GROUNDWATER CHEMISTRY AND MODELING OF AQUIFER DEPTH IN ISLAMABAD

BY

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APPROVAL OF EXAMINATION

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DEDICATION

I dedicate this thesis to my beloved parents and respectable teachers whose prayer and guidance has always been wheels for me that has always helped me to travel in this competitive era.

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.

ABSTRACT

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The present research in the Islamabad region involved the collecting and examination of 37 water samples from borewells for a variety of physical and chemical properties in order to map and evaluate the quality of groundwater for drinking purposes. Alongside this study, aquifer depth modeling was carried out to shed light on possible approaches to obtaining cleaner groundwater supplies. The goal of the project is to help build a sustainable and safe water supply for the people of Islamabad by integrating various approaches. In addition, a Water Quality Index (WQI) was computed using sample percentages classified as Excellent Water (5.41%), Good Water (86.49%), and Poor Water (8.11%) in order to measure overall water quality based on WHO recommendations. Through the use of IDW (Inverse Distance Weighted) interpolation and Geographic Information System (GIS) techniques, the aquifer depth model produced a spatially continuous representation that ranged from 25 feet to 399 feet, exposing notable differences in aquifer depth throughout the research area. In contrast to areas of deeper depths suggestive of restricted groundwater availability, the model highlights areas of shallower depths associated with enhanced groundwater accessibility and recharge potential. These results provide insightful information for the region's resource planning and groundwater management programs.

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INTRODUCTION

1.1 Background

Due to the constantly rising demand for water, the growing global problem of water shortage is becoming more urgent. The acute scarcity of domestic water in urban areas exacerbates the severity of the problem by creating a larger disparity between supply and demand. The issue of managing water resources sustainably is made more difficult by variables such population growth, a high number of migrants seeking employment from rural regions, insufficient surface water supplies, groundwater depletion, and climate variability (Khan et al., 2021). According to projections, Pakistan's 25 largest cities' current water demand (3.2 MAF) is expected to rise by around 1.5 times by 2030 and reach 7.0 MAF by 2050 (Basharat, 2019; Khan et al., 2021). Furthermore, by 2030, the industrial water demand is predicted to increase under the current scenario.

Groundwater is the most significant water resource in the planet (Tirkey et al, 2013). It provides more than 80% of the world's usable water storage and is crucial for industrial, municipal, and agricultural uses—especially in areas lacking access to alternate water sources. In 2012, Shirazi et al. Since groundwater is the world's principal supply of drinking water, both its quantity and quality are crucial. Rahman (2008) said. Nearly two billion people depend on groundwater for their daily needs, according to Kemper (2004). Groundwater is an important source of water because it is less vulnerable to pollution than surface water (EPA, 1985).

The majority of Islamabad's water supply is managed by the Capital Development Authority (CDA) through the Simly and Khanpur Dams, while about 30% of the city's groundwater supply comes from 190 tubewells located in certain districts. Both governmental and private wells are used to supply water to the capital city. The peak water supply of about 141 million cubic meters (85 million gallons/day) is insufficient to meet the water demand of approximately 407 million

MCM. Currently, 110 MCM (66 MGD) is used for water supply in urban areas, The peak water is about 141 million cubic meters (85 million gal/day) Not enough to meet the water demand in urban areas about 407 million. The latest census conducted by MCM Pakistan Bureau of Statistics shows that the population of the capital Islamabad will increase by 101 million in 2017 to 11.08 billion in 2023, a growth of approximately 159% (PBS 2023). On the other hand, the availability of water resources the target remains the same because there is no existing storage capacity, or the new storage plan. Current conditions are expected to widen the gap between water supply and demand.

Demand for the limited groundwater resources has been steadily rising as a result of a shortage of surface water supplies. Certain industries depend only on the already limited availability of groundwater. In the area of the Margalla highlands, the water table is shallow; the DTW (Depth to Water) rises with descent, especially in sections I-8, I-9, and I-10.

About 30 kilometers from Islamabad, the Rawal Dam supplies the majority of the city's water needs. The dam gathers about 60% water comes from the melting of Himalayan Glaciers while 30 to 40 % from the precipitation and provides the city with a place to store water (Abbas et al., 2015). The Rawal Water Treatment Plant treats the water from the Rawal Dam before supplying it to the city. The treatment plant removes bacteria, silt, and other contaminants from the water (Basharat, 2019).

The sewage of the city is managed by the Islamabad Sewage Treatment Plant. At the treatment facility, solids, bacteria, and other contaminants are removed from the wastewater. The treated wastewater is then discharged into the Rawal River (Azizullah et al., 2011).

Groundwater is relevant worldwide because of its several benefits, which include river quality, base flow regulation, ecological support, and, most crucially, human consumption. Because of numerous ion exchange, filtration, and aerobic decomposition processes that occur naturally in the soil column, it has been considered a cleaner type of water than surface water. This is among the factors contributing to the overuse and exploitation of this natural resource in rural and semi-rural areas across the globe.

Groundwater is a vulnerable and important water source for agricultural and drinking purposes, so it is important to manage it carefully to maintain purity within specified limits. Before the development of geographic information systems (GIS), groundwater assessment was conducted through laboratory experiments, but integrating various databases has become incredibly easy. GIS can be useful in finding answers for problems with water resources, such as managing water resources locally or regionally, evaluating water quality, and figuring out availability. When groundwater quality is evaluated by GIS-enabled mapping of pollutant distribution, water quality index (WQI) studies, and the associated data on water quality, policy makers may find it useful to implement remedial measures.

Utilizing a variety of water quality metrics, the water quality index is intended for drinking or irrigation and provides an overall water quality rating at a given location and time in the form of a single number, akin to a grade (Yogendra and Puttaiah, 2003). Its main objective is to simplify and make useful information out of complex data on water quality. These indices are regarded as some of the simplest methods for conducting an overall evaluation of water quality and as some of the most effective means of informing the public, relevant authorities, or decision-makers about water quality management. A water quality index (WQI) can also be defined as a rating that shows how various water quality metrics work together to affect the overall quality of the water. The ability of this quality index to easily and consistently condense a large amount of data on chemical, physical, and biological aspects into a single number is its main advantage (Dahan et al., 2009). It is true that water quality index (WQI) has been used all over the world to assess the water quality of various bodies of water (Rishnaiah et al., 2009).

1.2 Water Quality of Pakistan

For drinking purposes, surface and groundwater supplies close to canals and rivers provide the majority of the water Untreated industrial waste and agricultural and urban runoff enter water bodies, degrading surface water quality.

At the peak of the river's water flow, high solid suspension is required. The majority of rivers have been diluted and widened, and marine life is barely surviving. It is clear that these waterways are contaminated with faeces and require cautious treatment to remove toxins before being used by humans. Four of Pakistan's largest cities—Islamabad, Karachi, Hyderabad, and Rawalpindi—have utilized surface water.

About 70% of drinking water comes from aquifers. Groundwater quality is deteriorating due to excessive pumping and mixing of fresh and saline water. In Pakistan, groundwater quality is poor further away from major rivers, while fresh water is available nearby. The quality of drinking water is affected by the condition of the water supply network, the efficiency and level of treatment, and the quality of the water source . This kind of water is what people are compelled to drink in most of Pakistan, where groundwater is salinized and freshwater is scarce. The most annoying problem is the microbiological contamination of the water.Urban drinking water supplies regularly fail to meet WHO regulations. Sewer and drinking water supply lines mixing is primarily caused by microbial contamination. Surface water in most rural regions of Pakistan is utilized for drinking after being gradually filtered through sand; the water is not chlorinated by filtration systems. For water filtration, initial treatment services are typically not necessary in rural areas. Microbial contamination and low water quality are the root causes of all of this deficiency. According to Daud et al. (2017), wells and hand pumps are not protected against flooding and surface runoff.

1.3 Literature Review

Fecal pollution in Islamabad's natural streams has gotten worse because of a lack of adequate municipal waste facilities, especially in semi-urban regions, according to a study analyzing the water quality assessment of the city's natural streams. The extent of fecal pollution in semi-urban areas is so great that treatment is necessary. Higher bacterial concentrations are largely caused by surface runoff, increased nutrient accumulation, and industrial waste in urban areas. Fecal contamination has two main causes, which are now known to be anthropogenic and natural. Before it is sufficiently treated, high levels of fecal waste render water unfit for human consumption.

The water quality is decreasing at every location under consideration for a number of reasons, according to earlier studies on the Korang River Surface Water Quality Assessment. Farming, soil erosion, the disposal of solid waste, livestock waste, domestic water consumption, and site discharge without pre-treatment are among the most prevalent anthropogenic activities. To increase pollution, sample sites near populous areas such as Rawal Lake and the Angoori road have to be selected; in June, this load is larger than in April. June has more trash because there are more people around, summer heat, and a large number of people go to Murree Hills, the area that collects rainfall for each sampling site. Because of recreational activities near the test locations, the surface water source is significantly polluted. In all regions except WASA filtration, most standards are within acceptable ranges compared to USEPA, Pakistan Environmental Protection Agency and WHO requirements, except for COD, DO, TA, TSS and metals such as cadmium and lead. Plants that cannot be used for drinking purposes (Ali et al., 2015).

Even when the permissible quality criteria are met, the quantity of pollutants in Pakistani drinking water is increasing, making it unsafe for human consumption. WHO (World Health Organization) guidelines and limitations are contributing to an increase in the content of heavy metals. The most prevalent heavy metals are arsenic, chromium, iron, cadmium, and nickel. In some places, nitrates and fluoride are also dangerous; in some, fluoride levels are extremely high, while in others, they are very low. One major cause of water contamination is untreated industrial waste and uncontrolled urban garbage. Methods of disinfecting water, such chlorination, are either nonexistent or inefficient. Serious problems relating to people result from this.

Waterborne disease is the main worry brought on by chemical and bacterial contamination of public drinking water. The shortage of diagnostic technology and an inadequate database of water-related illnesses have resulted in an incomplete knowledge of these conditions, which has led to poor management (Riaz and Hashmi, 2019).

An analysis of the physical, chemical, and microbiological characteristics of the water in Rawal Lake revealed that all physical characteristics were within permissible bounds, with the exception of turbidity levels, which were caused by suspended materials such silt clay and finely split organic and inorganic waste. Although some heavy metals, including lead, cadmium, potassium, and others, were discovered, their quantities were extremely low. Some have fallen short of quantifiable cutoff points. The majority of trace elements, however, fall inside the WHO's permitted range. Furthermore, coliform bacteria were discovered in extremely significant amounts. The discharge of raw water into Lake Rawal is the source of coliform bacteria. Due to the lack of trees and other vegetation, the Korang River brings a large amount of sediments into the lake, which speeds up the weathering and erosion process.

Water samples taken from several parts of Rawal Lake and its source inlets have high levels of bacterial contamination, making the water unfit for human consumption and potentially harmful to health. Thus, by putting the pollution reduction management plan into practice, water might be rendered cleaner for drinking and other purposes.

The sources of lake water have far greater emission levels when it comes to environmental pollutants and heavy metals. On the other hand, almost every physical characteristic in the middle of the lake was below the permitted limits, which are very high in the source streams. Thus, one may claim that the middle of the lake has less pollution than the sources, which have seen more anthropogenic interference (Karakoç et al., 2003).

Feces are the primary and largest contaminant that is combined with drinking water as a result of insufficient drainage and sewerage systems. This was considered in a study that assessed the state of drinking water quality and pollution studies conducted in Pakistan. The second cause of contamination is hazardous chemical waste from industrial effluent, pesticides, nitrogen fertilizers, textile colorants, arsenic, and other substances. Existing treatment plants must continue to undergo routine inspections, which must be updated. At present, the government of Pakistan is constructing filters that can purify water. The findings have demonstrated how important it is to treat drinking water sewage contamination as a major environmental and public health concern (Daud et al., 2017).

1.4 Surface Geology

The study area is located in the Potwar plateau of Pakistan. In the north and northeast, it is bounded by the Margalla and Murree hills, which are covered with mixed scrub and coniferous forest. The dominant formations (e.g., the Murree and Kamlial belonging to the Rawalpindi Group of Miocene age) are composed of sandstone, shale, and lenses of conglomerates.

1.5 Hydrology of Islamabad

In the 1960s, Pakistan's capital, Islamabad, was designed and built as an entirely new metropolis. It is a truly unpredictable landscape. The capital has an area of 906 km² with an average altitude of 500-700 m above sea level. The region, with a maximum height of about 1,493 meters, is situated in the foothills of the Margalla Hills, which form Islamabad City's northern border. The southern section has a mild slope as it rises to the Margalla piedmont (Sheikh et al., 2008). The majority of the alluvial deposits that blanket the piedmont region are believed to have been washed out of the Margalla highlands, giving rise to a terrain with numerous valleys and slopes.

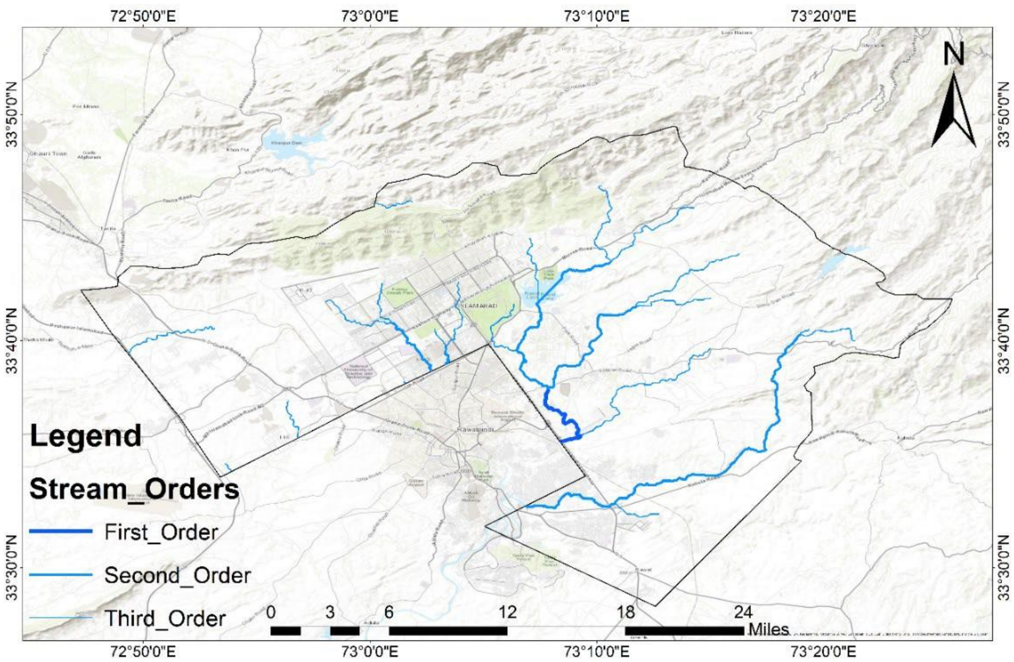


Figure 1. 1 Surface Hydrology map of Islamabad

Being a part of the Potohar plateau, Islamabad has an extremely complicated hydrogeology. Seepage from natural streams and precipitation infiltration at shallow depths are restricted by the prevalence of clay/shale lithology. It is highly unusual to find sand everywhere. Groundwater is found in the varying-thickness layers of gravel and/or boulders and the alternating bedding of shale and clay. This indicates that the Islamabad aquifer is composed of several strata. It gets natural recharge at the foot of the Margalla hills mostly from precipitation, which gives groundwater to the downstream lowlands.

1.6 Objectives of the Study

The following research goals are being pursued by this study:

- Analyze the spatial distribution of main ion and trace element contamination in groundwater.
- Using geospatial techniques and geochemical markers, identify and chart potential pollution sources.
- Develop a hydrogeological model to ascertain the aquifer's depth.

Chapter 2

MATERIALS AND METHODS

2.1 Study Area

Islamabad, the capital of the Islamic Republic of Pakistan lies in the square of 73° 39′ 20.9747″E 33° 51′ 15.7632″N, 73° 39′ 20.9747″E 33° 29′ 14.4005″N, 72° 47′ 14.4152″E 33° 29′ 14.4005″N and 72° 47′ 14.4152″E 33° 51′ 15.7632″N. UN World Urbanization Prospects (2018) states that the population was 40,000 in 1950, 110,000 in 1995, 678,000 in 2005, 1.095 million in 2018, and is projected to grow to 1.67 million by 2030. The urban agglomeration of Islamabad is covered by these data, which typically includes both the population of the city and the neighboring suburbs. As "unique" examples of big new metropolises that are "planned for the future and built for the present," the city complies fully with long-term planning, according to Frantzeskakis et al. (2009). It is located between 400 and 650 meters above sea level, with an approximate area of 906 km^3. Zones I through V represent the various residential sectors that make up the study area. Seasons include winter (November to February), spring (March to April), summer (May to June), monsoon (July to August), and fall (September to October). Most of the time, the climate is humid subtropical (Naeem et al., 2018). With a record high temperature of 46.5°C reached in 2005, June is the warmest month in Islamabad. In 2010, the maximum temperature reached above 40°C for four days in a row. The summer months of 2018 saw temperatures between 30 to 44°C, according to records, nevertheless. Between 1993 and 2012, there were eleven days with temperatures above 44°C. According to Butt et al. (2015), the geology is made up of limestone, tertiary sandstone, and a few alluvial deposits. The research area is indicated geographically in Figure 2.2.

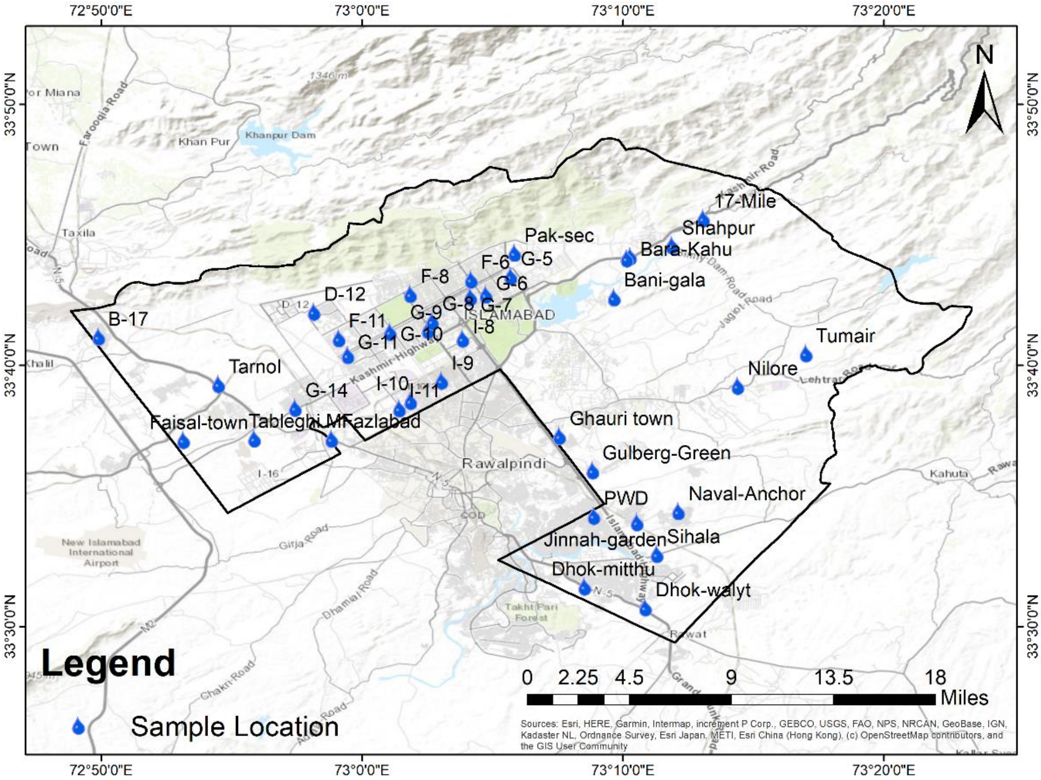


Figure 2. 1 Map showing sample locations.

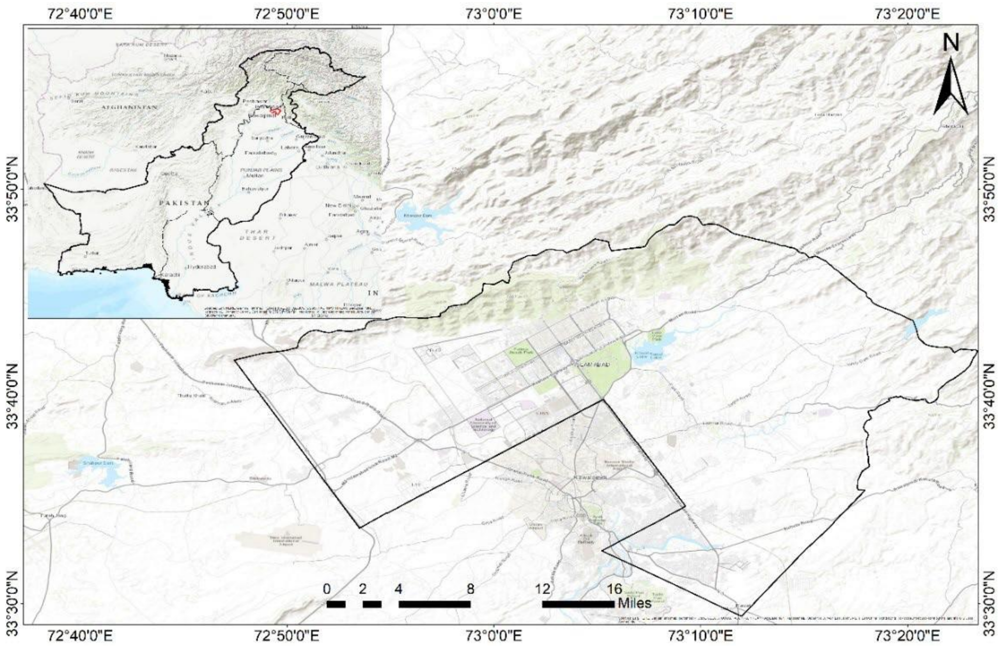


Figure 2. 2 Geographical Location of Islamabad

2.2 Tectonics and Geology of study area

With an extensive variety of rock formations and geological characteristics, Islamabad has a complex and varied geological foundation. The

Potohar Plateau, where the city is situated, is a region of folded and fractured rocks. The range of mountains known as the Margala Hills runs along the northern border of Islamabad and is the most notable geographical feature in the city. Sedimentary rocks that were deposited millions of years ago in a marine environment make up the Margala Hills (Afzal et al., 2023; Sheikh et al., 2008; Saleema et al., 2023).

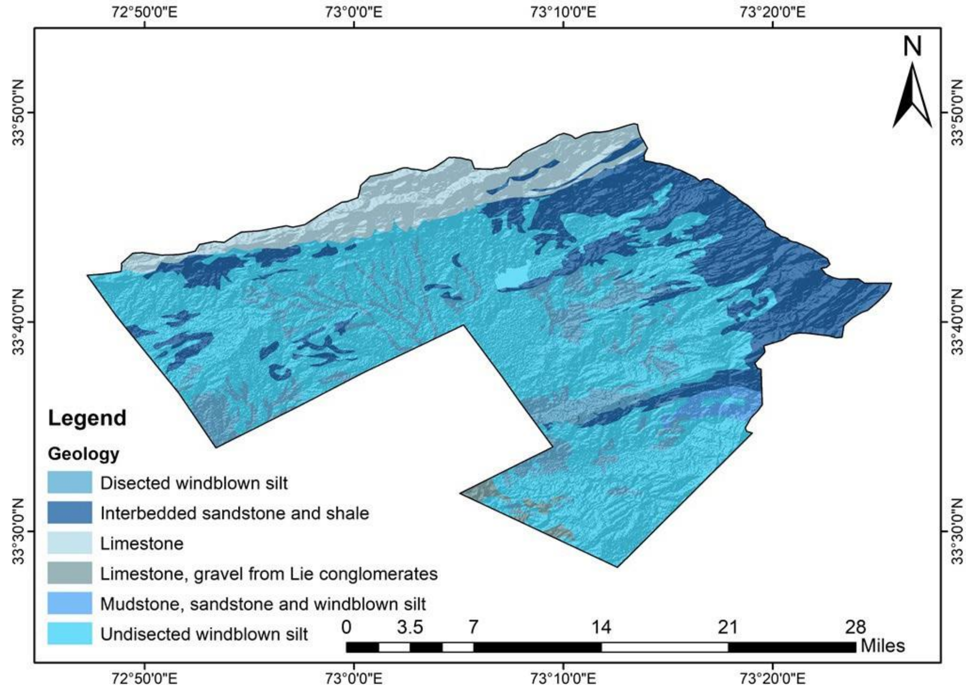


Figure 2. 3 Surface Geology of Islamabad Digitized after Khan et al. (2021)

2.3 Paleogeography of Indian and Eurasians plate throughout geological scale

The Indo-Eurasian collision has had a substantial impact on the geology of the Eastern Himalayas. The impact continued to cause earthquakes and mountain uplift, resulting in the creation of the Himalayas and Tibetan Plateau. Although the Himalayas' uplift may have had an indirect effect on the Abor Volcanics' creation, the collision did not directly affect their formation (Ali et al., 2012; Bhattacharya and Yatheesh, 2015; Searle, 2019).

2.4 Sample Collection

For physical and chemical investigation, a total of 37 samples, specifically from well-bores, were gathered from various places throughout Islamabad. Following the APHA (1995) recommended procedures for grab (or) catch samples, samples were collected for analysis in sterile vials. The methods outlined in APHA (1992) were used to analyze a variety of physical and chemical parameters, including pH, temperature, total hardness, alkalinity, chloride, sulphate, nitrate, TDS, and others. Analytical grade reagents and chemicals were all utilized. The solutions were prepared using D.D (Double-distilled) water.

2.4 Methodology

Analysis of samples are followed by sample collection then laboratory work.
After collection of samples, two parameters were measured in laboratory:

1. Physical
2. Chemical

2.4.1 Analysis of physical parameters

Ph, EC, TDS, Salts and Temperature are the Physical parameters for the potential of Groundwater contaminations.

Instruments Used:

Beaker

Graduated cylinder

Multiparameter tester

Chemicals used:

Distilled water

Water sample

2.4.1.1 Procedure

Prior to using the sample, a standard was used to calibrate the multimeter. A 50 ml water sample was measured in a graduated cylinder, put into a beaker, and the multimeter was dipped in it. It provides the value of each physical parameter, and each value was recorded after a minute.

2.4.2 Turbidity

Instruments:

Beaker

Graduated cylinder

Turbidity meter

Chemical used:

Distilled Water

Water Sample

2.4.2.1 Procedure

A 10 ml sample was obtained and placed in the included 10 ml bottle with cap. Subsequently, the bottle was inserted into the turbidity meter, and light was allowed to pass through the sample by pressing the Test/CAL button. A light beam directed at the sample was scattered by the suspended particles in the water. Instruments are then used to measure the scattered light at different angles from the incidence path, and the results are recorded.

2.4.3 Analysis of Chemical parameters

A water sample is used for various tests to determine the concentration of various ions and compounds in the sample. such as the carbonate, chloride, alkalinity, and hardness tests.

2.4.3.1 Carbonates Test

Instruments Used:

Burrette

Burrette Stand

Dropper

Erlenmeyer flask

Chemicals used:

Hydrochloric acid (HCL 0.1 M)

Methyl orange indicator

Formula used:

$M1v1=m2v2$

M1=molarity of sample

V1=volumes of sample

M2=molarity of HCL

V2=volume of HCL used

2.4.3.1.1 Procedure

Burrettes with 0.1 M hydrochloric acid reagent were used in the carbonate test. An Erlenmeyer flask was filled with ten milliliters of water that had been measured using a graduated cylinder. After titrating, the sample's color changed from orange to pink, pink being the end point—after two drops of methyl orange indicator were applied with the help of a dropper. Three measurements were taken for each sample to allow for human error. This method allows us to calculate the concentrations of Na_2CO_3, $NaHCO_3$, HCO_3, and CO_3 in our water samples.

2.4.3.2 Chloride Test

Instruments Used

Burrette

Burrette Stand

Dropper

Erlenmeyer flask

Chemicals used

Silver nitrate ($AgNO_3$ 0.01 M)

Potassium chromate

Formula used

Chlorides mg/L = v*N*35.54*1000/sample volume

N=Normality of silver nitrate

V=volume of reagent used

2.4.3.2.1 Procedure

A method called Mohr's Method is used to conduct this test. The reagent $AgNO_3$, with a molarity of 0.01 M, was added to the burette. The water sample was measured in the graduated cylinder, containing approximately 10 ml. Three drops of phenolphthalein indicator were then added to the sample in the Erlenmeyer flask with the assistance of a dropper, turning the sample light yellow after it reached its end point, which was a reddish color. To account for human error, each sample was measured three times. We can determine the concentrations of Na, Cl, and Na using this method.

2.4.3.3 Alkalinity Test

Instruments Used

Burrette

Burrette Stand

Dropper

Erlenmeyer flask

Ph meter

Chemicals used

Sulfuric acid ($H2SO4$ 0.02 M)

Phenolphthalein ($C2H1404$)

Formula used

Alkalinity mg/l =N*V*1000/Sample volume

N=normality of sulfuric acid

V=volume of reagent used

2.4.3.3.1 Procedure

In this experiment, a burrete was filled with 0.02 M molar H2SO4 acid. A 50 ml water sample was measured in a graduated cylinder and then added to the beaker. Two drops of methyl orange indicator were then added, and phenolphthalein indicator was used if the water sample's pH was higher than 8.5. After the titration, the water sample's end point was changed from orange to yellow, and it was then poured into the Erlenmeyer flask with indicator. Three measurements were made to account for human error.

2.4.3.4 Hardness Test

Instruments Used

Burrette

Burrette Stand

Beaker

Syringe

Ph meter

Chemicals used

Ethylene Diamine Triacetin Acid (EDTA)

Ammonium chloride

Eriochrome bank (EBT)

Formula used

Total Hardness = A*B*100/sample volume

A=EDTA used for a sample – EDTA used for a blank sample (distilled water)

B=Normality of EDTA

2.4.3.4.1 Procedure

Using a 1 ml syringe, we injected 2 ml of aluminum chloride (NH4Cl) to the 50 ml of distilled water sample that was measured in a graduated flask for this test. Then, we checked the sample's pH with a Ph meter to see if it was greater than or equal to 100. Next, use a dropper to add two drops of EBT, which causes the sample to color red. Its hue changes to blue after titration, marking the conclusion of the process. For each sample of water, the same process is carried out again. From the EDTA used for water samples, the value of the EDTA used for the sample will be deducted.

2.4.3.5 Sulphate Test

Reagents

Barium chloride crystals

24% NaCl solution

1:1 glycerol

mg/ml. sulphate standard solution

2.4.3.5.1 Procedure

Pour 50 milliliters of water sample into a 100-milliliter volumetric flask. Mix with 5 ml of the NaCl solution, 10 ml of the glycerol (1:1), and 80 ml of deionized water to dilute. To dissolve the crystals, add 0.2 g of BaCl and whirl. Dilute to 100 ml. Similarly, fill another flask with 5 ml of a standard sulphate solution (0.1 mg/mL) and carry out the identical procedures. At 425 nm, the absorbance of the sample and the standard are then measured.

2.4.3.6 Nitrate Test

Instrument Used

Uv 4000 spectrophotometer

2.4.3.6.1 Procedure

In order to obtain reliable measurements when analyzing nitrate in water samples with a UV-Vis spectrophotometer such as the UV 4000, the water sample must first be prepared by filtration and, if required, dilution. After that, the spectrophotometer is adjusted to the proper wavelength—typically, between 220-275 nm—for the nitrate assay. To connect absorbance to nitrate concentration, a calibration curve is created using recognized nitrate standards. The calibration curve is used to calculate the nitrate concentration after the sample absorbance is measured. Nitrate in water samples may be accurately and sensitively measured with this method, which is important for determining water quality and any environmental effects.

Chapter 3

RESULTS AND DISCUSSIONS

3.1 Physical Analysis of Water Samples

3.1.1 Ph

The pH of a water sample serves as an indicator for the hydrogen ion concentration. The quality of drinking water is significantly influenced by the intensity of the hydrogen ion concentration (pH). Guidelines for drinking water from the WHO state that the pH value should be between 6.5 and 8.5 (Khan et al., 2013). The results obtained from this investigation fall between 6.73 to 7.83.

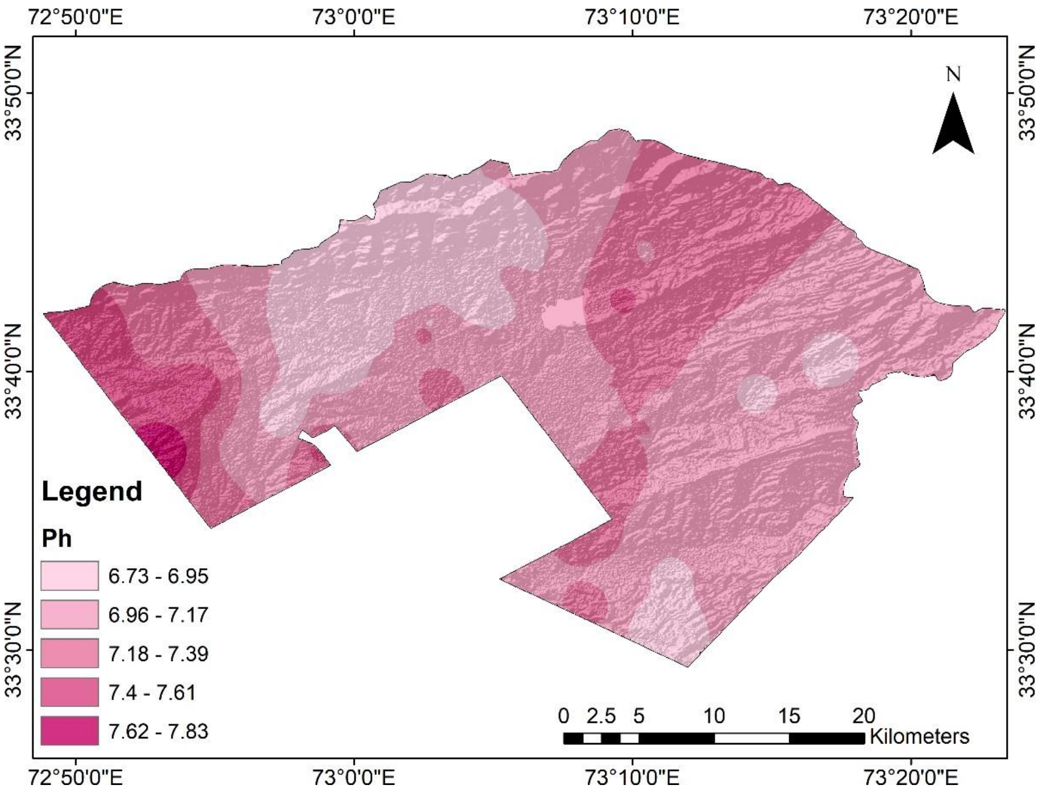


Figure 3. 1 Spatial distribution of Ph in Islamabad

3.1.2 Electrical conductivity:

The electrical conductivity of an electrolyte solution is a measurement of its electrical conductivity. It's a measurement of the ion concentration in water.

Its value serves as a reliable indicator of whether mineral salts are present in the water. There is a clear correlation between conductivity and total dissolved solids (TDS). According to the WHO's recommended value the electrical conductivity in drinking water is 1000(khan et al.,2013). The relationship between conductivity and total dissolved solids *(TDS) is simple.

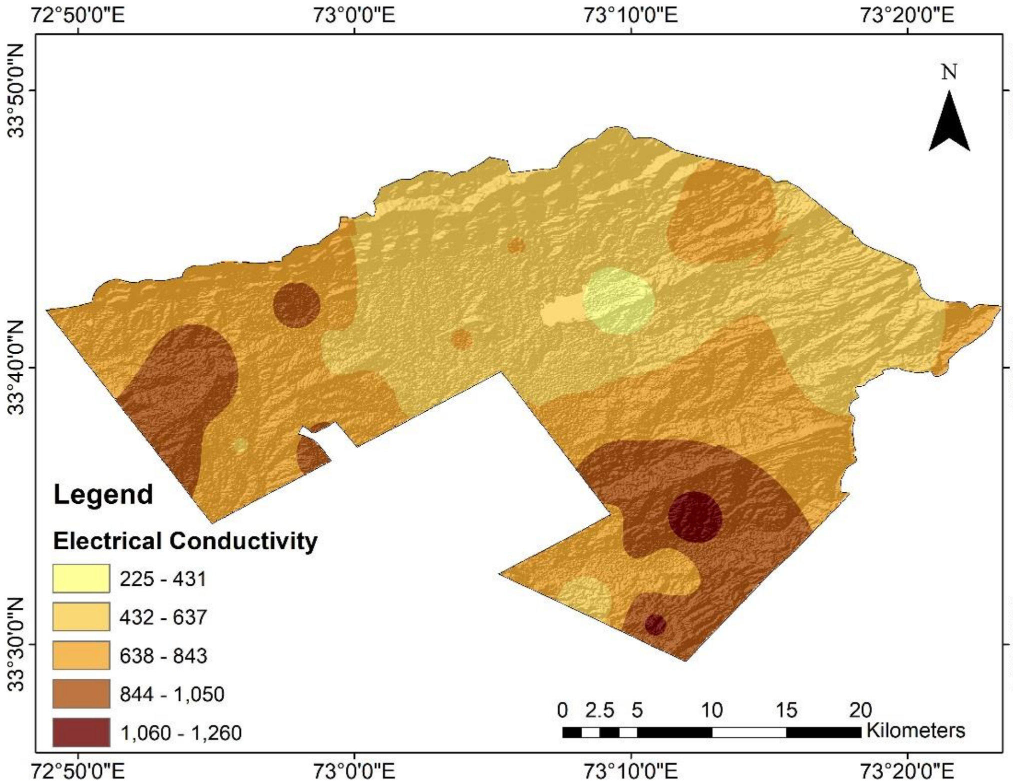


Figure 3. 2 Spatial distribution of Electrical Conductivity in Islamabad

3.1.3Total Dissolved solids (TDS):

An estimate of the inorganic and organic soluble salts in water is given by total dissolved solids. The WHO has recommended a 500 mg/L acceptable level for drinking. (Malikandothers,2000) High TDS values indicate that the water is heavily mineralized. TDS readings from the current investigation varied from 159 to 1080 mg/lt.

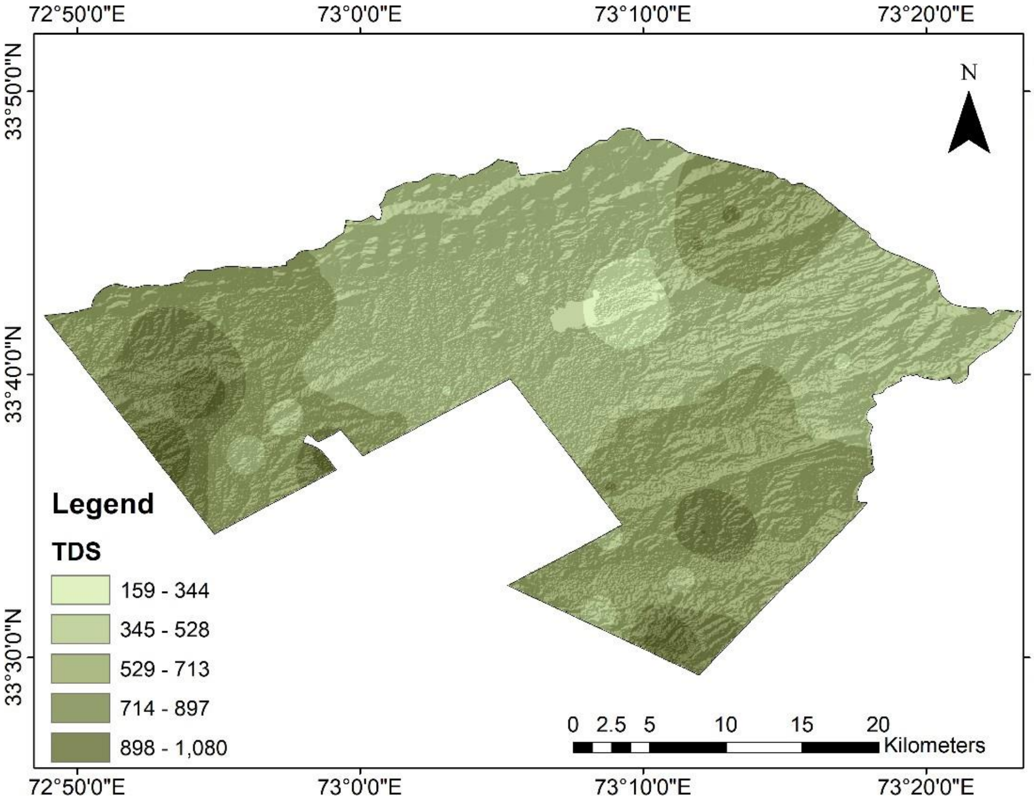


Figure 3. 3 Spatial distribution of Total Dissolved Solvents

3.1.4 Salts:

Carbonates, bicarbonates, chloride, sulfates, phosphates, nitrates, calcium, magnesium, sodium, potassium, iron, manganese, etc. are the main constituents of salts. They might not contain any of the minerals found on the earth's surface, gasses, colloids, or sediments. The dissolved minerals may provide an unfavorable taste or appearance (Malik et al., 2000). The WHO recommends a maximum of 200 mg/L of salt. The current analysis gives a range of 103 to 611.

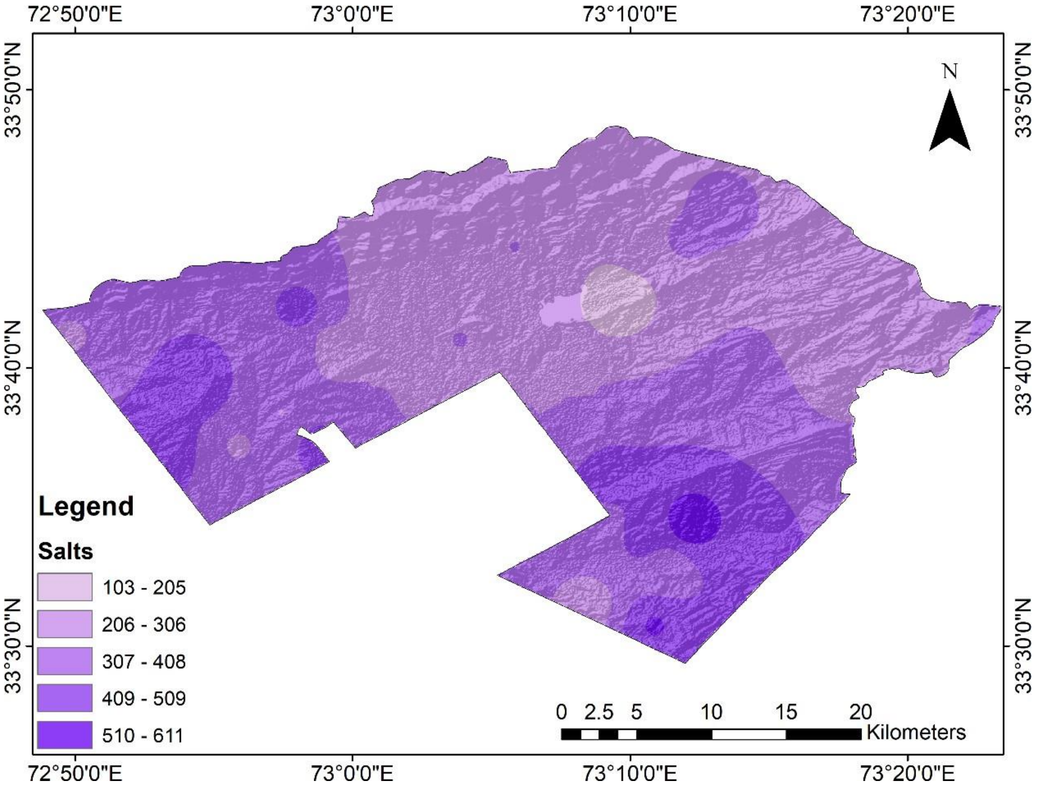


Figure 3. 4 Spatial distribution of salts in groundwater

3.1.5 Temperature:

An indirect indicator of contamination is temperature. An environment suitable for microbial growth exists at high temperatures. The three primary markers of chemical pollution are flavor, color, and dour. Drinking water shouldn't have any taste, color, or smell to it. in compliance with WHO recommendations.

The study's average temperature was 12.0 °C. Natural water undergoes pH variations as a result of industrial pollution and biological activity. Trihalomethanes, which are poisonous, are formed at higher pH levels (Trivedi 1986). The current investigation's pH readings fell between 7.0 and 8.5, which is the range recommended by the ICMR.

3.1.6 Turbidity:

When single suspended particles in water do not settle down quickly and are typically imperceptible to the human eye, the resultant cloudiness or haziness is known as turbidity. It can also result from the development of phytoplankton. People are more likely to suffer from gastrointestinal disorders if their drinking water has a higher turbidity level (Malik et al 2000).

From present study some samples show turbidity value while rest have no turbidity value.

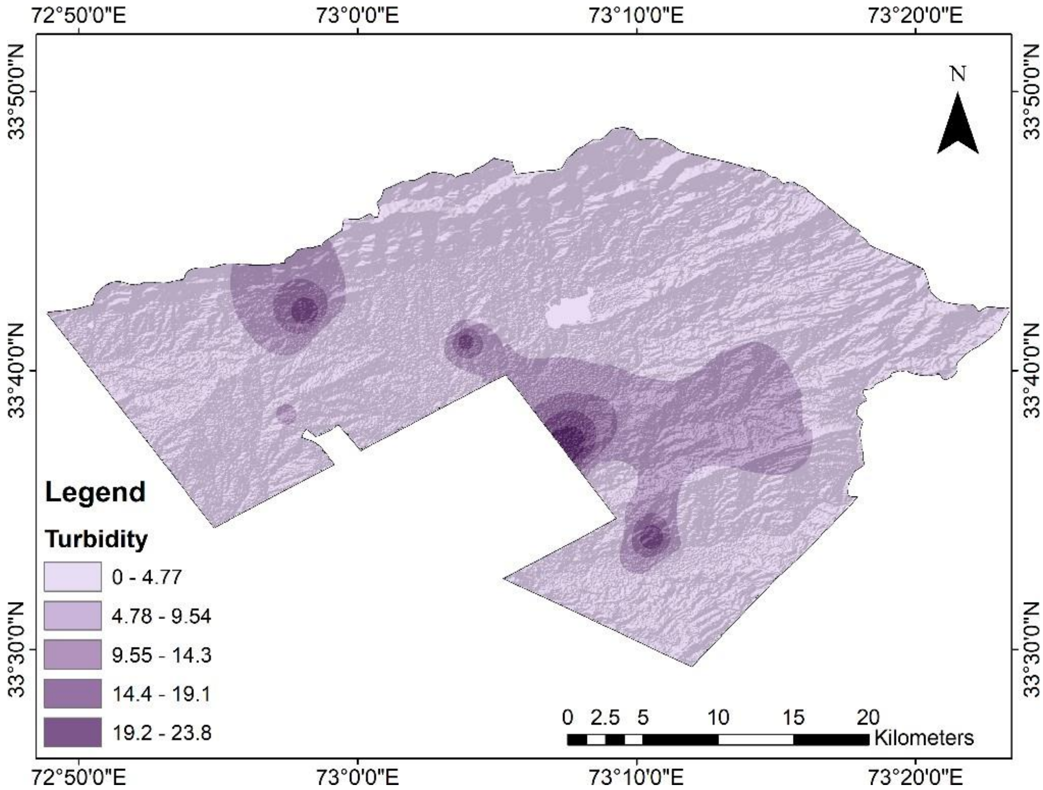


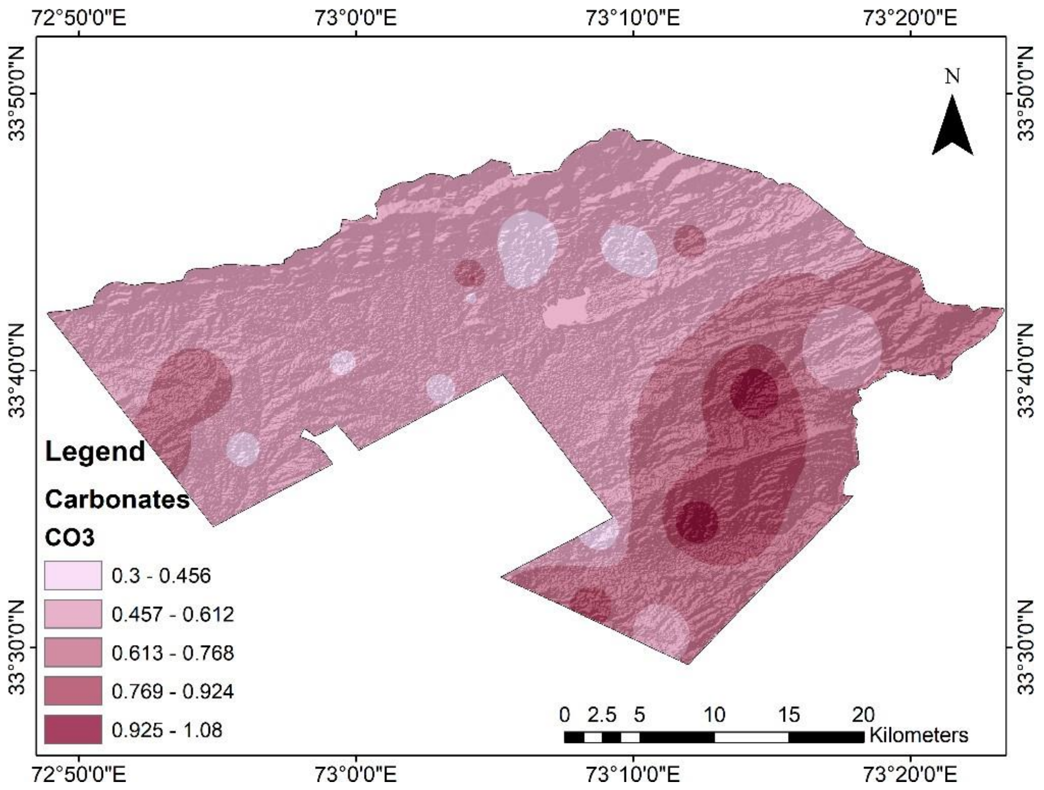
Figure 3. 5 spatial distribution of Turbidity in Groundwater

3.2 Chemical analysis:

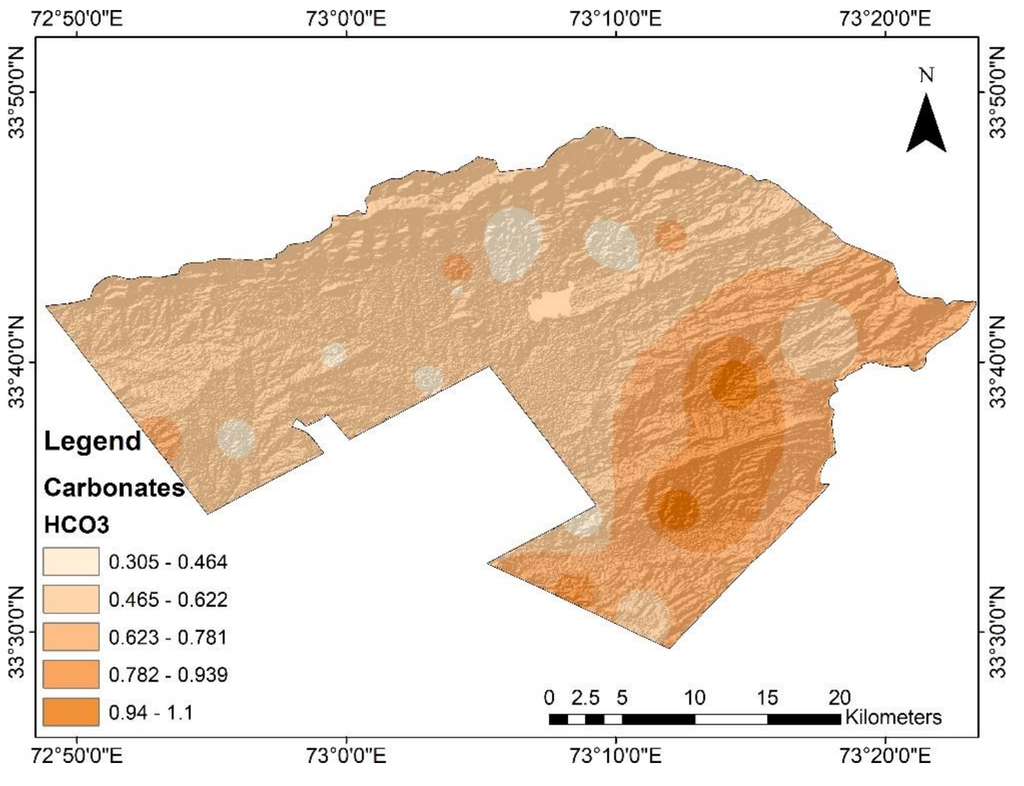
3.2.1 Carbonates:

The presence of carbonate ions (CO2-3) resulting from the dissolution of carbonate minerals defines carbonate as a salt of carbonic acid. The carbonate minerals found in chemically precipitated sedimentary rocks are abundant and widely distributed. Dissolving CO2 in pressured water produces carbonized water (Malik et al., 2000).

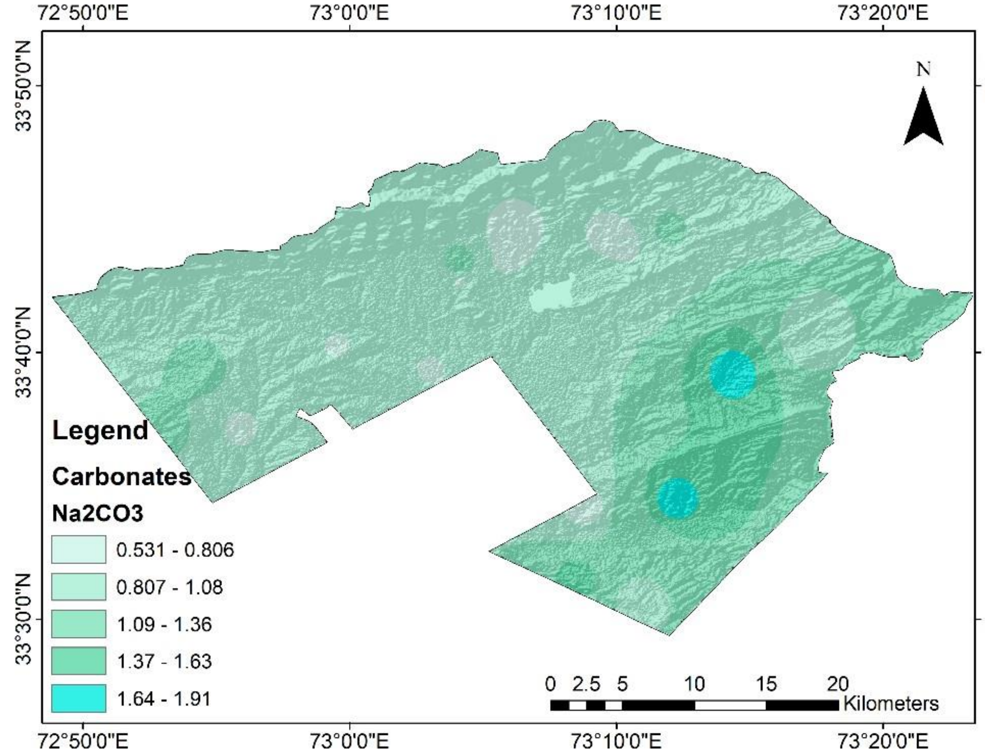
Both surface and subsurface waters contain bicarbonate, an important anion that is often found in concentrations between 25 and 400 ppm. Bicarbonate salts are transported to water sources by the weathering of carbonaceous rocks (Khan et al., 2013).



72°50'0"E
73°0'0"E
73°10'0"E
73°20'0"E
33°50'0"N
33°40'0"N
33°30'0"N
N
Legend
Carbonates
CO3
0.3 - 0.456
0.457 - 0.612
0.613 - 0.768
0.769 - 0.924
0.925 - 1.08
0 2.5 5 10 15 20
Kilometers



72°50'0"E
73°0'0"E
73°10'0"E
73°20'0"E
33°50'0"N
33°40'0"N
33°30'0"N
N
Legend
Carbonates
HCO3
0.305 - 0.464
0.465 - 0.622
0.623 - 0.781
0.782 - 0.939
0.94 - 1.1
0 2.5 5 10 15 20
Kilometers



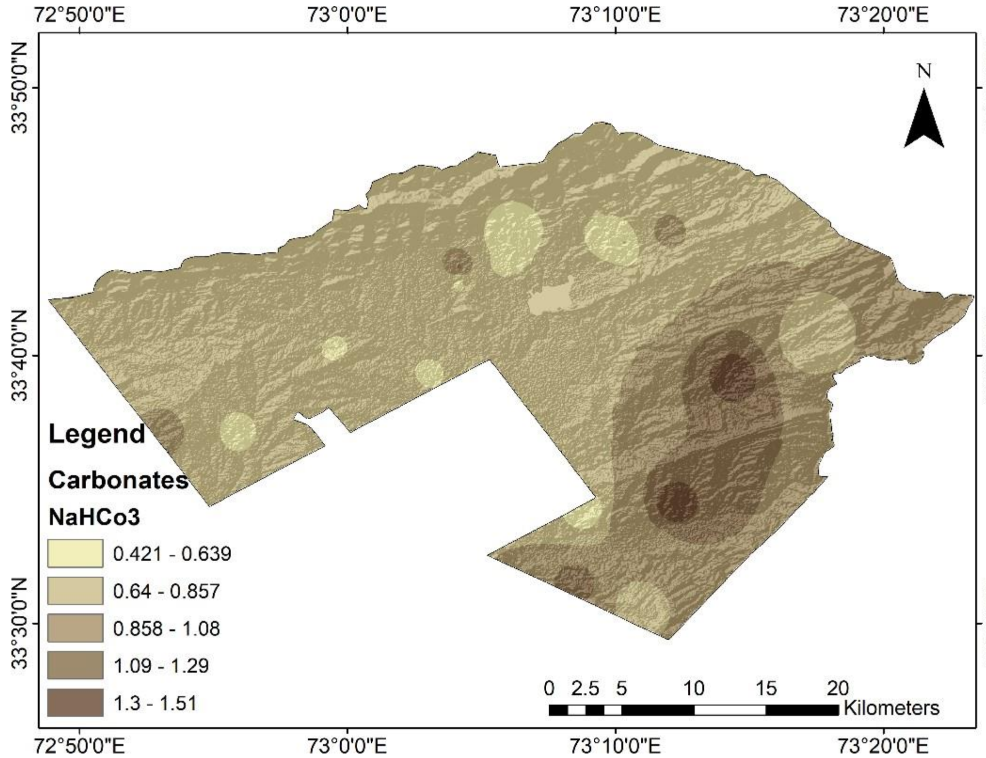


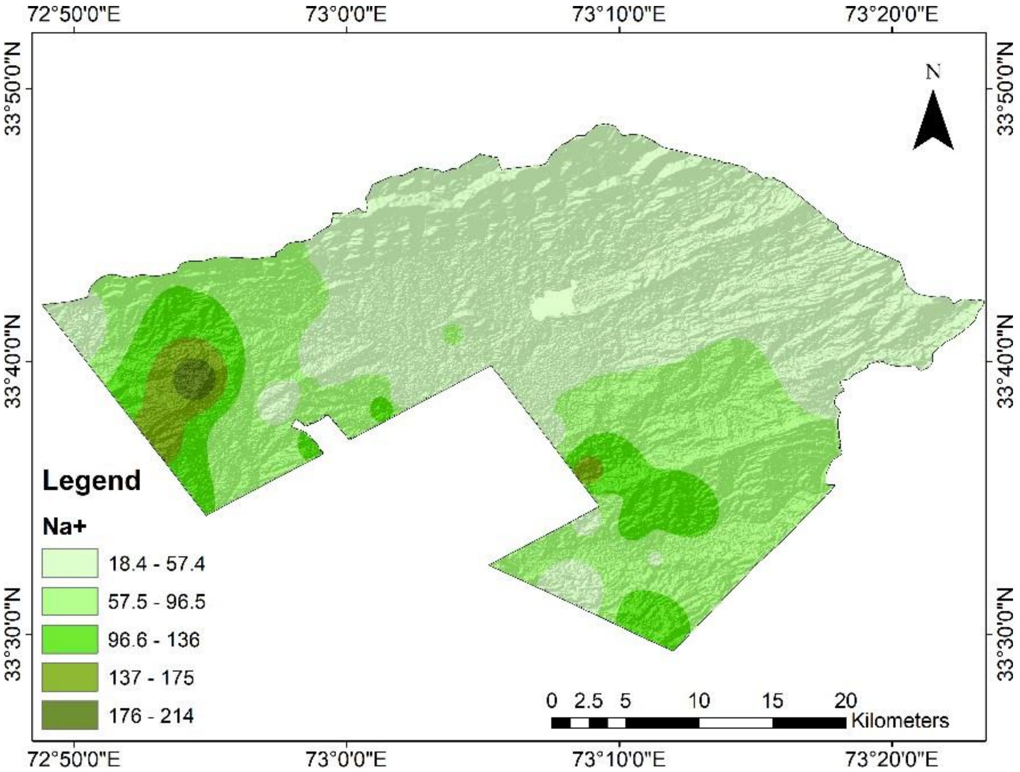
Figure 3. 6 Spatial distribution of (a) CO3 (b) HCO3 (c) NaCO3 (d) NaHCO3 in groundwater

3.2.2 Chlorides:

An anion known as chloride is mostly produced when hydrochloric acid salts from geological formations, such as NaCl, KCI, and CaCl2, dissociate.

Additionally, industrial waste, sewage pollution, and saltwater intrusion all contribute to its addition. Surface water usually has lower levels of chlorine than groundwater does. Chloride is required by the body for metabolism, the process through which food is converted into energy. It also aids in the preservation of the acid-base equilibrium in the body. The World Health Organization recommended in 1984 that the maximum allowable chloride value for drinking water be 250 mg/l (Malik et al., 2000).

Chloride values obtained in the study are found in the range between 18 to 214 mg / lt.



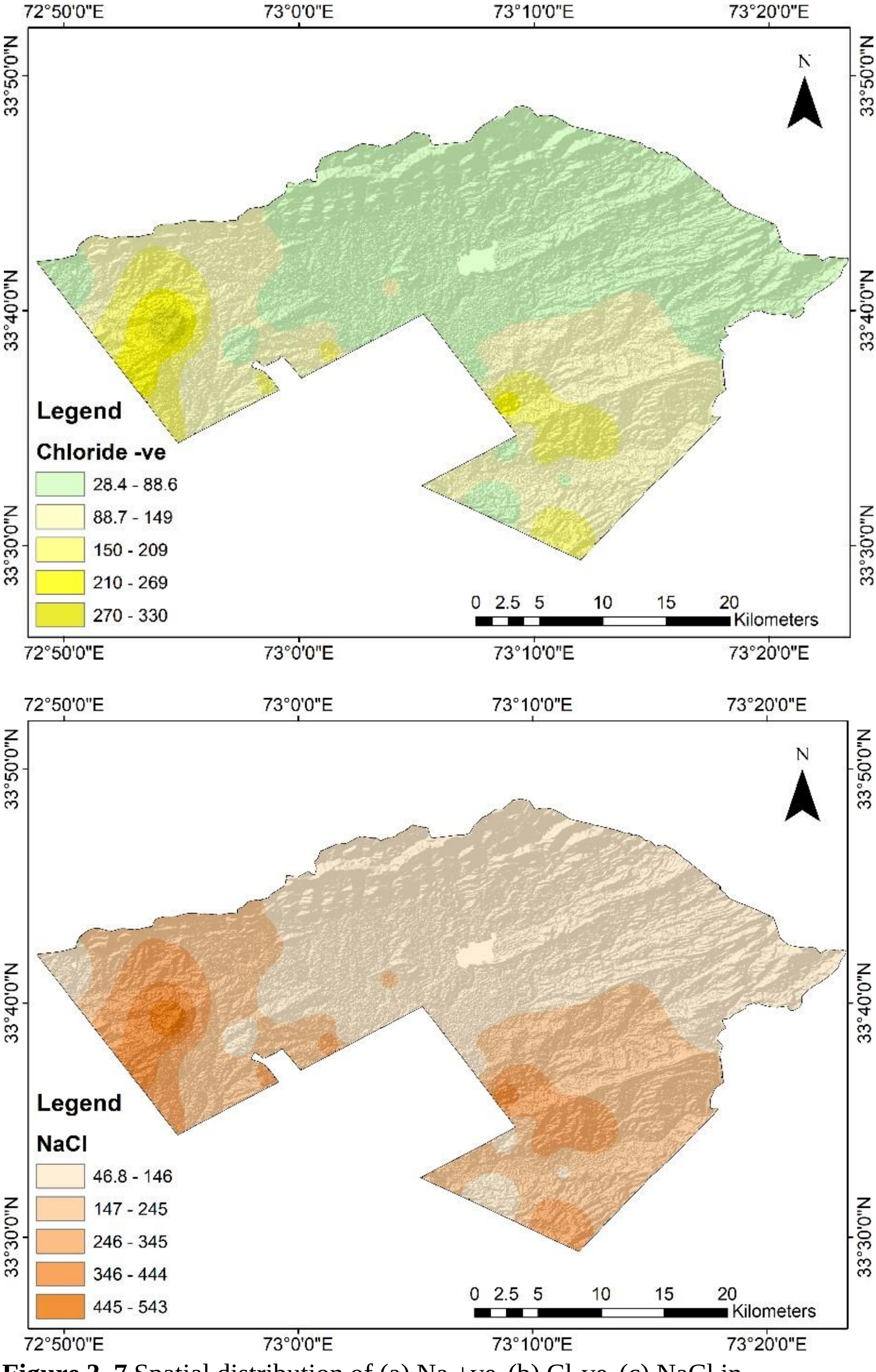


Figure 3. 7 Spatial distribution of (a) Na +ve (b) Cl-ve (c) NaCl in groundwater

3.2.3 Hardness (mg/L):

The main causes of hardness of water are carbonates, bicarbonates, chlorides, sulfates, calcium, and magnesium. A 500-ppm maximum is the maximum that can be found in drinking water, as to PCRWR and WHO guidelines. Excessive water hardness causes scaling, corrosion, and choking of the tubes and utensils, which further damages the economy. According to Khan et al. (2013), excessive hardness is also linked to kidney stones, cardiac issues, gastric illnesses, and diarrhea.

The hardness values of the present study were found to range between 420.4 to 1050 mg/lit.

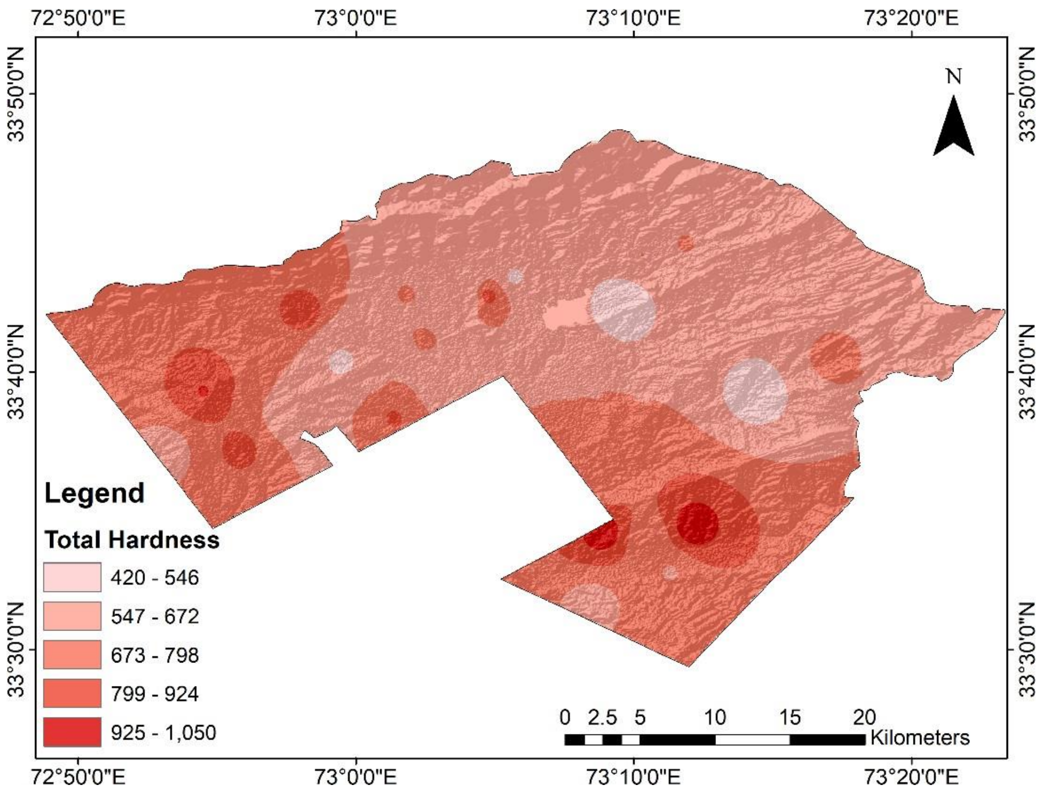


Figure 3. 8 Spatial distribution of Hardness in groundwater

3.2.4 Alkalinity (mg/L):

Alkalinity is the ability of water to balance acidity. The ions that primarily contribute to alkalinity are the chlorides, bicarbonate, and sulfate. Numerous processes contribute to the alkalinity of the water system, including biological uptake, mineral and rock weathering, soil ion exchange reactions, reduction of strong acid anions, and dust particle deposition from the atmosphere (Islam and Majumder, 2020). The WHO recommends a tolerable level of alkalinity of 200 mg/L.

In the present investigation the total alkalinity of the water samples is found in the Range 22.4 to 178.2 mg/lt.

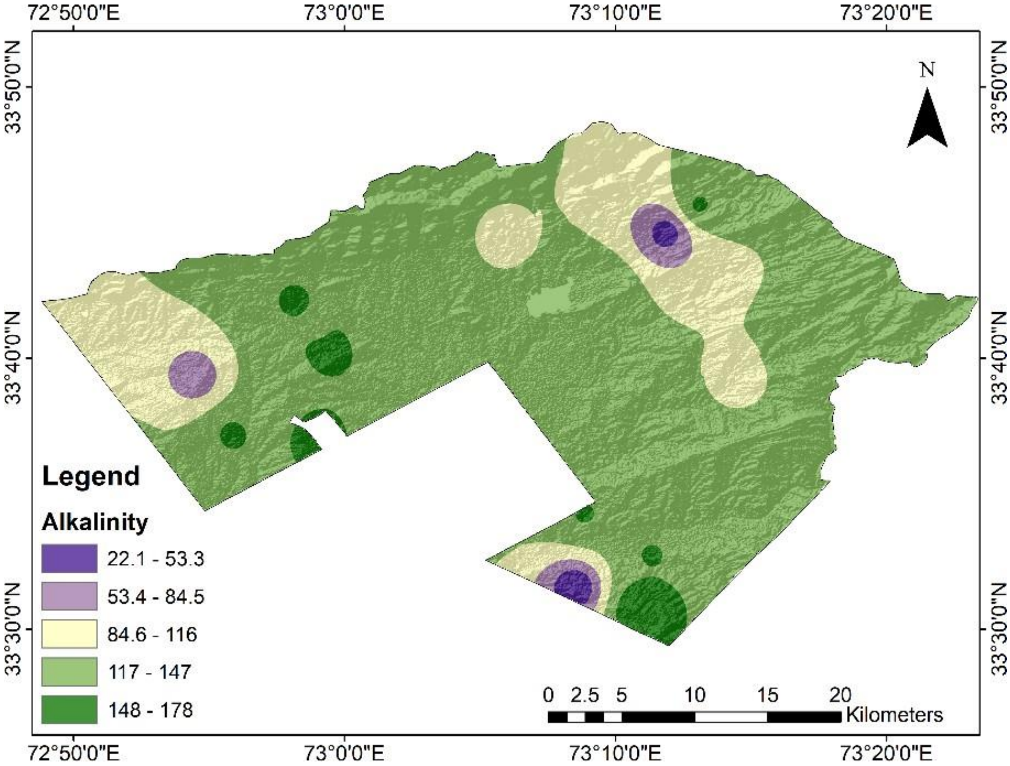


Figure 3. 9 Spatial distribution of Alkalinity in groundwater

3.2.5 Sulphates:

If sulfate ions are present in small amounts, they have no effect on the flavor of water. The WHO recommends a tolerable level of alkalinity of 250 mg/L.

The sulphate ion concentration in the present investigation varied from 102.18-15,318 mg/lt. This shows high deviation from standards.

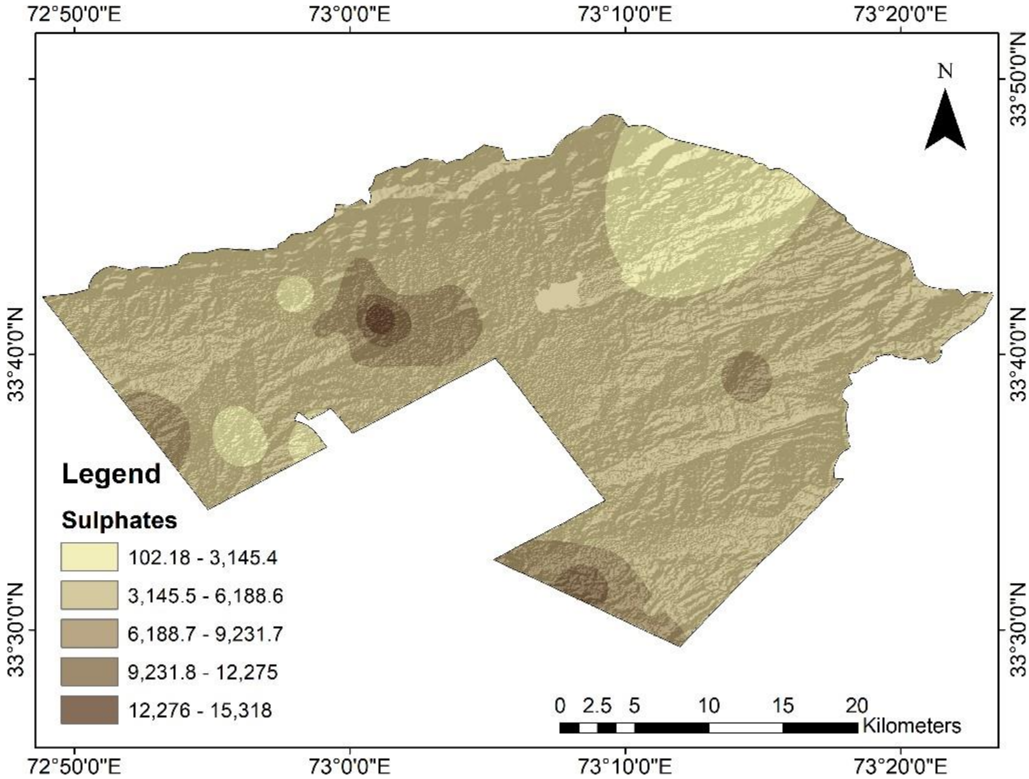


Figure 3. 10 Spatial distribution of Sulphates in groundwater

3.2.6 Nitrate:

The most crucial nutrient in an ecosystem is nitrate. Higher nitrate levels are typically found in water bodies that have been contaminated by organic waste. In the current investigation, water samples from a few sites had nitrate concentrations that were below BDV and considerably below standards-permissible values, whereas other stations had concentrations as high as 2.4 mg/lt.

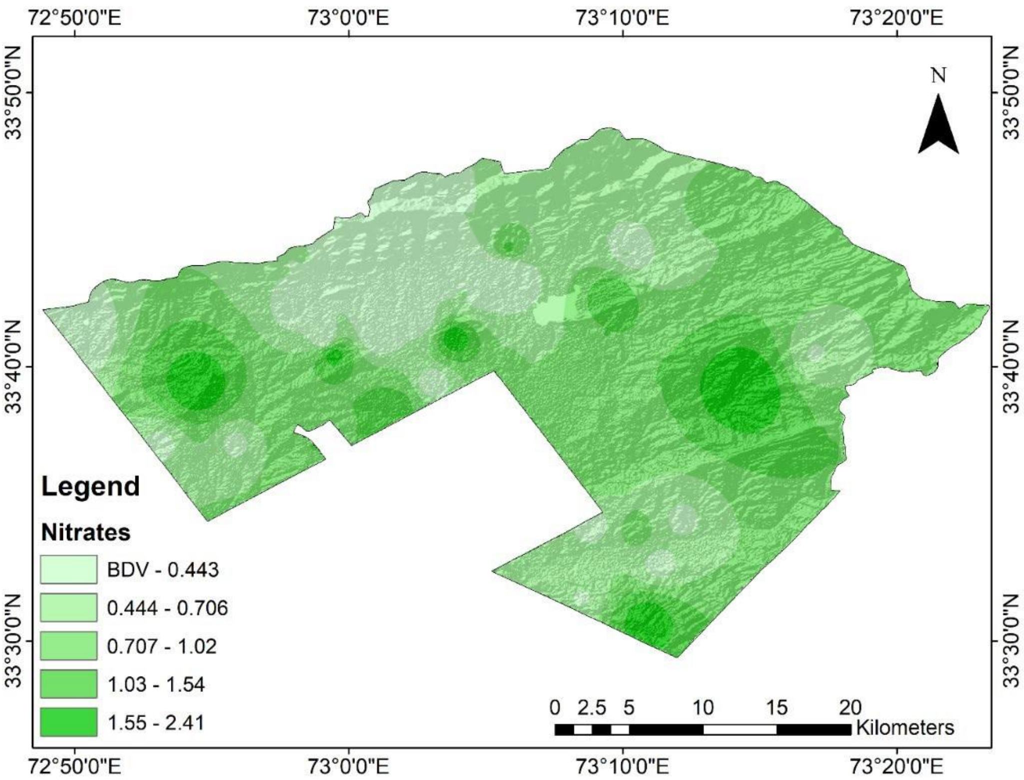


Figure 3. 11 Spatial distribution of Nitrates in groundwater

3.3 Water Quality Index (WQI):

A numerical depiction of the overall quality of water for a certain intended use is called the Water Quality Index (WQI). It is defined as a rating that shows the total effect of several water quality parameters that were included in the computation of the water quality index (WQI). Ranking among the top 68 strategies for educating the public, policymakers, and people working in the field of water quality management on trends in water quality are the indices. The way the water will be used determines the relative weight of various components in the water quality index. This is typically carried out with care for human consumption.

The balanced arithmetic index approach, which consists of three phases, is used in this work to calculate the water quality index (WQI) of groundwater from particular places. Water quality index (WQI) was calculated using eleven physico-chemical parameters, including pH, EC, TDS, Salts, Alkalinity, Total Hardness, Chlorides, Carbonates, Nitrates, Sulphates, and Turbidity. The formula to calculate the water quality index (WQI) is given as;

$$WQI = \sum_{i=1}^{n} SI_i \qquad (1)$$

Where $SSSSSS$ represents the sub-indices

$SSSS_{SS} = WW_{SS} \times QQ_{SS}$ (2)

First, a weightage (wi) in numbers ranging from 1 to 5 is assigned to each parameter based on its significance and effect on human health. Next, each parameter's relative weight (Wi) is determined by dividing its weight by the total weight of all the parameters (Table 2). The formula for calculation of relative weight is as under

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (3)$$

After that, Q_i value of each parameter is calculated by dividing the observed resulted value with the standard value of WHO (WHO 2011and their result then multiplied by 100.

$$Q_I = \frac{V_O}{V_S} \times 100 \quad (4)$$

At last, the water quality index (WQI) of every sample is determined by adding up all of the values obtained from equations (3) and (4) to equation (2), and then calculating the total of the individual values. The water is categorized into five groups (Table 1) based on the water quality index (WQI) values that were obtained. These categories include excellent, good, extremely poor, and not fit for drinking (Sahu et al., 2008).

Table 3. 1 Quality criteria of ground water with respect to its water quality index (WQI) value

Sr. No	WQI Range	Classification
1	0-50	Excellent water
2	50-100	Good water
3	100-200	Poor water
4	200-300	Very poor water
5	>300	Not fit for drinking

Table 3. 2 Standard values given by WHO, calculated weight and relative weight of selected parameters of the Islamabad groundwater

Parameters	Units	WHO Standards	Assigned weight wi	Relative weights (Wi)
Ph	--	7.5	3	0.809638655
EC	µS/cm	400	5	0.809638655
TDS	mg/l	1000	5	0.809638655
SALTS	mg/l	270	3	0.809638655
TURBIDITY	Ntu	25	1	0.809638655
sulphates	mg/l	250	5	0.809638655
nitrates	mg/l	50	5	0.809638655

nacl	mg/l	250	3	0.809638655
CL	mg/l	250	3	0.809638655
Na	mg/l	200	3	0.809638655
T.H	mg/l	500	2	0.809638655
alkalinity	mg/l	250	1	0.809638655
Nahco3	mg/l	400	3	0.809638655
Na2co3	mg/l	400	3	0.809638655
Hco3	mg/l	400	3	0.809638655
Co3	mg/l	400	3	0.809638655
			$\sum w_i = 52$	$\sum W_i = 1$

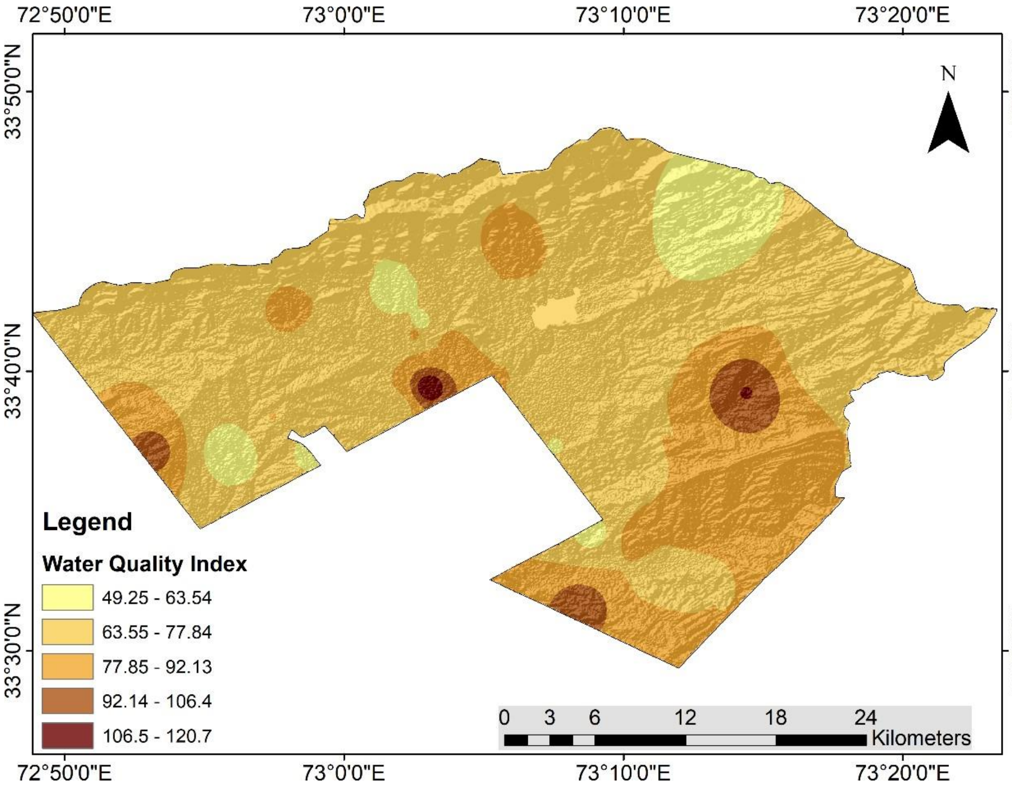


Figure 3. 12 Spatial distribution of WQI in Islamabad

Table 3. 3 Calculation of WQI for individual water samples

S.No	WQI	Classification	S.No	WQI	Classification	S.No	WQI	Classification
1	68.2	Good water	14	75.9	Good water	27	84.7	Good water
2	120.9	Poor water	15	69.7	Good water	28	80.9	Good water
3	82.3	Good water	16	83.9	Good water	29	68	Good water
4	81.8	Good water	17	77.2	Good water	30	80.9	Good water
5	54.1	Good water	18	78.1	Good water	31	104.9	Poor Water

6	63.7	Good water	19	107.1	Poor water	32	98.7	Good water
7	70.7	Good water	20	90.8	Good water	33	73.3	Good water
8	78	Good water	21	69.6	Good water	34	52.7	Good water
9	75.8	Good water	22	62.9	Good water	35	49.2	Excellent water
10	74.1	Good water	23	49.8	Excellent water	36	58.8	Good water
11	69	Good water	24	56.3	Good water	37	76.4	Good water
12	51.9	Good water	25	68.3	Good water			
13	64.5	Good water	26	72.7	Good water			

Table 3 displays the interpolation map of the sample sites for the study region. Of the groundwater samples, 86.49% showed "good water," 8.11% indicated "poor water," and the remaining samples represented "excellent water." The places where wastewater was discharged were closer to the areas with poor water quality. The water was categorized into multiple groups based on water quality index (WQI) in compliance with Table 1's water grading rules, which were also accepted by Sahu and Sikdar (2008) and Ketata-Rokbani et al. (2011). According to these standards, there was good to excellent water in most places around the wastewater discharge site, with fewer outstanding water finds. The bulk of the water near the wastewater discharge site was bad. Groundwater quality in the region of Rawalpindi and Islamabad is at risk due to industrial and urban waste, according to Haq and Cheema (2012). The recharging mechanism of the Lai Nullah and Korang Rivers, which transfer 0.545 million m3/day of water, is the primary cause of this contamination. The sewage system and rubbish disposal are two other significant causes of excessive concentration.

3.4 Aquifer Depth Modeling

Using Geographic Information System (GIS) approaches, we were able to create our aquifer depth model by utilizing a dataset that included 37 well observations. We produced a spatially continuous representation of the aquifer depth throughout the study area, ranging from 25 feet to 399 feet, by using kriging interpolation. Significant differences in aquifer depth are depicted on the resulting map, where areas of shallower depths are associated with areas of greater groundwater accessibility and possible aquifer recharge zones. On the other hand, regions with restricted groundwater availability align with deeper aquifer depths. Our model helps with resource planning and groundwater management plans by offering important insights into the spatial distribution of aquifer properties. In the provided map most of the areas are in patches form, which indicates that the subsurface geology of the Aquifer media is in the form of lenses.

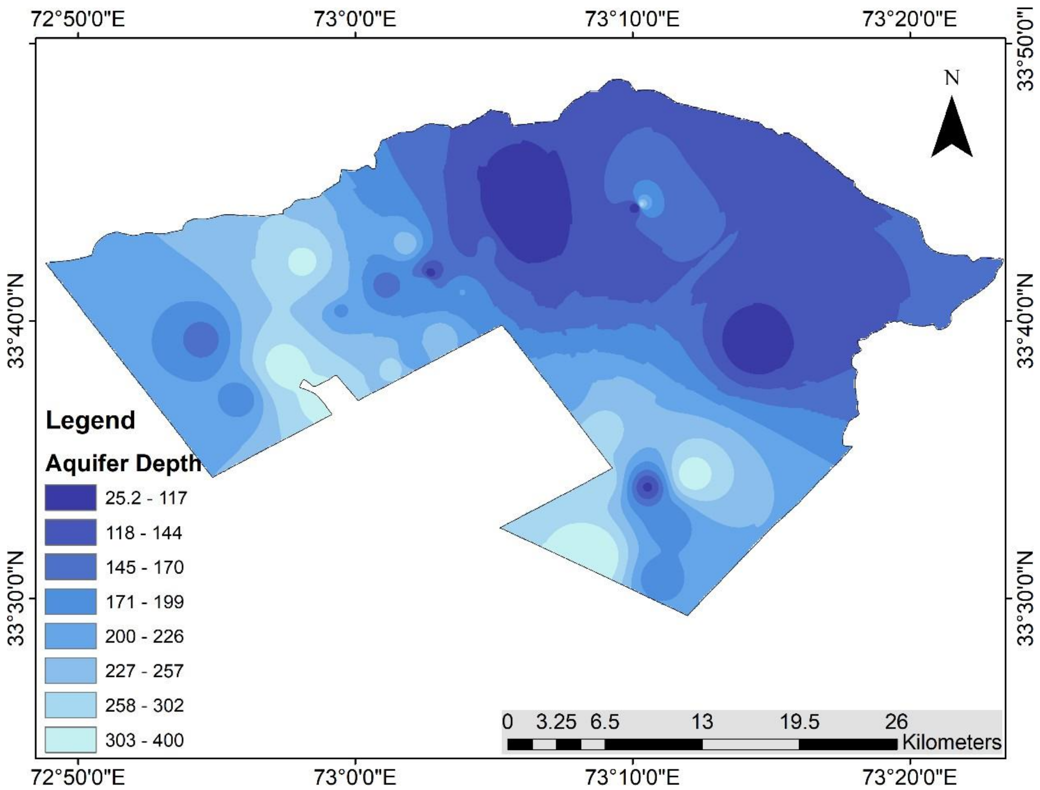


Figure 3. 13 Aquifer depth model for Islamabad

3.5 Regression Analysis

The low R-squared value of 0.0157 suggests that the association between the water quality index (WQI) and the aquifer depth model is weak, according to the regression analysis that was done. This indicates that modifications to the aquifer depth model can only account for about 1.57% of the variability observed in water quality index (WQI). The relationship has little practical value even though it is statistically significant. These findings highlight the complexity of the factors affecting water quality and suggest that changes in water quality index (WQI) may not be fully explained by aquifer depth alone.

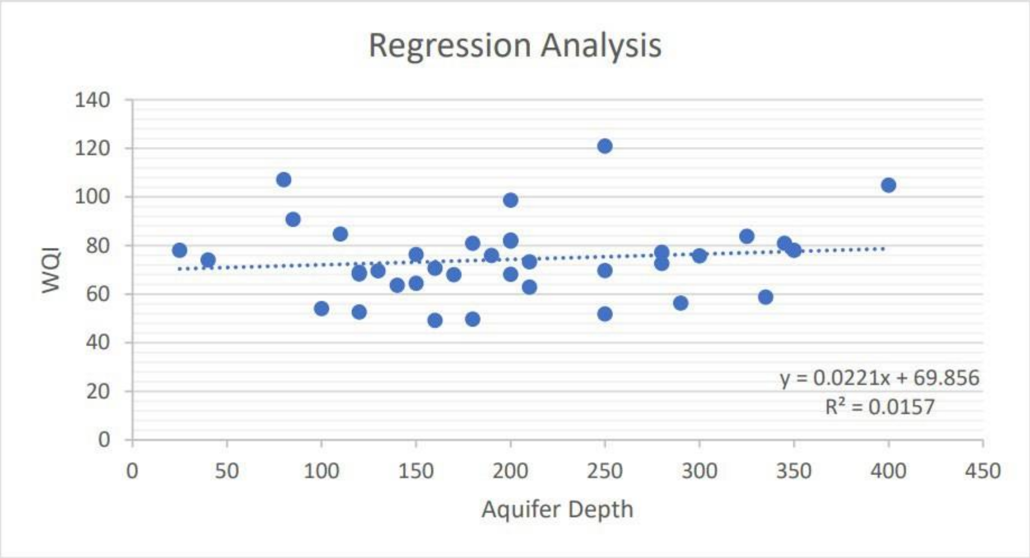


Figure 3. 14 Regression Analysis of WQI and Aquifer Depth Model of Islamabad

Chapter 4

IMPLICATIONS

4.1 Conclusions

i. The investigation found that there were notable differences in the concentrations of certain ions and trace elements in Islamabad's diverse regions. The World Health Organization (WHO) recommended limits were exceeded by some of the groundwater samples' levels of alkalinity (22.4 to 178.2 mg/L), nitrates (below BDV), and chloride (18-214 mg/L). Moreover, sulphate contents varied widely (102.18%–15318 mg/L), and hardness levels were consistently higher than the WHO standard of 500 mg/L. According to the classification of the Water Quality Index (WQI), 86.49% of the samples were classified as "Good water," and 8.11% as "Poor water."

ii. To locate possible sources of groundwater contamination, geospatial methods and geochemical markers were used. The lowest water quality was seen in the vicinity of wastewater discharge stations, indicating a strong human activity influence on groundwater contamination, according to the data. The investigation became clear that, in order to stop additional contamination, stronger rules must be implemented regarding the disposal of wastewater and industrial waste.

iii. An Aquifer depth model that is spatially continuous was created by applying kriging interpolation and Geographic Information System (GIS) techniques. According to the model, there were significant variations in the aquifer's depth throughout the research area, ranging from 25 feet to 399 feet. Greater groundwater accessibility and recharge capacity were linked to areas with shallower depths, whereas deeper aquifers showed limited groundwater availability. The regression study between the WQI and the aquifer depth model revealed a poor connection with a low R-squared value of 0.0157, highlighting the complexity of factors influencing water quality.

4.2 Recommendations

The recommendations for sustainable water resource management are based on the results of this study on the chemistry of groundwater and modeling of aquifer depth in Islamabad. These recommendations include:

i. Targeted Water Quality Monitoring: Concentrate continuing efforts to monitor water quality on areas that have been determined to be more contaminated due to the noted correlations between groundwater chemistry and depth. This can entail putting in more monitoring wells in locations with deeper aquifers that might be less affected by contamination or close to possible sources of contamination.
ii. Groundwater Contamination Mitigation Strategies: Put into practice specific mitigation techniques in accordance with the sources of contamination that have been located. This could entail more stringent laws and enforcement regarding industrial waste management, wastewater disposal procedures, and agricultural methods that increase the loading of nitrate or other contaminants.
iii. Encouraging Sustainable Water Use: To increase awareness of appropriate water usage and disposal techniques, public education initiatives may be launched. This can promote water conservation initiatives and lessen reliance on shallow, perhaps contaminated groundwater resources.
iv. Aquifer Recharge Management: In regions with deeper, less contaminated aquifers, investigate and put into practice methods for recharging aquifers using cleaner water sources. This could entail encouraging natural recharging through land cover management strategies or utilizing artificial recharge techniques.
v. Improved Aquifer Depth Modeling: As new data sources become available, include them into the aquifer depth model to further improve it. This could contain information from recent well drilling operations, long-term water level monitoring records, or geological data.
vi. Predictive Modeling for Contamination Management: Create a model that can forecast how future infrastructural improvements and changes in land use may affect the quality of groundwater. This can be applied to guarantee the long-term sustainability of Islamabad's groundwater supplies and proactively reduce pollution threats.

vii. Islamabad can advance toward a more knowledgeable and sustainable approach to groundwater management by putting these suggestions into practice. Through comprehending the intricate relationship between aquifer depth and groundwater chemistry, the city can protect its essential water resources for future generations.

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Appendices

S No	Location	Depth ft	Latitude	Longitude
1	I-10	200	33.6441	73.0312
2	I-9	250	33.6571	73.0509
3	I-8	200	33.6839	73.0644
4	G-9	200	33.6894	73.0422
5	G-8	100	33.6951	73.0451
6	G-7	140	33.7105	73.0695
7	G-6	160	33.7121	73.0792
8	G-5	25	33.7236	73.0951
9	Bara-Kahu	300	33.7364	73.1716
10	Bara-KahuII	40	33.7351	73.1694
11	F-6	120	33.7217	73.0698
12	F-8	250	33.7124	73.0311
13	G-10	150	33.6881	73.0181
14	G-11	190	33.6733	72.9911
15	F-11	250	33.6841	72.9853
16	D-12	325	33.7011	72.9694
17	I-11	280	33.6393	73.0239
18	G-14	350	33.6398	72.9575
19	Nilore	80	33.6537	73.2401
20	Pak-sec	85	33.7387	73.0975
21	Tumair	130	33.6745	73.2837
22	Ghauri town	210	33.6218	73.1263
23	Tableghi.M	180	33.6201	72.9314
24	PWD	290	33.5707	73.1482
25	Bani-gala	120	33.7101	73.1611
26	Gulberg-Green	280	33.5998	73.1474
27	Jinnah-garden	110	33.5667	73.1758
28	Naval-Anchor	345	33.5738	73.2023
29	Sihala	170	33.5464	73.1886
30	Dhok-walyt	180	33.5124	73.1812
31	Dhok-mitthu	400	33.5256	73.1424
32	Faisal-town	200	33.6132	72.8682
33	B-17	210	33.6853	72.8318
34	17-Mile	120	33.7606	73.2182
35	Shahpur	160	33.7435	73.1981
36	Fazlabad	335	33.6199	72.9808
37	Tarnol	150	33.6548	72.9085

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