GIS-BASED GROUNDWATER AND SOIL QUALITY ASSESSMENT OF HEAVY METAL CONTAMINATION: A CASE STUDY OF INDUSTRIAL AREA OF SAMBRIAL-SIALKOT, PAKISTAN

By

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(2020-NUST-MS-GIS-329546)

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Remote Sensing and GIS

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May, 2023

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DEDICATION

To Almighty Allah

&

My Sweet & Loving Family

Thanks for their love, care, and motivation since the start of my studies, and to all those who encouraged me and prayed for me for the completion of this thesis.

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 would like to thank my mother and family for their upbringing of me and their tireless efforts and support in every path I take to achieve my dreams and goals. 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. This research would have not been possible without the consistent support of my father who supported me in the data collection activities and my mother for her continuous prayers. It is a pleasure to pay tribute to all my sincere friends, colleagues and family members, particularly my parents for their sincere attitude, support, patience, and prayers which inspired me every moment towards successful completion of my tasks. At the end, I would specially highlight my sisters Aisha, Asma and Umm e Habiba for their extreme support throughout my entire degree.

Zainib Sajjad

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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
pH	Hydrogen Potential
SQI	Soil quality index
TDS	Total dissolved solids
WQI	Water quality index

Abstract

Heavy metal pollution of soils and groundwater is an environmental issue worldwide, especially in those countries where environmental protection policies exist but are not implemented. A study was designed to assess heavy metal pollution in the industrial area of Sialkot. The specific objectives of the study were to generate (a) spatial distribution maps of heavy metals (Ni, Cr, Pb) of the Industrial area of Sambrial-Sialkot and (b) assess the groundwater and soil quality in terms of heavy metals and their vulnerability to pollution using quality Indices. A total of 50 groundwater and soil samples were collected through random sampling. Samples physico-chemical properties (pH, EC, TDS), turbidity, and organic matter were analyzed using standard procedures. Heavy metals (nickel, chromium, and lead) were analyzed using ICP (inductively coupled plasma) optical emission spectrometry. Spatial distribution maps of heavy metal and physicochemical properties of soils and groundwater were generated using the Inverse Distance Weighted technique (IDW). The heavy metals (nickel, chromium, and lead) were above the permissible limits of WHO in soil and groundwater samples. Nickle (-0.61) and chromium (-0.54) had a significant ($p<0.05$) negative correlation with pH in water samples. Nickle had a significant ($p<0.05$) positive correlation (0.74) with chromium. In comparison nickel and chromium also had a significant ($p<0.05$) negative correlation with pH and organic matter. Using various physical-chemical properties, multiple linear regression techniques were used to generate predictive models for heavy metals in soils and groundwater. The spatial distribution maps show high variability in soil and groundwater physicochemical properties and heavy metal concentrations. The results of this study will help the policymaker better implement the environmental policy in the Sialkot industrial area.

CHAPTER 1

INTRODUCTION

1.1 Background Information

Water covers one-third of the surface of the earth. It is God's most valuable gift. On Earth's surface, oceans hold 97% of the water, while freshwater sources contain the remaining 3%. Only 0.01% of the freshwater in this 3% is good for human consumption (Majeed, Javaid, Gul, Farooq, and Tahir, 2020). Pakistan, currently is facing very severe water quality and availability issues. Increased industrialization and urbanization have resulted in the heavy metal pollution of the environment because their rate of transportation have significantly increased since 1950s (Alengebawy, Abdelkhalek, Qureshi, and Wang, 2021). Heavy metal pollution of soil and water due to irregular industrial activities have become a serious problem in Pakistan, therefore it has become crucial to assess extent of contamination of these resources especially around the areas closer to industries (Afzal et al., 2014). Contaminated water have significant health risk to people living in developing nations like Pakistan. The primary industries of Pakistan's industrial zones degrade the water supply, which in turn leads to a variety of health problems (Rehman, Zeb, Noor, and Nawaz, 2008). For any city's drinking and irrigation needs it is crucial to have groundwater quality map of the area that illustrates if it is safe for drinking as well as a preventative indicator of prospective environmental health issues (Chatterjee, Tarafder, Paul, and environment, 2010).

Among all the natural resources in the world water plays a fundamental role in supporting life (Sadat-Noori, Ebrahimi, and Liaghat, 2014). Groundwater acts as a principal source of drinking water. Nearly everywhere in the world, groundwater is crucial for human consumption, habitat support, and sustaining the standard of life. Nowadays, a growing number of soluble or dissolving chemicals from urban, industrial, and modern agricultural methods pose a concern. Pakistan as a developing country is currently facing a number of pollution challenges and among all these challenges, industrial pollution is playing a significant role. The third-highest exporting sector in Pakistan is the leather tanning industry (Abbas, Rahman, Safdar, and ASIA, 2012). Pakistan is at the 80th position in maintaining water quality standards from total 122 countries. According to the World Water Development Report by UNESCO, consuming contaminated water is thought to be the cause of almost 40% of all illnesses that have been documented in Pakistan (Connor, 2015). It is reported that 33% deaths in Pakistan are due to consumption of contaminated water that results in in a loss of PKR 25000–58000 million ($0.6–1.44% of GDP) in national income (Bibi, 2018).

More than 600 tanneries are located in three major towns in Pakistan, where leather processing is a significant economic activity (Kasur, Karachi, and Sialkot) (Ali, Malik, Shinwari, Qadir, and Technology, 2015). The industrial area in Sialkot has become a promising site for installing various industries like leather industries for few decades. Large tracts of land close to the industrial sector of Sialkot are no longer suitable for farming because of heavy metal contamination (Ali et al., 2015). According to International Monetary Fund(IMF), Pakistan is in the third place in the list of countries facing serious water shortage (Nabi, Ali, Khan, Kumar, and research, 2019). Only about 20% of the nation has access to clean drinking water while the other 80% of population depends on contaminated water due to the shortage of safe water (Daud et al., 2017).

The water demand is rising daily as a result of increasing population density, rapid urbanization, industrialization, and agricultural use; as a result, surface and groundwater levels are falling. Also, more than half of the people of this area drinks water directly from the groundwater and there is an agricultural land surrounding the industries. GIS makes data collection and processing easier and more accessible, which also acts as a potent computational tool for multimap integrations (Subramani, Krishnan, and Kumaresan, 2012).

Among the most dynamic ecological systems is the soil system, which links several essential life-sustaining processes on Earth. Soil contains minerals, organic matter, air, water and living things control these elements' natural cycles (Li & Huang, 2007). Soil has a significant role in the functioning of food chain (Guagliardi, Cicchella, De Rosa, and Pollution, 2012), and it also acts as key sink for different pollutants primarily for heavy metals (Moral, Gilkes, Jordán, and Pollution, 2005). Due to direct and indirect effects on human health, soil contamination due to heavy metals is the biggest concern these days. The build-up of excessive heavy metals in polluted soils can lead to various problems like adverse effects on human and animal health, reduced plant growth and ground cover and harmful impacts on soil microorganisms (Pérez-Esteban et al., 2013). Heavy metal pollution results from natural as well as human activities (Duan et al., 2020). Active amounts of heavy metals that can be easily ingested and inhaled by humans and animals have the potential to get into food chain and disrupt different metabolic pathways in plants, animals and humans (Jie, GUO, XIAO, MIAO, and WANG, 2009).

Soil properties and environmental conditions influence the non-biodegradability and retention properties of heavy metals in soil. As a result, the heavy metals can readily spread through soil matrix, absorbed by crops, leached into groundwater and accumulate in human bodies via food chain (Wang et al., 2020). Industrial operations are a major factor in the faster-than-ever degradation of soil quality (Khan, Singh, Upreti, Yadav, and Innovation, 2022). Because of the toxicity and migratory properties of heavy metal pollution, which have a tight relationship to the soil and food safety, it has received increased attention (X. Zhang et al., 2021). The ability of heavy metals to build up and leach relies primarily on the physicochemical characteristics of soils, including pH, clay fraction content, organic matter content, as well as the particular heavy metal's nature (Mazurek et al., 2017). The distribution pattern of the total metal analysis not only provides pollution hotspots but also indicate its sources (Z. Zhang, Abuduwaili, and Jiang, 2013).

Several chemicals, including sodium chloride, calcium hydroxide, sulfuric acid, and chromium sulfate are widely used for making leather. As a result the generated wastewater contains large amounts of sodium and chromium. The extensive discharge of Cr-contaminated wastewater from leather tanneries has led to the contamination of groundwater and soils with chromium at manufacturing locations, causing a significant threat to human health (Khalid et al., 2018). Many small-scale leather industries in Pakistan dispose of their wastes on the land because they lack any wastewater treatment facilities (Murtaza et al., 2021). Large portions of the industrial land in Karachi, Lahore and Sialkot have become unsuitable for agriculture due to contamination with multiple heavy metals. In these three cities, groundwater contamination by various metals is one of the major threats to human health (Ashraf, Ahmad, Sharif, Altaf, and Teng, 2021).

Around the world, numerous water quality indices have been developed. The water quality index (WQI) has been developed that is used for the evaluation of multiple water resources. It is one of the best methods for evaluating water quality, it serves as a significant parametric quantity for the management and analysis of water resources. Groundwater assessment data can be precisely described by WQI into a single, dynamic value (Majeed et al., 2020). The number of changes in soil physical, chemical and biological variables through organic amendments can be determined through Soil Quality Index(SQI) (Qiu, Peng, Wang, Wang, and Cheng, 2019). The soil quality index (SQI), a widely used indexing method for assessing the quality of service provided by soil, is a significant indication for managing the soil for potential use and reducing the challenges of soil for sustainable agriculture and ecology.

The current level of heavy metals in the soil and groundwater impacted by the leather industry's discharge in Sialkot must be evaluated to take appropriate action.

1.2 Water and Soil Quality Parameters

1.2.1 pH

The negative logarithm of the concentration of H+ ions in the solution is called its pH. It is a numerical indicator of how acidic or basic aqueous or other liquid solutions are. The range of pH scale lies between 0 to 14. pH levels are usually determined by pH meter that functions as a voltmeter. Even though the WHO standards for pH are not specified for health, it is still one of the significant operational parameters for soil and water. A pH value of 7 is ideally neutral because pure water and neutral soil have a pH level perfectly 7. When the pH value is below 7 they are considered acidic and those over 7 are considered acidic or alkaline. In case of pH less than 7, the water can dissolve metal pipes over time, resulting in leaks and raising the level of heavy metals in drinking water. In case of soil, at low pH a number of elements become less accessible to plants meanwhile others like iron, aluminium and manganese become harmful to plants. Different crops require different pH ranges for optimal plant growth. While certain crops grow in soil pH that is between 6.0 and 7.0, others grow in slightly acidic environments. Normally, the changes in pH do not affect the people consuming water but if the changes are great and exist for a long time such as pH levels under 4 or over 10 then swelling to eyes and irritation to skin may occur. According to WHO, the maximum pH allowed ranges between 6.5 and 8.5 and for soil is 6-7.5 (Meride and Ayenew, 2016).

1.2.2 Electrical Conductivity (EC)

Electrical conductivity expresses the amount of ionized chemicals in solution. It is the capacity of a medium to conduct electricity (Satoh and Kakiuchi, 2021). In case of soil it is a measure of the salinity within soil. It is measured using conductivity meter. Usually, it is determined in micro-siemens per centimetre (µS/cm) units. It is an indicator parameter that acts as a secondary means to measure total dissolved solids in water. Normally the EC of pure water has low value while that of sea water is high. If the water sample shows higher levels of EC it means that it contains high amount of ionized dissolved inorganic substances. The electrical conductivity of water is increased as the concentration of ions rises. EC has mostly been employed in agriculture as a measure of soil salinity, but in non-saline soils, it can also be used to estimate other soil qualities such soil depth and wetness. According to World Health Organization's recommendations should not be over 400µS/cm (Satoh and Kakiuchi, 2021) for water and 110-570µS/cm for soil.

1.2.3 Total Dissolved Solids (TDS)

TDS is an acronym for total dissolved solids. It is a term used to define the total amount of suspended materials in drinking water. TDS is composed of inorganic salts, minerals, dissolved metals and in addition a minor amount of organic matter as well. Inorganic salts comprises both positively charged cations and negatively charged anions. Calcium, magnesium, potassium and sodium are positively charged while carbonates, nitrates, bicarbonates, chlorides, and sulphates are negatively charged. TDS in drinking water results from several processes such as natural sources, urban run-offs, industrial discharge and water treatment processes. Industrial waste is the main cause of dissolved metals in water. Even though, high TDS levels in drinking water are not detrimental to health they do impart a salty, bitter or brackish flavour to water. The TDS level may assist to determine whether drinking water is suitable for drinking, needs filtration or is extremely polluted. TDS is measured in parts per million (ppm). The water with high TDS levels suggests that it has a significant mineral content. By changing the flavour and odour, these minerals can have a considerable impact on the quality of water. The preferable limit for TDS in water is 300ppm as that prescribed by WHO.

1.2.4 Turbidity

Turbidity refers to the cloudy appearance or haziness of water caused by little particles of silt, clay, plankton, organic and inorganic matter and some other elements dissolved in water that has a size between 10nm to 0.1mm in diameter (WHO, 1984). It is measured in Nephelometric Turbidity Units(NTU). Turbidity is a very helpful indicator that can offer useful information quickly, affordably, and consistently. (Organization, 2017). According to the WHO standards for turbidity of drinking water, it should not exceed 5NTU (Meride and Ayenew, 2016). Because of the natural filtration that takes place as water travels deep through the soil, groundwater often has relatively low turbidity. The turbidity of untreated water can vary greatly ranging between less than 1 and over 1000 NTU. Even a small amount of turbidity in drinking water is uncomfortable for most of people. Turbidity has influence on the taste and odour of water, along with, it also acts as barrier in identifying bacteria and viruses in water. In addition to giving off an unpleasant appearance, turbid drinking water may influence the treatment procedures and retention of chlorine levels. Pathogens may find food and protection in turbidity. The causes of high turbidity can encourage an increase of bacteria in the water and create water-related illness outbreaks if they are not eliminated. Although turbidity is not an evident sign of health risk (Schuster et al., 2005), numerous studies reveal a significant relationship between the removal of turbidity and the removal of protozoa. Turbidity particles as shelter for microbes by lowering their susceptibility to disinfectants. Additionally, it has been proposed that microbial adhesion to particulate matter increases bacterial survival. Episodes of gastrointestinal sickness have been associated to events where turbidity exceeded safe levels (Schuster et al., 2005). Removing turbidity from water also improves the efficiency of subsequent treatment processes.

1.2.5 Organic Matter

Soil organic matter is a dynamic mixture that improves crip yield, soil fertility and overall soil health. It is the portion of the soil that is made up of decomposed plant and animal tissue. Most of the productive agricultural soils contains 3 to 6% organic matter. Soils are categorized as either organic or mineral based on the amount of organic matter they contain. There are several ways in which soil organic matter improves the soil fertility. The autotrophic portion of the plant community is the primary source of this organic matter and the energy it contains. It involves progressive breakdown and dispersal in or on the soil (Spain, Isbell, and Probert, 1983). Organic matter is re-introduced into the soil either directly from crop leftovers or indirectly through manure. It not only acts a source of carbon for soil functioning but also work as sink for carbon dioxide emissions. Soil organic matter plays a significant role in the functioning of an ecosystem and changes in its nature and availability have major impact on many of the processes taking place in soil. It provides different physical, chemical and biological benefits to soil. The amount of organic matter in soils may vary from 0.1% to 100% in highly organic soils (Schnitzer and Khan, 1975). When it comes to enhancing soil structure, microorganisms and some of the active and some of the resistive soil organic components work together to bind soil particles into bigger aggregates. Aggregation plays a significant role for good soil structure, aeration, water infiltration, and resistance to erosion and crusting. High levels of heavy metals in unhealthy soil might slow down the mineralization rate of soil organic carbon, as a result the amount of organic carbon in the soil would increase that is difficult to degrade. Pollution from soil heaving metals may alter the pace at which soil organic matter is mineralized, affecting how quickly it accumulates and is distributed (M.-K. Zhang and Wang, 2007).

1.3 Heavy Metals' Health Impacts

Heavy metals are a major cause of environmental pollution and their harmful impact is a concern that is becoming more important for ecological, evolutionary, nutritional, and environmental reasons (Nagajyoti, Lee, and Sreekanth, 2010). Human health is being negatively impacted due to the rising level of environmental contamination caused by industries. Dysentery, lung infections, typhoid, and respiratory ailments are among the many illnesses that are regularly seen in locals living near leather industrial locations (Ahmad et al., 2021). Heavy metal pollutants not only deteriorate the water quality and biological habitats but also build up in essential human organs like liver, bones and kidneys posing a significant risk to human health (Wu et al., 2018). Toxic heavy metals can enter human body through several routes including oral absorption (by eating food), skin contact, and inhalation. From all, the major route is through oral intake of drinking water (Shahid et al., 2015). Prolonged exposure to high amounts of heavy metals can lead to various health issues. Following are some of the health impacts of different heavy metals included in the study:

1.3.1 Nickel

About 0.009% of the Earth's crust contains nickel, which can be found in soils, gases, and fluids as both soluble and insoluble compounds. Because of its unusual combination of exceptional physicochemical qualities, nickel is being used in variety of applications. It is also totally recyclable, very ductile, and resistant to oxidation, corrosion, and extremely high temperatures. Cheap jewellery, paper clips, zippers, snap buttons, belt buckles, stainless steel household utensils, electrical equipment, weaponry, coinage, alloys, metallurgical and food processing industries, pigments and catalysts are just a few items that employ nickel. Incinerators for trash and power plants both emit nickel into the air. It either falls to the ground or settles there after rain. In acidic soil, the mobility of nickel increases and it travels deep through the soil into groundwater (Candeias, Ávila, Coelho, Teixeira, and Sciences, 2018). For animals, nickel is a useful element in smaller amounts. Above maximum permissible limits, it becomes extremely harmful causing various cancers, particularly among organism that live close to refineries. Nickel exposure in humans can occur through inhaling contaminated air, drinking contaminated water, or eating contaminated food. IARC has designated nickel compounds as human carcinogenic (Group 1). While the classification for nickel, metals, and alloys is "possibly carcinogenic to humans" (Group 2B) (Candeias et al., 2018). As nickel vapours are respiratory irritants, inhaling nickel can result in pneumonitis. Those who are sensitive may get "nickel itch," a type of dermatitis, after being exposed to nickel and its derivatives.

1.3.2 Chromium

The seventh most frequent element on Earth is chromium (Monalisa, Kumar, & Biochemistry, 2013). Chromium can exist as a liquid, solid, or gas and is present in rocks, animals, plants, and soil. Chromium is widely used in various industries, including metallurgy, electroplating, the manufacture of paints and pigments, tanning, the preservation of wood, the creation of chemicals, and the manufacture of pulp and paper. These businesses contribute significantly to the chromium contamination that adversely affects biological and ecological species. Tanneries release a various harmful heavy metals and chemicals into the water streams. The release of industrial waste and groundwater pollution have significantly risen chromium levels in soil. Every year, more than 170,000 tons of wastes containing chromium are released into the environment around the world (Hussain and Memon, 2020). Chromium is a heavy metal that is frequently discharged by the leather industry. Various signs of chromium phytotoxicity includes reduced root growth. The biological functions of numerous plants, including maize, wheat, barley, cauliflower, citrullus, and vegetables, are significantly impacted by chromium toxicity. Plants that are affected by chromium develop chlorosis and necrosis. The presence of oxygen in the environment causes Cr (III) to be oxidised into Cr (VI), which is very hazardous and soluble in water. Breathing high levels of chromium can result in several problems like nose lining irritation, nose ulcers and breathing disorders including asthma, coughing, shortness of breath and sneezing. A prolonged exposure can irritate the skin and harm the liver, kidneys, circulatory system, and nerves.

1.3.3 Lead

As a consequence of different anthropogenic activities like burning of fossil fuels, mining, and manufacturing, lead and lead compounds can be examined everywhere in our environment including air, water and soil. Lead is used for producing various products like batteries, ammunition, metal goods like solder and pipes, and X-ray shielding (Martin, Griswold, and citizens, 2009). There are numerous routes for lead to enter the body. Leaded paint dust and waste fumes from leaded petrol can both be inhaled. It is present in very small concentrations in a number of foods, most notably fish, which is heavily contaminated by industrial pollution. Pb from soils can be absorbed by plants. Lead is an extremely poisonous metal, and its usage in many goods, including petrol, paints and pipe solder, has been significantly reduced recently due to health concerns. Pb is a harmful metal and majority of humans and animals receive their daily intake of Pb through food. Age and the degree to which Pb particles are digested in the stomach both influence the level that how much Pb will be absorbed. In comparison to young children, who have levels of 40–50% Pb absorbed from the gastrointestinal system, adults absorb about 10% of Pb (Mudgal, Madaan, Mudgal, Singh, and Mishra, 2010). High levels of lead exposure can adversely affect the brain and kidneys and finally result in death. During pregnancy, higher contact with lead may lead to miscarriage. Adults who are exposed for an extended period of time may score less well on various tests that assess how the neurological system is functioning, develop discomfort in their fingers, wrists, or ankles, experience slight rises in blood pressure, and develop anaemia.

1.4 GIS for Water and Soil Quality Parameters' Analysis

The development of GIS has made it a powerful tool for storing, analysing, and displaying spatial data as well as utilising this information for decision-making in a variety of industries, including engineering and environmental science. In order to analyse groundwater sensitivity to contamination, manage water and soil resources on an appropriate scale, and comprehend the natural environment, GIS is utilised as a useful tool to identify solutions for problems associated with water and soil resources. The most effective way for groundwater potential prediction zoning is integrated assessment of thematic maps utilising model-based GIS tools (Usali and Ismail, 2010).

Urban soil pH and organic matter spatial distribution and its effects on site-specific land uses were determined in Xuzhou, China. The authors established a connection between pH content, soil organic matter (SOM), and the kind of land use by applying GIS and geostatistics (linear kriging). Maps of pH and SOM spatial distribution were created using 172 collected soil samples. The study revealed that pH and SOM are known to reach high values in woodland areas, while lower values were seen in urban areas closer to industries. Spatial distribution maps that were generated could be helpful for environmental management and planning (Yu et al., 2014).

(Stafilov et al., 2010) calculated the contamination caused by heavy metals in the topsoil in the Republic of Macedonia near a lead and zinc smelter. The study used multivariate statistics and GIS technology to pinpoint the contamination-prone areas. The composition of As, Au, Cd, Cu, Hg, In, Pb, Sb, Se, and Zn received the most attention. (Bel-Lahbib et al., 2023) used IDW method In order to estimate the values of non-sampled places, spatial distribution maps of soil data. (Jisna, Nuskiya, and Iyoob, 2021) conducted a study to determine the dynamic soil pH & excessive usage of artificial fertilisers on agricultural land. 22 soil samples were gathered based on the pre- and post-application stages of chemical fertiliser using a simple random sampling procedure in 11 agricultural continents. GPS technology was utilised to pinpoint the position of the land. The gathered soil samples were evaluated for pH in order to determine its value. In light of this, the data were examined using ArcGIS 10.3 using the IDW method.

In another study for groundwater quality assessment, borehole's sampling location were marked using GPS. Inverse distance weighted (IDW) spatial interpolation was used to prepare the numerous thematic layers on hardness, pH, and ionic concentrations. The adequacy of the research area's groundwater for human intake was evaluated using WQI. More than 82% of the water samples, according to the WQI rating, are in the "Poor" and "Very Poor" categories claiming that groundwater quality is unfit for drinking (Jisna et al., 2021). (Gholami, Sharifi, and Renella, 2023) conducted a study to evaluate the environmental effects and fertilising potential of reusing the blood meal powder (BMP) made at the abattoir as an organic fertiliser in agriculture. In order to increase the soil's fertilising value, this study looked at the short-term release of nutrients in soil supplemented with BMP. In the current work, we provide an example of a method for choosing an MDS of soil characteristics using PCA to determine SQI.

The objectives of this study were to a) generate spatial distribution maps of heavy metals(Ni, Cr, Pb) of Industrial area of Sambrial-Sialkot (b) Groundwater and soil quality assessment in terms of heavy metals and their vulnerability to pollution using Indices.

CHAPTER 2

MATERIALS AND METHODS

2.1 Study Area

This study has been carried out on the Industrial area of Sambrial-Sialkot(

Figure 1) that lies between 32°24’ - 32°37’ N and 73°59’ - 75°02’E. The Sialkot city is placed in Punjab, Pakistan and is ranked as the 13^{th} most populous city of Pakistan. The rainfall is about 1000mm per annum. The weather remains warm during the summer season and becomes cool during the winter with maximum temperature exceeding 40°C and minimum to 3°C. June and July are the warmest months of the year. During summer season extensive rainfalls in the area cause accumulation of alluvium at some places. Clay loam soil type is most common in the area. This region also contains cultivated lands. Pakistan is a major distributor of leather products in the international market. Sialkot city of Pakistan is well known for its leather and sports products around the world. For the production of these products, the region contains a lot of industries and due to this industrial load the region is highly vulnerable to environmental contamination. There are different industrial sectors in the region with the prominent leather and sports sectors. There are over 900 leather sports’ industrial units and 264 tanneries in Sialkot where tanning industries playing role as the largest foreign exchange earning sector in Pakistan (Ullah et al., 2009). According to a report, in 2021-2022 the export of leather and leather goods was about US$ 953.707 million. The Sialkot leather tanneries produce effluents at a rate of 1.1 million litres per day due to a lack of economic activity, and this leads to the degradation of groundwater and soil resources. The waste is released in a variety of ways into the nearby agricultural lands or different water sources where it eventually mixes with groundwater. (Younas et al., 2022). There are different types of industries in the study area (Figure 4).

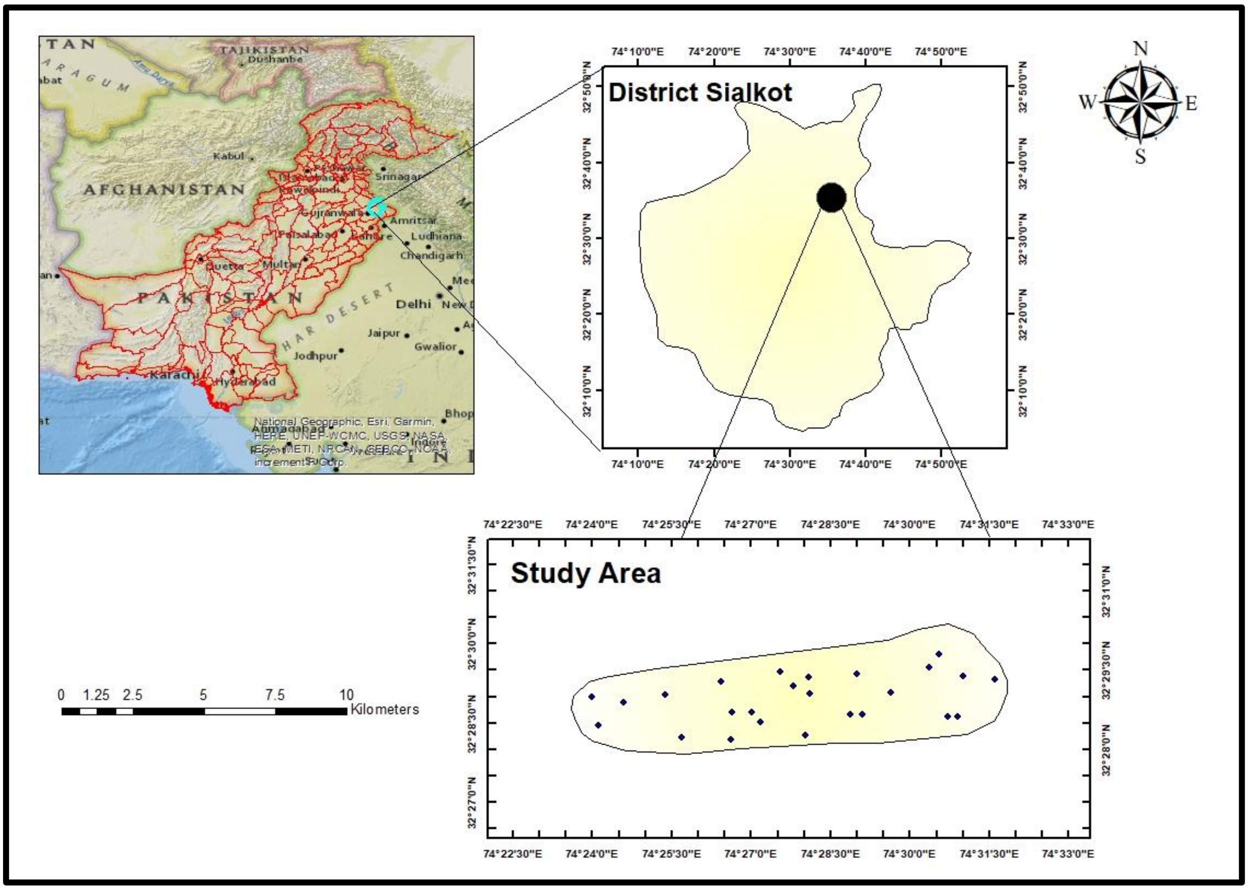

Figure 1. Study area map showing map of Pakistan, highlighting the Sialkot and the study area and randomly selected soil and groundwater samples locations.

2.2 Data Collection

2.2.1 GPS Coordinates

In this study, the sampling media involved groundwater and soil. A GPS survey was carried out to pinpoint the locations of 50 sampling sites using GARMIN GPS receiver (

Figure 1). These sampling coordinates utilised to create a feature class in a file geodatabase.

2.2.2 Water Sampling and Laboratory Analysis

Using a simple random sampling technique, groundwater samples were collected during the month of August, 2022. A survey was conducted in the study area to determine the water quality for which 25 sampling sites were designated from and around the industries randomly (Akoteyon, Soladoye, and Management, 2011)and samples were collected in polyethylene water bottles of 100ml. The samples were collected from different sources including hand pumps, motor pumps and tube wells and bores installed in the area surrounding the industries. These samples were then brought to the laboratory for analysis. Physicochemical parameters that were calculated include pH, EC, TDS and turbidity.

2.2.3 Soil Sampling and Laboratory Analysis

Samples were collected at a depth of 0-20cm which is a preferrable depth for proper determination of soil properties. For soil sampling random composite technique was used. A composite is created by combining various sample units and completely or partially merging them to create a new sample. Soil shovel was used to collect samples. Physical procedures like ball milling, sieving, shaking, or centrifuging can homogenise or preserve the integrity of the sample units that make up the composite (Lancaster and Keller-McNulty, 1998). All of the samples were stored in cleaned plastic bags with labels and were brought to National University of Sciences and Technology, Islamabad, IESE lab for additional processing and examination. Soil's physicochemical properties like pH, EC and Organic matter concentration were measured in IESE lab NUST. The organic matter concentration were calculated through Walkley-Dark chromic corrosive wet oxidation method (Rowell, Coetzee, and Soil, 2003). Soils samples were then set up for further analysis by removing larger particles with soft-bristled brush. These samples were dried in oven 65 ± 5 °C for 72 h and using an electric grinder, the samples were ground into a powder and put through a 0.3-mm mesh sieve. They were then retained in envelopes and put in a desiccator to protect from moisture (Nawab et al., 2018).

2.2.4 Acid Digestion of Soil Samples

These samples were used for acid digestion, which is a necessary step in order to analyse heavy metals. This procedure work by using 3:1 concentration of nitric acid and perchloric acid. Acid digestion helps in dissolving organic matter and other sample so that only trace metals are left behind. First the samples were oven dried and then grinded to make a powder like appearance. By combining 0.5 g of the dried sample with 10 ml of pure nitric acid (HNO3) in a beaker, the soil samples were acid digested and left overnight as shown in Figure 2. The samples were heated to 90 °C, and then 4 ml of perchloric acid (HClO4) was added. The mixture was then heated once more until it became transparent, and 50 ml of the final solution, which contained double-deionized water, was created following the filtration procedure (Zeng et al., 2011). After digestion, liquid samples were analysed for selected heavy metals (Ni, Cr and Pb).

Figure 2. Acid Digestion of soil samples, oven drying and heating on hot plates with nitric acid and perchloric acid.

2.2.5 Determination of Heavy Metals

After acid digestion of soil samples, both water and soil samples were sent for heavy metals' testing. For heavy metal's testing they were sent to Arid Agriculture University, Rawalpindi. Heavy metals' testing was performed through Inductively Coupled Plasma Optical Emission Spectrometry (Mankoula et al., 2021). It is an optical emission spectrometry technique. The component elements (atoms) of an analytical sample are stimulated when plasma energy is applied from the outside. The emission rays (spectrum rays) that match to the photon wavelength are released when the excited atoms return to their low energy positions. The position of the photon rays determines the element type, and the intensity of the rays determines the content of each element. Argon gas is initially supplied to the torch coil before high frequency electric current is given to the work coil at the torch tube's tip to create plasma. Argon gas is ionized and plasma is produced by using the electromagnetic field that the high frequency current creates in the torch tube. High electron density and temperature (10000K) are present in this plasma.

2.3 Analytical Framework

Analytical framework consists of different steps like data preparation, geodatabase generation, statistical analysis in MS Excel and geostatistical analysis in ArcMap 10.8.2, estimation of water and soil quality indices and Pearson's correlation coefficient of soil and water physicochemical properties with heavy metals' distribution in the study area. The methodological flowchart of the study is shown in Figure 3.

2.3.1 Data Preparation

For generating the shapefile of the study area a KML file was acquired from Google Earth Pro and was then converted into shapefile in ArcMap 10.8.2. An excel file containing the results from physicochemical parameters and heavy metals' concentration was generated and coordinate points were added in it. Correlation coefficient was performed in excel. This csv was then converted into point shapefile in ArcMap and linked to the study area shapefile.

2.3.2 Water Quality Index

Based on a number of water quality factors, the water quality index (WQI) delivers a single value that indicates the total water quality at a certain location and time. WQI's goal is to translate complicated water quality data into information that the general public can use and understand. A variety of indices have been devised to present data on water quality in a straightforward and understandable manner. The WQI basically uses mathematics to create a single number from a collection of test outcomes. To have a good representation of all water quality indicators, it is essential and crucial to choose relevant water quality criteria. The magnitude of the provided weight shows the parameter's significance and impact on the index. The weight assigned to each parameter is based on its corresponding standards. The parameters that are used includes pH, EC, turbidity, TDS and heavy metals(Ni, Cr, Pb).

Table 1 shows the weight factors given to the selected parameters. The relative weights of pH, EC, TDS and turbidity are 0.002, 0.0006, 0.0008 and0.004 respectively while nickel and chromium got 0.24 weight factors and lead have 0.49 value. In this study arithmetic index is used.

The WQI is calculated by taking an average of the individual index values of some or all of the parameters from four categories of water quality metrics that represent the level or status of water pollution including pH, EC, TDS and turbidity. The quality rating's numerical value (qi) is calculated using data on the quality of the water, and it is then multiplied by a weighting factor based on how important the test is to the water quality (Adelagun, Etim, Godwin, and assessment, 2021). To calculate qi, following formula was used:

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

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

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

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 is the rating based on the concentration of the ith parameter mentioned in Eq4 and SIi is the sub-index of the ith parameter mentioned in Eq5.

2.3.3 Soil Quality Index

As a quantitative measurementt, the soil quality index (SQI) method has been used to create relationship between a management objective and the physical, chemical, and biological components of soil that collectively make up soil health. Values for the soil quality index were calculated using the linear combination technique method. Following is the linear combination equation:

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

where Wi is the parameter i's weighting, Xi is the parameter i's sub-criteria score, and SQI is the soil quality index for agricultural use (Şenol, Alaboz, Demir, and Dengiz, 2020). Each soil sample was subjected to the above mentioned formula. Table 2 represents the weights assigned to the parameters. To compare different parameters with each other, unitless scores for soil quality indicators were converted from 0.1 to 1.0. Based on the their relative importance, organic matter were given the highest weight of 0.8, pH of 0.6 and EC of 0.3, further heavy metals were given less weight due to their less importance of 0.2 for nickel and chromium and 0.1 for lead with least significant.

To determine the overall SQI score for each soil sample, the normalised values of each indication were multiplied by the weight that was given to it and then the weighted scores of each indicators were added. This step was used for all the samples. A percentage or dimensionless index value can be used to represent the score.

Table 1. Water quality parameters and eight factors.

Variables	WHO standards	Weight factors
pH	8.5	0.002
EC(µS/cm)	400	0.0006
TDS(mg/l)	300	0.0008
Turbidity(NTU)	5	0.004
Nickel(ppm)	0.1	0.24
Chromium(ppm)	0.1	0.24
Lead(ppm)	0.05	0.49

Table 2. Soil quality parameters and weight factors.

Soil quality parameters	Weight factors
pH	0.6
EC	0.3
OM	0.8
Ni	0.2
Cr	0.2
Pb	0.1

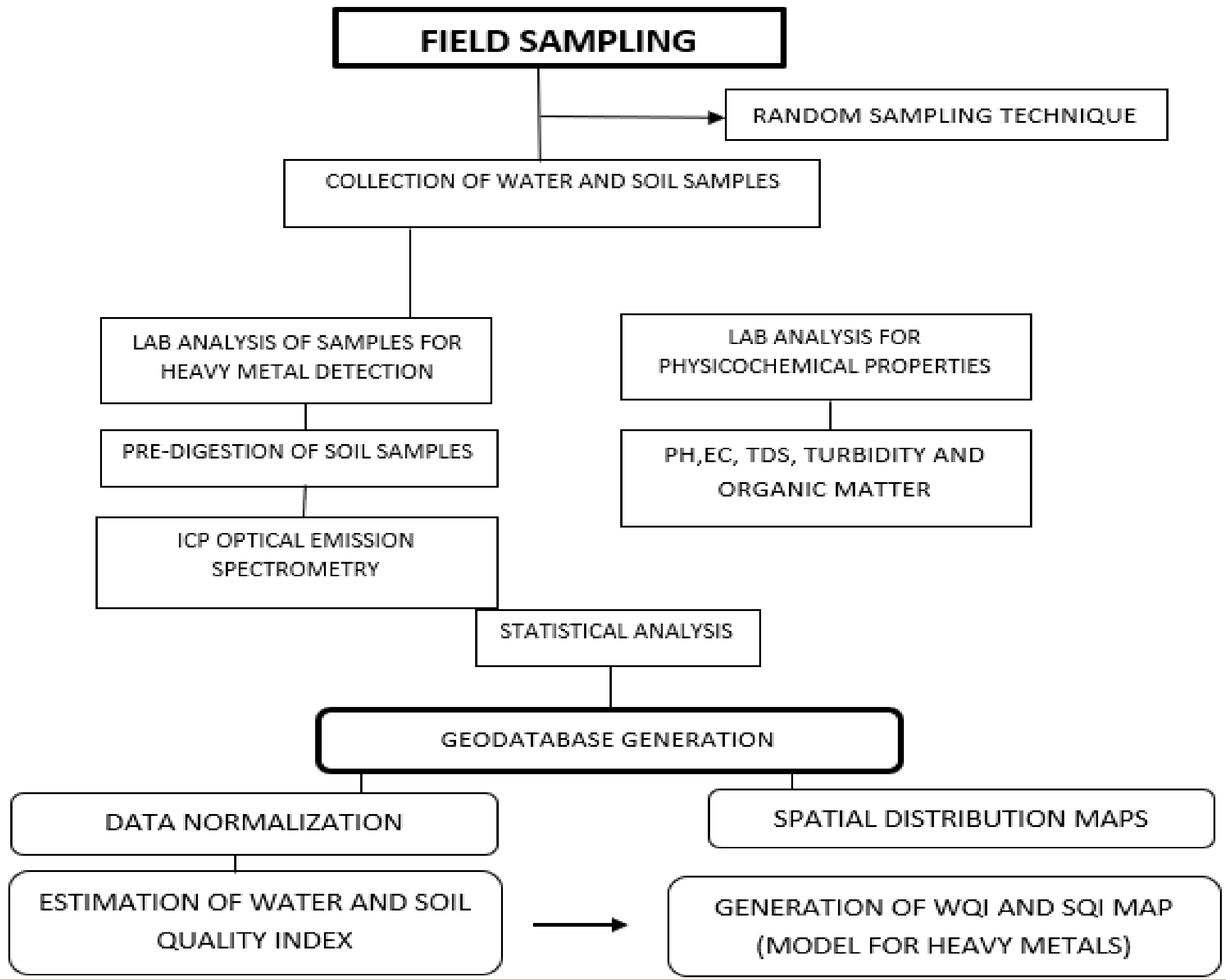

Figure 3. Methodological flowchart.

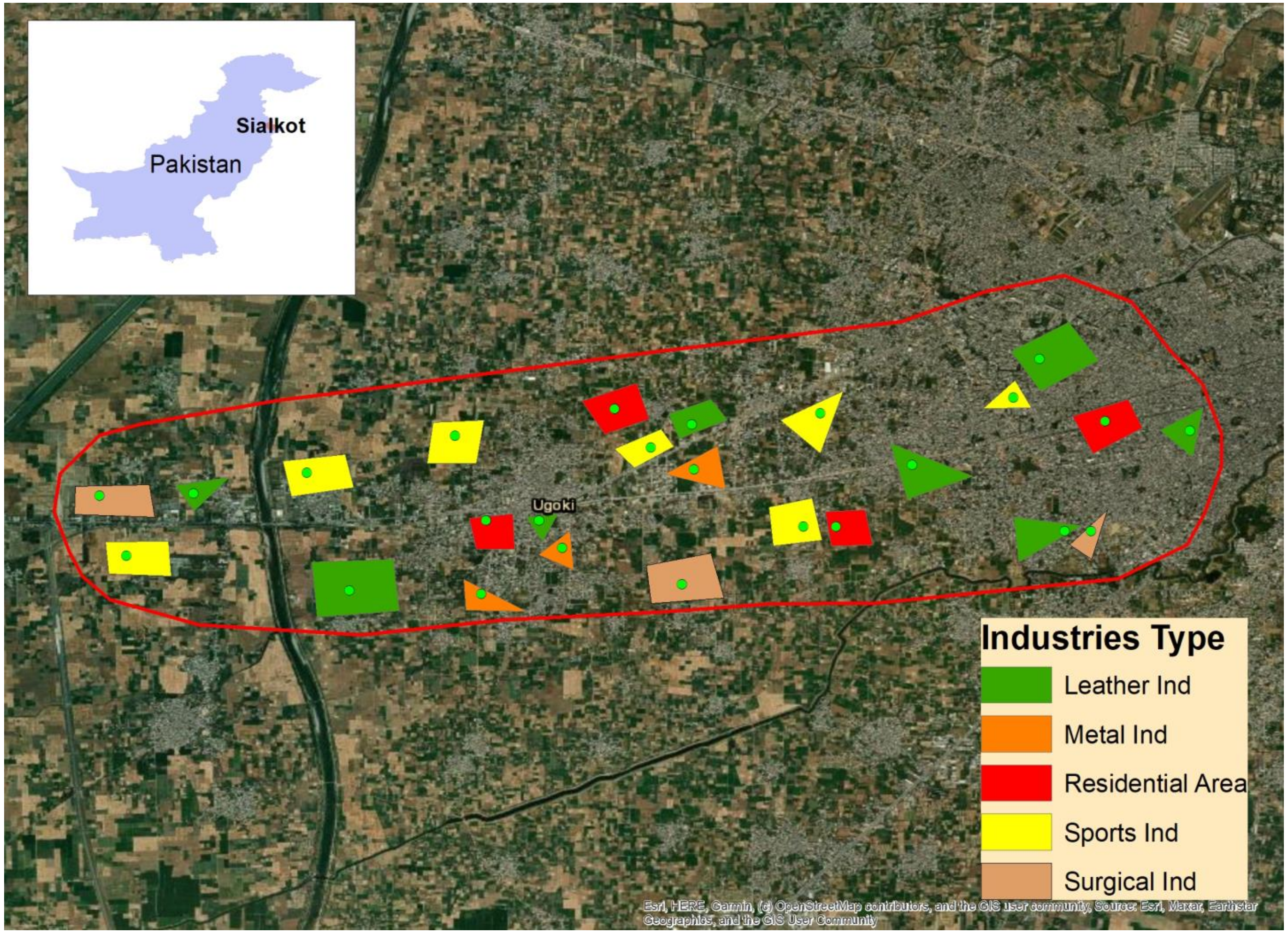

Figure 4. Types of industries in the study area.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Summary Statistics

3.1.1 Soil and Water Quality Parameters

Table 3 and Table 5 shows results of soil and water quality parameters using classical statistics on 50 samples. A statistical summary was generated that includes minimum value, maximum value, mean, standard deviation, skewness, and kurtosis. It was observed that water pH ranges between (5.6-8.95) mean value of 7.01, EC ranges between (222-1908) with mean value 776.72-above the permissible limit of 400µS/cm, TDS ranges between (115.44-992.16) with mean value 403.89-above the permissible limit of 300 ppm, turbidity ranges between (0.38-9.82) with mean value 1.78 that is below the WHO limit of 5NTU. In case of soil, soil Organic matter ranges between (0.02-0.81) with mean value of 0.25, pH ranges between (5.85-8.8) with mean value of 7.19, EC ranges between (285-2665) with range value of 1157 that is above the permissible limit of EC for soil prescribed by WHO(570µS/cm).

3.1.2 Statistics of Heavy Metals

In case of water, Ni ranges between (0-8.02) and mean of 1.27-above the permissible limit of WHO(0.02ppm), Cr between (0-10.01) and mean value 0.87-above the permissible limit of WHO(0.05ppm) and Pb ranges between (0-2.01) with mean value of 0.18-above the permissible limit(0.01ppm). In case of soil, Ni ranges between (0-9.05) with mean value of 1.20 that is above the permissible limit of WHO(0.05ppm), Cr ranges between (0-10.88) with mean value 0.98-above the permissible limit(0.1) and Pb ranges between(0-3.2) with mean value of 0.27-above the permissible limit(0.1ppm).

3.1.3 Correlation Analysis

Bivariate correlation analysis, commonly known as correlation analysis, focuses on determining that whether a relationship between variables exists or not before finding out its strength and course of action. Correlation was calculated among all the selected parameters that is shown in Table 4 and Table 6 describing the significant parameters at $p \geq 0.38$, i.e, those parameters have significant correlation with each other having value equal to or greater than 0.38. Correlation showed that there is a strong negative correlation between pH vs Ni and Cr in case of water (-0.61 for nickel and -0.54 for chromium), which means that the samples showing acidic values of pH contain high concentrations of nickel and chromium likewise, nickel and chromium have a strong positive correlation with each other (0.74) which shows that nickel and chromium are present side by side in high concentrations at majority of places, while strong positive correlation between EC and TDS(0.96) and a strong positive correlation between lead and turbidity(0.78).

In case of soil, like water there is a strong negative correlation between pH and Ni, Cr(-0.57 for nickel and -0.49 for chromium) with nickel and chromium having strong positive correlation with each other (0.66). As, chromium is the most abundant heavy metal used in leather industries, so it can be depicted from the results that majority of the contaminated samples contain chromium along with nickel in both soil and water, with lead present at very few sites.

Table 3. Summary statistics of water quality parameters.

	Min	**Max**	**Mean**	**Std**	**skew**	**Kurt**	**WHO limit**	**EPA limit**
pH	5.6	8.95	7.01	0.87	0.67	0.07	6.5-8.5	6.5-8.5
EC	222	1908	776.72	414.18	0.99	1.17	1000 µS/cm	50-1500 µS/cm
TDS	115.44	992.16	403.89	215.37	0.99	1.67	300 mg/l	500 mg/l
Turbidity	0.38	9.82	1.78	2.01	3.07	10.70	5NTU	1.6 NTU
Ni	0	8.02	1.27	2.58	1.91	2.28	0.02 ppm	0.1 ppm
Cr	0	10.01	0.87	2.19	3.52	13.48	0.05 ppm	0.1 ppm
Pb	0	2.01	0.18	0.48	3.07	9.31	0.01 ppm	0.05 ppm

Table 4. Correlation matrix of water.

	pH	***EC µS/cm***	***TDS (mg/l)***	***Turbidity (NTU)***	***Ni (ppm)***	***Cr (ppm)***	***Pb (ppm)***
pH	1						
EC(µS/cm)	0.12	1					
TDS(mg/l)	0.02	0.96*	1				
Turbidity(NTU)	0.22	0.08	0.10	1			
Ni (ppm)	-0.61*	-0.31	-0.34	-0.23	1		
Cr (ppm)	-0.54*	-0.23	-0.21	-0.19	0.74*	1	
Pb (ppm)	0.01	0.14	0.17	0.78*	-0.19	-0.15	1

***= significant at 5% probability level.**

Table 5. Summary statistics of soil quality parameters.

	Min	Max	Mean	Std	skew	Kurt	WHO limit
pH	5.85	8.8	7.19	0.83	0.22	-0.46	5.5-7.5
EC	285	2665	1157	640	0.76	0.237	110-570 µS/cm
OM	0.02	0.81	0.25	0.22	1.11	0.62	0.03-0.06
Ni	0	9.05	1.20	2.59	2.47	5.41	0.05 ppm
Cr	0	10.88	0.98	2.49	3.28	11.14	0.1ppm
Pb	0	3.2	0.27	0.72	3.48	12.24	0.1ppm

Table 6. Correlation matrix of soil.

	pH	***EC (µS/cm)***	***Ni (ppm)***	***Cr (ppm)***	***Pb (ppm)***	***OM %***
pH	1					
EC µS/cm	0.17	1				
Ni ppm	-0.57*	0.31	1			
Cr ppm	-0.49*	0.11	0.66*	1		
Pb ppm	0.06	-0.12	0.06	-0.14	1	
OM%	-0.46*	-0.06	0.29	0.37	0.02	1

***= significant at 5% probability level.**

3.2 Spatial Interpolation

3.2.1 Physicochemical Parameters

Various spatial interpolation techniques that are used to find the values at unsampled locations like kriging, co-kriging, IDW, spline etc present in ArcGIS geostatistical analyst. The interpolation technique that is used in this study is Inverse Distance Weighted(IDW). With the Inverse Distance Weighting (IDW) interpolation method, cell values are calculated by averaging the values of sample data points nearby each sampled cell. The more effect or weight a point has on the averaging process, the closer it is to the approximated cell's centre. IDW creates a surface that undergoes through all the points hence called as an exact interpolator. The inverse distance technique was used for pH, EC, TDS, turbidity, OM and for heavy metals' interpolation as well. For physiochemical parameters of both soil and water, total three classes have been used that include low, medium and high values of the variables. In case of groundwater's EC values are <400, 401-1400 and >1500, for TDS values are <300, 301-700,>700 and for turbidity values are 0-2, 2.1-4 and>4 for low medium and high. For soil parameters these values are 0-500, 501-1500 and above 1500 for EC and for organic matter these values are 0-0,04, 0.41-0.08 and above 0.08%. Different colours were used to represent the level of risk associated with each factor. The color red represents the areas that are highly contaminated either with heavy metals' concentration or have unacceptable physicochemical parameter. Spatial interpolation maps of water's physicochemical parameters in Figure 5 show that for water, pH values in the green zone represent values permissible by WHO (6.5-8.5). For EC the WHO acceptable limit of water is 400µS/cm so the areas other than green have levels higher than 400. Similarly, for TDS the acceptable value is 300ppm and for turbidity it is 5NTU so all the regions having red colours contains levels greater than these values. Due to strong positive correlation between EC and

TDS, both have the same red highlighted areas while there is no correlation between the rest of the parameters.

In case of soil's parameters, due to negative correlation between pH and organic matter the targeted regions having low pH values than the acceptable limit (5.5-7.5) are showing acceptable values for organic matter (0.03-0.06) as shown in Figure 7, while there is no correlation between EC/pH and EC/OM.

3.2.2 Heavy Metals

While comparing the spatial distribution maps for heavy metals' in case of water, shown in Figure 6, there are total five classes have been used with red showing the highly contaminated regions with values highly above the WHO permissible limits. From the it can be determined that the regions contaminated with nickel i.e, values above the permissible level (0.02 ppm) are the same as those of contaminated with chromium (0.05 WHO limit), showing their strong positive correlation. These regions are mostly on the eastern sides of the maps in both cases, while lead shows no correlation, neither with nickel nor with chromium. Also lead(0.01 WHO limit) was found at very few places in comparison with nickel and chromium.

Spatial distribution maps of soil heavy metals are shown in Figure 8. Like water, nickel and chromium shows strong positive correlation with each other in case of soil as well. The regions that are green in case of have values within permissible limits as prescribed by WHO of 0.05ppm for nickel, 0.1ppm for chromium and 0.1ppm for lead (Kinuthia et al., 2020). Lead is found in very few samples or is either absent showing no correlation with nickel and chromium like water. Highly contaminated region have values greater than 4.5ppm for nickel and 4ppm for chromium while greater than 2.5 for lead.

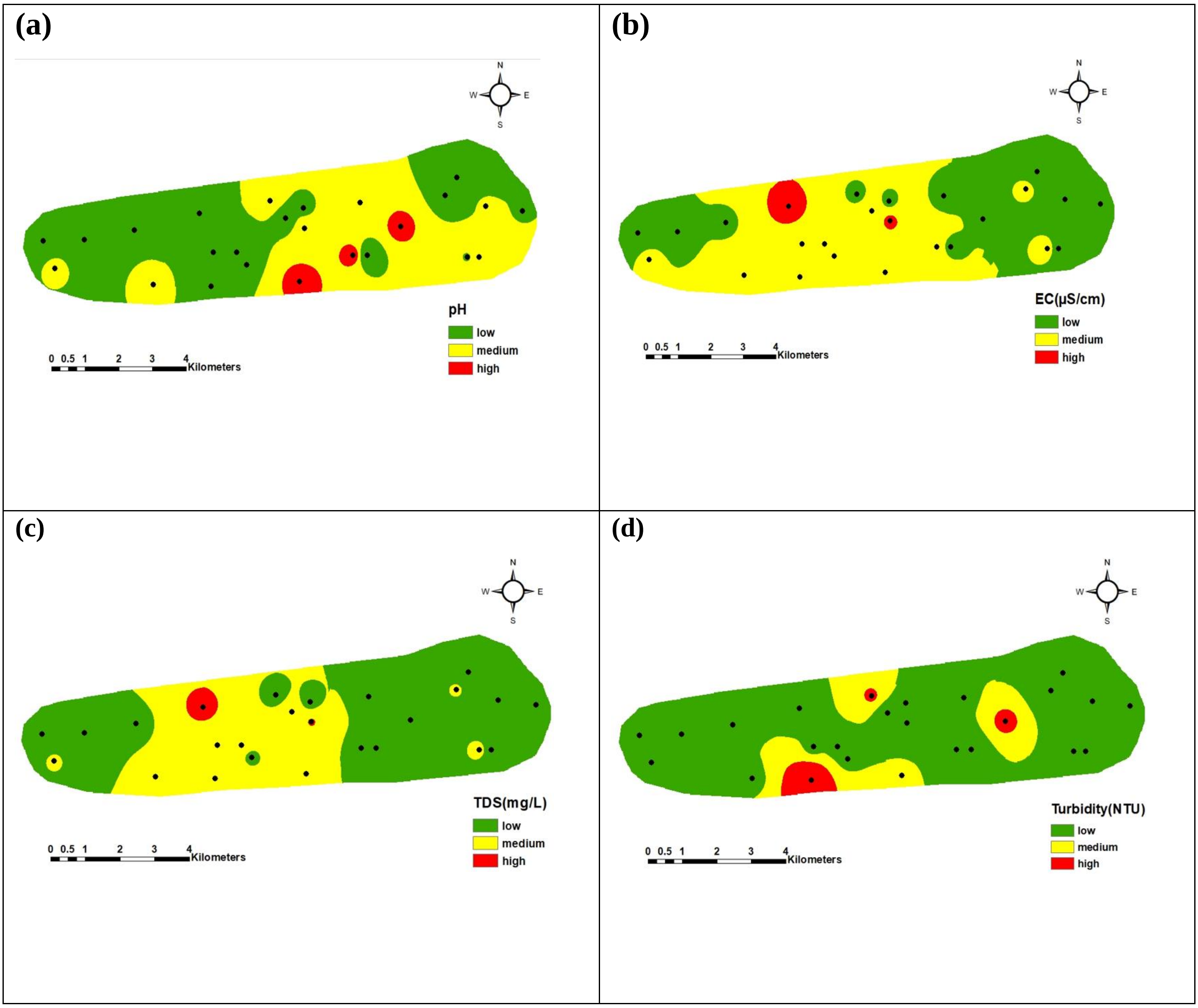

Figure 5. Spatial distribution maps of groundwater quality parameters(a)pH (b)EC (c)TDS(total dissolved solids) (d) turbidity.

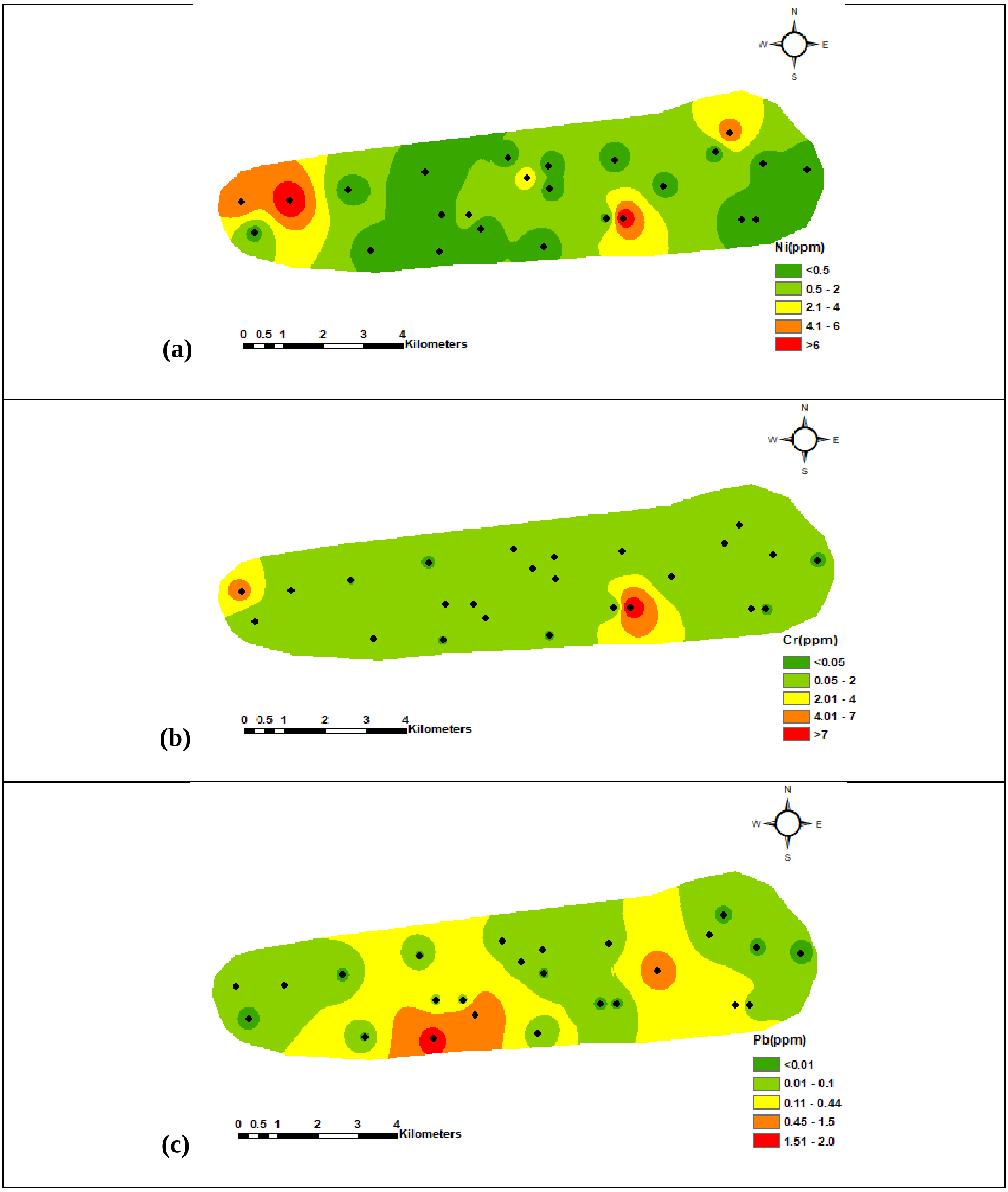

Figure 6. Spatial distribution maps of heavy metals' concentration in groundwater (a)Nickel (b)Chromium (c) Lead.

Figure 7. Spatial distribution maps of soil quality parameters (a)pH (b)EC (c)OM(organic matter.

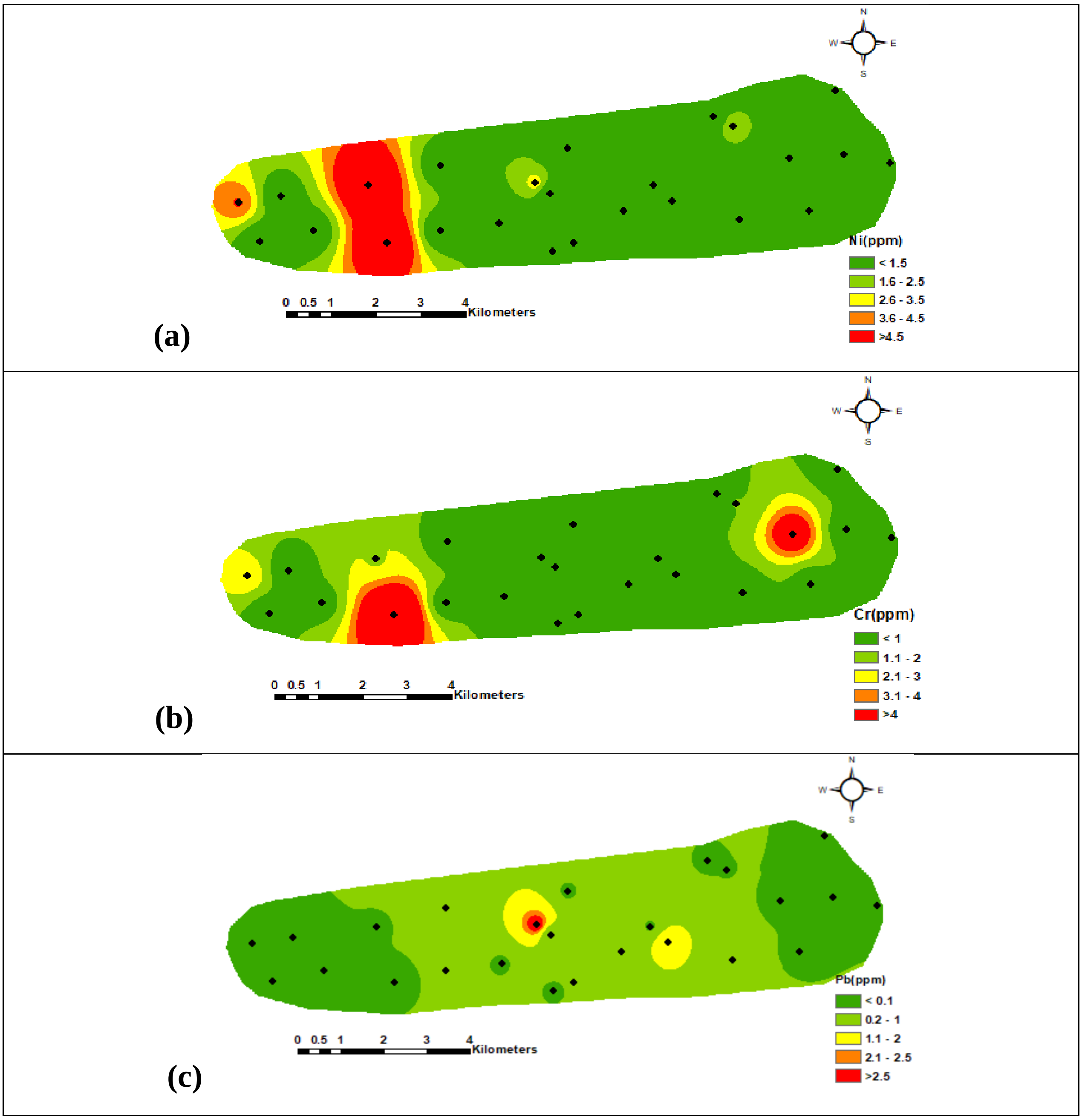

Figure 8. Spatial distribution maps of heavy metals' concentration in soil (a)Nickel (b)Chromium (c)Lead.

3.3 Quality Indices

3.3.1 Water Quality Index

Total three physicochemical parameters of water were used to calculate water quality index along with three heavy metals. Water quality index helps to understand the overall quality of groundwater in the region that whether it is suitable for drinking or not. For describing the quality of water total five classes have been assigned including excellent, good, poor, very poor and unfit for drinking as shown in the water quality index map in Figure 9. Excellent class have values less than 50, good between 50-100, poor between 101-200, very poor between 201-300 and samples having values above than 300 are within the category of unfit for drinking. The results of water quality index are shown in Table 7 summarizes that out of total 25 sampling points, 9 samples have values falling in the unfit class(E) i.e, 36% samples are highly contaminated, 4% in the very poor class(D) 12% in the good class(B) and 48% are in the excellent class(A), while neither sample lies in grade C.

3.3.2 Soil Quality Index

Soil quality index gives us the overall idea about the type of soil in the area that whether it is suitable for any agricultural activities or not. Soil quality index was divided in to five classes including very low, low, moderate good and vary good as shown in Figure 10. Very low class have values less than 0.4, low between 0.4-0.54, moderate between 0.55-0.69, good between 0.70-0.85 and very good class have values greater than 0.85 (Volchko, 2013). The results showed that out of 25 samples, 10 samples have values greater than 0.85 i.e, 40% of the samples have very good soil quality(1), 12% lie in good quality class(2), 8% have moderate quality(3), 20% have low quality(4) and 20% samples have very low quality(5) as mention in Table 8.

Table 7. Water quality classification based on water quality Index(WQI) value; (Ramakrishnaiah, Sadashivaiah, and Ranganna, 2009).

Water quality index level	Water quality status	Water quality grading	Percentage of water samples
<50	Excellent	A	48%
50-100	Good	B	12%
101-200	Poor	C	0
201-300	Very poor	D	4%
Above 300	Unfit for drinking	E	36%

Table 8. Soil quality classification based on soil quality Index(SQI) value.

Soil Quality Index Level	Soil Quality Status	Class	Percentage of soil samples
Above 0.85	Very good	1	40%
0.70-0.85	Good	2	12%
0.55-0.69	Moderate	3	8%
0.4-0.54	Low	4	20%
<0.4	Very low	5	20%

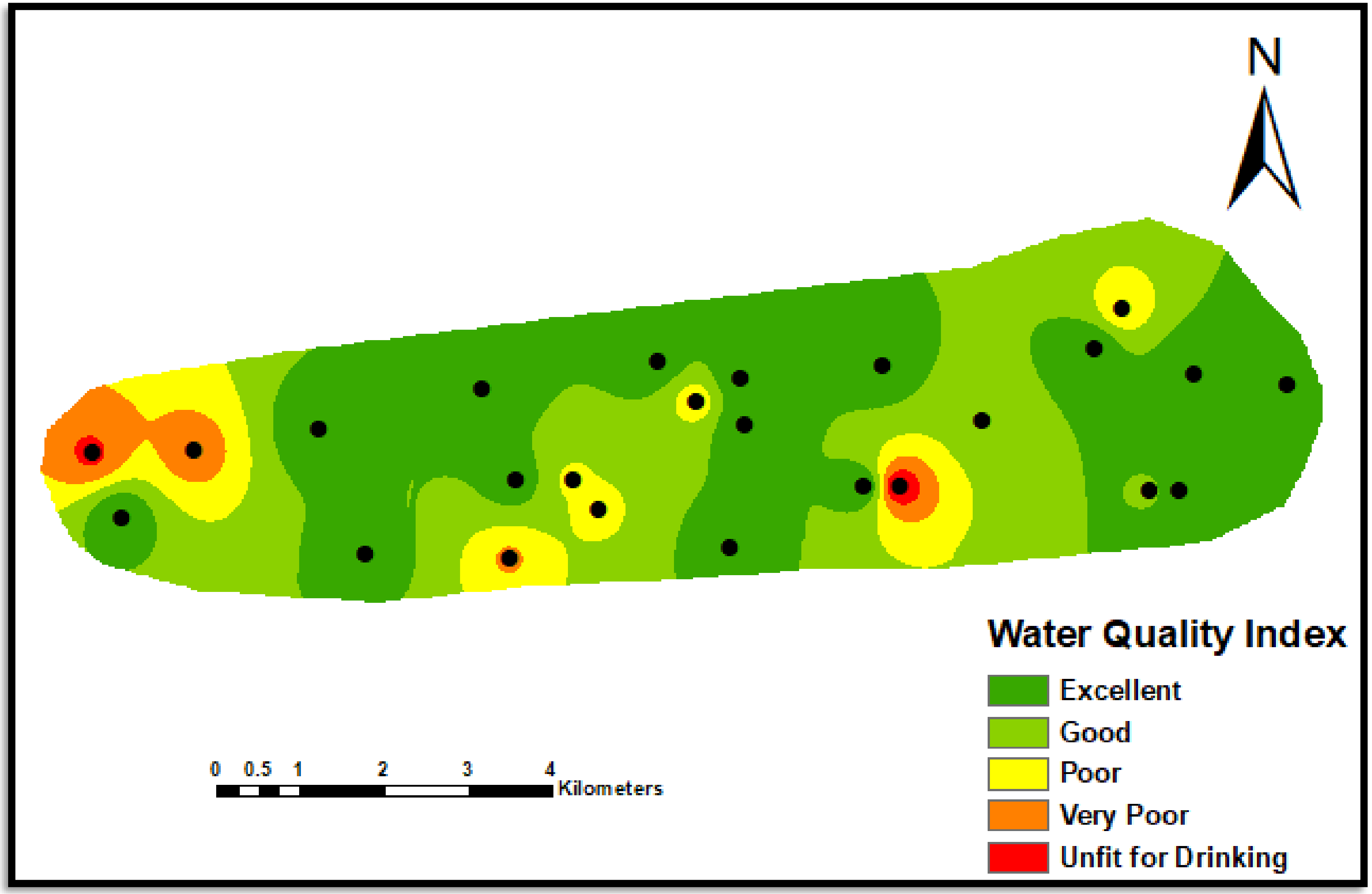

Figure 9. Water Quality Index Map of Sambrial-Sialkot.

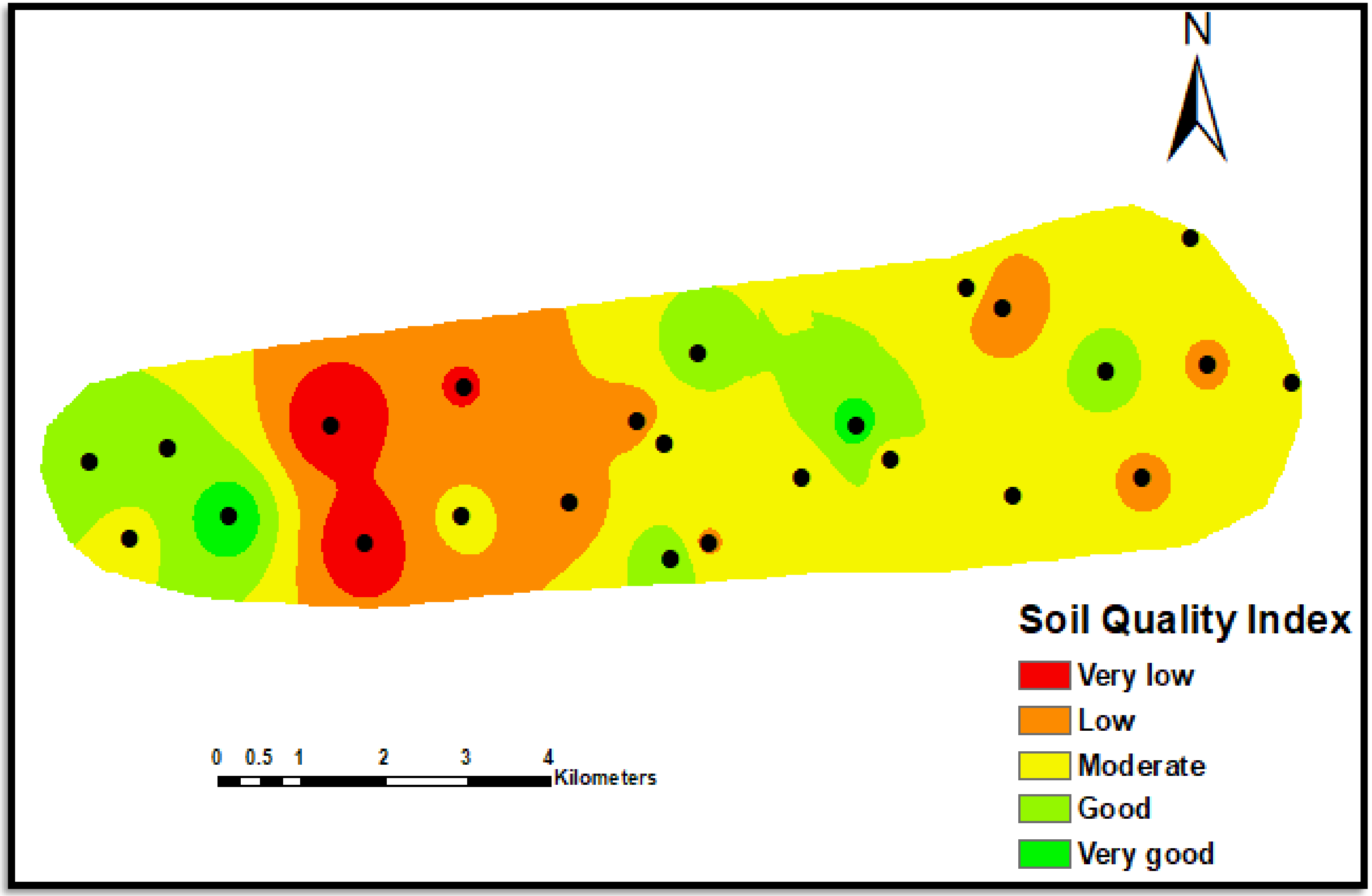

Figure 10. Soil Quality Index map of Sambrial-Sialkot.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Soil and water are the most precious natural resources. The release of heavy metals in industrial areas to environment poses a significant threat to soil and water quality as well as human health. Preserving the quality of soil, much like the preservation of air and water quality, should to be a fundamental objective of environmental policy at the national level. This research was conducted in Sambrial-Sialkot to assess water and soil quality around the industrial areas using GIS, WQI and SQI. The use of GIS and geostatistics in environmental studies is beneficial. They are applicable to a wide range of research fields, especially those in which spatial distribution may be important. The results of the study showed that majority of soil and water quality parameters and heavy metal concentrations are above the permissible limits as those of prescribed by World Health Organization(WHO). Water quality index in some parts of the study area is either bad or poor and unfit for human consumption, similarly soil quality index shows that soil quality is poor in some parts. Both WQI and SQI maps showed that water and soil quality is bad in the eastern sides of the study area. So, these areas are neither fit for water consumption nor soil is suitable for agricultural activities in While comparing the maps of WQI with heavy metals concentration and SQI with heavy metals' concentration in soil it is clear that the same regions have bad soil and water quality that have higher levels of heavy metals.

The results of the study concluded that for groundwater 36%, 45%, 20%, 14%, 34%, 30% and 16% of samples deviate from WHO permissible limits for pH, EC, TDS, turbidity, Ni, Cr and Pb while for soil 40%, 54%, 34%,48%,28% and 12% samples deviates from permissible limits for pH, EC, OM, Ni, Cr and Pb. Since groundwater is the most common source of water supply, a continuous monitoring system will ensure that the drinking water quality is sustained, that inhabitants have access to clean water, and that management is enhanced through sustainable groundwater development. This study would provide a guideline to general public and authorization, for solving water and soil quality problems in Sialkot, to take appropriate measures in case of any adverse results and would help to identify the most possible cause of pollution in soil and water.

4.2 Recommendations

- **i.** Additional study should be carried out on small scale like around major industries of the area in order to avoid biasness.
- **ii.** There is need to pay attention to those areas that have significant correlation coefficient values and WASA should differentiate safe and clean water sources from polluted sources.
- **iii.** There should be strict control check on the regulations for the release of waste from industries in an appropriate manner.
- **iv.** Those areas where heavy metals’ concentration is high in soils should be temporarily banned for agricultural activities till remediation.
- **v.** Employers and industry owners should review management policies regularly and get proper training.

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APPENDICES

Appendix-1. Details of water data

S. no	Lat	Long	pH	EC	TDS	Turbidity	Ni	Cr	Pb	WQI
1	32.4968	74.5091	5.8	278	144.56	0.46	5.31	1.7	0	638.69
2	32.4906	74.4833	7.22	566	294.32	1.73	0.01	0.07	0.03	50.03
3	32.4886	74.5267	6.97	472	245.55	0.89	0.02	0.02	0	10.26
4	32.4897	74.5168	7.06	222	115.44	0.38	0.02	0.05	0	17.64
5	32.4924	74.506	6.7	828	430.56	0.49	0.01	0.02	0.01	17.66
6	32.4776	74.4852	5.6	515	267.8	0.57	8.02	10.01	0	1100.60
7	32.4771	74.5151	8	285	148.2	1.6	0.01	0	0.02	22.76
8	32.4867	74.4634	6.3	1140	592.8	0.41	3.37	2.03	0.01	609.38
9	32.4842	74.4685	7.59	1606	835.12	1.02	0.02	0.01	0	7.84
10	32.4783	74.4441	6.71	1064	553.28	1.41	0.02	0.03	0.05	62.40
11	32.4752	74.453	6.9	696	361.92	1.55	0.02	0	1.32	514.78
12	32.488	74.4404	6.53	1908	992.16	0.4	0.02	0.02	0	10.24
13	32.4838	74.423	6.9	603	313.56	0.96	0.03	0.04	0	17.70
14	32.4814	74.4097	6.3	576	200	1.24	7.89	0.36	0.01	805.22
15	32.4771	74.3872	5.9	242	125.84	1.41	5.71	4.71	0.01	929.37
16	32.4743	74.4018	7.3	817	424.84	1.47	0.01	0.01	0	5.38
17	32.4703	74.428	7.4	862	448.24	1.48	0.02	0.31	0	82.26
18	32.4783	74.4503	5.9	912	474.24	1.18	1.15	1.98	0.01	486.48
19	32.4776	74.4813	8.77	1201	345.5	1.04	0.01	0	0	2.91
20	32.4847	74.4941	8.6	659	342.68	5.04	0.02	0.05	0.74	352.23
21	32.4771	74.512	6.91	952	495.04	1.66	0.01	0.23	0.31	267.46
22	32.4893	74.4682	6.79	481	250.12	1.69	0	0.03	0.01	17.77
23	32.471	74.4671	8.95	820	426.4	2.31	0	0	0.01	10.48
24	32.4911	74.4592	7.67	531	276.12	4.51	0.02	0.04	0.01	25.52
25	32.4699	74.4435	6.59	1182	614.64	9.82	0	0.03	2.01	702.55

Appendix-2. Details of soil data

S.no	Long	Lat	pH	EC	OM	Ni	Cr	Pb	Texture	SQI
1	74.5184	32.503	7.45	1340	0.07	0.007	0.003	0	clay loam	1.1
2	74.5201	32.4901	7.2	847	0.03	0.03	0.1	0	silt loam	0.9
3	74.5293	32.4883	7.83	1390	0.32	0.05	0.09	0.1	clay loam	1.1
4	74.513	32.4785	7.79	1228	0.04	0.09	0.1	0.03	clay loam	0.9
5	74.5092	32.4893	6.7	1129	0.09	0.05	6.45	0	sandy loam	0.3
6	74.4939	32.4978	6.01	285	0.62	0.001	0.21	0.04	clay	0.4
7	74.4979	32.4958	6.42	2345	0.33	2.34	1.02	0.09	clay loam	0.7
8	74.4856	32.4805	7.21	870	0.08	0.05	0.1	1.92	clay	1.1
9	74.4647	32.4913	6.76	865	0.24	0.09	0.03	0	clay loam	0.6
10	74.4393	32.4877	6.96	1772	0.34	0.33	0.07	0.1	clay loam	0.7
11	74.3932	32.4775	8.56	2665	0.06	0.001	0.002	0.1	clay loam	1.1
12	74.3856	32.4783	5.88	2300	0.31	4.6	2.92	0.002	clay	0.3
13	74.4137	32.4746	7.07	1372	0.76	0.05	0.25	0	clay loam	0.6
14	74.4617	32.4702	7.21	946	0.21	1.09	0.01	0.008	clay	0.4
15	74.482	32.4839	6.95	1372	0.08	0.02	0.1	0.009	sand	1.5
16	74.4582	32.4843	7.3	946	0.41	2.97	0.04	3.2	sand	0.8
17	74.4391	32.4746	6.7	395	0.18	0.13	0.1	0.1	silt loam	1
18	74.4248	32.4839	6.01	1867	0.05	8.93	1.91	0.08	clay loam	0.5
19	74.4284	32.472	5.85	1045	0.81	9.05	10.88	0.001	clay loam	0.2
20	74.4659	32.472	7.73	884	0.26	0.09	0	0.1	clay loam	0.9
21	74.4611	32.4821	7.8	1104	0.43	0.03	0.02	0	clay loam	1.1
22	74.4508	32.476	8.8	345	0.02	0	0.004	0	clay loam	0.4
23	74.4991	32.4768	6.81	386	0.45	0.003	0.06	0.23	silt loam	0.5
24	74.476	32.4785	8.05	890	0.08	0.05	0.1	0.65	clay loam	0.3
25	74.4071	32.4815	8.7	340	0.09	0.1	0	0	clay loam	0.2