

**Integrated Approach to Hydrogeochemical Appraisal and
Quality Assessment of Groundwater from Chunian Tehsil,
District Kasur Pakistan**



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Dedication

Dedicated to my family, especially to my **MOTHER.**

Acknowledgement

First and foremost, I am deeply grateful to Almighty Allah who gave me the strength to complete my work with determination and fortitude. His countless blessings and favors eased out my work and gave me the aptitude to do this research with purpose and produced meaningful results.

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Abstract

People all over the world using water for many purposes like economic, industrial, and household use. The availability and quality of groundwater is necessary because contaminated groundwater can cause serious health problems. In Pakistan mostly the groundwater is contaminated with Arsenic which is a heavy metal and its presence in groundwater can cause serious threat for human health. In this Study groundwater quality assessment is done for drinking and agriculture uses in terms of arsenic concentration as well as health risk assessment is done due to Arsenic exposure in Tehsil chunian. 85 groundwater samples were collected from different locations of tehsil chunian out of which 50 are functional. The results show that most of the groundwater samples lie within the given range of WHO. The concentration of Arsenic with an average value 8.78 ppb ranges from 0.22 – 24.13 ppb and about 47% of the groundwater samples exceed the given limit of WHO. The Gibbs plot indicate that the major controlling factor that change the groundwater chemistry is Rock dominance and some of the samples also lie in evaporation crystallization dominance. The health risk assessment is done by Average daily dose (ADD), Hazard quotient (HQ) and Carcinogenic risk (CR). 42.9% of the samples exceeds the allowed limit of Hazard quotient which is $HQ > 1$ which indicate that people are at higher risk due to the Arsenic contamination in drinking water therefore proper monitoring and management of groundwater in Chunian tehsil is necessary.

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Chapter: 1

Introduction

1.1. General Introduction:

Groundwater is a valuable source of drinking water, agriculture, industry, and can provide a sustainable supply of water in the areas where water sources most commonly surface water are present in limited amount (Abbas and Cheema 2015). Groundwater is replenished by precipitation that infiltrates into the ground and can be pumped out using wells. However, over-extraction of groundwater can lead to a decline in the water table and have a great impact on the environment and nearby ecosystem. Groundwater is one of the main sources of water for many communities and is essential for maintaining public health and well-being (Javeda, Chanda et al. 2021). High levels of contaminants in groundwater can pose significant health risks, including contaminated water. For irrigation purpose groundwater is also used and for other agricultural purposes, and the quality of the water can affect the growth of crops and yield. Contaminants in groundwater can also be taken up by crops, potentially affecting food safety (Ötleş and Çağındı 2010). Groundwater is used for industrial purposes such as cooling and process water, and the quality of the water can affect the efficiency and productivity of industrial operations. Groundwater is a critical component of the water cycle, and changes in its quality can have far-reaching effects on the environment. Contaminants in groundwater can negatively impact aquatic life and wildlife and can also affect the quality of surface water and the overall health of ecosystems. Poor quality of water can result in increased costs for water treatment and can also negatively impact economic activities such as agriculture, tourism, and industry (Nabi, Ali et al. 2019).

In Pakistan groundwater plays a crucial role in meeting the country's drinking water, agricultural, and industrial needs, and provides a critical source of water in times of water scarcity. Groundwater is a primary source of drinking water for many communities in Pakistan, especially in rural areas where access to safe drinking water is limited. Agriculture is a key economic activity in Pakistan, and groundwater plays a critical role in irrigation (Qazi, Khattak et al. 2014). The country's agriculture sector relies heavily on groundwater for irrigation, especially in arid and semi-arid regions. Surface water resources in Pakistan are limited, and in many areas, groundwater is the only available source of water. The increasing demand for water, combined with declining water availability, makes groundwater an important resource for the country. Climate change is affecting water resources in Pakistan, with the country experiencing more frequent and intense droughts and

floods. Groundwater, as a relatively stable source of water, can play an important role in mitigating the effects of climate change and ensuring water security. So, because of all these reasons the quality of groundwater is also important.

The increase in population can have significant effects on groundwater as populations grow, the demand for water also increases, putting additional pressure on groundwater resources. This increased demand can lead to over-extraction of groundwater, causing aquifers to become depleted and reducing the availability of water. An increase in population density can lead to increased pollution and contamination of groundwater (Hassan 2014). More people means more waste and pollution, which can seep into the ground and contaminate aquifers. As populations grow, the demand for housing and other development increases, leading to changes in land use. Land conversion from rural to urban areas can lead to changes in groundwater recharge and discharge patterns, affecting the overall health of the groundwater resource. As populations grow and urban areas expand, the amount of land available for recharge of groundwater decreases (Mandal and Suzuki 2002). This can lead to reduced recharge of aquifers and increased depletion of groundwater resources. As populations grow, there may be increased competition for water resources, including groundwater. This competition can lead to disputes over water allocation and can also drive up the cost of water so, It is important for communities to manage their groundwater resources carefully and to implement policies that ensure sustainable use of this critical resource.

Groundwater is also contaminated by chemicals can have significant impacts on public health, the environment, and the sustainability of the resource. It is important to monitor and assess groundwater quality regularly, and to implement measures to prevent contamination from occurring and to clean up contaminated sites. The tehsil chunian is mostly contaminated by HCO_3 and Arsenic (Abbas and Cheema 2015).

Arsenic is highly toxic and can cause serious health effects, including cancer, skin lesions, cardiovascular disease, and other chronic health problems. Arsenic is found in the earth's crust and can be present in soil, water, and air. It is also a by-product of some industrial processes, such as the smelting of metals decreases (Mandal and Suzuki 2002). Arsenic can contaminate groundwater, particularly in areas where there is a high concentration of arsenic in the soil. This can pose significant health risks to people who rely on the contaminated water for drinking and other purposes. Long-term exposure to arsenic can cause serious health effects, including cancer

of the skin, lung, bladder, kidney, and liver. It can also cause skin lesions, cardiovascular disease, and other chronic health problems. Arsenic is regulated by governments and international organizations, and guidelines have been established for the acceptable levels of arsenic in drinking water. Regular monitoring and testing of water supplies are important to ensure that levels of arsenic remain below the established guidelines. To reduce the risk of exposure to arsenic, it is important to implement measures to remove or reduce arsenic in drinking water, such as using appropriate water treatment methods, switching to alternative sources of water, and improving water management practices. Arsenic is a toxic chemical that can have serious health effects if people are exposed to it. It is important to monitor and regulate levels of arsenic in the environment and to implement measures to reduce exposure to this toxic element (Hassan 2014).

1.2. Objectives of Study:

The Objective of this study is to estimate.

- Groundwater quality assessment for drinking and agriculture purposes.
- Create a geographical distribution map of all chemicals in the study region.
- Calculate water quality Index of the area.
- Calculate the health risk assessment associated with consuming Arsenic-contaminated water.

1.3. Description of Study Area:

Chunian is one of the major tehsils of district Kasur, Punjab, Pakistan. It lies from 30° 58' N and 73° 51' E. Tehsil Chunian is located in the eastern part of Kasur District and borders the districts of Lahore and Sheikhpura. The population of Tehsil Chunian was approximately 455,000 people. Agriculture is a major source of livelihood for the people of Tehsil Chunian, with crops such as wheat, sugarcane, and vegetables being widely cultivated. There are also several industrial units in Tehsil Chunian, including textile mills, leather processing units, and ceramics factories. Tehsil Chunian has a number of educational institutions, including primary and secondary schools, colleges, and universities. This tehsil is well connected by road to other parts of the district and province, with a network of roads and highways. Tehsil Chunian has a rich cultural heritage, with traditional festivals and events being celebrated throughout the year. Tehsil Chunian is a diverse and dynamic area with a mix of agricultural and industrial activities, a strong educational and healthcare sector, and a rich cultural heritage (figure 1.1).

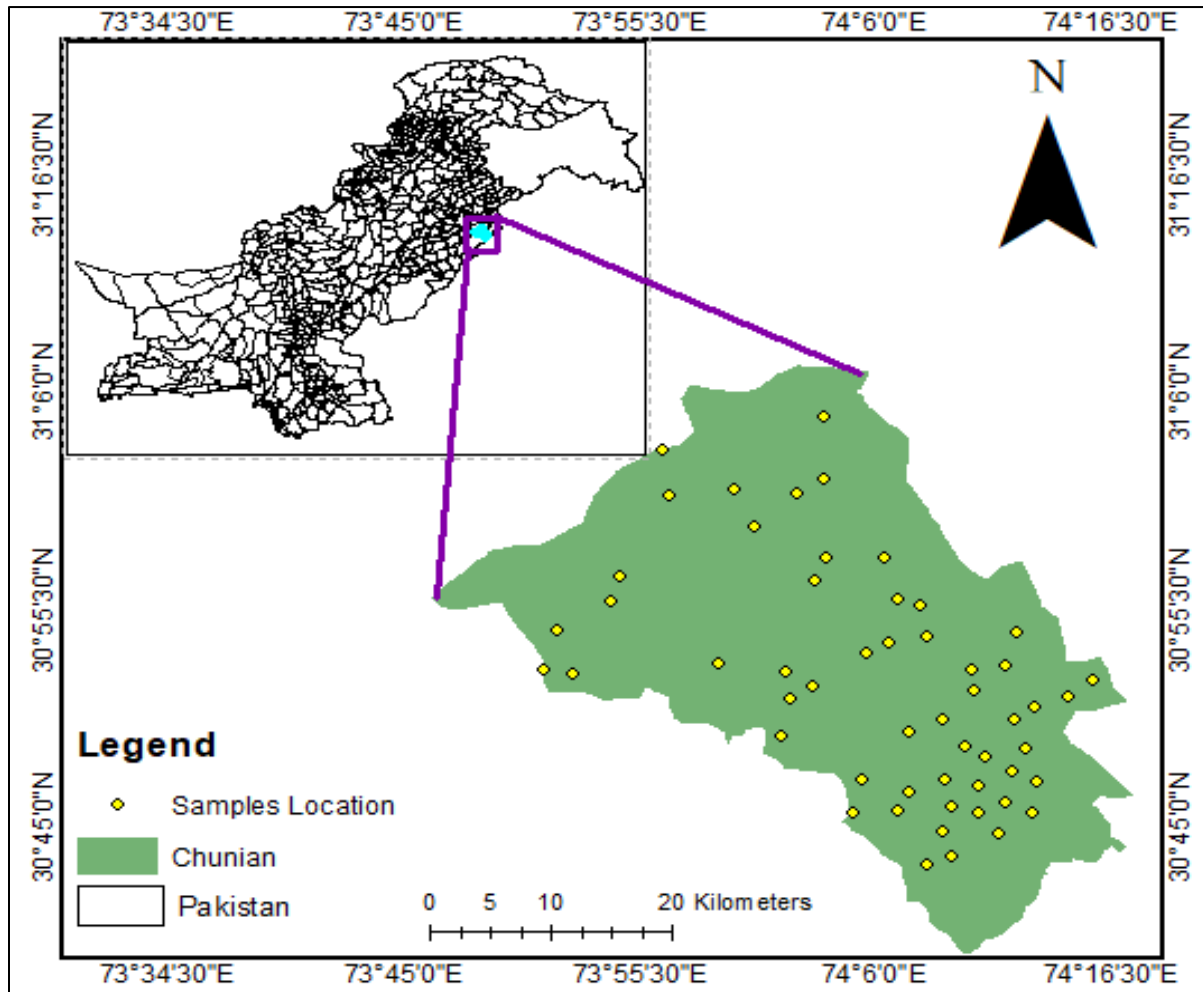


Figure 1.1 Showing study area map of Tehsil Chunian.

1.4. Groundwater Sampling and Parameters:

To evaluate the quality of groundwater in Tehsil Chunian Pakistan 85 different samples of groundwater were collected these 85 samples were collected from different locations of Chunian tehsil but 50 water schemes are functional. Groundwater is the main source of water supply which is used for drinking purpose and extracted through different techniques like handpump, Tube wells, Injector pumps, Dug well and Motor pump etc. GPS is used to record the location of samples. Polythene bottles are used to collect the water samples before collecting the samples the bottle is first washed with distilled water and nitric acid solution. 10-15 min before collecting the water samples the wells are pumped. in field the parameters like Total dissolve solid (TDS), Electrical

conductivity (EC) and PH were analyzed. The samples are sent to the laboratory with proper date and location mention on each sample.

Chapter: 2

Hydrogeology and Geology

2. Hydrogeology of Tehsil Chunian:

The hydrogeology of Tehsil Chunian, Pakistan is influenced by several factors including climate, Recharge sources and Groundwater flow system.

2.1. Climate:

The climate of Tehsil Chunian, is hot and dry in summers and cool in winters, affects the recharge of groundwater. Summer temperatures often reach over 40°C and are accompanied by low humidity and little precipitation. Winter temperatures are mild and can range from 10°C to 20°C, with occasional rain and snowfall. Annual precipitation is low, with rainfall is mostly occurring in the month of winter (Peeters 2014). The climate of Tehsil Chunian can impact various natural resources, such as groundwater and agriculture, as well as human activities and settlement patterns. Understanding the climate is important for sustainable resource management and planning in the area.

2.2. Recharge sources:

Recharge sources, such as precipitation, irrigation, and surface water runoff, play a very important part in the availability of groundwater in Tehsil Chunian. The recharge sources for groundwater in Tehsil Chunian, Pakistan can include:

2.2.1. Precipitation: The primary source of rainfall is recharge for groundwater in the area. The amount of recharge from precipitation can be affected by different factors such as climate, topography, and land use (Flörke et al., 2013).

2.2.2. Irrigation: Irrigation can also contribute to the recharge of groundwater in Tehsil Chunian, especially in areas where irrigation practices are not efficient, and water is allowed to percolate into the subsurface (Jiang et al., 2009).

2.2.3. Surface water runoff: Runoff from streams and rivers can also contribute to the recharge of groundwater in the area, particularly in areas with permeable soils and low-lying topography (Peeters 2014).

It is important to note that while these sources can contribute to groundwater recharge, they can also potentially impact the quality of the water.

2.3. Groundwater flow systems:

Groundwater systems flow are affected with the topography, geology, and recharge sources in the area. In Tehsil Chunian, groundwater is likely flowing towards rivers and streams, which can impact its quality and availability (Kumar et al., 2009). Groundwater flow systems in Tehsil Chunian, Pakistan are influenced by several factors including geology, climate, recharge sources, and topography. The direction and rate of groundwater flow can have important effect on the availability and quality of the resource.

2.3.1. Topography: The topography of Tehsil Chunian, including the elevation and slope of the land surface, affects the groundwater flow direction. Groundwater typically flows from higher to lower elevations, following the slope of the land (Rishi et al., 2020).

2.3.2. Recharge sources: Recharge sources, like precipitation, irrigation, and surface runoff water, can also impact the direction and rate of groundwater flow.

2.3.3. Geology: The geology of the area, including the type and distribution of rock layers, affects the permeability and porosity of the subsurface, which can impact the flow of groundwater.

Groundwater flow systems in Tehsil Chunian can impact the availability and quality of the resource, as well as other natural resources such as rivers and streams (Qureshi et al., 2010).

2.4. Geology of Tehsil Chunian:

The geology of Tehsil Chunian, Pakistan primarily consists of sedimentary rocks, including sandstones, shales, and limestones. These rocks were formed from the accumulation of sediment over millions of years and were then subjected to various geological processes such as tectonic uplift and erosion (Rasheed et al., 2022). The area may also contain smaller amounts of igneous and metamorphic rocks, which were formed through processes such as volcanic activity and high-pressure, high-temperature events. The geology of Tehsil Chunian affects the availability and quality of groundwater in the area, as well as other natural resources such as minerals and oil and gas reserves. Further study and data collection is necessary to fully understand the geology of Tehsil Chunian.

2.5. Precipitation In Tehsil Chunian:

The precipitation in Tehsil Chunian, Pakistan is primarily in the form of rainfall. Winter months typically see higher amounts of precipitation, with rain and snowfall being more common. Summer months are usually hot and dry, with little to no precipitation (Tropea et al., 2021). Annual precipitation totals for Tehsil Chunian can vary, but the average is typically low, ranging from 200-400 mm per year. The amount and distribution of precipitation in Tehsil Chunian can impact various natural resources, including groundwater, agriculture, and surface water, as well as human activities and settlement patterns. Understanding the precipitation patterns is important for sustainable resource management and planning in the area (Adeloju et al., 2021).

2.6. Rainfall In Tehsil Chunian:

Rainfall is a significant source of precipitation in Tehsil Chunian, Pakistan, particularly in the winter months. The amount and distribution of rainfall can vary greatly depending on several factors including location, topography, and climate. Winter months typically see higher amounts of rainfall, with rain being more common. Summer months are usually hot and dry, with little to no rainfall (Adebayo et al., 2021). Annual rainfall totals for Tehsil Chunian can vary, but the average is typically low, ranging from 200-400 mm per year. The amount and distribution of rainfall in Tehsil Chunian can impact various natural resources, including groundwater, agriculture, and surface water, as well as human activities and settlement patterns. Understanding the rainfall patterns is important for sustainable resource management and planning in the area (Tabassum et al., 2019).

2.7. Humidity In Tehsil Chunian:

The humidity levels in Tehsil Chunian in Summer months are typically hot and dry, with low humidity levels. Winter months tend to have higher humidity levels, especially during periods of rainfall. Humidity levels can also vary greatly depending on the proximity to bodies of water, such as rivers and streams, which can impact the local climate. The humidity levels in Tehsil Chunian can impact various factors such as human comfort, agriculture, and the growth of vegetation. Understanding the humidity patterns is important for sustainable resource management and planning in the area (Adebayo et al., 2021).

Chapter:3

Review of Literature

The groundwater quality is affected by different factors, which may include:

- Natural sources such as minerals, salts, and organic matter that dissolve in groundwater.
- Human activities such as agricultural practices, landfills, and industrial discharge, which can introduce pollutants into the groundwater.
- Physical processes such as soil filtration and geochemical reactions, which can alter the quality of groundwater.

The groundwater quality is typically measured in terms of its physical properties (such as temperature and turbidity), chemical properties (such as pH, total dissolved solids, and dissolved oxygen), and biological properties (such as presence of microorganisms). Groundwater quality can vary widely depending on location and the presence of pollutants, and it's important to regularly monitor and manage groundwater quality to ensure it remains suitable for its intended uses.

3. Quality of water analysis:

The analysis of water quality is necessary and for this form the study area different samples are collected and after the analysis of these sample they are compared with the standard WHO values.

The two methods are used for the analysis of water quality.

- ✓ Physical Methods
- ✓ Chemical Methods

3.1. Physical Method:

In physical methods different physical parameters are calculated like electrical conductivity (EC), PH concentration, turbidity.

3.1.1. Potential of Hydrogen:

pH stands for "potential of Hydrogen". It is a measure of the acidity or basicity (alkalinity) of a solution, on a scale of 0 to 14. A pH of 7 is considered neutral, values less than 7 are acidic, and values greater than 7 are basic (alkaline). The pH scale is logarithmic, meaning that a change of one unit in pH represents a ten-fold change in the acidity or basicity of the solution (Puri, et al. 2011).

Gupta et al. (2009) The corrosiveness of water can be influenced by its pH, as well as other factors such as temperature, concentration of dissolved minerals and gases, and flow rate. To minimize corrosion, it is important to maintain water within a pH range that is not too acidic or too alkaline.

Karant et al. (1987) A pH greater than 7 is an indication that there are more hydroxide ions (OH⁻) in the solution than hydrogen ions (H⁺), which gives the solution an alkaline or basic character. Alkaline solutions tend to neutralize acids and are often used in cleaning products and other applications where acidic soils need to be removed. However, it's important to note that an excessively high pH value can also cause issues such as scaling and mineral buildup in pipes and equipment, so it's important to maintain water within an appropriate pH range.

Sulochana et al. (2005) In general, natural rivers tend to have a pH range of 6.5 to 8.5, which is considered neutral to slightly alkaline. However, river water can also become more acidic due to pollution from human activities, such as agricultural runoff, industrial discharge, and sewage treatment plants. In these cases, the pH can drop significantly, sometimes below 6.0. River water is not typically used for drinking water because it can contain a variety of contaminants, such as bacteria, viruses, parasites, chemicals, and pollutants. Some of these contaminants can pose serious health risks if consumed, especially if the water is not treated properly (Gorde, et al. 2013). Additionally, the pH of river water can change rapidly due to weather conditions, seasonality, and other factors, making it difficult to consistently provide safe and potable water. For these reasons, most communities rely on treated and purified water from underground sources or reservoirs for drinking purposes.

3.1.2. Electrical conductivity (EC):

It is usually expressed as the reciprocal of electrical resistance and is commonly measured in units of siemens per meter (S/m). The electrical conductivity depends on many different factors, including its temperature, the type of ions present, and the density of free electrons in the material. Metals are generally good conductors of electricity, while insulators like rubber are poor conductors.

Navneet et al. (2010) with the electrical conductivity (EC) values of groundwater we measure the total dissolved solids (TDS). Groundwater with higher EC values generally indicates a higher concentration of dissolved salts and minerals, which can affect its overall quality. The EC of

groundwater can provide information on the presence of various ions such as sodium, calcium, magnesium, and chloride.

In general, low EC values (less than 1000 $\mu\text{S}/\text{cm}$) indicate pure or fresh groundwater, while high EC values (greater than 5000 $\mu\text{S}/\text{cm}$) can indicate groundwater contaminated with salts, minerals, or pollutants. The EC of groundwater can also provide a useful indicator of contamination from sources such as sewage, agricultural runoff, and industrial waste (Chandra, et al. 2012).

It is important that the EC of groundwater can vary depending on the type of minerals in the soil and rock formations and the specific location, so a thorough understanding of local geology and water conditions is necessary for accurate interpretation of EC data.

3.1.3. Total Dissolved Solid:

R Islam et al. (2017) studied Total Dissolved Solids (TDS) is a measure of the total amount of inorganic and organic substances present in a liquid, usually water. It is expressed as the total weight of solids in milligrams (mg) or parts per million (ppm) in a given volume of water.

M. S. Islam (2019) reported TDS can come from various sources, including natural minerals in the soil, runoff from land, discharge from industrial processes, and domestic sewage. High levels of TDS can affect the taste, odor, and appearance of water, as well as have potential health effects (Lung, et al. 1987).

The TDS measurement is then obtained by multiplying the conductivity measurement by a conversion factor. It is important to regularly monitor TDS levels in water sources to ensure that they meet safe drinking water standards.

3.2. Chemical Methods:

In chemical methods different Chemical parameters are calculated like CO_2 , SO_4 , Na, Ca, Mg etc.

3.2.1. Carbon dioxide:

It is a naturally occurring component of the atmosphere, but human activities have significantly increased its levels in recent decades.

Increased levels of CO_2 are causing the Earth's climate to change, leading to rising temperatures, changes in precipitation patterns, and other impacts such as sea level rise, more intense storms, and more frequent heat waves (Pradhan, et al. 2012).

Carbon dioxide is also used in a variety of industrial processes, including the production of carbonated beverages and the enhancement of oil and natural gas recovery. It is also used as a coolant in refrigeration systems and as a component in fire extinguishers.

Smith et al. (1997), Carbon dioxide (CO₂) can have an impact on groundwater quality that the dissolution of CO₂ into groundwater, which can result in an increase in the groundwater's acidity (lower pH) and a decrease in its alkalinity. This can lead to corrosion of pipes and other infrastructure, as well as the release of heavy metals and other toxic substances from soils and rocks into the groundwater.

However, it is important to note that CO₂ is not typically a primary contaminant of concern in groundwater, and its presence is usually a result of other factors such as the dissolution of atmospheric CO₂ or the presence of anthropogenic sources such as landfills or industrial activities. As such, the impact of CO₂ on groundwater quality is usually relatively minor compared to other contaminants such as nitrogen, phosphorus, and heavy metals.

3.2.2. Total Alkalinity:

Alkalinity refers to the capacity of water to neutralize acids, which is determined by the presence of carbonate, bicarbonate, and hydroxide ions. It is a measure of the ability of a solution to resist changes in pH that would make it more acidic. Alkalinity is important in aquatic systems because it helps to maintain a stable pH, which is essential for the survival of many aquatic species (Mahesh, et al. 2013).

Uduma et al. (2014) Additionally, high levels of alkalinity can increase the risk of scaling in plumbing systems, as well as potentially impacting the effectiveness of certain water treatment processes. On the other hand, low levels of alkalinity can indicate that the groundwater is vulnerable to acidic contamination, which can have serious consequences for water quality. In general, it is important to monitor and maintain appropriate levels of alkalinity in groundwater to ensure its quality and suitability for various uses.

3.2.3. Carbonate:

Carbonates are chemical compounds that contain the carbonate ion (CO₃)⁻², which is formed by the combination of a carbon atom and three oxygen atoms. Carbonates are commonly found in rocks and minerals, such as limestone and dolomite, and are a major component of the Earth's crust. They are also found in water, where they can exist as bicarbonates or carbonates, depending

on the pH of the water. Bicarbonates are the most common form of carbonates in groundwater and surface water, while carbonates are more commonly found in hard water and in water that has been in contact with carbonate-rich rocks.

Carbonate minerals can dissolve in water, releasing ions such as calcium and magnesium into the groundwater, which can affect the taste and odor of the water. High levels of carbonates can also increase the water hardness, making it more difficult to dissolve soap and other cleaning products, and potentially causing scaling in plumbing systems. On the other hand, carbonates can also help to maintain the alkalinity and pH of groundwater, which helps to ensure its quality and suitability for various uses. It is important to monitor and manage carbonate levels in groundwater to ensure its quality and suitability for various uses (Islam, et al. 2012).

3.2.4. Bicarbonate:

Bicarbonate is a chemical species composed of the hydrogen carbonate ion (HCO_3^-), which is formed by the combination of a carbon atom, two oxygen atoms, and a hydrogen atom. Bicarbonates are commonly found in water, especially in groundwater, and play an important role in maintaining the alkalinity and pH of the water. Bicarbonates are also used in various industrial and agricultural applications, such as in baking powder, as a buffer in blood, and as a source of CO_2 in the cultivation of algae and plants. Bicarbonates can impact groundwater quality in several ways, such as affecting the taste and odor of the water, and potentially impacting the effectiveness of certain water treatment processes. It is important to monitor and manage bicarbonate levels in groundwater to ensure its quality and suitability for various uses.

Bicarbonates can also impact the effectiveness of certain water treatment processes, such as reverse osmosis and ion exchange. On the other hand, bicarbonates play an important role in maintaining the alkalinity and pH of groundwater, which helps to ensure its quality and suitability for various uses. Low levels of bicarbonates can indicate that the groundwater is vulnerable to acidic contamination, which can have serious consequences for water quality.

3.2.5. Calcium:

Calcium is a chemical element with the symbol Ca and atomic number 20. Calcium is a key component of many minerals, such as limestone, dolomite, and gypsum, and is also present in many rocks and soils. It is important for the proper functioning of various physiological processes, such as muscle contraction and blood clotting. Calcium is also an important component of many

industrial and agricultural products, including fertilizers, construction materials, and water treatment chemicals. In water, calcium can exist as a dissolved ion, and its presence can impact the hardness and alkalinity of the water.

Moss B (1973) High levels of calcium can indicate the presence of calcium-rich minerals in the water, which can affect the taste and odor of the water, and increase the water hardness, making it more difficult to dissolve soap and other cleaning products. This can also lead to scaling in plumbing systems. Calcium is also important for the alkalinity of water, which helps to maintain a stable pH, which is essential for the survival of many aquatic species. On the other hand, low levels of calcium in water can indicate that the water is vulnerable to acidic contamination, which can have serious consequences for water quality (Yannawar, et al. 2013).

3.2.6. Magnesium:

It is a metal that is abundant in nature and is the eighth most abundant element in the Earth's crust. Magnesium is a key component of many minerals, such as dolomite, magnesite, and serpentine, and is also present in many rocks and soils. It is important for the proper functioning of various physiological processes, such as protein synthesis, energy metabolism, and DNA replication. Magnesium is also an important component of many industrial and agricultural products, including fertilizers, construction materials, and water treatment chemicals. In water, magnesium can exist as a dissolved ion, and its presence can impact the hardness and alkalinity of the water.

Magnesium in groundwater can impact its quality in several ways. High levels of magnesium can affect the taste and odor of the water, and increase the water hardness, making it more difficult to dissolve soap and other cleaning products. This can also lead to scaling in plumbing systems. Magnesium is also important for the alkalinity of groundwater, which helps to maintain a stable pH, which is essential for the survival of many aquatic species. On the other hand, low levels of magnesium in groundwater can indicate that the water is vulnerable to acidic contamination, which can have serious consequences for water quality. In general, it is important to monitor and manage magnesium levels in groundwater to ensure its quality and suitability for various uses.

3.2.7. Sodium:

Sodium is an essential element for life and plays a key role in many biological processes, including maintaining fluid balance and transmitting nerve impulses. It is widely used in industry and is a

major component of many common substances, such as sodium chloride (table salt) and sodium hydroxide.

Sodium is one of the primary ions found in groundwater and can have an impact on its quality. High levels of sodium in drinking water can make the water taste salty and affect its palatability. Additionally, sodium can interact with other minerals in the water to form deposits that can clog pipes and fixtures. For people on low-sodium diets, high levels of sodium in drinking water can also pose a health risk (Hussain, et al. 2011).

High levels of sodium in groundwater can be due to the dissolution of mineral deposits containing sodium, such as sodium chloride (common salt), or from the use of sodium-based compounds in agriculture, industry, or household products. To maintain good groundwater quality, it is important to monitor the levels of sodium and other contaminants, and to implement effective management practices to minimize their impact.

3.2.8. Turbidity:

Turbidity is usually measured in NTU (Nephelometric Turbidity Units), which are units of turbidity based on the amount of light that is scattered by the suspended particles. High turbidity levels can reduce the clarity of the water, making it difficult to see through, and can also interfere with the disinfection of the water and the operation of water treatment plants.

Turbidity is an important parameter in assessing the quality of water, as it can have significant impacts on the quality and safety of the water. High levels of turbidity can:

1. Interfere with disinfection processes: Turbidity can interfere with the effectiveness of chlorine and other disinfectants used to treat water, making it harder to remove pathogens and other harmful substances.
2. Reduce water clarity: High levels of turbidity can make water look cloudy or murky, affecting its appearance and taste.
3. Contain harmful substances: Suspended particles in the water can contain pollutants, such as chemicals, heavy metals, and pathogens, which can pose health risks.
4. Harm aquatic life: Turbidity can reduce light penetration in aquatic environments, affecting the growth and survival of aquatic plants and animals.

Turbidity levels in water can be influenced by a variety of factors, including weather conditions, human activities, and the presence of natural sources of suspended particles. It is important to regularly monitor turbidity levels in water sources to ensure that they are within safe limits and to take appropriate measures to reduce turbidity levels if necessary (Gaikwad, et al. 2013).

3.2.9. Total Hardness:

Hardness in water can come from various sources, including natural minerals in the soil and rock, as well as from human activities such as the use of hard water in industrial processes and the discharge of effluent from treatment plants.

High levels of total hardness can cause scaling and buildup in pipes, water heaters, and appliances, and can also interfere with the performance of industrial processes. On the other hand, low levels of total hardness can result in water that is too soft, causing corrosion in pipes and fixtures.

Total hardness is an important parameter in assessing the quality of water.

1. Drinking water: Hard water can have a noticeable taste and can leave deposits on appliances and fixtures. It can also interfere with the lathering of soaps and detergents.
2. Industrial processes: Total hardness reducing the efficiency of industrial processes and leading to increased maintenance costs.
3. Domestic use: Hard water can cause buildup in pipes, water heaters, and appliances, reducing their lifespan and performance.
4. Agricultural use: Hard water can affect the growth and quality of crops, as well as the performance of pesticides and fertilizers.

FJ et al. (2011) reported total hardness levels in drinking water should be between 60 and 120 mg/L, depending on local and regional standards. It is important to regularly monitor total hardness levels in water sources to ensure that they are within safe limits and to take appropriate measures to treat water if necessary. The appropriate treatment for high hardness levels will depend on the specific source and composition of the hardness, and may include methods such as ion exchange, reverse osmosis, or lime softening (Pejaver, et al. 2008).

3.2.10. Fluoride:

Fluoride is a naturally occurring element and a common constituent of many minerals. In drinking water, fluoride is present in the form of fluorine ions and is measured in milligrams per liter (mg/L) or parts per million (ppm). The optimal concentration of fluoride in drinking water for the prevention of tooth decay is typically between 0.7 and 1.2 mg/L, depending on local and regional standards.

Saxena et al. (2013) reported that Fluoride is considered both a nutrient and a contaminant, as it can have both beneficial and harmful effects on health, depending on the dose and duration of exposure. Low levels of fluoride are believed to strengthen teeth and prevent tooth decay, while high levels of fluoride can cause dental and skeletal fluorosis, which is a condition characterized by discoloration and brittleness of the teeth and bones (Khan, et al. 2012).

It is important to monitor fluoride levels in drinking water to ensure that they are within safe limits and to take appropriate measures to treat water if necessary.

Chapter: 4

Materials and Methods

Groundwater is important and the major water supply source which is used for different purposes and extracted through different techniques like hand pump, Tube wells, Injector pumps, Dug well and Motor pump etc. GPS is used to record the location of samples (Rehman and Cheema, 2016). Polythene bottles are used to collect the water samples and the samples are collected when the bottle is first washed with distilled water and nitric acid solution. 10-15 min before collecting the water samples the wells are pumped. In field the parameters like Total dissolved solid (TDS), Electrical conductivity (EC) and PH were analyzed. The samples are sent to the laboratory with proper date and location mention on each sample.

4.1. Parameters and the Methods used for water Quality Analysis:

Parameters refer to the various water characteristics such as biological, chemical, and physical that are used to assess that either which is good for drinking use, irrigation use and for industrial use (Sarfranz et al., 2019). Some parameters that are used for the analysis of water quality include:

1. pH: It measures the water acidity.
2. Total Dissolved Solids (TDS): It measures the inorganic and organic amount of matter that are present in the water.
3. Conductivity: It is measuring the ability of the water to conduct an electric current, which is proportional to the concentration of dissolved ions.
4. Total Hardness: It measures the calcium and magnesium number of ions in the water.
5. Chlorine: measures the amount of free chlorine, which is used as a disinfectant.
6. Turbidity: measures the cloudiness or clarity of the water.
7. Nitrates and Nitrites: measure the presence of nitrogen-based pollutants.
8. Phosphates: measure the presence of phosphorous-based pollutants.

The methods used for analyzing water quality parameters vary depending on the parameter being measured. Some common methods include:

1. pH meters and strips: used to measure the pH of the water.
2. Conductivity meters: used to measure the conductivity of the water.
3. Titration: used to measure the amount of chlorine, nitrates, and phosphates in the water.
4. Spectrophotometry: used to measure the turbidity of the water.

4.1.1. Method to analyze Alkalinity:

The standard method (1992) used to analyze alkalinity in water is the Titration Method. This method involves titrating a sample of water with a standardized acid solution (such as sulfuric acid) to determine the amount of acid needed to neutralize the basic substances (carbonates, bicarbonates, hydroxides, etc.) in the water (Peeters 2014).

The procedure generally involves adding a few drops of an indicator solution (such as phenolphthalein) to the water sample and titrating with the standardized acid until the endpoint is reached (when the color of the solution changes from pink to colorless). The amount of acid used in the titration is then used to calculate the alkalinity of the water.

This method is widely used because it is simple, reliable, and can be performed in the field or in a laboratory setting. The results of this method are commonly reported as total alkalinity or bicarbonate alkalinity, depending on the particular application (Rehman and Cheema, 2016).

4.1.2. Method to analyze Arsenic (As):

The AAS Vario 6 Analytik Jena AG method is a type of Atomic Absorption Spectrometry (AAS) used to analyze the concentration of arsenic in water and other environmental samples. AAS is a widely used analytical technique for the determination of metal ions in solution (Sheikhy Narany et al., 2015).

In the AAS Vario 6 Analytik Jena AG method, a sample of the water or environmental sample is introduced into a flame or a graphite furnace, where the arsenic is atomized and vaporized.

It is also relatively simple to perform and can be automated, making it a popular choice for routine analysis in environmental laboratories. However, it is important to note that sample preparation and sample digestion can be critical steps in the analysis of arsenic using AAS and must be performed carefully to ensure accurate results (Sheikhy Narany et al., 2015).

4.1.3. Method to analyze Bicarbonate:

The standard method (1992) used to analyze bicarbonate in water is the Titration Method. This method involves titrating a sample of water with a standardized acid solution (such as sulfuric acid) to determine the amount of acid needed to neutralize the bicarbonates in the water. The bicarbonate concentration of the water is then calculated as the equivalent amount of bicarbonic acid in milligrams per liter (mg/L)

The procedure generally involves adding a few drops of an indicator solution (such as phenolphthalein) to the water sample and titrating with the standardized acid until the endpoint is reached (when the color of the solution changes from pink to colorless). The amount of acid used in the titration is then used to calculate the bicarbonate concentration of the water (Doneen, 1964).

4.1.4. Method to analyze Calcium (mg/l):

The 3500-Ca-D Standard method (1992) is a standard method for the analysis of water and wastewater for the determination of calcium ions (Ca^{+2}). Calcium ions are important in many natural water systems and are used as an indicator of water hardness.

The 3500-Ca-D Standard method (1992) involves complexing the calcium ions with a chelating agent, such as EDTA, and then determining the calcium ion concentration by atomic absorption spectrophotometry (AAS) (Ravikumar et al., 2011).

The procedure generally involves adding the chelating agent to the water sample and then measuring the concentration of the chelated calcium ion by AAS or ICP-AES.

This method is widely used because it is accurate and precise and can be automated for high-throughput analysis. It is also useful for the determination of calcium ions in complex matrices, such as water and wastewater. However, it is important to note that sample preparation and sample digestion can be critical steps in the analysis of calcium using this method and must be performed carefully to ensure accurate results (Zheng et al., 2010).

4.1.5. Method to analyze Carbonate (mg/l):

The 2320 standard method, also known as the ASTM D2320-92 standard method, is a method used to analyze carbonate in water samples. This method involves the addition of an acid to the water sample, which reacts with the carbonate to produce carbon dioxide gas. The amount of gas produced is then measured and used to calculate the concentration of carbonate in the sample. This method is commonly used in environmental analysis and water quality testing.

4.1.6. Method to analyze Chloride (mg/l):

The titration using silver nitrate is a standard method used to determine the concentration of chloride ions in a solution.

The basic principle of the method involves the reaction between silver nitrate and chloride ions to form silver chloride, which is insoluble in water. The reaction is stoichiometric, meaning that a fixed amount of silver nitrate reacts with a fixed amount of chloride ions. The amount of silver nitrate used in the reaction can be determined through titration with a standardized solution of sodium thiosulfate, which reacts with the silver ions to form silver sulfide. The endpoint of the titration is determined using a suitable indicator. The concentration of chloride ions can then be calculated from the amount of silver nitrate used in the reaction (Ahada and Suthar, 2019; Bibi et al., 2021).

4.1.7. Method to analyze Conductivity:

The Hach-44600-00, USA EC meter likely uses the two-electrode method to measure conductivity. In this method, a voltage is applied between two electrodes immersed in the solution, and the current flowing through the solution is measured. The conductivity of the solution is then calculated from the current and the applied voltage. The EC meter may also include temperature compensation to correct for variations in conductivity due to changes in temperature (Rehman et al., 2022).

It is important to note that the specific methodology used by the Hach-44600-00, USA EC meter may vary depending on the manufacturer and the configuration of the instrument. It is always best to consult the user manual or technical specifications of the specific EC meter for more information on its method of analysis.

4.1.8. Methods to analyze Lead (ppb):

This instrument is used to analyze lead and other elements in a wide range of samples, including water, soil, and biological materials.

AAS is a type of spectroscopy that measures the absorption of light by atoms in a sample. In the case of lead analysis, the sample is atomized, usually by heating or by nebulization, and the light absorbed by the lead atoms is measured at a specific wavelength. The amount of light absorbed is proportional to the concentration of lead in the sample (Ullah et al., 2022).

AAS Vario 6 may be equipped with a graphite furnace or a flame for atomization, depending on the application and sample type. The instrument is capable of measuring trace levels of lead and provides high accuracy and precision. The method of analysis and the specific configuration of the instrument may vary depending on the manufacturer, so it is always best to consult the user manual or technical specifications for more information.

4.1.9. Method to analyze Hardness (mg/l):

EDTA titration is a standard method used to determine the total hardness of water, which is a measure of the concentration of calcium and magnesium ions in the water. This method is described in the ASTM D1139-92 standard.

EDTA reacts with the metal ions to form a soluble complex, effectively removing the hardness from the water. The endpoint of the titration is determined using a suitable indicator, and the amount of EDTA required to react with all of the hardness-causing ions is used to calculate the total hardness (Jiang et al., 2009).

It is important to note that this method measures only the total hardness and does not differentiate between calcium and magnesium ions. Other methods, such as ion chromatography, may be used to determine the specific concentrations of individual ions.

4.1.10. Method to analyze Nitrate (mg/l):

The cadmium reduction (Hach-8171) by spectrophotometer method is a method used to determine the concentration of nitrate in water samples. This method is manufactured by Hach Company, a water analysis company, and is performed using a spectrophotometer.

The basic principle of the method involves the reduction of nitrate ions to nitrite ions using cadmium metal as the reducing agent. The resulting nitrite ions are then measured using a spectrophotometer, which detects the absorption of light at a specific wavelength. The amount of light absorbed is proportional to the concentration of nitrite, and the concentration of nitrate can be calculated from the amount of nitrite produced (Rasheed et al., 2022).

This method provides a simple and accurate means of determining nitrate concentration in water and is commonly used in environmental analysis and water quality testing. The specific methodology and configuration of the spectrophotometer may vary depending on the manufacturer

and the instrument, so it is always best to consult the user manual or technical specifications for more information.

4.1.11. Method to analyze PH:

The pH meter Hanna Instrument Model 8519 is an electronic instrument used to measure the pH of a solution, which is a measure of its acidity or basicity.

The Model 8519 pH meter likely uses a combination of electrodes and a digital meter to measure pH. The electrode consists of a glass bulb filled with a pH-sensitive solution, which is in contact with the solution being tested. The electrode generates a voltage proportional to the pH of the solution, and this voltage is measured by the digital meter. The pH meter may also include temperature compensation to correct for variations in pH due to changes in temperature.

It is important to note that the specific methodology used by the Hanna Instrument Model 8519 pH meter may vary depending on the manufacturer and the configuration of the instrument. It is always best to consult the user manual or technical specifications of the specific pH meter for more information on its method of analysis (Peeters, 2014).

4.1.12. Method to analyze Potassium (mg/l):

A flame photometer is a type of spectrophotometer that is used to determine the concentration of certain metal ions in a sample. The PFP7 flame photometer manufactured by a UK company is used to analyze potassium ions in a sample.

The basic principle of the flame photometer is to atomize the sample in a flame, causing the metal ions to become excited. The light emitted by the excited metal ions is then measured at a specific wavelength, and the intensity of the light is proportional to the concentration of the metal ions in the sample. In the case of potassium analysis, the flame photometer measures the light emitted at a specific wavelength corresponding to the potassium ion (Adebayo et al., 2021).

The PFP7 flame photometer is a compact and portable instrument that provides rapid and accurate analysis of potassium levels in a wide range of samples, including soil, water, and biological materials. The specific methodology and configuration of the flame photometer may vary depending on the manufacturer and the instrument, so it is always best to consult the user manual or technical specifications for more information.

4.1.13. Method to analyze Sodium (mg/l):

A flame photometer is a type of spectrophotometer that is used to determine the concentration of certain metal ions in a sample. The PFP7 flame photometer manufactured by a UK company is used to analyze sodium ions in a sample.

The basic principle of the flame photometer is to atomize the sample in a flame, causing the metal ions to become excited. The light emitted by the excited metal ions is then measured at a specific wavelength, and the intensity of the light is proportional to the concentration of the metal ions in the sample. In the case of sodium analysis, the flame photometer measures the light emitted at a specific wavelength corresponding to the sodium ion.

The PFP7 flame photometer is a compact and portable instrument that provides rapid and accurate analysis of sodium levels in a wide range of samples, including soil, water, and biological materials. The specific methodology and configuration of the flame photometer may vary depending on the manufacturer and the instrument, so it is always best to consult the user manual or technical specifications for more information.

4.1.14. Method to analyze TDS (mg/l):

The 2540C standard method (1992) is a method used to determine the total dissolved solids (TDS) in a water sample. TDS is a measure of the inorganic and organic substances dissolved in water, excluding suspended solids. The 2540C standard method is a well-established and widely used method for TDS analysis in water samples.

The basic principle of the method involves evaporating a measured volume of water sample to dryness, and then weighing the residual solids. The TDS concentration is calculated as the weight of the residual solids divided by the volume of the water sample. The 2540C standard method is considered to be a relatively simple and straightforward method for TDS analysis, but it can be time-consuming and may require specialized equipment (Mandal and Suzuki 2002).

It is important to note that the specific methodology and requirements of the 2540C standard method may vary depending on the source and the specific implementation. It is always best to consult the original standard or a trusted reference for more information on the method and its requirements.

4.1.15. Method to analyze Fluoride (mg/l):

The 4500-F C iron selective electrode is a type of electronic sensor that is used to measure the concentration of fluoride ions in a solution. The iron selective electrode measures the potential difference between a reference electrode and the fluoride-selective electrode, which is proportional to the concentration of fluoride ions in the solution (Tabassum et al., 2019).

This method is based on the principle that fluoride ions interfere with the oxidation-reduction potential of iron in solution, causing a change in the potential of the iron electrode. The electronic sensor measures this potential change and converts it into a measurement of fluoride ion concentration.

The 4500-F C iron selective electrode is widely used for the analysis of fluoride in water, wastewater, and other aqueous solutions. The method is considered to be a fast, reliable, and easy-to-use method for fluoride analysis, and it is well-suited for routine testing in a variety of settings.

4.1.16. Method to analyze Iron (mg/l):

The basic principle of the method involves adding a TPTZ reagent to a water sample containing iron ions, which forms a complex with the iron ions. The complex has a characteristic absorption spectrum, and the intensity of the absorption at a specific wavelength is proportional to the concentration of iron ions in the sample (Adeloluju et al., 2021).

The TPTZ method is widely used for the analysis of iron in a variety of water samples, including drinking water, wastewater, and process water. The method is considered to be a reliable and accurate method for iron analysis, and it is well-suited for routine testing in a variety of settings.

It is important to note that the specific methodology and requirements of the TPTZ method may vary depending on the source and the specific implementation. It is always best to consult the original method or a trusted reference for more information on the method and its requirements.

4.2. Statistical Analysis:

statistical analysis of physiochemical parameters is a critical tool for understanding the quality and behavior of water and soil samples, and for making informed decisions about the management and protection of these resources. In this study the minimum, maximum and average values, and percentage are calculated for all the physiochemical parameters and comparing them with the world health organization (WHO) given limit (Rehman and Cheema, 2016).

4.3. Correlation:

Correlation is a statistical method used to measure the relationship between two variables. It gives an indication of the strength and direction of the relationship and can range from -1 to +1. A value of -1 represents a perfect negative correlation (as one variable increases, the other decreases), a value of +1 represents a perfect positive correlation (as one variable increases, the other also increases), and a value of 0 represents no correlation between the variables (Sarfraz et al., 2019).

4.4. Graphical Methods:

Two types of Graphical methods are also use for better understanding of ion distribution in water.

- ✓ Piper Diagram
- ✓ Gibbs Diagram

4.4.1. Piper plot:

Piper plot, also known as a Piper diagram or a trilinear diagram, is a graphical representation used in hydrogeology and water chemistry to analyze the major ion composition of groundwater. The plot is named after its inventor, Richard A. Piper, who introduced it in 1944 (Piper 1944).

In a Piper plot, the three major ions found in groundwater, calcium (Ca), magnesium (Mg), and bicarbonate (HCO_3), are plotted on three axes, with the amount of each ion represented by the length of the axis. The plot is used to classify water types based on their ionic composition and to identify patterns or trends in groundwater quality (Peeters, 2014).

The Piper plot can be used to:

1. Identify the major ionic species in groundwater and their relative concentrations.
2. Classify groundwater into different water types, such as calcium-bicarbonate, magnesium-bicarbonate, and sodium-chloride.
3. Identify trends in groundwater quality, such as changes in the relative concentrations of major ions over time.
4. Assess the potential impact of human activities, such as land use change, pollution, and abstraction, on groundwater quality.

5. Provide information for water treatment and management, by identifying the most appropriate methods for removing specific contaminants or adjusting the pH or other chemical properties of the water.

4.4.2. Gibbs diagram:

Gibbs diagrams are used to analyze the composition of water either it is ground or surface water, and to visualize the relationships between major ions, minerals, and other chemical species in these water systems.

Gibbs diagrams are used to:

1. Visualize the relationships between different ions and chemical species in groundwater and surface water.
2. Determine the dominant ionic species and their relative concentrations.
3. Identify water types based on their ionic composition, such as calcium-bicarbonate, sodium-chloride, and magnesium-sulfate waters.
4. Evaluate the mineralization of water, including the presence and concentration of dissolved minerals and other chemical species.
5. Assess the water quality and check whether it is suitable for various uses, such as drinking, irrigation, and industrial applications.

Gibbs diagrams can be used to study the chemical composition of groundwater and surface water over time, and to identify trends or changes in water quality. This information can be useful for water management, as it can help to prioritize actions to protect or improve water quality, and to identify potential risks to human health or the environment (Rehman, Siddique et al. 2022).

Gibbs plot is based on different climate conditions that have impact on the water chemistry of the study area. In these two plots are constructed one for anions $Cl/(Cl + HCO_3^-)$ and the other one is for cation $(Na + K)/(Na + K + Ca)$. The Gibbs plot is divided into five classes evaporation dominance, Evaporation crystallization dominance, Rock dominance, atmospheric precipitation dominance and Rainfall Dominance (Gibbs 1970).

4.5. Water Quality Index:

Water Quality Index (WQI) is a numerical value used to express the overall quality of a water body. The following are some key points about Water Quality Index:

1. It integrates multiple parameters: WQI combines multiple water quality parameters such as pH, temperature, total dissolved solids, biochemical oxygen demand, and others into a single numerical value.
2. Indicator of water suitability: WQI is used to determine the suitability of water for various uses such as drinking, irrigation, industrial, and recreational activities.
3. Classification system: WQI uses a classification system to assign a score to water quality, typically ranging from 0 to 100, with higher scores indicating better water quality.
4. Varies by region: The parameters and weighting factors used to calculate WQI may vary depending on the region and intended use of the water.
5. Limitations: WQI is a useful tool, but it has limitations as it may not reflect the complex interactions between water quality parameters or other factors that can affect water quality.
6. Used for water management: WQI is used by water management agencies and organizations to monitor and assess water quality and make decisions about water management practices.

All standard and observed values have the same units (mg/L). K (constant) was calculated (eq 4.1) (Rahman and Hasegawa 2011).

$$1/S = \sum 1/S_n \quad (4.1)$$

Then divided this with one (eq 4.2) (Abbas and Cheema 2015).

$$K = 1 / (\sum 1/S_n) \quad (4.2)$$

Weight for each parameter was then calculated as, where W_i is the weight of each parameter (eq 4.3) (Shahid, Khalid et al. 2018).

$$W_i = K/S_n \quad (4.3)$$

The next step is to calculate the Q_i of every parameter for all the samples. Q stands for quality rating scale. It is calculated by dividing the observed value from the standard value and multiplying it with 100. The observed value is denoted by “ C_n ” (eq 4.4) (Mandal and Suzuki 2002).

$$Q_i = (C_n/S_n) \times 100 \quad (4.4)$$

The last step is to multiply Q_i with the W_i of all parameters from all samples and then the individual sum of all samples to finalize the result (eq 4.5) (Rahman and Hasegawa 2011).

$$EWQI = \sum Q_i \times W_i \quad (4.5)$$

This is one of the most reliable methods for groundwater quality assessment. Several researchers have used the same technique to describe the quality of groundwater.

4.6. Silicate Weathering:

Silicate weathering has a significant impact on groundwater chemistry. Groundwater is water that is found underground in the pores and fractures of rocks and soils. As groundwater moves through the subsurface, it can come into contact with silicate minerals in rocks and soils, which can lead to silicate weathering (Flörke et al., 2013).

The weathering of silicate minerals can have several effects on groundwater chemistry. For example:

1. Alkalinity: Silicate weathering can lead to the release of positively charged ions, such as sodium (Na^+) and potassium (K^+), into the groundwater. These ions can contribute to the overall alkalinity of the water, which can affect its pH.
2. Dissolved ions: The weathering of silicate minerals can also release a range of dissolved ions, including bicarbonate (HCO_3^-), calcium (Ca^{2+}), and magnesium (Mg^{2+}), into the groundwater. These ions can contribute to the overall chemical composition of the water and can affect its conductivity and total dissolved solids.
3. Changes in water composition: Silicate weathering can also lead to the formation of new minerals in the groundwater, such as carbonates, which can change the overall composition of the water.

The effects of silicate weathering on groundwater chemistry can vary depending on the type of rock or soil that the water is in contact with, as well as on other factors such as the flow rate of the water, the pH of the water, and the presence of other chemicals in the water. In general, silicate weathering can lead to a substantial alteration of the chemical composition of groundwater, which can affect its suitability for various uses, such as drinking water and irrigation

4.7. Ion exchange:

In groundwater chemistry, positive ion exchange and reverse ion exchange refer to two different types of ion exchange processes.

Positive ion exchange occurs when positively charged ions in groundwater, such as sodium (Na^+) or calcium (Ca^{+2}), are exchanged for negatively charged ions in minerals or soils, such as hydroxides (OH^-). This type of ion exchange results in an increase in the concentration of positively charged ions in the groundwater and a decrease in the concentration of negatively charged ions.

Reverse ion exchange occurs when negatively charged ions in groundwater, such as bicarbonates (HCO_3^-), are exchanged for positively charged ions in minerals or soils, such as hydrogen ions (H^+). This type of ion exchange results in an increase in the concentration of negatively charged ions in the groundwater and a decrease in the concentration of positively charged ions (Flörke et al., 2013).

Positive and reverse ion exchange can both have significant impacts on the chemical composition of groundwater, as the exchange of ions can alter the balance of positively and negatively charged ions in the water. For example, positive ion exchange can result in an increase in the concentration of sodium in the groundwater, which can affect the water's suitability for various uses, such as drinking water or irrigation. Similarly, reverse ion exchange can result in an increase in the acidity of the groundwater, which can have implications for the groundwater's suitability for various uses and for the stability of minerals in the subsurface

Overall, positive, and reverse ion exchange are important processes in groundwater chemistry, and they play a role in controlling the chemical composition of groundwater and the distribution of different ions in the subsurface.

4.8. Carbonate and sulfate Dissolution:

Carbonate and sulfate dissolution are important processes in groundwater chemistry. They refer to the dissolving of carbonate and sulfate minerals in the subsurface due to the movement of groundwater.

Carbonate dissolution occurs when groundwater comes into contact with carbonate minerals, such as calcite or dolomite, and reacts with them to form dissolved carbon dioxide (CO_2) and

bicarbonates (HCO_3^-). This process can result in a decrease in the concentration of carbonates in the subsurface and an increase in the concentration of bicarbonates in the groundwater.

Sulfate dissolution occurs when groundwater comes into contact with sulfate minerals, such as gypsum or anhydrite, and reacts with them to form dissolved sulfates (SO_4)⁻². This process can result in a decrease in the concentration of sulfates in the subsurface and an increase in the concentration of sulfates in the groundwater (Adebayo et al., 2021).

Both carbonate and sulfate dissolution can have significant impacts on the chemical composition of groundwater, as the dissolved ions can alter the balance of positively and negatively charged ions in the water. For example, carbonate dissolution can result in an increase in the alkalinity of the groundwater, which can affect the water's pH and its suitability for various uses, such as drinking water or irrigation. Similarly, sulfate dissolution can result in an increase in the concentration of sulfates in the groundwater, which can have implications for the water's suitability for various uses and for the stability of minerals in the subsurface.

Overall, carbonate and sulfate dissolution are important processes in groundwater chemistry, and they play a role in controlling the chemical composition of groundwater and the distribution of different ions in the subsurface.

4.9. Fluoride Dissolution:

Fluoride dissolution refers to the process of dissolving fluoride-containing minerals in the subsurface due to the movement of groundwater. Fluoride is a naturally occurring ion that is present in many minerals, including fluorite and fluorspar.

When groundwater comes into contact with fluoride-containing minerals, the fluoride ions can dissolve into the water and become part of the groundwater. The concentration of fluoride in the groundwater can vary widely, depending on the geology of the area, the minerals present, and the water-rock interactions that occur (Abbas et al., 2021).

Fluoride can have a significant impact on the chemical composition of groundwater, as it can alter the balance of ions in the water. In some cases, high concentrations of fluoride in groundwater can pose a risk to human health, as fluoride can cause dental and skeletal fluorosis if consumed in large quantities over a long period of time (Rather et al., 2016).

On the other hand, low to moderate levels of fluoride in drinking water have been shown to have beneficial effects on oral health, as it helps to strengthen teeth and prevent cavities. In fact, fluoride is often added to public drinking water supplies to provide these benefits.

Overall, fluoride dissolution is an important process in groundwater chemistry, and it plays a role in controlling the concentration of fluoride in groundwater and its potential impact on human health and the environment.

4.10. Agriculture Analysis:

Bad quality of water is one of the major reason due to which diseases attack human body. So, for a good healthy body the quality of drinking water should be in a good condition. In this study groundwater quality assessment for drinking water is conducted by analyzing Total dissolved solid (TDS) ranges.

Now for the agricultural purpose the groundwater quality assessment is done by using Salinity index, Sodium adsorption ratio, sodium percentage, Kelley's ratio, and Magnesium ratio analysis (Sridharan and Senthil Nathan 2017).

The salinity hazard is the most effective water quality assessment method used for agriculture purpose. Salinity hazard is classified on the bases of electrical conductivity values. Salinity hazard is classified into nine classes the first one ranges from 0 – 250 and the last one is based on the values which are > 100,000.

Sodium adsorption ratio is the concentration of calcium, Sodium and Magnesium in meq/l. SAR analysis is use for irrigation purpose and calculated by using equation (eq 4.6) (Sheikhy Narany et al., 2015) .

$$\text{SAR} = \text{Na} / \{(\text{Ca} + \text{Mg}) / 2\}^{1/2} \quad (4.6)$$

If irrigation water contains high level of Magnesium, then water will not be able to reach the root of the plants properly because water is absorbed between clay and magnesium. Magnesium Hazard is calculated by the equation (eq 4.7) (Doneen, 1964).

$$\text{MH} = ((\text{Mg}^{2+}) * 100) / (\text{Ca}^{2+} + \text{Mg}^{2+}) \quad (4.7)$$

Kellys ratio is define as Balance between the calcium, megnessium and sodium in water. Its assessment is also used for irrigation purpose Kellys ratio is calculated by using equation (eq 4.8) (Ravikumar et al., 2011).

$$\mathbf{KR = Na^+ / (Ca^{2+} + Mg^{2+})} \quad \mathbf{(4.8)}$$

4.11. Health Risk Assessment:

In chunian groundwater is mostly contaminated by Arsenic which is the naturally occurring heavy metal that contaminate the drinking water due to which many health problems occur. In this study we calculated the non-carcinogenic and Carcinogenic health risks assessment. The non-carcinogenic health risk assessment is calculated by using the (eq 4.9) (Zheng, Liu et al. 2010).

$$\mathbf{ADD = \frac{C * IR * ED * EF}{BW * AT}} \quad \mathbf{(4.9)}$$

Where ADD is the Average daily dose, C represents the concentration of Arsenic (mg/L), IR represents the daily ingestion rate of water (2L/day), ED represents exposure duration (67 years), EF represents the exposure frequency that is 365 days/year, BW represents the average body weight (72kg) and AT represents average exposure time which is 24455 days.

After that hazard Quotient values are calculated for Arsenic two conditions are given for hazard quotient if (HQ > 1) then it is considered to be harmful for health and if the (HQ < 1) then it is considered to be safe and good quality water for drinking. Where RFD represents the reference dose and RFD for Arsenic in drinking water= 0.3mg kg⁻¹ day⁻¹ or 0.0003mg kg⁻¹ day⁻¹ (eq 4.10) (Ahada and Suthar 2019).

$$\mathbf{HQ = \frac{CDI}{RFD}} \quad \mathbf{(4.10)}$$

The carcinogenic risk is calculated by multiplying the average daily dose with Arsenic slope factor whose value is 1.5mg (eq 4.11) (Rehman, Siddique et al. 2022).

$$\mathbf{CR = ADD * CSF} \quad \mathbf{(4.11)}$$

Chapter: 5

Results and Discussion

The electrical conductivity ranges from 143 - 5044 $\mu\text{S}/\text{cm}$ and about 70% of groundwater samples are within the limits and 30% exceeds the WHO limits with an average value of 1463. The TDS values ranges from 254 - 3462 mg/L and about 73% of groundwater samples are within the limits of WHO and 27% exceeds the WHO limits with an average value of 968 mg/L. The PH values range from 7 - 8.3 with an average value of 7.45 and about 100% of the groundwater samples are within the limits of WHO. The value of HCO_3 varies from 160-1030 mg/L with an average value 424.4 mg/L however 31% samples for HCO_3 are within the WHO limit and 69% of the groundwater samples exceeds the limit of WHO. The concentration of Ca and Mg vary from 8 – 180 mg/L and 2 -118 mg/L with an average value 75.57 mg/L and 40.90 mg/L and both of these elements are 100% within the limit of WHO. The Cl and SO_4 ranges from 13-945 mg/L and 20-1174 mg/L and about 87% and 86%of groundwater samples are within the limits of WHO and 13% and 14% of groundwater samples exceeds the WHO limits with an average value of 115.9 mg/L and 248.1 mg/L. The Hardness ranges from 50 - 765 mg/L and about 84% of groundwater samples are within the limits and 16% exceeds the WHO limits with an average value of 352.9 mg/L. The concentration of Na and K vary from 18 – 1212 mg/L and 2 -30 mg/L with an average value 218.8 mg/L and 8.07 mg/L and about 79% and 80% of the groundwater samples are within the limits of WHO and 21% and 20% of groundwater samples exceeds the limit of given WHO. The F ranges from 0 – 2.26 mg/L and about 89% of groundwater samples are within the limits and 11% exceeds the WHO limits with an average value of 0.56 mg/L. The As ranges from 0.22 – 24.13 PPb and about 53% of groundwater samples are within the limits and 47% exceeds the WHO limits with an average value of 8.78 PPb. Other elements like NO_3 , PO_4 , and Fe vary from 0.01 – 8.04 mg/L, 0.01 -0.3 mg/L and 0.01 -0.47 mg/L with an average value 1.70 mg/L, 0.07 mg/L and 0.12 mg/L and all of these elements are 100% within the limit of WHO (table 5.1).

Table 5.1 Statistical analysis of Physiochemical Parameters and their comparison with the given WHO limits.

Parameters	Units	Min	Max	Avg	WHO	Percentage (%) within Limits	Percentage (%) Exceeds limit
EC	μS/cm	143	5044	1463	1500	70%	30%
TDS	mg/L	254	3462	968	1000	73%	27%
PH	----	7	8.3	7.45	6.5–8.5	100%	0
HCO ₃	mg/L	160	1030	424.4	350	31%	69%
CO ₃	mg/L	0	10	0.71	200	100%	0
Cl	mg/L	13	945	115.9	250	87%	13%
SO ₄	mg/L	20	1174	248.1	400	86%	14%
Ca	mg/L	8	180	75.57	300	100%	0
Mg	mg/L	2	111	40.90	150	100%	0
Hardness	mg/L	50	765	352.9	500	84%	16%
Na	mg/L	18	1212	218.8	200	79%	21%
K	mg/L	2	30	8.07	10	80%	20%
NO ₃ (N)	mg/L	0.01	8.04	1.70	45	100%	0
PO ₄	mg/L	0.01	0.3	0.07	0.3	100%	0
F	mg/L	0	2.26	0.56	1.5	89%	11%
Fe	mg/L	0.01	0.47	0.12	3	100%	0
As	(PPb)	0.22	24.13	8.78	10	53%	47%
Pb	(PPb)	0.16	8.49	2.64	10	100%	0

5.1. Spatial Distribution pattern Analysis:

The groundwater characteristics is influenced by various factors including geology, topography, land use, and human activities. In general, groundwater chemistry is strongly affected by the different minerals in the rock and soil, and the type and number of pollutants present in the surrounding environment. Groundwater can contain high levels of dissolved minerals such as calcium, magnesium, and iron, as well as dissolved salts and other contaminants such as nitrates, pesticides, and bacteria. These contaminants can be transported through the groundwater flow system, leading to spatial patterns of varying chemical quality. In some cases, the spatial pattern of groundwater chemistry may be predictable and consistent, while in other cases, it may be more complex and variable. Understanding the spatial pattern of groundwater chemical characteristics is important for managing groundwater resources, assessing water quality, and preventing contamination of aquifers. Interpolation method is used in ArcGIS software by using IDW tool to construct spatial distribution maps.

The value of water table depth varies between 5 and 60 low values are indicated by yellow Colour and high values are indicated by dark orange Colour, in case of Electrical conductivity varies from 153 to 3,889 $\mu\text{S}/\text{cm}$ the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of EC most of the study area have the Electrical conductivity values in-between 801 to 1639 $\mu\text{S}/\text{cm}$. The values of PH varies from 7 to 8.5 the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of PH almost all the study area is lying in-between the values 7.1 to 7.5. The values of Turbidity varies from 0 to 7 mg/L the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of Turbidity almost 50% of the study area is lying in-between the values 2 to 3 mg/L and the 50% of the area is lying in-between the values 0 to 1 mg/L and 4 to 7 mg/L. The values of TDS varies from 255 to 2542 mg/L the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of TDS almost 73% of the study area is lying in-between the values 501 to 1,170 mg/L and the other 27% of the area is lying in-between the values 1171 to 2542 mg/L (figure 5.1).

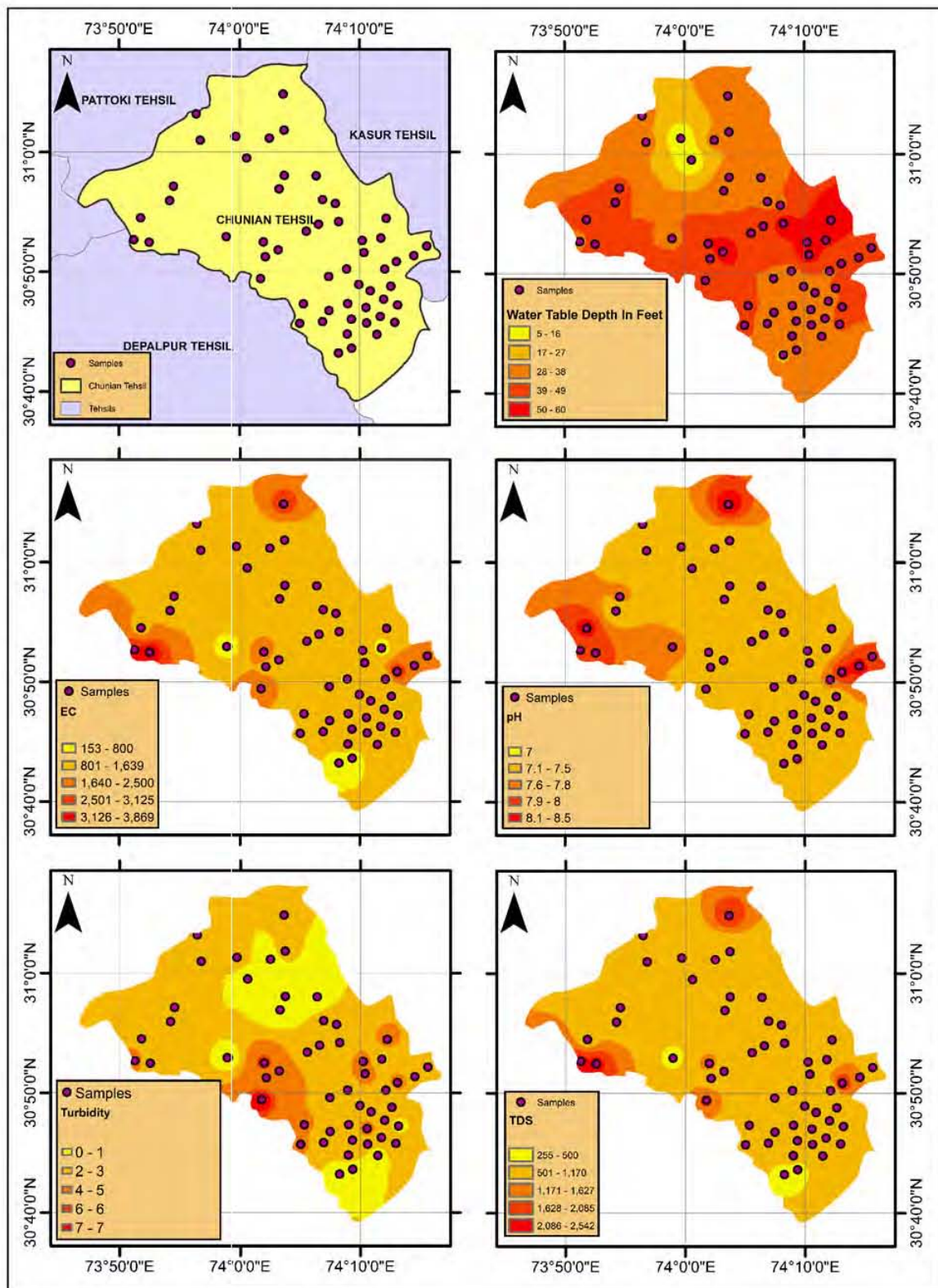


Figure 5.1 Spatial Distribution map of Water table, EC, PH, Turbidity and TDS.

The values of Alkalinity varies from 3 to 21 mg/L the low values are represented by yellow Color, and high values are represented by dark orange Color. In case of Alkalinity almost all the study area is lying in-between the values 4.4 to 10.2 mg/L. The values of HCO_3 varies from 161 to 1029 mg/L the low values are represented by yellow Color, and high values are represented by dark orange Colour. In case of HCO_3 almost 31% of the study area is lying in-between the values 161 to 350 mg/L and the other 69% of the area is lying in-between the values 350 to 1029 mg/L. The values of CO_3 varies from 0 to 10 mg/L the low values are represented by yellow Color, and high values are represented by dark orange Color. In case of CO_3 almost 80% of the study area is lying in-between the values 0 to 2 mg/L and the other 20% of the area is lying in-between the values 3 to 10 mg/L. The values of Cl varies from 13 to 588 mg/L the low values are represented by yellow Color, and high values are represented by dark orange Color. In case of Cl almost 80% of the study area is lying in-between the values 13 to 128 mg/L. The values of SO_4 varies from 20 to 715 mg/L the low values are represented by yellow Color, and high values are represented by dark orange Color. In case of SO_4 almost 50% of the study area is lying in-between the values 160 to 250 mg/L and the other 20% of the area is lying in-between the values 20 to 159 mg/L and 251 to 715 mg/L (figure 5.2).

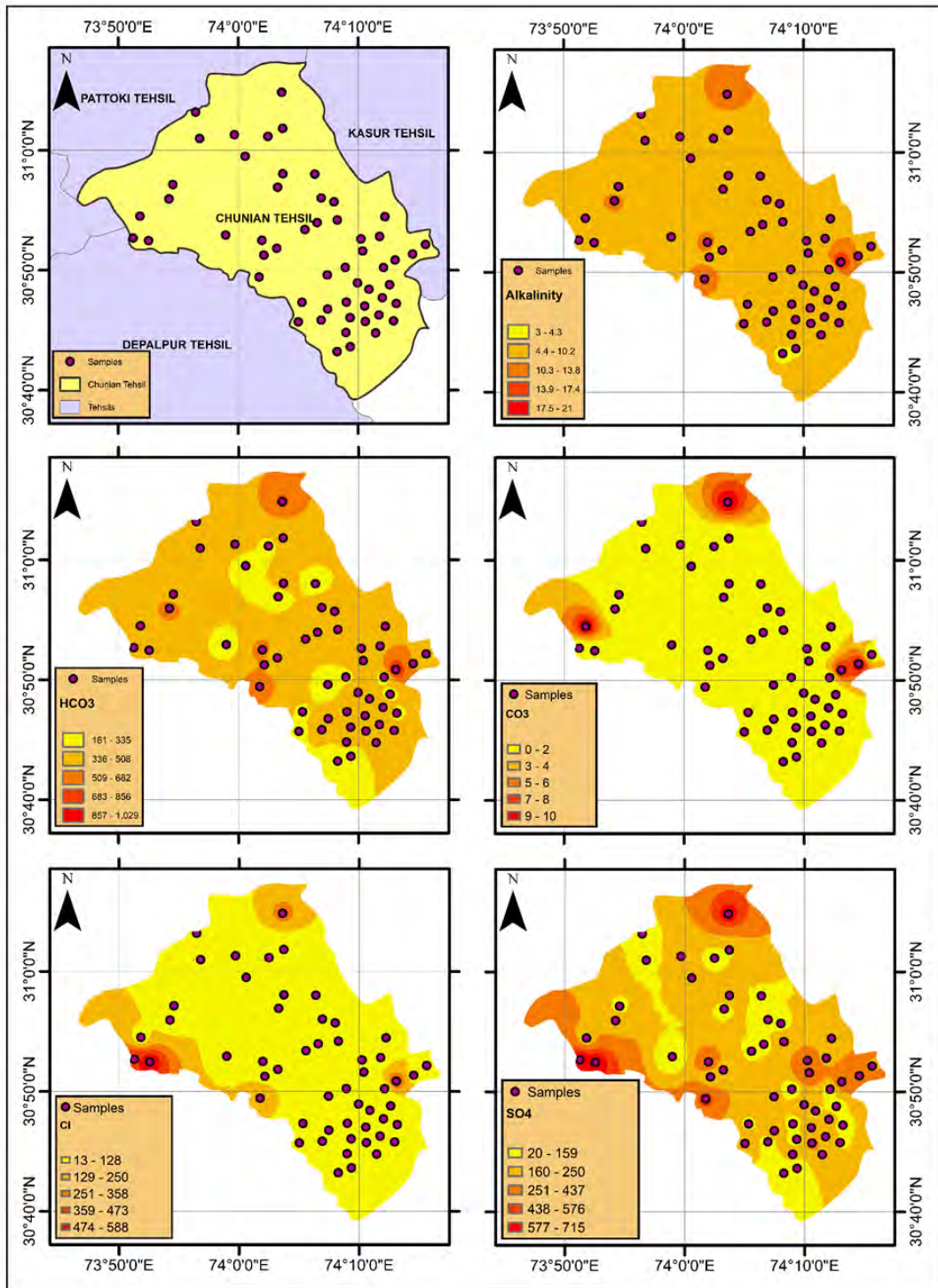


Figure 5.2 Showing Spatial Distribution map of Alkalinity, HCO₃, CO₃, Cl and SO₄.

The values of calcium varies from 0 to 144 mg/L the low values are represented by yellow Color, and high values are represented by dark orange Color. In case of calcium almost 80% the study area is lying in-between the values 36 to 144 mg/L. The values of Magnesium varies from 2 to 110 mg/L the low values are represented by yellow Color, and high values are represented by dark orange Color. In case of Magnesium almost 70% of the study area is lying in-between the values 31 to 45 mg/L and the other 20% of the area is lying in-between the values 2 to 30 mg/L and 46 to 110 mg/L. The values of Hardness varies from 50 to 594 mg/L the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of Hardness almost 80% of the study area is lying in-between the values 487 to 594 mg/L and the other 20% of the area is lying in-between the values 50 to 300 mg/L. The values of Potassium varies from 2 to 30 mg/L the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of Potassium almost 60% of the study area is lying in-between the values 2 to 8 mg/L and 40% of the study area is covered by the values lying between 9 to 30 mg/L. The values of NCO_3 varies from 0 to 8 mg/L the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of NCO_3 almost 80% of the study area I lie in-between the values 0 to 1 mg/L and the other 20% of the area is lying in-between the values 2 to 8 mg/L (figure 5.3).

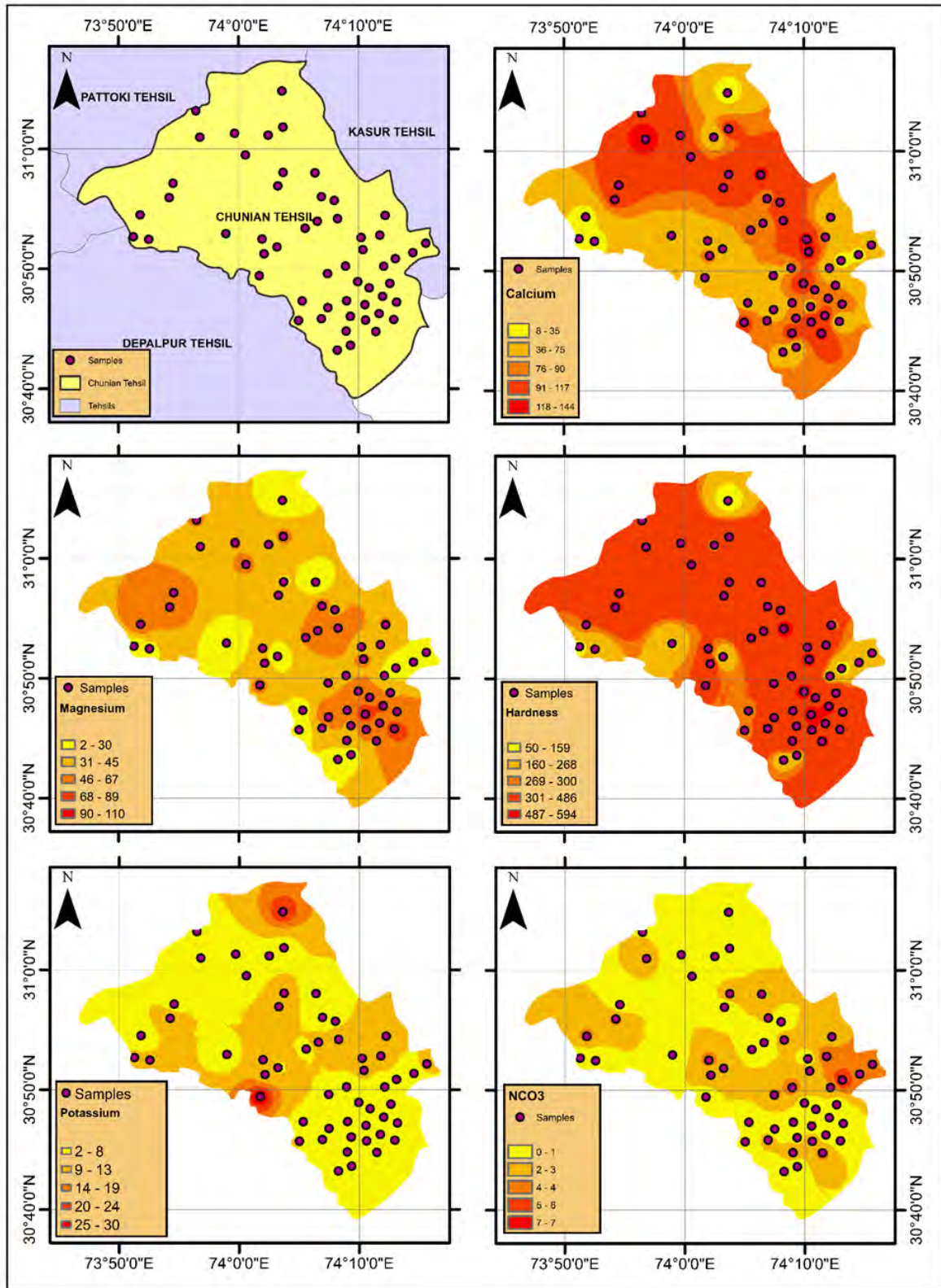


Figure 5.3 Showing Spatial Distribution map of Calcium, Magnesium, Potassium, NCO₃ and Hardness.

The values of PO₄ varies from 0.01 to 0.3 mg/L the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of PO₄ almost 50% of the study area is lying in-between the values 0.01 to 0.07 mg/L and the other 50% of the study area is covered with the values lying between 0.08 to 0.3 mg/L .

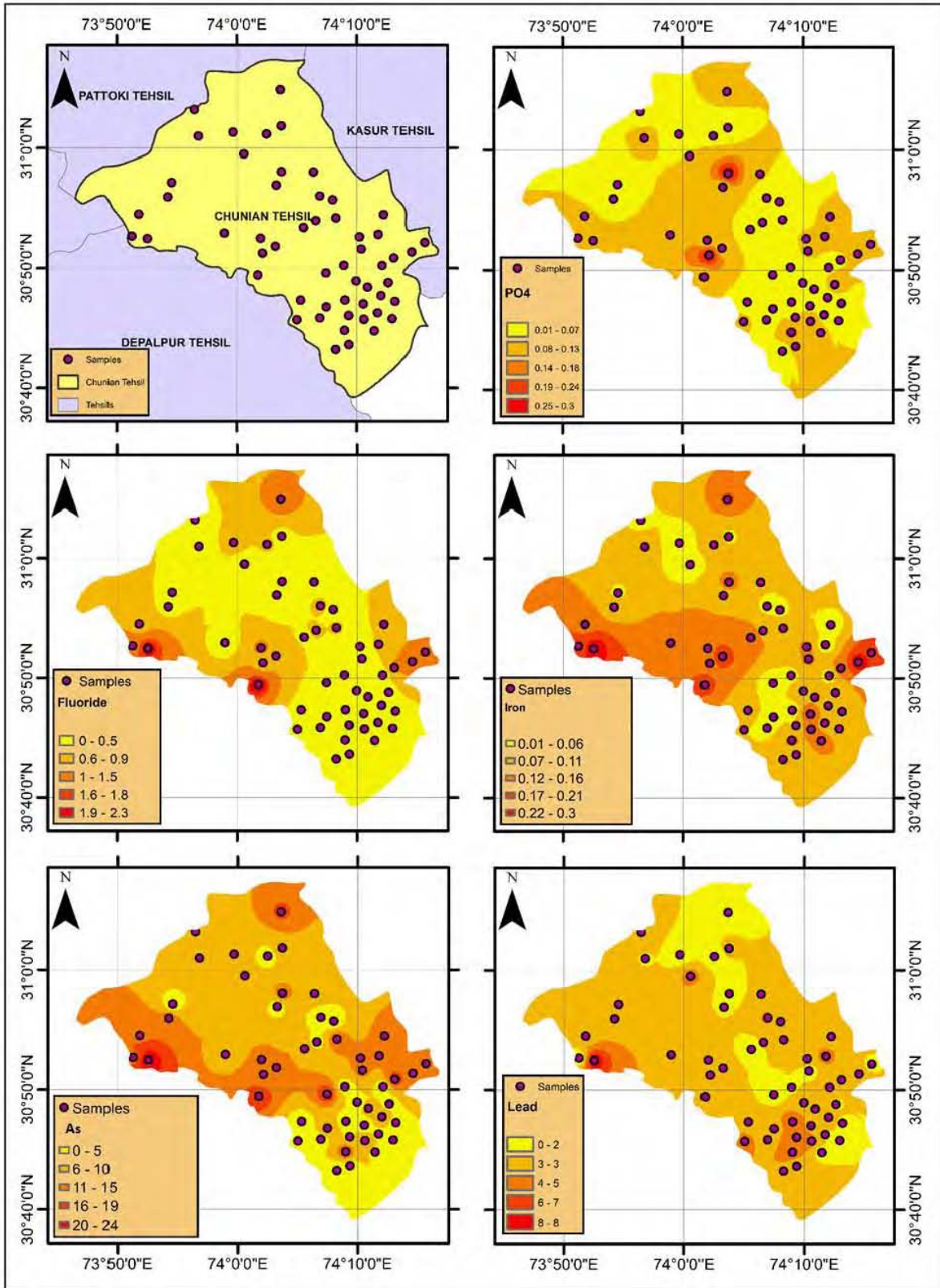


Figure 5.4 Showing Spatial Distribution map of PO₄, Sodium, Iron, Lead, and Arsenic

The values of Fluoride varies from 0 to 2.3 mg/L the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of Fluoride almost 80% of the study area is lying in-between the values 0 to 0.5 mg/L and the other 20% of the area is lying in-between the values 0.6 to 2.3 mg/L. The values of Iron varies from 0.01 to 0.3 the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of Iron almost 70% of the study area is lying in-between the values 0.12 to 0.16 mg/L and the other 30% of the area is lying in-between the values 0.01 to 0.06 mg/L and 0.17 to 0.3 mg/L. The values of As varies from 0 to 24 ppb the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of As almost 53% of the study area is lying in-between the values 1 to 10 ppb. The values of Lead varies from 0 to 9 ppb the low values are represented by yellow Colour, and high values are represented by dark orange Colour. In case of Lead almost 80% of the study area is lying in-between the values 2 to 3 ppb and the other 20% of the area is lying in-between the values of 4 to 9 ppb (figure 5.4).

5.2. Correlation:

Correlation analysis tells the relation between the ions the ions which have positive correlations are because their source is same but those which have negative correlations means that they have different source This correlation is a very important type of tool to understand the relation between different parameters of groundwater. It also indicates the type of rocks these ions must have been generated from and their solubility. Also suggests the involvement of humans in the pollution of such water sources.

TDS have values greater than 0.7 with EC it has 0.97 so it has positive relation with EC, Alkalinity have values 0.71 with EC and 0.75 with TDS, HCO_3 also have positive relation with EC and TDS with values 0.72 and 0.76, CO_2 have positive relation with PH with value 0.77 and Cl have positive relation with EC and TDS and SO_4 have positive relation with EC, TDS and Cl with values greater than 0.7, Ca have negative relation with all, Na have positive relation with EC, TDS, Cl and SO_4 with values 0.93, 0.96, 0.91 and 0.84 all the other parameters have either negative values or have values smaller than 0.7 (table 5.2).

Par	EC	PH	TUR	TDS	AIK	HCO ₃	CO ₃	Cl	SO ₄	Ca	Mg	Na	K	NO ₃	PO ₄	Fe	As	Pb
EC	1.00																	
PH	0.53	1.00																
TUR	0.44	0.09	1.00															
TDS	0.97	0.50	0.43	1.00														
AIK	0.71	0.34	0.49	0.75	1.00													
HCO ₃	0.72	0.34	0.48	0.76	1.00	1.00												
CO ₃	0.47	0.77	0.09	0.45	0.56	0.55	1.00											
Cl	0.91	0.54	0.27	0.92	0.54	0.55	0.33	1.00										
SO ₄	0.90	0.38	0.41	0.93	0.55	0.56	0.31	0.83	1.00									
Ca	-0.31	-0.70	-0.21	-0.32	-0.17	-0.18	-0.48	-0.39	-0.22	1.00								
Mg	-0.14	-0.37	0.18	-0.15	0.13	0.12	-0.20	-0.25	-0.11	0.16	1.00							
Na	0.93	0.65	0.40	0.96	0.70	0.71	0.55	0.91	0.84	-0.51	-0.33	1.00						
K	0.48	0.15	0.40	0.55	0.47	0.48	0.14	0.43	0.54	-0.14	0.00	0.48	1.00					
NO ₃	0.25	0.19	0.09	0.28	0.49	0.47	0.39	0.15	0.11	-0.11	-0.14	0.31	0.06	1.00				
PO ₄	0.20	-0.03	-0.03	0.19	0.13	0.14	0.08	0.17	0.17	0.08	-0.16	0.16	0.15	0.19	1.00			
Fe	0.65	0.38	0.31	0.58	0.38	0.39	0.34	0.54	0.57	-0.24	-0.04	0.55	0.25	0.15	0.38	1.00		
As	0.64	0.29	0.27	0.66	0.50	0.50	0.31	0.59	0.63	-0.19	-0.05	0.60	0.47	0.38	0.28	0.45	1.00	
Pb	0.04	-0.06	-0.02	0.06	-0.07	-0.06	-0.11	0.15	0.07	0.00	-0.01	0.04	0.00	-0.05	0.07	0.00	0.11	1

Table 5.2 shows correlation of all the heavy metals.

5.3. Piper Plot:

In piper plot the groundwater samples of tehsil Chunian in case of cations 10 samples lie in calcium type (Zone A), 22 samples lie in no dominant type (Zone B) and 17 samples lie in sodium Type (Zone D) while in case of anions most of the groundwater samples lie in bicarbonate type (Zone E) which are 43 samples , 5 samples lie in no dominant type (Zone B) and only 2 samples lie in Sulphate type (Zone F). The mixture of anions and cation are shown in diamond shape in piper plot most of the samples of groundwater lie in $\text{HCO}_3\text{-Ca}$ type (Zone 4) which are 28 samples, and, 5 samples lie in $\text{SO}_4\text{ Cl-Na}$ type (Zone 2) and 17 samples in $\text{HCO}_3\text{-Na}$ type (Zone 3) (figure 5.5).

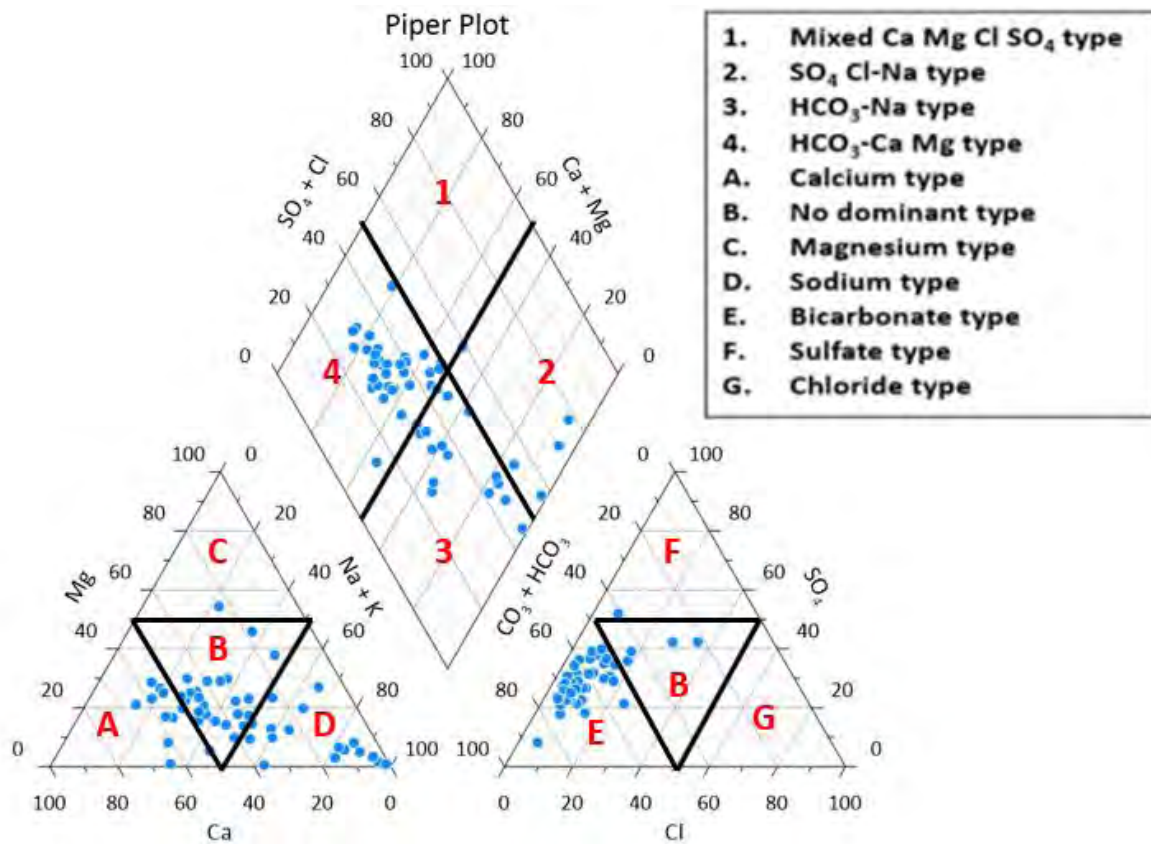


Figure 5.5 Showing Piper diagram of Tehsil Chunian.

5.4. Gibbs diagram:

The Gibbs plot identifies the groundwater chemistry controlling factors in tehsil chunian. The groundwater chemistry was control by different factors like weathered condition, minerology of the aquifer and many other. The two Gibbs plots were constructed one for cations and the other one for anions. In Gibbs diagram the main processes include evaporation dominance, Evaporation crystallization dominance, Rock dominance, atmospheric precipitation dominance and Rainfall Dominance. The cation and anions both plots show that all the samples of the study area lie in the evaporation crystallization dominance and rock dominance zones. Most of the samples lie between the TDS range 100 – 1000 which is a rock dominance zone, and few samples lie between the TDS range 1000 – 10000 which is evaporation crystallization dominance zone. About 80% of the samples lie in rock dominance and 20% samples lie in evaporation crystallization zone.

In Gibbs plots, the "Rock Dominance Zone" is a region in which the rock type can be determined based solely on its chemical composition, without considering any additional information such as mineralogy or texture. The samples in this zone are said to be "rock-dominated" because their chemical composition is controlled primarily by the rock-forming minerals, rather than by any other processes such as alteration or contamination (figure 5.6).

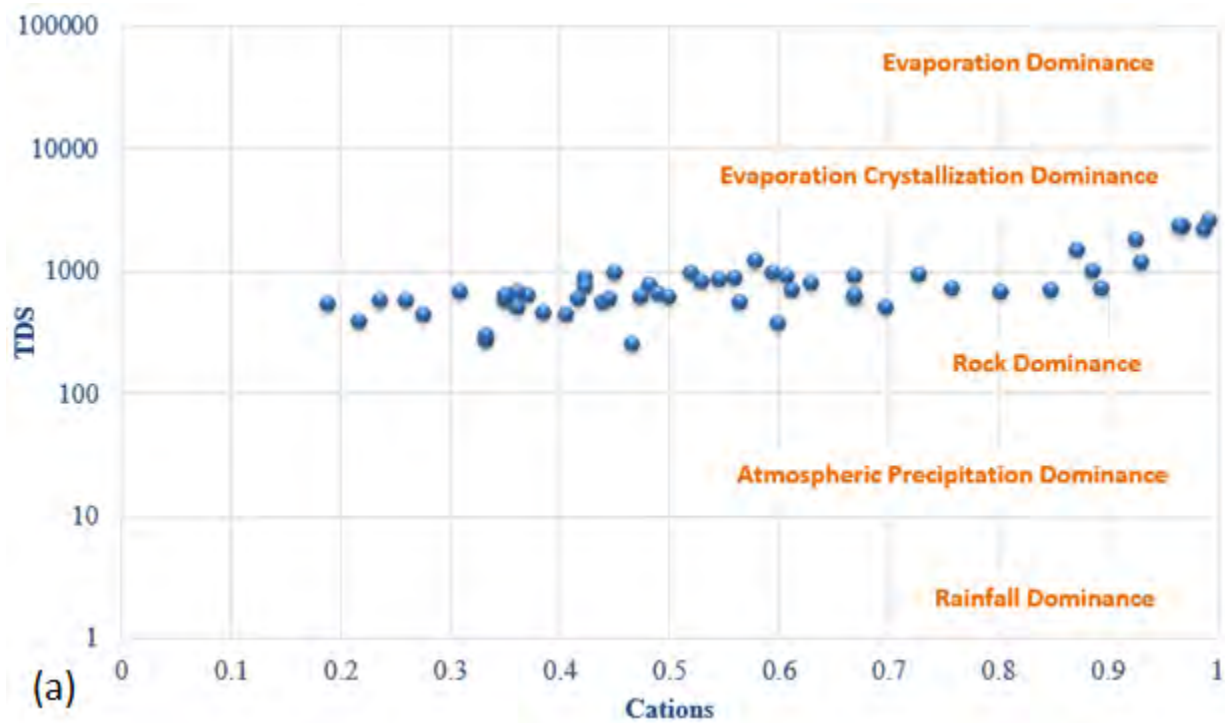
In this zone, the ratio of elements that are abundant in the rock-forming minerals (such as Si, Al, and Fe) is constant, while the ratios of elements that are not abundant in the rock-forming minerals (such as K, Rb, Sr, and other trace elements) vary in response to other processes. By plotting the chemical composition of a sample in a Gibbs plot, you can determine whether it falls within the Rock Dominance Zone, and if so, what rock type it is likely to be.

In Gibbs plots, the "Evaporation-Crystallization Dominance Zone" is a region in which the chemical composition of a sample is controlled primarily by processes of evaporation and crystallization. This means that the ratios of elements in the sample are determined by the number of elements that were present in the original solution, as well as by the conditions under which the solution was evaporated and the minerals were crystallized (figure 5.6).

Samples that fall within the Evaporation-Crystallization Dominance Zone are typically found in geological environments such as evaporite deposits, salt pans, and hot springs. In these environments, the minerals formed by evaporation and crystallization can be used to reconstruct

the chemical composition of the original solution, as well as to infer the conditions under which the minerals were formed (figure 5.6).

By plotting the chemical composition of a sample in a Gibbs plot, you can determine whether it falls within the Evaporation-Crystallization Dominance Zone, and if so, what type of environment it is likely to have formed in. This information can be useful in a variety of geological applications, including understanding the evolution of sedimentary basins, reconstructing past climates, and exploring for minerals and other resources (figure 5.6).



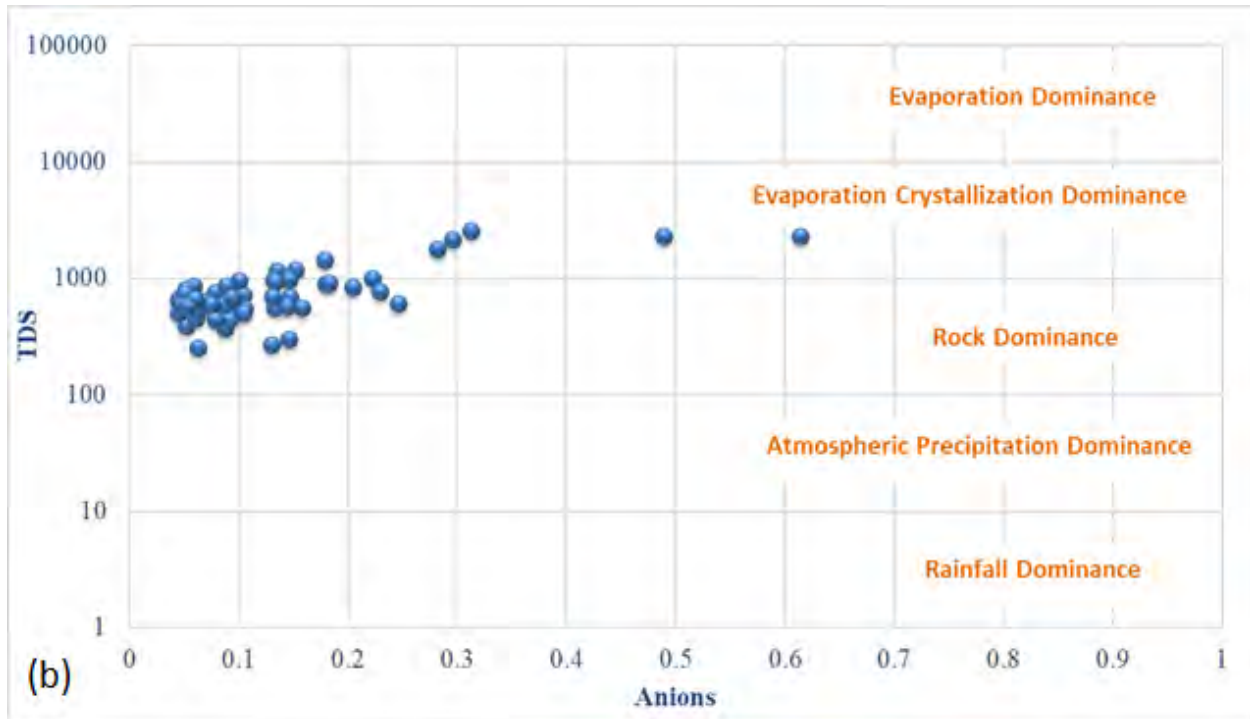


Figure 5.6 Showing Gibbs plot of Tehsil Chunian (a) Cation map (b) Anion map.

5.5. Water Quality Index Calculations:

The water quality index analysis are performed in Chunian tehsil groundwater samples are analyzed. The water quality index analysis shows that 34% of the groundwater samples lie in the excellent class, 36% groundwater samples lie in good water quality class, 20% lie in poor class, 10% in very poor class and no sample lie in worse class so most of the samples lie in the good class which shows that the water quality of Chunian is good (Table 5.3).

Table 5.3 Showing Water quality Index Calculations of Tehsil Chunian

Water Quality Index (Chunian)			
Water Quality Index (WQI)	Samples	Percentage (%)	Property
0-25	18	36%	Excellent
26-50	17	34%	Good
51-75	10	20%	Poor
76-100	5	10%	Very Poor

Table 5.4 Showing table of Water quality index values of each sample and their ranks.

Samples	EWQI Values	EWQI Quality Rank	Water Quality
Sample no 1	55.64	3	Poor
Sample no 2	57.42	3	Poor
Sample no 3	33.14	2	Good
Sample no 4	59.62	3	Poor
Sample no 5	34.75	2	Good
Sample no 6	48.87	2	Good
Sample no 7	64.78	3	Poor
Sample no 8	48.29	2	Good
Sample no 9	59.67	3	Poor
Sample no 10	29.05	2	Good
Sample no 11	47.81	2	Good
Sample no 12	36.37	2	Good
Sample no 13	69.87	3	Poor
Sample no 14	78.91	4	Very Poor
Sample no 15	87.64	4	Very Poor
Sample no 16	90.57	4	Very Poor
Sample no 17	82.54	4	Very Poor
Sample no 18	35.62	2	Good
Sample no 19	70.42	3	Poor
Sample no 20	56.65	3	Poor
Sample no 21	89.67	4	Very Poor
Sample no 22	28.45	2	Good
Sample no 23	23.38	1	Excellent
Sample no 24	18.11	1	Excellent
Sample no 25	20.38	1	Excellent
Sample no 26	29.18	2	Good
Sample no 27	30.81	2	Good
Sample no 28	22.70	1	Excellent
Sample no 29	75.27	3	Poor
Sample no 30	19.06	1	Excellent
Sample no 31	47.69	2	Good
Sample no 32	17.08	1	Excellent
Sample no 33	21.28	1	Excellent
Sample no 34	50.84	2	Good
Sample no 35	18.66	1	Excellent
Sample no 36	9.98	1	Excellent
Sample no 37	12.24	1	Excellent
Sample no 38	16.53	1	Excellent
Sample no 39	28.64	2	Good

Sample no 40	32.35	2	Good
Sample no 41	50.74	2	Good
Sample no 42	60.44	3	Poor
Sample no 43	30.19	2	Good
Sample no 44	14.18	1	Excellent
Sample no 45	14.60	1	Excellent
Sample no 46	23.72	1	Excellent
Sample no 47	35.74	2	Good
Sample no 48	19.56	1	Excellent
Sample no 49	11.37	1	Excellent
Sample no 50	9.03	1	Excellent

The water quality classification is divided into four classes excellent, good, poor and very poor that is represented by Colour green to red Colour the excellent class is represented by dark green Colour, the good class is represented by light green, the poor class is represented by orange Colour, and the very poor class is represented by red Colour. The map shows that 34% of the groundwater samples lie in the good class which is represented by light green Colour and the 36% of the groundwater samples lie in the excellent class, which is represented by dark green Colour, 20% of the groundwater samples lie in poor class which is represented by orange Colour and 10% of the groundwater samples lie in very poor class which is represented by red Colour (table 5.4).

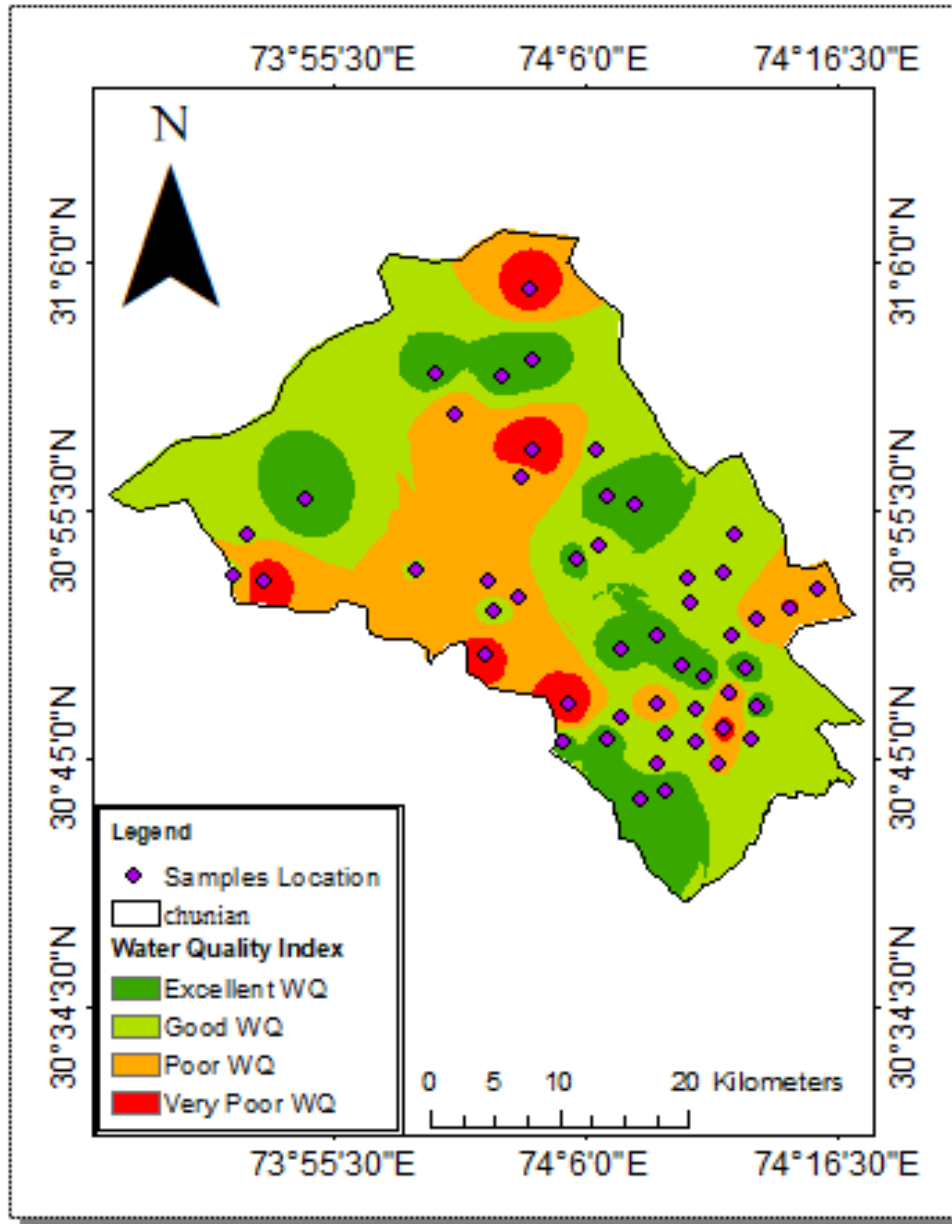


Figure 5.7 Showing Water Quality Index map of Tehsil Chunian.

5.7. Area Map:

Table 5.5 showing the Calculations of Area

Area		
1	Excellent Water Quality	1438 sq.km
2	Good Water Quality	1359 sq.km
3	Poor Water Quality	799 sq.km
4	Very Poor Water Quality	399 sq.km

5.6. Silicate Weathering analysis:

The effect of silicate weathering on the relationship between sodium (Na) and chloride (Cl) in groundwater can be represented by a graph showing the concentration of Na and Cl in different water samples. In this graph, most of the samples typically lie below the 1:1 line, which represents a theoretical relationship between Na and Cl in water (figure 5.8).

Silicate weathering is a process that occurs when groundwater reacts with silicate minerals in the subsurface, such as feldspar or quartz. During silicate weathering, cations (positively charged ions) in the groundwater, such as Na^+ and Cl^- , are exchanged for other ions in the minerals, such as hydroxyl (OH^-) and aluminum (Al^{3+}).

The effect of silicate weathering on the Na and Cl content of groundwater can be seen in the graph, as most of the samples will lie below the 1:1 line. This is because the exchange of ions during silicate weathering results in a decrease in the concentration of Na^+ and Cl^- in the groundwater and an increase in the concentration of other ions, such as OH^- and Al^{3+} . This can alter the balance of ions in the groundwater and result in a deviation from the theoretical 1:1 relationship between Na and Cl (figure 5.8).

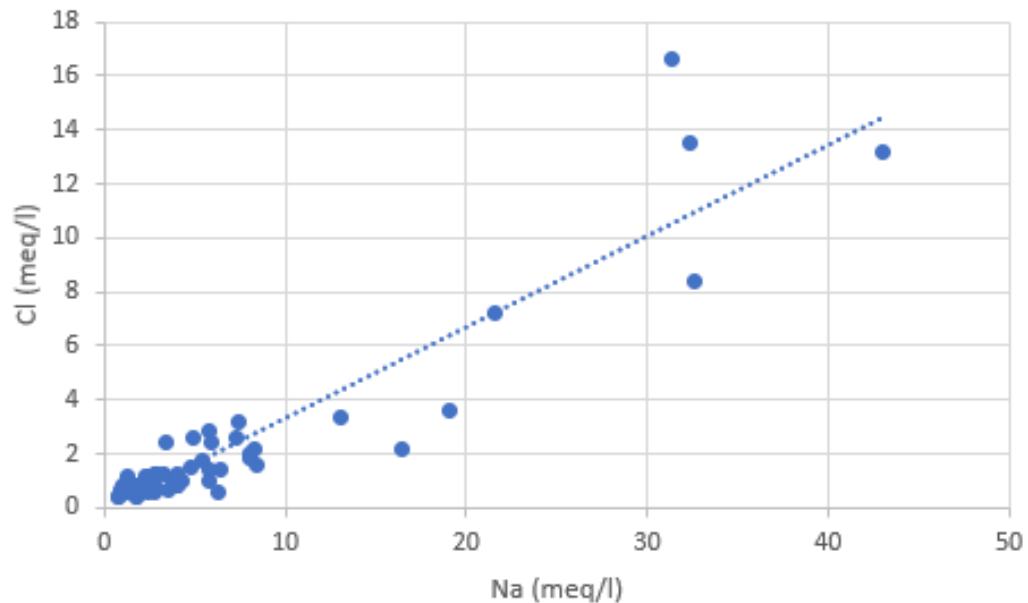


Figure 5.8 Showing graph of silicate weathering between Na and Cl

In general, the deviation from the 1:1 line in the graph indicates that silicate weathering has played a role in controlling the concentration of Na and Cl in the groundwater and has altered the balance of ions in the water. This can have implications for the chemical composition of the groundwater and its suitability for various uses, such as drinking water or irrigation (figure 5.9).

The effect of silicate weathering on the relationship between bicarbonate (HCO_3^-) and the sum of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in groundwater can be represented by a graph showing the concentration of HCO_3^- and $\text{Ca}^{2+} + \text{Mg}^{2+}$ in different water samples. In this graph, most of the samples typically lie above the 1:1 line, which represents a theoretical relationship between HCO_3^- and $\text{Ca}^{2+} + \text{Mg}^{2+}$ in water.

Silicate weathering is a process that occurs when groundwater reacts with silicate minerals in the subsurface, such as feldspar or quartz. During silicate weathering, cations (positively charged ions) in the groundwater, such as Ca^{2+} and Mg^{2+} , are exchanged for other ions in the minerals, such as hydroxyl (OH) and aluminum (Al^{3+}). At the same time, the reaction between the groundwater and minerals can result in the formation of bicarbonate (HCO_3^-) from dissolved carbon dioxide (CO_2) (figure 5.9).

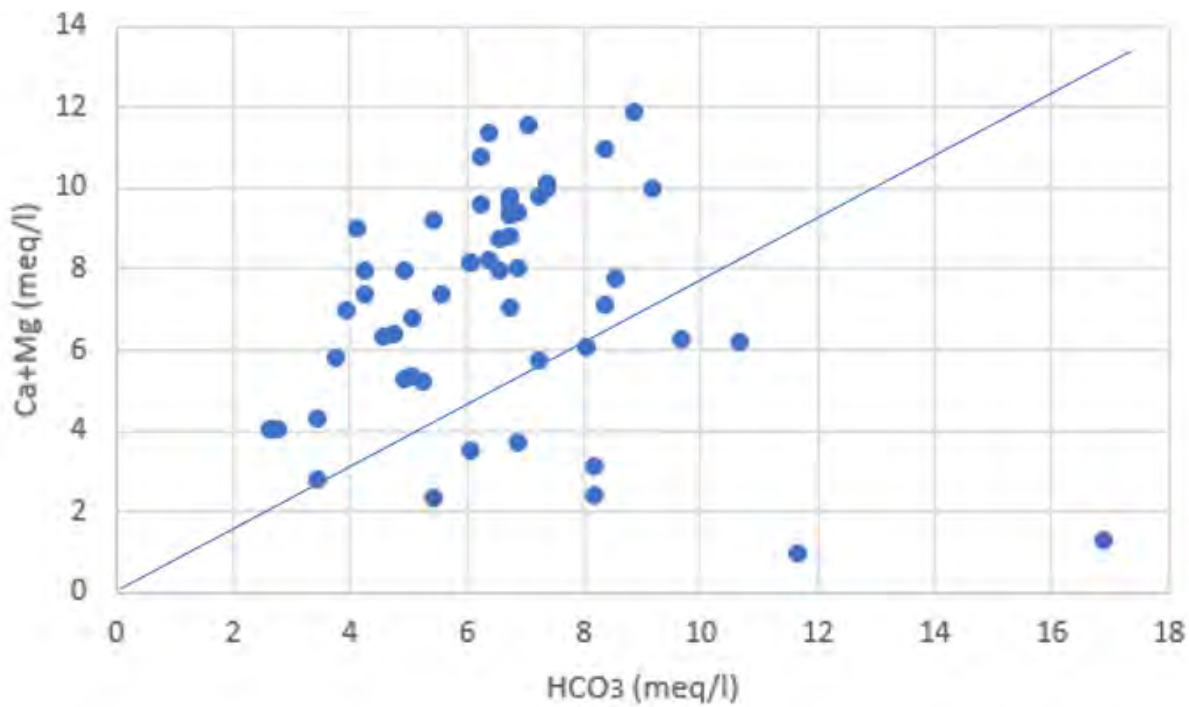


Figure 5.9 Showing graph of silicate weathering between HCO_3^- and $\text{Ca} + \text{Mg}$.

The effect of silicate weathering on the HCO_3^- and $\text{Ca}^{2+} + \text{Mg}^{2+}$ content of groundwater can be seen in the graph, as most of the samples will lie above the 1:1 line. This is because the exchange of ions during silicate weathering results in an increase in the concentration of HCO_3^- in the groundwater, while the concentration of Ca^{2+} and Mg^{2+} remains relatively constant. This can alter the balance of ions in the groundwater and result in a deviation from the theoretical 1:1 relationship between HCO_3^- and $\text{Ca}^{2+} + \text{Mg}^{2+}$.

In general, the deviation from the 1:1 line in the graph indicates that silicate weathering has played a role in controlling the concentration of HCO_3^- and $\text{Ca}^{2+} + \text{Mg}^{2+}$ in the groundwater and has altered the balance of ions in the water. This can have implications for the chemical composition of the groundwater, such as increasing the alkalinity of the water, and its suitability for various uses, such as drinking water or irrigation.

5.7. Ion exchange analysis:

A scatter plot between sodium (Na) and chloride (Cl) on one axis, and the sum of calcium (Ca^{2+}) and magnesium (Mg^{2+}) and the sum of bicarbonate (HCO_3^-) and sulfate (SO_4^{2-}) on the other axis, can be used to represent the relationship between these ions in groundwater samples and to identify whether positive or reverse ion exchange is occurring.

Positive ion exchange refers to a process in which cations (positively charged ions) in groundwater are exchanged for cations in minerals, such as silicate minerals. This can result in an increase in the concentration of cations such as Na^+ , Ca^{2+} , and Mg^{2+} in the groundwater.

Reverse ion exchange refers to a process in which cations in minerals are exchanged for cations in groundwater, resulting in a decrease in the concentration of cations such as Na^+ , Ca^{2+} , and Mg^{2+} in the groundwater.

In the scatter plot, groundwater samples representing positive ion exchange will typically have a high concentration of Na^+ and Cl^- and a high concentration of $\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{HCO}_3^- + (\text{SO}_4)^{2-}$. This is because positive ion exchange results in an increase in the concentration of cations in the groundwater, as well as the formation of bicarbonate from dissolved carbon dioxide.

Groundwater samples representing reverse ion exchange will typically have a low concentration of Na^+ and Cl^- and a low concentration of $\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{HCO}_3^- + (\text{SO}_4)^{2-}$. This is because reverse

ion exchange results in a decrease in the concentration of cations in the groundwater, as well as a decrease in the concentration of bicarbonate.

In general, the scatter plot between Na-Cl and $\text{Ca}^{+2} + \text{Mg}^{2+} - \text{HCO}_3 - (\text{SO}_4)^{2-}$ can provide valuable information about the ion exchange processes occurring in groundwater and help to better understand the chemical composition of the water (figure 5.10).

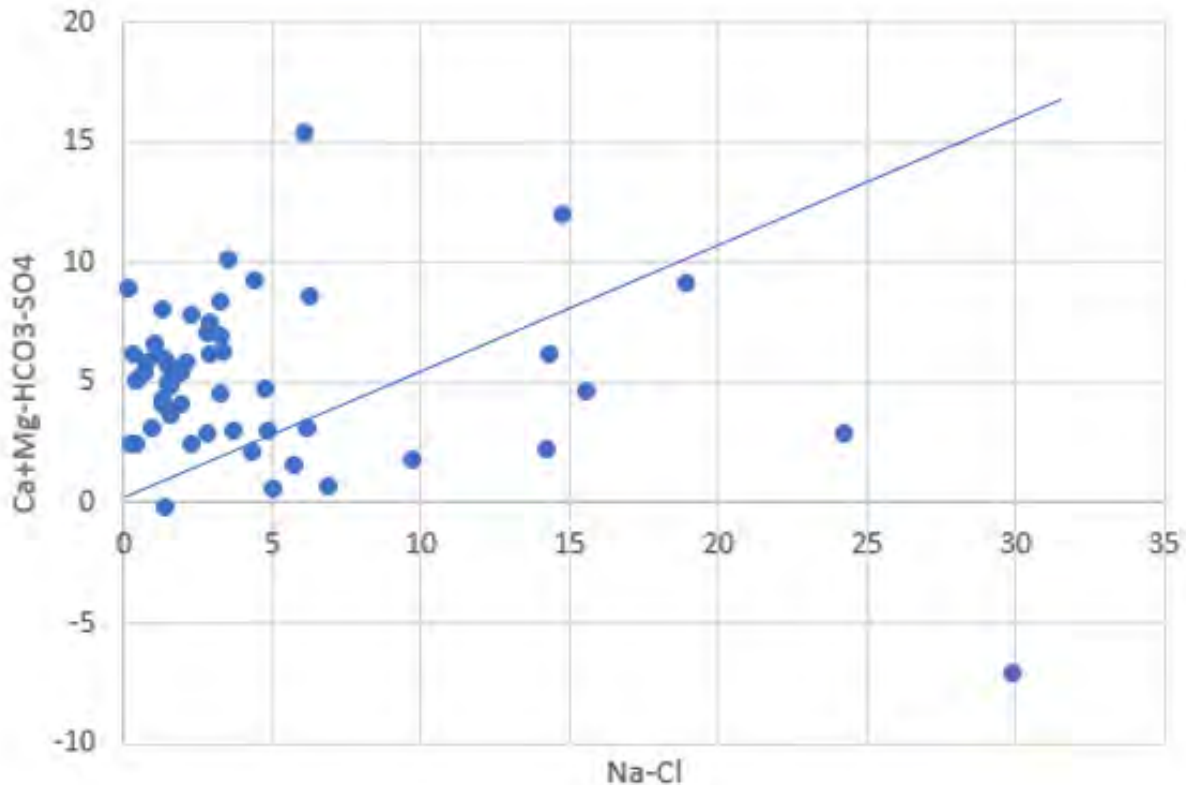


Figure 5.10 Showing graph of Ion exchange.

5.8. Carbonate and sulfate Dissolution analysis:

A scatter plot between the sum of bicarbonate (HCO_3^-) and sulfate ($(\text{SO}_4)^{2-}$) on one axis, and the sum of calcium (Ca^{2+}) and magnesium (Mg^{2+}) on the other axis, can be used to represent the relationship between these ions in groundwater samples and to understand the processes controlling the chemical composition of the water.

Carbonate minerals, such as calcite (CaCO_3) and dolomite ($\text{Ca+Mg}(\text{CO}_3)_2$), are important sources of bicarbonate (HCO_3^-) in groundwater. Dissolution of these minerals can result in the release of HCO_3^- into the groundwater, which can increase the concentration of HCO_3^- in the water.

Sulfate (SO_4)⁻² in groundwater can originate from sulfate minerals, such as gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), or from other sources, such as agricultural runoff or industrial discharge. Dissolution of sulfate minerals or the input of sulfate from other sources can increase the concentration of (SO_4)⁻² in the groundwater.

In the scatter plot, groundwater samples with high concentrations of $\text{HCO}_3^- + (\text{SO}_4)^{-2}$ and high concentrations of $\text{Ca}^{2+} + \text{Mg}^{2+}$ are likely to represent water that has been influenced by carbonate and sulfate dissolution. This can result in a deviation from the theoretical 1:1 relationship between $\text{HCO}_3^- + (\text{SO}_4)^{-2}$ and $\text{Ca}^{2+} + \text{Mg}^{2+}$, as the dissolution of these minerals can alter the balance of ions in the groundwater (figure 5.11).

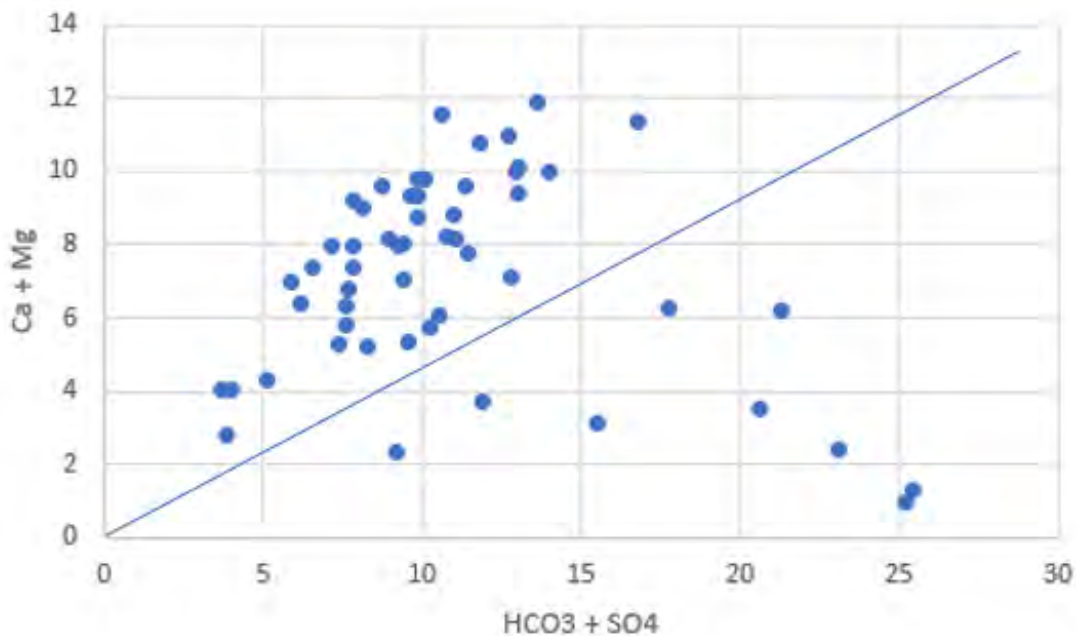


Figure 5.11 Showing graph of carbonate and silicate dissolution between $\text{HCO}_3 + \text{SO}_4$ and $\text{Ca} + \text{Mg}$.

Groundwater samples with low concentrations of $\text{HCO}_3^- + (\text{SO}_4)^{-2}$ and low concentrations of $\text{Ca}^{2+} + \text{Mg}^{2+}$ are likely to represent water that has not been influenced by carbonate and sulfate dissolution, or water that has been influenced by processes that remove these ions from the water, such as ion exchange or precipitation.

In general, the scatter plot between $\text{HCO}_3^- + (\text{SO}_4)^{-2}$ and $\text{Ca}^{2+} + \text{Mg}^{2+}$ can provide valuable information about the sources and processes controlling the chemical composition of groundwater

and help to better understand the suitability of the water for various uses, such as drinking water or irrigation.

A scatter plot between chloride (Cl^-) on one axis and the ratio of calcium (Ca^{2+}) to sulfate (SO_4^{2-}) on the other axis can be used to represent the relationship between these ions in groundwater samples and to understand the processes controlling the chemical composition of the water.

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is a sulfate mineral that can dissolve in groundwater and release calcium (Ca^{2+}) and sulfate (SO_4^{2-}) into the water. Dissolution of gypsum can result in a decrease in the concentration of Cl^- in the groundwater, as Cl^- ions can be displaced by (SO_4^{2-}) ions during the dissolution process.

In the scatter plot, groundwater samples with high ratios of Ca^{2+} to (SO_4^{2-}) and low concentrations of Cl^- are likely to represent water that has been influenced by gypsum dissolution. This can result in a deviation from the theoretical relationship between Cl^- and the ratio of Ca^{2+} to (SO_4^{2-}), as the dissolution of gypsum can alter the balance of ions in the groundwater (figure 5.12).

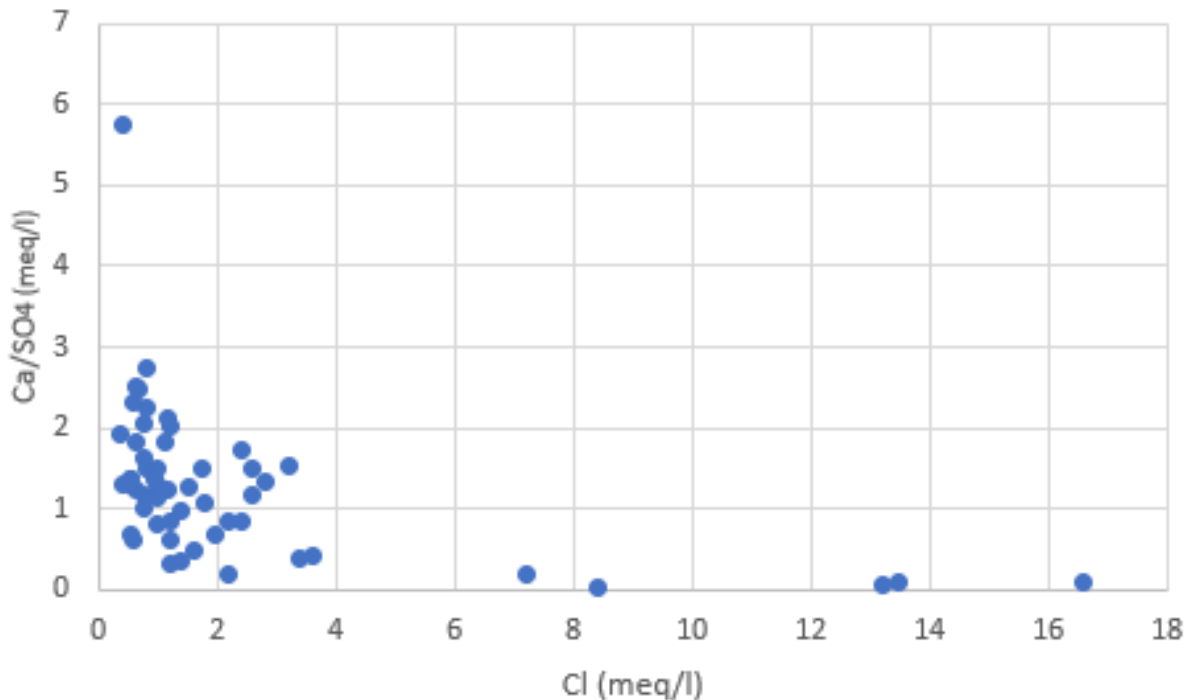


Figure 5.12 Showing graph of carbonate and silicate dissolution between cl and Ca/SO4.

Groundwater samples with low ratios of Ca^{2+} to (SO_4^{2-}) and high concentrations of Cl^- are likely to represent water that has not been influenced by gypsum dissolution, or water that has been

influenced by processes that remove calcium and sulfate from the water, such as precipitation or ion exchange.

In general, the scatter plot between Cl^- and the ratio of Ca^{2+} to $(\text{SO}_4)^{-2}$ can provide valuable information about the sources and processes controlling the chemical composition of groundwater and help to better understand the suitability of the water for various uses, such as drinking water or irrigation. Additionally, the plot can help to identify areas where gypsum dissolution is occurring and to evaluate the potential impacts of this process on the water quality.

5.9. Fluoride Dissolution analysis:

A scatter plot between sodium (Na^+) on one axis and fluoride (F^-) on the other axis can be used to represent the relationship between these ions in groundwater samples and to understand the processes controlling the chemical composition of the water.

Fluoride (F^-) in groundwater can originate from the dissolution of fluoride-bearing minerals, such as fluorite (CaF_2), or from other sources, such as agricultural runoff or industrial discharge. Dissolution of fluoride-bearing minerals or the input of fluoride from other sources can increase the concentration of F^- in the groundwater.

In the scatter plot, groundwater samples with high concentrations of F^- and high concentrations of Na^+ are likely to represent water that has been influenced by fluoride dissolution. This can result in a deviation from the theoretical relationship between Na^+ and F^- , as the dissolution of fluoride-bearing minerals can alter the balance of ions in the groundwater (figure 5.13).

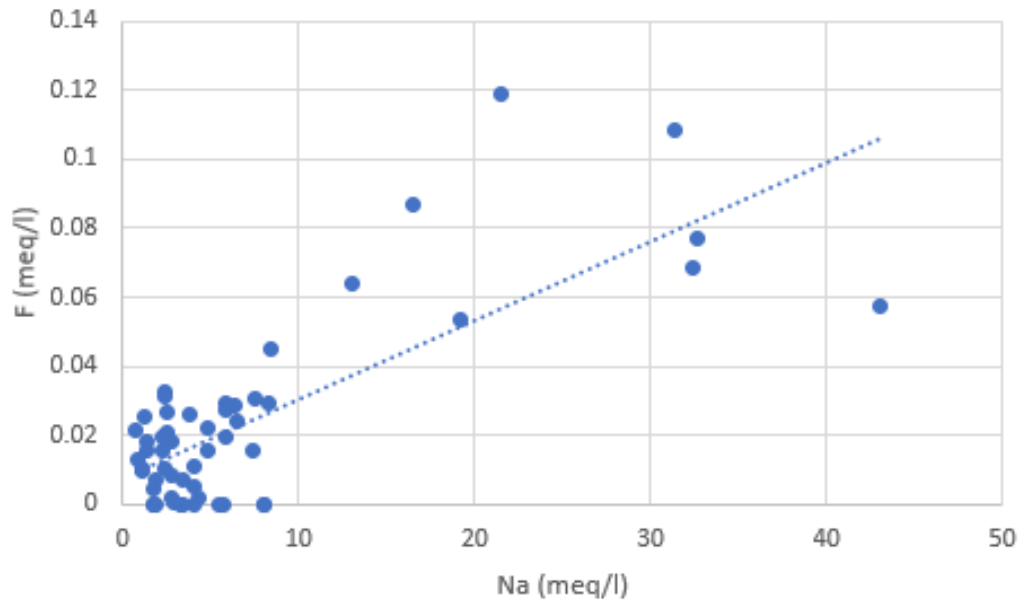


Figure 5.13 Showing fluoride dissolution map between Na and F.

Groundwater samples with low concentrations of F^- and low concentrations of Na^+ are likely to represent water that has not been influenced by fluoride dissolution, or water that has been influenced by processes that remove fluoride from the water, such as precipitation or ion exchange.

In general, the scatter plot between Na^+ and F^- can provide valuable information about the sources and processes controlling the chemical composition of groundwater and help to better understand the suitability of the water for various uses, such as drinking water or irrigation. Additionally, the plot can help to identify areas where fluoride-bearing minerals are dissolving and to evaluate the potential impacts of this process on the water quality.

The fluoride dissolution scatter plot between HCO_3^- and F^- is a graph that illustrates the relationship between two variables: HCO_3^- (bicarbonate) and F^- (fluoride). In this scatter plot, the horizontal axis represents the concentration of bicarbonate, and the vertical axis represents the concentration of fluoride. Each point on the scatter plot represents the measurement of these two variables for a sample of water.

The relationship between bicarbonate and fluoride in water can provide valuable information about the water quality and the presence of fluoride in the environment. For example, a positive relationship between bicarbonate and fluoride may indicate that the presence of bicarbonate is

contributing to the dissolution of fluoride in the water. This could be the result of the presence of fluoride-containing minerals that dissolve in the presence of bicarbonate, leading to higher concentrations of fluoride in the water (figure 5.14).

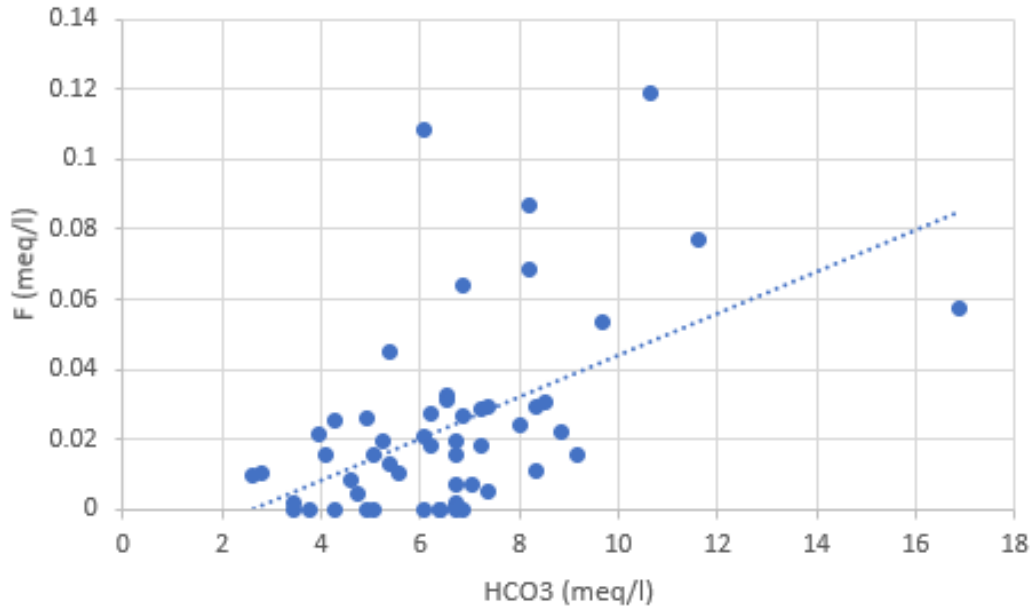


Figure 5.14 Showing graph between HCO3 and F.

In general, scatter plots are used to visualize relationships between two variables and can provide a quick way to identify patterns and trends in data. In the case of the fluoride dissolution scatter plot, it can be used to help understand the factors that influence the concentration of fluoride in water and to make informed decisions about water management and treatment strategies.

The fluoride dissolution scatter plot between Ca (calcium) and F (fluoride) is a graph that illustrates the relationship between the concentrations of these two variables in water. In this scatter plot, the horizontal axis represents the concentration of calcium, and the vertical axis represents the concentration of fluoride. Each point on the scatter plot represents the measurement of these two variables for a sample of water.

The relationship between calcium and fluoride in water can provide valuable information about the water quality and the presence of fluoride in the environment. For example, a positive

relationship between calcium and fluoride may indicate that the presence of calcium is contributing to the dissolution of fluoride in the water. This could be the result of the presence of fluoride-containing minerals that dissolve in the presence of calcium, leading to higher concentrations of fluoride in the water (figure 5.15).

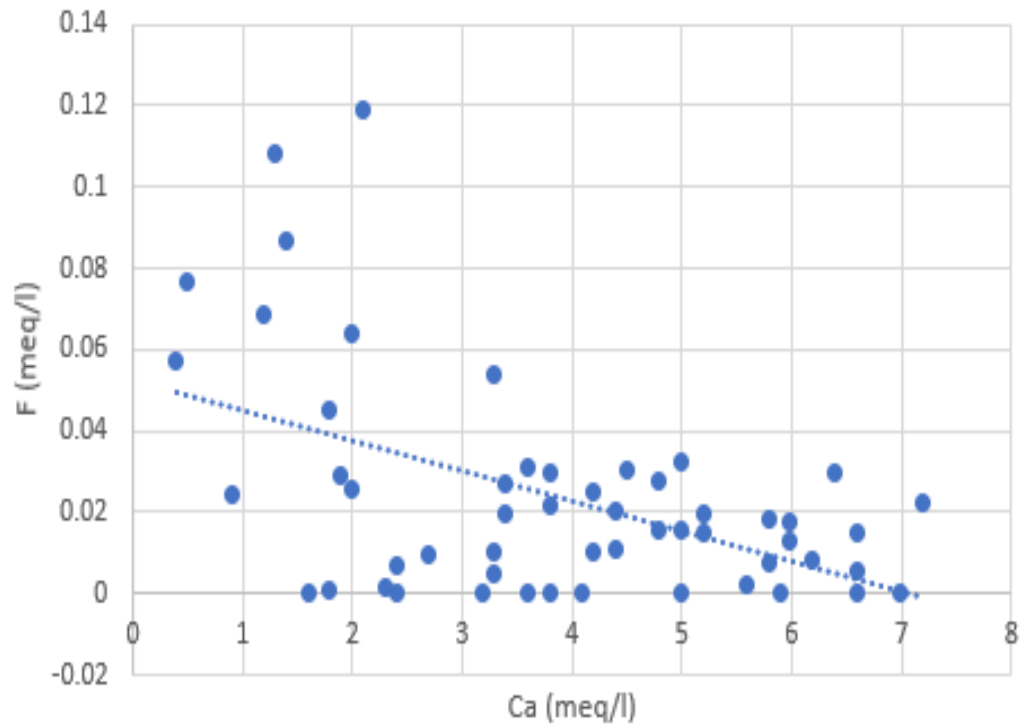


Figure 5.15 Showing graph between Ca and F.

In general, scatter plots are used to visualize relationships between two variables and can provide a quick way to identify patterns and trends in data. In the case of the fluoride dissolution scatter plot between Ca and F, it can be used to help understand the factors that influence the concentration of fluoride in water and to make informed decisions about water management and treatment strategies. By examining the relationship between calcium and fluoride, researchers and water management professionals can determine the sources of fluoride in the environment and the factors that contribute to its presence in water, which can help guide the development of effective management and treatment strategies.

5.10. Agriculture Potential indices:

Sodium adsorption ratio results shows that 20% of the water samples lie in an excellent water quality category. 48% water samples lie in a good water quality class and 24% lie in doubtful category and 8% in unsuitable category. (table 5.6).

The result of the sodium percentage analysis shows that 24% samples lie in an excellent class 32% water sample are classified in good water quality category 21 % samples lie in permissible class 13% water samples in doubtful class and 10% in unsuitable category (table 5.6).

Classification of water samples according to the magnesium hazard shows that 80% of the water samples lie in suitable water quality category and 20% of the water samples lie in harmful water quality category (table 5.6).

S.NO	Sodium Adsorption Ratio (SAR)	Water Quality	Percentage (%)
1	<10	Excellent	20%
2	10 – 18	Good	48%
3	19 – 20	Doubtful	24%
4	>20	Unsuitable	8%
S. NO	Sodium Percentage (Na%)	Water Quality	Percentage (%)
1	<20	Excellent	24%
2	20 – 40	Good	32%
3	40 – 60	Permissible	21%
4	60 – 80	Doubtful	13%
5	>80	Unsuitable	10%
S. No	Magnesium Hazard (MH%)	Water Quality	Percentage (%)
1	<50	Suitable	80%
2	>50	Harmful	20%

S. No	Kelly's Ratio	Water Quality	Percentage (%)
1	<1	Suitable	37%
2	1 – 2	Marginal Suitable	47%
3	>2	Unsuitable	16%

The results of the Kelly's ratio shows that 37% of the samples lie in suitable water quality category 47% are classified in marginal suitable class and rest of the 16% lie in unsuitable class (table 5.6).

Table 5.6 Showing agriculture potential calculation (SAR, Na%, KR, MH%,) of Tehsil Chunian.

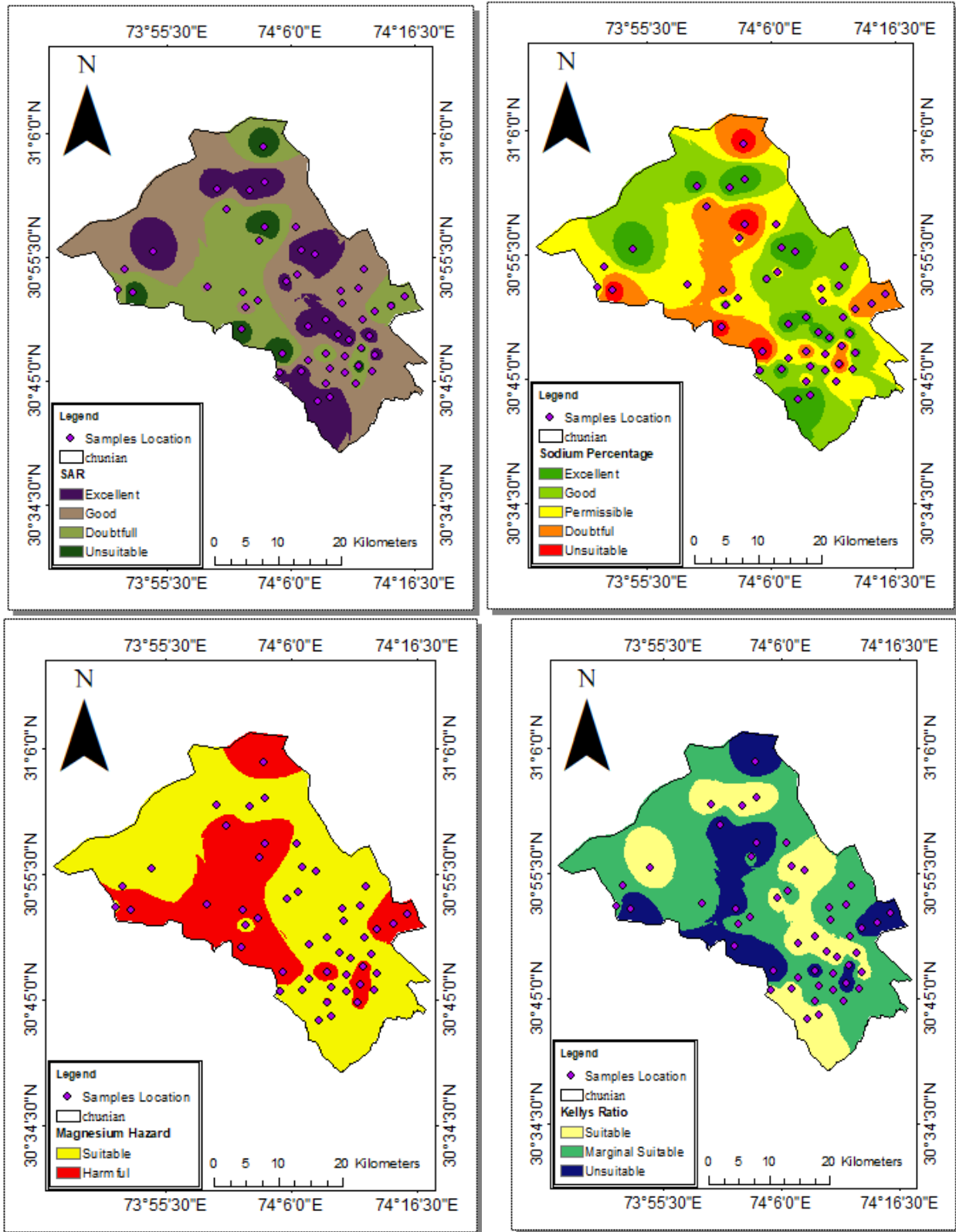


Figure 5.16 Showing Agriculture potential maps (SAR, Na%, KR and MH)

Table 5.7 Showing the table of area of agriculture analysis.

Area (SAR)		
1	Excellent Water Quality	799 sq.km
2	Good Water Quality	1920 sq.km
3	Doubtful Quality	959 sq.km
4	Unsuitable Water Quality	319 sq.km
Area (Sodium Percentage)		
1	Excellent Water Quality	959 sq.km
2	Good Water Quality	1278 sq.km
3	Permissible Water Quality	839 sq.km
4	Doubtful Water Quality	519 sq.km
5	Unsuitable Water Quality	399 sq.km
Area (Magnesium Hazard)		
1	Suitable	2968 sq.km
2	Harmful	1027 sq.km
Area (Kelly's Ratio)		
1	Suitable	741 sq.km
2	Marginal Suitable	2569 sq.km
3	Unsuitable	685 sq.km

Salinity index range shows that the electrical conductivity values smaller than $750\mu\text{S}/\text{cm}$ are considered to be good for irrigation purpose. According to the calculations 51% Samples lie in class 2 consider to be good for irrigation purpose. 43% samples lie in permissible class having high salinity consider to be class 3 and the rest of the 6% samples lie in class 4 having very high saline water (table 5.8).

Table 5.8 Showing Salinity Hazard calculations for tehsil Chunian.

S. No	EC	Water Salinity	Classification	Percentage (%)
1	0-250	Low (Excellent Quality)	Class-1	NIL
2	251-750	Medium (Good)	Class-2	51%
3	751-2250	High (Permissible)	Class-3	43%
4	2251-6000	Very high	Class-4	6%
5	6001-10,000	Extensively High	Class-5	NIL

6	10,001-20,000	Brines Weak Concentration	Class-6	NIL
7	20,001-50,000	Brines Moderate Concentration	Class-7	NIL
8	50,001-100,000	Brines High Concentration	Class-8	NIL
9	>100,000	Brines Extensively High concentration	Class-9	NIL

5.11. Ingestion Pathway:

Ingestion pathway of arsenic in groundwater refers to the route by which arsenic-contaminated water is consumed by humans or animals, leading to exposure to arsenic. This typically occurs through drinking water from wells or other sources that are contaminated with naturally occurring arsenic, which can cause serious health problems over time, including skin lesions, cancers, and cardiovascular disease.

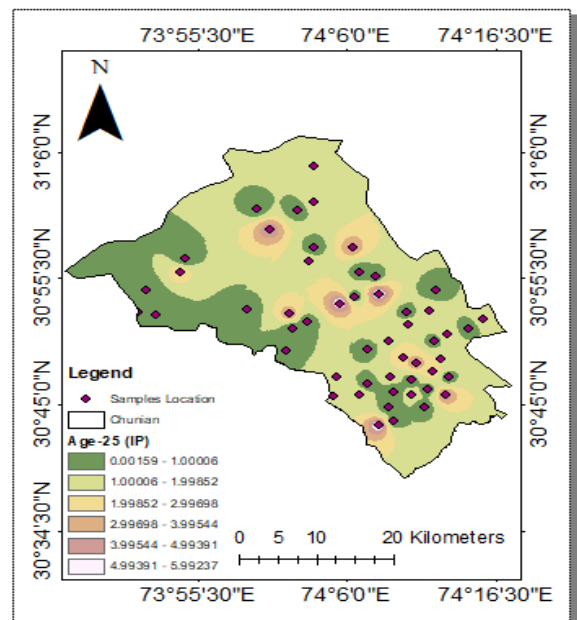
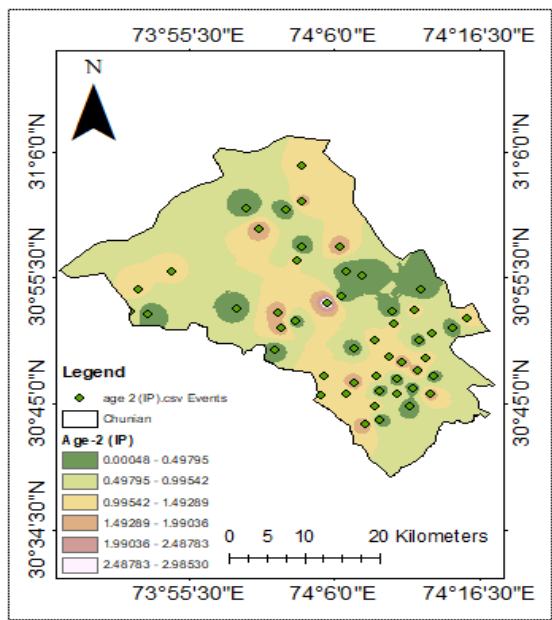
Table 5.9 Showing table of Ingestion pathway.

Age 60	Age 25	Age 2
0.023707	0.005690	0.001897
2.018433	1.304424	1.101475
2.015540	0.003730	1.101243
0.028152	0.006756	0.002252
0.216240	0.003898	1.201299
0.012530	0.003007	0.001002
2.012717	2.003052	1.401017
3.323543	2.005650	1.101883
0.013778	0.003307	0.001102
0.012145	0.002915	2.000972
8.012378	4.002971	2.000990
0.012215	0.002932	0.000977
2.217967	2.004312	1.201437

0.012985	0.003116	2.001039
0.013382	0.003212	0.001071
5.012507	4.003002	2.001001
0.007163	0.001719	0.000573
2.011958	1.602870	1.100957
0.015050	0.003612	1.401204
0.003103	0.000745	0.000248
5.220720	2.004973	1.101658
0.004935	0.001184	0.000395
2.011935	1.702864	1.300955
0.000257	0.000062	0.000021
4.301365	3.000328	1.300109
3.524733	2.005936	1.301979
0.001097	0.000263	0.000088
2.012448	1.602988	1.100996
3.012833	2.003080	1.501027
0.001318	0.000316	0.000105
7.001085	5.000260	2.000087
2.310978	2.002635	1.200878
0.006405	0.001537	0.000512
4.001575	2.000378	1.400126
6.001855	4.400445	2.000148
0.000642	0.000154	0.000051
9.010022	6.002405	2.000802
3.001867	2.000448	1.200149
0.000443	0.000106	0.000035
0.002298	0.000552	0.000184
4.204445	3.001067	2.000356
0.000525	0.000126	0.000042
7.016135	5.003872	2.001291

0.004363	0.001047	0.000349
0.000735	0.000176	0.000059
8.001178	6.000283	3.000094
0.000618	0.000148	0.000049
0.011690	0.002806	0.000935
3.002135	2.000512	1.700171
5.001482	3.000356	1.100119

The result of Ingestion pathway of Arsenic in the groundwater of tehsil Chunian shows that the Hazard quotient range from 0.000257 to 9.010022 for (age 60), 0.000062 to 6.002405 for (age 25), and 0.000021 to 3.000094 for (age2). The ADD_{intake} shows that 58% of the samples exceed the given limit HQ>1 for (age 6), 30% of the samples exceed the given limit HQ>1 for (age 25), 28% of the samples exceed the given limit HQ>1 for (age 60) (fig: 5.17).



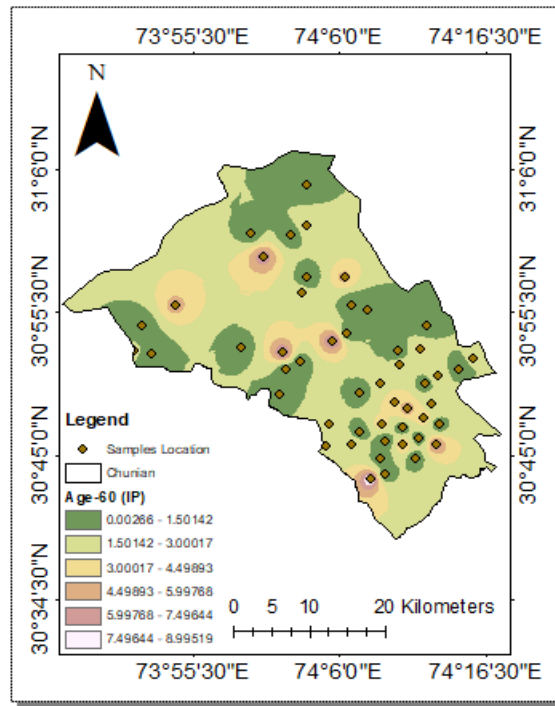


Figure 5.17 Showing maps of Ingestion Pathway.

5.12. Dermal Pathway:

The dermal pathway of exposure to groundwater contaminated with arsenic refers to the absorption of arsenic through the skin. Arsenic can be found naturally in rocks and soils, and in some areas, it can leach into the groundwater. Chronic exposure to arsenic through drinking water has been associated with various health problems, including skin lesions, cancer, and cardiovascular disease.

When a person comes into contact with arsenic-contaminated groundwater, the skin can absorb some of the arsenic, which can then enter the bloodstream. The extent of dermal absorption depends on several factors, such as the concentration of arsenic in the water, the duration and frequency of exposure, the integrity of the skin barrier, and the presence of other contaminants that may enhance or inhibit absorption.

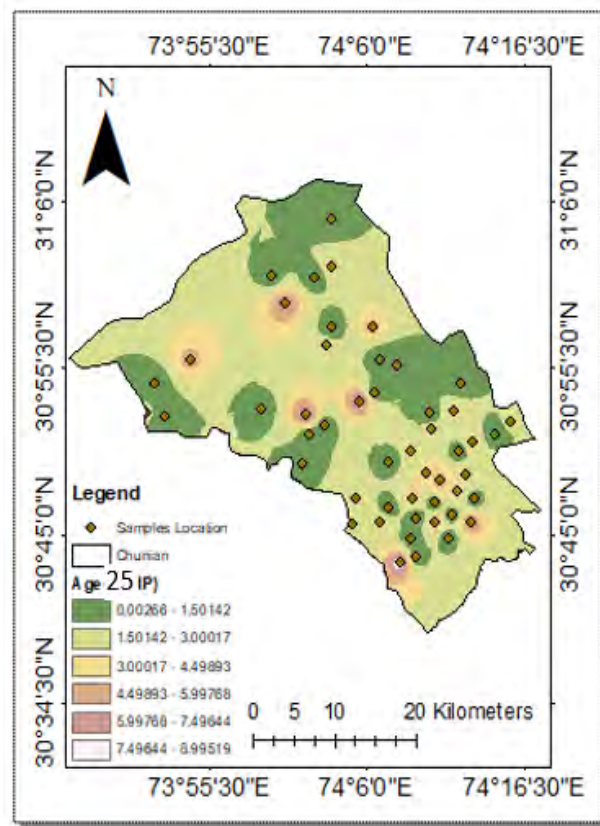
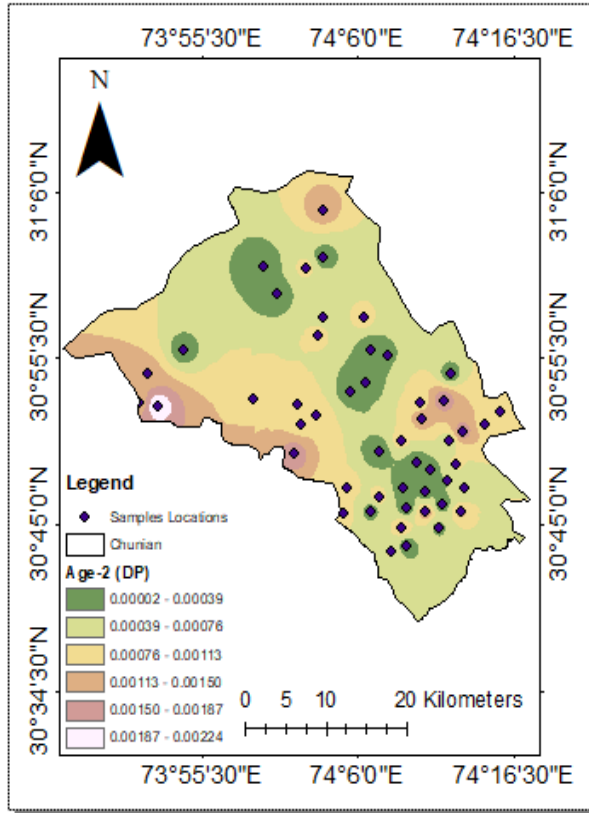
To reduce the risk of dermal exposure to arsenic, it is recommended to avoid contact with contaminated water as much as possible, especially for prolonged periods. Protective clothing and gloves can also be used to minimize skin contact. In addition, regular monitoring of groundwater quality and treatment of contaminated sources can help prevent exposure to arsenic and other harmful substances.

Table 5.10 Showing table of Dermal pathway.

Age 60	Age 25	Age 2
0.023707	0.005690	0.001897
0.018433	0.304424	0.001475
0.015540	0.003730	0.001243
0.028152	0.006756	0.002252
0.016240	0.003898	0.001299
0.012530	0.003007	0.001002
0.012717	0.003052	0.001017
0.023543	0.005650	0.001883
0.013778	0.003307	0.001102
0.012145	0.002915	0.000972
0.012378	0.002971	0.000990
0.012215	0.002932	0.000977
0.017967	0.004312	0.001437
0.012985	0.003116	0.001039
0.013382	0.003212	0.001071
0.012507	0.003002	0.001001
0.007163	0.001719	0.000573

0.011958	0.002870	0.000957
0.015050	0.003612	0.001204
0.003103	0.000745	0.000248
0.220720	0.004973	0.001658
0.004935	0.001184	0.000395
0.011935	0.002864	0.000955
0.000257	0.000062	0.000021
0.301365	0.000328	0.000109
0.524733	0.005936	0.001979
0.001097	0.000263	0.000088
0.012448	0.002988	0.000996
0.012833	0.003080	0.001027
0.001318	0.000316	0.000105
0.001085	0.000260	0.000087
0.010978	0.002635	0.000878
0.006405	0.001537	0.000512
0.001575	0.000378	0.000126
0.001855	0.000445	0.000148
0.000642	0.000154	0.000051
0.010022	0.002405	0.000802
0.001867	0.000448	0.000149
0.000443	0.000106	0.000035
0.002298	0.000552	0.000184
0.204445	0.001067	0.000356
0.000525	0.000126	0.000042
0.016135	0.003872	0.001291
0.004363	0.001047	0.000349
0.000735	0.000176	0.000059
0.001178	0.000283	0.000094
0.000618	0.000148	0.000049

0.011690	0.002806	0.000935
0.002135	0.000512	0.000171
0.001482	0.000356	0.000119



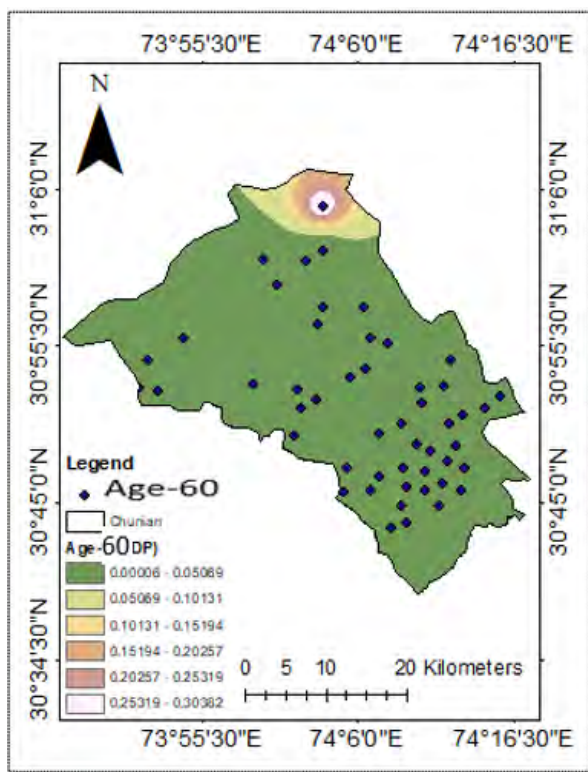


Figure 5.18 Showing maps of Dermal Pathway.

The result of Dermal pathway of Arsenic in the groundwater of tehsil Chunian shows that the Hazard quotient range from 0.000257 to 0.524733 for (age 60), 0.000062 to 0.304424 for (age 25), and 0.000021 to 0.002252 for (age 2). The calculated ADD_{derm} pathway values are less as compared to the calculated values of ADD_{inj} pathway. Thus our results suggests that ADD_{derm} pathway possess less risk than the ADD_{inj} . (Table 5.10).

5.13. Hazard Quotient Analysis:

Hazard quotient map is a type of map that shows the relative risk of exposure to a particular environmental hazard, such as toxic chemicals, in a given area. The hazard quotient is calculated by dividing the estimated exposure level of a substance by its reference dose, which is a level of exposure believed to be safe. The resulting value, which is expressed as a ratio, provides a measure of the potential risk associated with exposure to the substance. Hazard quotient maps are commonly used in environmental health assessments and risk management planning to identify areas where people may be at increased risk from exposure to hazardous substances.

The map shows that almost 42.9% of the groundwater samples exceeds the given limit of Hazard quotient which is $HQ > 1$ and only 57.1% of the groundwater samples lie within the given limit of Hazard quotient (HQ) which is $HQ < 1$ (figure 5.19).

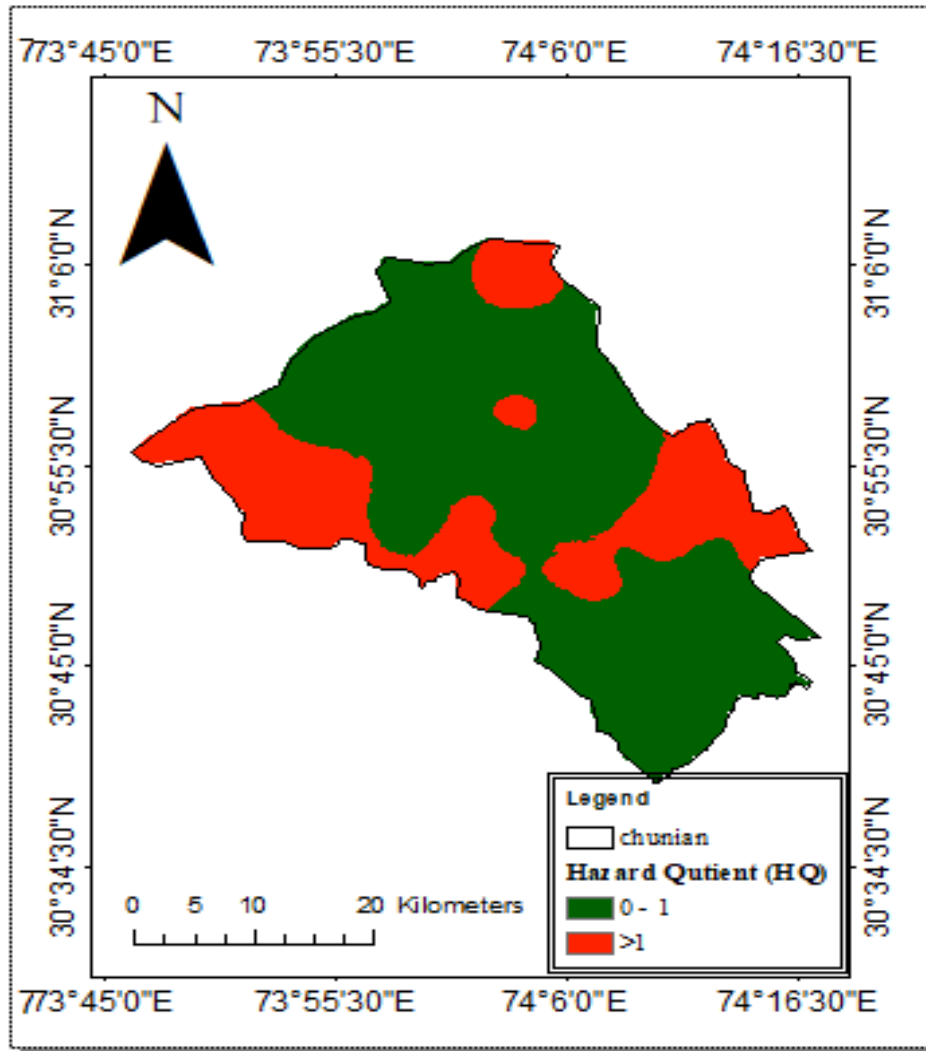


Figure 5.19 Showing Hazard Quotient Map.

Table 5.11 Showing area of Hazard quotient maps.

Area (Hazard Quotient)		
1	Suitable	2281 sq.km
2	Harmful	1713 sq.km

6. Conclusion:

In conclusion, the integrated approach to hydrogeochemical appraisal and quality assessment of groundwater in Chunian Tehsil, District Kasur Pakistan, provides valuable insights into the chemical characteristics and quality of the groundwater in the area. By combining various methods such as Gibbs plotting, geochemical modeling, and statistical analysis, it is possible to identify the major processes controlling the chemical composition of the groundwater, assess its suitability for different uses, and identify any potential risks to human health and the environment.

The results of the study indicate that the groundwater in Chunian Tehsil is predominantly of the calcium-bicarbonate type, with elevated levels of sodium, chloride, and sulfate in some wells.

The concentration of As in 42.9% of the samples exceeds the given limit of WHO, which is indeed alarming for the human health. The results also suggest that the groundwater is influenced by both natural processes, such as rock-water interaction and evaporation, as well as human activities, such as agriculture and industry.

The result of agricultural potential calculation shows that the groundwater of tehsil chunian is suitable for the use of irrigation purpose. Water quality index results shows that 36% of the water samples lie in the good quality zone and Hazard Quotient result shows that almost 42.9% of the groundwater samples exceeds the given limit of Hazard quotient which is $HQ > 1$ and only 57.1% of the groundwater samples lie within the given limit of Hazard quotient (HQ) which is $HQ < 1$.

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