Assessment of Groundwater Quality and its Relationship with Human Health: A Case Study of Industrial Area Sialkot, Pakistan

By

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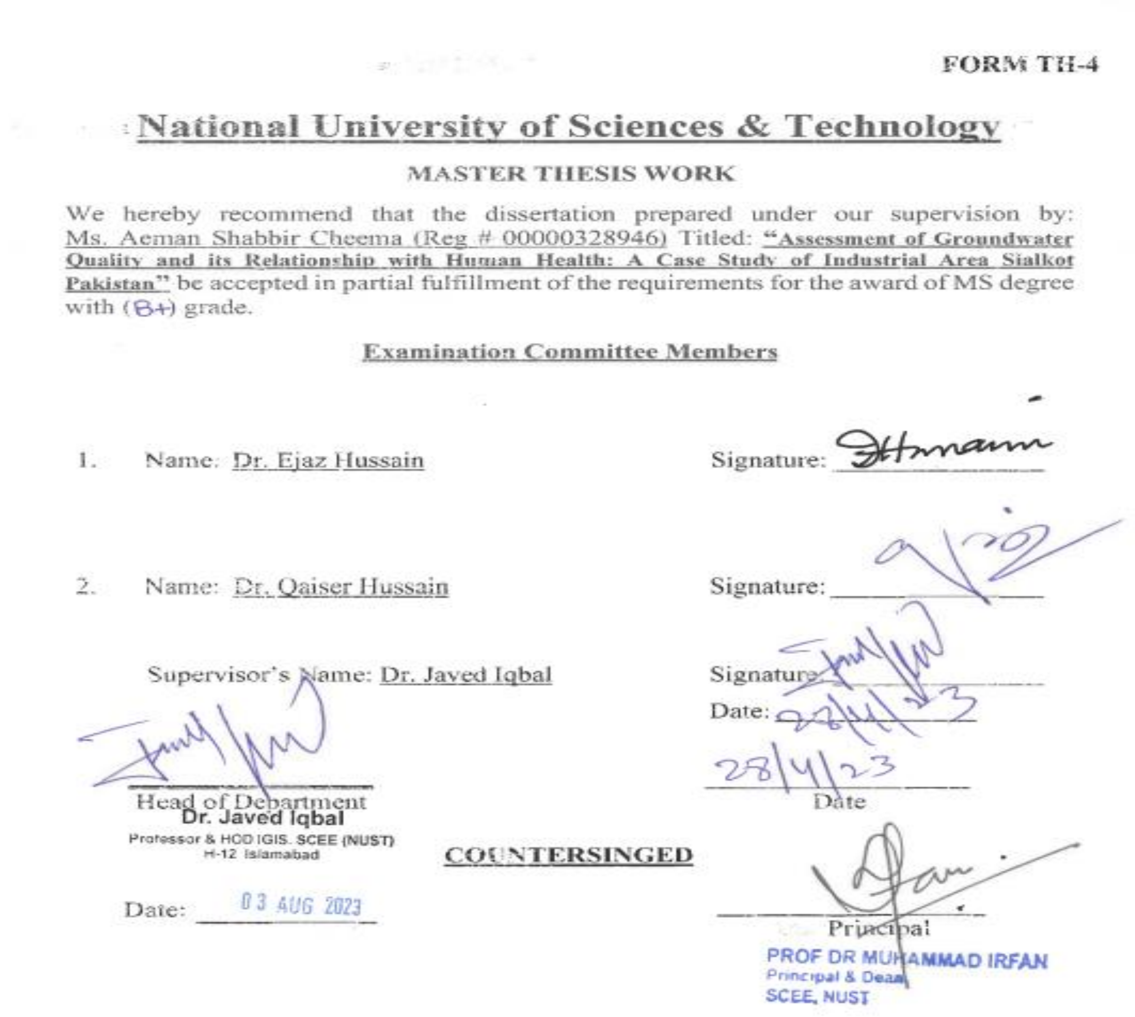

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Dedication

To

My Lovely Family

A special feeling of gratitude to my beloved Parents, Brothers (Shahid & Fahid) for their unwavering support, and encouragement throughout my journey.

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

ASSESSMENT OF GROUNDWATER QUALITY AND ITS RELATIONSHIP WITH HUMAN HEALTH IN THE INDUSTRIAL AREA OF SIALKOT, PAKISTAN

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List of Abbreviations

Abbreviation	**Explanation**
GPS	Global positioning system
IDW	Inverse distance weighted
Cr	Chromium
Pb	Lead
As	Arsenic
pH	Power of hydrogen ions
EC	Electrical Conductivity
TDS	Total Dissolved solid
UN	United Nations
WHO	World Health Organization
EPA	Environmental Protection Agency

ABSTRACT

Groundwater pollution is of high concern due to industrialization and exponential increase in population. Most of the third world countries do not have environmental protection policies and even if they have, they are not implemented. Due to which hazardous industrial waste is released in open surface streams, rivers or dug holes. Sialkot considered a industrialize hub of Pakistan is suffering from groundwater pollution due to long term rapid industrialization. To determine the extent of groundwater pollution a study was designed to (1) analyze the Physico-chemical and heavy metal properties of groundwater samples, (2) conduct a field survey of health issues related to groundwater quality in the industrial area. A total of 35 samples of groundwater were collected from community Tube wells, and hand pumps of different sites of Sialkot city. Global Positioning System (GPS) was used for recording the coordinates of sample locations. Inverse Distance Weighted (IDW) techniques was used for the interpolation of ground water quality data. The result indicates that pH value ranged from 5.3-9.13, TDS 147-651ppm, EC 195-1676 μS/cm, and Turbidity 0.01-10.5 Nephelometric turbidity units. Values for Arsenic, Chromium and Lead ranges from 0-4.98 ppm, 0.01-3.99 ppm, and 0-3.94 ppm respectively. Results indicated that arsenic 68.5% of the data points, 34% of Lead samples, and 57% Chromium samples exceeded the WHO permissible limits. The hospital patient data indicate that the associated health impacts due to consumption of contaminated water include disease including diarrheal diseases, pulmonary illness, tumors, neurological issues, and coronary heart disease were found to be prevalent. The results of this study could be used to build and construct wastewater treatment plant facilities for the District Sialkot reducing contaminant seepage rates into groundwater.

CHAPTER 1

INTRODUCTION

In the last few decades, one of the greatest global issues has been groundwater degradation (Umar, Ahmed, & Alam, 2009). Tube Wells, Pumps, and boreholes provide approximately 50% of the groundwater consumed in developing-country urban areas, such resources are utilized by 1000 million Asians and 150 million South Americans (Clarke, Lawrence, & Foster, 1995). Atmospheric rainfall, overland surface water, and deep geochemical processes all affect groundwater quality. Periodic variations in groundwater quality might be caused by human causes, hydrologic variables, and temporal changes in the source, and composition of the recharged water tasks for every individual in the world to preserve the environment and water quality (Vasanthavigar et al., 2010) (Kuriqi, 2014). Pakistan is projected to be a country with "scarce" water by 2035 (Alamgir et al., 2016). A healthy life may be maintained with convenient access to clean drinking water. The growth of the global economy depends significantly on the quality and use of water (Chennakrishnan, Stephen, Manju, & Raveen, 2008)

1.1 Ground Water Pollution

Groundwater, an invisible and convenient resource, is in danger of being diminished in some regions because of exploitation beyond its sustainable level (Harter, 2003). Therefore, it is necessary to take measures to maintain the long-term effectiveness and protection of this valuable component (Pius, Jerome, et al. 2012). Pakistan had 5,600 m3 of water accessible for each person in the middle of the twentieth century, which has since been dramatically reduced to only approximately 1,000 m3. This crisis has pushed Pakistan to the edge of becoming a water-stressed country (Shahid, Iqbal, Hasnain, & Assessment, 2014). According to the Pakistan Council of Research on Water Resources, approximately, waterborne diseases cost the country's economy roughly USD 380-883 million each year (Akhtar et al., 2019). The total costs that arise out of water-related diseases and fatalities are expected to exceed 1.8% of Pakistan's GDP (Information & Department, 2006). Water quality degradation is the greatest global danger to human health(Islam, Siddiqui, Zahid, Tasnim, & Rahman, 2020). So, the purpose of this research is to evaluate the concentrations of As, Cr, Pb, and other heavy metal pollutants in groundwater. Furthermore, attempts were undertaken to assess the interrelationship between important water quality variables such as Heavy metals and physicochemical properties pH, Turbidity, etc. Anthropogenic activities, such as inappropriate disposal of municipal, and industrial pollutants and unplanned use of crop pesticides are critical contributors to the degradation of water quality (Iqbal et al., 2020). Eutrophication, reduction in water quality, biodiversity decline, negative impacts on human well-being and social security, accumulation of nitrates and other toxins, acidification, and significant economic losses are the results of these actions (Kraemer, Choudhury, & Kampa, 2001).

1.2 Sources of Water Contamination:

The term "groundwater contamination" refers to the infiltration of harmful contaminants into groundwater as a result of human activity (Abdul Hameed M Jawad, Haider S, Bahram K, & Protection, 2010). Groundwater contamination varies from surface water because it is undetectable and recovery of this resource is challenging with existing technologies (Chesnaux, 2008). There are various types of toxins found in groundwater, they may generally be divided into three groups chemical contaminants, biological contaminants, and radioactive contaminants. These toxins may originate from both natural and man-made sources (Elumalai et al., 2020). Chemical Contaminants include Heavy Metals and metalloids like Arsenic, Zinc, Lead, Chromium, etc, and metalloids like selenium which pose serious problems even in minute concentrations (Hashim, Mukhopadhyay, Sahu, & Sengupta, 2011). The biological contaminants category includes Bacteria, Protozoa, and algae in water. There have been four hundred types of Bacteria detected in human feces with a hundred types of viruses (Yu et al., 2022). Nuclear waste comes in the class of radioactive contaminants. These contaminants are very stable, and very difficult to remove them from traditional technologies.

1.3 Health Issues:

In Sialkot and the nearby districts, there are cases of dysentery, cholera, typhoid, and other diseases. Because a huge portion of the rural population relies on natural water sources for their drinking water requirements, the impacts of effluent might persist and enter the food chain and it can be expected that the livestock and other living bodies suffer (Ahmad, 2000). The associated health impacts due to contaminated water include disease in nearly all body systems, including diarrheal diseases, pulmonary illness, tumors, neurological issues, and coronary heart disease (Vaishaly, Mathew, & Krishnamurthy, 2015). The most prevalent diseases due to bathing in contaminated water are abdominal pain, aches, loss of hair, hand stiffness, decreased appetite, eye diseases, dermatitis, and fever. According to Tahir and Bhatti (1994), between 20 and 40 percent of hospital beds in Pakistan are filled by individuals with diseases related to poor water and sanitation, including cholera, gastroenteritis, diarrhea, hepatitis, amoebiasis, parasitic infections, and intestinal worm infections.

In Sindh, cancer patients are increasing (TI, Tahir, & Rasheed). Ahmad (2000) found that around 82% of bowel disorders, including diarrhea, are caused by drinking water polluted by leather factories' effluents. Sialkot is recognized as Pakistan's biggest industrial hub and is home to a variety of businesses in the textile, metallurgical, leather products, large pharmaceutical industries, and other related sectors. Sialkot's surface water and groundwater have deteriorated as a result of the city's growing industrialization, urbanization, and agricultural practices (Evans, Hanjra, Jiang, Qadir, & Drechsel, 2012). Just tanneries are estimated to produce about 1.1 million liters of wastewater each day (Daily, 2006).

1.4 Role of Geoinformatics

In 1854, John Snow constructed a map that demonstrated the connection between cholera patients' localities and the water pumps they frequented. This was a huge advancement to figure out disease transmission and inequalities in public health. There has been a considerable rise in the popularity of maps that portray the frequency and distribution of illnesses in recent years. These disease maps are updated with the latest using modern Geographic Information System (GIS) software, which may dramatically improve public health management (Nelly & Mutua, 2016). With GIS, it is feasible to construct layers by interpolating point data, which is an important tool used by several researchers to analyze the physiochemical characteristics of groundwater (Subramani, Krishnan, & Kumaresan, 2012). Groundwater quality assessment is a worldwide activity that strives to keep safe drinking water available. It is significant to map the parameters of groundwater in Sialkot City since this assists in the detection of zones that may be at risk of future environmental health concerns. Regular groundwater contamination monitoring is important to ensure the consistent use of safe water sources (Asadi, Vuppala, et al. 2007). IDW maps are used to see geographical patterns and trends in data, making it simple to spot locations with high or low values.

The use of the Water Quality Index (WQI) is highly beneficial in evaluating water quality as it is a useful and efficient method. It also serves as an effective tool for communicating the overall quality of water (Pradhan, Patnaik, et al. 2001). An online survey was conducted to assess the quality of drinking water and explore the popular diseases in the Sialkot area. The present condition of groundwater quality in Sialkot City is evaluated in this study. It looks at the key sources of pollution. The research also explores initiatives to adopt techniques for reducing water pollution to minimize the impacts on public Health.

CHAPTER 2

MATERIALS AND METHODS

2.1 Study Area

2.1.1 Geography and Landscape

Punjab's Sialkot district has a fertile northern part and a slightly productive southern area close to the Chanab River. The Chanab River supplies water to the city, which produces a variety of crops including wheat, grain, corn, rice, cereal, and sugarcane. Jammu and Kashmir state borders the city to the northeast, and Gujrat District, Gujranwala District, and Narowal District, respectively, to the northwest, west, and southeast. The area is around 840 feet above sea level and has the coordinates 32°22' 30" and 32°52' 30" latitude and 74°15' 00" and 74°41' 15" longitude. Variations in temperature and precipitation are noticeable throughout the area. The study area covers about 2.97 million hectares and is situated on the upper side of Rachna Doab.

It is well known for having an active alluvial complex. The region is built up of Pleistocene reservoirs that go down thousands of meters, with the upper 200 meters being mostly silty sand and thin clay layers. Little to medium-grained sand, silt, and clay make up the majority of the area's alluvial complex, which has led to the formation of groundwater reservoirs. The complex was created as a consequence of lithological processes that were triggered by shifting river routes. (Khan, Qadir, et al. 2019).

The study focuses particularly on Sialkot City's Factory area, which serves as the region's main industrial hub. In the area, there are 92 tanneries, over 244 businesses that produce leather goods and clothing, over 900 industries that make sports equipment, 57 units that husk rice, and 14 flour mills. Figure 1 shows the study area's location and groundwater sampling stations, while Figure 4 depicts the Generic methodology flow chart. A field survey was conducted to evaluate the quality of groundwater in Sialkot City. The survey was focused on 35 sites in the urban area, which consist of different types of Industries like Hydroloical Tools, Leather Goods, Metal Industry, Sports Goods, and Surgical Instruments industry (Figure 5).

2.1.2 Random Sampling Approach

To collect water samples in our study area, the proposed technique was Random Sampling. This technique ensures that each sample has an equal chance of being selected. Groundwater samples for water quality testing were collected from various sources such as hand pumps, motor-operated tube wells, and boreholes (Butt, Ghaffar, et al. 2012). Thirty-five (35) groundwater samples from the city's industrial area were collected. The water samples were then taken to the Environmental Sciences Laboratory at NUST, Islamabad, where they were analyzed for physicochemical properties and heavy metal contamination. The data obtained was organized using MS Excel and compared against international guidelines.

2.1.3 Climatic Circumstances

The weather in the region fluctuates throughout the year, with an average of 11.6°C in Jan and an average maximum of 32.2°C in Jun, according to climate and monthly weather predictions for Sialkot, Pakistan. During the coldest three months, the temperature is around 12.7°C lower than in Lahore.

Furthermore, the area receives 957mm of yearly rainfall, with more than half of this amount falling during the monsoon season. As a result, the monsoon season is Sialkot's primary source of rain. Figure 2 and 3 are showing annual long term rain fall and temperature in Sialkot city.

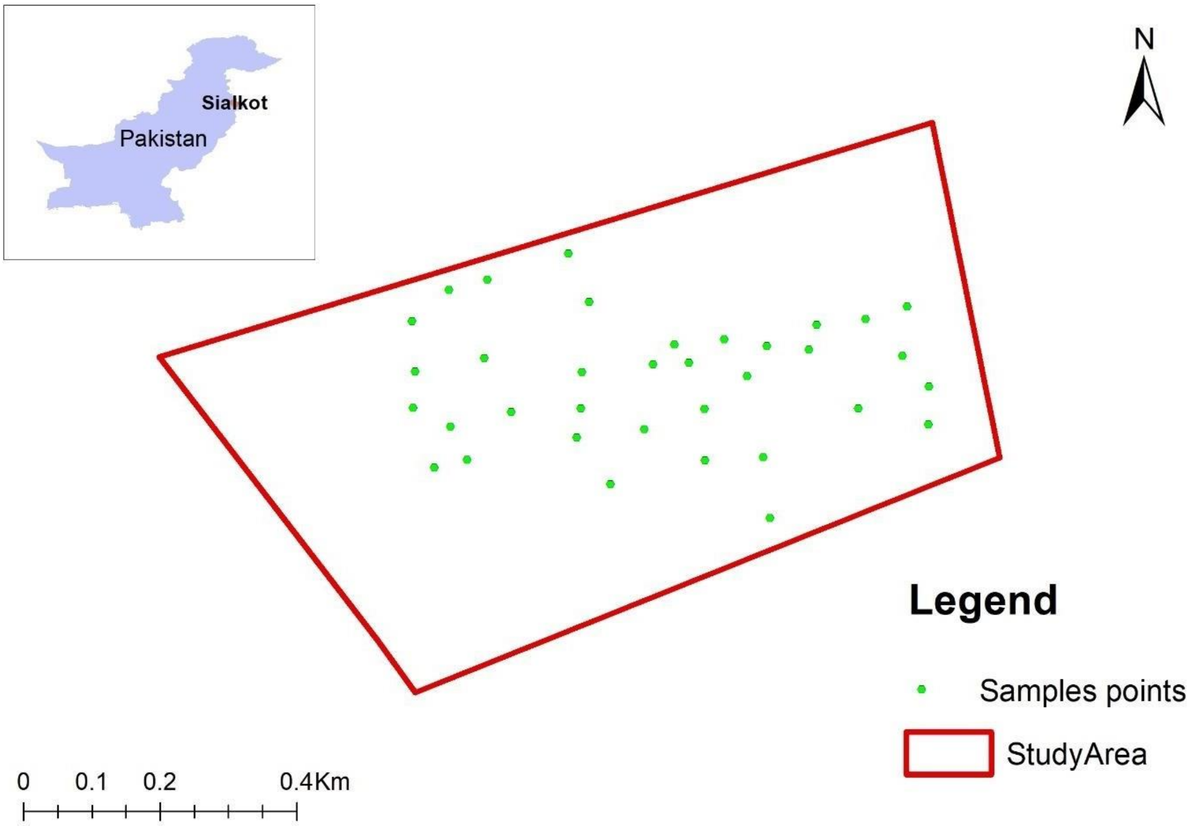
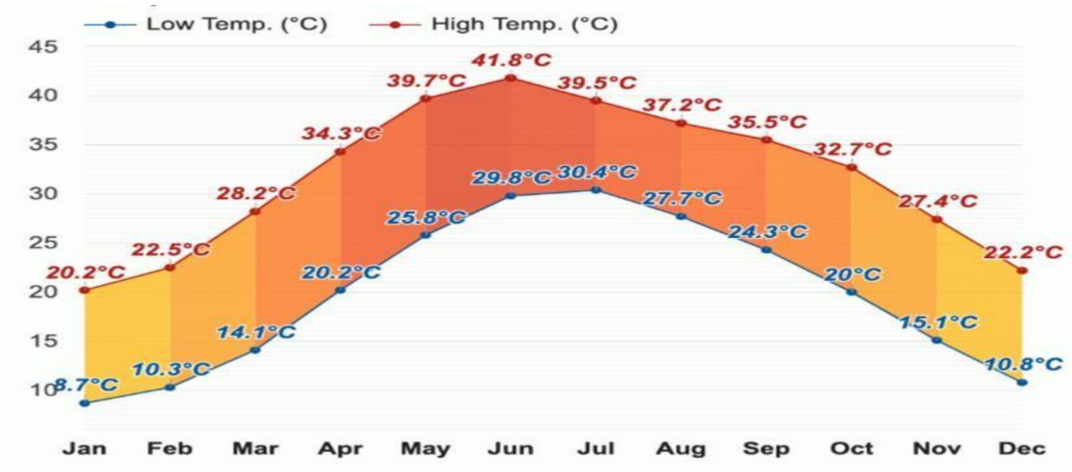


Figure 1. Showing the location of the study area and ground water sampling locations.

https://www.weather-atlas.com/en/pakistan/sialkot-climate

Figure 2. Illustrating average long-term rainfall in Sialkot City.



https://www.weather-atlas.com/en/pakistan/sialkot-climate

Figure 3. Describing average long-term temperature in Sialkot City.

2.2 Flow Chart Diagram

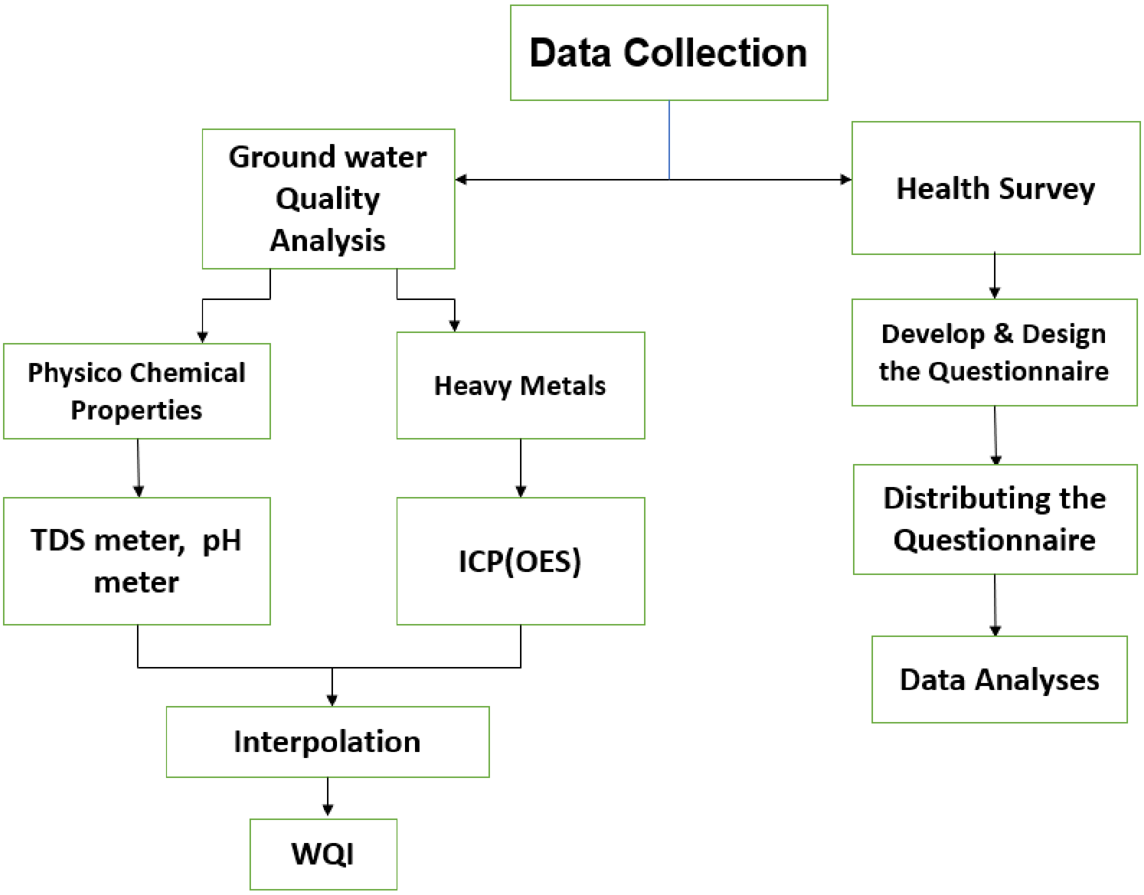


Figure 1. Generic methodology flow chart.

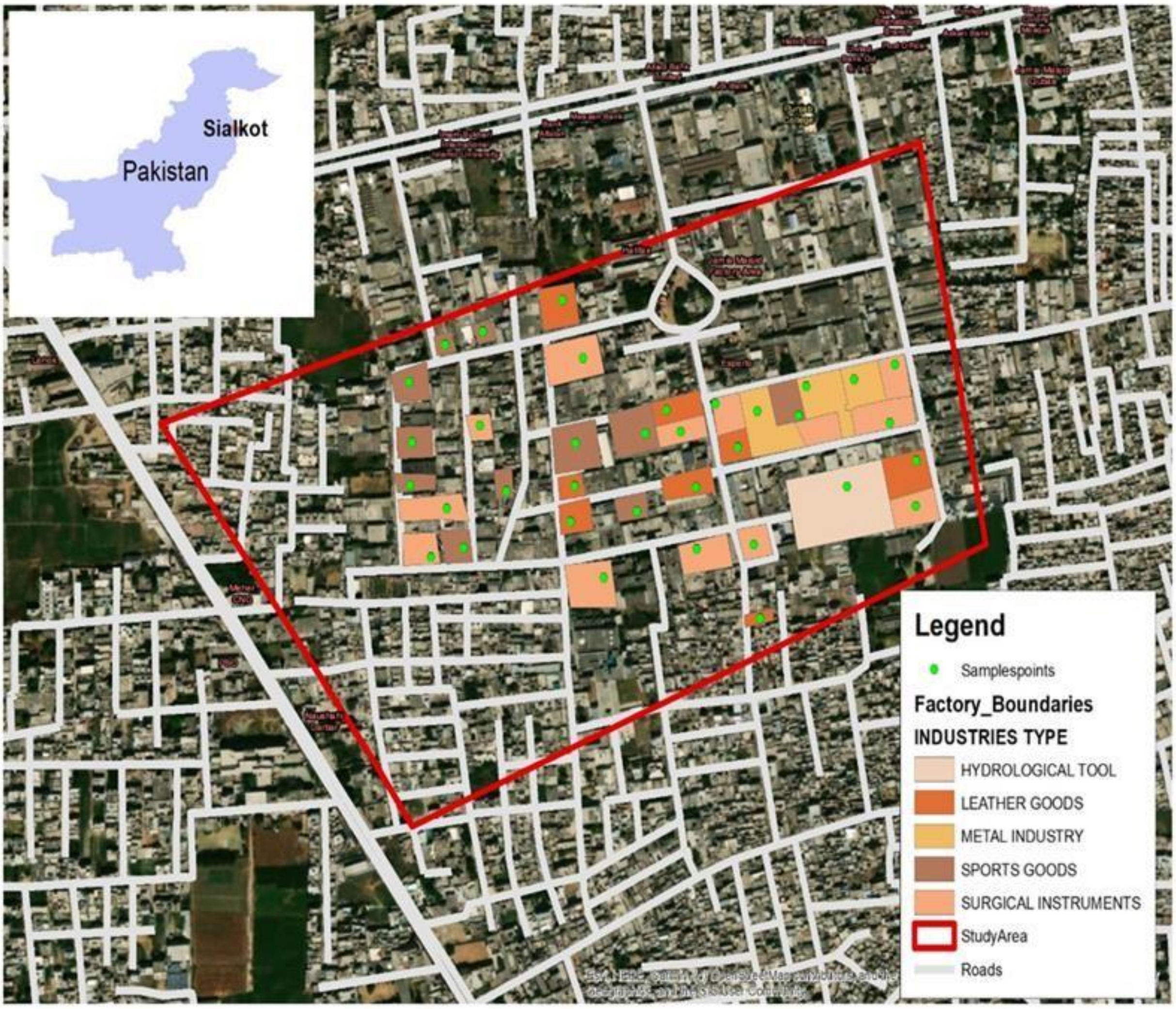


Figure 2. Type of Industries in study area.

CHAPTER 3

RESULTS AND DISCUSSIONS

3.1 Summary Statistics

Water samples from these study sites were tested in the lab. The results revealed that the concentration of various pollutants was above the limits established by regulatory organizations including the WHO, EPA, and PEPA. Arc GIS 10.8.2 software was used to examine the spatial data modeling outputs and calculate the mean values for various pollutants.

Except for TDS, turbidity, and EC, which were below permissible limits but had higher values in some locations, all of the variables evaluated in the research region were found to exceed the permitted levels defined by WHO, PEPA, and EPA. TDS measures the total mass of dissolved ions present in water that might alter the water's smell, turbidity measures the cloudiness or haziness directly caused by the light being reflected by particles in water. When deciding whether water is suitable for various uses, groundwater EC gives an indicator of the amount of dissolved salts and other inorganic compounds that are present in the water. Electrical Conductivity, EC, and TDS maximum allowable limits by WHO are 250-1500us/cm, 500 respectively. Turbidity ideally should be 1 Nephelometric Turbidity Unit but it can be up to 5NTU.

A low pH number indicates water's very acidic nature, whereas a high pH value indicates water's highly alkaline character. TDS concentrations exceeded the suggested limit in 46% of the samples taken from the Sialkot region, with the maximum value being 651.04 ppm and the smallest being 147.68 ppm (Table 1). Just 20% of the samples, on the other hand, went beyond the WHO-set threshold; the remainder were within the permitted range.

All samples' turbidity values were found to be below 5 NTU and within the acceptable limit. 68.5% of the sample points for arsenic testing showed results greater than the WHO recommended limit of 0.01 ppm, with the largest value being 4.98 ppm and other samples having a concentration of 0 ppm. The results of the chromium study found that the lowest value was 0.01ppm and the maximum value was 3.99ppm. Heavy Metals and pH average values were higher than WHO recommended values, which means most samples of these four variables were above allowable limits. Arsenic, Chromium, and Lead WHO threshold level are 0.01, 0.05, and 0.01 but the mean of thirty-five samples for these metals is 1.29, 0.97, and 0.48 respectively. Skewness values for pH, As, Cr, and Pbb are 0.53, 1.27. 1.28 and 2.2. Whereas values for these variables Kurtosis are 0.76, 0.72, 0.42, and 4.13.

3.2 Correlation Analysis

Correlation analysis is a statistical approach for determining how strongly two variables are linked together. Positive numbers indicate that different processes had a considerable impact on the water variables, whereas negative values show that the equilibrium of the water chemistry remained unaffected. Table 2 is showing that pH and heavy metals are negatively correlated. Where pH is less there is a high release of Heavy metals in acidic conditions.

It means the sharp rise of heavy metals observed under acidic conditions. But Cr, As, and Pb are positively correlated with others. Where Cr concentration is high As and Pb are also at high levels. Electrical Conductivity has a negative correlation with Turbidity and Heavy metals but positive relation with Total Dissolved Solids.

Turbidity has negative relation with Arsenic but a positive one with Chromium and Lead. The total Dissolved Solids relation with all other parameters is negative. Where TDS concentration is high Turbidity, Arsenic, Chromium and Lead concentrations will be low. All seven variables are interconnected, but the pH has more influence on Heavy Metals.

3.2.1 Classical Statistical Exploration

Table 1. Showing summary statistics of water samples.

Variables	**Max**	**Min**	**Mean**	**Standard Deviation**	**Kurtosis**	**Skewness**	**WHO limit**
pH	9.13	5.3	6.64	0.84	0.76	0.5	6.5-8.5
EC	1676	195	749.7	495.09	-0.88	0.63	50-1500 uS /cm
TDS	651	147	349.5	125.7	0.11	0.93	500 ppm
Turbidity	10.5	0.01	1.73	2.42	8.61	2.94	1-5 NTU
As	4.98	0	1.29	1.48	0.72	1.27	0.01ppm
Cr	3.99	0.01	0.97	1.26	0.42	1.28	0.1 ppm
Pb	3.94	0	0.48	1	4.13	2.2	0.01ppm

Table 2. Correlation matrix of heavy metals and physico-chemical properties.

Variable	**pH**		**TDS**	**Turbidity**	**As**	**Cr**	**Pb**
pH	1						
EC	0.27	1					
TDS	0.16	0.60	1				
Turbidity	-0.23	-0.19	-0.11	1			
As(ppm)	-0.65	-0.43	-0.08	0.28	1		
Cr	-0.67	-0.18	-0.11	-0.01	0.70	1	
Pb	-0.56	-0.35	-0.24	0.45	0.75	0.59	1

3.3 IDW Maps for Physico-Chemical Properties and Heavy Metals

To determine water quality, the Idw (inverse distance weighted) can be used. A pH IDW map displays the distribution of pH levels within a certain area, with varying colors symbolizing differing levels of pollution. Grey and red colors represent locations with greater pollution levels. Also, they represent a bigger danger to human health and demand more consideration from legislators and regulators. Only samples found in the green region fall inside the permitted range. The values in the green zone range from 6.5 to 8.5, however, the points in the grey zone are acidic Figure 6(a). The numbers in the red section are above the WHO-acceptable level. Figure 6(b) displays the different classes of Electrical Conductivity in drinking water that must be between 250 and 1500 uS/cm. Water quality readings that are within grey areas are considered suitable for drinking. However, readings that fall within the red region are above the WHO-recommended level, signifying that they may be potentially dangerous and unfit for consumption. Each of the three categories on the Total Dissolved Solids (TDS) IDW map represents a different water quality level, from good to bad Figure 6(c). A score of 1-300 ppm indicates a good class, whereas a score of 501-700 indicates a poor class. As the values rise between the ranges of the good and bad classes, the intermediate class shows a stable (good) water quality. The Turbidity water quality map in Figure 6(d) is divided into classes to represent different water quality levels. Although the green areas on the map depict places with turbidity levels between 4-5 NTU, which are regarded as safe for consumption, the grey areas on the map show regions with very low turbidity levels of less than 5 NTU. However, the red portion has a small number of values above the turbidity threshold. Groundwater quality was measured using an arsenic IDW map based on the amount of heavy metals detected. The World Health Organization (WHO) has established a drinking water arsenic guideline threshold of 0.01 ppm. As a result, any arsenic concentration below this threshold would be regarded as safe and given a low-risk score on the IDW map. A significant risk score on the IDW map is represented by a concentration of 0.02-2.50 ppm, above the WHO recommendation limit. Arsenic levels of 2.5–5.00 ppm are regarded as extremely high Fig 7(e) and can be dangerous to human health. Idw map displays the lead (Pb) content of the water in the Sialkot region. The degree of lead pollution in the water is indicated on the map by color coding and scale. Lead in water is acceptable in concentrations no greater than 0.01 parts per million (ppm). Any value above this level is considered outside of the acceptable range and potentially dangerous to human health. According to this Pb IDW map, sites with lead levels below 0.01 ppm are safe, those between 0.02 and 2.5 ppm are potentially unsafe, and those between 2.51 and 4.00 ppm are extremely dangerous (red).Figure 7(g)

The distribution of chromium in different areas is depicted on an IDW map for chromium (Cr) in groundwater. Chromium in drinking water is allowed up to 0.05 ppm. Chromium levels below the prescribed limits of 0.05 ppm are assigned to certain areas. Grey normally be used for a low-risk score. Locations with chromium concentrations between 0.06-4.00 ppm are considered beyond the allowed limit and have been given a moderate to high-risk score; these areas are often highlighted in green, blue, and red. Very high-risk zones are often shown in red if the concentration of chromium is 1.76–4.00 ppm. In the case of Physico-chemicals parameters pH 51%, EC 60%, TDS 42% Turbidity 91% samples were within safe limits but 49%, 40%, 58%, and 9%, cross the recommended limits respectively. Arsenic which is cancer-causing heavy metal was high in 43% of samples but low than the permissible limit in 57% of specimens. In 60% of samples, chromium was in the allowable range but in 40% above the limits. Another Heavy metal Lead directly affects the nervous system and was high almost in 98% of samples, this may be due to the leather industry which is the main source of lead. In the Study area, there are almost 244 leather industries producing lead and chromium. Points having high values are closer to these hazardous pollutant-generating industries.

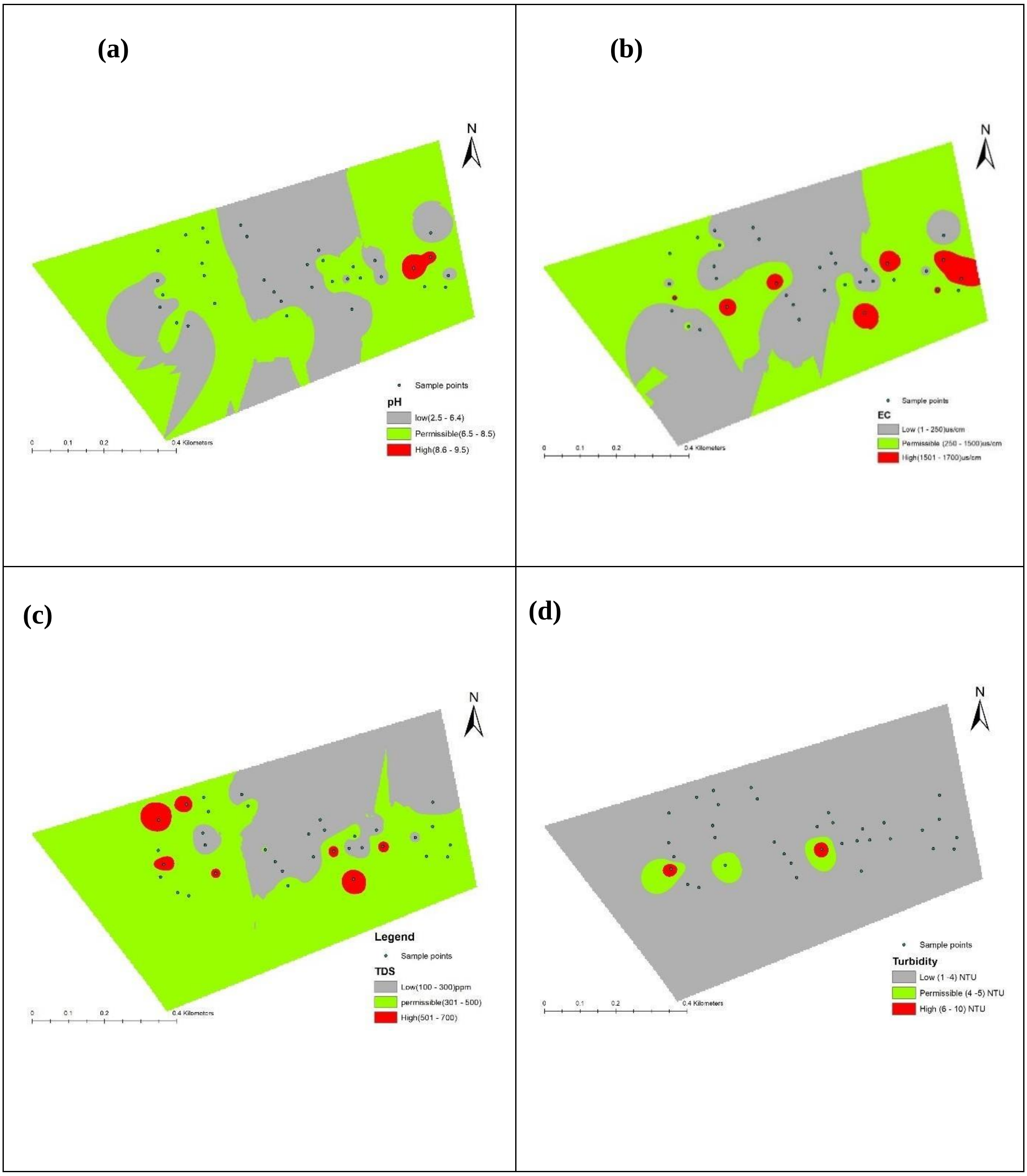


Figure 3. Showing IDW maps for physico-chemical properties(a) pH (b)EC (c) TDS (d) Turbidity.

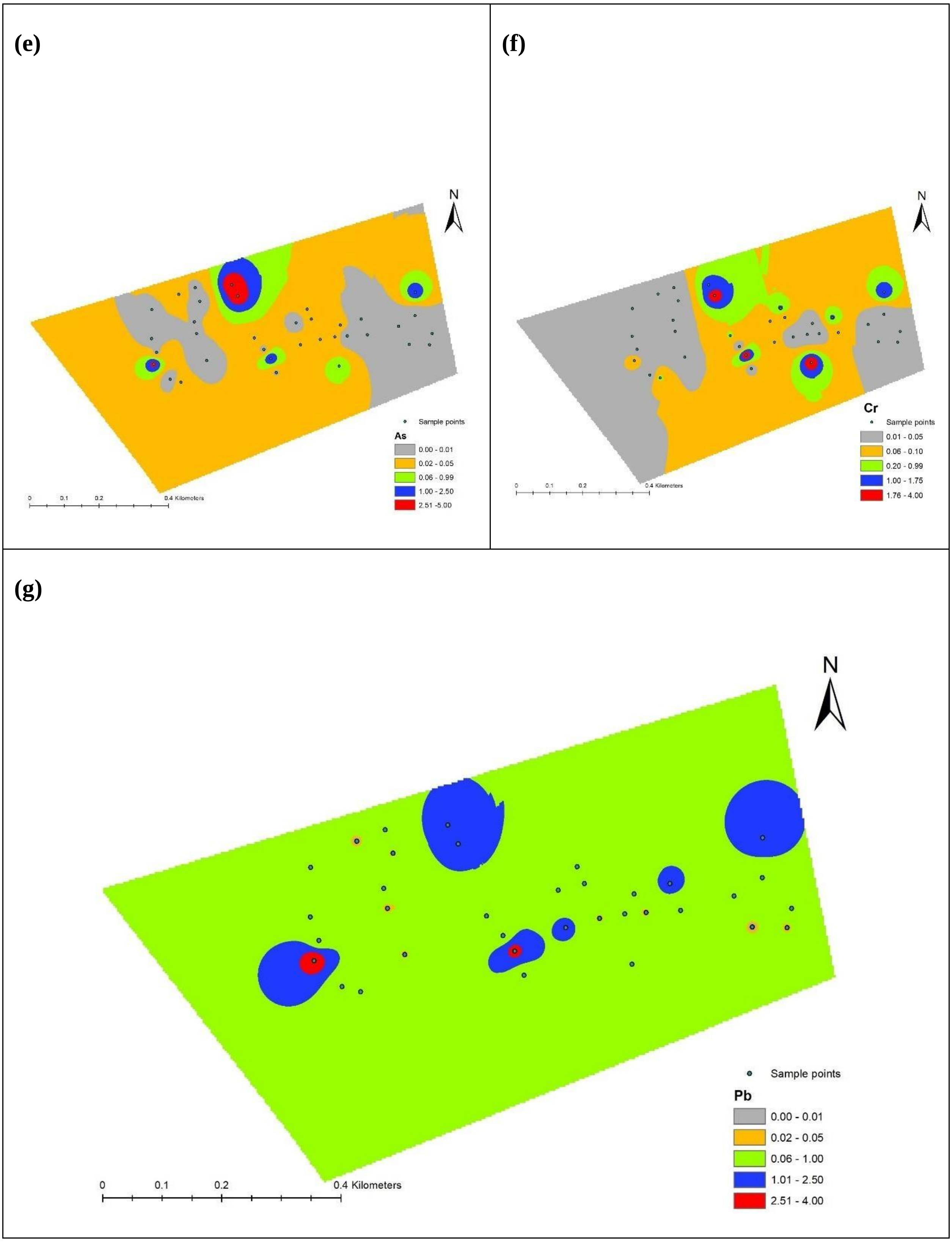


Figure 4. Showing IDW maps for heavy metals (e)As (f) Cr (g) Pb.

3.4 Water Quality Index Estimation

The Water Quality Index (WQI) is a key tool to evaluate water quality in terms of governance and portability point of view. It is a water rating scale for evaluating water that is based on the assessment of various quality parameters and demonstrates the impact of several parameters on the overall quality of drinking water.

Its major goal is to reduce a significant amount of water quality data in a clear and useful manner. It is particularly successful at giving the public, policymakers, and management authorities access to water quality data in a very straightforward manner. These metrics are widely used to evaluate the water quality in different parts of the world (Abdul Hameed M Jawad et al., 2010).

As far back as 1965, water quality indices have been documented in the literature (Kachroud, Trolard, et al. 2019). The present study utilized an arithmetic WQI method, which was originally proposed by Horton and later developed by Brown et al. and Cude. The most important variable that significantly affects the general quality of water for human consumption was given weight in the first phase. In the current study, the essential physicochemical parameters, including pH, TDS, Turbidity, Cr, As, and Pb, were taken into consideration while calculating the water quality index. Each analyzed parameter was given a weight (wi) based on how important it was in affecting the water quality (Table 3). Standards that are used for WQI are WHO-recommended limits. The smaller the recommended value for a given pollutant, the more harmful it is known to be. In the case of Heavy metals, very small concentrations are allowed by WHO. Because these metals directly impact living organisms. Mostly Pb and Cr concentrations are high in sites that are close to Leather Industries. So WQI map indicates the areas which are contaminated and in a few years may reach to deterioration level.

Table 3. Illustrating the relative weights for different variables.

Variables	**WHO Limit**	**Unit weight**
pH	8.5	0.006
EC	1500	0.004
TDS	500	0.004
Turbidity	5	0.006
Arsenic	0.01	0.8
Chromium	0.1	0.08
Lead	0.05	0.1

Except for pH, all units of variables are in ppm (Abbasi and Abbasi 2012). The following equation was used to calculate the relative weight (Wi):

$$\mathrm{WQI} = (\Sigma \mathrm{qiWi}) / \Sigma \mathrm{Wi}) \text{.................. Eq.1}$$

Wi is the weight of each parameter, whereas Wi is the relative weight and n is the number of variables.

In the second phase, a quality rating scale (qi) was generated by multiplying the result by 100 and then dividing the measured concentration of each parameter by its corresponding WHO (2011) standard.

$$\mathrm{Qi} = (\mathrm{Ci}/\mathrm{Si})*100\text{………………………Eq.2}$$

Whereas "Si" stands for WHO standards and "Ci" stands for the measured concentration of each parameter.

For each water quality parameter, SI was calculated in the WQI's final step by multiplying the relative weight (Wi) with the quality rating scale (qi). The water quality index is equal to the sum of SI.

$$\mathrm{SI} = \mathrm{Wiqi}\ \text{…………………………..Eq.3}$$

$$\mathrm{WQI} = \sum \mathrm{SIi}\text{…………………………Eq.4}$$

In the present research, it was observed that the water quality index (WQI) fell within a range of values 6.9 – 1655.5 ppm.

Any value exceeding 100 on this water quality index indicates pollution and renders the water unfit for human consumption (Balamurugan, Kumar, Shankar, Nagavinothini, & Vijayasurya, 2020). The results of the WQI analysis showed that 25 out of the 35 groundwater samples examined in the study area had values above the permissible limit of 100.

This means that these samples cannot be used for human consumption due to their high levels of contaminants. The study's assessment of the water quality index in the present study zone revealed a higher value, which indicates that the overall water quality is in a state of deterioration. The map is classified into five classes. Where Water Quality Index values are below a hundred this area is classified as good, as it is shown in sky blue color on the map. Those sections which have values greater than a hundred are classified in terms of poor, very poor, inappropriate, and deteriorate. A safe zone may have a lesser number of industries which that's why the water quality of this section is good. Almost ten samples have values less than the recommended limit. 40% of samples lie in the good category because they have values in 50-100. 17% exist in the poor class because their values range from 100-200.

Approximately 22% of the sample falls within the range of 200 to 300, which is considered to be a very poor range. A total of 6% of the samples in the data set are classified as being in the inappropriate class due to having values that fall within the range of 300 to 500. These data points are categorized as such because they do not fit within the desired range for the class. The deteriorate class contains approximately 14% of the samples in the data set because their values exceed 500. It means classes next to the good category have high concentrations of Arsenic, Lead, and Chromium. Inhabitants of Sialkot which is known as an industrial city drink mostly polluted water as disclosed by lab analysis of samples. Almost 60% of samples were next to the good category. It means most water is contaminated. Samples that exist in deteriorated class are close to the leather industry producing cancer-causing Chromium and lead which directly affect the nervous system. These metals persist in soil for a long time and then come in contact with water. If industries stop producing these metals it will take many years to treat water due to their long effect. Mostly those specimens fall in the good category which is distant to industries. Figure 8 is showing sample locations, industries locations near these samples, and categories of areas into different classes.

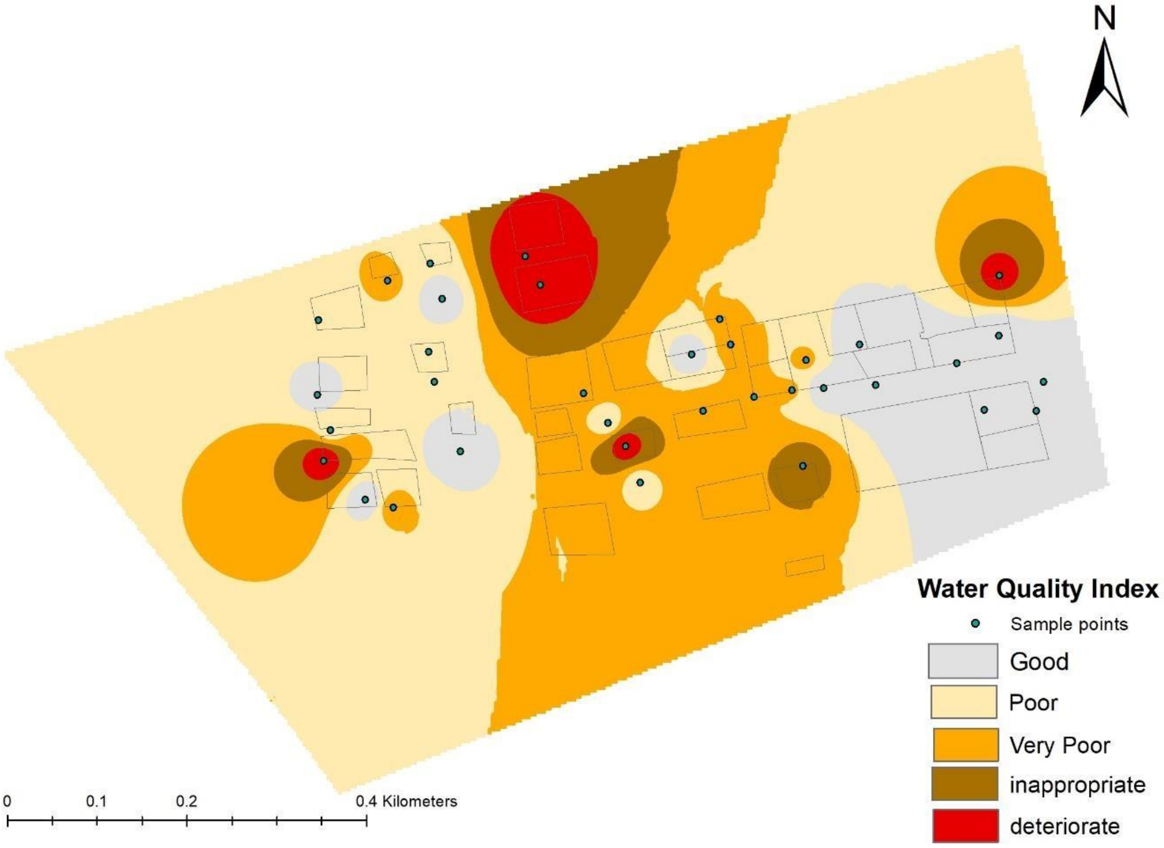


Figure 5. Showing water quality index map.

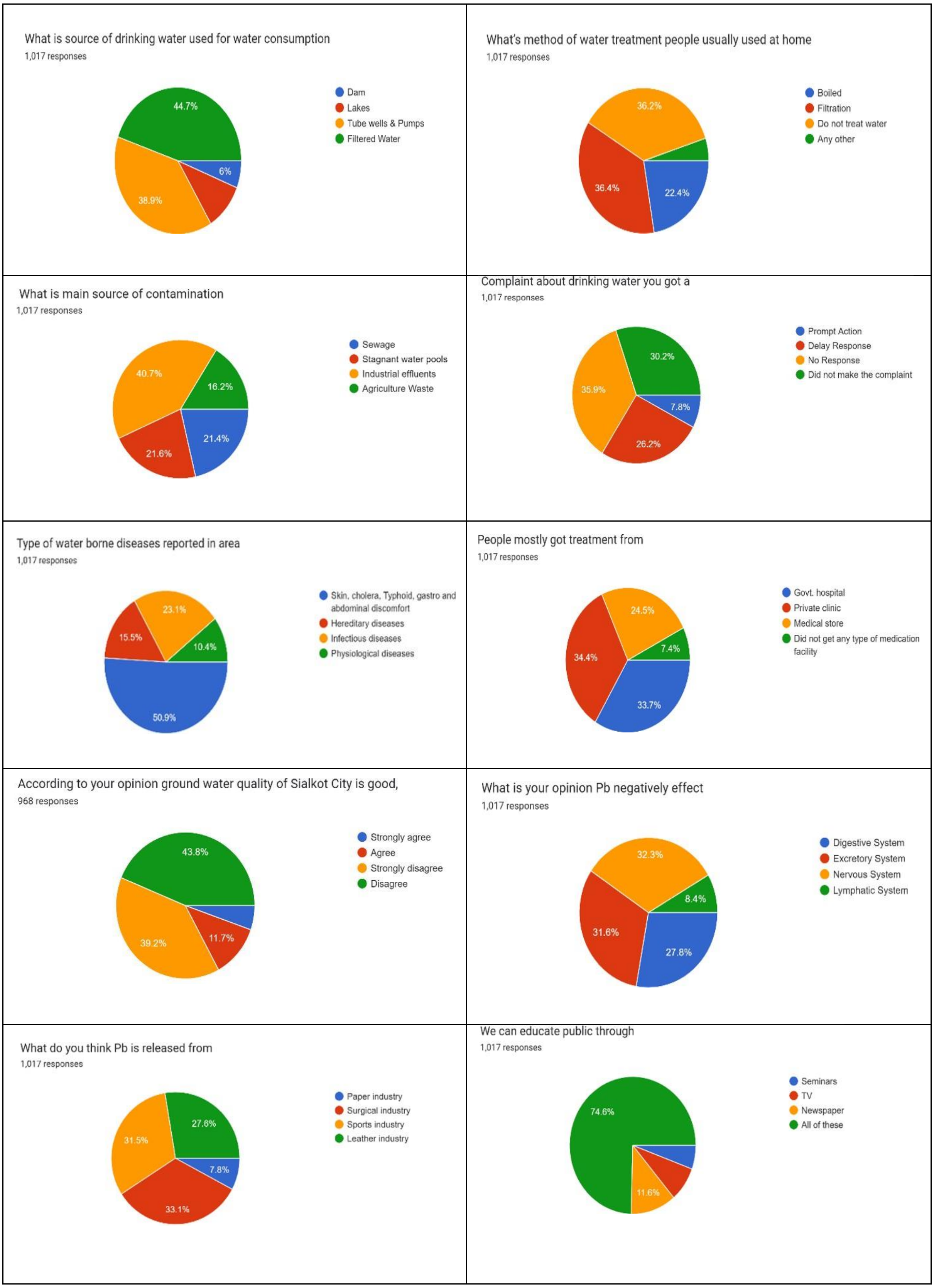
3.5 Ground Water Quality Survey Responses

An online survey was conducted to assess the quality of drinking water and the associated health concerns. A total of 1017 respondents responded to this questionnaire, which contained questions about their demographic information, awareness of drinking water quality, methods of water treatment and sanitation, and waterborne illnesses. The survey included a question asking the respondents about the source of drinking water they used for consumption. 44.7% of people used filtered water, and 38.9% used Tube Wells and Pumps. It was found that to treat water 36.4% of people use filtration,36.2% don't even treat water and 22.4% of respondents replied that they boil water to clean it. When they were asked what is the main source of contamination 40.7% participants of viewed industrial effluents are the main source of contamination, 21.6% replied stagnant water pools, 16.2% answered agriculture waste and 21.4% think sewage. It was also inquired about the response of liable authorities when people complained 35.9% of participants replied that they got No Response, 26.2% received delayed response,7.8% acquired Prompt and 30.2% people did not submit any objection to related departments.

Individuals were queried about the specific waterborne illnesses that have been reported in the area. 50.9% of people view skin, cholera, Typhoid, gastro, and abdominal discomfort are water-borne diseases in Sialkot. 15.5% of respondents answered Hereditary diseases, 23.1 % reported Infectious diseases, and 10.4% a small number of people agreed physiological diseases are types of waterborne diseases reported in the area. In a survey, people were asked about the source of their treatment. The results showed that 33.7% received treatment from a government hospital, 34.4% got medication from a private clinic, and 24.5% took medical care from a medical store. However, a minor number of people, approximately 7.4% did not have access to any type of medication facility in the surveyed area. One question was made regarding the standard of water quality in the city of Sialkot.

The analysis utilized a four-point scale ranging from "strongly agree" to "strongly disagree". The findings indicated that (43.8%) of respondents strongly disagree drinking water quality of Sialkot City is good, while 39.2% of perpetrators did not agree. The majority disagreed about the good quality of water. Only 11.7% of partakers agree on the water in Sialkot city is preferable. Contributors were questioned about the main source of lead in the area. The findings revealed that 31.5% of respondents prospected Sports Industry, 27.6% Leather Industry, 33.1% Surgical Industry and a few people 7.8% eye view that lead is released from the paper industry.

When inquired about contributors' opinions that lead negatively affects which organ most. 32.3% replier believed that the Digestive System, 31.6% Excretory System, 27.8% Digestive System, and 8.4% of people thought that Pb negatively affects the Lymphatic system. The last Question was, how we can educate people. The results of the analysis revealed that (11.6%) of informants agree only with the newspaper and 74.6% standpoint, that seminars, TV, and Newspaper can be the best way to educate people. From the questionnaire we can depict that locals are not taking this issue seriously even though 38.9% of people still drinking tube wells and pumps water, and 35.9% public did not make the complaint (Figure.9). So there is a need to educate the public through special sources because its need of time if want that present generation and then next to it not suffer water-borne diseases. By educating the public about industries, the type of chemicals these are producing and their reverse reactions on human health, and then how to control these harmful substances we can safe water.



What is source of drinking water used for water consumption

What's method of water treatment people usually used at home

What is main source of contamination

Complaint about drinking water you got a

Type of water borne diseases reported in area

People mostly got treatment from

According to your opinion ground water quality of Sialkot City is good,

What is your opinion Pb negatively effect

What do you think Pb is released from

We can educate public through

Figure 6. Depicting contributors responses

3.6 Ground Water Contamination and Health Issues

Water pollution is a leading factor that contributes to various health issues among humans. Approximately 2.3 billion individuals around the globe are affected by illnesses caused by contaminated water. Unclean water and inadequate sanitation are responsible for the deaths of over 2.2 million people annually in developing countries. Data regarding waterborne illnesses were gathered from the Tehsil Head Quarters Daska (THQ). In 2018 number of patients suffering from diarrhea was 2469 but in the next four years, this trend go upward and reached up to 2654. Cholera victims in 2018 were 1634 and this number moved to 2062 in 2022. There were around 1740 reported cases of Typhoid Fever in 2018 and this figure increased significantly to approximately 4066 cases in 2022. The number of reported cases of peptic ulcer declined from 2018 to 2022. Reduction in peptic ulcer cases over four years is a positive development as patient numbers fall from 5249 to 414. A few cases of chronic liver (37) and liver diseases (12) are also outlined in this area. Figure 10 is illustrating the number of patients with Gastro Intestinal Diseases in two years 2018 and 2022.

3.6.1 Skin Diseases

Scabies and dermatitis exhibit varied patterns over four years, as seen in Figure 11. In the years 2018 to 2022, scabies appears to have decreased from 8666 to 7890 cases. While Dermatitis occurred more often, from 1146 occurrences in 2018 to 3470 cases in 2022.

3.6.2 Other Water-Borne Diseases

Urinary tract infections increased from 3386 occurrences in 2018 to 6925 cases in 2022. The number of cases of urinary tract infections increased from 2076 to 5436 between 2018 and 2022. The number of depression cases in the same area increased considerably, from 15 in 2018 to 61 in 2022. In that region, just one female was reported to have breast cancer in 2018, but by 2022, there were four cases. Figure 12 exhibits the different waterborne Diseases.

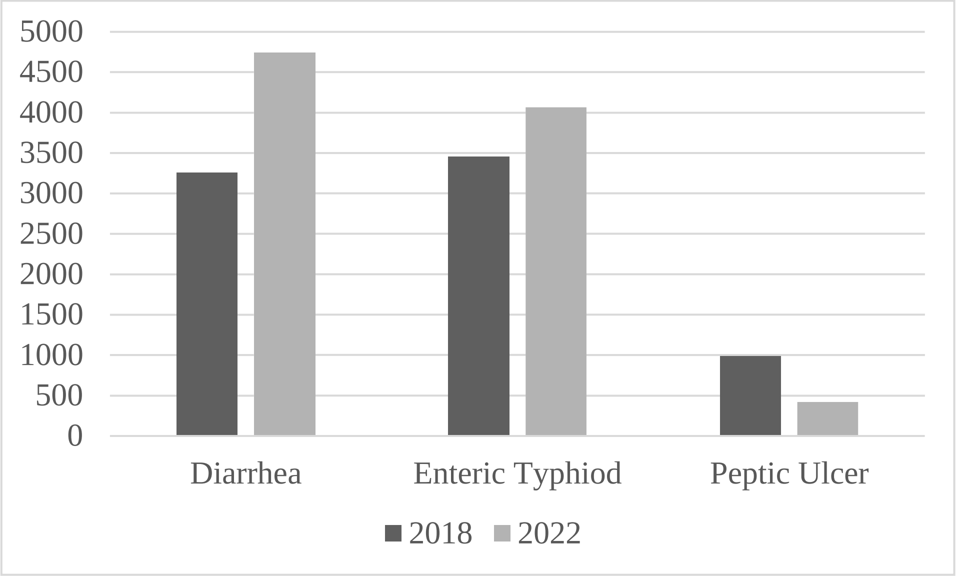


Figure 7. Showing the number of patients with Gastro Intestinal diseases.

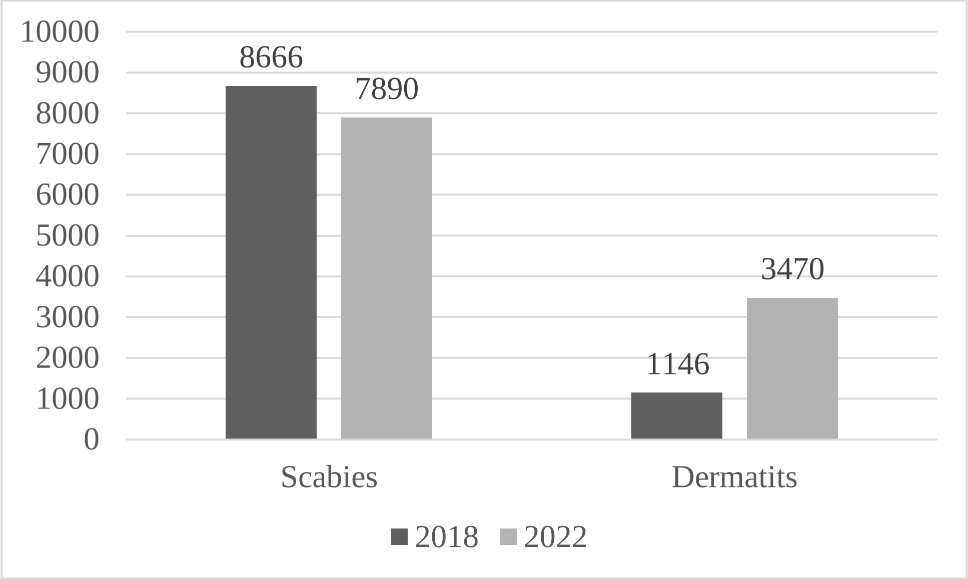


Figure 8. Displaying the number of patients with skin diseases.

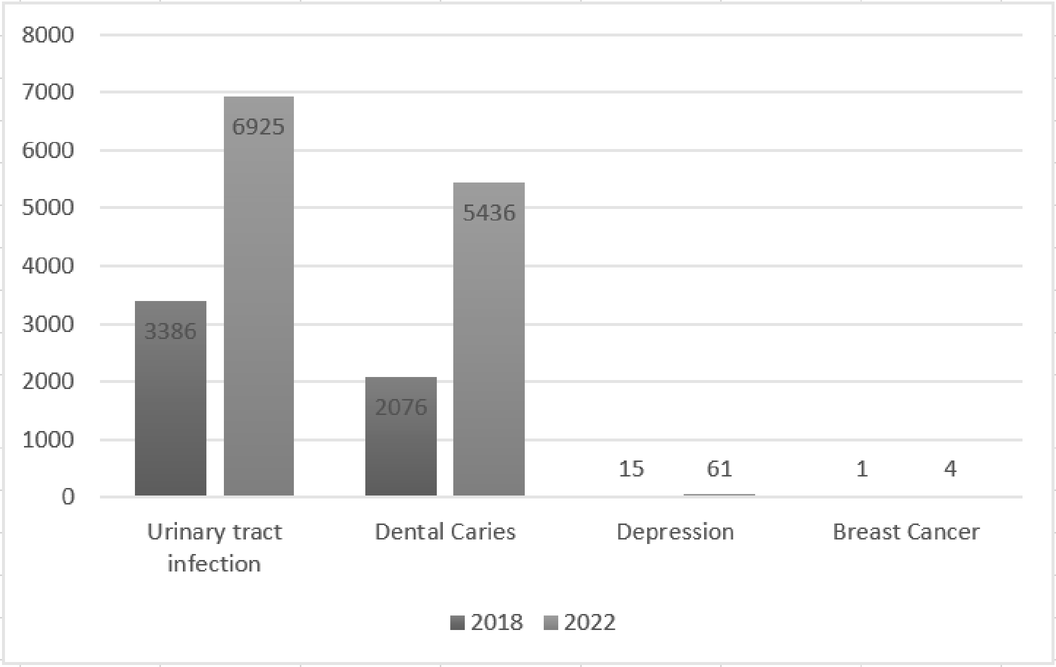


Figure 9. Exhibiting the different water borne diseases.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

For groundwater to remain a precious asset for agricultural use and human consumption in the future, its quality must be monitored. It is common practice to assess the physicochemical characteristics of groundwater to determine whether it's suitable for irrigation and consumption. A water quality index was used in the district of Sialkot to evaluate the quality of groundwater in locations close to active industries, and it was successful in evaluating the overall quality of the water. The study's conclusions showed that the majority of the water quality measures exceeded the World Health Organization's maximum allowed levels (WHO). The Sialkot district's groundwater was of poor quality and unfit for drinking, according to the water quality index (WQI). The study's findings can be summarized by saying that the water quality index (WQI) is an important instrument for fully comprehending the quality of groundwater. The general public and the legal authorities can use this information to plan and conduct management policies aimed at protecting this important resource for future usage. A considerable portion of the groundwater utilized for drinking in the research region is found to be polluted with heavy metals, according to the results of groundwater sample analysis and questionnaire survey. Also, because of their high turbidity, total dissolved solids, electrical conductivity, pH, and high levels of heavy metals including lead, chromium, and arsenic, several samples were considered unfit for human consumption. The majority of groundwater collected from boreholes nowadays is unfit for human consumption. The drinking water quality in the study region has degraded to an alarming degree. The accumulation of heavy metals in the groundwater, which has resulted in waterborne illnesses among locals, is thought to be caused by the discharge of industrial effluents from a variety of companies, particularly those lacking treatment facilities.

4.2 Recommendations

The study emphasizes how essential it is to solve the problem of groundwater pollution with heavy metals. This issue might affect the availability of clean drinking water for people if it is not resolved. The results show that there is a need for urgent actions by local authorities and they must raise environmental awareness, adopt regulations, and manage pollution sites. To reduce industrial water pollution, pollution control rules must be strictly enforced, and due measures must be implemented to stop untreated effluents from being dumped close to industrial locations. Comprehensive analysis is necessary due to the region's high concentration of heavy metals and other dangerous elements in groundwater quality, particularly in Sialkot City.

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APPENDICES

Appendix – 1 . Details of Sample points while Surveying

S.no	**Lat**	**Long**	**pH**	**EC**	**TDS**	**Turbidity**	**As**	**Cr**	**Pb**	**WQI**
1	32.34342	74.52348	7.22	1406	501	6	0.01	0.05	0.01	83.83889
2	32.48445	74.51739	5.96	1609	602	1.44	2.89	3.92	0.06	22495.45
3	32.4848	74.51903	7.2	1200	387	1.18	0	0.2	0	15.39635
4	32.48489	74.51935	6.14	1676	315.64	2.09	0.01	0.31	0.09	128.2656
5	32.485	74.51973	7.45	702	365.04	0.73	0	0.05	0.01	6.956909
6	32.48558	74.51937	8.12	1601	383.76	0.91	0.01	0.03	0.02	85.46981
7	32.48548	74.51893	9.13	582	302.54	0.22	0.05	0.4	0.05	429.8465
8	32.48547	74.51589	6.3	195	147.68	0.18	0	1.31	0.03	109.7808
9	32.48536	74.51809	6.2	1643	276.12	0.01	0.01	2.54	1.65	778.0394
10	32.48526	74.51812	6.29	1036	538.72	0.01	0	1.15	0.05	103.5508
11	32.48523	74.5176	7.51	386	200.72	0.71	0.01	0.06	0	81.39128
12	32.48521	74.51728	6.5	522	271.44	1.32	1.48	0.07	0.02	11368.16
13	32.48522	74.51739	6.63	629	327.08	1.6	1.58	0.06	0.01	12131.68
14	32.48514	74.5169	6.77	1104	574.08	1.59	1.51	0.08	0	11593.01
15	32.485	74.51639	6	234	234	10.5	1.73	1	1.34	13763.28
16	32.48488	74.51544	6.5	379	197.08	1.6	0.67	0.02	0.01	5145.805
17	32.48479	74.51547	5.9	235	304.72	1.18	4.11	3.99	3.12	32801.46
18	32.48466	74.51492	6.23	1608	319.28	0.5	1.53	1.65	0.07	11888.37
19	32.48475	74.5148	6.71	487	253.24	0.01	0.94	0.03	0.01	7218.352
20	32.4847	74.51481	7.29	660	343.2	1.9376	0.88	0.4	0.06	6801.78
21	32.48636	74.51936	5.5	208	217.88	1.49	3.76	3.05	2.43	29831.84
22	32.48592	74.51656	5.3	205	244.92	1.12	1.49	2.56	0.02	11635.88

S.no	**Lat**	**Long**	**pH**	**EC**	**TDS**	**Turbidity**	**As**	**Cr**	**Pb**	**WQI**
23	32.48573	74.51617	7.31	490	254.8	2.23	1.74	0.84	0.08	13440.82
24	32.48611	74.51461	7.57	494	256.88	2.75	0.96	0.03	0.02	7375.027
25	32.48646	74.51465	5.53	200	336.44	1.6	4.76	3.78	1.56	37294.22
26	32.48655	74.51461	5.32	195	277.16	0.71	4.98	2.65	2.13	39070.58
27	32.48638	74.5137	6.92	700	364	0.91	0.01	0.05	0.01	83.66484
28	32.48648	74.51366	7.18	610	317.2	2.23	0.76	0.04	0.02	5841.073
29	32.48591	74.51254	7.11	1094	568.88	0.55	0.79	0.2	0.05	6092.706
30	32.48516	74.51253	6.43	640	332.8	0.24	0.25	0.5	0.05	1972.038
31	32.48481	74.51266	6.96	1252	651.04	0.65	0.79	0.06	0.01	6069.681
32	32.4845	74.51259	5.3	245	306.28	10.3	4.35	1.23	3.94	34683.22
33	32.48403	74.51329	5.84	231	332.28	1.34	1.74	1.76	0.04	13499.04
34	32.48411	74.51301	7.38	729	379.08	0.45	0.01	0.01	0.01	80.6085
35	32.48645	74.51304	7	1055	548.6	0.33	1.64	0.02	0	12585.92