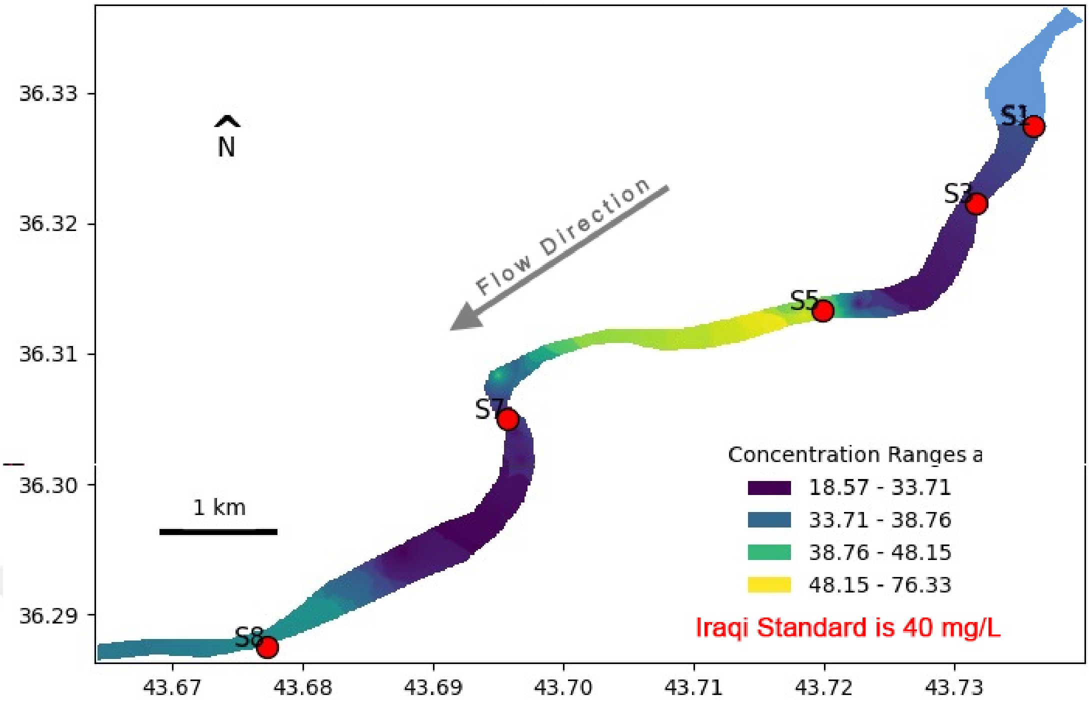

Figure 5.4. Water Quality Map of BOD5

From all discharges that affected the biological oxygen demand in the Great Zab River Cola North Iraq plant and thermal power plant discharged wastewater with the highest level of BOD_5 which clearly affected the river in mixing point samples that discharged to the river, the highest value of Cola north Iraq plant wastewater was 107 mg/L and the highest value of thermal power plant wastewater discharge was 94 mg/L, from the samples of the study that was taken from a mixing point of the Great Zab river the BOD_5 level was decreased in the discharge stream channels from their way flowing to the Great Zab river, the BOD_5 level of Erbil refinery was lower comparing to another wastewater discharges, the highest BOD_5 value was 40 mg/L at spring 2023, these results are extremely lower than other researchers results like Genanaw et al. (2021) which was about 2409 to 3770 mg/L in South Ethiopia.

The findings of this study align with previous research on water quality assessment and management in river basins. Research on the Tigris-Euphrates River basin in Iraq has emphasized the importance of understanding the spatial-temporal control of groundwater recharge (Al-Kubaisi et al., 2022). Additionally, studies have highlighted the contribution of tributaries to the flow of major rivers, such as the Great Zab contributing about 35% of the Tigris flow (Abbas et al., 2018). Furthermore, the assessment of water quality using different water quality index methods has been a subject of research, indicating the broader interest in evaluating and managing water quality in river systems (Ahmed et al., 2020).

Moreover, the impact of climate change on water resources and river systems has been a significant area of study, emphasizing the need for effective water management strategies in the face of changing climatic conditions (Osman et al., 2017).

5.3. Effects Dissolved Oxygen (DO):

The DO levels in the Great Zab River at various points during different seasons and industrial sites reflect dynamic patterns. DO concentrations for the upstream segment are from 5.1 to 7.9 mg/L (Figure 5.5), all of which show a substantial increase during the winter season, due to their temperature dependence on solubility in water. Comparatively, there is a reduction in the levels downstream which is relevant to Ahmed et al. (2020) results that was about 5 mg/L in Iraq-Lower Zab river.

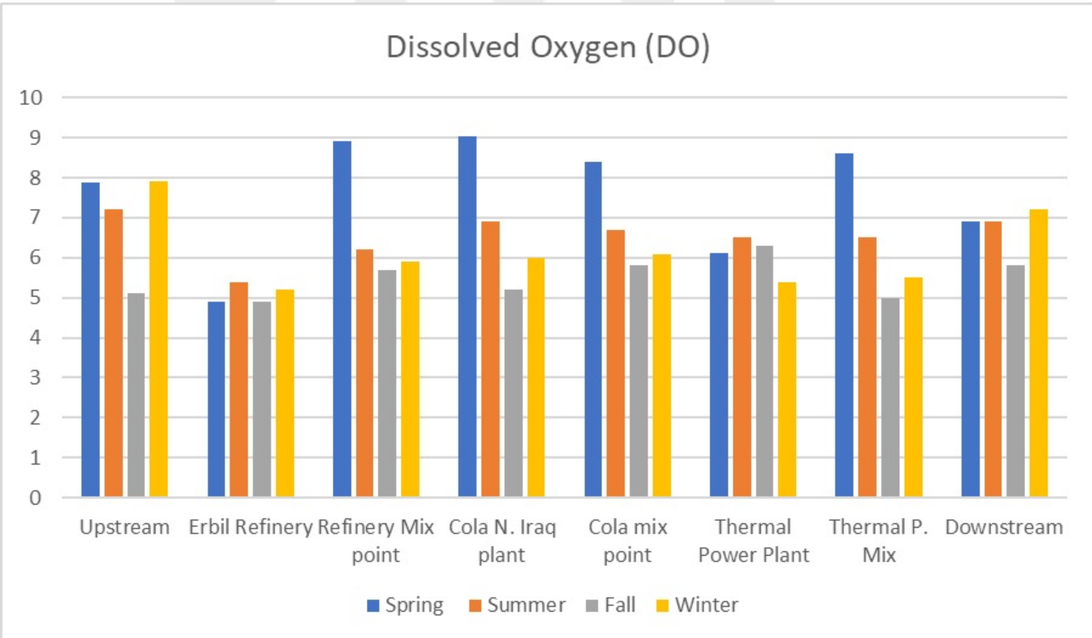

Figure 5.5. Change of Dissolved Oxygen Concentrations

DO values at the Erbil Refinery are always low across different seasons ranging between 4.9-5.4 mg/L, which could be an indication of pollution or introduction into streams that promote oxygen-demanding substances. Inversely, the mixing of the river with refinery effluent creates a noticeable increase in DO – this would imply that dilution and natural processes within the river are mitigating factors. In the Cola site, both raw effluent and its mixing with the river show a seasonal change ranging between 5.2-9.02 mg/L, usually due to production processes and dilution effects (Ahmed et al., 2020). These results are the same as Banerjee et al. (2019) recorded in their study in d in the Birbhum district of the state of West Bengal is above the critical level of 4.5 mg/L.

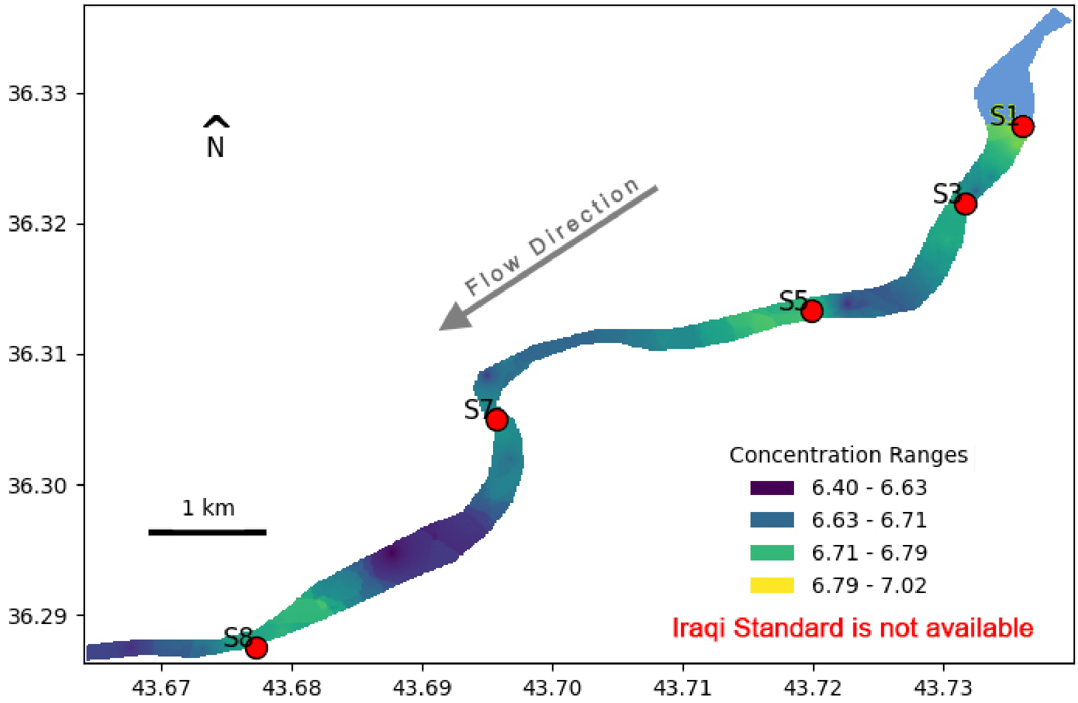

Figure 5.6. Water Quality Map of DO

On the one hand, DO levels at Thermal Power Plant are stable but slightly lower than those recorded upstream, the record of both the plant and the mixing with the river is 5-8.4 mg/L, which could indicate thermal pollution or oxygen consumption from the plant activities (Figure 5.6). However, when the thermal power plant effluent is mixed with the river it results in a significant increase in DO especially during spring which reveals that dilution and natural processes and the presence of wetlands enhance water quality (Banerjee et al., 2019).

Downstream of the river, DO levels are lower than upstream but still remain acceptable for freshwater systems, thus warranting more monitoring and management to ensure water quality protection.

Overall, the Dissolved Oxygen results indicate a complicated relationship between natural processes, industrial activities, and dilution effects along the Great Zab River. As such, tracking these parameters is paramount in evaluating the general health of an ecosystem within a river and thus directing suitable environmental management practices. Further studies on the individual pollutants and operations affecting DO can provide helpful information that aids conservation efforts aimed at specific aspects of nature, including pollution control (Wei et al., 2019).

These findings underscore the complex interplay of natural processes, industrial activities, and dilution effects in shaping the DO levels along the Great Zab River, emphasizing the importance of tracking these parameters for ecosystem health evaluation and environmental management (Hussain et al., 2022).

The amounts of dissolved oxygen (DO) in water are dependent on several important factors. Temperature holds great significance, as the amount of oxygen that warmer water is able to hold is less than that of cooler water, and consequently, the respiratory processes of aquatic organisms are affected. With salinity, the DO level also drops due to the lower oxygen solubility in a highly saline environment. The DO levels may change due to the pressure variations, and this is because the gas solubility is affected by the depth and height. Furthermore, biological factors like photosynthesis, respiration rates of aquatic plants and animals, and organic matter decomposition, contribute to DO variations and, therefore, stress the interplay of physical, chemical, and biological factors in aquatic ecosystems' oxygen dynamics (Sánchez et al., 2007).

The study emphasizes the significance of DO as an indicator of river water quality and its sensitivity to various factors, including industrial activities, seasonal variations, and natural processes. It underscores the need for further research on individual pollutants and operations affecting DO to inform targeted conservation efforts and pollution control measures (Kannel et al., 2007).

5.4. Effects of Chemical Oxygen Demand (COD):

The COD of the study area ranged between 12-232 mg/L the highest value at all was recorded in the Thermal power plant in the spring of 2023. As shown in Figure 5.7 while the lowest level was recorded in upstream of the Great Zab River during the summer season, the spring season recorded the highest value of COD compared to other seasons in general these results were much lower than other studies like Genanaw et al. (2021) so their result was about 4302 mg/L in south Ethiopia.

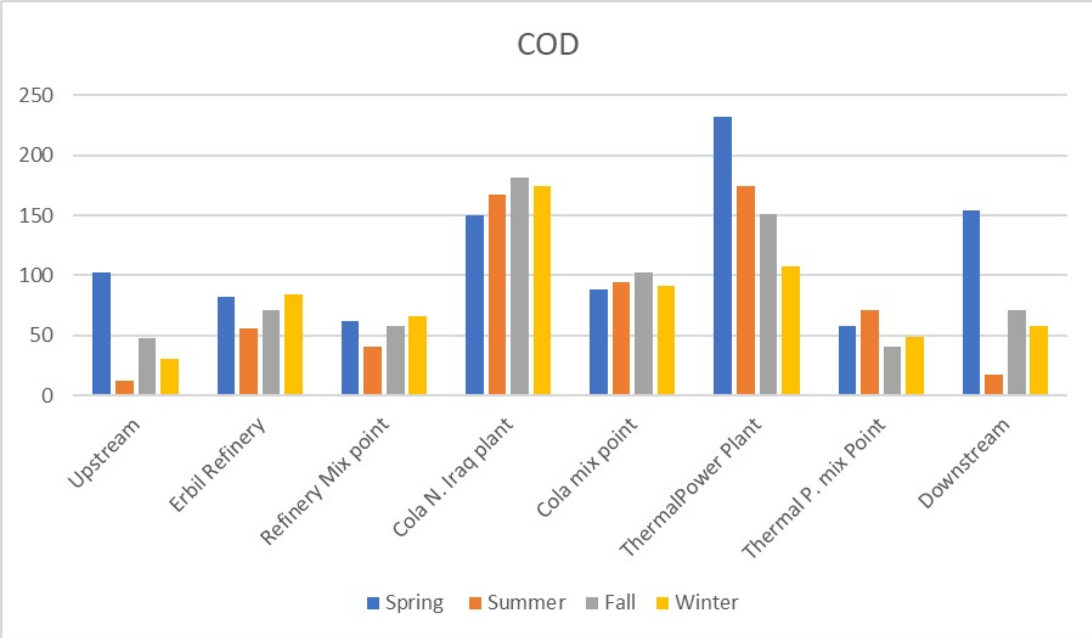

Figure 5.7. Change of COD Concentrations

Similarly to Aziz and Fakhrey (2016) study the upstream of the Great Zab River in the study area COD level ranged between 12-102 mg/L, the spring season was the highest, and the summer season was the lowest value, while the downstream of the study area in the Great Zab river was ranged between 17-154 mg/L, also the highest value was recorded at spring season.

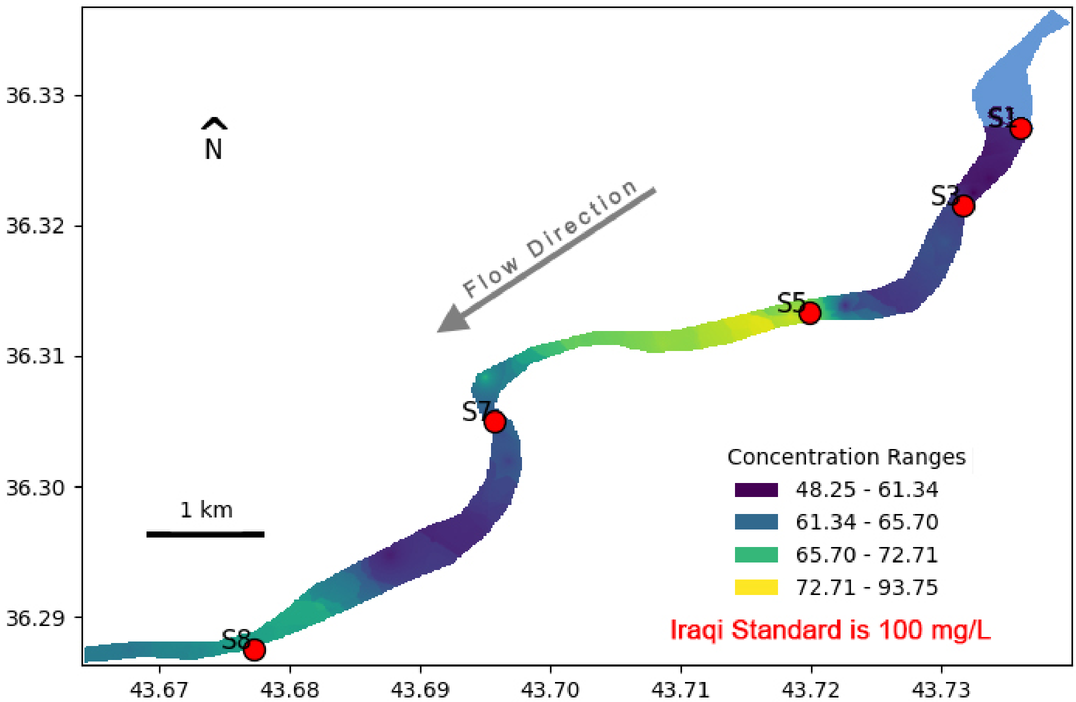

Figure 5.8. Water Quality Map of COD

Erbil refinery wastewater discharge ranged between 56-84 mg/L the highest level was at winter season while the lowest value was at summer season, while the COD recorded a high level from all seasons in Cola north Iraq base, the highest value was 181 mg/L in fall season and the lowest value was 150 mg/L at spring season, Thermal power plant the last site of the study area the COD level ranged between 108-232 mg/L, the highest value was recorded at spring season and the lowest value was at winter season, this results are near to Rahi et al. (2021) which was between 150 to 250 mg/L in oil refineries in Iraq. All sites that discharged the COD level decreased after the discharges flowed to the Great Zab River in the mixing point samples.

The study area's COD levels varied significantly across different sites and seasons. The highest COD value recorded at the Thermal Power Plant in spring 2023 was 232 mg/L, while the lowest level was observed upstream of the Great Zab River during the summer season 12 mg/L. Additionally, the upstream and downstream of the Great Zab River exhibited varying COD levels, with the highest values generally recorded in the spring season. Moreover, the Erbil refinery wastewater discharge and BOD levels at different sites also showed variability across seasons. It is noteworthy that all sites that discharged the BOD5 level experienced a decrease after the discharges flowed into the Great Zab River at the mixing point samples.

However, besides the chemical oxygen demand (COD), there are several other parameters that are used in water quality assessment. Some of these are BOD (Biochemical Oxygen Demand) which measures the amount of dissolved oxygen used by microorganisms while they are decomposing the organic matter found in water, TOC (Total Organic Carbon) which shows the concentration of organic carbon compounds in the water, turbidity, which is an indicator of water clarity due to the presence of suspended particles, pH levels, which affect water acidity They present together these parameters that bring information about organic and inorganic pollution, water quality as a whole, and the possible environmental effects (Razif, 2022).

The findings align with Ismaiel et al. (2018), who emphasized the influence of geogenic and anthropogenic controls on water quality assessment and resource management in river catchments. Furthermore, the correlation between BOD5 and COD, as highlighted by Rudaru et al. (2022), underscores the importance of understanding the biodegradability of wastewater, which is crucial in assessing the impact of various discharges on river water quality. Additionally, the study by Razif

(2022) on BOD5, COD, and TSS predictions from DO measurement results for the Surabaya River in Indonesia further supports the significance of understanding water quality parameters and their interrelationships in river systems.

5.5. Effects of Total Dissolved Solids (TDS):

The TDS level of the study ranged between 226-2270 mg/L, the lowest value was in upstream of the Great Zab River during the spring season, while the highest level was 2270 mg/L recorded in thermal power plant wastewater discharge during the summer season (Figure 5.9) results were aligned with Ahmed et al. (2020) results in lower Zab river in Iraq.

Upstream of the Great Zab River recorded TDS levels between 226-687 mg/L, the lowest was during the spring season while the highest value was recorded during the winter season. The downstream of the Great Zab River from the study area recorded TDS levels between 231-502 mg/L and from all points reached a maximum of 2270 mg/L in the thermal power plant, the lowest was at spring season and the highest value was at winter season, this shows that Genanaw et al. (2021) results were about 3226 mg/L in south Ethiopia and Lokhande et al. (2012) results were five times higher about 12023.6 mg/L in Mumbai, India.

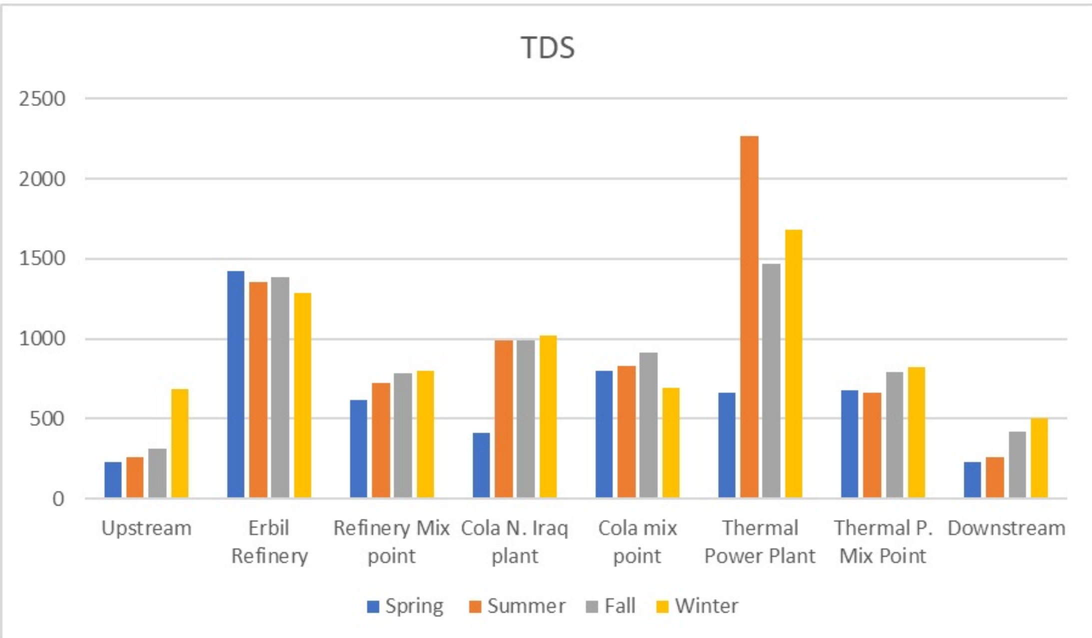

Figure 5.9. Change of TSD Concentrations

The wastewater discharges recorded different values of TDS values, and results were aligned with Genanaw et al. (2021) Erbil refinery wastewater discharge recorded the TDS level ranged between 1284-1421 mg/L, the lowest during the winter season while the highest was in the spring season. Cola North Iraq plant wastewater discharge ranged between 409-1021 mg/L, the lowest was at spring season and the highest was at winter season, the last site is the thermal power plant recorded the lowest value of 662 (mg/L) and the highest value of the study at all 2270 mg/L at summer season, the TDS decreased from all wastewater discharges after flowed to the Great Zab river.

The wastewater discharges from various sources, such as the Erbil refinery, Cola North Iraq plant, and thermal power plant, showed distinct TDS levels at different seasons, indicating fluctuations in TDS concentrations based on the source and time of discharge (Karanikola et al., 2018).

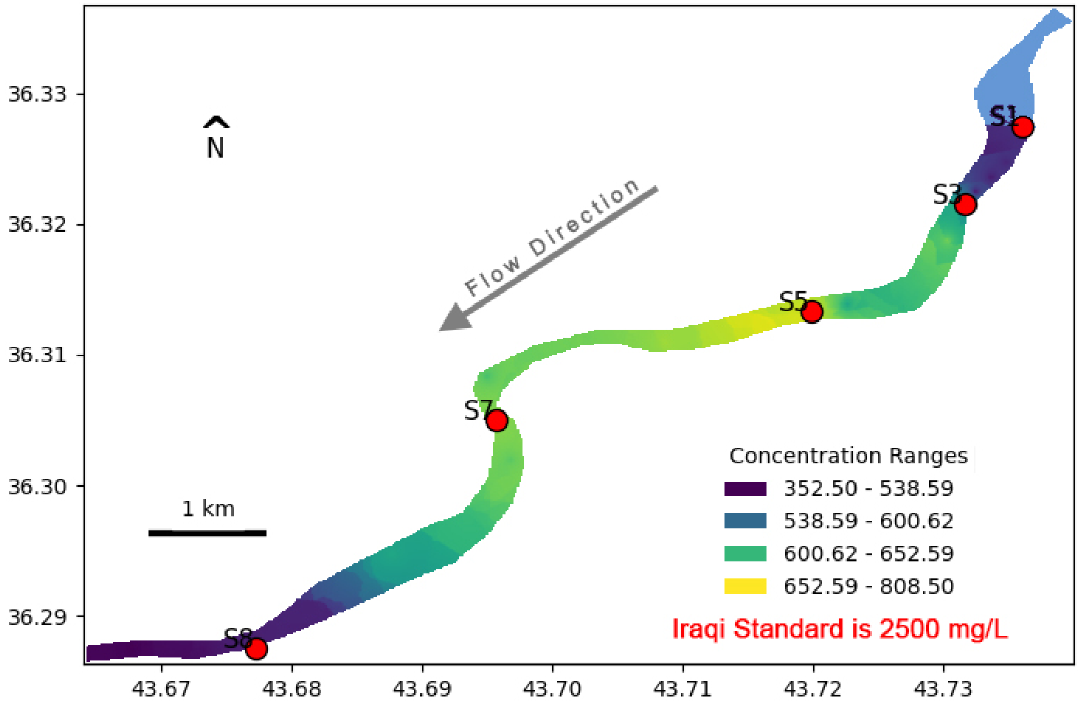

Figure 5.10. Water Quality Map of TDS (Total Dissolved Solids)

The TDS levels observed in the study are indicative of the impact of various industrial and natural processes on water quality. The TDS levels in the wastewater discharges from the Erbil refinery, Cola North Iraq plant, and thermal power plant reflect the influence of industrial activities on water quality, with seasonal variations suggesting potential changes in production or operational processes. Moreover, the fluctuations in TDS levels in upstream and downstream of the Great Zab River indicate the dynamic nature of natural water bodies and their susceptibility to environmental factors, including seasonal variations and anthropogenic influences (Genanaw et al., 2021).

The TDS of a water body can be affected by more than just the magnitude of mineralized and salts in it. Temperature has an effect, as warmer water will tend to dissolve more dissolved solids than cooler water. pH levels have a tendency to impact TDS, and in more acidic conditions, TDS will increase. The inputs of organic materials such as dead plants, industrial pollutants, and agricultural runoff among others are among the factors that contribute to the levels of TDS. Besides that, localization that is close to mineral-rich sources and geological formations has a huge impact on the TDS levels in water resources. Identifying these interrelated factors is a prerequisite while measuring water quality, and any environmental or health complications that result from high TDS levels (Genanaw et al., 2021).

The high TDS levels observed in the thermal power plant wastewater discharge during the summer season are particularly noteworthy, as they indicate a substantial impact on water quality. This finding aligns with previous research on the effects of thermal discharge from power plants on water bodies. Studies have shown that thermal discharge can have negative impacts on water quality, including changes in thermocline characteristics and the abundance of phytoplankton, which can further affect the overall ecosystem of the receiving water body (Huang et al., 2019). Additionally, the decrease in TDS levels after the wastewater discharges flowed into the Great Zab River suggests the potential for dilution and dispersion of pollutants in natural water bodies, highlighting the complex interactions between industrial effluents and receiving environments (Rosen et al., 2015).

The observed TDS levels and their variations underscore the importance of effective wastewater treatment and management practices. Research on the efficiency of wastewater treatment plants (WWTPs) has indicated the need for comprehensive removal of chemical pollutants and microbial contaminants to mitigate the impact of industrial discharges on water quality (Hamed et al., 2016). Furthermore, the study of thermal pollution caused by wastewater discharges from coal-fired power plants emphasizes the significance of evaluating the thermal impact on rivers and coastal areas, highlighting the need for sustainable water resource assessment and management in the context of power plant operations (Fan et al., 2021).

5.6. Effects of Electrical Conductivity:

The Conductivity levels in the Great Zab River at different collection spots present significant seasonal and locational differences across seasons as well as industrial sites. Conductivity varies from 353 to 1082 µS/cm in the upstream segment, with a significant jump during winter (Figure 5.11). Alternatively, the high winter values could suggest increased levels of ion concentration owed to natural processes or elevated runoff from nearby regions during this time these results are lower by three times than Hamdan et al. (2018) which was about 3721 µS/cm in Shatt Al-Arab River and its branches in Iraq and also their results were higher than highest conductivity point (Erbil refinery) which was lower than 2500 µS/cm.

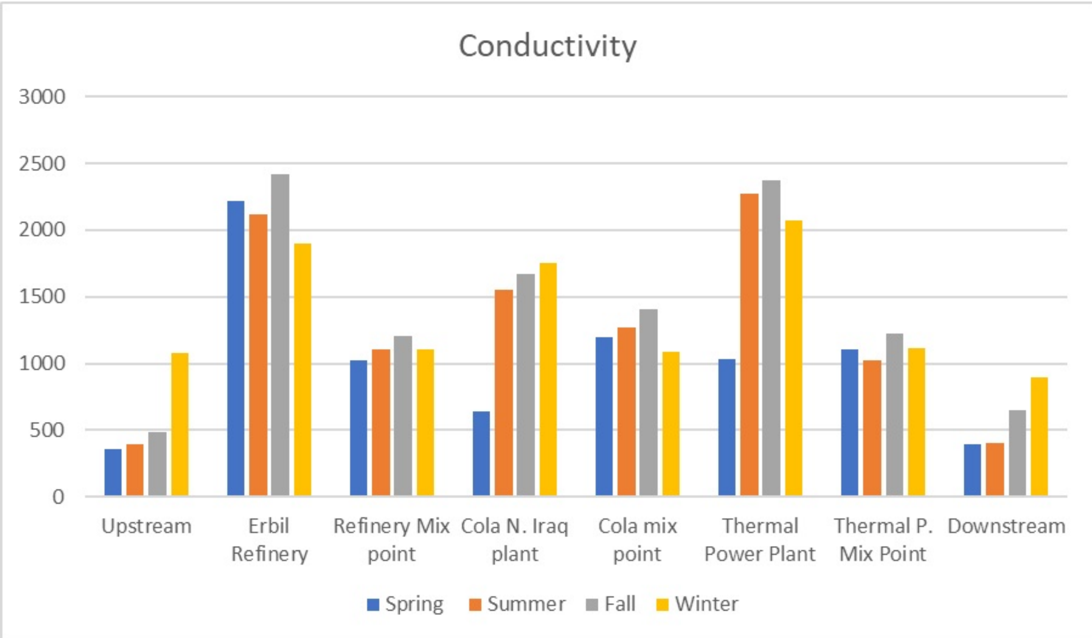

Figure 5.11. Change of Conductivity of the Samples

At Erbil Refinery, Conductivity values hit a maximum of 2416 µS/cm in the fall, which is much higher than those upstream. Since different pollutants and dissolved substances, such as chloride, sulfate, and nitrate, increase the conductivity of water (Chidiac et al., 2023). This implies that ions or pollutants are introduced into water possibly from industrial activities. A slight decrease in Conductivity is also observed when the refinery effluent mixes with river water, indicating that processes within the river itself dilute and help reduce its concentration.

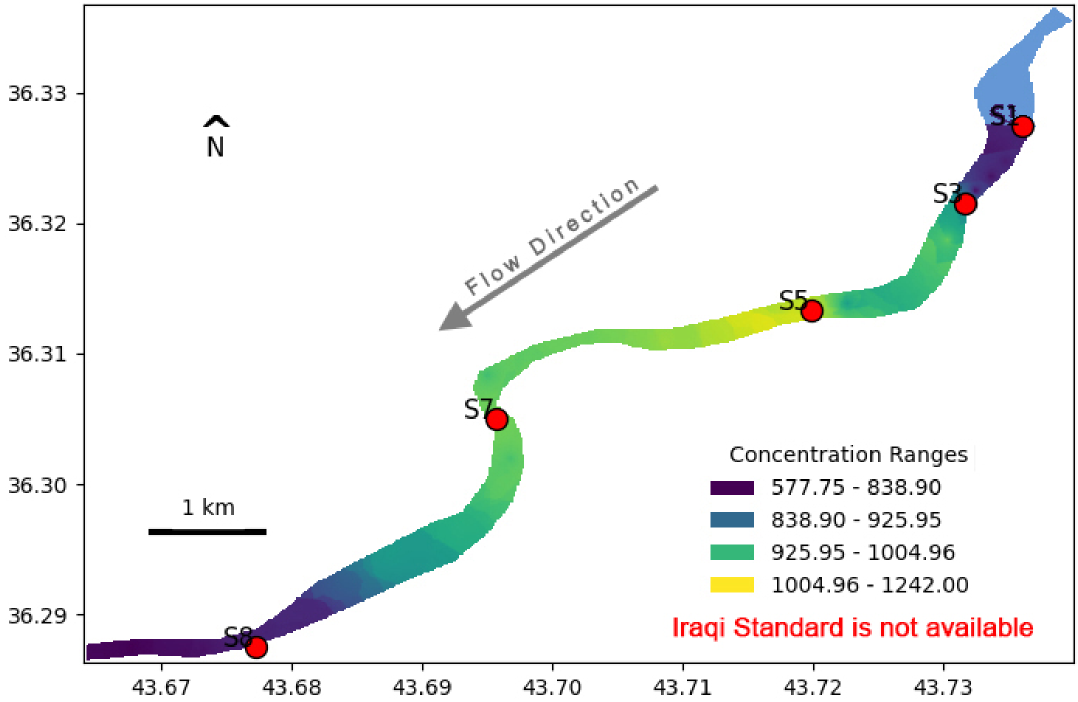

Figure 5.12. Water Quality Map of EC

Much lower than Gazzaz et al. (2013) reported in their case in Thailand (22,164µS/cm), the Cola north Iraq plant sampling point shows different Conductivity levels, the highest values are those recorded in winter 1751µS/cm (Figure 5.11), this may be linked with the manufacturing processes or introduction of ions from raw materials used in Cola production. A decrease in Conductivity occurs when the Cola effluent mixture into river water, indicating that it is only through natural processes of rivers which makes them able to reduce ion concentration as shown in Figure 5.11.

The conductivity of water might be changed by some factors, such as temperature, ion concentration, as well as the presence of impurities. Temperature is the big player here through the temperature dependence of the conductivity. The higher the temperature, the more the conductivity is enhanced through the increased mobility of ions. The concentration of the ions, especially of dissolved salts like sodium chloride, also is one of the direct factors that affect conductivity—the higher the ion concentration, the higher the conductivity. Additionally, conductivity is affected by impurities including organic matter, heavy metals, or contaminants which can change the ion content and movement in water. Hence, conducting the water conductivity test, and taking these variables into account is necessary for the proper measurement and understanding (Hamdan et al., 2018).

It is observed that the Conductivity levels of the Thermal Power Plant vary greatly; with the highest values (2370 μS/cm) recorded in the fall and this was aligned with Hamdan et al. (2018) in Shatt Al-Arab River in Iraq. This could be tied to thermal discharges or the emission of ions from power plant operations. Conductivity increases slightly when the thermal power plant effluent mixes with the river – an effect that could be due to increased ions and pollutants from this large facility.

In the downstream of the river, Conductivity levels show a seasonal difference such that its minimum result in spring is 394 μS/cm and the maximum reads in winter is 892 μS/cm lower than Hamdan et al. (2018) in Shatt Al-Arab River in Iraq. While downstream values are not much higher than industrial points, they are greater than the upstream indicating that there is a gradual increase in industrial inputs on water quality.

The Conductivity results highlight the dynamic interplay of industrial activities, natural processes, and seasonal variations in River Great Zab. Monitor readings of these parameters are important to understand the overall health status of the river ecosystem and manage environmental practices effectively. Regular evaluations and focused inquiries about the causes of high conductivity will help create solutions for reducing industrial releases that affect water quality (Gazzaz et al., 2013).

The conductivity levels in the Great Zab River exhibit significant seasonal and locational variations, particularly in industrial areas. Upstream, the conductivity ranges from 353 to 1082 μS/cm, with a notable increase during winter, possibly due to elevated ion concentration from natural processes or increased runoff from nearby regions as Aziz and Maulood (2015) discovered in their study in Iraq. At the Erbil Refinery, conductivity peaks at 2416 μS/cm in the fall, indicating the introduction of ions or pollutants from industrial activities, with a slight decrease observed when the refinery effluent mixes with river water (Ismaiel et al., 2018). Similarly, the Cola North Iraq plant sampling point shows higher conductivity levels in winter (1751 μS/cm), possibly linked to manufacturing processes or the introduction of ions from raw materials, with a subsequent decrease when the effluent mixes with river water (Said et al., 2004). The Thermal Power Plant exhibits varying conductivity levels, with the highest values (2370 μS/cm) recorded in the fall, likely attributed to thermal discharges or ion emissions from plant operations. Downstream, conductivity levels show seasonal differences, with minimum values in spring (394 µS/cm) and maximum in winter (1892 µS/cm), indicating a gradual increase in industrial inputs on water quality (Ismaiel et al., 2018).

The dynamic interplay of industrial activities, natural processes, and seasonal variations in the Great Zab River underscores the importance of monitoring these parameters to understand the river's overall health status and effectively manage environmental practices. Regular evaluations and focused inquiries into the causes of high conductivity are crucial for developing solutions to reduce industrial releases that impact water quality (Ismaiel et al., 2018).

5.7. Effects of Total Suspended Solids (TSS):

TSS concentrations in the Great Zab River display considerable fluctuations during seasons and at different sampling points, throwing light on how industrial activities affect water quality. TSS levels differ from 38 to 78 mg/L in the upstream section of (Figure 5.13); it reaches its greatest value during spring. This might be due to various reasons like enhanced activity by the vegetation or runoff during this period (Razif, 2022). The upstream values can be used as a reference point to understand the normal variations of suspended solids in nature results were similar to Hamdan et al. (2018) in Iraq which was about 48 to 974 mg/L this comparison is true for all points except the Erbil refinery and its mix point which is dramatically higher about 14 times more.

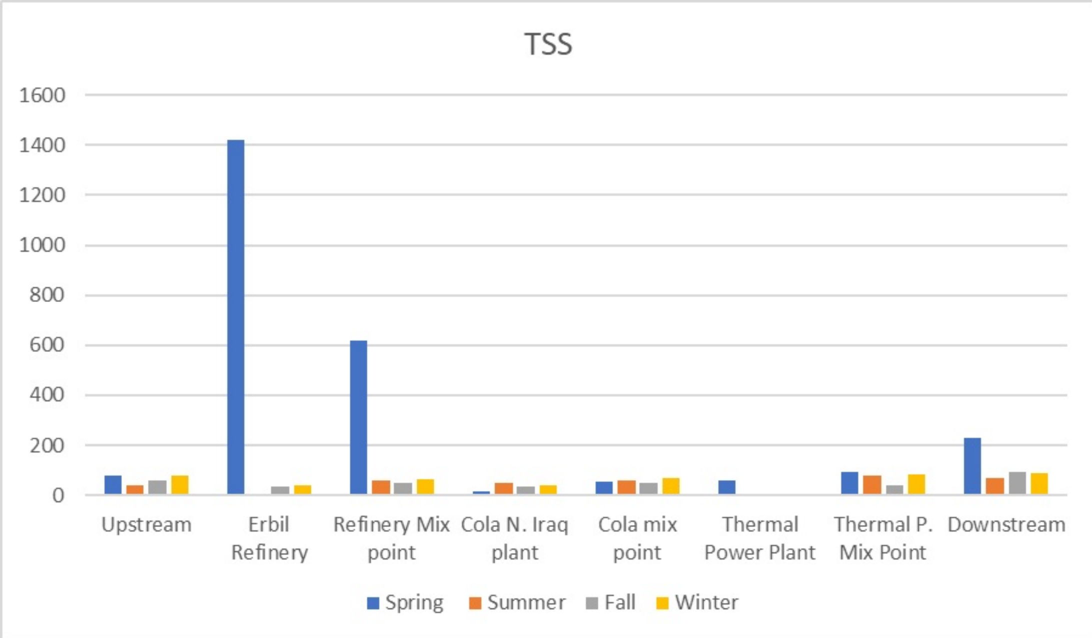

Figure 5.13. Change of TSS Concentrations

The picture contrasts with the Erbil Refinery, where TSS levels span from 4 to an amazingly high number of 1421 mg/L reported in spring (Figure 5.13) aligned with Razif (2022) in Surabaya River, Indonesia. This large increase indicates a possibly significant contribution from industrial effluents, which could additionally include the release of suspended particles into the Mixing of refinery effluent with the river water reducing TSS thus highlighting that it is doing so due to dilution effect and there seems also a possibility for natural processes within the stream itself bring about reduction in inverse relationship (Genanaw et al., 2021).

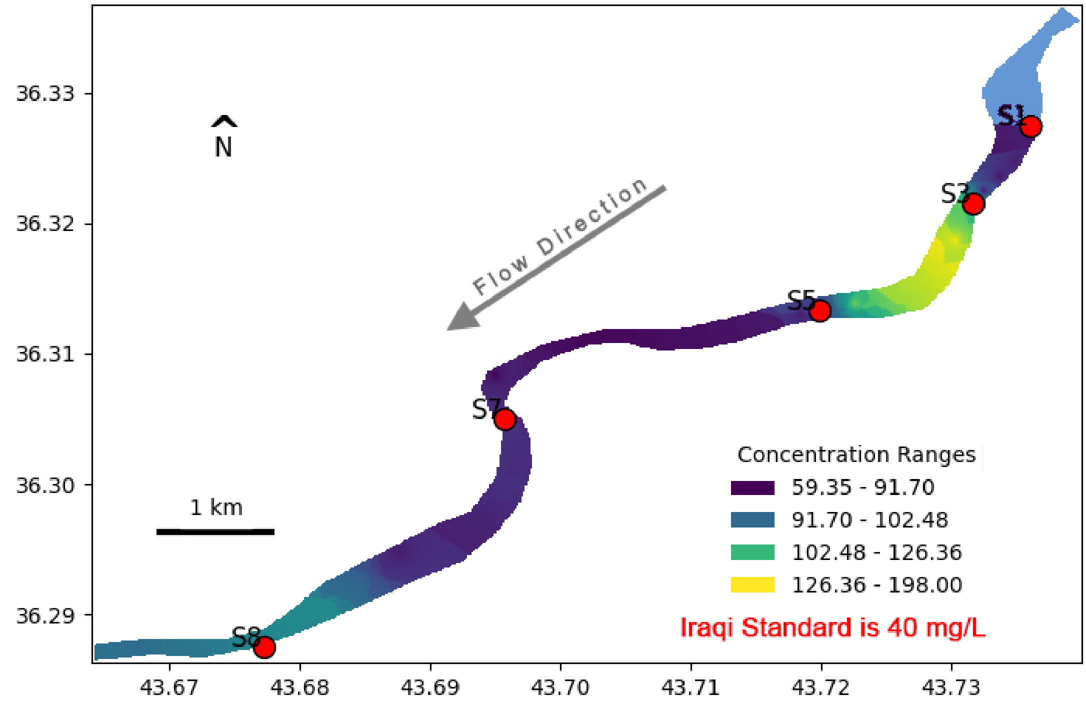

Figure 5.14. Water Quality Map of TSS

TSS levels at Cola North Iraq plant sampling points show a difference; the highest concentrations are observed in summer. This may imply production processes or the possibility of suspended solids coming from raw materials used in Cola could be having some effects on this phenomenon. For instance, high concentration of TSS from Cola effluent in river water indicates limited dilution effect which may pose a challenge to control suspended solids originating from industrial discharge.

TSS levels at Thermal Power Plant are evidence for relatively low variability during the season with the highest concentration recorded in spring. This may relate to particular plant activities (Razif, 2022). TSS increases, mostly during winter when the effluent from the Thermal power plant mixes with river water. The fact that limited dilution effect in winter indicates a somewhat restrained ability for natural river processes to lessen amounts of suspended solids during colder seasons (Kannel et al., 2007).

Downstream of the river, TSS concentrations are seasonal – during spring they reach their highest levels while in summer it is lowest. The downstream values are usually greater than the upstream, suggesting an accumulation effect of industrial inputs in suspended solids. The observed patterns highlighted the roles of natural processes and industrial activities in shaping TSS levels along the Great Zab River (Tumbarski et al., 2019).

The TSS results highlight the importance of industrial activities in determining suspended solids concentrations for that selected portion of the Great Zab River. Therefore, it is essential to monitor and control the TSS levels in order to maintain water quality as well as conserve river ecosystem health. The results stress the importance of implementing focused pollution control policies and further research to establish a clearer understanding of what sources cause these suspended solids in this river system (Genanaw et al., 2021).

The Total Suspended Solids (TSS) concentrations in the Great Zab River exhibit significant fluctuations across seasons and sampling points, shedding light on the impact of industrial activities on water quality (Zhao et al., 2020). The TSS levels vary from 38 to 78 mg/L in the upstream section, with the highest values observed during spring, possibly due to increased vegetation activity or runoff. This variability serves as a reference point for understanding natural TSS variations (Zhao et al., 2020). Conversely, the Erbil Refinery reports TSS levels ranging from 4 to remarkably high values, particularly in spring, indicating a substantial contribution from industrial effluents (Guo et al., 2020). The mixing of refinery effluent with river water reduces TSS, highlighting the dilution effect and the potential for natural processes to reduce TSS levels (Guo et al., 2020).

5.8. Effects of Nitrate:

The quantities of nitrate (NO_3) in the Great Zab River provide a detailed representation of water quality, demonstrating unique trends throughout different seasons and sampling locations. In the upstream segment, the nitrate levels vary between 0.792 and 7.4 mg/L (Figure 5.15), with the highest concentration occurring during the winter season. The observed oscillations may be influenced by natural variables, such as increasing runoff and biological activity, indicating a possible interplay of these elements, results are similar to Ahmed et al. (2020) in Lower Zab River, which was about 3.8 mg/L.

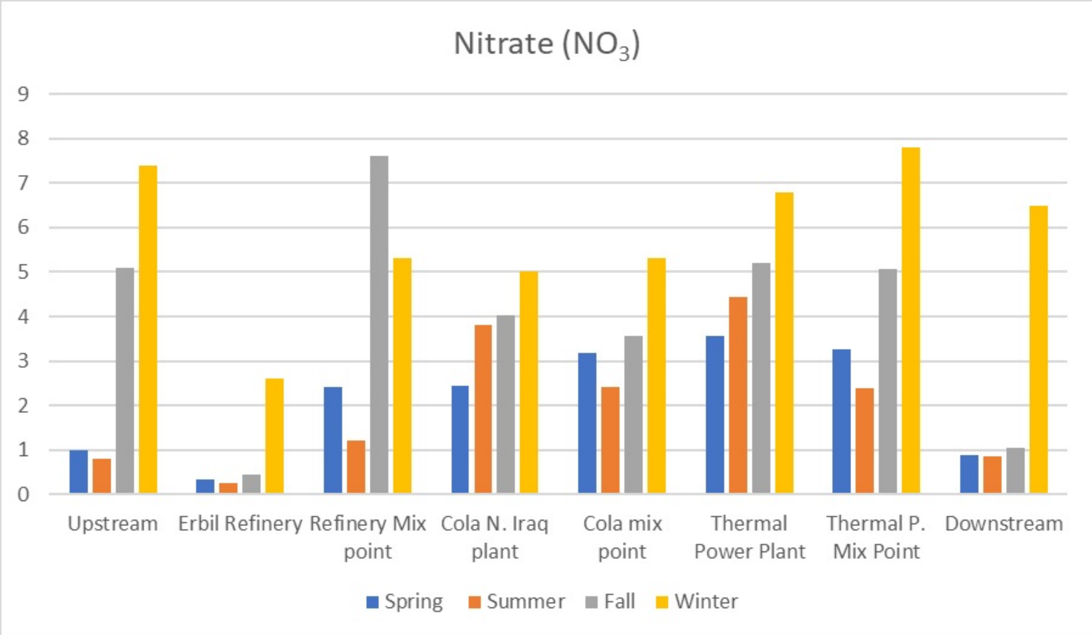

Figure 5.15. Change of Nitrate Concentrations

The Erbil Refinery exhibits a range of nitrate concentrations, ranging from 0.238 to 2.6 mg/L, with the most elevated values observed during the winter season aligned with Ahmed et al. (2020) in south Iraq which was around 3.8 mg/L. The refinery seems to contribute extra nitrate content to the river, potentially associated with industrial discharges or runoff caused by winter precipitation. The combination of the refinery effluent and the river water leads to fluctuating levels of nitrate concentrations, reaching their highest point during the autumn season. This highlights the necessity for rigorous pollution control measures to alleviate the influence of industrial activity on nitrate levels in the river.

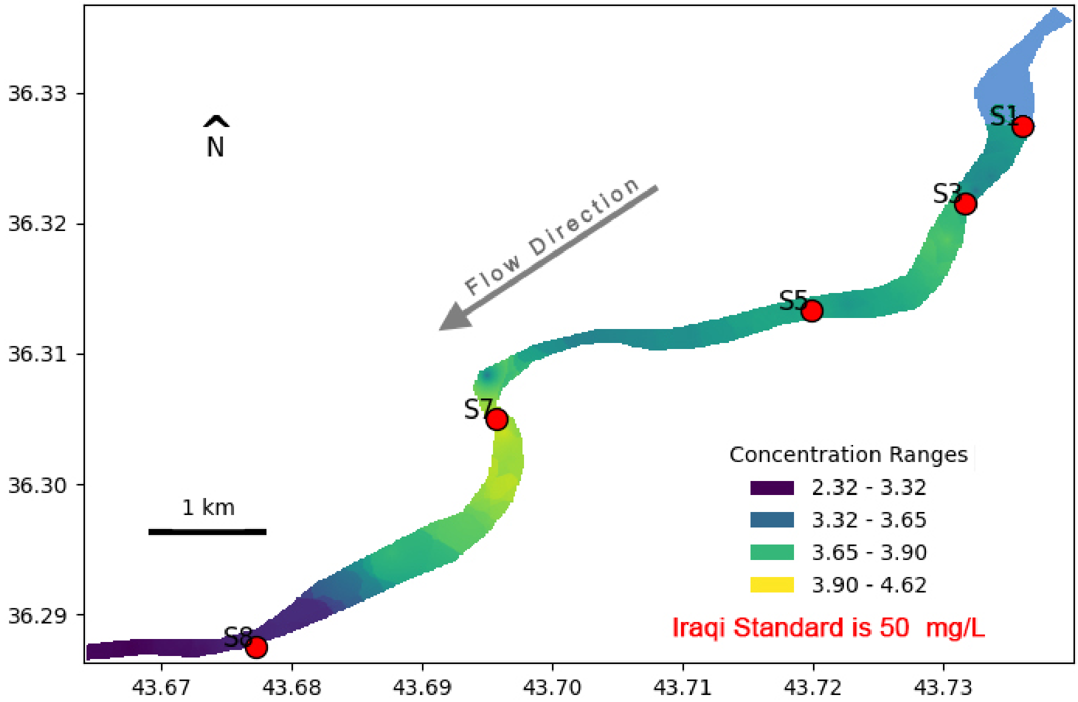

Figure 5.16. Water Quality Map of Nitrate:

Nitrate levels in water can be affected by different parameters such as agriculture, industrial activities, and urban runoffs which are sources of nitrogen compounds in water bodies. Environmental factors such as the temperature, the pH of the water, and the presence of organic matter can affect the nitrogen species transformations, and influence the nitrate concentrations. Moreover, water flow rates and duration of water trapped in the aquatic systems influence the buildup of nitrates or dilution of nitrates. Human activities such as sewage dumping and fertilizer usage are also among the greatest contributors to nitrate levels in water. This demonstrates that the understanding and management of nitrate pollution in aquatic ecosystems often involve various linked factors (Mousavi et al., 2013).

The nitrate concentrations in Cola North Iraq plant sampling stations exhibit significant variability, with levels ranging from 2.44 to 5.01 mg/L as aligned with Banerjee et al. (2019) in India between 0.285-5 mg/L and lower than Hamdan et al. (2018) in Iraq that was between 1.56 to 10.24 mg/L. The winter season exhibits the most elevated levels, suggesting a plausible correlation with manufacturing procedures or the raw materials employed in the production of the Cola North Iraq plant. The mixing of Cola effluent with river water leads to fluctuations in nitrate concentrations, indicating the necessity of implementing efficient wastewater management techniques to reduce the ecological consequences.

The Thermal Power Plant causes fluctuations in nitrate levels, which range from 3.55 to 6.8 mg/L aligned with Banerjee et al. (2019) determined in their research in India between 0.285-5 mg/L, with the maximum amounts occurring during the winter season. The combination of thermal power plant effluent with river water leads to fluctuating nitrate concentrations, which reach their highest point during winter. This highlights the possible impact of industrial emissions on the concentration of nitrates in the water downstream and emphasizes the importance of implementing sustainable water management strategies. In order to safeguard the water quality of the Great Zab River and its surrounding ecosystem, it is crucial to consistently monitor and thoroughly investigate the particular sources and processes that are causing high levels of nitrate (Cude, 2001). This will enable the implementation of focused measures to address the issue.

The Great Zab River experiences fluctuations in nitrate (NO_3) levels, with distinct variations observed across different seasons and sampling locations. In the upstream segment, nitrate concentrations range from 0.792 to 7.4 mg/L aligned with Hamdan et al. (2018) in Iraq, Shatt Al-Arab river that was between 1.56 to 10.24 mg/L., peaking during the winter season. Sigurdarson et al. (2018) found that these oscillations are influenced by natural variables such as runoff and biological activity, indicating a complex interplay of environmental elements. The Erbil Refinery contributes to the river's nitrate content, with concentrations ranging from 0.238 to 2.6 mg/L, reaching the highest levels during winter (Figure 5.15). This suggests a potential association with industrial discharges or winter precipitation runoff. Similarly, the Thermal Power Plant leads to fluctuations in nitrate levels, ranging from 3.55 to 6.8 mg/L aligned with Banerjee et al. (2019) study results in the Birbhum district of the state of West Bengal, India, with the highest concentrations occurring during winter. The combination of industrial effluents with river water results in fluctuating nitrate concentrations, emphasizing the impact of industrial emissions on water quality. Furthermore, the Cola sampling stations exhibit significant variability in nitrate levels, ranging from 2.41 to 5.01 mg/L, with elevated levels during the winter season. This suggests a plausible correlation with manufacturing procedures or raw materials used in Cola production (Sigurdarson et al., 2018).

5.9. Effects of Nitrite

The concentrations of nitrite (NO_2) in the Great Zab River show dynamic changes within seasons and sampling points, enabling an understanding of how industrial activities may affect water quality. In the upstream segment, NO_2 levels are between 0.001 and this varies from 0.014 mg/L in seasonal showing winter slightly higher values (Figure 5.17) as it aligned with Sun et al. (2014) in Hong Kong 0.02-0.15 mg/L. These concentrations are typical of those measured in freshwater systems, indicating that the upstream area is not greatly affected by human activities.

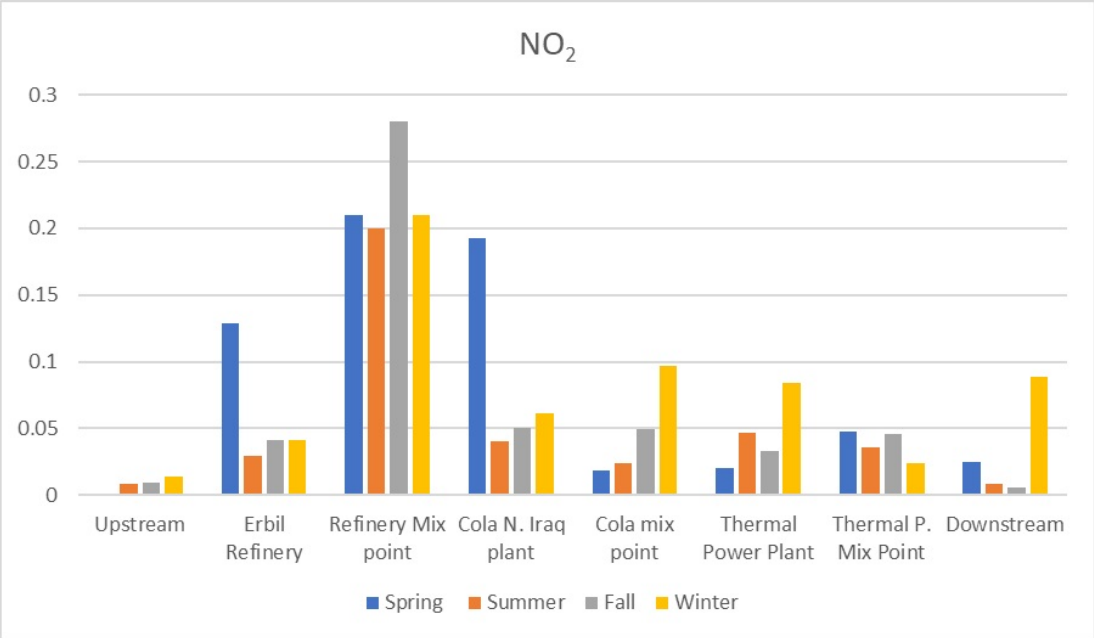

Figure 5.17. Change of Nitrite Concentrations

The Erbil Refinery causes considerable variation in NO_2 concentrations with a range from 0.029 to 0.129 mg/L; peak levels are recorded during spring periods (Figure 5.17). This would imply a probable correlation between industrial activities at the refinery and nitrogen compounds being let into the water. The next mixing of refinery effluent with the water in the river enhances NO_2 up to 0.28 mg/L in the fall This indicates that nitrogen compounds from the refinery make an identifiable contribution to the river which points to a necessity for efficient pollution control, as well as if look at Sun et al. (2014) results vary between 0.22-0.42 mg/L which is similar to this study results in Dongjiang River in Hong Kong.

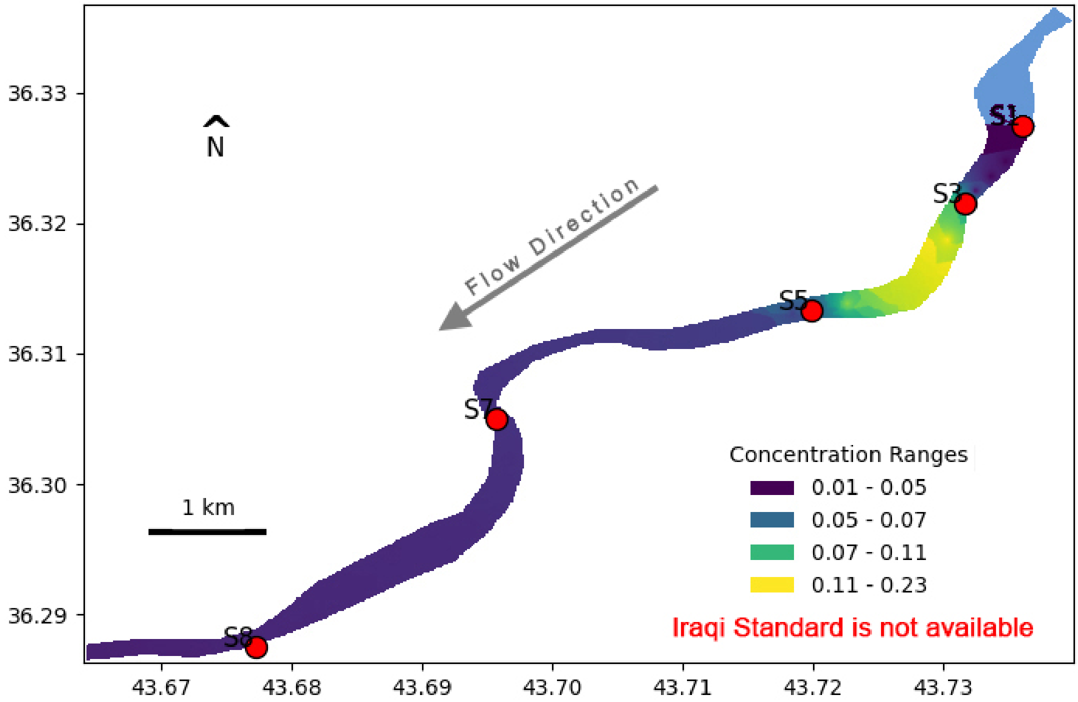

Figure 5.18. Water Quality Map of Nitrite

NO_2 values vary at different Cola sampling points; in spring, the highest concentrations are observed amounting to 0.193 mg/L. When Cola effluent is added to river water, as Mousavi et al. (2013) found in their research in Iran ranged from 0.115-0.245 mg/L, it leads to the levels of NO_2 rising with winter recording the highest concentration at 0.193mg/L These results suggest that industrial effluents may have an effect on nitrogen compound concentrations in the river, highlighting the need to monitor and control these inputs.

The Thermal Power Plant brings variation in NO_2 levels, which vary from 0.02 mg/L to high Concentrations of NO_2 when the effluent from a thermal power plant mixes with river water implying that power plant activities might be contributing to nitrogen compound levels in the river, similar to Ahmed et al. (2020) in Iraq which range between 0.100 to 0.483 mg/L.

Downstream of the river, NO_2 concentrations show a strong seasonal pattern; in winter they reached their maximum value at 0.089 mg/L. these values are well within acceptable limits for freshwater systems, although the results of winter may suggest some impacts from industrial inputs downstream similar to Ahmed et al. (2020) in Iraq which range between 0.100 to 0.483 mg/L.

The Nitrite outcomes highlight those industrial activities may bring about changes in nitrogen compound concentration levels within the Great Zab River. Monitoring NO_2 concentration is an important indicator in determining the quality of water and developing appropriate pollution control interventions. So targeted strategies for preserving the health of the river ecosystem should be developed after further investigations into more specific sources and processes that are associated with higher NO_2 concentrations (Sun et al., 2014).

The concentrations of nitrite (NO_2) in the Great Zab River exhibit dynamic changes within seasons and sampling points, providing insights into the potential impact of industrial activities on water quality. In the upstream segment, NO_2 levels range between 0.001 and 0.005 mg/L and vary seasonally, with slightly higher values in winter, typical of those found in freshwater systems, indicating minimal human activity influence (Ismaiel et al., 2018). However, downstream, NO_2 concentrations show a strong seasonal pattern, reaching their maximum value in winter, suggesting potential impacts from industrial inputs (Ismaiel et al., 2018). The Erbil Refinery and Cola effluents contribute to increased NO_2 levels, with peak concentrations recorded during spring and winter, respectively (Forti et al., 2021). Similarly, the Thermal Power Plant causes variations in NO_2 levels when its effluent mixes with river water, indicating a potential contribution to nitrogen compound levels in the river (Forti et al., 2021). These findings underscore the influence of industrial activities on NO_2 concentrations in the Great Zab River.

The observed variations in NO_2 concentrations highlight the potential impact of industrial effluents on water quality, emphasizing the need for monitoring and pollution control interventions (Forti et al., 2021). This is consistent with the understanding that industrial activities may lead to changes in nitrogen compound concentration levels within the river (Ismaiel et al., 2018). Furthermore, the study emphasizes the importance of NO_2 concentration monitoring as an indicator of water quality and the development of targeted strategies for preserving the health of the river ecosystem (Ismaiel et al., 2018). The need for efficient pollution control measures is evident, particularly in areas where industrial activities contribute to elevated NO_2 levels, such as the Erbil Refinery, Cola sampling points, and the Thermal Power Plant (Forti et al., 2021).

The potential impact of industrial activities on NO_2 concentrations in the Great Zab River aligns with previous research on the correlation between nitrite concentration and the abundance of specific bacterial communities (Sun et al., 2014).

Additionally, the seasonal fluctuations in NO_2 levels and the identification of specific sources contributing to elevated concentrations are consistent with the need for targeted strategies to preserve the river ecosystem (Ismaiel et al., 2018). The findings underscore the importance of understanding the specific sources and processes associated with higher NO_2 concentrations, emphasizing the necessity of efficient pollution control interventions (Ismaiel et al., 2018).

5.10. Effects of Residual Chlorine:

Throughout the Great Zab River, one can observe fluctuations in Residual Chlorine (Cl_2) concentrations that change in both time and location, indicating the potential impact of natural occurrences and human activities. The upper portion of the river contains levels varying from 0.01 to 0.08 mg/L much lower than Al-Ridah et al. (2020) study in Hillah river in Iraq, which is about 50 mg/L, with the highest concentration present during the winter season (Figure 5.19). The rise in levels during this time could be linked to factors like temperature that can affect the stability of chlorine, emphasizing the importance of taking into account seasonal changes when evaluating water quality.

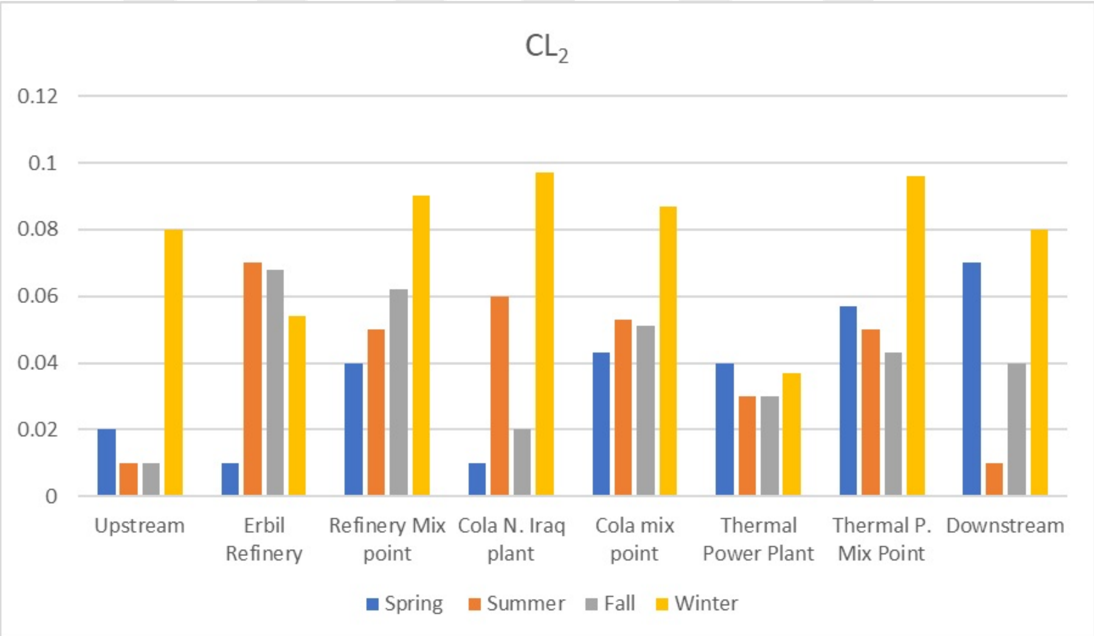

Figure 5.19. Change of Residual Chlorine Concentrations

At the Erbil Refinery, the levels of residual chlorine fluctuate between 0.01 to 0.07 mg/L same as Hernández-Romero et al. (2004) in southern Mexico between 0.008 to 0.084 mg/L, with the highest concentrations observed during the summer months. This indicates the utilization of chlorine-based disinfectants or chemicals at the refinery, potentially leading to heightened levels in the nearby river water. The mixing of the refinery effluent with the natural waterway results in variable chlorine concentrations, with the peak levels observed in winter. This highlights the possible interaction between industrial discharges and environmental factors, emphasizing the importance of a comprehensive approach to water quality control.

Similarly, at the Cola sampling point, residual chlorine levels exhibit variability, with the highest concentrations observed in winter (up to 0.097 mg/L). The winter increase may signify the impact of industrial processes or substances used in Cola production on chlorine concentrations. When Cola effluent mixes with the river water, the resulting chlorine concentrations vary seasonally, with elevated levels in winter. This implies that the effluent from Cola contributes to the overall chlorine content in the river, and compared to Hernández-Romero et al. (2004) in Mexico was much lower than their results vary between 0.09-1.8 mg/L aligned with Mohammad et al. (2021) study which chlorine levels vary between 0.01 to 3.56 m/L in Khosar and Tigris rivers in Basrah, Iraq.

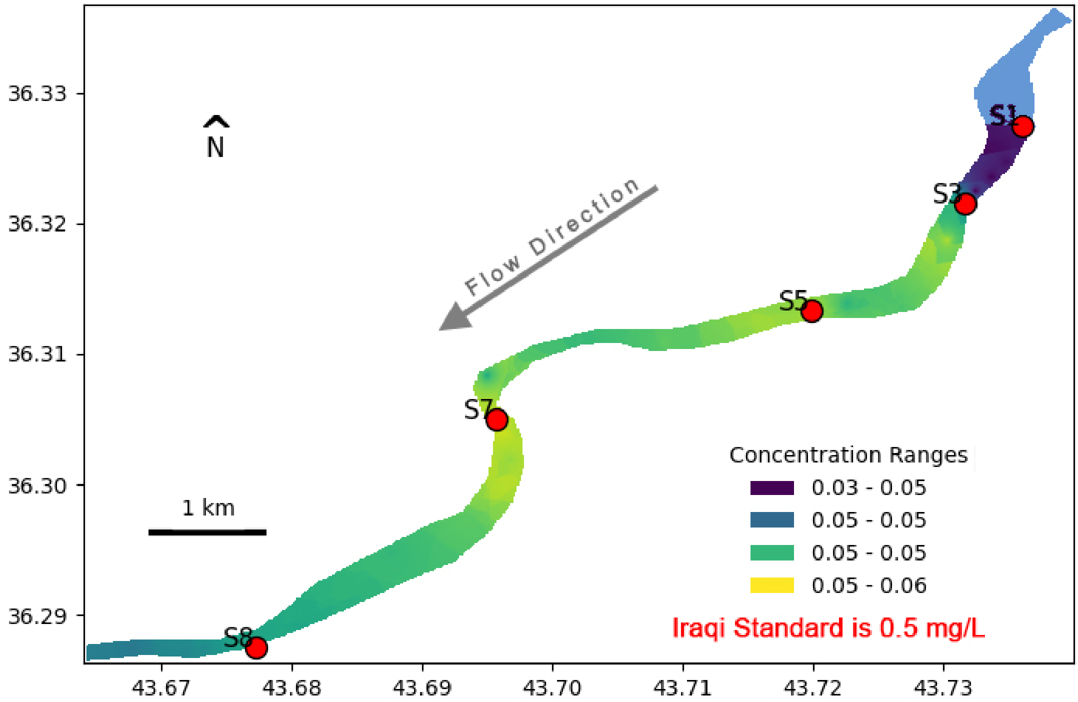

Figure 5.20. Water Quality Map of Residual Chlorine

The Thermal Power Plant introduces relatively stable residual chlorine levels across seasons, ranging from 0.03 to 0.04 mg/L aligned with Mohammad et al. (2021) study in which chlorine levels vary between 0.01 to 3.56 m/L in Khosar and

Tigris rivers in Basrah, Iraq. However, mixing the thermal power plant effluent with the river water leads to variable chlorine concentrations, with the highest values observed in winter. This suggests that both industrial discharges and natural processes in the river influence chlorine levels downstream.

Water residual chlorine (Cl_2) levels are affected by a lot of factors most of them being the temperature, the pH levels, the contact time, the initial chlorine concentration, and also the presence of organic and inorganic substances. Higher temperatures can facilitate chlorine disintegration, and pH levels might affect the production of the different chlorine species, which will influence the disinfection efficiency. Prolonged contact time with chlorine usually causes the production of chlorine organics which are formed during reactions between the chlorine and organic matter. The first thing that affects the chlorine demand is the initial chlorine concentration itself, the higher the concentration, the more residual chlorine is produced. Besides, the natural compounds may soak up chlorine, thus reducing residual levels, while inorganic substances such as ammonia can produce chloramines that can be changed into disinfection byproducts. Such parameters as pH, temperature, and residual chlorine are essential for making sure the water treatment is appropriate and safe (Roth and Cornwell, 2018).

Downstream of the river, residual chlorine concentrations display seasonal variability (Figure 5.19), with the highest values recorded in winter. While these values fall within the acceptable range for disinfection, the observed increase in winter may indicate the cumulative impact of industrial inputs. Continued monitoring and further investigation into the specific sources and processes contributing to residual chlorine levels are essential for effective water quality management and ensuring the sustainability of the Great Zab River ecosystem (Hernández-Romero et al., 2004).

Based on the provided references, it is evident that residual chlorine concentrations in the Great Zab River exhibit fluctuations influenced by both natural occurrences and human activities. The upper portion of the river displays varying levels of residual chlorine, with the highest concentrations observed during the winter season (Roth and Cornwell, 2018). This seasonal variation may be attributed to factors such as temperature, which can impact the stability of chlorine, emphasizing the significance of considering seasonal changes when assessing water quality (Roth and Cornwell, 2018).

Furthermore, at the Erbil Refinery and the Cola North Iraq plant sampling point, the levels of residual chlorine fluctuate, with the highest concentrations observed during the summer and winter months, respectively. These fluctuations suggest the potential impact of industrial activities on chlorine levels in the nearby river water. Additionally, the Thermal Power Plant introduces relatively stable residual chlorine levels across seasons, but the mixing of its effluent with the river water leads to variable chlorine concentrations, with the highest values observed in winter. Downstream of the river, residual chlorine concentrations display seasonal variability, with the highest values recorded in winter, indicating the cumulative impact of industrial inputs (Roth and Cornwell, 2018).

The references provide valuable insights into the factors influencing residual chlorine concentrations in water bodies. It is evident that industrial activities, such as those at the Erbil Refinery, Cola sampling point, and Thermal Power Plant, can contribute to fluctuations in residual chlorine levels in nearby river water. The seasonal variations observed in residual chlorine concentrations underscore the complex interplay between natural processes and human activities, emphasizing the need for a comprehensive approach to water quality control (Roth and Cornwell, 2018).

5.11. Effects of Oil and Grease:

Oil & Grease concentrations in the Great Zab River have a rather complicated nature, reflecting also seasonal patterns apart from industrial discharges. In the upstream section, it varies from 3.6 to 5.2 mg/L with a summer peak sighted in this section as well (Figure 5.21) as Singh and Shikha (2018) in Iraq that were around 5 mg/L determined in their study. These values set a standard for basic changes in oil and grease contents prior to any form of direct industrial input. Such a small increase observed in summer may be associated with greater runoff or the supply of organic matter.

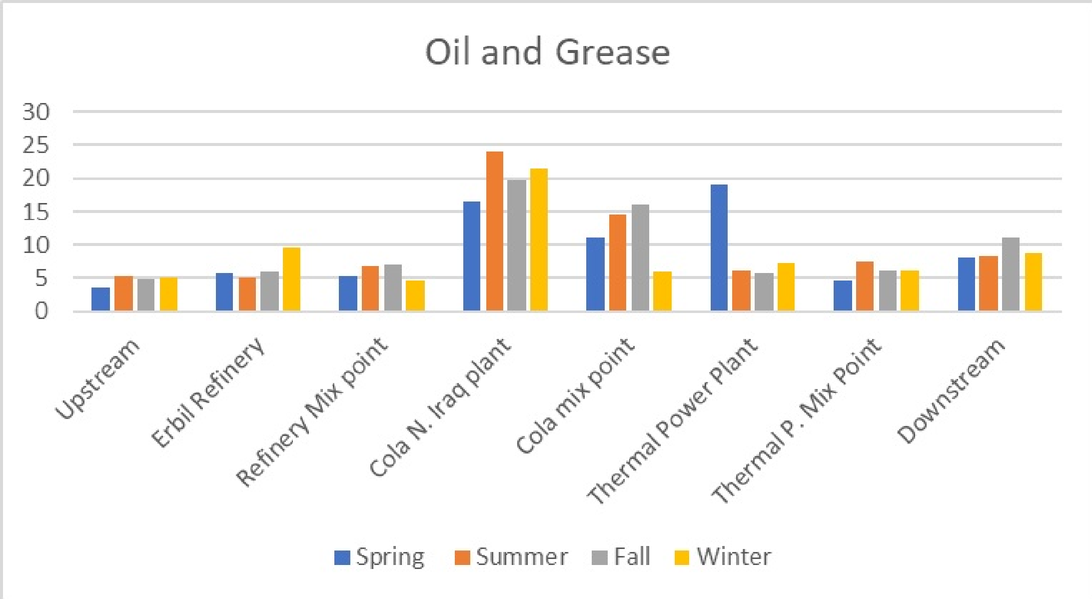

Figure 5.21. nge of Oil and Grease Concentrations

At the Erbil Refinery, Oil & Grease concentrations show significant disparities; readings vary from 5 to 9.6 mg/L The maximum amount is observed in winter periods lower than Hernández-Romero et al. (2004) study in tropical coastal wetlands in southern Mexico. This indicates that there are substantial influences from industrial activities suggesting probable discharge of oil and grease into the river. The refinery effluent when added to river water gives different concentrations that peak during fall. This duality indicates the complicated relationships between industrial effluence and the natural processes of this river.

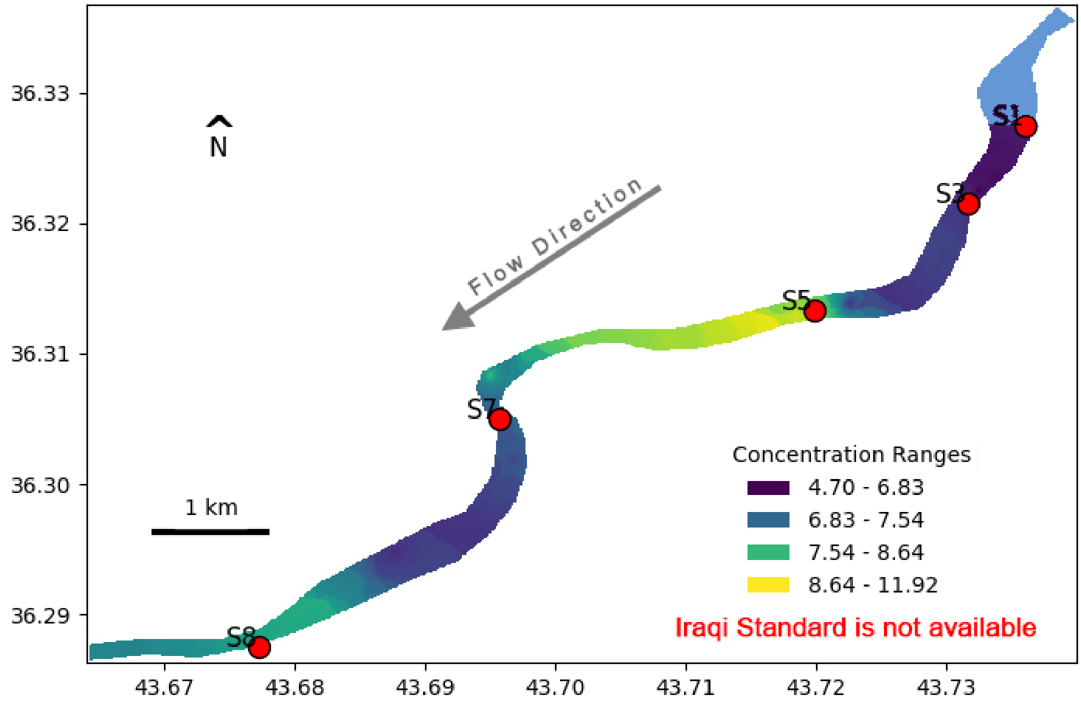

Figure 5.22. Water Quality Map of Oil & Grease

Oil and grease at the Cola North Iraq plant are highest compared to other wastewater discharges, the lowest is 16.5 mg/L and the highest is 24 mg/L this high level of Oil and grease may associated with the production process or the raw materials these ranges are much higher as Hernández-Romero et al. (2004) study in the southern coastal wetland in Mexico, and higher than Eljaiek-Urzola et al. (2019) study in the city of Cartagena, Colombia which ranged between 0-3.8 mg/L. If Cola effluent merges with the river, concentrations are reduced and they underline the dilution effect but also natural processes that mitigate industrial inputs.

The Thermal Power Plant brings in variations of Oil and Grease concentrations from 5.8 to 19 mg/L, where the highest was seen during the spring season. The effluent from the thermal power plant when mixed up with river water gives various amounts which is high in summer (Figure 5.21). This variability may perhaps be due to certain plant activities or emissions into the river which affect oil and grease content downstream results of this parameter are higher than other researchers like Singh and Shikha (2018) in Iraq which was around 5 mg/L.

In the case of water, Oil and Grease there are several factors interconnected, which on the one hand are indicators of their environmental impact and on the other hand, they define the norms for their management. These are such particulate matter as Total Suspended Solids (TSS), which form a cloud of solid particles in water. Such solids are used as indicators of water pollution. The chemical oxygen demand (COD) is an indicator of the oxygen in the chemical processes of the water (often elevated by oil and grease). pH level is the most important factor that determines the solubility of WOG components, and it also provides suitable conditions for biological processes in the water bodies. Also, the conductivity and turbidity measurements could be a valuable tool in revealing the presence and concentration of water, Oil and Grease which in turn could enhance the monitoring of pollution and strategies to mitigate it (Eljaiek-Urzola et al., 2019).

As the river progresses downstream, Oil and Grease concentrations also show seasonal trends with peak values observed in the fall. Although these concentration levels are within acceptable limits for freshwater systems, the increase in fall shows that environmental stress has been accumulating downstream at industrial inputs. Developing appropriate pollution control measures and the ecological integrity of the Great Zab River requires continued monitoring, and targeted investigations at source specifics relating to oil and grease.

Oil and grease concentrations in the Great Zab River exhibit a complex nature, influenced by seasonal patterns and industrial discharges. In the upstream section, concentrations range from 3.6 to 5.2 mg/L, with a summer peak observed. These variations are likely associated with increased runoff or organic matter supply (Ismaiel et al., 2018). At the Erbil Refinery, significant disparities in oil and grease concentrations are noted, varying from 5 to 9.6 mg/L, with the highest levels observed in winter, indicating substantial influences from industrial activities. Similarly, the Thermal Power Plant introduces variations in concentrations, ranging from 5.8 to 19 mg/L, with the highest levels observed during the spring season. As the river progresses downstream, oil and grease concentrations exhibit seasonal trends, with peak values observed in the fall, indicating the accumulation of environmental stress from industrial inputs (Singh and Shikha, 2018).

5.12. Effects of Fluoride:

The levels of fluoride in the Great Zab River vary significantly across different seasons and sample locations, indicating the complex interaction between natural factors and potential industrial impacts. The fluoride levels in the upstream region vary between 0.2 and 0.411 mg/L, with the spring exhibiting the maximum concentration (Figure 5.23) higher than Jimenez-Farfan et al. (2004) results in

Mexico City and lower than Mutlak (1985) study in Iraq which was around 0.8 mg/L. The observed values are within the anticipated range for freshwater systems, indicating a natural reference point for the fluoride concentration in the absence of notable human influences.

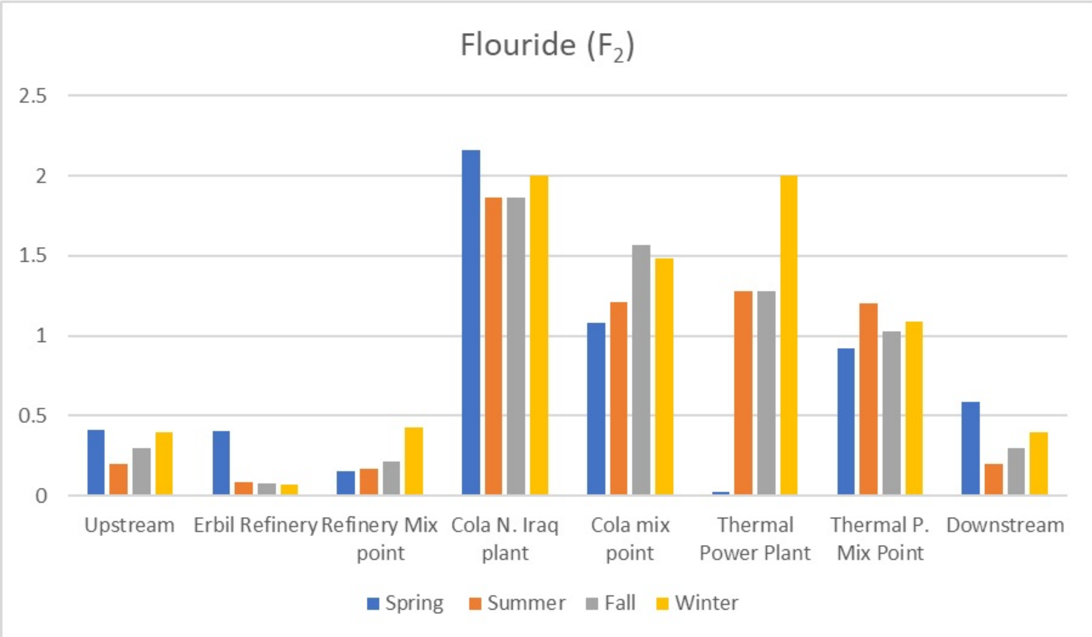

Figure 5.23. Change of Fluoride Concentrations

Fluoride concentrations at the Erbil Refinery range from 0.071 to 0.403 mg/L, with the maximum levels seen during the spring season approximately similar to Jimenez-Farfan et al. (2004) results in Mexico City lower than Mutlak (1985) study in Iraq which was around 0.8 mg/L. This unpredictability may be associated with industrial operations at the refinery, suggesting the possible discharge of fluoride into the river. The subsequent blending of refinery effluent with the river water leads to fluctuating fluoride concentrations, with the most elevated levels reported around winter. These findings indicate that industrial emissions are a contributing factor to variations in fluoride levels, which in turn impact the overall quality of the river's water.

The fluoride levels in Cola north Iraq plant sampling points exhibit significant variation, with amounts ranging from 1.86 to 2.16 mg/L in spring, these results are aligned with Yousefi et al. (2019) research results in northwest Iran which was between 0.29 to 6.68 mg/L. The elevated levels of fluoride detected at the Cola North Iraq plant location may be linked to the manufacturing procedures or the specific ingredients utilized in the production of the Cola North Iraq plant. Fluoride concentrations in the river water exhibit fluctuation when mixed with Cola North Iraq plant wastewater, with the peak amounts being seen during the autumn season. The observed oscillations may be attributed to the dilution effect and natural processes occurring in the river (Yousefi et al., 2019). The fluoride concentrations ranged between 0.29 to 6.68 and 0.1 to 11.4 mg/L in the cold and warm seasons.

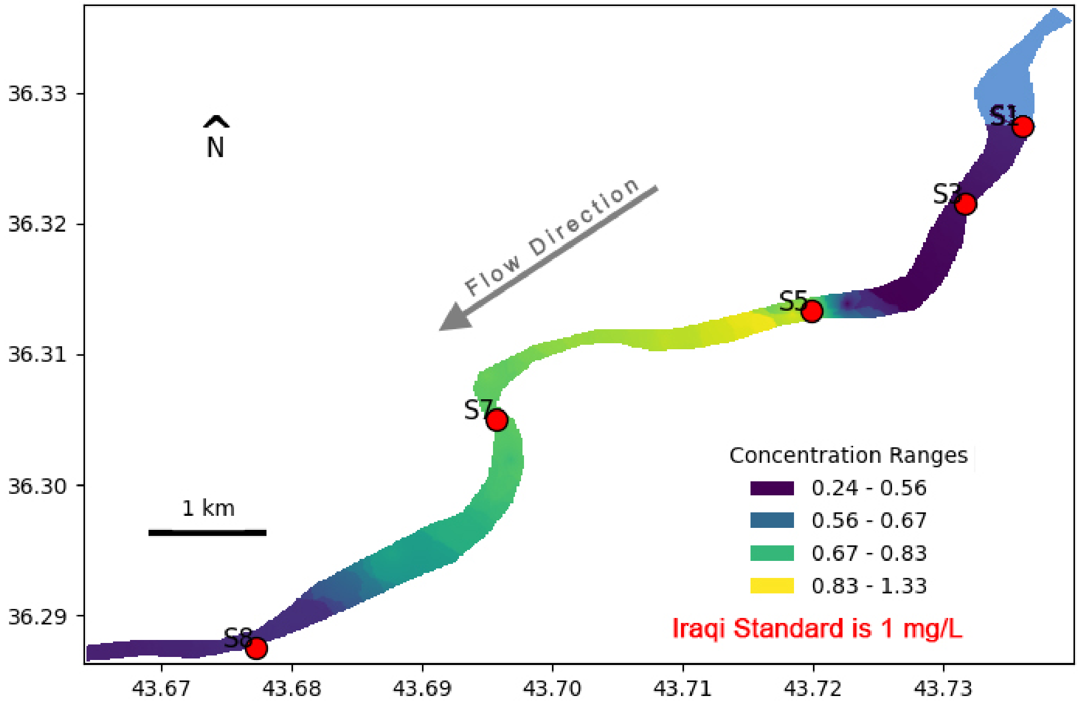

Figure 5.24. Water Quality Map of Fluoride

The Thermal Power Plant causes notable fluctuations in fluoride levels, which range from 0.025 to 2 mg/L, with the highest amounts occurring during winter, these ranges are similar to those Jimenez-Farfan et al. (2004) determined in their study in Mexico City, and near the result of Karanikola et al. (2018) result in united states which ranged between 0.18 to 3.6 mg/L, with the highest amounts occurring during winter, suggesting the influence of industrial operations or emission characteristics on fluoride levels (Jimenez-Farfan et al., 2004). This unpredictability could be associated with certain operations conducted at the power plant or the characteristics of the emissions. Fluoride concentrations in the river water fluctuate when it combines with the thermal power plant effluent, with the peak levels occurring during the summer season. The observed oscillations underscore the possible influence of both industrial discharges and natural processes on the amounts of fluoride in the river downstream.

While speaking about fluoride in water, one should remember that there are other factors to be taken into account next to its concentration. Some of the examples are the fluoride source which could be natural or through the fluoridation programs; the overall quality of the water which includes pH levels and the mineral content that can affect the solubility and availability of fluoride; the population being served as different age groups and health conditions could require varying levels of fluoride exposure; and the regulations set by the health authorities to ensure the safety and effectiveness of Fluor (Aoun et al., 2018).

The findings of the Fluoride study emphasize the importance of ongoing surveillance and examination of the precise origins and mechanisms responsible for the levels of fluoride in the Great Zab River. Comprehending the inherent fluctuations in nature and discerning possible impacts from human activities are essential measures for successful water quality control and safeguarding the river's biological well-being (Jimenez-Farfan et al., 2004).

The levels of fluoride in the Great Zab River exhibit significant variations across different seasons and sample locations, indicating a complex interplay between natural factors and potential industrial impacts. The fluoride concentrations in the upstream region range from 0.2 to 0.411 mg/L, with the highest levels observed during the spring season (Jimenez-Farfan et al., 2004). These values fall within the expected range for freshwater systems, suggesting a natural reference point for fluoride concentration in the absence of significant human influences (Yousefi et al., 2019). However, at the Erbil Refinery, fluoride concentrations range from 0.071 to 0.403 mg/L as shown in Figure 5.23, with the highest levels occurring during the spring, indicating potential industrial impacts on the river's fluoride levels (Jimenez-Farfan et al., 2004). The blending of refinery effluent with river water leads to fluctuating fluoride concentrations, with the highest levels reported around winter, further emphasizing the influence of industrial emissions on fluoride variations (Jimenez-Farfan et al., 2004).

5.13. Effects of Phosphate

The quantities of phosphate (PO_4) in the Great Zab River exhibit a varied seasonal and regional pattern, indicating the complex interaction between natural processes and possible industrial inputs. The phosphate levels in the upstream region vary between 0.29 and 3.6 mg/L, with the peak concentration occurring during the winter season (Figure 5.25) these ranges are not aligned with Hamdan et al.

(2018) study in Iraq which ranges between 0.25 to 2.47 mg/L. The observed fluctuation in seasons indicates the impact of variables such as temperature, biological processes, and possible drainage from nearby regions. The heightened phosphate levels seen during winter may suggest an augmentation in nutrient influx or modified ecological dynamics occurring in the colder months.

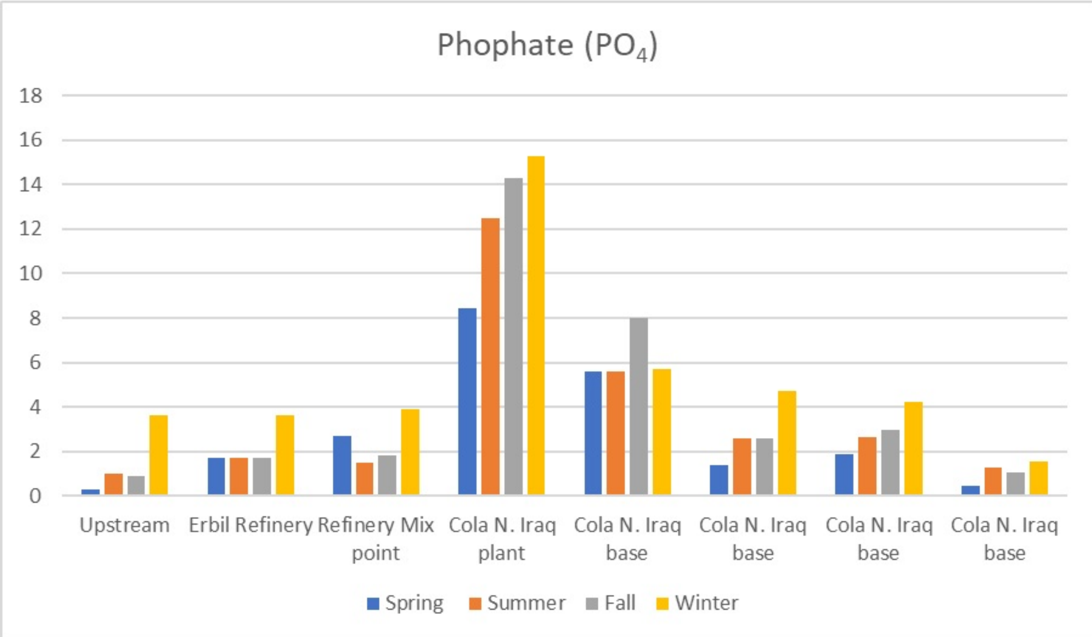

Figure 5.25. Change of Phosphate Concentrations

The phosphate concentrations at the Erbil Refinery remain constant at 1.7 mg/L throughout three seasons (Figure 5.25). The consistent nature of this data indicates a consistent discharge of phosphates from industrial operations at the refinery throughout the whole year. Only during winter fluctuating levels of phosphate concentrations, reach a maximum of 3.6 mg/L during the winter season. This highlights the influence of industrial emissions on phosphate levels, especially in colder seasons when there may be a decrease in biological processes this point results are aligned with Hamdan et al. (2018) study results in Iraq which range between 0.25 to 2.47 mg/L.

The sampling sites for the Cola North Iraq plant indicate a notable variation in phosphate levels, ranging from 8.44 to 15.3 mg/L higher than Hamdan et al. (2018) results in Shatt Al-Arab in the south of Iraq, with the highest amounts seen during the winter season. The variation in phosphate discharge from Cola North Iraq plant manufacture may be caused by differences in production procedures or the raw materials utilized, suggesting that industrial activities could have an impact.

Phosphate concentrations in the river water show fluctuations when Cola North Iraq plant waste combines with it, with the peak values occurring during the autumn season. The seasonal dynamics of phosphate concentration in the river are influenced by the dilution impact and the involvement of natural processes, according to Banerjee et al. (2019) in Birbhum district of the state of West Bengal, India, these results are higher than normal so their results were around 4-6 mg/L.

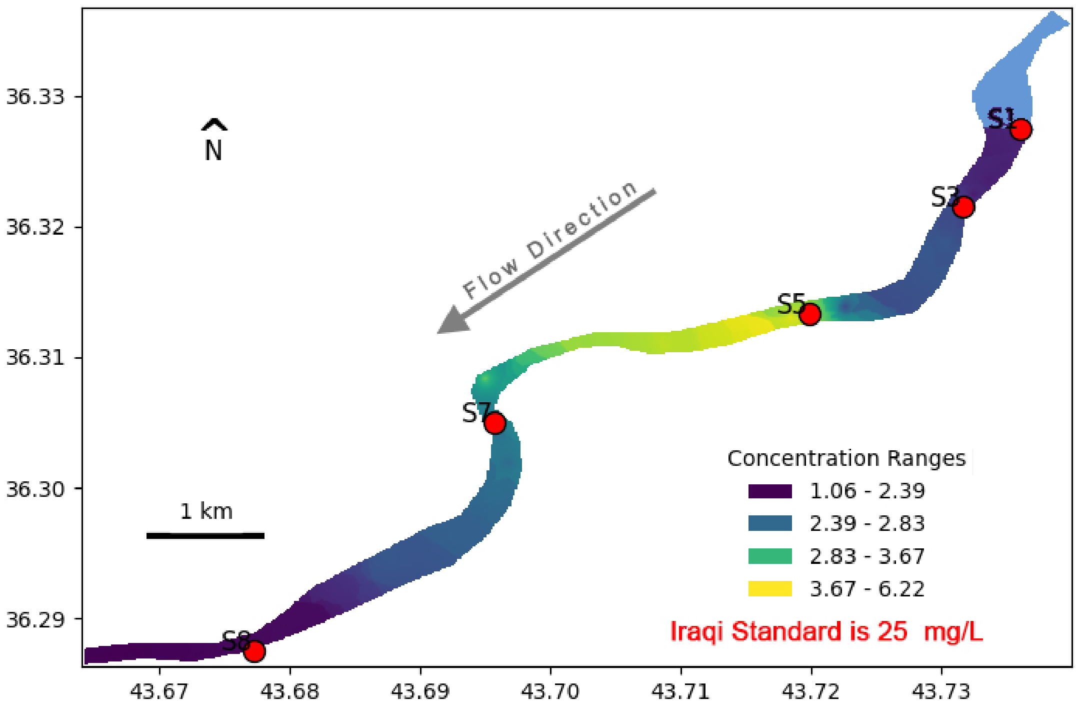

Figure 5.26. Water Quality Map of Phosphate

The Thermal Power Plant causes fluctuations in phosphate levels, which can range from 1.39 to 4.7 mg/L approximately similar to Banerjee et al. (2019) findings in Birbhum district of the state of West Bengal, India. The highest concentrations are typically found during the winter season. The mixing of thermal power plant effluent and river water leads to fluctuating levels of phosphate concentrations, with a maximum of 4.2 mg/L seen during the winter season. This emphasizes the possible influence of both industrial emissions and seasonal fluctuations on the concentration of phosphate in the downstream area (Banerjee et al., 2019).

Phosphate concentrations in the river's downstream exhibit seasonal fluctuations, reaching their peak during winter at a measured value of 1.52 mg/L aligned with Hamdan et al. (2018) study in Shatt Al-Arab in Iraq which ranges between 0.25 to 2.47 mg/L. Although the observed changes in phosphate content generally fall below permissible ranges for freshwater systems, they may suggest the cumulative impact of industrial inputs on these values. It is essential to continue monitoring and conducting thorough research to identify the precise sources that are causing high levels of phosphate in order to implement efficient water quality management measures and maintain the biological equilibrium of the Great Zab River (Hamdan et al., 2018).

The phosphate levels in the Great Zab River exhibit a varied seasonal and regional pattern, indicating the complex interaction between natural processes and possible industrial inputs. The upstream region shows phosphate levels varying between 0.29 and 3.6 mg/L, with the peak concentration occurring during the winter season this fluctuation suggests the impact of variables such as temperature, results are aligned with Hamdan et al. (2018) in Iraq, biological processes, and possible drainage from nearby regions. The heightened phosphate levels during winter may suggest an augmentation in nutrient influx or modified ecological dynamics occurring in the colder months (Hamdan et al., 2018).

5.14. Effects of Lead (Pb):

The concentrations of lead (Pb) in the Great Zab River offer valuable insights into the possible impact of human-induced activities on the quality of water. The lead concentrations observed upstream in the Great Zab River are relatively low, varying between 0.077 and 0.114 mg/L (Figure 5.27) aligned with Tonkin et al. (2017) results in United States and lower than Al-Asadi et al. (2020) study in Shatt Al-Arab River, Basra, Iraq which was between 12.2 to 21.3 mg/L. The observed values are consistent with the expected background levels in freshwater systems, indicating that the environment upstream is comparatively uncontaminated by human activities.

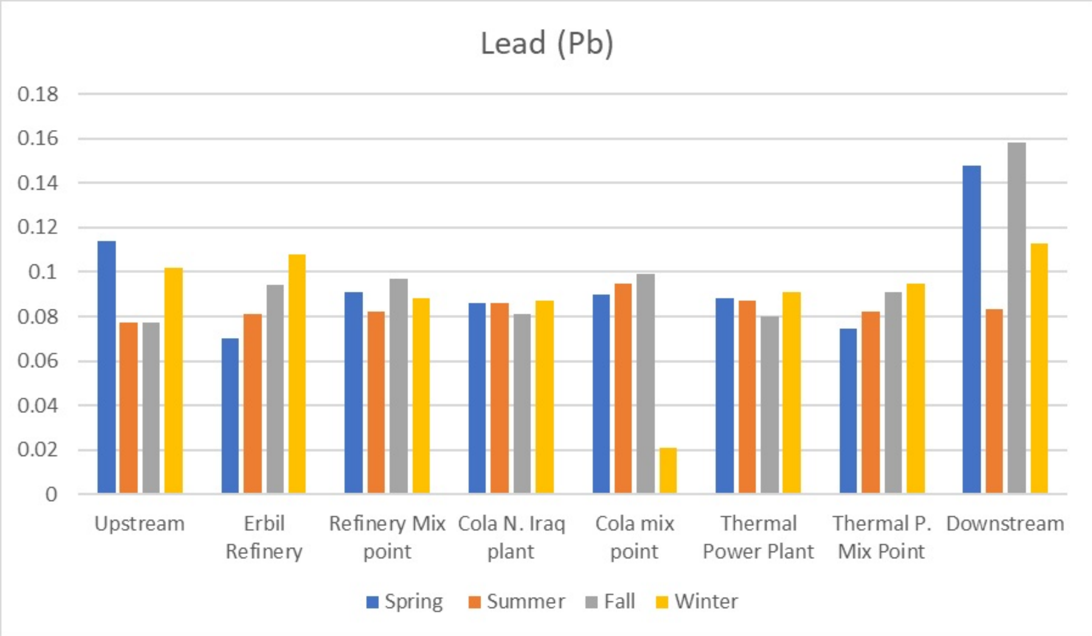

Figure 5.27. Change of Lead (Pb) Concentrations

Seasonal fluctuations in lead concentrations are evident at the Erbil Refinery, where winter months yield the maximum levels at 0.108 mg/L aligned with Tonkin et al. (2017) in the United States and lower than Al-Asadi et al. (2020) study in Shatt Al-Arab River, Basra, Iraq which was between 12.2 to 21.3 mg/L. Although the concentrations persist at low levels, the seasonal variations could potentially signify the impact of refinery-related industrial activities, especially during the winter season. The lead concentrations in the river water and refinery effluent are comparable, suggesting that the refinery has a consistent impact on lead levels throughout the entire year.

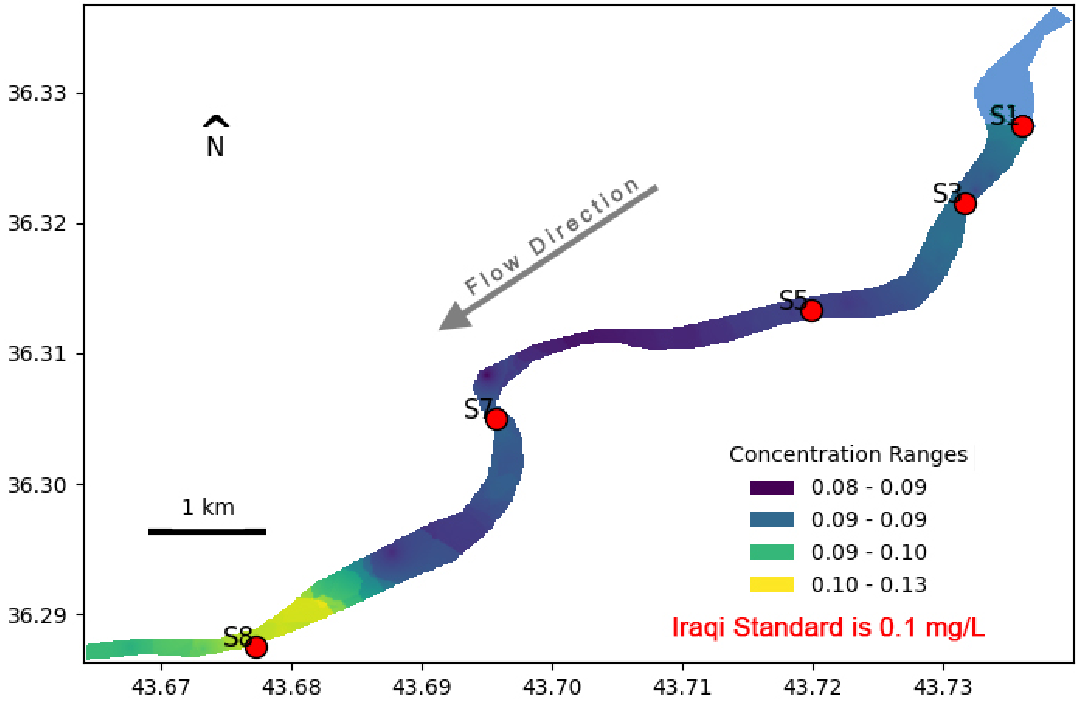

Figure 5.28. Water Quality Map of Pb (Lead)

Seasonally, lead concentrations at the Cola North Iraq plant site range between 0.081 and 0.087 mg/L, which is a stable and consistent value. This indicates that the manufacturing processes of the Cola North Iraq plant have a minimal effect on the lead concentrations in the river. However, lead concentrations fluctuate when Cola North Iraq plant effluent mixes with river water; the minimum value recorded is 0.021 mg/L in winter, while the maximum value is 0.0991 mg/L in autumn results were similar to Rasul et al. (2023) findings in wastewater channel of Erbil in Iraq which ranges between 0.006 to 0.86 mg/L. The seasonal fluctuations observed at this mixture point suggest that lead concentrations may be impacted by both natural phenomena and industrial inputs, Fawkes and Sansom (2021) in the United States, Texas showed that their lead concentration is about 0.18- 0.8 mg/L which is absolutely higher than Great Zab River results.

Likewise, the Thermal Power Plant demonstrates relatively low levels of lead, albeit with seasonal variations in concentration. The lead concentrations in river water that result from the mingling of effluent from thermal power plants are comparable, indicating that the power plant has a relatively consistent effect on lead levels throughout the year. Seasonal variability is observed in lead concentrations downstream in the Great Zab River, where autumn yields the maximum recorded values of 0.158 mg/L (Figure 5.27) aligned with Rasul et al. (2023) results in wastewater channel of Erbil in Iraq which ranges between 0.006 to 0.86 mg/L. Although these concentrations are typically modest, the seasonal increase in autumn indicates possible impacts from industrial activities upstream.

The parameters associated with lead (Pb) contamination deal with the concentration levels which are measured in parts per million (ppm) or micrograms per liter (µg / L), and they are important in evaluating the health risks that lead exposure poses. pH levels can also cause lead leaching from plumbing systems, within which acidic conditions most usually enhance lead release. The water temperature and other ions such as chloride, sulfate, and phosphate can have an effect on lead solubility, hence affecting its transport and persistence in water systems. Besides, the age and composition of distribution pipes, corrosion control techniques, and regulations are vital factors for controlling and even preventing lead in the water supply (Fawkes and Sansom, 2021).

At the Erbil Refinery, winter months yield maximum levels at 0.108 mg/L, potentially signifying the impact of refinery-related industrial activities, especially during winter. Similarly, lead concentrations at the Cola site range between 0.081 and 0.087 mg/L, indicating a minimal effect on the river's lead concentrations. However, when Cola effluent combines with river water, seasonal fluctuations suggest impacts from both natural phenomena and industrial inputs (Tonkin et al., 2017). The Thermal Power Plant also demonstrates relatively low lead levels with seasonal variations, indicating a consistent effect on lead levels throughout the year. Downstream in the Great Zab River, seasonal variability is observed, with autumn yielding maximum lead concentrations of 0.158 mg/L, indicating possible impacts from industrial activities upstream.

The observed seasonal fluctuations in lead concentrations at specific sampling locations impacted by industrial effluents suggest the need for ongoing monitoring to comprehend the potential effects on water quality and ecosystem health. This is crucial for implementing efficient water quality control measures and safeguarding the ecological integrity of the Great Zab River (Tonkin et al., 2017).

5.15. Effects of Copper (Cu):

The levels of Copper (Cu) in the Great Zab River vary significantly across different seasons and sampling locations, indicating a complex interplay between natural phenomena and potential industrial impacts. Copper concentrations in the upstream portion vary between 0.04 and 0.56 mg/L, with the greatest amount seen during the spring season (Figure 5.29) results were aligned with Manne et al. (2022) findings which range between 0.009 to 0.823 mg/L in India. The observed variability indicates that seasonal influences, such as heightened runoff or alterations in biological activity, may potentially impact the copper concentration in the river.

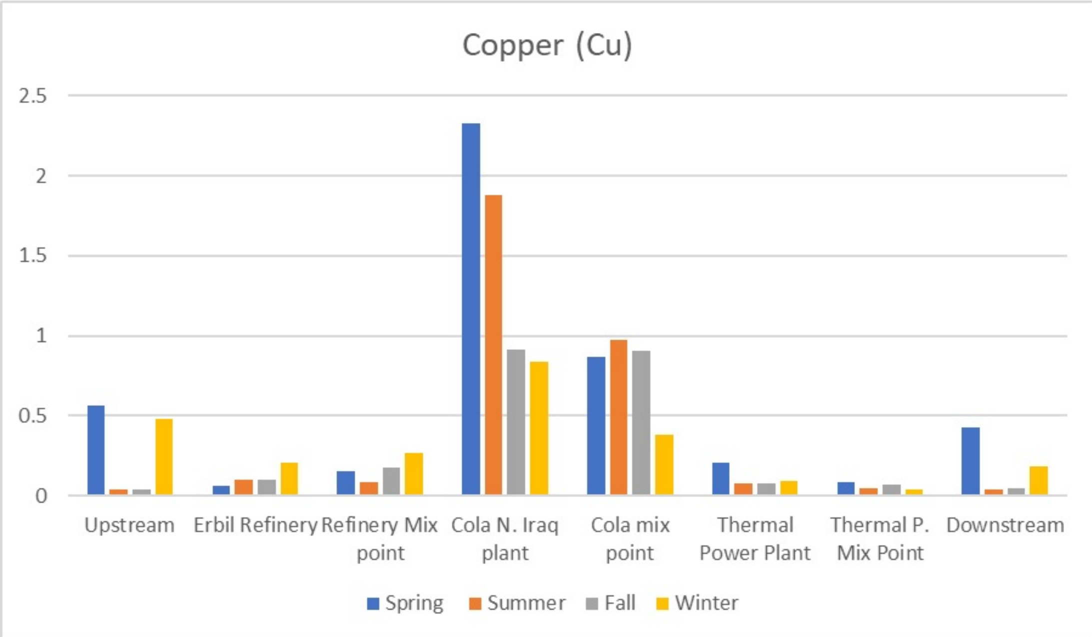

Figure 5.29. Change of Copper (Cu) Concentrations

The Erbil Refinery experiences variations in copper concentrations, which range from 0.06 to 0.21 mg/L same as Manne et al. (2022) determined in their research which range between 0.009 to 0.823 mg/L in India. The maximum values are observed during the winter season. This indicates a possible impact from industrial emissions linked to the refinery, especially in the colder seasons. The combination of refinery wastewater and river water leads to fluctuating copper concentrations, with the highest levels occurring during the winter season. The statement highlights the refinery's impact on copper levels in the surrounding area, underlining the necessity of implementing efficient pollution control measures.

The copper concentrations at the Cola North Iraq plant point display significant diversity, with levels ranging from 0.84 to 2.33 mg/L similar to Lukhabi et al. (2023) in Africa and higher than Manne et al. (2022) results which range between 0.009 to 0.823 mg/L in India. The spring season exhibits the most significant levels of concentration, indicating a plausible correlation with the manufacturing procedures or the raw materials employed in the production of the

Cola North Iraq plant. The combination of Cola North Iraq plant wastewater and river water results in seasonal fluctuations in copper content, highlighting the interaction between industrial discharges and natural river processes.

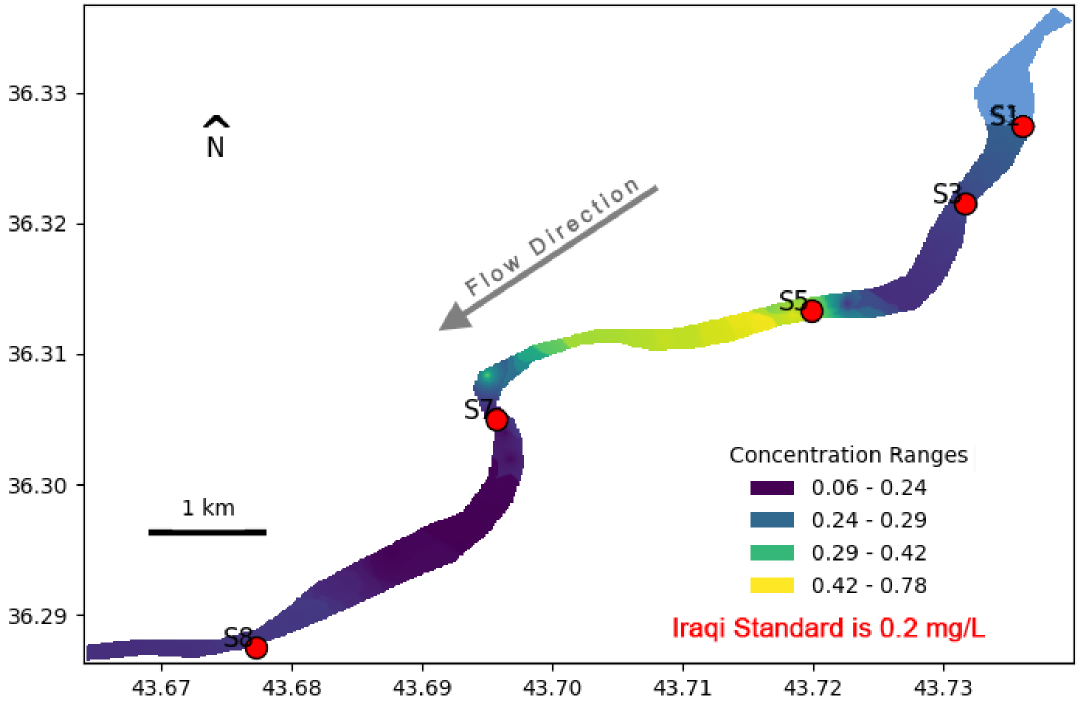

Figure 5.30. Water Quality Map of Cu (Copper)

The Thermal Power Plant causes fluctuations in copper levels, which range from 0.077 to 0.21 mg/L (Figure 5.29) aligned with Manne et al. (2022) in India. The highest concentration is found during the spring season. The combination of thermal power plant effluent and river water leads to fluctuating levels of copper concentrations, highlighting the importance of comprehending both industrial contributions and seasonal changes when evaluating the data, Manne et al. (2022) showed that ranges from 0.009 to 0.823 mg/L, which indicates as time increases simultaneously copper content also raises in the stored water which means that Great Zab river results are much higher, this may be due to factories and power plant that caused this increase of copper concentration.

Copper concentrations in the river downstream exhibit seasonal fluctuations, reaching their peak in spring at a documented value of 0.43 mg/L same as Manne et al. (2022) determined in India. Although these values generally fall within the permissible range for freshwater systems, the observed fluctuations indicate the possibility of cumulative effects resulting from industrial activity upstream.

The levels of copper (Cu) in the Great Zab River exhibit significant variations across different seasons and sampling locations, indicating a complex interplay between natural phenomena and potential industrial impacts (Manne et al., 2022). The upstream portion of the river shows copper concentrations ranging from 0.04 to 0.56 mg/L, with the highest levels observed during the spring season (Figure 5.29). This variability suggests that seasonal influences, such as heightened runoff or alterations in biological activity, may potentially impact the copper concentration in the river.

5.16. Effects of Zinc (Zn):

The contents of Zinc (Zn) in the Great Zab River display a complex pattern, with variations observed in different seasons and sample locations. The zinc levels in the upstream Great Zab River range from 0.005 to 0.089 mg/L, with the maximum concentration observed around winter (Figure 5.31) aligned with Li et al. (2019) findings in China that were around 0.0017 to 0.0230 mg/L. The fluctuation in seasons can be impacted by natural elements such as meteorological patterns, precipitation, and alterations in water flow, underscoring the importance of thorough monitoring.

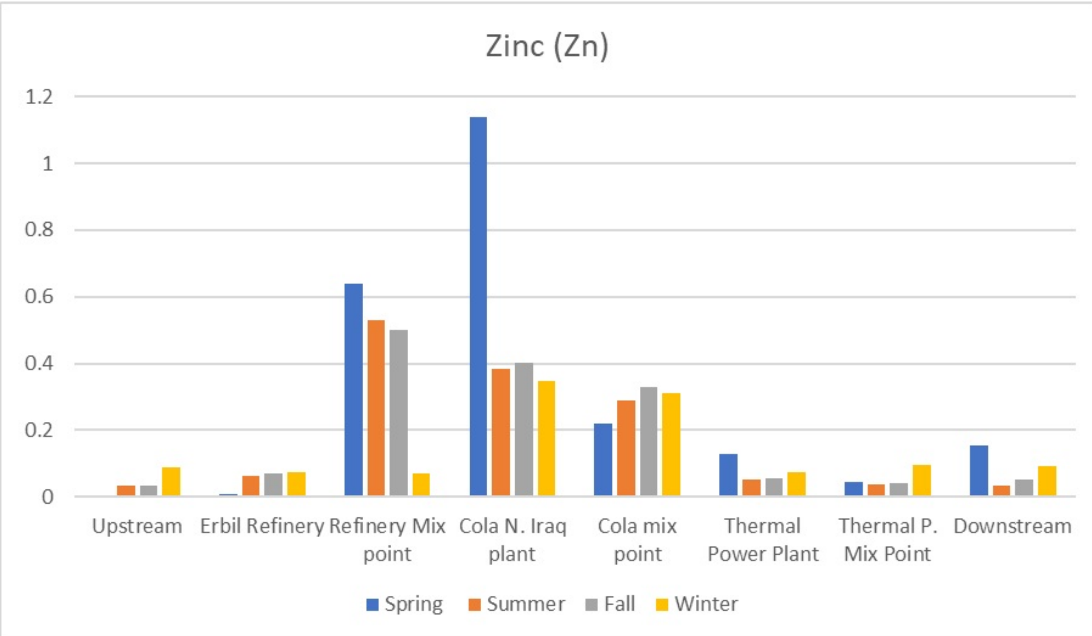

Figure 5.31. Change of Zinc (Zn) Concentrations

The Erbil Refinery exhibits fluctuations in zinc concentrations ranging from 0.006 to 0.074 mg/L similar to Li et al. (2019) in China and lower than Gazzaz et al.

(2013) results in Malaysia which is up to 0.24 mg/L, with the highest values occurring during the winter season. The elevated amounts seen during colder months indicate a possible correlation with industrial operations related to the refinery. The combination of refinery effluent and river water leads to a significant rise in zinc levels, especially during the autumn and spring seasons, indicating a considerable influence on the overall quality of water downstream.

The sampling locations for the Cola North Iraq plant display substantial variability, with zinc values ranging from 0.346 to 1.14 mg/L. The spring season exhibits the most elevated levels, indicating possible impacts stemming from the manufacturing procedures or the raw materials employed in the production of the Cola North Iraq plant. The combination of Cola North Iraq plant effluent and river water results in varying levels of zinc concentrations, highlighting the complex interaction between industrial waste and natural phenomena in the river, this showed that results are normal except Cola North Iraq factory as well as its lower than Li et al. (2019) results which vary between 0.950-2.423 mg/L in China.

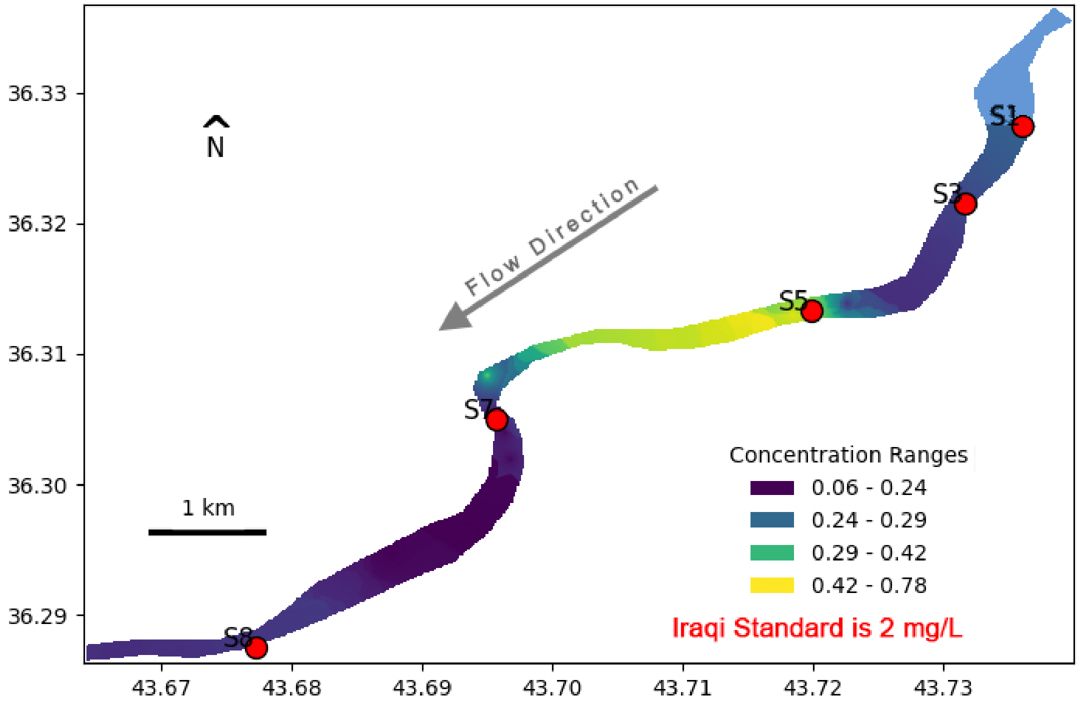

Figure 5.32. Water Quality Map of Zinc (Zn):

The Thermal Power Plant causes fluctuations in zinc levels, which range from 0.051 to 0.127 mg/L, with the peak concentration observed during the spring season (Figure 5.31) lower than Li et al. (2019) results in China. The variations in zinc levels downstream of the power plant can be ascribed to particular activities or emissions. The zinc contents in the downstream Great Zab River exhibit seasonal fluctuations, reaching their peak in spring at a measured value of 0.153 mg/L. Although the concentrations often remain within acceptable thresholds for freshwater systems, the observed variations give rise to concerns regarding the possible cumulative effects of industrial inputs from upstream sources (Arantes et al., 2016).

Comprehending the intricate dynamics of zinc levels in the Great Zab River necessitates continuous monitoring and thorough examinations of the precise origins and mechanisms that contribute to these variations. Efficiently controlling and reducing the effects of industrial discharges on zinc concentrations are essential for upholding water quality and safeguarding the biological balance of the Great Zab River (Eldos et al., 2022).

The levels of Zinc (Zn) in the Great Zab River exhibit seasonal variations, with the highest concentration observed in winter. The upstream Great Zab River has zinc levels ranging from 0.005 to 0.089 mg/L, while the Erbil Refinery shows fluctuations in zinc concentrations ranging from 0.006 to 0.074 mg/L, with the highest values occurring during the winter season. The combination of refinery effluent and river water leads to a significant rise in zinc levels, especially during the autumn and spring seasons, indicating a considerable influence on the overall water quality downstream. The sampling locations for Cola display substantial variability, with zinc values ranging from 0.346 to 1.14 mg/L, these results are lower than Li et al. (2019) aligned with Arantes et al. (2016) in Brazil and the spring season exhibits the most elevated levels. The Thermal Power Plant causes fluctuations in zinc levels, ranging from 0.051 to 0.127 mg/L, with the peak concentration observed during the spring season. The zinc contents in the downstream Great Zab River exhibit seasonal fluctuations, reaching their peak in spring at a measured value of 0.153 mg/L. Although the concentrations often remain within acceptable thresholds for freshwater systems, the observed variations give rise to concerns regarding the possible cumulative effects of industrial inputs from upstream sources (Gazzaz et al., 2013).

5.17. Effects of Cadmium (Cd):

The levels of Cadmium (Cd) in the Great Zab River exhibit a dynamic pattern, displaying seasonal and geographical fluctuations at different sampling locations. The cadmium levels in the upstream Great Zab River vary between 0.025 and 0.16 mg/L aligned with Al-Asadi et al. (2020) study in which Cadmium levels were lower than 0.1 m/L in Iraq, with the peak concentration occurring during the summer season (Figure 5.33). The fluctuations in cadmium level in the river are attributed to seasonal oscillations, which are mostly influenced by natural processes such as weathering and runoff.

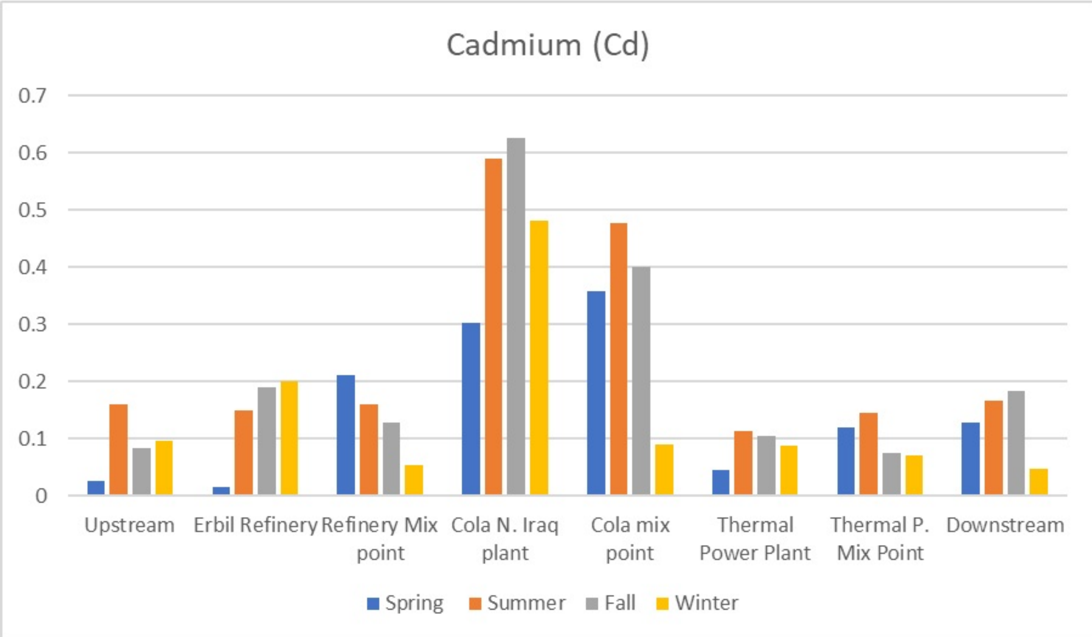

Figure 5.33. Change of Cadmium (Cd) Concentrations

At the Erbil Refinery, cadmium contents exhibit substantial fluctuation, ranging from 0.016 to 0.2 mg/L, with peak levels recorded in winter aligned with Kubier et al. (2019) aligned with Al-Asadi et al. (2020) study which Cadmium levels were lower than 0.1 m/L in Iraq. The variations in seasons indicate a possible influence from industrial operations linked to the refinery, especially in colder months when the flow patterns may be affected.

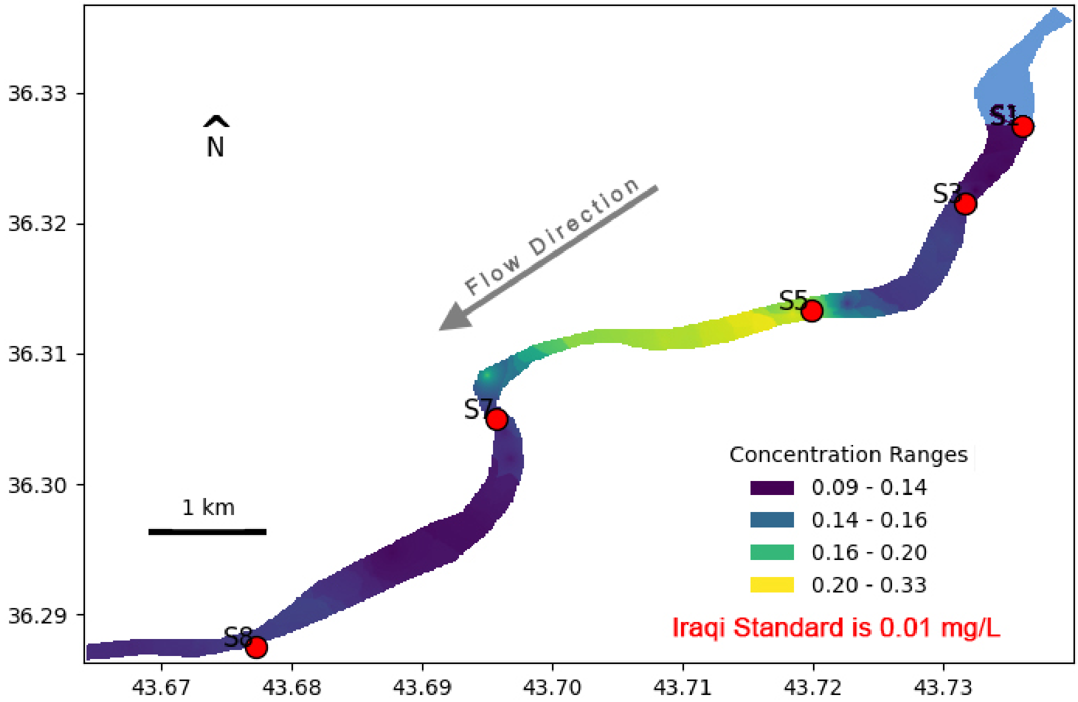

Figure 5.34. Water Quality Map of Cd (Cadmium)

The Erbil Refinery effluent and river water mixture exhibits seasonal variations in cadmium contents, with the highest levels occurring in spring. This underlines the refinery's influence on downstream cadmium levels, stressing the need to address both industrial flows and seasonal trends in assessing water quality, Arantes et al. (2016) were cadmium resulted around 0.7-1.96 mg/L is above this research results.

The fluctuations in cadmium levels at the Cola North Iraq plant site, ranging from 0.303 to 0.627 mg/L higher than Al-Asadi et al. (2020) study in which Cadmium levels were lower than 0.1 m/L in Iraq, especially in autumn, may be caused by factors such as manufacturing methods or the types of raw materials used, this was expected to some detergents that used for cleaning inside the factory and their domestic wastewater is a cause of high cadmium levels in Cola north Iraq plant wastewater (Sani and Shehu, 2018). This underscores the complex interplay between industrial emissions and natural phenomena in the river ecosystem.

The Thermal Power Plant exhibits fluctuation in cadmium levels, which range from 0.044 to 0.114 mg/L aligned with Al-Asadi et al. (2020) study in which Cadmium levels were lower than 0.1 m/L in Iraq with the peak concentration observed during the summer season. The observed oscillations could potentially be linked to particular operations or emissions originating from the power plant. The cadmium contents in the river water fluctuate periodically when the effluent from the thermal power plant mixes with it, illustrating the intricate connection between industrial contributions and the inherent patterns of the river.

At a location downstream of the river, the levels of cadmium show fluctuations throughout the seasons (Figure 5.33), reaching their peak in autumn at a measurement of 0.184 mg/L results were higher than Al-Asadi et al. (2020) study in which Cadmium levels were lower than 0.1 m/L in Iraq, and lower than Arantes et al. (2016) results in Brazil. Although the observed oscillations in freshwater systems are generally below acceptable bounds, they give rise to concerns over the possible cumulative effects of industrial inputs from upstream sources. To effectively manage water quality in the Great Zab River, it is crucial to conduct thorough monitoring and study to identify the exact sources responsible for the high amounts of cadmium.

The levels of cadmium (Cd) in the Great Zab River exhibit a dynamic pattern, displaying seasonal and geographical fluctuations at different sampling locations. The cadmium levels in the upstream Great Zab River vary between 0.025 and 0.16 mg/L, with the peak concentration occurring during the summer season. The fluctuations in cadmium level in the river are attributed to seasonal oscillations, which are mostly influenced by natural processes such as weathering and runoff (Arantes et al., 2016). At the Erbil Refinery, cadmium contents exhibit substantial fluctuation, ranging from 0.016 to 0.2 mg/L, with peak levels recorded in winter. The variations in seasons indicate a possible influence from industrial operations linked to the refinery, especially in colder months when the flow patterns may be affected (Arantes et al., 2016).

The Erbil Refinery effluent and river water mixture exhibits seasonal variations in cadmium contents, with the highest levels occurring in spring, stressing the need for addressing both industrial flows and seasonal trends in assessing water quality. The fluctuations in cadmium levels at the Cola North Iraq plant site, ranging from 0.303 to 0.627 mg/L aligned with Al-Asadi et al. (2020) study in which Cadmium levels were lower than 0.1 m/L in Iraq and lower than Arantes et al. (2016) results, especially in autumn, may be caused by factors such as manufacturing methods or the types of raw materials used. The observed reduction in cadmium level at the mixing point with the river may be attributed to the presence of wetlands, which have the capacity to absorb a substantial amount of cadmium during the interaction between Cola North Iraq plant wastewater and river water, underscoring the complex interplay between industrial emissions and natural phenomena in the river ecosystem (Arantes et al., 2016).

The observed oscillations could potentially be linked to particular operations or emissions originating from the power plant. The cadmium contents in the river water fluctuate periodically when the effluent from the thermal power plant mixes with it, illustrating the intricate connection between industrial contributions and the inherent patterns of the river (Kubier et al., 2019). At a location downstream of the river, the levels of cadmium show fluctuations throughout the seasons, reaching their peak in autumn at a measurement of 0.184 mg/L. Although the observed oscillations in freshwater systems are generally below acceptable bounds, they give rise to concerns over the possible cumulative effects of industrial inputs from upstream sources. To effectively manage water quality in the Great Zab River, it is crucial to conduct thorough monitoring and study to identify the exact sources responsible for the high amounts of cadmium (Arantes et al., 2016).

5.18. Effects of Nickel (Ni):

The concentrations of Nickel (Ni) in the Great Zab River exhibit a complex pattern, which results from a combination of natural processes and probable industrial impacts. The nickel levels in the upstream Great Zab River vary between 0.092 and 0.5 mg/L aligned Abdullah (2013) that were between 0.063 to 0.259 mg/L in Diyala River, Iraq, with the highest concentration observed during the winter season (Figure 5.35). The fluctuation in nickel content in the river over different seasons could be a result of either natural sources or activities occurring upstream. This emphasizes the importance of continuous monitoring to determine the reasons that are responsible for these changes, these results are similar to Genchi et al. (2020) which reaches about 1 mg/L at peak.

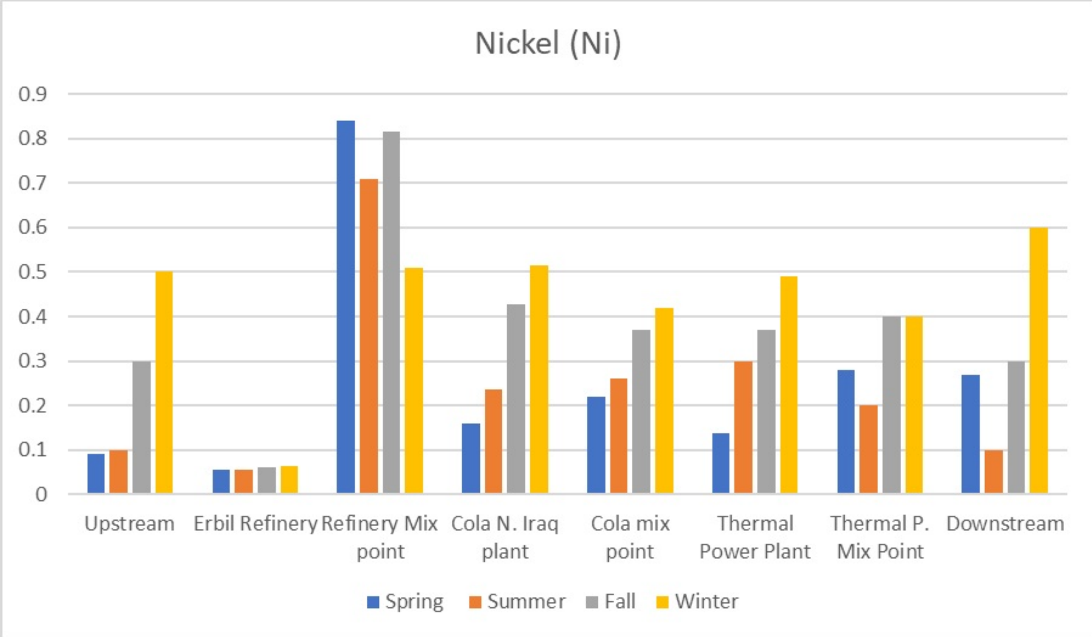

Figure 5.35. Change of Nickel (Ni) Concentrations

The nickel concentrations at the Erbil Refinery exhibit minimal variation (Figure 5.35), with values ranging from 0.054 to 0.063 mg/L throughout several seasons lower than Genchi et al. (2020) and aligned Abdullah (2013) that were between 0.063 to 0.259 mg/L in Diyala river, Iraq. The little variations observed indicate that the refinery has only a minor effect on the amounts of nickel in the river. This highlights the need to comprehend the precise industrial procedures and their potential impact on water quality.

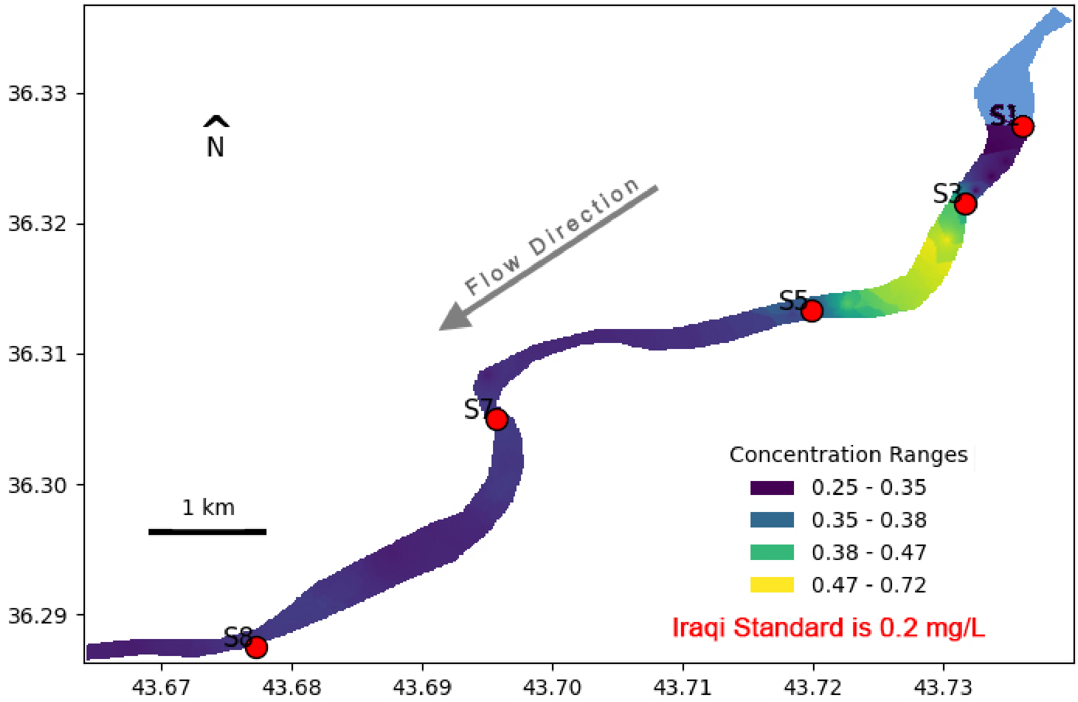

Figure 5.36. Water Quality Map of Nickel (Ni)

Nevertheless, the mixing of the refinery effluent and river water results in elevated levels of nickel, especially during the spring and winter seasons, with concentrations ranging from 0.51 to 0.84 mg/L approximately aligned with Genchi et al. (2020) findings in Italy. This suggests a noticeable impact of the refinery on nickel levels in the lower part of the water system, highlighting the importance of considering seasonal variations when evaluating changes in water quality.

The Cola point displays significant fluctuations in nickel contents, ranging from 0.159 to 0.514 mg/L which is much higher than Abdullah (2013) that were between 0.063 to 0.259 mg/L in Diyala River, Iraq, with the highest levels occurring during the winter season. The changes in nickel inputs may be influenced by the manufacturing processes or raw materials employed in Cola production, thus requiring a more thorough investigation of the individual industrial activities responsible for these contributions.

The Thermal Power Plant causes fluctuations in nickel levels (Figure 5.35), which range from 0.136 to 0.49 mg/L aligned Abdullah (2013) that were between 0.063 to 0.259 mg/L in Diyala River, Iraq, with the maximum concentration observed during winter. Seasonal variations could be linked to certain activities or emissions from the power plant, underscoring the significance of comprehending the temporal dynamics of industrial impacts on water quality.

At a location further along the river, the levels of nickel vary throughout the year, with the highest measurements occurring during the winter season, reaching 0.6 mg/L. Although the concentrations often comply with acceptable thresholds for freshwater systems, the observed variations raise concerns regarding the potential cumulative effects of industrial inputs from upstream sources. In order to effectively manage the water quality in the Great Zab River, it is crucial to consistently monitor and thoroughly investigate the specific sources and activities that contribute to the levels of nickel present (Genchi et al., 2020).

The concentrations of Nickel (Ni) in the Great Zab River exhibit a complex pattern, influenced by natural processes and industrial impacts. The upstream Great Zab River shows varying nickel levels, with the highest concentration observed during winter, ranging from 0.092 to 0.5 mg/L. The Erbil Refinery exhibits minimal variation in nickel concentrations, ranging from 0.054 to 0.063 mg/L throughout several seasons, indicating a minor effect on the river's nickel amounts. However, the combination of the refinery effluent and river water results in elevated nickel levels, especially during spring and winter, with concentrations ranging from 0.51 to 0.84 mg/L, signifying a noticeable impact of the refinery on the lower part of the water system (Liu et al., 2019).

The Cola point and the Thermal Power Plant also show significant fluctuations in nickel contents, with the highest levels occurring during the winter season, suggesting the need for a thorough investigation of the individual industrial activities responsible for these contributions. The observed variations raise concerns regarding the potential cumulative effects of industrial inputs from upstream sources, emphasizing the importance of consistent monitoring and investigation of specific sources and activities contributing to the nickel levels in the Great Zab River (Liu et al., 2019).

5.19. Effects of Cyanides (Total free Cn):

The concentrations of Total Free Cyanide in the Great Zab River display a dynamic pattern, showing fluctuations throughout seasons and sampling points that indicate the presence of both natural and human impacts. Concentrations in the upstream Great Zab River vary between 0.009 and 0.081 mg/L, with the maximum levels occurring around winter (Figure 5.37) which is near to the result of Abdulnabi

(2020) study in the Shatt Al-Arab River in Iraq which is between 0.013 to 0.254 mg/L. The variation in seasonal patterns can be ascribed to variables like industrial emissions, erosion, or alterations in environmental conditions throughout the winter season, as well as some researchers such as Mousavi et al. (2013) in Iran showed that their results reached 0.04 at the maximum point.

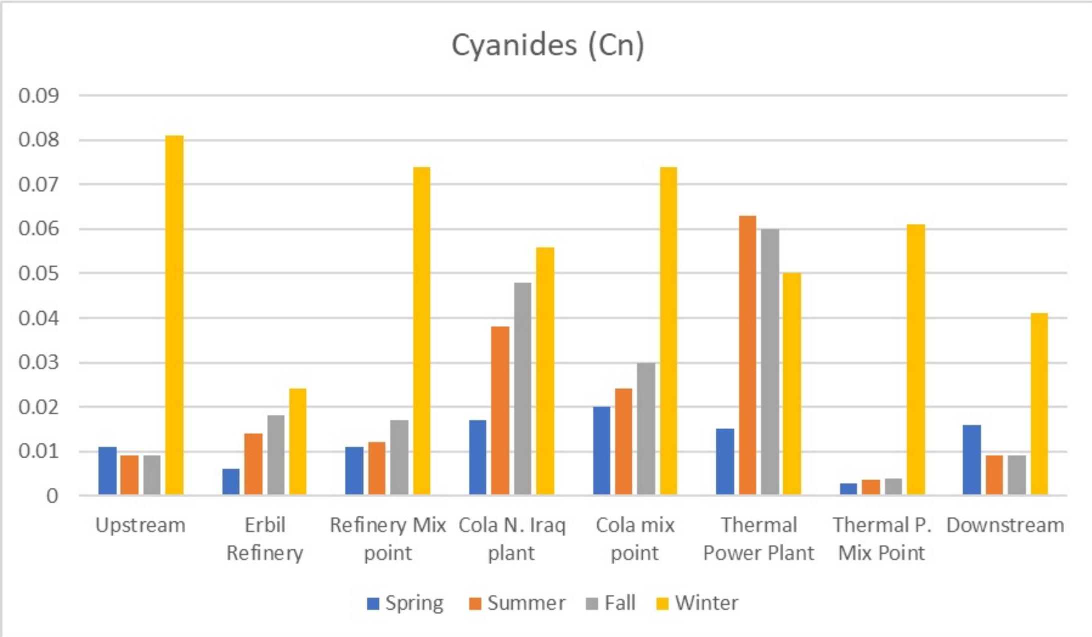

Figure 5.37. Change of Cyanides (Total free Cn) Concentrations

The Erbil Refinery exhibits slight fluctuations in cyanide concentrations, ranging from 0.006 to 0.024 mg/L throughout different seasons which makes it lower than Mousavi et al. (2013) findings and aligned with Forti et al. (2021) in Iraq which was between 0.01 to 0.058 mg/L, with the maximum values found during winter. Although the refinery seems to have a minor effect on cyanide levels, it is important to closely examine the seasonal variations to comprehend any potential effects that may occur under specific weather conditions.

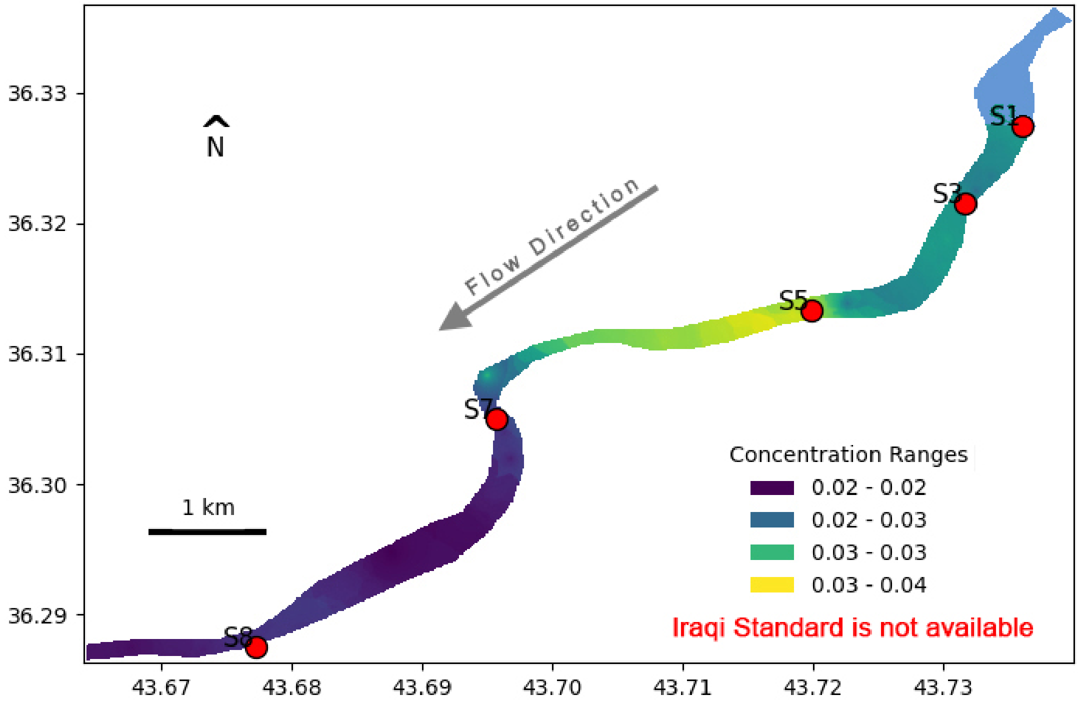

Figure 5.38. Water Quality Map of Cyanides

During the mixing of refinery effluent with river water, notably in winter, elevated levels of cyanide are detected, with concentrations reaching as high as 0.074 mg/L aligned with Mousavi et al. (2013) in Iran. This highlights the cyclical influence of the refinery on the subsequent levels of cyanide downstream. During the winter months, there may be a rise in industrial operations or changes in discharge conditions, which might lead to higher levels of cyanide in the mixed water.

The Cola North Iraq plant point exhibits significant fluctuations in cyanide levels, ranging from 0.017 to 0.056 mg/L aligned with Forti et al. (2021) in Iraq, with the highest amounts occurring during winter. The changes in Cola North Iraq plant output may be influenced by the manufacturing techniques or the raw materials utilized. The mixture of Cola North Iraq plant wastewater with river water results in varying cyanide concentrations, with the highest levels being reported during the winter season. This emphasizes the significance of taking into account both industrial emissions and seasonal fluctuations when evaluating water quality (Mousavi et al., 2013).

The Thermal Power Plant causes fluctuations in cyanide levels, which range from 0.0027 to 0.063 mg/L aligned with Mousavi et al. (2013) in Iran, with the highest concentration observed during the summer season. The winter oscillations, particularly when the river is mixed, may indicate diverse origins of cyanide or swings in industry emissions during colder months. Conducting additional research on the specific operations of the thermal power plant is essential in order to comprehend the observed seasonal patterns.

Cyanide concentrations downstream of the river display seasonal fluctuations, reaching their peak around winter (0.041 mg/L) aligned with Forti et al. (2021) in Iraq. Although the concentrations are often under acceptable thresholds for freshwater systems, the observed variations prompt concerns regarding the potential cumulative effects of industrial inputs upstream. In order to effectively manage the water quality in the Great Zab River, it is crucial to consistently monitor and thoroughly investigate the precise sources and processes that contribute to the levels of cyanide.

The levels of Cyanides in the Great Zab River exhibit a dynamic pattern, with fluctuations across seasons and sampling points, indicating the influence of both natural and human factors. The upstream Great Zab River shows variations between 0.009 and 0.081 mg/L similar to Sun et al. (2019) in China, with peak levels during winter. These seasonal variations are attributed to factors such as industrial emissions, erosion, and changes in environmental conditions during the winter season(Mousavi et al., 2013). The Erbil Refinery and the Cola point also display fluctuations in cyanide concentrations, with maximum levels observed during winter. The Thermal Power Plant causes fluctuations in cyanide levels, with the highest concentration observed during the summer season, suggesting diverse origins of cyanide or fluctuations in industrial emissions during colder months. Downstream of the river, cyanide concentrations exhibit seasonal fluctuations, reaching their peak around winter, prompting concerns about the potential cumulative effects of industrial inputs upstream (Mousavi et al., 2013).

5.20. Effects of Sulfide (S):

The quantities of sulfide (S) in the Great Zab River show significant fluctuations throughout different seasons and sampling locations, indicating an intricate interaction between natural processes and probable human influences. The sulfide levels in the upstream Great Zab River vary between 0.02 and 0.21 mg/L aligned with Al-Saady and Abdullah (2014) that was between 0.297 to 0.412 mg/L in Tigris River within Missan Governorate eastern part of the Mesopotamia Plain–Iraq, with the peak concentration occurring during the winter season (Figure 5.39). The difference in seasons could be ascribed to variables such as changes in temperature, interactions with silt, or possible discharges from industrial activity upstream.

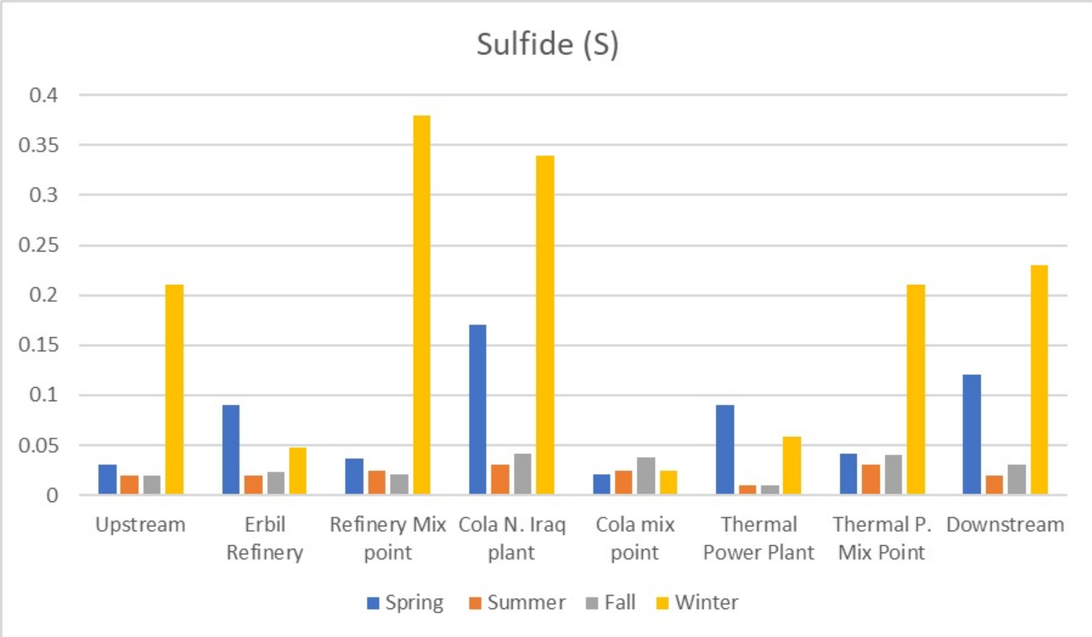

Figure 5.39. Change of Sulfide (S) Concentrations

The Erbil Refinery experiences fluctuations in sulfide concentrations, which range from 0.02 to 0.09 mg/L during different seasons. The highest values are typically reported during spring. The impact of the refinery on sulfide levels is clearly apparent, especially in the spring season, indicating that specific industrial activities or emissions may be responsible for the increased sulfide concentrations in the river, this is aligned with Al-Saady and Abdullah (2014) that was between 0.297 to 0.412 mg/L in Tigris River within Missan Governorate eastern part of the Mesopotamia Plain–Iraq and aligned to Ahmed et al. (2020) in Iraq which ranged around 0.25 mg/L.

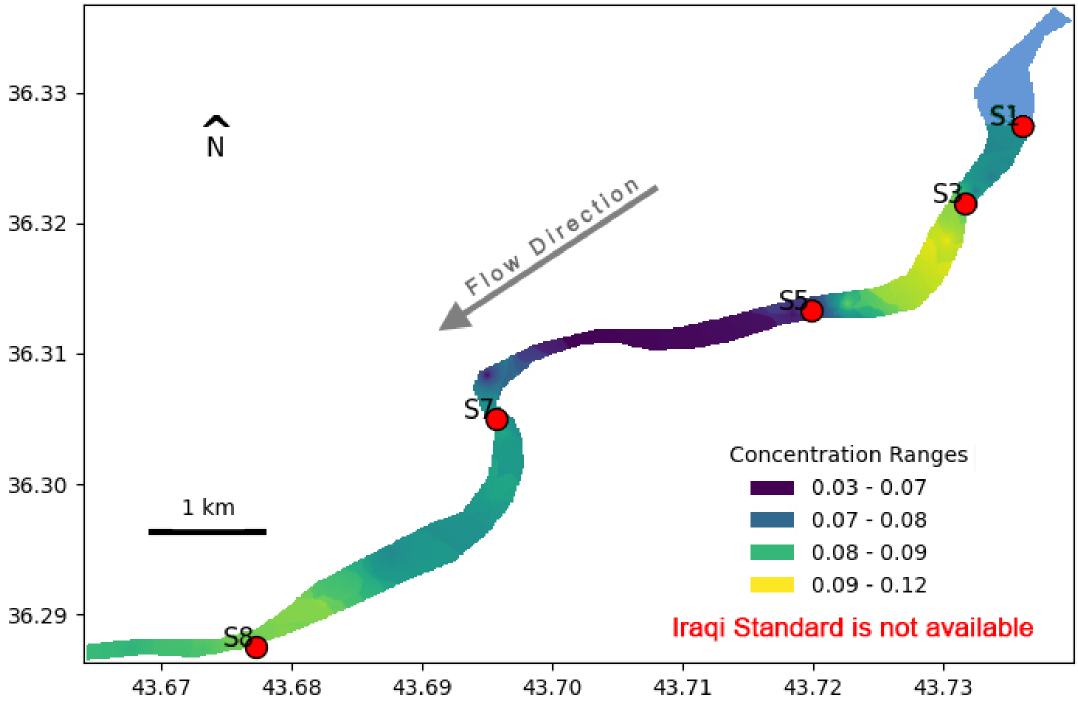

Figure 5.40. Water Quality Map of Sulfides

During the mixing of refinery effluent and river water, the levels of sulfide grow, reaching a maximum concentration of 0.38 mg/L during winter similar to aligned with Al-Saady and Abdullah (2014) that was between 0.297 to 0.412 mg/L in Tigris River in Missan Governorate eastern part of the Mesopotamia Plain–Iraq and aligned to Ahmed et al. (2020) in Iraq which ranged around 0.25 mg/L. The notable increase suggests that the refinery has a considerable influence on sulfide levels downstream, particularly in certain seasons. This could be attributed to heightened industrial operations or modified discharge conditions in colder months (Kubier et al., 2019).

The levels of sulfide at the Cola point exhibit notable fluctuations, spanning from 0.03 to 0.34 mg/L this is the same result as Bouchareb et al. (2021) findings in Algeria, with the most elevated amounts reported during the winter season. The variability in sulfide inputs necessitates a thorough investigation of the precise industrial operations that lead to these oscillations, particularly in terms of the manufacturing processes and raw materials employed in Cola production.

The Thermal Power Plant causes fluctuations in sulfide levels, which range from 0.01 to 0.09 mg/L aligned with Al-Saady and Abdullah (2014) that was between 0.297 to 0.412 mg/L in Tigris River within Missan Governorate eastern part of the Mesopotamia Plain–Iraq, with the peak concentration observed during the spring season. An in-depth examination of the power station's operations and their potential effects on sulfide levels in the river is required to determine if the seasonal variations are linked to specific activities or discharges from the plant.

Sulfide concentrations downstream of the river exhibit seasonal fluctuations, reaching their peak during winter at a measured value of 0.23 mg/L aligned with Kareem (2016) in Iraq aligned with Al-Saady and Abdullah (2014) that was between 0.297 to 0.412 mg/L in Tigris River within Missan Governorate eastern part of the Mesopotamia Plain–Iraq. Although the concentrations are often under acceptable thresholds for freshwater systems, the observed variations prompt concerns regarding the potential cumulative effects of industrial inputs from upstream sources. It is crucial to continuously monitor and conduct thorough investigations into the precise sources and activities that contribute to the levels of sulfide in order to effectively regulate the water quality in the Great Zab River (Kubier et al., 2019).

The fluctuations in sulfide levels in the Great Zab River and its tributaries are influenced by a combination of natural processes and human activities, particularly industrial operations. The upstream Great Zab River experiences variations in sulfide concentrations, with peak levels occurring during the winter season (Mertes, 1997). Similarly, the Erbil Refinery and the Cola North Iraq plant point also exhibit fluctuations in sulfide concentrations, with the highest values reported during specific seasons. Furthermore, the mixing of refinery effluent and river water leads to increased sulfide levels, particularly during the winter season. The Thermal Power Plant also causes fluctuations in sulfide levels, with the peak concentration observed during the spring season. Downstream of the river, sulfide concentrations exhibit seasonal fluctuations, reaching their peak during winter. These variations raise concerns about the potential cumulative effects of industrial inputs from upstream sources, necessitating continuous monitoring and thorough investigations into the precise sources and activities contributing to sulfide levels in the Great Zab River (Mertes, 1997).

Winter sulfide abundance increase might be due to a synergic consequence of a decline in temperature and precipitation by the way mechanisms remained unclear. The cool climate in winter means that surface water cooling occurs. This actually makes water able to hold more oxygen because it requires less gas to affect the solution in a greater percentage. The consequential occurrence of more soluble residues can stimulate microbial activity in particular that of sulfate-reducing bacteria mostly found in anaerobic sites of the water and which advantageously produce sulfide by reducing sulfur atoms in the water. Besides, water flowing in rivers very high can result in winter precipitation. These going on cope with make possible the formation of sulfides through the enhancement of the growth of sulfate-reducing bacteria. By many studies that incorporate both natural processes and human activities, increased sulfide rates in the winter months is the effect very likely observed coming through (Holmberg and Jørgensen, 2023).

5.21. Effects of Chromium (Cr):

The contents of Chromium (Cr) in the Great Zab River vary significantly across different seasons and sampling locations, indicating the combined effects of natural processes and potential human activities. The chromium levels in the upstream Great Zab River range from 0.02 to 0.14 mg/L these results are aligned with Al-Janabi et al. (2012) in Iraq which was around 0.05 mg/L, with the peak concentration occurring during the winter season (Figure 5.41). The fluctuation in water quality across different seasons can be explained by temperature-dependent geochemical processes and fluctuations in industrial discharges. This highlights the importance of gaining a thorough understanding of both natural and human-induced factors that impact water quality.

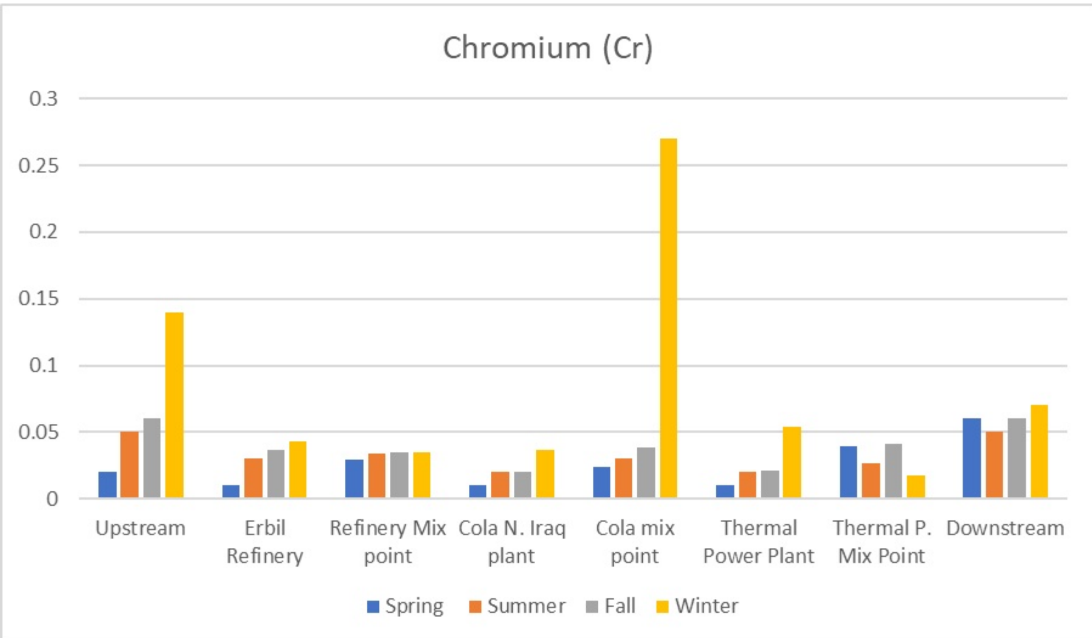

Figure 5.41. Change of Chromium (Cr) Concentrations

The Erbil Refinery has chromium concentrations ranging from 0.01 to 0.043 mg/L across different seasons same as Arantes et al. (2016) found in their study in

Brazil which was about 0.035 mg/L, with the most elevated levels occurring during winter. The impact of the refinery on chromium levels seems to be minimal, and the concentrations typically comply with the permitted thresholds for freshwater ecosystems. Nevertheless, the oscillations that have been seen require continuous monitoring to guarantee that refinery operations do not result in unanticipated effects on water quality (Al-Janabi et al., 2012).

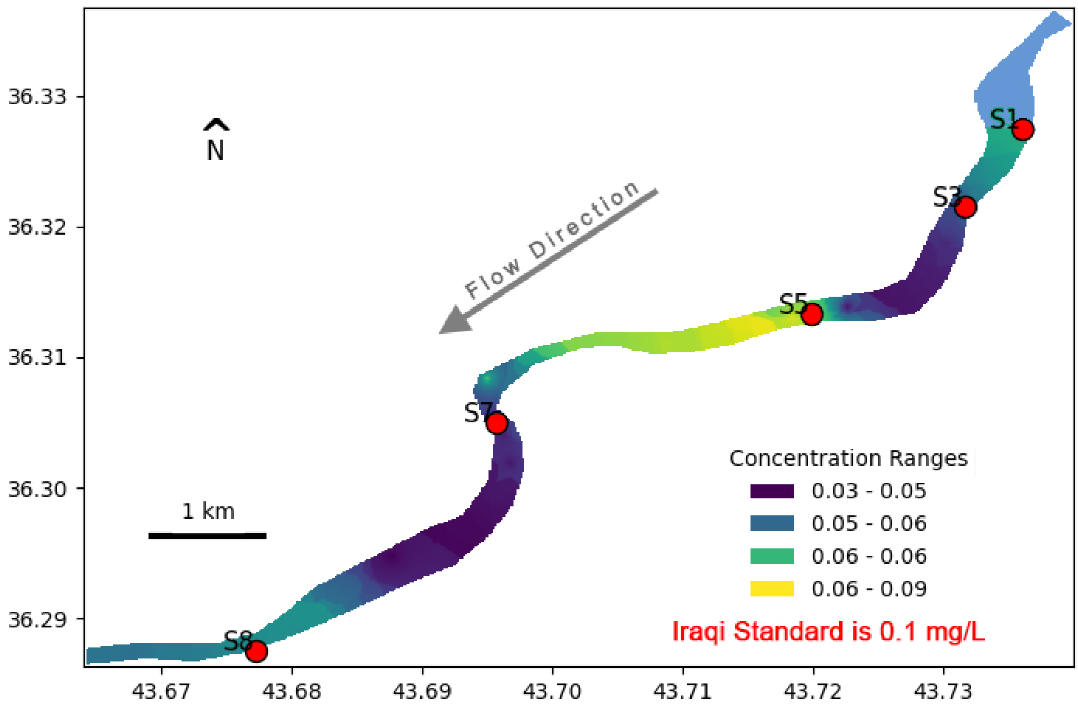

Figure 5.42. Water quality map of Chromium (Cr):

The mixing of the refinery effluent and the river water leads to consistent chromium levels, which range from 0.029 to 0.035 mg/L aligned with Arantes et al. (2016) results in Brazil. The small changes indicate successful dilution and dispersion of chromium in the river, emphasizing the need to comprehend the interplay between industrial discharges and natural processes in influencing the overall water quality.

The Chromium levels at the sampling point for the Cola North Iraq plant exhibit fluctuation, spanning from 0.01 to 0.037 mg/L aligned with Arantes et al. (2016), with the most elevated amounts reported during the winter season. The oscillations in water quality can be attributed to the manufacturing techniques and raw materials employed in the production of the Cola North Iraq plant, highlighting the influential role of industrial activities in determining water quality dynamics.

The mixing of Cola North Iraq plant wastewater and river water leads to fluctuating levels of chromium, with a significant rise noted during the winter season (0.27 mg/L) due to welding and painting some oil pipes from the upper part near the river at the same time, is the main cause peaking Chromium level at this sample point, or due to inadvertent leakage from excavator trucks that used in the mining process in extraction of River Gravel, Sand and Rocks near the same place, however, this result was near to Sharma et al. (2022) findings in their study in India which was about 0.12 to 0.54 mg/L. The notable increase in chromium levels observed during colder months necessitates a more thorough investigation of possible industrial discharges during this time. This is because temperature-dependent mechanisms can affect how chromium behaves and moves in aquatic systems.

Chromium concentrations in the river downstream exhibit seasonal fluctuations, reaching their peak during winter at a measured value of 0.07 mg/L aligned with Al-Janabi et al. (2012) in Iraq which was around 0.05 mg/L. Although the concentrations are often under safe thresholds, the oscillations reported raise concerns regarding the potential cumulative effects of industrial inputs from upstream sources. It is crucial to continuously monitor and conduct thorough investigations into the precise sources and activities that contribute to chromium levels in order to effectively manage the water quality of the Great Zab River in a sustainable manner.

Essentially, it is vital to comprehend the complex relationship between natural processes and human activities in order to evaluate the observed fluctuations in Total Chromium concentrations. Employing a comprehensive methodology that encompasses ongoing surveillance, meticulous chemical examinations, and a comprehensive evaluation of industrial procedures will significantly aid in the efficient management of water quality and the formulation of plans to alleviate any environmental consequences in the Great Zab River (Al-Janabi et al., 2012).

The Great Zab River exhibits significant variations in Chromium (Cr) levels across different seasons and sampling locations, indicating the combined effects of natural processes and potential human activities. The chromium levels in the upstream Great Zab River range from 0.02 to 0.14 mg/L, with the peak concentration occurring during the winter season. The fluctuation in water quality across different seasons can be explained by temperature-dependent geochemical processes and fluctuations in industrial discharges (Arantes et al., 2016).

5.22. Effects of Total Iron (Fe):

The Great Zab River exhibits varied patterns of Total Iron (Fe) concentrations at different sampling stations and during different seasons, suggesting a complex interaction between natural and human-induced processes that impact water quality Iron naturally occurs in some bed rocks from the study area. The iron levels in the upstream Great Zab River exhibit consistent stability, with fluctuations ranging from 0.48 to 0.57 mg/L (Figure 5.43) aligned with Tabrez et al. (2022) in India ranging between 0.065 to 0.77 mg/L. These slight differences can be ascribed to geological reasons and the gradual erosion of rocks in the watershed.

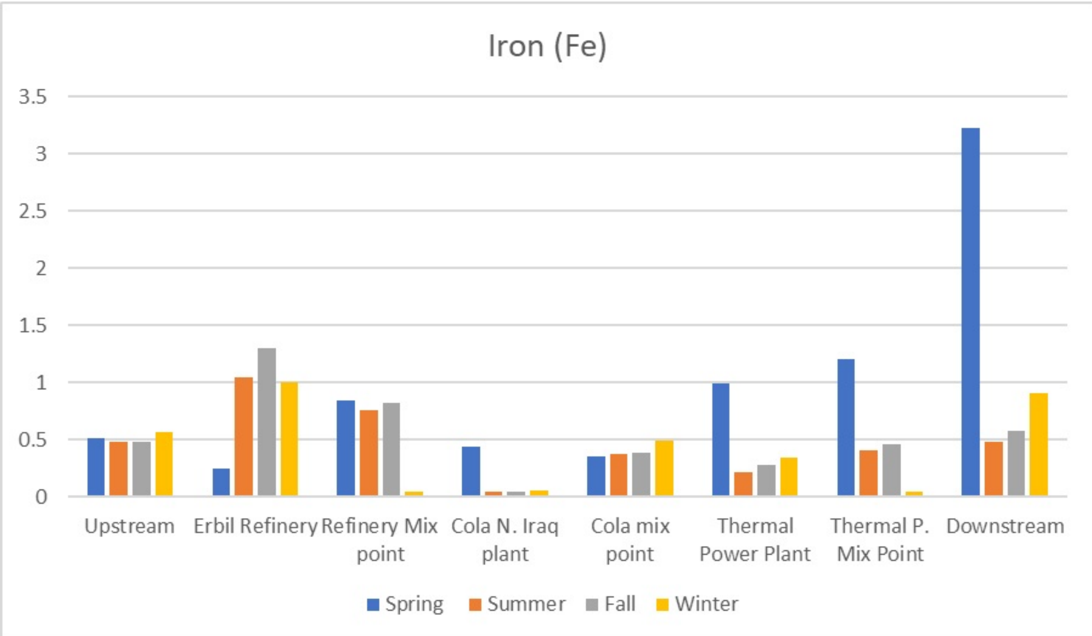

Figure 5.43. Change of Total Iron (Fe) Concentrations

Iron concentrations at the Erbil Refinery exhibit notable variations, ranging from 0.25 to 1.3 mg/L across different seasons. The high concentration seen throughout autumn indicates a possible influence from industrial operations at the refinery. Additional inquiry is necessary to comprehend the precise mechanisms that contribute to heightened iron levels and to evaluate the environmental consequences of these releases.

The iron concentrations in the river vary between 0.049 and 0.84 mg/L when the Erbil Refinery wastewater is mixed with it results were aligned with Tabrez et al. (2022) in India which range between 0.065 to 0.77 mg/L. The winter reduction may suggest a decline in industrial operations or an increase in dilution during this time of year. Gaining a comprehensive understanding of these periodic fluctuations is essential for implementing efficient water quality control measures.

The iron concentrations at the Cola north Iraq plant sampling point display fluctuation, ranging from 0.04 to 0.44 mg/L similar to Al-Janabi et al. (2012) that was about 0.4 mg/L in Iraq, with the maximum amounts found during the spring season. The changes in Cola North Iraq plant output may be influenced by the manufacturing techniques or raw materials utilized. Furthermore, the combination of Cola North Iraq plant effluent with river water leads to fluctuations in iron content, with the highest levels observed during the winter season. It is important to carefully examine any industrial emissions during colder seasons.

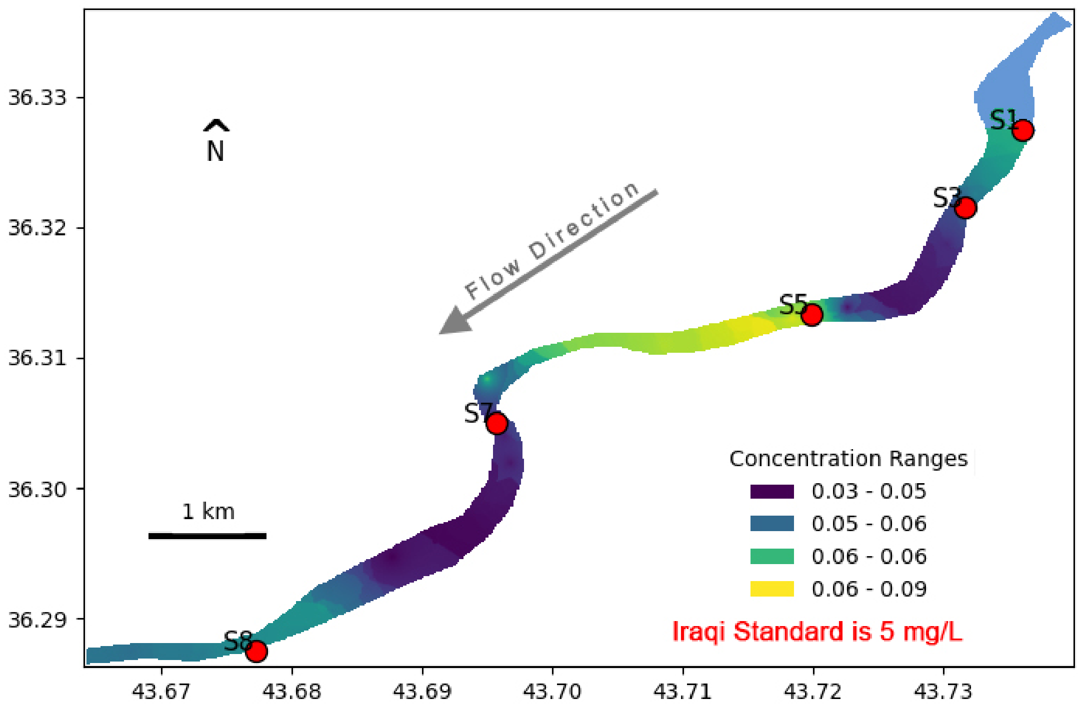

Figure 5.44. Water quality map of Iron (Fe)

The Thermal Power Plant causes fluctuations in the levels of iron, with values ranging from 0.21 to 0.99 mg/L higher than Birkett (1998) results in United States. Seasonal variations could be linked to certain activities or emissions originating from the power plant. The combination of thermal power plant effluent and river water leads to fluctuating iron concentrations, with the most elevated levels occurring during the spring season. The observed trends indicate that both industrial inputs and natural processes have an influence on the levels of iron in the river.

Iron concentrations in the river downstream exhibit seasonal fluctuations, peaking at 3.23 mg/L during the spring season. Although the concentrations mostly comply with acceptable thresholds, the observed variations raise concerns regarding the potential cumulative effects of industrial inputs from upstream sources. For sustainable water quality management in the Great Zab River, it is crucial to continuously monitor and conduct thorough investigations into the precise sources and activities that contribute to iron levels (Tabrez et al., 2022).

The varied patterns of Total Iron concentrations emphasize the importance of comprehending the intricate interplay between natural and human-induced factors that affect water quality. Continuous surveillance, meticulous chemical examinations, and thorough evaluations of industrial procedures are vital for formulating efficient tactics to alleviate probable ecological repercussions in the Great Zab River (Tabrez et al., 2022).

The Great Zab River exhibits diverse patterns of Total Iron (Fe) concentrations at different sampling stations and during various seasons, indicating a complex interplay between natural and human-induced processes impacting water quality. The upstream Great Zab River shows consistent stability in iron levels, with slight fluctuations attributed to geological reasons and gradual erosion of rocks in the watershed (Birkett, 1998). However, at the Erbil Refinery, notable variations in iron concentrations are observed across different seasons, with high levels during autumn, possibly influenced by industrial operations. When the Erbil Refinery wastewater is mixed with the river, the iron concentrations vary, suggesting a decline in industrial operations or an increase in dilution during the winter. Similarly, the Cola sampling point and the Thermal Power Plant also contribute to fluctuations in iron levels, influenced by manufacturing techniques, raw materials, and activities or emissions from the power plant, respectively. Downstream, the river exhibits seasonal fluctuations in iron concentrations, with peak levels during the spring season, raising concerns about the potential cumulative effects of industrial inputs from upstream sources (Birkett, 1998).

Significance of each Source:

Erbil Refinery Source (S2) and its mixing point with the Great Zab River (S3):

t-value: The t-value measures the difference between the means of the two groups (S2 and S3) in terms of standard error units. In this case, the t-value is 4.427.

Significance (p-value): The significance value (p-value) indicates the probability of obtaining the observed t-value (or one more extreme) if the null hypothesis were true. In other words, it tells us how likely it is to observe such a difference in means by random chance alone. In this case, the p-value is 0.004.

Now, regarding the significance of Erbil Refinery on the water quality of the Great Zab River:

Since the p-value (0.004) is less than a typical significance level of 0.05, we can conclude that there is a statistically significant difference in water quality between the Erbil Refinery Source (S2) and its mixing point with the Great Zab River (S3).

Therefore, based on this analysis, it seems that the Erbil Refinery has a significant impact on the water quality of the Great Zab River, particularly at the mixing point (S3), as shown in Table 5.1.

Cola North Iraq plant (S4) and its mixing point with the Great Zab River (S5):

t-value: The t-value represents the calculated difference between the means of the two groups (S4 and S5) relative to the variability within the groups. A higher t-value indicates a greater difference between the means of the two groups. In this case, the t-value is 6.56.

Since the p-value (0.002) is less than the conventional significance level of 0.05, this rejects the null hypothesis. This implies that there is enough evidence to conclude that there is a significant in water quality between the Cola North Iraq plant (S4) and its mixing point with the Great Zab River (S5). In other words, the presence of the Cola North Iraq plant has a significant impact on the water quality of the Great Zab River at the specified mixing point (Table 5.1).

Thermal power plant (S6) and its mixing point with the Great Zab River (S7):

t-value Interpretation: The t-value of 2.981 suggests that there is a significant difference between the water quality at the Thermal power plant (S6) and its mixing point with the Great Zab River (S7).

Significance (p-value) Interpretation: The significance level of 0.025 is below a common threshold of significance such as 0.05. This suggests that there is strong evidence to reject the null hypothesis. Therefore, the result is statistically significant, as shown in Table 5.1.

Table 5.1. Statistical Evaluation of Sample Points

Sources	t-value	p-value
Erbil Refinery Source (S2) and its mixing point with the Great Zab River (S3)	4.427	0.004<0.05
Cola North Iraq plant (S4) and its mixing point with the Great Zab River (S5)	6.56	0.002<0.05
Thermal power plant (S6) and its mixing point with the Great Zab River (S7)	2.981	0.025<0.05

6. CONCLUSION

The study noticeably depicts the remarkable influence of industrial emissions and refinery effluents as the source of the river's pollution in the case of the Upper Great Zab River in Northern Iraq which emphasizes the state of urgency to counter the pollution by setting more rigorous measures.

The ecological issues arising from industrial wastewater discharge can be seen in lower oxygen levels, disturbance of temperature ranges, and damage to habitats, in the end, the affected species' well-being and the ecosystem health.

Recommendations for tackling the wastewater management problem consist of both the creation of environmentally sustainable policy and the implementation of regulations that will keep any negative impact on the country's environment at bay.

Research going into the future should concentrate on tracking the status of watersheds including possible contamination risks, evaluating the efficiency of management measures including whether the pollutions are managed or not, and looking for alternative solutions for pollution prevention and remediation.

The literature review illustrates that the Great Zab River is the main natural resource in the region, and, as such, its preservation is crucial for the area's ecological ecosystem and socio-economic prosperity. There is a need to reduce pollution levels from industrial activities.

A lot of research has been done on the effects of industrial wastewater on water quality parameters such as pH, COD, BOD5, DO, TDS, conductivity, TSS, nitrate, nitrite, heavy metals (cyanide, sulfide, chromium) and (oil, grease) total iron.

The fact that we come to the conclusion that this is why we need to keep watching, targeted investigations, and pollution treatment measures that work as fast as possible to protect water quality and ecosystem health.

The use of the Water Quality Index (WQI) is an important instrument for the determination of water quality, quantifying the levels created naturally and to what extent they are affected by people.

Measurements prove that these sources greatly disturb the environment's ability to keep water clean; therefore, we highlight issues concerning water management, implementing policies on the water quality's maintenance and control of pollution.

7. RECOMMENDATIONS

Based on the findings and conclusions drawn from the study on industrial wastewater impacts on the Upper Great Zab River, the following recommendations are proposed:

1. Enhanced Regulatory Frameworks: Creating strong regulatory strategies for sewage effluent from industrial plants is important. Performing stricter regulatory action, regular control, and punishing penalties for those who don't do the same may restrict industries from polluting water resources.

2. Investment in Wastewater Treatment Infrastructure: The appreciation of sectors to embrace the use of high-tech wastewater treatment devices will lead to a significant drop in the amount of pollutants released into the effluents. Authorities and authorities together must offer a favorable institutional environment like tax breaks or subsidies which encourage enterprises to use less pollution or carbon production techniques.

3. Promotion of Sustainable Practices: Supporting industrial processes with the same focus on decreasing water consumption, preventing pollution, and increasing resource effectiveness will be critical. The sectors should be supported to practice a closed-loop system, recycle materials, and implement eco-production processes aimed at reducing their carbon footprints.

4. Community Engagement and Awareness: Protecting local people's life involvement by publicizing information about water, educational programs, and participation of citizens in the decision process can play an important role in the production of a feeling of ownership and responsibility for water resources. From public educational programs on the significance of water conservation to community-based efforts for environmental protection, this approach may encourage and mobilize the public to act for the goals of environmental protection.

5. Collaborative Research and Monitoring: Such as collaborating between government agencies, research institutions, industries, and local communities is useful for the implementation of the complete science, monitoring, and management of the quality of water. The establishment of joined-up monitoring programs, persons with a common approach, and the conducting of interdisciplinary research can help to deepen the understanding and step forward process of decision-making.

6. Integration of Green Infrastructure: Incorporating techniques like constructed Wetlands, bioswales, and vegetated buffer strips into the industrial area can decrease the effects of industrial runoff thus giving the chance for better water quality. The productive inclusion of nature-based solutions through city planning – including industrial developments – is a feasible and sustainable way to deal with pollution.

7. Continuous Monitoring and Evaluation: Establishing a strong monitoring infrastructure that continuously assesses water quality variations, locates the polluted sites, and determines the outcomes of control actions is essential. Frequent monitoring shall be followed by data analysis and reporting procedures, where the degrees of attainment in water quality improvement goals can be easily traced over time.

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