GIS-based Soil and Groundwater Quality Assessment and Heavy Metal Contamination

A Case Study of Industrial Sector of Islamabad

By

MAHNOOR ARSHAD ABBASI

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Remote Sensing and Geographical Information System

Institute of Geographical Information Systems
School of Civil and Environmental Engineering
National University of Sciences and Technology
Islamabad, Pakistan
July,2023

THESIS ACCEPTANCE CERTIFICATE

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by **Mahnoor Arshad Abbasi (Registration No. MSRSGIS 000330547), of Session 2020 (Institute of Geographical Information systems)** has been vetted by undersigned, found complete in all respects as per NUST Statutes/Regulation, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature:
Name of Supervisor (Dr.Javed Iqbal)
Date: 7-9-2023

Dr: Javed Iqbal
Professor & HOD IGIS. SCEE (NUST)
H-12, Islamabad

Signature (HOD):
Date: 7-9-2023

Dr. Javed Iqbal
Professor & HOD IGIS. SCEE (NUST)
H-12, Islamabad

Signature (Associate Dean):
Date: 07/09/2023

Dr. Ejaz Hussain
Associate Dean, IGIS, SCEE (NUST)
H-12, ISLAMABAD

Signature (Principal & Dean SCEE):
Date: 12 SEP 2023

PROF DR MUHAMMAD IRFAN
Principal & Dean
SCEE, NUST

DEDICATION

To Almighty Allah

&

My Sweet & Loving Family

A special feeling of gratitude to my beloved Parents, my grandmother and my friends for their unwavering support, and encouragement throughout my journey.

Academic Thesis: Declaration of Authorship

I, **Mahnoor Arshad Abbasi** declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

GIS-BASED SOIL AND GROUNDWATER QUALITY ASSESSMENT FOR HEAVY METAL CONTAMINATION IN INDUSTRIAL SECTOR (I-9) OF ISLAMABAD

I confirm that:

1. This work was done wholly by me in candidature for an M.S. research degree at the National University of Sciences and Technology, Islamabad.
2. Wherever I have consulted the published work of others, it has been clearly attributed.
3. Wherever I have quoted from the work of others, the source has been always cited.
4. I have acknowledged all main sources of help.
5. Where the work of thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.
6. None of this work has been published before submission. This work is not plagiarized under the H.E.C. plagiarism policy.

Signed: ………………………………

Date: 14-09-2023

ACKNOWLEDGEMENTS

First of all, I would like to thank God Almighty for giving me the opportunity and guidance to achieving my goal and to be successful in this part. Then, praises are also addressed to our Prophet Muhammad SAW who has guided us to the better life today. I am forever indebted to my father and my mother for their unwavering support and dedication. Their hard work, encouragement, and belief in my abilities have been a constant source of motivation for me. Their guidance and wise counsel have shaped my academic journey and inspired me to strive for excellence. I am truly grateful for their sacrifices and the countless hours they dedicated to ensuring my success.

I owe my sincere gratitude and pleasure to my respected research supervisor Dr. Javed Iqbal, for his devoted guidance and encouraging attitude throughout the research. I am also grateful to all my guidance and examination committee members, Dr. Ejaz Hussain and Dr. Imran Hashmi for their coordination and constructive criticism which directed me towards a better understanding of research and successful accomplishment of its objectives.

I would like to thank my friends for their understanding, encouragement, and unwavering belief in my abilities. Their words of motivation and support have provided me with the strength to overcome challenges and persevere during the demanding phases of this research. Finally, I express my heartfelt appreciation to all the individuals who may not be mentioned here but have in some way contributed to the completion of this thesis. Your support, whether big or small, has played a significant role in my academic journey. Completing this thesis would not have been possible without the collective efforts and support of all these individuals. I am truly grateful for their contributions, and I hope that my research will contribute to the body of knowledge in this field and ultimately lead to positive environmental outcomes

Mahnoor Arshad Abbasi

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	**Explanation**
EC	Electrical Conductivity
GIS	Geographical Information system
IARC	International Agency for research on cancer
ICP	Inductively coupled plasma
IDW	Inverse distance weighted
OM	Organic matter
SQI	Soil quality index
TDS	Total dissolved solids
WQI	Water quality index

ABSTRACT

The unchecked industrialization and exponential expansion in population in third world countries have led to a grave issue of groundwater and soil pollution. These nations frequently need more effective environmental protection policies; even when they have, they are rarely implemented. As a result, hazardous industrial waste is routinely discharged into rivers, streams, and temporary disposal sites, posing severe environmental and public health threats. Therefore, it is essential to determine the soil and groundwater contamination levels in the industrial areas. The current study's objective were to investigate the possible problems of soil and water pollution with heavy metals deposited from Steel and iron factories in the I9 sector of Islamabad and their surrounding areas. The objectives of the current study were (a) Groundwater and Soil quality assessment in terms of heavy metals and their vulnerability to pollution using Pollution Indices, (b) Spatial distribution maps of heavy metals (Fe, Zn, and Cr) of the industrial area of Islamabad. A total of 50 groundwater and soil samples were collected through random sampling. The samples were taken to the laboratory to measure their physicochemical properties. The samples were examined for Fe, Cr and Zn by ICP (inductively coupled plasma) optical emission spectrometry. Sample points were located using Garmin GPS. A Geographical Information System(GIS) generated distribution maps of water and soil quality parameters. The Water Quality Index (WQI) and Soil Quality Index (SQI) were used to determine the acceptability of the water and soil for use, culminating in the construction of index maps. The results showed that in most investigated sites, heavy metal concentrations were above the permitted limits. Further analysis using correlation exploration revealed a strong positive association between iron (Fe) and chromium in the soil and water samples, with a correlation coefficient of at least 0.38 ($p \leq 0.05$). The worrisome levels of heavy metal pollution in the afflicted areas are brought home by these findings, which highlight the urgent need for corrective measures.

CHAPTER 1

INTRODUCTION

1.1. Background

Heavy metal contamination in soil and groundwater has become an increasing concern worldwide in recent years, particularly in places with considerable industrial activity. Heavy metals harm human health and the environment, and their presence in soil and groundwater can significantly impact ecosystems and public health. The industrial sector in Pakistan has been quickly increasing, resulting in increased heavy metal pollution in metropolitan areas. (George, Venugopal, & Vashisht, 2023).

The two most important and fundamental resources for life on earth are soil and water. In Pakistan, soils and groundwater are becoming more and more deteriorated, and this deterioration is accelerating (Luo et al., 2022). As a global environmental problem, soil and groundwater quality decline poses a serious danger to farming by reducing crop yields and undermining the long-term viability of various agricultural systems. The main causes of soil and water degradation are human activities, such as improper industrial practices and poor administration of irrigation water and agrochemical inputs (Ugochukwu et al., 2022).

I. Water

Groundwater is one of the world's most vital resources, supporting human requirements such as drinking water, agriculture, and industrial activities. However, due to anthropogenic activities such as mining, industrialization, and urbanization, the quality of groundwater is becoming increasingly threatened (Singha & Navarre-Sitchler, 2022). Ground water is a type of water that pervades all geological strata. It is estimated that ground water accounts for approximately 30.1% of all fresh water on the planet. Thus, it is an important source of fresh water and is frequently consumed for that purpose. Of the total water on Earth, just 3% is considered drinkable, while the remaining 97% is salty and should be avoided.

In the form of ice caps and glaciers, the Earth stores one-fifth of the world's fresh water (Megdal, 2018). The contamination of groundwater supplies with heavy metals is one of the most pressing organic issues facing the globe today. Heavy metal contamination is one of the most important challenges affecting groundwater quality, and assessing it is critical to ensuring the resource's safety and sustainability. Cadmium, lead, chromium, mercury, and arsenic are examples of heavy metals having large atomic weights and densities. Even in little concentrations, they are poisonous and can have serious health consequences such as cancer, kidney damage, and neurological issues. Groundwater is contaminated with heavy metals from a variety of sources, including industrial waste discharge, mining activities, agricultural runoff, and poor waste management (P. Li, Karunanidhi, Subramani, & Srinivasamoorthy, 2021).

Water is essential for all forms of life. Pakistan is fortunate to have both surface and ground water resources; yet, the country's water supply has been severely stressed due to fast population expansion, urbanization, and excessive water use in agriculture and industry. Water is essential for all forms of life. Although Pakistan has access to both surface and ground water resources, this has proven to be a source of contention (Einarson & Mackay, 2001). The country's water supplies have been severely stressed due to rapid population increase, urbanization, and excessive water use in agriculture and industry. Despite being the most popular and widely accepted water supply, groundwater is highly susceptible to contamination by commercial and agricultural operations. The erosion of natural water sources is a growing environmental concern around the world. Natural, human, and indirect recharging of the aquifer bring groundwater to the surface and into the interior of the landmass. More than 2 billion individuals worldwide utilised it (Tzanakakis, Paranychianakis, & Angelakis, 2020). As well as geographical disobedience, the ease with which something valuable may be accessed nearby provides one explanation for this resource infringement. The loss of this essential resource is possible if the depletion of aquifers in high-demand areas continues unchecked (Qureshi, 2020).

Heavy metals are among the most common pollutants found in groundwater. However, the concentration of heavy metals in the atmosphere impacts their toxicity. As the quantity of heavy metals in the environment rises and soils lose their capacity to store the element, it begins to leak into groundwater and soil solutions. When they move up the food chain, these toxic heavy metals can build up in increasingly higher concentrations in the bodies of higher-level organisms. As ground water travels from the recharge location to the discharge area, its quality degrades due to chemical interactions along the way (Tchounwou, Yedjou, Patlolla, & Sutton, 2012). Human activities like mining and the use of heavy metal fertilizers in agriculture, as well as the un - treated release of metal-containing industrial effluents from businesses like steel factories, batteries, and thermal power plants, contribute to the already significant levels of heavy metals in the environment. Irrigation, home use, and industrial production all rely on a reliable supply of freshwater. Contrarily, groundwater contamination is exacerbated by a rise in population, the spread of industry, and the concentration of metropolitan areas. It's difficult to clean up the polluted groundwater. Thus, protecting the quality of groundwater is essential. WHO estimates that 80 percent of infections can be traced back to contaminated ground water (Suwanaruang, 2023).

Pollution of ground water is a global problem caused by industry, agriculture, and government. Particularly alarming is the fact that groundwater might contain tiny amounts of metals. Although necessary metals like copper, iron, manganese, zinc, and cobalt are typically present, excessive levels can have severe effects on health (F. Li, Wu, Xu, Yang, & Du, 2023).

In recent years, Geographic Information System (GIS) technology has evolved as a valuable tool for analysing groundwater quality. GIS analyses and visualises complex environmental problems by integrating many forms of data, including geographical and non-spatial data. The system provides a spatially explicit and user-friendly platform for identifying the causes and extent of groundwater pollution, predicting pollutants' movement and fate, and evaluating their potential impact on human health and the environment (Chakraborty et al., 2023).

II. Soil

One of the most vital materials on Earth is its soil. Soil is an essential resource for human survival, and its quality is critical to ensuring that it can sustain a variety of critical ecosystem services such as food production, carbon storage, and water filtration. However, various factors, including heavy metal contamination, can degrade soil quality. Soil is a complex and dynamic natural system that is critical to the survival of life on Earth. It serves as a home for a variety of organism groups, promotes plant growth, and is essential for nutrient cycling and carbon storage. Soil quality, on the other hand, is rapidly deteriorating, and human activities, particularly industrial activities, are key contributors to this deterioration (Seybold, Herrick, & Brejda, 1999).

Heavy metal contamination has the potential to harm both soil quality and human health. Over time, these metals can build in the soil, causing long-term damage of the soil's physical, chemical, and biological qualities (C. Li et al., 2019). Furthermore, heavy metals can be absorbed by plants and enter the food chain, posing a health risk to humans. Human survival and well-being are dependent on healthy soil. Anthropogenic activities, on the other hand, jeopardise and harm soils all over the planet. Soil health is crucial to human existence and prosperity. Yet, human actions threaten and damage soils everywhere in the world (Ikenaka et al., 2010).

As both natural and human-caused processes have accelerated, heavy metal soil pollution has spread. Because of the poor quality of these soils, plant development, performance, and yield all suffer. As both natural and human-caused stresses increase, heavy metal soil contamination spreads. Because of this, plants are unable to thrive in these environments and yield significantly less (Duruibe, Ogwuegbu, & Egwurugwu, 2007). Among these are the mining and smelting of metals, the burning of fossil fuels, the use of pesticides and fertilizers in agriculture, the production of batteries and other metal items in industry, the disposal of sewage sludge, and the use of fertilizers and pesticides in agriculture (Huamain, Chunrong, Cong, & Yongguan, 1999).

Unlike organic pollutants, which are oxidized by microorganisms to carbon (IV) oxide, most metals do not degrade microbial or organically, and their entire level in soils stays high for a long time after they are introduced. Soil is particularly effective in soaking up heavy metals that have been released into the environment as a result of the aforementioned human activities. Their accessibility and chemical compositions (evolutionary divergence) are, however, dynamic. Dangerous metals in the soil can significantly slow down the natural decomposition of organic pollutant (I. Sharma, 2020).

Soil contaminated with heavy metals poses risks to human health and the environment through a variety of pathways, including ingestion, contact, the food system (soil to plants to humans or plants to animals to humans), utilization of polluted groundwater, Eco toxicity, subpar food quality (safety and marketability), diminished land usability for agricultural operations, and concerns over land title (Abioye, 2011).

The water quality index (WQI) is a frequently used tool for evaluating different water resources that provides a comprehensive and simple way of analyzing water quality (Harkins, 1974). The WQI is a critical instrument for water resource management, assisting in the identification of possible issues and informing management decisions. The WQI offers a single, dynamic number that measures the overall quality of the water resource by analyzing multiple characteristics such as pH, dissolved oxygen, and nutrient levels (Uddin, Nash, & Olbert, 2021). Similarly, the Soil Quality Index (SQI) is a useful instrument for assessing soil quality. It provides a complete and quantitative assessment of soil physical, chemical, and biological properties, allowing for a more comprehensive understanding of soil health. The SQI is very useful for determining the efficacy of organic additions in improving soil quality. The SQI gives a valid measure of the success of soil management practices by analyzing changes in several soil characteristics like as nutrient levels, organic matter content, and microbial activity (Mukherjee & Lal, 2014). The current level of heavy metals in the soil and groundwater in Islamabad that have been impacted by industrial discharge must be assessed in order to take necessary action.

1.2 Water and Soil Quality Parameters

1.2.1 pH

pH is defined as the negative logarithm of the concentration of H+ ions. As a result, the meaning of the word pH is justified as hydrogen power. The pH of a solution, such as water or soil, indicates its acidity or basicity. The pH scale goes from 0 to 14, with 7 being neutral. A pH less than 7 implies acidity, while a pH greater than 7 suggests basicity (Addy, Green, & Herron, 2004). pH is an important characteristic for water and soil quality since it influences plant and animal growth and survival, as well as the solubility and mobility of numerous compounds in the environment.

The pH of water can affect the toxicity of chemicals and metals to aquatic species. Metals such as aluminum and lead, for example, can become more soluble and hazardous to fish and other aquatic species at low pH levels. Furthermore, pH can influence the efficacy of certain water treatment processes, such as disinfection and coagulation (Bailey, Nelson, & Fonteno, 2000).

pH is critical for nutrient availability and plant growth in soil. Different plant species require different pH levels, and soil pH can influence the solubility and availability of nutrients like nitrogen, phosphorus, and potassium. For example, if the pH of the soil is too low (i.e., acidic), aluminum and manganese can become poisonous to plants, but if the pH is too high (i.e., alkaline), some nutrients such as iron, zinc, and copper can become less available (Šimek, Jíšová, & Hopkins, 2002). pH levels should be monitored and changed as needed to maintain optimal water and soil quality. The proper pH range will differ depending on the application and ambient conditions.

1.2.2 Electrical Conductivity (EC)

Electrical conductivity (EC) is a measurement of how well a solution conducts electricity. The concentration of dissolved salts and other charged particles in water or soil is measured using EC in the context of water and soil quality.

EC is usually expressed in milliSiemens per centimeter (mS/cm) or micro Siemens per centimeter (S/cm) units. The higher the EC value, the more dissolved salts there are in the water or soil. EC is an important metric in agriculture for assessing soil fertility and salinity. Dissolved salt levels in the soil can hinder plant growth and diminish crop yields. Farmers can evaluate whether the soil is getting too salted and adopt suitable mitigation actions, such as flushing the soil with freshwater or planting salttolerant crops, by monitoring the EC of soil and irrigation water (Hanson, 2006).

EC is also used to assess water quality in aquaculture, industrial processes, and wastewater treatment. High amounts of dissolved salts and other charged particles in these applications might impair the performance and efficiency of various systems and equipment. The World Health Organization recommends that water not exceed 400 S/cm and soil not exceed 110-570 S/cm (Hayashi, 2004).

1.2.3 Total Dissolved Solid(TDS)

The entire amount of inorganic and organic components dissolved in water is measured as total dissolved solids (TDS). Minerals, salts, metals, chemical molecules, and other dissolved particles are examples of these things. TDS is usually expressed in parts per million (ppm) or milligrams per liter (mg/L). TDS is an important water quality metric because high TDS levels can influence the taste, appearance, and safety of drinking water, as well as the health of aquatic ecosystems (ETEMAD, Afshar, Alikia, & Moshfeghi, 2009). TDS can be measured using many techniques including as gravimetric analysis, conductivity, and calorimetry. The electrical conductivity of water is measured and then translated to TDS using a calibration factor in conductivity-based tests. A reagent is given to the water sample, which reacts with the dissolved solids to produce a colour that can be detected using a spectrophotometer. larger TDS levels, in general, can indicate a larger concentration of dissolved salts and other compounds in water. Natural minerals such as calcium and magnesium, as well as man-made pollutants such as industrial chemicals and fertilisers, are typical causes of TDS in drinking water (Corwin & Yemoto, 2020).

1.2.4 Turbidity

Turbidity is a measure of a liquid's cloudiness or haziness, such as water. The presence of suspended particles in the liquid, such as clay, silt, plankton, and other minute organisms, causes it. Because these particles scatter and absorb light, the liquid appears cloudy or opaque. Turbidity is commonly measured with a turbidimeter or a nephelometer and reported in terms of Nephelometric Turbidity terms (NTU) or Formazin Nephelometric Units (FNU). A light source is transmitted through the liquid in these devices, and the amount of light scattered or absorbed by the suspended particles is measured and converted to a turbidity value (Kitchener, Wainwright, & Parsons, 2017).

Turbidity is an important metric for evaluating water quality since it can indicate the presence of suspended solids and other particles that can impair the quality and safety of drinking water. Turbidity, for example, can reduce the effectiveness of disinfection methods, allowing hazardous bacteria and viruses to linger in the water. Turbidity can also have an impact on the flavor, color, and odor of drinking water, as well as the overall health of aquatic ecosystems (Davies-Colley & Smith, 2001).

Untreated water can have turbidity levels between 1 and 1000 NTU. The majority of individuals are bothered by even minor turbidity in their drinking water. Turbidity affects the taste and odour of water, as well as acting as a barrier in recognizing germs and viruses in water. Turbid drinking water, in addition to having an unpleasant look, may have an impact on treatment methods and the retention of chlorine levels. If the reasons of excessive turbidity are not addressed, they can promote the growth of bacteria in the water and lead to outbreaks of water-borne illness. Despite the fact that turbidity is not an obvious indicator of a health danger, multiple studies show a substantial association between turbidity reduction and protozoa eradication. Turbidity particles serve as a haven for germs by making them less susceptible to disinfectants. Furthermore, it has been proposed that bacterial survival is increased by microbial adhesion to particulate matter. GGI episodes have been linked to situations where turbidity levels surpassed permissible levels. Turbidity removal improves the effectiveness of subsequent treatment operations (Kitchener et al., 2017).

1.2.5 Organic Matter

Organic matter is a soil component made up of decomposing plant and animal material. It is an important component of soil since it affects the soil's health and productivity. Organic matter gives essential nutrients to plants, enhances soil structure, and boosts the soil's water-holding capacity (Oades, 1989).

Soil organic matter is composed of various organic elements such as plant roots, leaves, stems, and animal waste products. As these materials decompose, they release nutrients essential for plant growth such as nitrogen, phosphorus, and potassium. Organic matter decomposition also contributes to the formation and maintenance of a soil structure that allows for adequate water drainage and aeration (Nelson & Oades, 1998). Industrial activities can have a substantial impact on organic matter in the soil. Land use changes caused by industrial development, for example, might result in the elimination of natural plant cover, reducing organic matter input into the soil. This can result in soil erosion and a loss of soil fertility. Furthermore, some industrial activities, such as mining and manufacturing, can release dangerous chemicals and pollutants into the environment. These contaminants can have a deleterious impact on soil microbes, resulting in slower organic matter breakdown rates and poor soil health (Larney & Angers, 2012).

1.3 Health Impacts of Heavy Metals

Heavy metals are a major source of pollution in the environment and a substantial threat to human health. Heavy metal exposure can occur through a variety of methods, including oral absorption, skin contact, and inhalation, with drinking water being the most common. Prolonged heavy metal exposure can have a variety of negative health impacts, making it a severe public health concern (Mahurpawar, 2015).

Heavy metals can build up in different human organs, including the liver, bones, and kidneys, causing major health problems. Heavy metal exposure can result in respiratory problems, lung infections, dysentery, typhoid, and other disorders. In addition, long-term heavy metal exposure can result in developmental and reproductive problems, cancer, and other chronic diseases. Because heavy metal contamination is chronic and extensive, it is critical to understand the health effects of various heavy metals and to take precautions to prevent exposure. To avoid and reduce the adverse impacts of heavy metal pollution on human health and the environment, governments, companies, and communities must work together (Rehman, Fatima, Waheed, & Akash, 2018)

Following are some of the health impacts of different heavy metals included in the study:

1.3.1 Iron (Fe)

Iron has the chemical symbol Fe and the atomic number 26. It is one of the most prevalent elements on the planet and is required by most living species. Because of its strong strength, durability, and magnetic characteristics, iron is also widely employed in industry. Excess iron, on the other hand, can be hazardous to both the environment and human health. Natural weathering processes and industrial activity are both potential causes of iron contamination (Jolly, Islam, & Akbar, 2013).

Iron poisoning can occur when there is a high quantity of iron in water or food, especially ferrous iron (Fe2+). Excess iron consumption can cause gastrointestinal issues, liver and kidney damage, and even death in severe situations. Iron has also been linked to the development of dangerous free radicals in the body, which can cause cellular damage and increase the risk of chronic diseases including cancer and heart disease (Ullah et al., 2022).

Iron is a ubiquitous component of many industrial processes, notably those involving the production of steel and other metal products. Iron can enter the environment through a variety of channels, including wastewater discharge, mining runoff, and air deposition from combustion processes. Iron contamination can have an impact on both surface and groundwater, posing a concern to both human health and the environment. Excessive iron levels in drinking water, for example, can produce discoloration, an unpleasant taste, and odor, as well as staining of home equipment and clothing. Furthermore, iron contamination can have an impact on aquatic ecosystems, resulting in decreased water quality and disruption of aquatic life. Excessive iron levels in soil can cause issues such as soil acidity, which can affect plant growth and diminish agricultural land productivity. High iron levels in soil can also cause the creation of iron oxide deposits, which can stain and discolor soil and water resources (Liu et al., 2022). As a result, it is critical to monitor and manage the release of iron into the environment caused by industrial activities, as well as to ensure that iron levels in food and water sources are safe for human consumption. Proper industrial waste and effluent treatment and management can help reduce the danger of iron contamination in the environment and safeguard human health (Liu et al., 2022).

1.3.2 Chromium (Cr)

Chromium is a naturally occurring element that is frequently employed in a variety of industrial processes, including electroplating, leather tanning, and pigment production. It can occur in a variety of oxidation states, such as trivalent chromium (Cr(III)) and hexavalent chromium (Cr(VI)). While Cr(III) is an essential component for human health and may be found in foods such as meats, whole grains, and vegetables, Cr(VI) is very toxic and poses serious threats to both human health and the environment (Hossini et al., 2022). The concentration of chromium in soil and water fluctuates according to pollution sources and natural geochemical processes. The concentration of chromium in soil and water fluctuates according to pollution sources and natural geochemical processes. Chromium can occur in several forms, including trivalent (Cr(III)) and hexavalent (Cr(VI)). Because it is less poisonous and more stable than Cr(VI), Cr(III) is the most frequent type of chromium in soil and water. In contrast, Cr(VI) is extremely soluble and mobile in water, and it can quickly leach into the soil and groundwater. Industrial activities, waste dumping, mining, and natural weathering of rocks and minerals can all cause chromium pollution in soil and water. Chromium concentrations in soil and water can be greatly enhanced in places with high levels of industrial activity, such as metal plating, leather tanning, and textile dyeing (P. Sharma, Singh, Parakh, & Tong, 2022).

High chromium levels in soil and water can have serious health consequences, including respiratory issues, skin irritation, liver and kidney damage, and an increased risk of cancer. As a result, it is critical to monitor chromium concentrations in soil and water and take actions to limit contamination. Remediation of chromium-contaminated areas can be accomplished using a variety of techniques, including chemical treatment, bioremediation, and phytoremediation. Furthermore, rules governing the disposal and use of chromium in industrial processes can aid in the prevention of contamination and the reduction of dangers to human health and the environment (Bao, Feng, Tu, Li, & Li, 2022).

1.3.3 Zinc (Zn)

Due to industrial activity, the heavy metal zinc (Zn) can be found in both soil and groundwater. Zinc contamination can result from industrial activities like mining, metal smelting, manufacturing, and waste disposal that release the metal into the environment.

Industrial effluents containing zinc that are discharged or leak into the ground can contaminate groundwater. Zinc and other heavy metals may be released into groundwater sources as a result of improper waste management techniques, such as the untreated dumping of industrial effluent. Zinc can linger in groundwater for a very long time and harm drinking water sources (Mortvedt, 1985). Industrial operations can contaminate soil with zinc through a number of different channels. Zinc can enter the soil through mining operations and the application of insecticides or fertilizers that contain zinc in agriculture. Industrial waste that is dumped on soil surfaces may include high zinc concentrations, such as sludge or ash from metal processing plants. Zinc can build up in the soil over time, particularly in locations where there are frequent industrial activity or poor waste management techniques (Kumar, Balomajumder, & Mondal, 2011). Zinc can be harmful to the environment and people's health when it is present in soil and groundwater. Groundwater that contains a lot of zinc may not be safe to drink or use for irrigation. Zinc can also accumulate in plants as a result of uptake from tainted irrigation water or soil, which could endanger consumer health and impair crop production.

High quantities of zinc exposure can have both immediate and long-term negative effects on human health. While acute exposure to increased zinc levels can cause symptoms of acute poisoning such as nausea, vomiting, and stomach pain, persistent exposure can have negative effects on the immune system, reproductive system, and brain processes (Nazir, Malik, Ajaib, Khan, & Siddiqui, 2011).

1.4 GIS for Water and Soil Quality Parameters Analysis

The Geographic Information System (GIS) is a useful tool for analyzing and visualizing water and soil quality characteristics. GIS technology can be used to map, analyze, and integrate many sorts of data, such as geospatial data, environmental data, and socioeconomic data. Water quality metrics such as dissolved oxygen, pH, temperature, and nutrients can be analysed using GIS in various water bodies such as rivers, lakes, and groundwater sources. Data can be gathered from a variety of sources, including government agencies, academic institutes, and citizen science programmes (AbdelRahman & Tahoun, 2019). The data can be mapped and analysed to find patterns and trends in water quality metrics at various spatial and temporal dimensions. GIS can also be used to analyse soil quality factors such as texture, pH, organic matter, and nutrient concentration. This data can be used to construct soil maps, identify high and poor soil fertility areas, and establish soil management programmes. GIS can also be used to examine the impact of many factors on water and soil quality, such as land use, climate change, and pollution. GIS analysis data can be utilised to establish successful environmental policy and management strategies (Simsek & Gunduz, 2007). GIS technology was utilized in this work to analyze water and soil quality characteristics in location of KMML,Chavara (Peter & Sreedevi, 2012). The study sought to ascertain the spatial distribution of contaminants such as pH, COD, ammonia nitrogen (NH3-N), and total nitrogen (TN) in the area. The inverse distance weighting (IDW) method was used in the study to interpolate the values of non-sampled locations and construct spatial distribution maps of the water and soil quality metrics.

In another study conducted by Megahed, the quality of groundwater resources in southern Egypt's Wadi El-Assiuti is evaluated. The main goal is to determine whether the local groundwater is appropriate for drinking and irrigation. In order to do this, a total of 159 groundwater samples were taken from Wadi El-Assiuti's exit and centre. These samples were collected in the autumn of 2019—more particularly, in the months of October and November. The presence of main ions, trace elements, and heavy metals was then determined by analysing the samples that had been collected. GIS was used to produce maps that show how groundwater quality parameters were distributed throughout Wadi El-Assiuti. The interpretation and dissemination of study findings are aided by these maps' clear visual representation of the spatial patterns and fluctuations in water quality (Megahed, 2020).

(Oumenskou et al., 2018) conducted a study in which he used several geoaccumulation indices and Geographical Information Systems (GIS) to evaluate the heavy metal contamination in the Beni Amir irrigated perimeter in the Tadla plain, Morocco. Zn, Cr, Pb, Cu, and Cd concentrations in 47 subsurface agricultural soil samples were examined. The spatial distribution of heavy metal concentrations and pollution indices in the Beni Amir irrigated perimeter was depicted on themed maps using GIS. These maps offered a visual representation of the levels and hotspots of contamination, assisting in the identification of locations that need management or remediation measures. In another study, researchers looked into the environmental qualities of urban parks to determine the possibility of heavy metals being mobilised into the biosphere. The city of Faisalabad's sixteen busiest urban parks were examined for Copper, Zinc, Nickel, and Lead contamination. The experimental observations served as the basis for the research. Heavy metal concentrations were analytically determined using ICP (Inductively Coupled Plasma) optical emission spectroscopy. With the aid of SPSS 14, multivariate geospatial studies were carried out using GIS (Geographic Information System) methods and statistical analysis (Parveen, Ghaffar, Shirazi, & Bhalli, 2012).

(Khan, Singh, Upreti, & Yadav, 2022) conducted study is to examine the soil quality in Rajasthan's Bagru region. By taking into account a minimal range of interconnected biophysical and chemical factors, research attempts to conduct a full quantitative evaluation of soil quality. This evaluation will be conducted using multivariate statistical techniques inside an integrated Geographic Information System (GIS) environment.

Another study was conducted by (Khan et al., 2022), the goal of the study is to evaluate the level of contamination, the sources of the heavy metals, and the health risks associated with them in the industrial soils of Aurangabad. With a sampling density of 3-5 composite soil samples, a total of 15 soil samples were obtained. The creation of spatial distribution maps utilized geographic information system (GIS) technology such as inverse distance weighted interpolation (IDW) and kriging.

Objectives

The objectives of study are:

1. Groundwater and Soil quality assessment in terms of heavy metal and its vulnerability to pollution using Pollution Indices.
2. Spatial distribution maps of heavy metals (Fe, Zn, and Cr) of industrial area of Islamabad.

CHAPTER 2

MATERIALS AND METHODS

2.1 Study Area

The study has been carried out on industrial area of Islamabad (I-9). The I-9 sector of Islamabad, Pakistan's capital city, is regarded as one of the important areas in Islamabad and is known for its economic and industrial significance. The precise latitude and longitude of the I-9 sector are roughly 33.6573° N and 73.0572° E (Fig 1). The study area experiences distinct seasons characterized by significant temperature variations. During winter, the mean maximum temperature averages around 17.7°C, while the mean minimum temperature drops to approximately 2.6°C. In contrast, summer brings considerably higher temperatures, with the mean maximum reaching nearly 40°C and the mean minimum staying around 24°C. Throughout the year, the prevailing winds generally originate from the north or southeast directions. However, during summer, there are occasional short periods of wind activity. This developed area, which is located in the city's southern region, is heavily populated and provides a variety of essential services and contemporary facilities. I-9 is further divided into four sub-parts, namely I-9/1, I-9/2, I-9/3, and I-9/4, just like other sectors in Islamabad. I-8 and I-10 both encircle the sector's eastern and western edges, respectively. The study area consists of variety of industries and main focus of study will be on Iron and Steel industry. Due to its contributions to industry, Sector I/9 has significant relevance not just for the nation's capital but for the entire country. The largest dangers to the life of the locals were air and water pollution. "Pollution created by the industrial units in Sector I/9 goes unchecked, beneath the nose of official monitoring departments, adding known and undiscovered concerns to the population' health. Unfortunately, because of enterprises that produce pollution close to residential areas, the city's environmental problems are getting worse. There are different types of industries in the study area that are being mentioned in Figure 3.

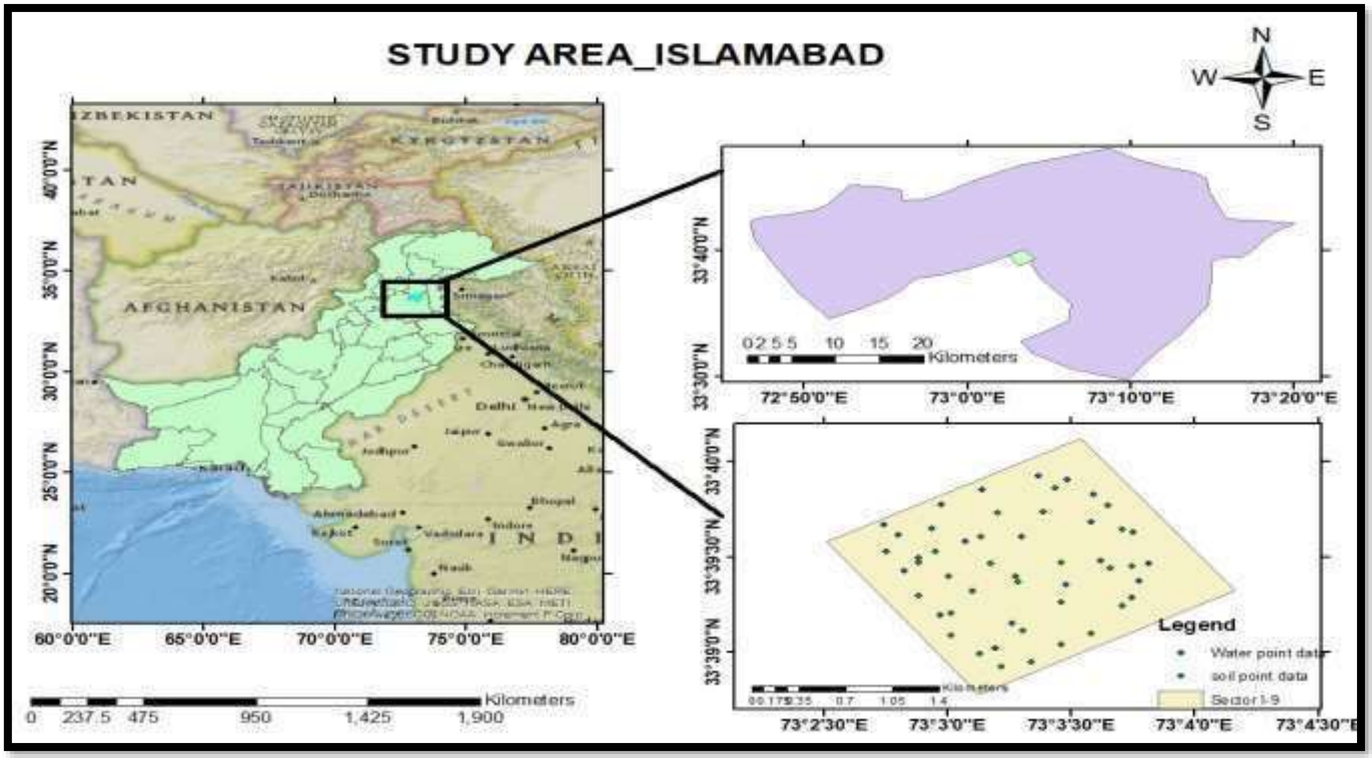

Figure 1. Study area map showing the industrial sector of Islamabad.

2.2 Data Collection

2.2.1 GPS Coordinates

The study focused on taking soil and groundwater samples. A GARMIN GPS receiver was used to carry out a GPS survey to find the sampling locations (Dumas, 2022). 50 sites were identified by the survey, and the locations of these sampling points were noted. A feature class in a file geodatabase was then created using these coordinates. It should be remembered that in confined spaces, GPS accuracy may be compromised. Figure 1 shows where the sampling spots are located.

2.2.2 Water Sampling and Laboratory Analysis

During the month of June, groundwater samples were collected using a simple random sampling technique. The purpose was to assess the water quality in the study area. The researchers designated 25 sampling sites from various locations, including those in proximity to industrial areas, in a random manner.

The samples were collected in 100ml polyethylene water bottles. The samples from the areas around the industries were collected using a variety of groundwater sources, including hand pumps, motor pumps, tube wells, and bores. The samples were taken to the lab for additional analysis after being collected. Several physicochemical traits were examined in the lab to assess the water quality.

These characteristics included turbidity (water clarity or cloudiness), total dissolved solids (TDS), electrical conductivity (EC), pH (water acidity or alkalinity), and total dissolved solids (measures the quantity of inorganic and organic components) (Patil, Sawant, & Deshmukh, 2012).

2.2.3 Soil Sampling and Laboratory Analysis

The depth for collecting soil samples in order to accurately determine soil parameters was between 0 and 20 cm. For soil sampling, a random composite technique was used, in which various sample units were joined and either totally or partially merged to form a new composite sample. A dirt shovel was employed to gather the soil samples.

The composite sample was subjected to a number of physical processes, including ball milling, sieving, shaking, and centrifugation, to guarantee its integrity and homogeneity. These techniques aid in creating an even combination of the various sample units. After being carefully packaged in clean plastic bags with the proper labels, the gathered samples were delivered to the IESE lab at the National University of Sciences and Technology (NUST) in Islamabad for additional processing and inspection.

The physicochemical characteristics of the soil, including as pH, electrical conductivity (EC), and organic matter concentration, were assessed at the IESE lab. The Walkley-Dark chromic corrosive wet oxidation method was employed to assess the organic matter concentration (Chaudhari, 2013). The soil samples were further prepared by using a soft-bristled brush to remove bigger particles. The samples were then dried in an oven for 72 hours at 65 5 °C. The dried materials were crushed into a powder using an electric grinder and put through a 0.3-mm mesh filter to simplify further examination. The processed samples were then meticulously kept in envelopes and kept in a desiccator to avoid absorbing moisture.

2.2.4. Acid Digestion of Soil Samples

The soil samples underwent an essential step known as acid digestion, which is necessary for the analysis of heavy metals. An acid digestion is used to dissolve both organic and inorganic components of a sample, and is particularly useful for the analysis of trace elements and heavy metals. Strong acids are used to dissolve the sample matrix and extract the necessary components, commonly nitric acid (HNO3) and occasionally perchloric acid (HClO4) in a 3:1 concentration. Acid digestion aids in dissolving organic matter and other components of the sample, leaving behind trace metals for analysis (GÜVEN & Akinci, 2011).

A beaker containing 10 ml of pure nitric acid and 0.5 g of the dried soil sample was used to perform acid digestion. Figure 2: Acid Digestion shows what happened after the combination was left overnight. After reaching 90 °C, 4 cc of perchloric acid was added to the sample. The solution was heated continuously until it became translucent. Following the filtration process, a final solution made up of double-deionized water was produced. This final solution contained 50 cc of liquid. The liquid samples were prepared for analysis after the acid digestion procedure to find the amounts of a few specific heavy metals, such as Ni, Cr, and Fe.

Figure 2. Acid digestion

2.2.5 Determination of Heavy Metals

Both water and soil samples were chosen for assessing the presence of heavy metals after the acid digestion of soil samples. The samples were delivered to PMAS Arid Agriculture University Rawalpindi for examination. Using ICP-OES, or inductively coupled plasma optical emission spectrometry, heavy metals were tested. The analytical method known as ICP-OES, or inductively coupled plasma optical emission spectrometry, is used to identify the elements present in a variety of samples. Inductively coupled plasma (ICP) and optical emission spectrometry concepts are combined in this method to get extremely accurate and exact findings (Hou & Jones, 2000).

In the ICP-OES procedure, a sample was first put into an argon plasma that was created by ionising argon gas using a high-frequency electromagnetic field. The components of the sample were atomized and excited when the plasma reaches temperatures of about 10,000 K. The excited atoms emit distinctive light at particular wavelengths as they transition back to their lower energy states (Fassel & Kniseley, 1974). The light is then directed into a spectrometer, where it is divided into its constituent wavelengths by a diffraction grating. The scattered light is picked up by a photomultiplier or charge-coupled device (CCD) detector, and the resulting emission spectrum is recorded. The concentration of different elements in the sample were calculated by examining the intensity of the emitted light at particular wavelengths. Each element emits distinctive emission lines, making it possible to identify and measure many elements at once. A calibration curve was created using calibration standards with known concentrations of the target elements for precise measurement. This plasma has a high electron density and a high temperature (10000K) (Fassel & Kniseley, 1974).

2.3 Analytical Framework

The data preparation and establishment of a geodatabase are the first two crucial steps in the analytical framework. MS Excel is used for statistical analysis, and ArcMap 10.8.2 is used for geostatistical analysis. Additionally, water and soil quality indices are estimated, and using Pearson's correlation coefficient, the relationship between soil and water physicochemical characteristics and the distribution of heavy metals in the research region is looked at. The data is first organised and structured properly for analysis as part of the preparation process. The spatial data is then stored in a geodatabase, which is created as a means of managing and analysing the data effectively. Next, MS Excel is used for statistical analysis. To acquire insights into the dataset, this entails running numerous calculations and statistical tests. A variety of tools and functions in Excel make it easier to analyse and comprehend the data.

2.3.1 Database

The study area's shapefile was created using a KML file that was downloaded from Google Earth Pro. ArcMap 10.8.2 was then used to convert the KML file into a shapefile format. The findings of the physicochemical parameters and the concentration of the heavy metals were simultaneously recorded in an Excel file. This Excel file now contains coordinate points matching to the sampling locations. Using the information from the Excel file, a correlation coefficient study was carried out in Excel to look into the relationship between the variables. The data points were then connected to the study area shapefile by converting the Excel file into a point shapefile in ArcMap.

2.3.2 Water Quality Index

The overall quality of water is measured by the Water Quality Index (WQI), a numerical score based on many water factors. The index assigns a single value to a number of elements, which defines the quality of the water. The process of calculating the water quality index entails evaluating the combined effect of both naturally occurring and artificially produced activities on particular hydro-geometric features of the water sample. To determine the WQI values for each sampling location, the average concentrations of the determinants (TDS, EC, pH, turbidity, and heavy metals (Ni, Cr, and Fe)) were employed (Brown, McClelland, Deininger, & Tozer, 1970).

All obtained samples' laboratory analysis findings were used to determine the quality of each sample. The World Health Organization's drinking water quality standards were used in the development of the Water Quality Index (WQI). The allowable limits of physicochemical parameters were established using these principles as a guide. The physicochemical parameters are given weights in the Water Quality Index (WQI) computation based on their respective significance in determining the overall quality of water for water supply needs. These weights represent the importance of each criterion in determining the quality of the water.

Depending on a number of water quality factors and how they are used in the environment, the WQI displays the total water quality at each water body both in time and space (Tyagi, Sharma, Singh, & Dobhal, 2013). Table shows the weight factors for the parameters included. The relative weights of pH, EC, TDS and turbidity are 0.002, 0.0006, 0.0008 and0.004 respectively while Fe and chromium got 0.24 weight factors and Zn have 0.49 value.

The Water Quality Index (WQI) is computed in this study using the arithmetic index approach. The WQI is calculated by averaging the individual index values of four categories' worth of water quality criteria, which each represent a different level or state of pollution. These groups consist of turbidity, pH, EC, and TDS. A weighting factor that indicates the relative significance of each criterion in determining water quality is added to the numerical value (qi) indicating the quality rating. This factor is produced from the data on water quality.

Table 1. Water quality parameters and weight factors

Variables	**WHO standards**	**Weight factors**
pH	8.5	0.25
EC	400	0.15
TDS	300	0.2
Turbidity	5	0.15

Fe	1.0	0.40
Cr	0.1	0.40
Zinc	0.5	0.26

$$qi = \frac{ci}{si} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..Eq1$$

where,

q_i, = quality rating scale.

c_i, = concentration of *i* parameter.

s_i = WHO standard value of *i* parameter.

Relative weight is calculated by

$$W = \frac{1}{Si} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.Eq2$$

In order to determine the relative weight (wi), following formula was used

$$Wi = \frac{wi}{\sum_1^n wi} \ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots.Eq3$$

Its sub-index Calculations of Si and WQI are based on the following relation:

$$SI = Wi * qi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..Eq4$$

$$WQI = SIi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..Eq5$$

Where,

Qi= rating based on the concentration of the ith parameter

SIi = sub-index of the ith parameter

2.3.3 Soil Quality Index

The Soil Quality Index (SQI), a quantitative measure, incorporates several soil-related characteristics to assess the general health and fertility of a specific soil. It provides a number that indicates the overall quality of the soil based on a number of indicators or parameters. The SQI considers the physical, chemical, and biological characteristics of the soil, including its structure, organic matter content, pH, availability of nutrients, and texture (de Paul Obade & Lal, 2016).

$$SQI = \sum_{i=1}^{n} (Wi.Xi) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.Eq6$$

In order to create a SQI, relevant indicators must be chosen, each indicator must be given a weight based on how important it is, and the combined indicators must result in a single index value. In order to compare the soil quality of various soil samples or track changes in soil quality over time, this index value offers a standardised and simple to understand measure of soil quality (Mukherjee & Lal, 2014).

Researchers, farmers, and land managers can assess the health and fertility of soils, pinpoint problem areas, and make well-informed decisions on soil management practises by utilising a Soil Quality Index. It is a useful tool for conserving soil, maximising agricultural productivity, and managing land use sustainably while minimising adverse environmental effects (Granatstein & Bezdicek, 1992).

The weights given to the parameters are displayed in Table 2. For the purpose of comparing various factors, unit less ratings for soil quality indicators were transformed from 0.1 to 1.0. Organic matter was given the highest weight, 0.7, pH 0.6 and EC with 0.15. Heavy metals were given the weight of 0.5 for

Fe, Cr with 0.5 and 0.1 for Zn

Table 2. Soil Quality Parameters and Weight Factors

Soil quality parameters	**Weight factors**
pH	0.6
EC	0.15
OM	0.7
Fe	0.5
Cr	0.5
Zn	0.1

.

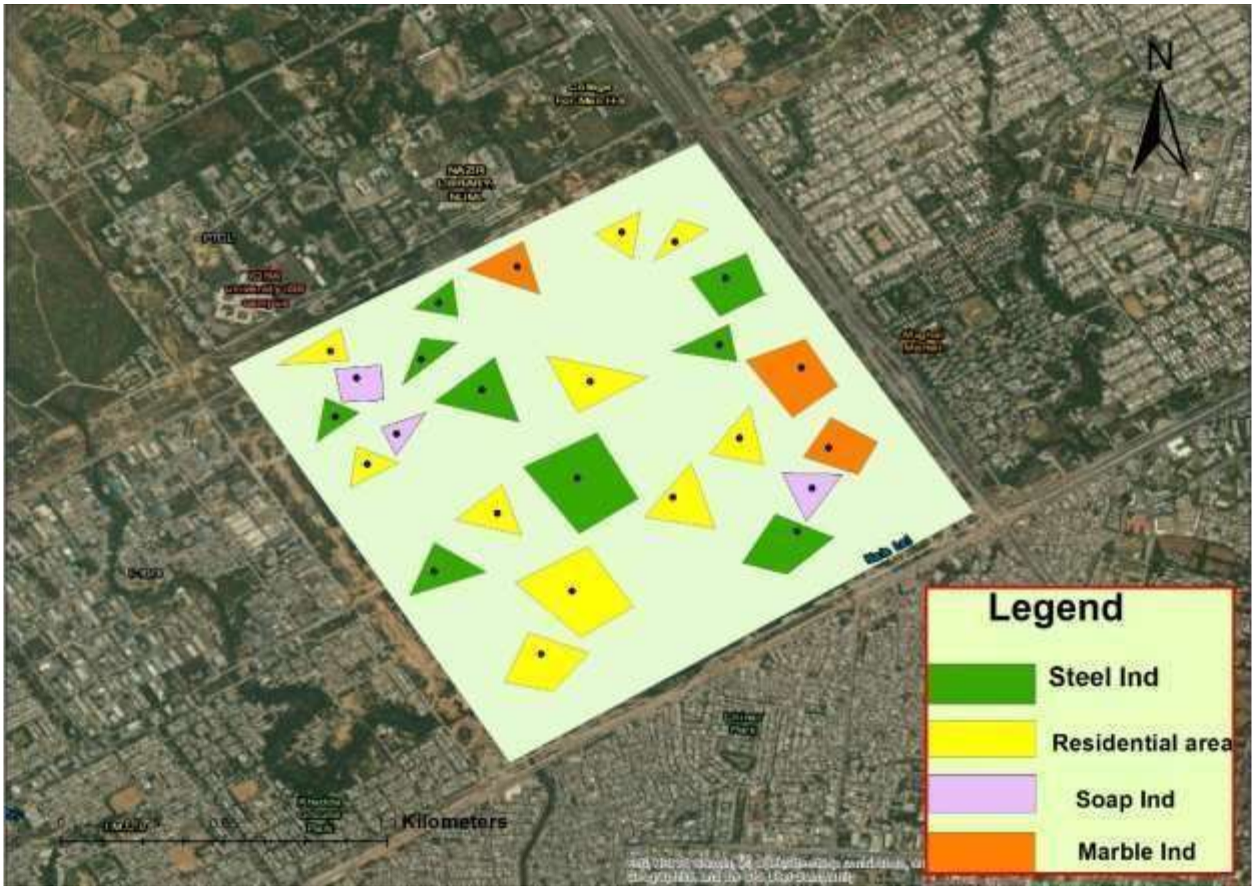

Figure 3. Type of industries in study area (I-9 Islamabad).

CHAPTER 3

RESULTS AND DISCUSSION

3.Summary Statistics

3.1.1 Soil and Water Quality Parameters

The findings of the statistical analysis of the features of the soil and water quality, as displayed in Tables 3 and 5, shed light on significant components of the samples. The results were summarised using important statistical metrics like the minimum and maximum values, mean, standard deviation, skewness, and kurtosis. The computed mean value for water pH was 6.87, indicating a slightly acidic tendency. This range suggests that the majority of the water samples were neutral to slightly alkaline, with a relatively balanced pH level suited for a variety of applications.

Furthermore, research into electrical conductivity (EC) yielded surprising results. The observed EC values fluctuated, with measurements ranging from 400 microsiemens per centimetre (uS/cm) to beyond. Particularly, the mean EC value calculated from the dataset was 708.7 uS/cm. This value exceeds the allowable limit, raising concerns about the overall water quality. Elevated EC levels frequently indicate the presence of dissolved salts or other potentially toxic chemicals, making the water unsuitable for certain purposes.

3.1.2 Statistics of Heavy Metals

The concentrations of iron (Fe), chrome (Cr), and zinc (Zn) in water samples varied. The Fe content ranged from 0.001 to 88.1, with an average of 26.43 exceeding the WHO's allowable limit of 1.0 ppm. Similarly, the Cr concentration ranged from 0 to 6.26, with an average of 0.94, exceeding the WHO's acceptable limit of 0.1 ppm. Furthermore, the Zn concentration ranged from 0.32 to 16.25, with an average of 4.64, exceeding the allowable limit of 0.5 ppm.

The concentration of Fe in soil samples ranged from 0.04 to 97.67, with an average of 39.39, exceeding the WHO's acceptable limit of 0.1 ppm. Similarly, Cr concentrations ranged from 0 to 5.34, with an average of 0.689 surpassing the allowable limit of 0.1 ppm. In the case of Zn, however, the concentration in the soil samples ranged from 0.04 to 12.25, with an average of 1.70, falling below the allowed limit of 0.1 ppm.

3.1.3 Correlation Analysis

Correlation analysis is a statistical technique for determining the strength and direction of a relationship between two or more variables. It is primarily used to determine the degree to which two variables are connected or associated with one another. The correlation coefficient is a quantitative statistic provided by correlation analysis that reveals the degree and direction of the relationship between variables (Yu, Du, Chen, Song, & Zhou, 2023).

A thorough correlation study was carried out among the selected parameters, with an emphasis on significant correlations with a p0.38 criteria. Only correlations with values of 0.38 or higher were considered statistically significant. The correlation analysis for water samples revealed some interesting results. pH was found to have a substantial negative association with iron (Fe), zinc (Zn), and chromium (Cr) contents, with correlation coefficients of -0.53, -0.38, and -0.47, respectively. This means that water samples with an acidic pH have larger amounts of Fe, Cr, and Zn. Samples with higher pH levels, on the other hand, may contain lower concentrations of these components.

Fe and Cr were also shown to be strongly positively correlated, with a correlation coefficient of 0.39. This suggests that a large majority of places or samples tend to contain Fe and Cr in high quantities combined. Additionally, there was a 0.45 significant positive connection between Cr and turbidity. This shows that a rise in turbidity is frequently followed with an increase in chromium content. Similar to water samples, a strong negative association between pH and the levels of iron (Fe) and chromium (Cr) was seen in the context of soil analysis. pH and Fe and pH and Cr had correlation values of -0.71 and -0.55, respectively.

Fe and Cr were also found to have a substantial positive link in the soil samples, with a correlation coefficient of 0.39. This shows that high quantities of Fe and Cr are typically found together in the majority of soil samples. Additionally, electrical conductivity (EC) and Fe (0.52) and Cr (0.43) showed a strong positive correlation in the soil samples. This implies that higher soil Fe and Cr contents and higher EC values are connected.

Table 3. Summary Statistics of Water Quality Parameters

Variables	**Max**	**Min**	**Mean**	**Standard Deviation**	**Kurtosis**	**Skewness**	**WHO limit**	**EPA limit**
pH	9.13	5.82	6.87	0.841	1.31	1.14	6.5-8.5	6.5-8.5
EC	853	270	708.7	132.05	4.06	-1.80	50-1500 uS /cm	50-1500 uS/cm
TDS	443.5	140.4	368.6	68.67	4.07	-1.81	300 ppm	500 ppm
Turbidity	10.5	0.01	1.93	2.23	8.95	2.75	5 NTU	1.0 NTU
Fe	88.8	0.001	26.43	32.37	-0.90	0.82	1.0 ppm	0.3 ppm
Cr	6.26	0	0.94	1.65	1.09	1.92	0.1 ppm	0.1 ppm
Zn	16.25	0.32	4.64	5.35	-0.23	1.09	0.5 ppm	5 ppm

Table 4. Correlation Matrix of Water

	pH	***EC***	***TDS***	***Turbidity (NTU)***	***Fe(ppm)***	***Cr (ppm)***	***Zn (ppm)***
pH	1						
EC	0.01	1					
TDS	0.01	0.99	1				
Turbidity(NTU)	-0.12	0.16	0.16	1			

Fe (ppm)	-0.53*	-0.02	-0.02	0.17	1		
Cr (ppm)	-0.38*	0.14	0.14	0.45*	0.39*	1	
Zn (ppm)	-0.47	0.11	0.11	0.13	0.22	0.12	1

Table 5. Summary Statistics of Soil Quality Parameters

	MIN	**MAX**	**MEAN**	**STDEV**	**SKEW**	**KURTOSIS**	**WHO LIMIT**
pH	5.56	9.09	7.26	0.86	0.12	0.39	5.5-7.5
EC uS/cm	106	1354	772.16	288.35	-0.31	0.31	110-570 (uS/cm)
Organic Matter %	0.28	0.84	0.51	0.16	0.25	-0.65	0.03-0.06%
Fe(ppm)	0.04	97.67	39.39	27.91	0.34	-0.631	---
Cr(ppm)	0	5.34	0.689	1.3644	2.761	7.04	0.1 ppm
Zn (ppm)	0.04	12.25	1.70	3.09	3.07	8.66	10 ppm

Table 6. Correlation Matrix of Soil

	pH	**EC**	**Fe**	**Cr**	**Zn**	**Organic matter**
pH	1					
EC	-0.37	1				

Fe	**-0.71**	**0.52**	1			
Cr	**-0.55**	**0.43**	**0.39**	1		
Zn	0.02	-0.25	-0.23	-0.05	1	
Organic matter	-0.13	-0.22	0.11	0.17	-0.05	1

n=25; *= significant at 0.05 level of significance

3.2 Spatial Interpolation

3.2.1 Physicochemical Parameters

The goal of spatial interpolation techniques is to estimate values at un sampled places using the data that is already available. Tools like ArcGIS Geostatistical Analyst use a number of techniques, including kriging, co-kriging, inverse distance weighting (IDW), and spline interpolation. The Inverse Distance Weighted (IDW) interpolation method has been selected for the specific study at hand (Conolly, 2020). By averaging the values of nearby sample data points surrounding each target cell, the IDW interpolation method determines the values of the cells. A data point's influence or weight during the averaging process depends on how close it is to the approximation cell's centre. The interpolated value is more affected by points that are near the centre than by points that are farther from it.

Physiochemical parameters have been separated into three colour scales (green, red, and yellow) to illustrate varying degrees of values. Each category is assigned a different colour on a scale from green to red to visually represent the associated danger level. The colour red, in particular, designates highly contaminated areas, denoting excessive levels of heavy metals or unsatisfactory values for the physicochemical characteristics.

The figure shows maps that depict the physical-chemical characteristics of water in relation to space. The pH values in the green zone are those that are within the World Health Organization's (WHO) recommended range (5.6-8.5). On the other hand, areas outside of this green zone signify pH levels that are higher than allowed. The WHO has established 400 S/cm as the upper allowable level for water's electrical conductivity (EC). As a result, any areas on the map that are not green represent EC values more than 400 S/cm. The WHO has also established 5NTU for turbidity and 300ppm for total dissolved solids (TDS) as acceptable limits. As a result, the red areas on the map represent values that are higher than the corresponding criteria.

Notably, EC and TDS show a strong positive association, which explains why they share the same regions that are underlined in red. But there is no link between the other factors. There is no association between the various physicochemical parameters in the case of soil parameters. This indicates that changes in one parameter do not consistently affect or have a consistent relationship with the values of the other parameters. Each characteristic is autonomous and is influenced by various soil-environment processes.

3.2.2 Heavy Metals

Following an analysis of the spatial distribution maps shown in Figure, three different classes are used to represent different degrees of heavy metal contamination in water. The areas highlighted in red are severely contaminated places where the observed values greatly exceed the acceptable limits established by the World Health Organisation (WHO).

An interesting finding is that places where chromium (Cr) contamination is over the WHO limit of 0.05 ppm correlate with areas where iron (Fe) contamination is above the allowed maximum of 1.0 ppm. This connection suggests that the levels of iron and chromium in the water samples have a strong positive association. Additionally, iron (Fe) concentrations exceeding the advised limit of 0.05 ppm were found in numerous areas, highlighting its prevalence and potential health risks.

In contrast, the content of Fe in soil is high across the board and exceeds WHO recommendations. As opposed to the red and yellow marked spots in Cr, the green patches show the safe areas. In comparison to Fe and chromium, Zn (10 ppm WHO limit) was only identified in a relatively small number of locations.

While Fe and Cr have a significant positive association.

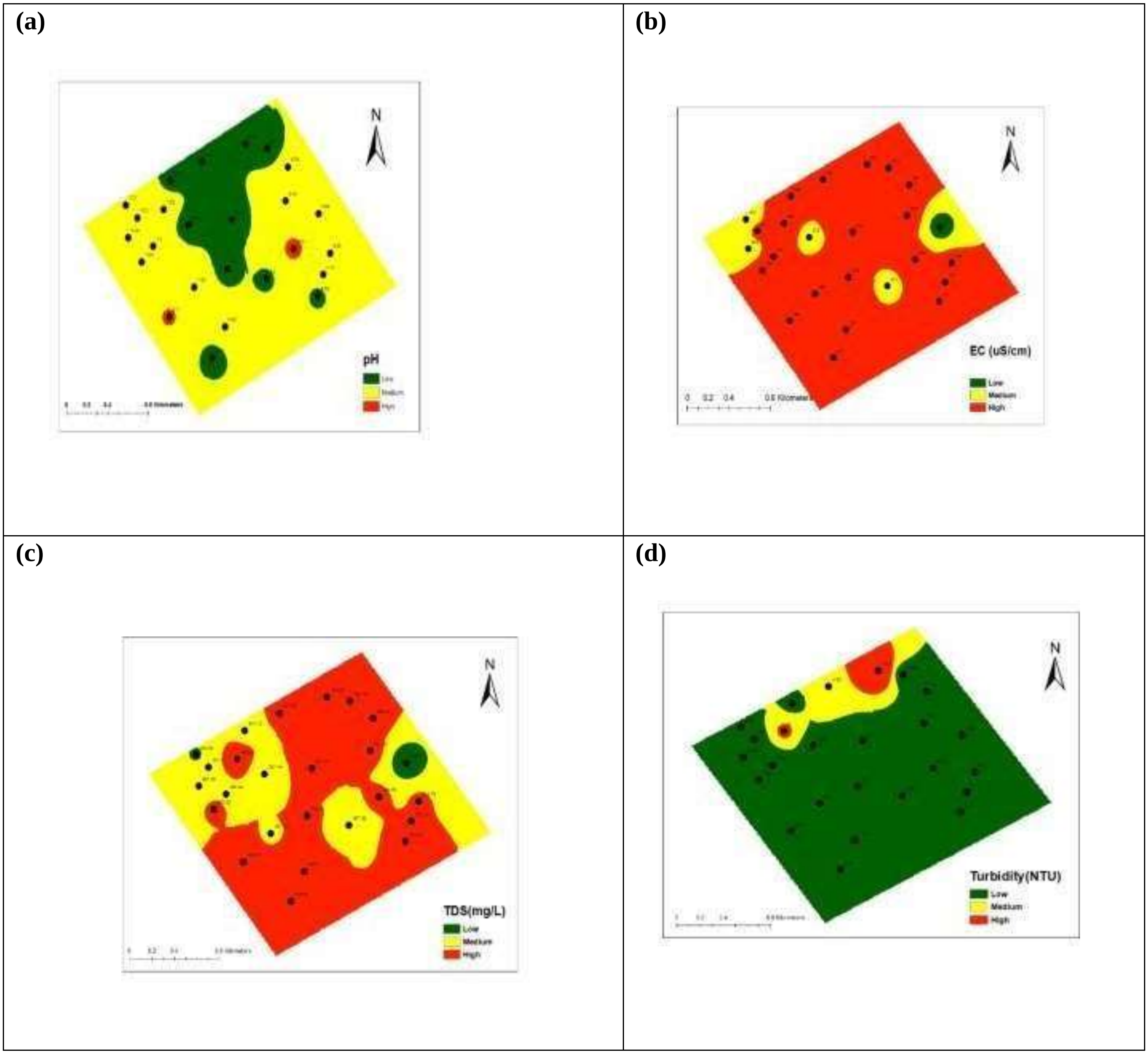

Figure 4: Spatial distribution maps of groundwater quality parameters (a) pH(b) EC (c)TDS(d)Turbidity

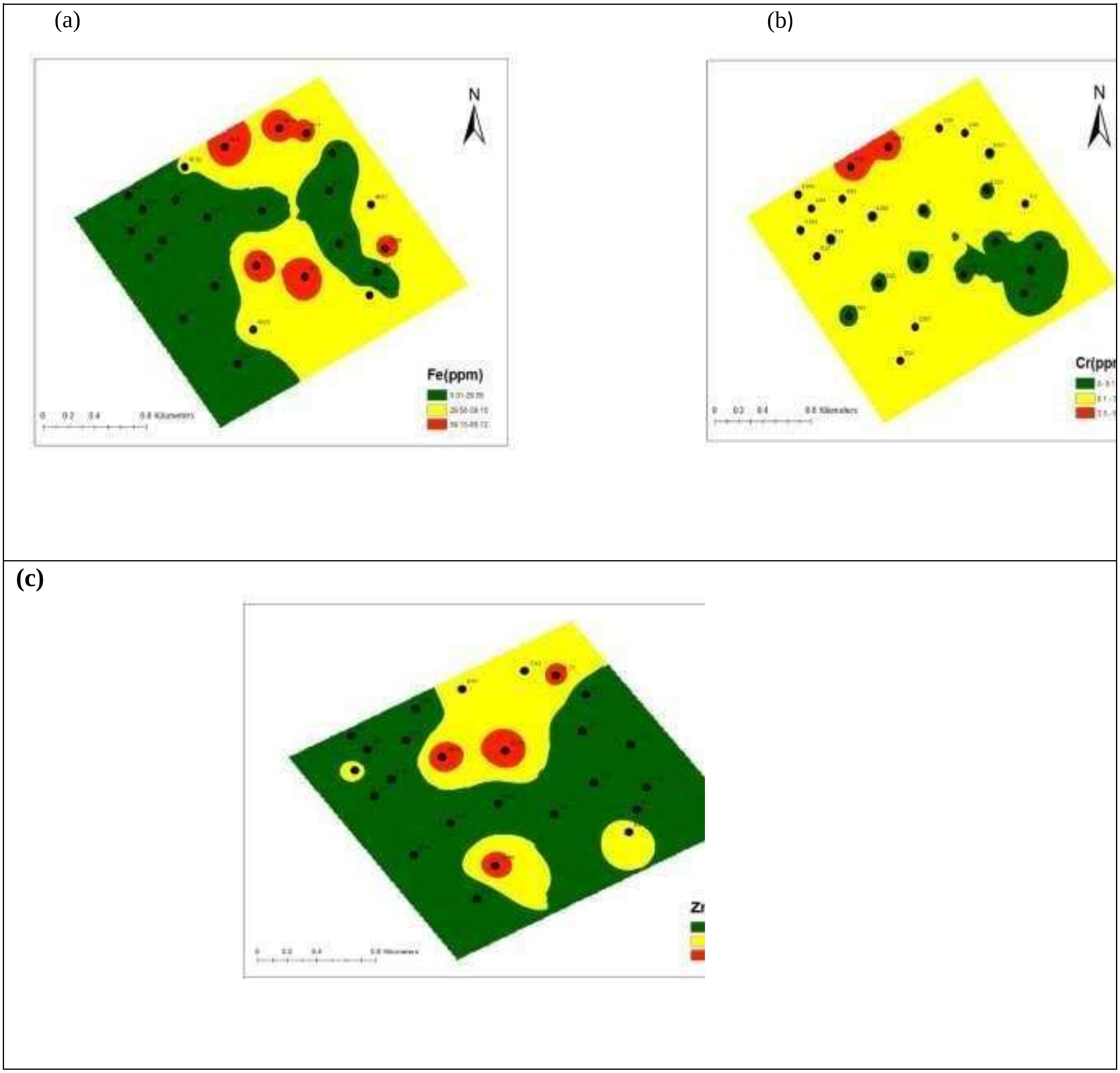

Figure 5. Spatial distribution maps of heavy metals concentration in groundwater (A)Fe (B)Cr (C) Zn

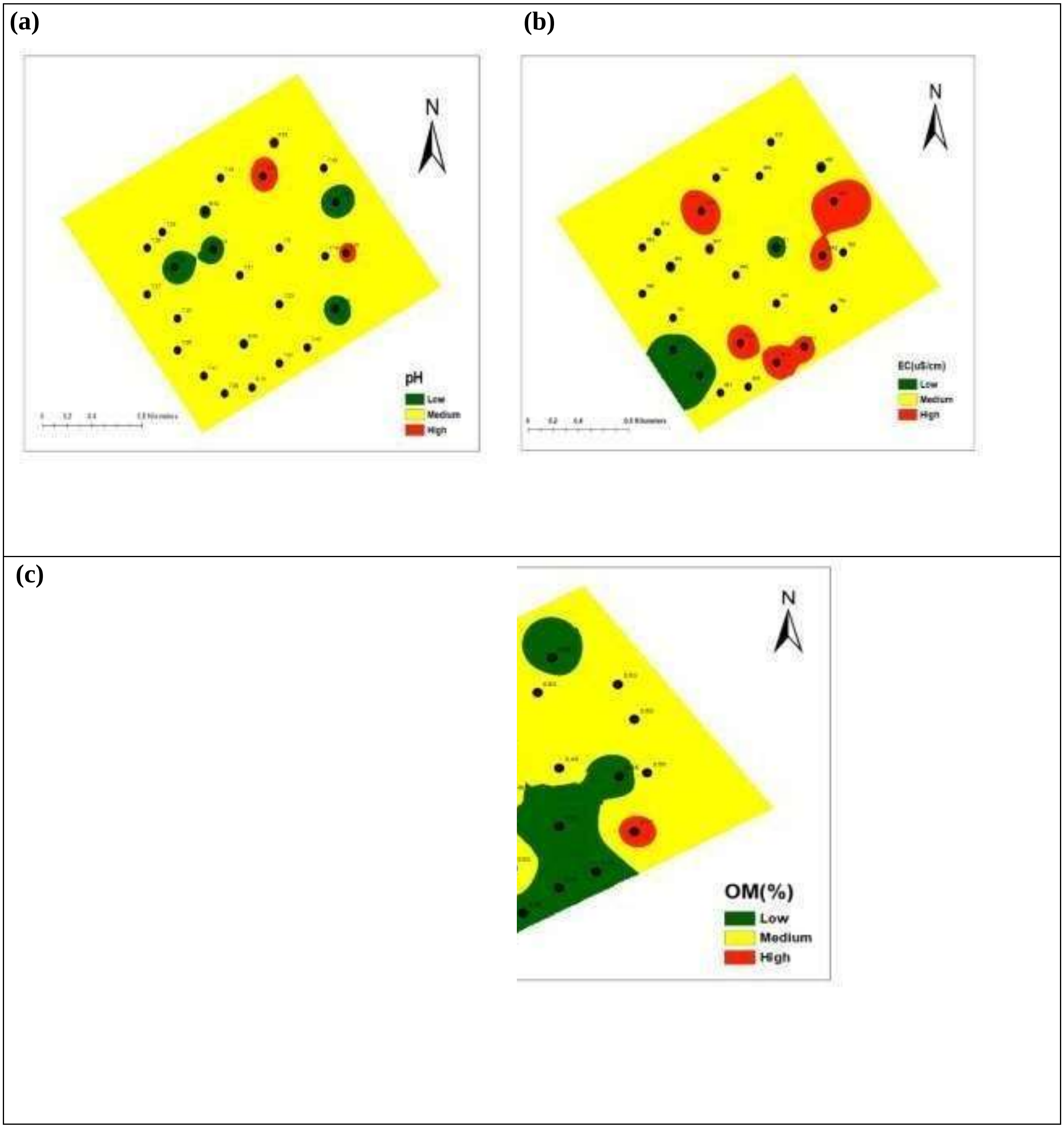

Figure 6. Spatial distribution maps of soil quality parameters (A)pH(B)EC (C)OM(Organic Matter)

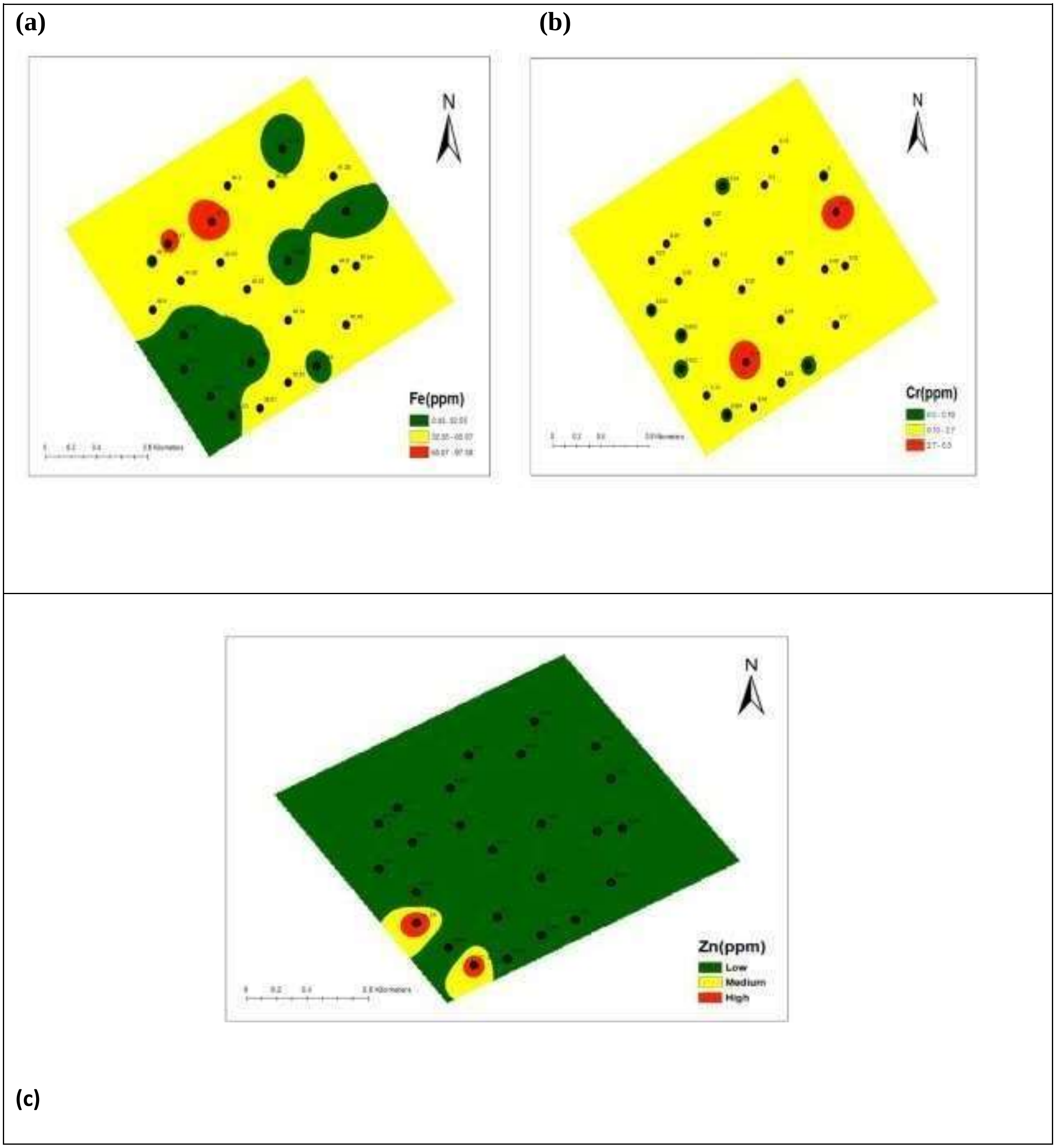

Figure 7. Spatial distribution maps of heavy metals concentration in soil (A)Fe (B)Chromium (C)Zn

3.3 Quality Indices

3.3.1 Water Quality Index

Groundwater's overall quality is evaluated and summarized using the Water Quality Index (WQI), a numerical indicator based on different water quality criteria. Numerous factors are included by the WQI, including pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), and pollutant concentrations (Brown et al., 1970).

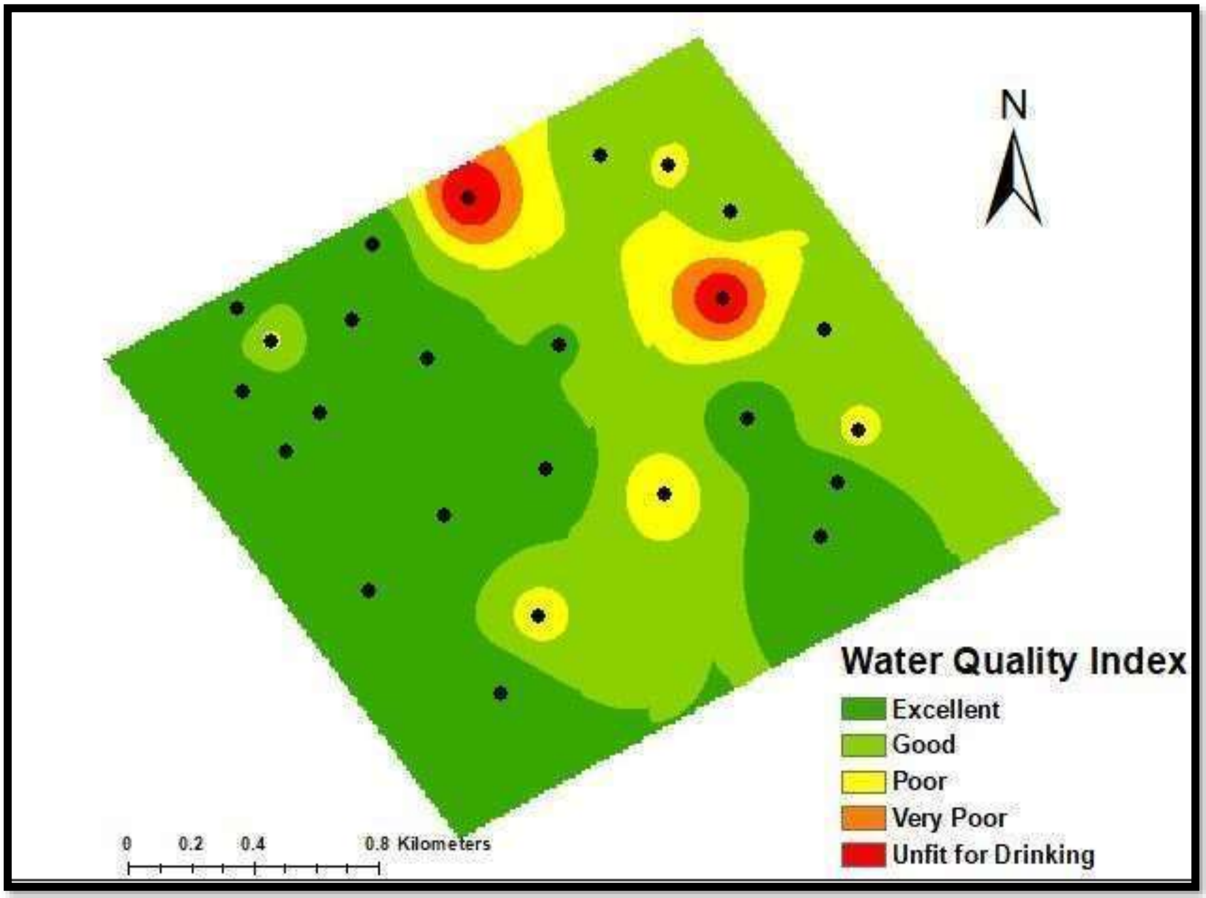

Figure 8. Water quality index map of I-9 Islamabad

3.3.2 Soil Quality Index

Based on several soil quality parameters, the Soil Quality Index (SQI) is a numerical indicator used to evaluate and summarise the overall quality of soil. The SQI considers a number of variables, including the soil's physical, chemical, and biological characteristics (Granatstein & Bezdicek, 1992)

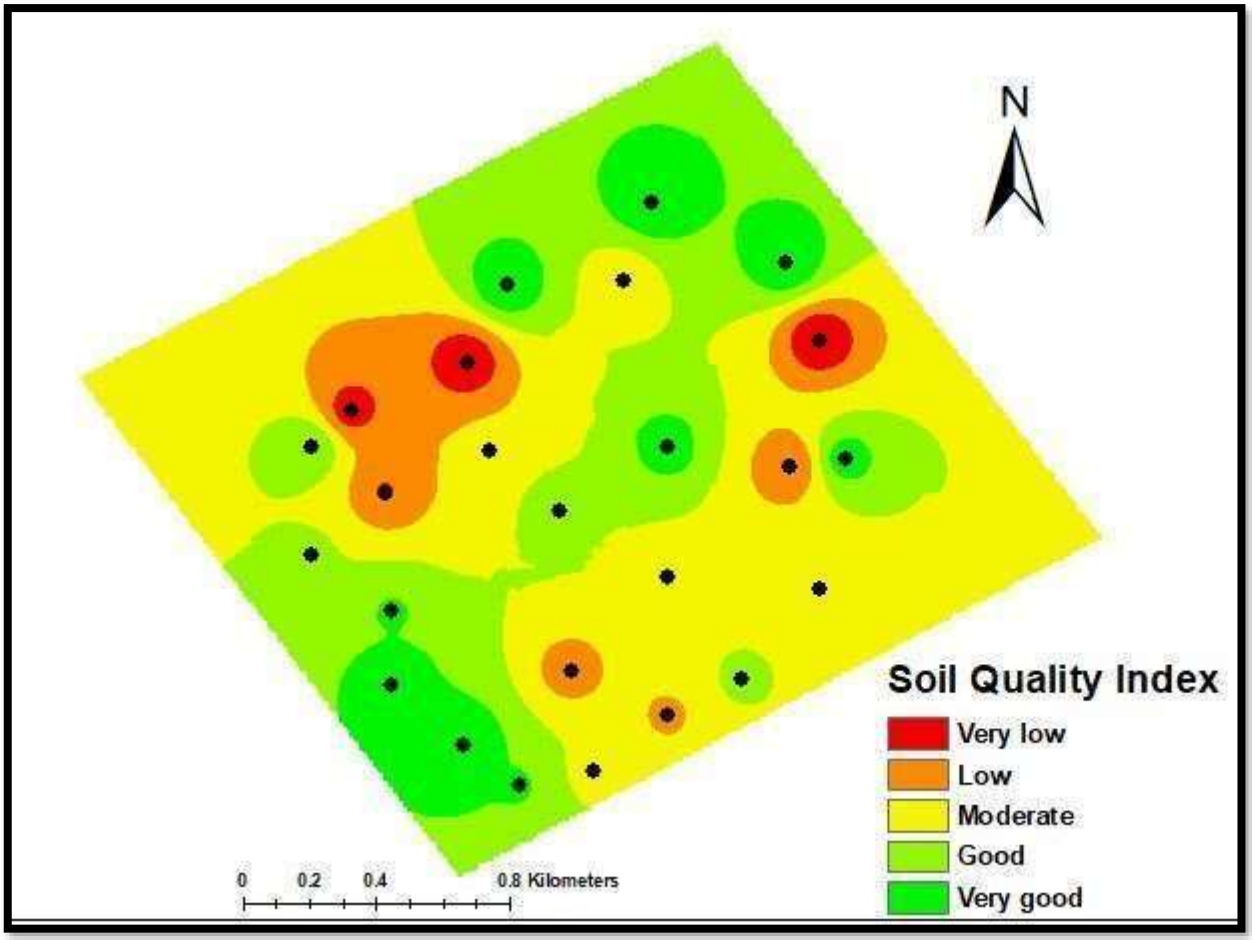

Figure 9. Soil Quality Index Map of I-9 Islamabad

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Due to rising industrial activity, heavy metal contamination in soil and groundwater is a major concern worldwide, including in Pakistan. The presence of heavy metals in soil and groundwater can have negative effects on both human health and the ecosystem. In Pakistan, deteriorating soil and groundwater quality is mostly the result of human activity, such as inefficient industrial practices, ineffective irrigation water management, and insufficient waste management.

Similar to maintaining the quality of the air and water, maintaining the quality of the soil should be a primary goal of national environmental policy. Using GIS, the Water Quality Index (WQI), and the Soil Quality Index (SQI), a research study was carried out in the I-9 area of Islamabad to assess the water and soil quality surrounding industrial zones. Environmental research benefits from the use of GIS and geostatistics, especially in areas where spatial distribution is important. It is essential to determine the present concentrations of heavy metals in impacted places like Islamabad, Pakistan, in order to address the problems of heavy metal contamination in soil and groundwater. Groundwater quality analysis using Geographic Information System (GIS) technology has proven to be a useful method for identifying pollution sources and evaluating potential effects by combining different data sources. In order to assess and reduce heavy metal contamination, it is crucial to monitor and manage water and soil quality indices as pH, electrical conductivity (EC), total dissolved solids (TDS), and turbidity.

The study's findings showed that the majority of soil and water quality indices, as well as heavy metal concentrations, exceeded the World Health Organization's (WHO) acceptable limits.

The water quality index in several regions of the study site showed either low or bad water quality, making it unfit for human consumption. Similar to this, the area's soil quality index indicated several areas with poor soil quality. The WQI and SQI maps showed areas where it was assessed that the water and soil quality was poor.

As a result of the degraded water and soil quality, these locations are unsuitable for water consumption and agricultural activity. A multifaceted strategy is needed to address heavy metal contamination, including implementing good industrial practices, better waste management, supporting sustainable agriculture, and putting in place efficient water and soil quality monitoring programmes. The safety and sustainability of soil and groundwater resources are also dependent on public awareness, education, and regulatory measures.

4.2 Recommendation

The following suggestions can be made based on the assessment and evaluation of groundwater and soil quality as well as the presence of heavy metals in industrial areas**:**

1. To reduce the release of pollutants into the environment, enforce strict restrictions and monitoring systems for industries operating in the area. This involves keeping an eye on solid waste management procedures, air pollutants, and wastewater discharge.
2. Encourage enterprises to adopt environmentally friendly waste management practises by promoting best practises in waste management, such as proper treatment of industrial effluents and disposal of hazardous material. Implementing programmes for reuse and recycling can also aid in lowering trash production.
3. Establish a thorough monitoring programme for the quality of the soil and groundwater in industrial regions. To monitor changes over time and find probable pollution sources, routine sampling and analysis should be done. This will allow for prompt mitigation and intervention strategies.

4. Launch awareness campaigns and educational initiatives to enlighten policymakers, business stakeholders, and local people on the significance of soil and groundwater quality. Encourage the people to participate in environmental conservation initiatives and promote sustainable practises
5. Create remediation strategies for contaminated sites in the industrial region, and put them into action. This could entail remediation methods for soil and groundwater, including the application of cutting-edge technologies like phytoremediation or bioremediation.
6. Promote the use of sustainable business practices and cleaner manufacturing technologies across industries. Develop and deploy green technologies that minimize the production of pollutants and minimize their impact on the environment, and offer incentives and support for their use.
7. Examine and improve current rules governing industrial operations, with particular attention to limiting the emission of heavy metals and other pollutants. Strict enforcement procedures and penalties for non-compliance are used to ensure compliance.
8. To completely address groundwater and soil quality challenges, foster collaboration among government agencies, business groups, academic institutions, and community organizations. This can involve coordinated efforts for sustainable environmental management, shared data and expertise, and combined research endeavors.
9. To assist reduce the effects of pollution on groundwater and soil, create green buffer zones surrounding industrial areas that serve as natural filters and barriers. Before toxins get to sensitive locations, these zones might have vegetation that can absorb and filter them.
10. Environmental policies and regulations should be reviewed and updated often to reflect new scientific knowledge and emerging problems. Ensure that the policies continue to be effective at preserving the quality of the soil and groundwater by taking into account stakeholder and expert feedback.

By putting these suggestions into practice, it will be possible to preserve human health, limit the negative effects of industrial activity on groundwater and soil quality, and encourage sustainable development in industrial areas.

References

1. AbdelRahman, M. A., & Tahoun, S. (2019). GIS model-builder based on comprehensive geostatistical approach to assess soil quality. *Remote sensing Applications: society and Environment*, *13*, 204-214.
2. Abioye, O. P. (2011). Biological remediation of hydrocarbon and heavy metals contaminated soil. *Soil contamination*, *7*, 127-142.
3. Addy, K., Green, L., & Herron, E. (2004). pH and Alkalinity. *University of Rhode Island, Kingston*.
4. Bailey, D. A., Nelson, P. V., & Fonteno, W. C. (2000). Substrates pH and water quality. *Raleigh: North Carolina Sate University*.
5. Bao, Z., Feng, H., Tu, W., Li, L., & Li, Q. (2022). Method and mechanism of chromium removal from soil: a systematic review. *Environmental Science and Pollution Research*, *29*(24), 35501-35517.
6. Brown, R. M., McClelland, N. I., Deininger, R. A., & Tozer, R. G. (1970). A water quality index-do we dare. *Water and sewage works*, *117*(10).
7. Chakraborty, T. K., Islam, M. S., Ghosh, G. C., Ghosh, P., Zaman, S., Habib, A., . . . Imran, M. A. (2023). Human health risk and hydro-geochemical appraisal of groundwater in the southwest part of Bangladesh using GIS, water quality indices, and multivariate statistical approaches. *Toxin Reviews*, *42*(1), 285-299.
8. Chaudhari, K. G. (2013). Studies of the physicochemical parameters of soil samples. *Advances in Applied Science Research*, *4*(6), 246-248.
9. Conolly, J. (2020). Spatial interpolation. In *Archaeological Spatial Analysis* (pp. 118-134): Routledge.
10. Corwin, D. L., & Yemoto, K. (2020). Salinity: Electrical conductivity and total dissolved solids.

Soil science society of America journal, 84(5), 1442-1461.

11. Davies-Colley, R., & Smith, D. (2001). Turbidity suspeni) ed sediment, and water clarity: a review 1. *JAWRA Journal of the American Water Resources Association, 37*(5), 1085-1101.
12. de Paul Obade, V., & Lal, R. (2016). A standardized soil quality index for diverse field conditions. *Science of the total environment, 541*, 424-434.
13. Dumas, J. (2022). Accuracy of Garmin GPS Running Watches over repetitive trials on the same route. *arXiv preprint arXiv:2203.00491*.
14. Duruibe, J. O., Ogwuegbu, M., & Egwurugwu, J. (2007). Heavy metal pollution and human biotoxic effects. *International Journal of physical sciences, 2*(5), 112-118.
15. Einarson, M. D., & Mackay, D. M. (2001). Peer reviewed: predicting impacts of groundwater contamination. In: ACS Publications.
16. ETEMAD, S. A., Afshar, A., Alikia, H., & Moshfeghi, H. (2009). Total dissolved solid modeling; Karkheh reservoir case example.
17. Fassel, V. A., & Kniseley, R. N. (1974). Inductively coupled plasma. Optical emission spectroscopy. *Analytical Chemistry, 46*(13), 1110A-1120a.
18. George, A., Venugopal, A., & Vashisht, A. K. (2023). Heavy metal contamination in soil and groundwater around industrial areas of Kollam District, Kerala, India. *Environmental Monitoring and Assessment, 195*(2), 265.
19. Granatstein, D., & Bezdicek, D. (1992). The need for a soil quality index: local and regional perspectives. *American Journal of Alternative Agriculture, 7*(1-2), 12-16.
20. GÜVEN, D., & Akinci, G. (2011). Comparison of acid digestion techniques to determine heavy metals in sediment and soil samples. *Gazi University Journal of Science, 24*(1), 29-34.
21. Hanson, B. (2006). Electrical conductivity. *Agricultural Salinity and Drainage, 2nd edition. California: Department of Land, Air, and Water Resources, University of California, Davis*, 7-8.

22. Harkins, R. D. (1974). An objective water quality index. *Journal (Water Pollution Control Federation)*, 588-591.
23. Hayashi, M. (2004). Temperature-electrical conductivity relation of water for environmental monitoring and geophysical data inversion. *Environmental Monitoring and Assessment, 96*, 119-128.
24. Hossini, H., Shafie, B., Niri, A. D., Nazari, M., Esfahlan, A. J., Ahmadpour, M., . . . Mirzaei, N. (2022). A comprehensive review on human health effects of chromium: insights on induced toxicity. *Environmental Science and Pollution Research, 29*(47), 70686-70705.
25. Hou, X., & Jones, B. T. (2000). Inductively coupled plasma/optical emission spectrometry. In (Vol. 2000, pp. 9468-9485): John Wiley & Sons Chichester, UK.
26. Huamain, C., Chunrong, Z., Cong, T., & Yongguan, Z. (1999). Heavy metal pollution in soils in China: status and countermeasures. *Ambio*, 130-134.
27. Ikenaka, Y., Nakayama, S. M., Muzandu, K., Choongo, K., Teraoka, H., Mizuno, N., & Ishizuka, M.(2010). Heavy metal contamination of soil and sediment in Zambia. *African Journal of Environmental Science and Technology*, *4*(11), 729-739.
28. Jolly, Y. N., Islam, A., & Akbar, S. (2013). Transfer of metals from soil to vegetables and possible health risk assessment. *SpringerPlus, 2*, 1-8.
29. Khan, J., Singh, R., Upreti, P., & Yadav, R. K. (2022). Geo-statistical assessment of soil quality and identification of Heavy metal contamination using Integrated GIS and Multivariate statistical analysis in Industrial region of Western India. *Environmental Technology & Innovation*, *28*, 102646.
30. Kitchener, B. G., Wainwright, J., & Parsons, A. J. (2017). A review of the principles of turbidity measurement. *Progress in Physical Geography*, *41*(5), 620-642.

31. Kumar, J., Balomajumder, C., & Mondal, P. (2011). Application of Agro-Based Biomasses for Zinc Removal from Wastewater–A Review. *CLEAN–Soil, Air, Water, 39*(7), 641-652.
32. Larney, F. J., & Angers, D. A. (2012). The role of organic amendments in soil reclamation: A review. *Canadian Journal of Soil Science, 92*(1), 19-38.
33. Li, C., Zhou, K., Qin, W., Tian, C., Qi, M., Yan, X., & Han, W. (2019). A review on heavy metals contamination in soil: effects, sources, and remediation techniques. *Soil and Sediment Contamination: An International Journal, 28*(4), 380-394.
34. Li, F., Wu, J., Xu, F., Yang, Y., & Du, Q. (2023). Determination of the spatial correlation characteristics for selected groundwater pollutants using the geographically weighted regression model: A case study in Weinan, Northwest China. *Human and Ecological Risk Assessment: An International Journal, 29*(2), 471-493.
35. Li, P., Karunanidhi, D., Subramani, T., & Srinivasamoorthy, K. (2021). Sources and consequences of groundwater contamination. *Archives of environmental contamination and toxicology, 80,* 1-10.
36. Liu, L., Wu, Q., Miao, X., Fan, T., Meng, Z., Chen, X., & Zhu, W. (2022). Study on toxicity effects of environmental pollutants based on metabolomics: A review. *Chemosphere, 286,* 131815.
37. Luo, D., Liang, Y., Wu, H., Li, S., He, Y., Du, J., . . . Pu, S. (2022). Human-Health and Environmental Risks of Heavy Metal Contamination in Soil and Groundwater at a Riverside Site, China. *Processes, 10*(10), 1994.
38. Mahurpawar, M. (2015). Effects of heavy metals on human health. *Int J Res Granthaalayah, 530,* 1-7.
39. Megahed, H. A. (2020). GIS-based assessment of groundwater quality and suitability for drinking and irrigation purposes in the outlet and central parts of Wadi El-Assiuti, Assiut Governorate, Egypt. *Bulletin of the National Research Centre, 44,* 1-31.
40. Megdal, S. B. (2018). Invisible water: the importance of good groundwater governance and management. *NPJ Clean Water, 1*(1), 15.

41. Mortvedt, J. (1985). *Plant uptake of heavy metals in zinc fertilizers made from industrial by-products* (0047-2425). Retrieved from

42. Mukherjee, A., & Lal, R. (2014). Comparison of soil quality index using three methods. *PloS one, 9*(8), e105981.

43. Nazir, A., Malik, R. N., Ajaib, M., Khan, N., & Siddiqui, M. F. (2011). Hyperaccumulators of heavy metals of industrial areas of Islamabad and Rawalpindi. *Pak J Bot, 43*(4), 1925-1933.

44. Nelson, P., & Oades, J. (1998). Organic matter, sodicity and soil structure. In: Oxford University Press.

45. Oades, J. M. (1989). An introduction to organic matter in mineral soils. *Minerals in soil environments, 1,* 89-159.

46. Oumenskou, H., El Baghdadi, M., Barakat, A., Aquit, M., Ennaji, W., Karroum, L. A., & Aadraoui, M. (2018). Assessment of the heavy metal contamination using GIS-based approach and pollution indices in agricultural soils from Beni Amir irrigated perimeter, Tadla plain, Morocco. *Arabian Journal of Geosciences, 11*(22), 692.

47. Parveen, N., Ghaffar, A., Shirazi, S., & Bhalli, M. (2012). A GIS based assessment of heavy metals contamination in surface soil of urban parks: a case study of Faisalabad City-Pakistan. *Journal of the Geography of Natural Disasters, 2*(5).

48. Patil, P., Sawant, D., & Deshmukh, R. (2012). Physico-chemical parameters for testing of water–A review. *International journal of environmental sciences, 3*(3), 1194-1207.

49. Peter, S., & Sreedevi, C. (2012). *Water Quality Assessment and GIS mapping of ground water around KMML industrial area, Chavara.* Paper presented at the 2012 International Conference on Green Technologies (ICGT).

50. Qureshi, A. S. (2020). Groundwater governance in Pakistan: From colossal development to neglected management. *Water, 12*(11), 3017.

51. Rehman, K., Fatima, F., Waheed, I., & Akash, M. S. H. (2018). Prevalence of exposure of heavy metals and their impact on health consequences. *Journal of cellular biochemistry, 119*(1), 157-184.

52. Seybold, C., Herrick, J. E., & Brejda, J. (1999). Soil resilience: a fundamental component of soil quality. *Soil science, 164*(4), 224-234.

53. Sharma, I. (2020). Bioremediation techniques for polluted environment: concept, advantages, limitations, and prospects. In *Trace metals in the environment-new approaches and recent advances*: IntechOpen.

54. Sharma, P., Singh, S. P., Parakh, S. K., & Tong, Y. W. (2022). Health hazards of hexavalent chromium (Cr (VI)) and its microbial reduction. *Bioengineered, 13*(3), 4923-4938.

55. Šimek, M., Jíšová, L., & Hopkins, D. W. (2002). What is the so-called optimum pH for denitrification in soil? *Soil Biology and Biochemistry, 34*(9), 1227-1234.

56. Simsek, C., & Gunduz, O. (2007). IWQ index: a GIS-integrated technique to assess irrigation water quality. *Environmental Monitoring and Assessment, 128*, 277-300.

57. Singha, K., & Navarre-Sitchler, A. (2022). The importance of groundwater in critical zone science. *Groundwater, 60*(1), 27-34.

58. Suwanaruang, T. (2023). The Toxicity Processes of Environmental Pollutants. *The Toxicity Processes of Environmental Pollutants*, 1-119.

59. Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. *Molecular, clinical and environmental toxicology: volume 3: environmental toxicology*, 133-164.

60. Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2013). Water quality assessment in terms of water quality index. *American Journal of water resources, 1*(3), 34-38.

61. Tzanakakis, V. A., Paranychianakis, N. V., & Angelakis, A. N. (2020). Water supply and water scarcity. In (Vol. 12, pp. 2347): MDPI.

62. Uddin, M. G., Nash, S., & Olbert, A. I. (2021). A review of water quality index models and their use for assessing surface water quality. *Ecological indicators*, *122*, 107218.

63. Ugochukwu, U. C., Chukwuone, N., Jidere, C., Ezeudu, B., Ikpo, C., & Ozor, J. (2022). Heavy metal contamination of soil, sediment and water due to galena mining in Ebonyi State Nigeria: Economic costs of pollution based on exposure health risks. *Journal of environmental management, 321*, 115864.

64. Ullah, N., Ur Rehman, M., Ahmad, B., Ali, I., Younas, M., Aslam, M. S., . . . Rezakazemi, M. (2022). Assessment of heavy metals accumulation in agricultural soil, vegetables and associated health risks. *PloS one, 17*(6), e0267719.

65. Yu, D.-G., Du, Y., Chen, J., Song, W., & Zhou, T. (2023). A correlation analysis between undergraduate students' safety behaviors in the laboratory and their learning efficiencies. *Behavioral Sciences*, *13*(2), 127

Appendices

Appendix 1: Details of water data- 1

Site	latitude	longitude	PH	EC	TDS	TURBIDITY	Fe	CR	Zn
W1	33.6608	73.049	7.22	852	443.04	6	0.5	0.02	0.68
W2	33.6597	73.0512	5.96	572	297.44	2.09	0.002	0.008	16.25
W3	33.6582	73.0481	7.2	702	365.04	1.44	0.03	0.01	0.39
W4	33.6611	73.0457	7.27	479	249.08	2.69	5.66	0.003	4.5
W5	33.6553	73.0517	7.29	696	361.92	0.73	0.1	0.032	0.59
W6	33.6614	73.0597	8.12	789	410.28	0.91	0.02	0.023	1.04
W7	33.658	73.0604	9.13	748	388.96	0.22	0.001	0.045	1.03
W8	33.6559	73.058	6.3	591	307.32	0.18	85.5	0.06	3.44
W9	33.6547	73.0625	6.29	777	404.04	0.01	35.54	0.034	9.9
W10	33.6562	73.063	7.14	716	373.32	0.01	0.24	0	0.46
W11	33.6577	73.0636	6.63	738	383.76	0.71	75.66	0.01	1.76
W12	33.6605	73.0626	6.88	270	140.4	1.32	45.01	0.3	1.45
W13	33.6638	73.0599	6.78	787	409.24	1.6	22.31	0.001	3.03
W14	33.6651	73.0581	6	853	443.56	1.59	64.4	2.45	12.77
W15	33.6654	73.0562	6.5	801	416.52	10.5	65.44	3.55	7.83
W16	33.6642	73.0524	5.9	726	377.52	4.52	88.8	4.003	9.41
W17	33.6629	73.0496	6.23	656	341.12	2.43	32.22	6.26	0.44
W18	33.6602	73.0467	6.72	707	367.64	2.01	2.33	2.34	0.9
W19	33.6588	73.0459	7.43	553	287.56	1.36	0.79	0.002	7.77
W20	33.6571	73.0471	7.04	741	385.52	1.6	0.01	0.27	1.3
W21	33.6532	73.0495	8.71	788	409.76	2.23	0.3	0.004	0.49

W22	33.6503	73.0533	6.21	807	419.64	1.18	0.29	2.04	0.83
W23	33.6525	73.0544	6.96	835	434.2	1.49	44.03	2.027	14.26
W24	33.6566	73.0546	6.1	724	376.48	0.5	79.5	0.021	0.32
W25	33.6601	73.055	5.82	811	421.72	1.12	12.2	0	15.39

Appendix 2: Details of Soil data- 2

SITE	**latitude**	**longitude**	**PH**	**ec**	Fe	**cr**	**zn**	**lab1_organ**
1	33.6498	73.0522	7.41	106	0.04	0.12	0.06	0.84
2	33.6514	73.0503	7.69	246	0.11	0.002	12.25	0.63
3	33.6534	73.0503	7.28	731	1.38	0.003	0.39	0.49
4	33.6549	73.0481	7.27	946	49.6	0.023	0.4	0.84
5	33.6566	73.0501	5.8	488	88.86	2.32	0.59	0.56
6	33.6578	73.0481	7.35	684	29.3	0.23	0.04	0.28
7	33.6588	73.0492	7.28	814	75.07	0.26	1.03	0.56
8	33.6601	73.0523	6.42	1205	97.67	0.27	0.44	0.56
9	33.6622	73.0534	7.45	744	40.2	0.034	0.9	0.56
10	33.6623	73.0565	9.09	668	13.28	0.3	0.46	0.63
11	33.6644	73.0573	8.53	535	2.59	0.19	1.76	0.35
12	33.6628	73.0609	7.43	495	61.29	0	1.45	0.63
13	33.6607	73.0618	5.56	1354	77.03	4.45	3.03	0.63
14	33.6573	73.061	7.19	1042	24.8	0.45	0.77	0.35
15	33.6578	73.0577	7.6	421	16.84	0.36	0.83	0.49
16	33.6543	73.0577	7.23	755	46.34	0.39	0.41	0.28

17	33.6561	73.0548	7.21	898	48.08	0.28	0.44	0.49
18	33.6518	73.0551	6.43	1120	49.59	5.34	0.9	0.63
19	33.6577	73.0529	6.24	947	52.09	1.3	1.77	0.35
20	33.6516	73.0597	7.43	967	23.84	0	1.3	0.28
21	33.6506	73.0577	7.21	1011	55.81	0.03	0.49	0.28
22	33.6491	73.0557	8.13	895	25.81	0.35	0.83	0.42
23	33.6487	73.0537	7.28	687	29.03	0.001	11.26	0.35
24	33.654	73.0618	6.05	750	60.48	0.21	0.32	0.77
25	33.6575	73.0625	8.95	795	15.84	0.32	0.39	0.56