Hydrogeochemical Investigation and Groundwater Quality Assessment in Tehsil Gujrat, Pakistan

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Dedication

Dedicated to those who inspire us to seek knowledge and strive for excellence

Acknowledgement

First and foremost, I express my heartfelt gratitude to Almighty Allah for granting me the resilience and determination to successfully complete this research. His countless blessings and unwavering support have made this journey possible and endowed me with the capacity to conduct meaningful research.

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Abstract

Worldwide, people utilize water for various purposes, including economic, industrial, and household needs. Ensuring the availability and quality of groundwater is crucial, as contaminated groundwater can pose significant health risks. In Pakistan, groundwater contamination with arsenic, a heavy metal, is a prevalent issue and a serious threat to human health. This study focuses on assessing groundwater quality for drinking and agricultural purposes, specifically examining arsenic and fluoride concentrations in Tehsil Gujrat. A total of 60 groundwater samples were collected from various locations in Tehsil Gujrat, with 40 of them being functional wells. The results indicate that the majority of groundwater samples fall within the acceptable range defined by the World Health Organization (WHO). However, the concentration of arsenic, with an average value of 8.78 parts per billion (ppb), varies between 0 and 24.13 ppb, and approximately 43% of the groundwater samples exceed the WHO's recommended limit. The Gibbs plot analysis suggests that the primary controlling factors affecting groundwater chemistry are rock dominance, with some samples also showing signs of evaporation crystallization dominance. Health risk assessment was conducted using parameters such as Average Daily Dose (ADD), Hazard Quotient (HQ), and Carcinogenic Risk (CR). Alarmingly, 57.1% of the samples exceeded the permissible Hazard Quotient limit (HQ>1), indicating that people face a heightened risk due to arsenic contamination in drinking water. Therefore, it is imperative to implement proper monitoring and management practices for groundwater in Tehsil Gujrat to safeguard public health.

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Introduction

1.1. General Background:

Water, a valuable resource, is one of the basic elements for sustaining life and supporting individual people's activities. It is not only a basic human right to clean and safe drinking water but also an essential condition for sustainable social development and the protection of the environment (Nabi et al. 2019). To meet these diverse needs, groundwater, which constitutes a significant part of the planet's freshwater reserves, has a key role to play. It is a reliable source of water in many areas, such as domestic consumption, agriculture, industry processes and environmental balance.

Unlike surface water sources, groundwater has an uncommonly low pollution and evaporation susceptibility because of its secret nature under layers of rock and soil. That feature provides a vital source of water supply to areas in which surface water resources are limited, undependable or polluted. Nonetheless, a key factor determining its usefulness and sustainability is the quality of groundwater. Contamination of water with pollutants and contaminants poses a serious problem, which can endanger people's health, environmental systems as well as business activities that rely on this resource (Abbas and Cheema 2015).

Groundwater is playing an important role in meeting water demands in Pakistan, where the issue of water scarcity continues to be a serious problem. It is the case in regions with a limitation of surface water availability due to factors such as abnormal rainfall patterns or groundwater management practices. (Javeda et al. 2021). However, the issue of water quality has been identified as a major challenge. Given its potential for serious health impacts and environmental damage, the contamination of groundwater with heavy metals such as arsenic and fluoride has become a matter of concern.

There is an element called arsenic in the Earth's crust. A geological process where Arsenic rich minerals are dissolved in the water, or from manmade activities like mining and industrial discharges, may contribute to their presence on groundwater. Releases of arsenic in groundwater could contaminate the water sources that communities depend on to supply their drinking water, as well as supplementary needs. Chronic exposure to arsenic-contaminated water can result in numerous health problems, ranging from skin lesions and cardiovascular diseases to various forms of cancer (Hassan 2014)

In a variety of countries, including regions like Bangladesh and parts of India that are facing serious health crises about the contamination of their drinking water aquifers, there is documented widespread prevalence of Arsenic in groundwater. (Rehman et al., 2020) In Pakistan, it has been observed that arsenic contamination of groundwater is occurring in several provinces such as Punjab. In Punjab, arsenic is naturally present in some of the reservoirs and has led to increased groundwater concentrations from these sources.

Despite current knowledge about the contamination of groundwater with arsenic, it is still necessary to carry out local and comprehensive assessments that consider special geological, water quality and economic conditions in individual regions. In Punjab, Pakistan, Tehsils Gujrat represent regions where groundwater has a key role to play in the preservation of farming practice, industry operation and domestic water supply (Abbas and Cheema 2015).

The objective of this study is to bridge the present research gap by carrying out a detailed assessment of groundwater quality in Tehsils Gujrat with an eye on risks for health due to Arsenic and fluoride contamination. In this study, by means of an extensive analysis which includes factors such as arsenic concentrations and fluoride concentration, spatial delimitation and health risk assessment, a holistic understanding is to be drawn for how much groundwater contamination there is and its implications for different water use patterns.

1.2. Objectives of the Study:

The primary objectives of this study are as follows:

- To assess the quality of groundwater for both drinking and agricultural purposes in Tehsils Gujrat.
- To create a geographical distribution map of various chemical parameters across the study area.
- To calculate the health risk associated with the consumption of arsenic and fluoride contaminated groundwater.
- To calculate a water quality index for the study area.

1.3. Description of the Study Area:

In the province of Punjab, Pakistan, the tehsils of Gujrat are located. The Tehsil Gujrat is located at latitudes 32 34'N and longitude 74 5'E. This tehsil is located in a very large Gujrat district, which lies to the east of Punjab (Mandal and Suzuki 2002) (Figure 1.1).

Most of the population in Tehsils Gujrat are rural and suburban communities. According to the 2017census, it is estimated that there are a total population of about 2508968 in this tehsil. There are different communities in this tehsils, with people from various ethnic, cultural, and socioeconomic backgrounds.

Local aquifers are in great difficulty because of demand for groundwater resources, driven by both national and industrial needs. Unchecked groundwater extraction can have an adverse impact on water tables, which could affect resource sustainability for a longer period. In addition, water quality is an important concern in the light of reports of arsenic and fluoride contamination in some regions of Punjab (Gujarat 2023).

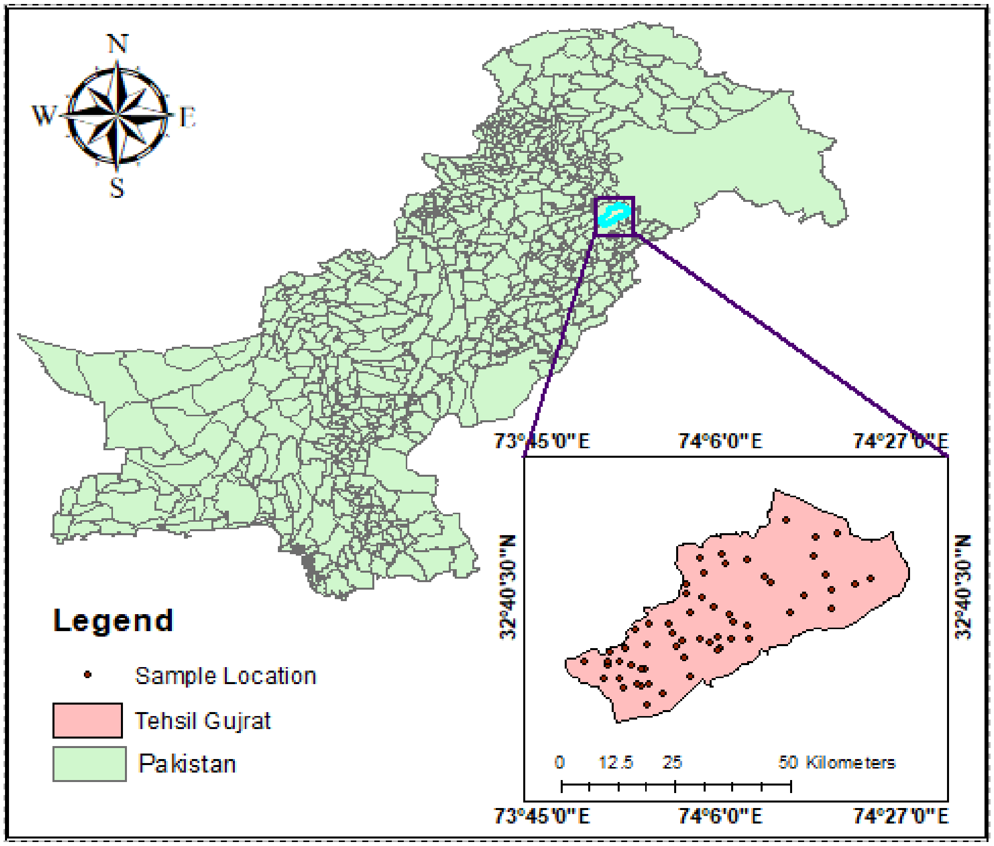


Figure 2.1 Study area map

1.4. Groundwater Sampling and Parameters:

It is essential to collect suitable water samples in Tehsils Gujrat for the assessment of groundwater quality. A procedural approach has been adopted with a view to ensuring that the data gathered are reliable and precise. The total number of groundwater samples was 60 at various locations across the study area. Several methods of extraction commonly used in the area, such as hand pumps, tube pipelines, injection lines and digging boreholes have been used to collect these samples.

Prior to use, the collection process involved a thorough cleaning of polythene bottles with distilled water and nitric solution acid. These prior cleaning procedures ensured that no contamination of the sample obtained was due to residues from bottles themselves. In addition, so as to obtain accurate knowledge of water conditions in the groundwater field, wells have been drained for around 15 minutes prior to sampling. This step aimed to eliminate stagnant water and capture water that exactly reflected the aquifer's characteristics (Figure 1.2).

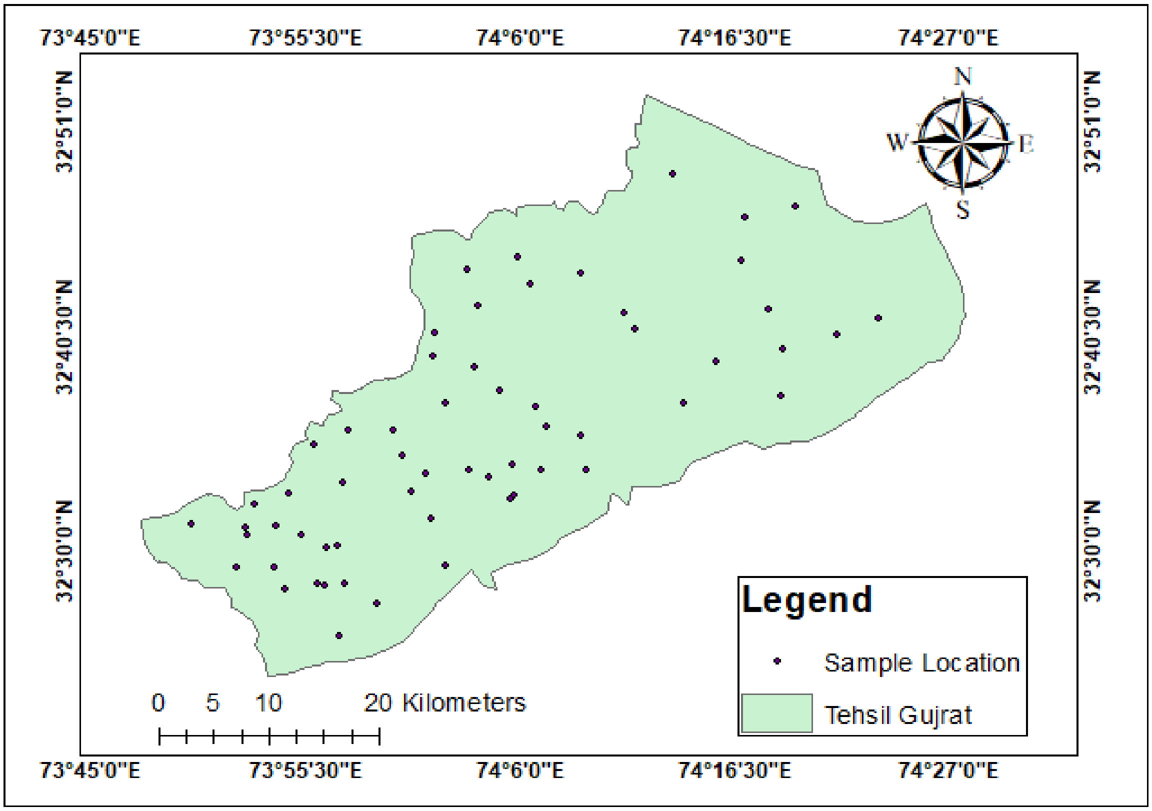


Figure 1.2 Tehsil Gujrat Sample location map

Chapter: 2

Hydrogeology and Geology

2.1. Hydrogeology:

Different factors, such as climatic conditions, groundwater recharging sources and water drainage systems are also influencing the hydrogeology of Tehsils Gujrat in Pakistan.

2.1.1. Climate:

In Tehsil Gujrat, climate change may have a significant influence on water supply and availability. The summer's usually hot and dry, with temperatures which reach as high as 40C during the colder months. Winter is relatively cool, from 10 to 20 C accompanied by occasional rain or snow. (Peeters 2014). There is a general scarcity of rainfall during the year, and this can vary, having an impact on recharges and groundwater replenishment.

2.1.2. Recharge Sources:

For the aims of groundwater replenishment, recharging sources are important. Key recharge sources in these regions are as follows:

- **Precipitation:** Rainwater is the prime source for recharging groundwater. The amount and intensity of the rain change the rate at which it recharges. A change in the precipitation season has an impact on groundwater availability (Flörke et al., 2013).
- **Irrigation:** The farming methods, including irrigation, are accountable for the recharge of groundwater. Lack of effective irrigation methods may lead to unnecessary water leakage into soils and groundwater restoration (Jiang et al., 2009).
- **Surface Water Runoff:** In addition, groundwater can be injected into the ground and recharged by streams and rivers. This is especially essential for areas with porous soil and shallow topography.

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

2.1.3. Groundwater Flow Systems:

The groundwater flow systems in Tehsils Gujrat are affected by a wide range of factors, e.g., topographical characteristics, geology, or water recharge sources. These causes, which also affect groundwater flow direction and availability, have a direct consequences on the region's situation.

2.1.4. Topography:

The topography of Tehsil Gujrat, which includes elevation and slope on the soil surface, plays an important role in shaping groundwater flow patterns. Groundwater flows generally from higher elevations to lower ones, in line with a natural geological gradient of land. (Kumar et al., 2009). This horizontal influence on groundwater movement has had a significant effect on the distribution of groundwater resources.

2.1.5. Recharge Sources:

Recharge sources have contributed to the recharging of groundwater at both Tehsils Gujrat which include rainfall, irrigation or surface water discharge. The direction and rate of groundwater flow shall be affected by the availability and distribution of these recharging sources. Water from these sources flows into the soil, filling aquifers and influencing groundwater movement (Rishi et al., 2020).

2.2. Geology:

A major role in the groundwater flow system shall be played by geological characteristics of Tehsil Gujrat including rock types and distribution. The permeability and porosity of the rock are different, which has an impact on how easy water is flowing across it. Geology determines the way in which groundwater can be taken, as well as its potential to store water underground. (Qureshi et al., 2010).

In Tehsil Gujrat the interaction between these factors is creating an intricate water flow system based on topography, groundwater recharge sources as well as geology. It is likely that groundwater will move upstream, affecting its quality and availability (Rasheed et al., 2022). In order for water resources to be effectively used and sustainably managed, the identification of such groundwater flow schemes as well as their quality is necessary in respect of both groundwater and adjacent sources like rivers and streams.

2.2.1. Geology of Tehsil Gujrat:

The geological area of Tehsil Gujrat in Pakistan is mostly characterized by sedimentary rock formations such as sandstones, shales or limestones which have formed over a period of many years through sediment accumulation and geological processes like Tectonic activity and erosion.

(Tropea et al., 2021). The forces of tectonic uplift and erosion, as well as the shaping of the terrain, have been experienced by these basic layers. Although the occurrence of localized occurrences of Igneous and metamorphic rocks is unlikely to be common, they may result from processes such as volcanic activity or rock formation deep in the Earth's crust. Geology has a cumulative effect on the availability and quality of groundwaters as well as precious resources, such as minerals or possibly hydrocarbons. To fully understand the geological composition's impacts on resource management and land use planning in this region, a comprehensive research and data collection is needed.

2.2.2. Precipitation in Tehsil Gujrat:

In Tehsils Gujrat in Pakistan, precipitation patterns have a major influence on the availability of water as well as an overall ecosystem. In the area, there is a particularly humid climate and distinct periods of rain and drought (Adeloju et al., 2021).

Rainfall is the predominant form of precipitation in these areas. There is usually more precipitation during the winter months, often accompanied by rain and occasional snow. (Adebayo et al., 2021). On the contrary, summer months are characterized by hotter and drier climate with little to no rainfall. There may be variations in the annual precipitation range, usually between 200 and 400 mm.

This variability of rainfall has a wide-ranging effect on local environments, impacting groundwater recharge, agricultural practice, surface water availability, climate change and the settlement patterns of humans. Effective management of natural resources and sustainable development in this area requires that these precipitation patterns are understood and analyzed (Tabassum et al., 2019).

2.2.3. Rainfall in Tehsil Gujrat:

In Tehsil Gujrat in Pakistan rainfall plays a significant role in the water cycle and processes of nature. It plays an important role in different environmental areas, e.g., groundwater recharging, growth of vegetation and agricultural productivity (Adebayo et al., 2021).

The occurrence of rain, which in turn contributes to recharging groundwater aquifers and surface waters, tends to be higher during the winter months. By contrast, the summer months have been characterized by a lack of rainfall that could lead to dry weather conditions and reduced water availability (Rasheed et al., 2022).

To develop strategies for the effective management of water resources, sustain agricultural activities and support various economic activities in Tehsil Gujrat, it is essential to understand rainfall patterns both as a matter of frequency and quantity.

2.2.4. Humidity in Tehsil Gujrat:

Humidity levels are a fundamental aspect of the climate in Tehsil Gujrat, Pakistan, influencing various ecological and human-related factors.

The humidity levels in these regions tend to remain weak throughout the summer months, which results in a cooler and drier climate overall. People's comfort, production of agricultural products and vegetation growth may be affected by the lack of air in this period (Adebayo et al., 2021)

In contrast, winter months are likely to have a higher humidity level, when there's rain. The degree of moisture may be influenced by factors like the proximity to water bodies, e.g., rivers and streams, which can influence local climatic conditions.

In Tehsils Gujrat understanding humidity patterns is essential to manage scarce resources effectively through sustainable agriculture as well as improve the overall quality of life.

Chapter: 3

Literature Review

Groundwater quality can be influenced by a variety of factors, encompassing both natural sources like minerals, salts, and organic substances that dissolve into the groundwater, as well as human activities including agricultural practices, industrial discharges, and waste disposal that introduce contaminants (Puri, et al. 2011). Moreover, physical processes like soil filtration and chemical reactions can modify the groundwater's composition.

To assess groundwater quality, its physical properties (temperature, turbidity), chemical properties (pH, total dissolved solids, dissolved oxygen), and biological attributes (microorganism presence) are typically measured. This evaluation is crucial due to the wide-ranging variability in groundwater quality based on geographical location and pollutant presence. Consistent monitoring and effective management are essential to ensure that groundwater remains suitable for its intended uses.

Regarding water quality analysis, it's imperative to collect samples from the study area for comparison against WHO (World Health Organization) standards. This analysis involves two primary methods: physical and chemical.

3.1. Physical Method:

In the realm of physical methods, various parameters such as electrical conductivity (EC), pH concentration, and turbidity are calculated.

pH, representing "potential of Hydrogen," gauges a solution's acidity or alkalinity on a scale from 0 to 14. A pH of 7 is neutral, values below 7 are acidic, and values above 7 are alkaline. Notably, the pH scale is logarithmic, signifying that a one-unit change in pH signifies a tenfold alteration in the solution's acidity or alkalinity

Gupta et al. (2009) emphasize that the corrosiveness of water is affected by multiple factors including pH, temperature, concentrations of dissolved minerals and gases, and flow rate. To mitigate corrosion, maintaining water within a suitable pH range—neither overly acidic nor excessively alkaline is essential.

Sulochana et al. (2005) underscore that a pH higher than 7 indicates an alkaline or basic nature due to an abundance of hydroxide ions (OH-) compared to hydrogen ions (H+). Alkaline solutions counteract acids and find application in cleaning products and acid removal tasks. However, it's crucial to recognize that an excessively elevated pH can lead to challenges such as scaling and mineral accumulation in pipes and equipment. Thus, keeping water within an appropriate pH range is vital.

Karanth et al. (1987) note that natural rivers typically exhibit a pH range of 6.5 to 8.5, falling within the neutral to slightly alkaline spectrum. Pollution from human activities like agricultural runoff, industrial discharges, and sewage treatment plants can induce acidity, causing the pH of river water to plummet, occasionally dropping below 6.0. River water usually isn't suitable for drinking due to its potential contamination with bacteria, viruses, parasites, chemicals, and pollutants. Ingesting such water, untreated, can pose serious health hazards. Moreover, river water's pH can swiftly fluctuate due to weather, seasonal variations, and other dynamics, posing challenges in consistently delivering safe and potable water. This drives most communities to rely on treated and purified water from underground sources or reservoirs for drinking purposes.

Electrical conductivity (EC) measures the electrical resistance of a substance and is typically expressed in Siemens per meter (S/m). Several factors, including temperature, types of ions, and electron density, influence EC. Metals are known for their high conductivity, while insulators like rubber exhibit poor conductivity.

Gorde, et al. 2013, established a correlation between EC values in groundwater and total dissolved solids (TDS), which represents the quantity of dissolved inorganic and organic substances in a liquid, often water. TDS is quantified in milligrams (mg) or parts per million (ppm) per unit volume of water. Elevated EC levels indicate a higher concentration of dissolved salts and minerals, impacting the overall quality of groundwater. EC data can provide insights into the presence of various ions, including sodium, calcium, magnesium, and chloride.

In general, low EC values (below 1000 µS/cm) suggest pure or freshwater sources, while high values (above 5000 µS/cm) indicate the presence of salts, minerals, or pollutants. EC can also help identify potential pollution sources such as sewage discharge, agricultural runoff, or industrial waste. It's important to note that EC varies depending on the mineral composition of the soil and rocks, necessitating a thorough understanding of local geology and water conditions for accurate interpretation.

Total Dissolved Solids (TDS) measurements, as studied by Lindroth (1996), encompass all inorganic and organic substances found in a liquid, typically water. TDS levels originate from various sources, including natural minerals, runoff from the land, industrial discharges, and sewage. Elevated TDS concentrations can affect the taste, odor, appearance, and potentially the safety of water. Measuring TDS involves converting the conductivity value using a specific factor. Regular monitoring of TDS in water sources is crucial to ensure compliance with safe drinking water standards.

3.2. Chemical Method:

The examination of various chemical parameters, such as CO2, SO4, Na, Ca, Mg, among others, constitutes chemical methods (Chandra, et al. 2012). These parameters are pivotal in assessing groundwater quality and potential contamination.

The increase in atmospheric CO2 due to human activities has far-reaching effects on climate, leading to rising temperatures, shifting precipitation patterns, and various environmental consequences. Islam et al. (2017), CO2 is utilized in industrial processes like carbonated beverage production, oil and gas recovery, refrigeration, and fire extinguishing.

CO2 can influence groundwater quality by dissolving into it, causing increased groundwater acidity (lower pH) and reduced alkalinity, which can lead to infrastructure corrosion and the release of toxins from soils and rocks (Smith et al., 1997). Typically, CO2 is not a primary groundwater contaminant; its presence is often linked to factors like atmospheric dissolution or anthropogenic sources such as landfills and industrial activities.

Total alkalinity is a measure of water's capacity to neutralize acids, relying on carbonate, bicarbonate, and hydroxide ions. It plays a crucial role in maintaining stable pH levels necessary for aquatic species' survival (Pradhan, et al. 2012). Elevated alkalinity can increase scaling risks in plumbing systems and affect certain water treatment processes. Conversely, low alkalinity may indicate vulnerability to acidic pollution, significantly impacting water quality.

Bicarbonate, denoted by the hydrogen carbonate ion (HCO3^-), emerges from the combination of a carbon atom, two oxygen atoms, and a hydrogen atom. These bicarbonates are widely dispersed in water, particularly in groundwater, and hold a pivotal role in preserving water alkalinity and pH levels. Beyond their influence on water, bicarbonates serve diverse functions in both industrial and agricultural domains. They function as a buffering agent in blood, contribute to the formulation of baking powder, and supply essential CO2 for the growth of algae and plants.

The impact of bicarbonates on groundwater quality is multifaceted, extending to taste and odor. Furthermore, they can exert influence, both positive and negative, on specific water treatment methods, such as reverse osmosis and ion exchange. Significantly, bicarbonates play a critical role in maintaining the stability of groundwater's alkalinity and pH, which are pivotal factors in ensuring water quality for a wide range of applications (Smith et al., 1997). Inadequate levels of bicarbonates may serve as an indicator of groundwater's susceptibility to acidic contamination, which poses a substantial threat to water quality.

Magnesium, a plentiful metal and the Earth's eighth most abundant element, is intricately linked to various minerals like dolomite, magnesite, and serpentine, as well as various rocks and soils. Its significance extends to vital physiological processes encompassing protein synthesis, energy metabolism, and DNA replication (Mahesh, et al. 2013). Beyond its biological relevance, magnesium plays an indispensable role in both industrial and agricultural sectors, featuring prominently in fertilizers, construction materials, and chemicals used in water treatment. In aquatic environments, magnesium takes the form of a dissolved ion, exerting an influence on water hardness and alkalinity.

Elevated magnesium levels within groundwater, similar to heightened calcium levels, can impact various water attributes, including taste, hardness, soap solubility, and the potential for scaling within plumbing systems. Additionally, magnesium contributes significantly to groundwater alkalinity, a pivotal factor in maintaining pH stability, which, in turn, is vital for the well-being of aquatic species. Conversely, low levels of magnesium suggest that groundwater may be vulnerable to contamination by acidic substances, posing a severe risk to overall water quality. Hence, the consistent monitoring and effective management of magnesium levels remain indispensable for the maintenance of groundwater quality across its diverse applications (Islam, et al. 2012).

Carbonates represent chemical compounds encompassing the carbonate ion (CO3^2-), formed through the fusion of a carbon atom with three oxygen atoms. These compounds are abundantly present in various rock formations, including limestone and dolomite, and constitute a substantial proportion of the Earth's crust. The presence of carbonates in water is contingent upon the prevailing pH conditions, existing either as bicarbonates or carbonates.

Bicarbonates predominantly feature in groundwater and surface water, while carbonates are more commonly encountered in hard water and water sources in proximity to carbonate-rich geological formations Moss B (1973) Notably, carbonate minerals possess the capacity to dissolve in water, releasing essential ions such as calcium and magnesium into groundwater. This dissolution process significantly influences the taste and odor of the water.

Elevated levels of carbonates in water can escalate water hardness, creating complications in the dissolution of soap and cleaning products, potentially leading to scaling issues within plumbing systems. However, it's imperative to acknowledge the dual role of carbonates, as they also contribute positively to groundwater quality. By bolstering water alkalinity and ensuring pH stability, carbonates enhance the suitability of groundwater for a diverse array of applications. Thus, maintaining careful vigilance over carbonate levels in groundwater is vital to guarantee its fitness for various uses.

Sodium, an elemental component essential for sustaining life, plays a pivotal role in fluid balance regulation and the transmission of nerve impulses. Beyond its biological importance, sodium finds extensive application in various industrial processes and represents a fundamental constituent of everyday substances such as table salt (sodium chloride) and sodium hydroxide.

Groundwater quality can be profoundly affected by sodium levels within the water source. Elevated concentrations of sodium can impart a salty taste to the water, influencing its overall palatability. Additionally, sodium's interactions with other minerals present in the water can culminate in the formation of deposits that have the potential to clog pipes and fixtures, thereby posing health risks, particularly for individuals adhering to low-sodium dietary regimens. Elevated levels of sodium in groundwater may arise from various sources, including the presence of sodium-rich minerals like sodium chloride, as well as sodium-based compounds originating from agricultural practices, industrial activities, or household products. Effective management and ongoing monitoring are imperative for preserving groundwater quality and mitigating the potential adverse effects associated with elevated sodium content.

Calcium (Ca), characterized by its atomic number 20, constitutes a fundamental chemical element with versatile applications. It prominently figures in various minerals, including limestone, dolomite, and gypsum, and is pervasive within rocks and soil formations. Beyond geological significance, calcium plays a crucial role in supporting essential physiological functions such as muscle contraction and blood clotting. Moreover, calcium holds significance in both industrial and agricultural sectors, where it contributes to the formulation of fertilizers, construction materials, and chemicals employed in water treatment processes.

In aquatic environments, calcium assumes the form of dissolved ions, exerting a discernible influence on water hardness and alkalinity (Yann war, et al. 2013). Elevated levels of calcium may serve as indicators of the presence of calcium-rich minerals within the water source, ultimately affecting water attributes including taste, odor, and water hardness. This, in turn, can render the dissolution of soap and cleaning products more challenging, potentially leading to scaling issues within plumbing systems. However, it's essential to underscore calcium's dual role, as it actively contributes to maintaining water alkalinity, a pivotal factor in pH stabilization, which, in turn, is crucial for preserving the well-being of aquatic species. Conversely, insufficient calcium levels may signify the water source's susceptibility to contamination by acidic substances, representing a substantial threat to overall water quality. Thus, diligent monitoring and effective management of calcium levels remain indispensable for safeguarding water quality across its myriad applications.

Turbidity, a parameter typically measured in Nephelometric Turbidity Units (NTU), serves as a critical indicator of water quality. Elevated levels of turbidity can have multifaceted implications for various aspects of water use and safety.

First and foremost, heightened turbidity interferes with disinfection processes, reducing the effectiveness of disinfectants like chlorine. This reduction in effectiveness can make the removal of pathogens and harmful microorganisms more challenging, potentially compromising the safety of drinking water. Moreover, increased turbidity results in reduced water clarity, leading to visually cloudy or murky water, which not only affects its appearance but also influences its taste(Hussain, et al. 2011).

Beyond aesthetics, turbidity can introduce suspended particles into the water, including pollutants such as chemicals, heavy metals, and pathogens. These pollutants pose potential health risks to consumers, emphasizing the importance of maintaining low turbidity levels in drinking water. Furthermore, turbidity can have ecological consequences by decreasing the penetration of light into water bodies, which, in turn, can affect the growth and survival of aquatic plants and animals.

Various factors influence turbidity levels, including weather conditions, human activities, and the presence of natural sources of suspended particles. Therefore, it is essential to regularly monitor turbidity and implement appropriate measures to mitigate its effects, ensuring that water quality remains within safe and acceptable limits(Gaikwad, et al. 2013).

Total hardness, another critical water quality parameter, arises from diverse sources, including soil minerals and human activities such as industrial processes and effluent discharge. Elevated levels of total hardness can lead to troublesome issues, notably scaling, which can disrupt industrial operations, damage appliances, and disrupt routine activities (FJ et al., 2011) .

Conversely, inadequate levels of total hardness can result in corrosion in pipes and fixtures, which can have its own set of challenges. In the context of drinking water, elevated hardness can impart an unpleasant taste, leave deposits on appliances, and reduce the effectiveness of soaps and detergents during usage.

Industries are not exempt from the impacts of total hardness, as it can interfere with their processes, leading to reduced efficiency and increased maintenance costs. On a domestic level, the accumulation of hardness minerals in pipes and appliances can curtail their operational life and performance. Even in agriculture, hard water can impede crop growth and adversely affect the effectiveness of pesticides and fertilizers.

Given these implications, it is essential to regularly monitor water hardness and apply appropriate treatments to maintain water quality within acceptable limits. The recommended levels of drinking water hardness typically fall within the range of 60 to 120 mg/L in line with local standards (Pejaver, et al. 2008). To address high levels of hardness, various techniques such as ion exchange, reverse osmosis, or lime softening can be effectively employed to safeguard water quality and ensure it remains suitable for diverse applications.

Fluoride, a naturally occurring element, is found in drinking water and is typically measured in milligrams per liter (mg/L) or parts per million (ppm). To promote dental health and prevent tooth decay, the recommended concentration of fluoride in drinking water typically falls within the range of 0.7 to 1.2 mg/L, in accordance with local standards and guidelines.

The unique aspect of fluoride is its dual role, as elucidated by (Saxena et al., 2013). At lower concentrations, fluoride serves as a beneficial nutrient that contributes to the strengthening of teeth, thereby enhancing dental health (Saxena et al., 2013). However, it's important to note that excessively high levels of fluoride in drinking water can have detrimental effects, leading to conditions such as dental fluorosis and even skeletal fluorosis. These conditions can manifest as tooth discoloration and weakening, as well as potential adverse effects on bone health.

Given the significance of maintaining safe fluoride levels in drinking water, continuous monitoring is essential. Adequate measures should be taken as needed to treat water sources, ensuring that fluoride concentrations remain within the recommended range. This comprehensive approach accounts for both the advantageous and potentially harmful effects of fluoride on human health (Khan, et al. 2012).

3.3. Heavy Metals:

Arsenic (As) in Groundwater:

Arsenic contamination in groundwater has garnered significant attention due to its severe health implications for communities relying on groundwater sources for drinking water. This literature review aims to provide an overview of arsenic contamination, its sources, and the associated health risks.

Sources of Arsenic Contamination: Arsenic contamination primarily arises from natural geological processes and anthropogenic activities. In regions with arsenic-rich geological formations, such as Bangladesh and West Bengal, arsenic leaches into groundwater over time. Anthropogenic sources include mining, industrial discharge, and the use of arsenic-containing pesticides.

Health Effects of Arsenic Exposure: Exposure to elevated levels of arsenic in drinking water is associated with various health problems. Long-term ingestion of arsenic-contaminated water can lead to skin lesions, cardiovascular diseases, diabetes, and various cancers, including skin, lung, and bladder cancer (Khan, et al. 2012).

Regulatory Standards and Mitigation Strategies: Regulatory bodies like the World Health Organization (WHO) and the U.S. Environmental Protection Agency (EPA) have set maximum allowable levels for arsenic in drinking water. Mitigation strategies include the use of alternative water sources, such as surface water or treated piped water, and installing household-level arsenic removal systems.

Lead (Pb) in Drinking Water:

Lead contamination in drinking water is a critical public health concern, and this review delves into the sources, health effects, regulatory standards, and mitigation strategies associated with lead exposure through drinking water.

Sources of Lead Contamination: Lead enters drinking water primarily through corroded lead pipes, plumbing fixtures, and solder. The age and condition of plumbing infrastructure play a crucial role in lead leaching (Pejaver, et al. 2008).

Health Effects of Lead Exposure: Lead is especially harmful to children and can lead to developmental delays, cognitive impairments, and behavioral problems. In adults, lead exposure is linked to cardiovascular issues, kidney problems, and reproductive health concerns.

Regulatory Standards and Mitigation Efforts: Regulatory bodies, such as the U.S. EPA, have set strict standards for lead in drinking water. Mitigation strategies include replacing lead pipes, using corrosion control treatments, and employing point-of-use filters for affected households.

Iron (Fe) in Groundwater:

Iron is a common constituent of groundwater, and its presence can have both positive and negative implications for water quality and public health. This review explores the occurrence, health effects, and management of iron in groundwater.

Occurrence of Iron in Groundwater: Iron naturally occurs in groundwater due to its prevalence in geological formations. It often presents as dissolved ferrous iron (Fe^{2+}) or insoluble ferric iron (Fe^{3+}).

Health Implications of Iron in Drinking Water: While iron itself is not typically considered harmful at moderate levels, excessive iron concentrations can lead to aesthetic issues, such as rusty-colored water and metallic taste. Iron can also promote the growth of iron-related bacteria, affecting water quality.

Mitigation and Treatment of Iron in Drinking Water: Treatment methods for iron in groundwater include aeration, oxidation, and filtration. The choice of treatment depends on the form and concentration of iron in the water (Hussain, et al. 2011).

Chapter: 4

Materials and Methods

Groundwater plays a vital role as a major water supply source, serving various purposes and extracted through diverse techniques including handpumps, tube wells, injector pumps, dug wells, and motor pumps (Rehman and Cheema, 2016). The Global Positioning System (GPS) is employed to accurately record sample locations. Water samples are collected in polythene bottles, ensuring they are thoroughly washed with distilled water and nitric acid solution prior to collection. Before sampling, wells are pumped for around 10-15 minutes. During fieldwork, parameters such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), and pH are analyzed on-site. Samples are then sent to the laboratory, each properly labeled with date and location details

4.1. Water Quality Analysis:

Water quality analysis involves the assessment of a wide spectrum of characteristics, spanning biological, chemical, and physical aspects, with the purpose of determining its appropriateness for drinking, irrigation, and industrial applications (Peeters 2014). This analysis encompasses crucial parameters:

Water quality analysis encompasses a spectrum of essential parameters, each shedding light on specific aspects of water suitability. The pH measurement reveals the water's acidity level, while Total Dissolved Solids (TDS) quantifies the presence of both inorganic and organic substances. Conductivity evaluation gauges water's electrical conductivity, intrinsically tied to dissolved ion concentration, while Total Hardness detection pinpoints calcium and magnesium ions (Rehman and Cheema, 2016). Chlorine assessment quantifies free chlorine content, serving as a disinfectant, and Turbidity assessment gauges water's clarity or cloudiness. Nitrates and Nitrites identification targets nitrogen-based pollutants, and Phosphates indicate the presence of phosphorus-based pollutants.

The analysis employs a diverse array of tailored methodologies to ensure accurate parameter evaluation. Commonly employed techniques include pH meters and strips for precise pH measurement, conductivity meters to assess water's conductivity, titration to determine chlorine, nitrates, and phosphates concentration, and spectrophotometry to quantify water turbidity and provide insights into its optical clarity.

This comprehensive approach to water quality analysis enables a holistic evaluation of water's suitability for intended applications, facilitating informed decision-making related to its use and management. By dissecting water characteristics from various angles, this process enhances our understanding of water quality, its potential impact, and the measures needed for maintaining its fitness for specific purposes (Sheikhy et al., 2015).

4.1.1. Analyzing Alkalinity:

The established technique for assessing alkalinity in water, as outlined in the standard method of 1992, is the Titration Method. This method involves a systematic process of titrating a water sample with a standardized acid solution, often sulfuric acid, to determine the quantity of acid required to neutralize the alkaline substances present in the water, which can include carbonates, bicarbonates, hydroxides, and others (Peeters 2014).

The procedure typically commences with the addition of a few drops of an indicator solution, such as phenolphthalein, to the water sample. Subsequently, the titration process begins, during which the standardized acid is added incrementally until the endpoint is achieved (Sheikhy et al., 2015). This endpoint is marked by a distinct color change in the solution, transitioning from pink to colorless. The quantity of acid consumed during the titration is then employed to calculate the alkalinity of the water.

This method is favored in practice due to its simplicity, reliability, and adaptability for use in both field and laboratory settings. The outcomes of this method are typically reported as either total alkalinity or bicarbonate alkalinity, contingent on the specific requirements of the analysis (Rehman and Cheema, 2016).

4.1.2. Analyzing Arsenic (As):

The AAS Vario 6 Analytic Jena AG method is a variant of Atomic Absorption Spectrometry (AAS) employed to gauge the concentration of arsenic in water and various environmental samples. AAS stands as a prevalent analytical technique for determining metal ion concentrations in solution (Sheikhy et al., 2015).

Within the AAS Vario 6 Analytic Jena AG method, a sample of the water or environmental specimen is introduced into either a flame or a graphite furnace. In this controlled environment, arsenic is atomized and vaporized for subsequent analysis.

This technique offers the advantage of relative simplicity and automation, rendering it a preferred choice for routine environmental analyses in laboratories. However, it is vital to acknowledge that meticulous sample preparation and digestion are critical aspects of arsenic analysis via AAS, and they must be executed with precision to ensure accurate results (Sheikhy et al., 2015).

4.1.3. Analyzing Bicarbonate:

The conventional method employed for bicarbonate analysis in water is the Titration Method, as established in the 1992 standard. This technique entails titrating a water sample with a standardized acid solution, such as sulfuric acid, to ascertain the quantity of acid necessary for neutralizing the bicarbonates present in the water. The bicarbonate concentration is then calculated in terms of the equivalent amount of carbonic acid, typically expressed in milligrams per liter (mg/L) (Doneen, 1964).

The procedure typically commences with the introduction of a few drops of an indicator solution, such as phenolphthalein, to the water sample. The titration process is initiated, with the standardized acid solution being added incrementally until the titration endpoint is achieved. This endpoint is signified by a distinct shift in the solution's color, transitioning from pink to colorless. The quantity of acid utilized during the titration process is subsequently used to determine the bicarbonate concentration in the water.

This method is commonly preferred due to its reliability and widespread applicability. It ensures accurate assessments of bicarbonate concentrations, making it valuable in various analytical contexts (Doneen, 1964).

4.1.4. Analyzing Calcium (mg/l):

The 3500-Ca-D Standard method (1992) is a widely recognized technique for the quantitative analysis of calcium ions (Ca^2+) in water and wastewater. Calcium ions hold significance in various natural water systems and serve as an indicator of water hardness.

This method, defined by the 3500-Ca-D Standard (1992), involves a complexation process where calcium ions are complexed with a chelating agent, commonly EDTA (ethylenediaminetetraacetic acid). Subsequently, the concentration of calcium ions is determined through atomic absorption spectrophotometry (AAS) (Ravikumar et al., 2011).

The procedure typically entails the addition of the chelating agent to the water sample, followed by the measurement of the concentration of the chelated calcium ion using AAS or ICP-AES.

This method is extensively utilized for its precision and accuracy and can be automated to facilitate high-throughput analyses. It is particularly valuable for quantifying calcium ions in complex matrices like water and wastewater. However, it's crucial to emphasize that careful sample preparation and sample digestion are pivotal aspects of the calcium analysis process when employing this method, ensuring the attainment of precise results (Zheng et al., 2010).

4.1.5. Analyzing Carbonate (mg/l):

The 2320 standard method, also known as ASTM D2320-92, serves as an established technique for the analysis of carbonate in water samples. This method involves the introduction of an acid into the water sample, initiating a reaction with carbonate that results in the production of carbon dioxide gas. The quantity of gas generated is subsequently measured and used to calculate the concentration of carbonate present in the sample. The 2320 method finds frequent application in environmental analysis and water quality assessment.

4.1.6. Analyzing Chloride (mg/l):

The titration method employing silver nitrate stands as a standard approach for determining the concentration of chloride ions in a solution.

This method hinges on the fundamental principle of a chemical reaction between silver nitrate and chloride ions, leading to the formation of silver chloride, which is insoluble in water. The reaction is stoichiometric, implying that a fixed amount of silver nitrate reacts with a fixed quantity of chloride ions. The precise 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 produce silver sulfide. The titration endpoint is identified using a suitable indicator. Subsequently, the concentration of chloride ions is calculated based on the quantity of silver nitrate consumed during the reaction (Ahada and Suthar, 2019; Bibi et al., 2021).

4.1.7. Analyzing Conductivity:

The Hach-44600-00 EC meter, likely manufactured in the USA, typically employs the two-electrode method for measuring electrical conductivity (EC). In this method, a voltage is applied between two electrodes submerged in the solution, and the resulting current passing through the solution is quantified. The EC of the solution is then derived from the measured current and the applied voltage. Additionally, the EC meter may incorporate temperature compensation to account for variations in conductivity arising from temperature fluctuations (Rehman et al., 2022).

It's important to recognize that the specific methodology employed by the Hach-44600-00 EC meter can vary depending on the manufacturer and instrument configuration. To obtain detailed information about the method of analysis for this specific EC meter, referring to the user manual or technical specifications is recommended.

4.1.8. Analyzing Lead (ppb):

The instrument used for lead analysis and other elemental determinations across various sample types, including water, soil, and biological materials, often relies on Atomic Absorption Spectrometry (AAS).

AAS is a spectroscopic technique that measures the absorption of light by atoms within a sample. For lead analysis, the sample is typically atomized, commonly achieved through heating or nebulization. The instrument then quantifies the light absorbed by the lead atoms at a specific wavelength. The extent of light absorption is directly proportional to the concentration of lead present in the sample (Ullah et al., 2022).

The AAS Vario 6 instrument may be equipped with either a graphite furnace or a flame for atomization, chosen based on the specific application and type of sample. It boasts the capability to detect trace levels of lead while ensuring high accuracy and precision. However, it's essential to note that the method of analysis and the instrument's precise configuration can vary among manufacturers. Thus, referring to the user manual or technical specifications for detailed information is advisable.

4.1.9. Analyzing Hardness (mg/l):

The determination of total water hardness, indicative of the concentration of calcium and magnesium ions in water, typically involves the use of the EDTA (ethylene-diamine-tetraacetic acid) titration method, as outlined in the ASTM D1139-92 standard.

In this method, EDTA is introduced to the water sample, leading to the formation of a soluble complex as it reacts with the metal ions responsible for water hardness. The titration process reaches its endpoint, typically indicated by a suitable indicator. The quantity of EDTA required to react with all hardness-causing ions is then employed to calculate the total hardness of the water (Jiang et al., 2009).

4.1.10. Analyzing Nitrate (mg/l):

The cadmium reduction method (Hach-8171) by spectrophotometer is employed to quantify the concentration of nitrate in water samples. This method, developed by the Hach Company, a reputable water analysis firm, leverages a spectrophotometer for analysis.

Fundamentally, this method involves the reduction of nitrate ions to nitrite ions using cadmium metal as a reducing agent. Subsequently, a spectrophotometer is utilized to measure the resulting nitrite ions by detecting light absorption at a specific wavelength. The extent of light absorption is directly proportional to the nitrite concentration, allowing for the calculation of nitrate concentration based on the nitrite produced (Rasheed et al., 2022).

This method is recognized for its simplicity and accuracy in determining nitrate levels in water, commonly finding application in environmental analysis and water quality assessments. Nevertheless, it's worth noting that the specific methodology and configuration of the spectrophotometer may vary depending on the manufacturer and instrument model. For precise information about the analysis procedure, consulting the user manual or technical specifications of the specific spectrophotometer is advisable.

4.1.11. Analyzing pH:

The pH meter Hanna Instrument Model 8519 is an electronic device designed to measure the pH of a solution, a parameter indicative of its acidity or alkalinity.

The Model 8519 pH meter typically employs a combination of electrodes and a digital meter for pH measurement. The pH-sensitive glass electrode contains a solution that interacts with the test solution, generating a voltage proportional to its pH. This voltage is then quantified by the digital meter. Additionally, the pH meter may incorporate temperature compensation to correct pH variations caused by temperature fluctuations.

It's important to recognize that the specific methodology employed by the Hanna Instrument Model 8519 pH meter can vary based on the manufacturer and instrument configuration. Therefore, referring to the user manual or technical specifications of the particular pH meter is recommended for a comprehensive understanding of the analysis method (Peeters, 2014).

4.1.12. Analyzing Potassium (mg/l):

A flame photometer, such as the PFP7 model manufactured by a UK-based company, serves as a spectrophotometric instrument for determining the concentration of specific metal ions in a sample. In the case of the PFP7, it is used to analyze potassium ions in various sample types.

The fundamental principle of a flame photometer involves atomizing the sample in a flame, leading to the excitation of metal ions. The emitted light from these excited ions is then measured at a specific wavelength. The intensity of the emitted light is directly proportional to the concentration of the metal ions within the sample. For potassium analysis, the flame photometer measures the light emitted at a wavelength specific to potassium ions (Adebayo et al., 2021).

The PFP7 flame photometer is known for its compact and portable nature, making it suitable for rapid and precise potassium level analysis across a wide range of samples, including soil, water, and biological materials. Nonetheless, it's essential to acknowledge that the methodology and configuration of flame photometers may differ depending on the manufacturer and instrument model. To gain precise insights into the analysis process, referring to the user manual or technical specifications of the specific flame photometer is advisable.

4.1.13. Analyzing Sodium (mg/l):

A flame photometer, akin to the PFP7 model produced by a UK-based company, is a type of spectrophotometer used to determine the concentration of specific metal ions in a given sample. In this context, the PFP7 flame photometer is employed to analyze sodium ions within a sample.

The fundamental principle behind the flame photometer involves atomizing the sample in a flame, causing the metal ions present to become excited. The emitted light from these excited metal ions is subsequently measured at a specific wavelength. The intensity of this emitted light is directly proportional to the concentration of the metal ions within the sample. For sodium analysis, the flame photometer detects the light emitted at a wavelength specific to sodium ions.

The PFP7 flame photometer is known for its compact and portable nature, rendering it suitable for rapid and precise sodium level analysis across a wide range of sample types, including soil, water, and biological materials. However, it is important to acknowledge that the methodology and configuration of flame photometers may vary depending on the manufacturer and instrument model. Therefore, for precise insights into the analysis procedure, consulting the user manual or technical specifications of the specific flame photometer is advisable.

4.1.14. Total Dissolved Solids (TDS, mg/l):

The 2540C standard method (1992) represents a widely employed approach for determining the total dissolved solids (TDS) in a water sample. TDS encompasses both inorganic and organic substances dissolved in water, excluding suspended solids. This method is well-established and frequently utilized for TDS analysis in water samples.

The fundamental principle underlying this method involves evaporating a measured volume of the water sample to dryness, followed by the measurement of the weight of the residual solids. The TDS concentration is then calculated as the weight of the remaining solids divided by the volume of the original water sample. While the 2540C standard method is deemed relatively straightforward, it can be time-consuming and may necessitate specialized equipment (Mandal and Suzuki, 2002).

It's essential to recognize that the specific methodology and requirements of the 2540C standard method may vary based on the source and the particular implementation. Therefore, for comprehensive information regarding the method and its requisites, referring to the original standard or a reputable reference source is recommended.

4.1.15. Analyzing Fluoride (mg/l):

The 4500-F C iron-selective electrode represents an electronic sensor employed to measure the concentration of fluoride ions in a solution. This electrode operates by quantifying the potential difference between a reference electrode and the fluoride-selective electrode, and this potential difference is directly proportional to the concentration of fluoride ions in the solution (Tabassum et al., 2019).

The method relies on the principle that fluoride ions impact the oxidation-reduction potential of iron in solution, resulting in a change in the potential of the iron electrode. The electronic sensor interprets this potential shift and converts it into a measurement of fluoride ion concentration.

The 4500-F C iron-selective electrode is extensively used for fluoride analysis in water, wastewater, and other aqueous solutions. This method is regarded as a swift, reliable, and user-friendly approach for fluoride analysis, well-suited for routine testing across diverse settings.

4.1.16. Analyzing Iron (mg/l):

The method for analyzing iron in water samples involves the addition of a TPTZ (2,4,6-tripyridyl-s-triazine) reagent to the sample containing iron ions. This reagent forms a complex with the iron ions, generating a characteristic absorption spectrum. The intensity of the absorption at a specific wavelength is directly proportional to the concentration of iron ions within the sample (Adeloju et al., 2021).

The TPTZ method is widely employed for iron analysis in various water samples, including drinking water, wastewater, and process water. It is recognized for its reliability and accuracy in iron analysis, making it suitable for routine testing in a variety of settings.

However, it's important to note that the specific methodology and requirements of the TPTZ method may vary depending on the source and the specific implementation. For comprehensive insights into the method and its prerequisites, referring to the original method or a trusted reference source is advisable.

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. Graphical Methods:

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

- Piper Diagram
- Gibbs Diagram

4.3.1. 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.

4.3.2. 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).

4.4. 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).

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

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

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

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

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

The next step is to calculate the Qi 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 "Cn" (eq 4.4) (Mandal and Suzuki 2002).

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

The last step is to multiply Qi with the Wi 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).

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

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.

4.5. 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) .

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

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).

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

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).

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

4.6. Health Risk Assessment:

In Gujrat 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 et al., 2010).

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

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).

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

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

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

4.7. Saturation Index:

Saturation Index (SI) in the context of water chemistry and quality assessment is a critical parameter used to evaluate the tendency of water to be either under saturated, saturated, or oversaturated with respect to certain minerals or compounds, primarily calcium carbonate (CaCO3), gypsum (CaSO4·2H2O), and other minerals. SI is a valuable tool for understanding the potential for scaling or corrosion in water distribution systems, industrial processes, and natural aquatic environments.

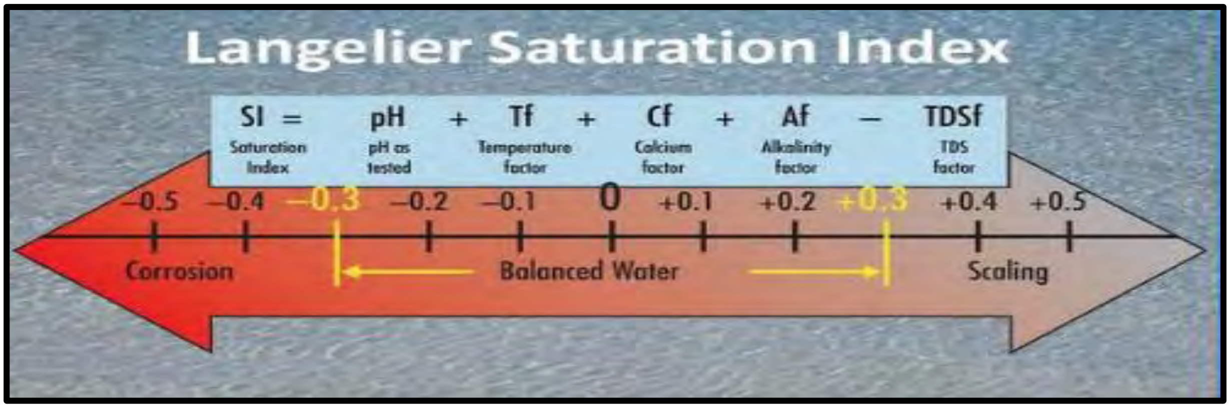


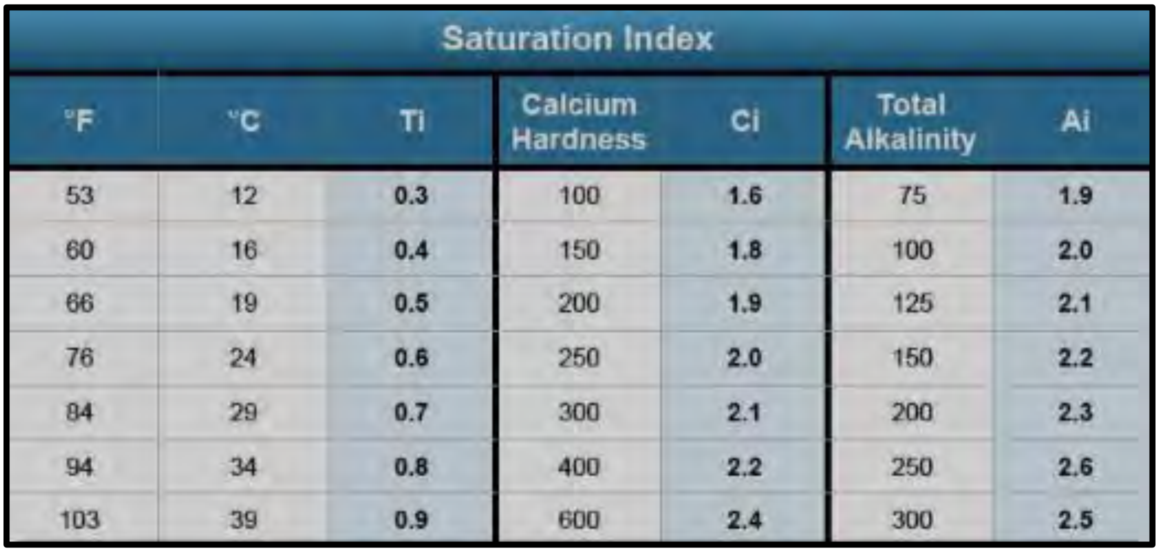
Figure 4.1 Shows Langelier saturation index Scale (Sarfraz et al., 2019)

Here are some key points about the Saturation Index:

1. **Conceptual Basis**: The Saturation Index is based on the principle of chemical equilibrium between water and the dissolved minerals it contains. It assesses whether the concentration of these minerals in the water is in equilibrium with the water's chemical properties. When the water is in equilibrium with a particular mineral, it is said to be saturated. When the concentration of the mineral exceeds its equilibrium level, the water is supersaturated, and if it falls below, the water is under saturated.
2. **Calculation**: The Saturation Index is typically calculated using the following formula:

$$LSI=pH-pH_s$$

SI values greater than zero indicate super saturation, SI equal to zero indicates saturation, and SI values less than zero indicate under saturation.



Saturation Index

°F	°C	Ti	Calcium Hardness	Ci	Total Alkalinity	Ai
53	12	0.3	100	1.6	75	1.9
60	16	0.4	150	1.8	100	2.0
66	19	0.5	200	1.9	125	2.1
76	24	0.6	250	2.0	150	2.2
84	29	0.7	300	2.1	200	2.3
94	34	0.8	400	2.2	250	2.6
103	39	0.9	600	2.4	300	2.5

Figure 4.2 Saturation Index chart (Sarfraz et al., 2019)

3. **Relevance to Water Quality**:
    - **Scaling**: When the SI is positive (super saturation), the water has a higher potential for mineral scaling. This means that minerals can precipitate and accumulate on surfaces, such as pipes and heating elements, leading to scale formation, reduced water flow, and increased energy consumption.

- **Corrosion**: Conversely, when the SI is negative (under saturation), the water may be aggressive and potentially corrosive, causing damage to metal surfaces and equipment.

4. **Control and Management**: Understanding the SI of water is essential for managing water quality in various applications. In the context of water treatment, adjusting the SI by controlling factors such as pH, temperature, and chemical additives can help prevent scaling or corrosion.

5. **Environmental Impact**: In natural aquatic ecosystems, the Saturation Index can also provide insights into the health and equilibrium of aquatic environments. Changes in SI can influence the solubility of minerals essential for aquatic life and impact aquatic habitats.

6. **Monitoring and Assessment**: Regular monitoring of water chemistry parameters, including the SI, is crucial for maintaining water quality, especially in industrial processes, cooling towers, swimming pools, and potable water systems.

Chapter: 5

Results and Discussion

5.1. Physiochemical Parameters Analysis:

The groundwater samples underwent comprehensive analysis encompassing a range of critical parameters, including electrical conductivity (EC), total dissolved solids (TDS), pH, bicarbonate (HCO3), carbonate (CO3), chloride (Cl), sulfate (SO4), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), nitrate (NO3), phosphate (PO4), fluoride (F), iron (Fe), arsenic (As), and lead (Pb). The recorded measurements fell within specified intervals, although certain values surpassed the thresholds established by the World Health Organization (WHO).

The EC values exhibited a span from 7.6 to 2040 µS/cm, with a mean of 994.8 µS/cm, and approximately 90% of samples adhered to WHO guidelines, while 10% exceeded them. TDS measurements ranged from 284 to 4232 mg/L, with a mean of 647.7 mg/L, and approximately 92.9% of samples adhered to WHO limits, whereas 7.1% exceeded them. The pH levels encompassed a range of 7 to 9, averaging at 7.5, thereby aligning with the WHO's pH range of 6.5–8.5. HCO3 concentrations spanned from 60 to 590 mg/L, with an average of 374.9 mg/L, and only 47% of samples complied with WHO standards, while 53% exceeded them. CO3 values consistently registered below the detection threshold of 0 mg/L, satisfying WHO requirements. The Cl concentrations ranged from 7 to 320 mg/L, averaging at 51.1 mg/L, and approximately 98.6% of samples aligned with WHO limits, with 1.4% surpassing them. SO4 concentrations ranged from 2.5 to 420 mg/L, with an average of 66.3 mg/L, and about 98.6% of samples adhered to WHO standards, while 1.4% exceeded them. For Ca concentrations, falling between 20 to 234 mg/L and averaging at 68.9 mg/L, all samples remained within WHO's calcium limit. Mg concentrations varied from 2 to 87 mg/L, averaging at 26.4 mg/L, and all samples conformed to WHO's magnesium limit. Na concentrations spanned from 2.4 to 390 mg/L, with an average of 109.9 mg/L, and approximately 84% of samples adhered to WHO limits, while 16% exceeded them. K concentrations ranged from 1 to 189 mg/L, averaging at 17.8 mg/L, with around 86% of samples aligning with WHO limits, and 14% surpassing them. NO3 concentrations ranged from 0 to 43 mg/L, averaging at 6 mg/L, and all samples adhered to WHO's nitrate limit. PO4 concentrations spanned from 0.01 to 0.7 mg/L, averaging at 0.1 mg/L, and roughly 94% of samples aligned with WHO limits, while 6% exceeded them. F concentrations varied from 0.01 to 2.75

mg/L, with an average of 0.3 mg/L, and around 64% of samples met WHO standards, while 36% exceeded them. Fe concentrations ranged from 0 to 2.2 mg/L, averaging at 0.1 mg/L, and all samples adhered to WHO's iron limit. As concentrations spanned from 0.22 to 24.13 ppb, averaging at 8.78 ppb, with approximately 54% of samples complying with WHO limits, and 46% exceeding them. Finally, Pb concentrations ranged from 0.01 to 1.97 ppb, averaging at 0.5 ppb, with about 89% of samples adhering to WHO standards, and 11% exceeding them.

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	7.6	2040	994.8	1500	90%	10%
TDS	mg/L	284	4232	647.7	1000	92.9%	7.1%
PH	----	7	9	7.5	6.5–8.5	90%	10%
HCO_3	mg/L	60	590	374.9	350	47%	53%
CO_3	mg/L	0	0	0	200	100%	0
Cl	mg/L	7	320	51.1	250	98.6%	1.4%
SO_4	mg/L	2.5	420	66.3	400	98.6%	1.4%
Ca	mg/L	20	234	68.9	300	100%	0
Mg	mg/L	2	87	26.4	150	100%	0
Na	mg/L	2.4	390	109.9	200	84%	16%
K	mg/L	1	189	17.8	10	86%	14%
NO_3(N)	mg/L	0	43	6	45	100%	0
PO_4	mg/L	0.01	0.7	0.1	0.3	94%	6%
F	mg/L	0.01	2.75	0.3	1.5	71%	29%
Fe	mg/L	0	2.2	0.1	3	100%	0

As	(PPb)		24.13	8.78	10	57%	43%
Pb	(PPb)	0.01	1.97	0.5	10	89%	11%

5.2. Spatial Distribution Analysis:

Groundwater quality is shaped by a multitude of factors, including geological formations, topographical features, land usage, and human interventions. Primarily, the chemical composition of groundwater is heavily influenced by the minerals present in the surrounding rocks and soil, as well as the types and quantities of pollutants introduced by the environment. Groundwater commonly contains elevated concentrations of mineral components like calcium, magnesium, and iron, along with dissolved salts and various contaminants such as nitrates, pesticides, and bacteria. The movement of these contaminants through the groundwater system gives rise to distinct spatial patterns characterized by varying chemical compositions. In some instances, these patterns may exhibit predictability and consistency, while in others, they can be more intricate and subject to variation. Accurately comprehending the spatial distribution of groundwater chemical attributes holds paramount importance for effective groundwater resource management, water quality assessment, and the prevention of aquifer contamination. To achieve this understanding, interpolation methods, specifically the Inverse Distance Weighting (IDW) tool within ArcGIS software, are employed to generate spatial distribution maps.

The water table depth in the area exhibits a range from 20 to 200, with lower values indicated by a yellow color and higher values by a dark blue color. Similarly, for Electrical Conductivity (EC), the values span from 8 to 2035 µS/cm, with lower values represented in yellow and higher values in dark blue. Notably, a significant portion of the study area falls within the range of 691 to 1250 µS/cm for EC. Regarding pH levels, they vary from 0 to 9, with lower pH values depicted in yellow and higher values in dark blue. The majority of the study area falls within the pH range of 0 to 2. For Turbidity, the values range from 0 to 28 mg/L. Yellow represents lower turbidity levels, while dark blue indicates higher turbidity. Approximately 80% of the study area falls within the turbidity range of 0 to 3 mg/L, while the remaining 20% is distributed among the ranges of 4 to 28 mg/L.

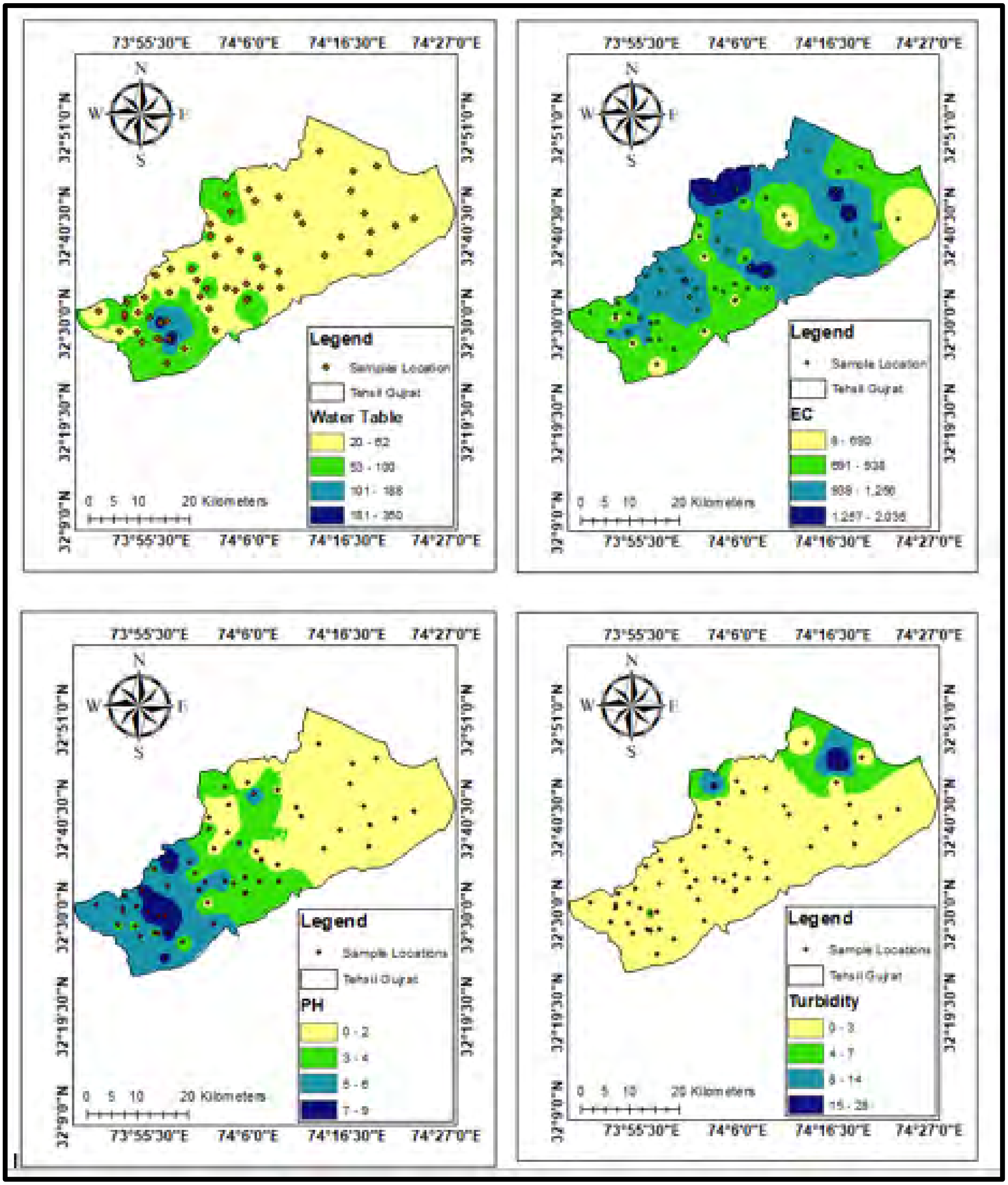


Figure 5.1 Spatial Distribution map of Water table, EC, PH, Turbidity.

The Total Dissolved Solids (TDS) in the area range from 234 to 4221 mg/L, with lower values denoted by yellow and higher values by dark blue. Notably, around 50% of the study area falls within the TDS range of 234 to 566 mg/L. The remaining 50% of the area is distributed between the ranges of 267 to 4221 mg/L. As for bicarbonate (HCO3) levels, they vary from 60 to 589 mg/L, with yellow indicating lower values and dark blue representing higher values. Approximately 50% of the study area falls within the HCO3 range of 316 to 359 mg/L. The remaining 50% is divided among the ranges of 60 to 315 mg/L and 360 to 589 mg/L. Chloride (Cl) levels span from 9 to 319 mg/L, with yellow indicating lower concentrations and dark blue indicating higher concentrations. Around 80% of the study area falls within the Cl range of 42 to 390 mg/L. Sulfate (SO4) values range from 2 to 333 mg/L, with yellow signifying lower values and dark blue signifying higher values. Approximately 80% of the study area falls within the SO4 range of 41 to 333 mg/L. The remaining 20% is distributed between the ranges of 2 to 40 mg/L.

The calcium levels in the area range from 20 to 233 mg/L, with yellow indicating lower concentrations and dark blue indicating higher concentrations. Impressively, nearly 60% of the study area falls within the calcium range of 20 to 85 mg/L. In terms of magnesium content, it varies from 2 to 80 mg/L, with yellow representing lower values and dark blue signifying higher values. Around 80% of the study area is distributed within the magnesium range of 22 to 80 mg/L. The remaining 20% is between the range of 2 to 21 mg/L. Potassium levels span from 1 to 187 mg/L, with yellow denoting lower concentrations and dark blue representing higher concentrations. Notably, approximately 90% of the study area falls within the potassium range of 1 to 17 mg/L, while the remaining 10% encompasses values ranging from 18 to 187 mg/L.

The NCO3 levels span from 0 to 42 mg/L, with yellow indicating lower concentrations and dark blue representing higher concentrations. Impressively, nearly 70% of the study area has NCO3 values ranging from 6 to 42 mg/L, while the remaining 30% falls within the 0 to 5 mg/L range. When it comes to PO4 concentrations, they range from 0.01 to 0.60 mg/L, with yellow signifying lower values and dark blue indicating higher ones. Approximately 90% of the study area falls within the PO4 range of 0.01 to 0.06 mg/L, while the other 10% covers values between 0.07 to 0.60 mg/L. Fluoride levels vary from 0 to 0.79 mg/L, with yellow representing lower concentrations and dark blue denoting higher ones. Remarkably, nearly 80% of the study area falls within the fluoride range of 0.12 to 0.79 mg/L, while the remaining 20% falls within the 0 to 0.11 mg/L range.

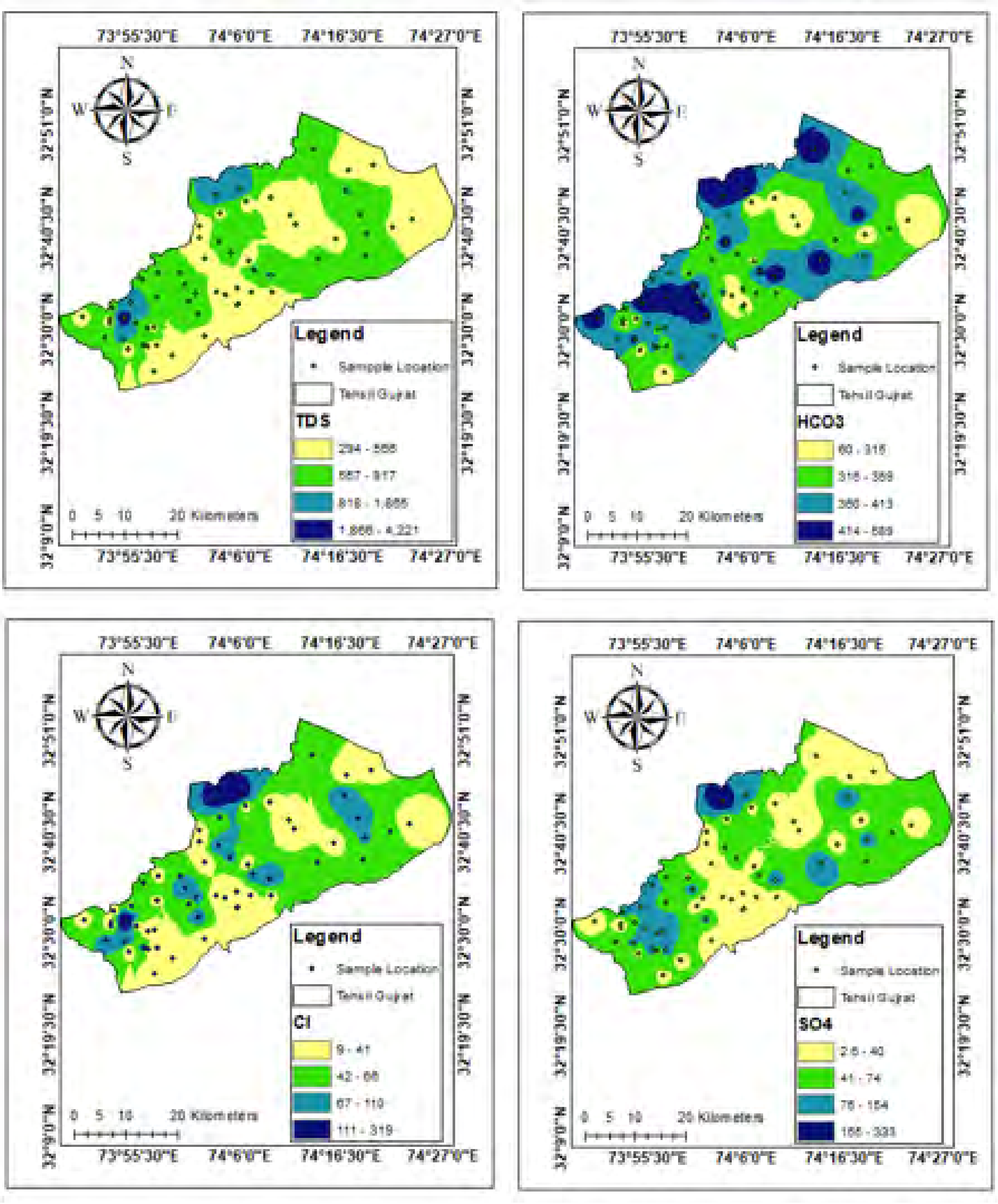


Figure 5.2 Spatial Distribution map of TDS, HCO_3, Cl, and SO_4.

Lead concentrations span from 0 to 20 ppb, with yellow indicating lower values and dark blue representing higher values. Notably, approximately 80% of the study area falls within the lead range of 0 to 4 ppb, while the remaining 20% encompasses values ranging from 5 to 20 ppb.

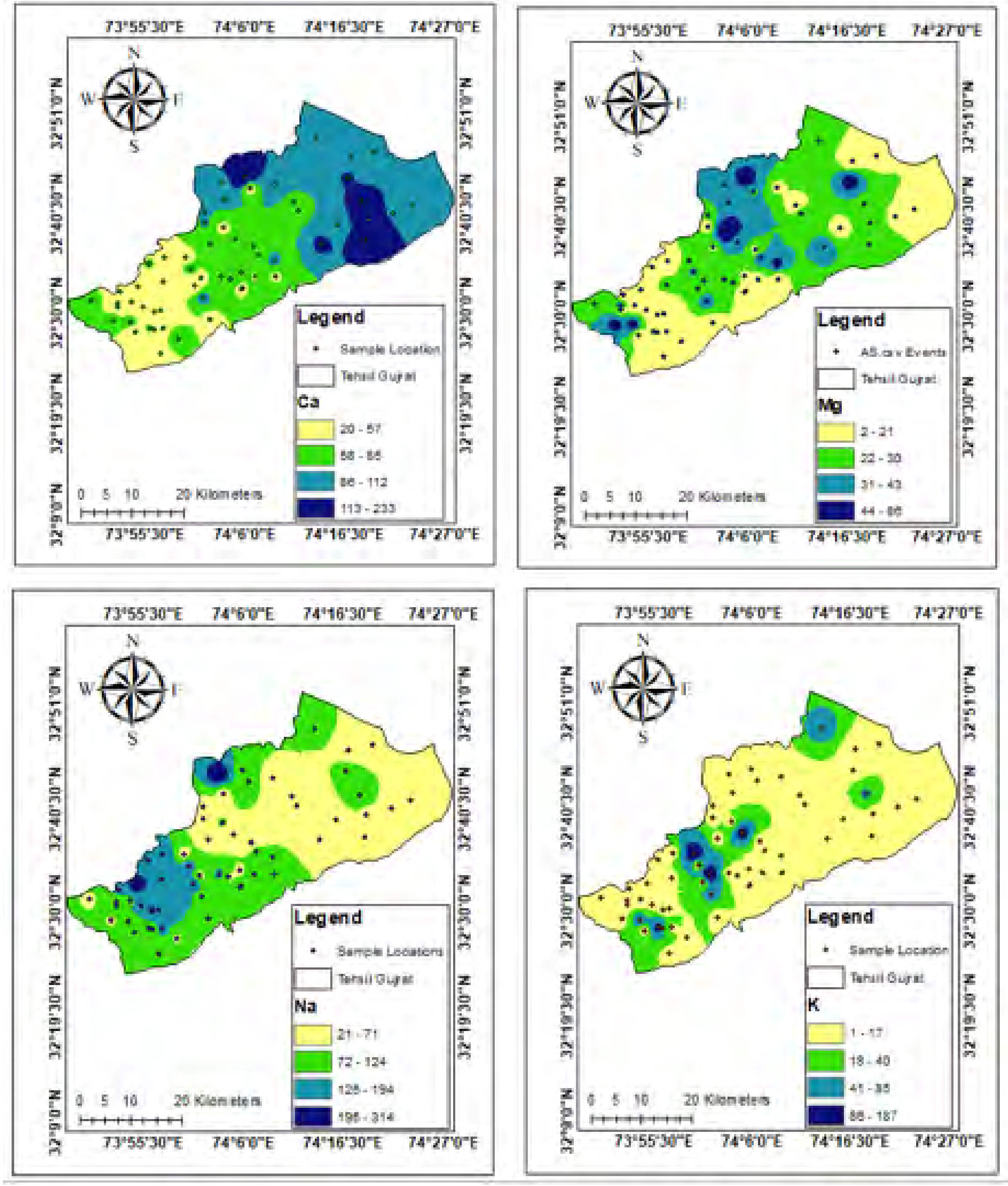


Figure 5.3 Spatial Distribution map of Ca, Mg, Na, and K.

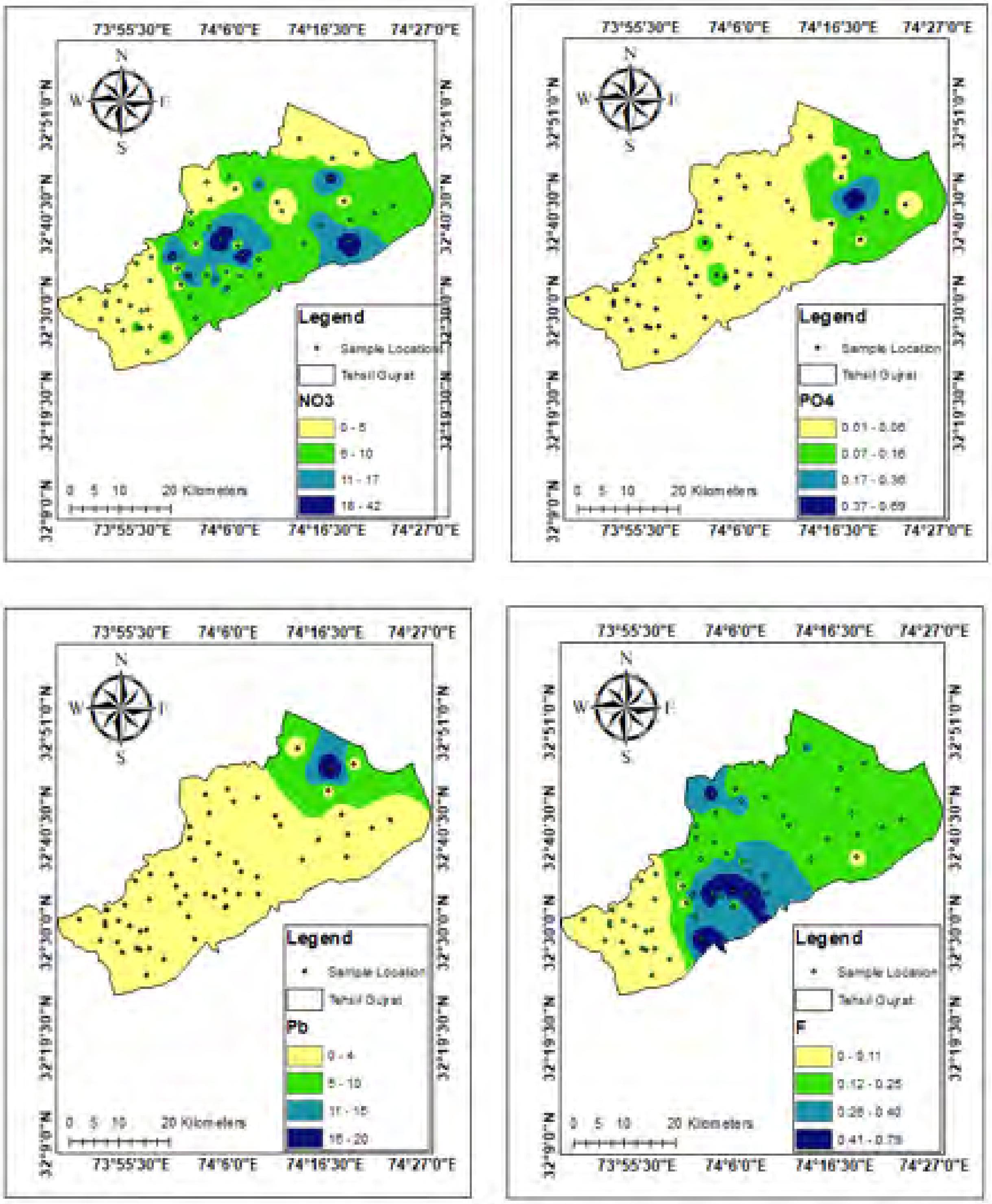


Figure 5.4 Spatial Distribution map of NO3, PO4, Pb, and F.

5.3. Correlation Analysis:

Correlation analysis is a valuable tool for understanding the relationships between various ions in groundwater. When ions exhibit positive correlations, it often suggests a common source for these constituents, while negative correlations typically indicate different origins. This analysis not only helps elucidate the connections between different groundwater parameters but also provides insights into the types of geological formations responsible for ion generation and their solubility characteristics. Furthermore, it can signal human activities that may be contributing to water source pollution.

The relationships among various parameters in the water analysis are as follows:

1. Total Dissolved Solids (TDS) exhibit a strong positive correlation of 0.97 with Electrical Conductivity (EC), indicating a close relationship between these two factors.
2. Alkalinity shows positive correlations of 0.71 with EC and 0.75 with TDS, signifying their interdependence.
3. Hydrogen Carbonate (HCO3) demonstrates positive relationships of 0.72 with EC and 0.76 with TDS, emphasizing their connection.
4. Carbon Dioxide (CO2) is positively associated with pH, with a correlation coefficient of 0.77.
5. Chloride (Cl) displays positive correlations with EC and TDS, indicating a strong relationship, while Sulfate (SO4) has positive correlations with EC, TDS, and Cl, all with coefficients exceeding 0.7.
6. Calcium (Ca) exhibits negative correlations with all parameters.
7. Sodium (Na) is positively correlated with EC (0.93), TDS (0.96), Cl (0.91), and SO4 (0.84), highlighting their strong connections.
8. Other parameters either display negative correlations or have coefficients smaller than 0.7 (Table 5.3).

Table 5.2 shows correlation of all the elements

Par	**EC**	**PH**	**TUR**	**TDS**	**HCO3**	**Cl**	**SO4**	**Ca**	**Mg**	**Na**	**K**	**NO3 (N)**	**PO4**	**F**	**Fe**	**As**	**Pb**
EC	1																
PH	0.53	1															
TUR	0.44	0.09	1														
TDS	0.97	0.50	0.43	1													
HCO3	0.72	0.34	0.48	0.76	1												
Cl	0.47	0.77	0.09	0.45	0.56	1											
SO4	0.91	0.54	0.27	0.92	0.54	0.55	1										
Ca	0.90	0.38	0.41	0.93	0.55	0.56	0.31	1									
Mg	-0.31	-0.70	-0.21	-0.32	-0.17	-0.18	-0.48	-0.39	-1								
Na	-0.14	-0.37	0.18	-0.15	0.13	0.12	-0.20	-0.25	-0.11	1							
K	0.93	0.65	0.40	0.96	0.70	0.71	0.55	0.91	0.84	-0.51	-1						
NO3	0.48	0.15	0.40	0.55	0.47	0.48	0.14	0.43	0.54	-0.14	0.00	1					
PO4	0.25	0.19	0.09	0.28	0.49	0.47	0.39	0.15	0.11	-0.11	-0.14	0.31	1				
F	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	1			
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	1		
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	1	
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	1

5.4. Piper Diagram:

In the Piper plot analysis conducted on groundwater samples from Tehsil Gujrat, distinct patterns emerge in relation to cations and anions. For cations, the findings reveal that 16 samples align with the calcium type (Zone A), while 21 samples demonstrate no dominant type (Zone B), and an additional 22 samples correspond to the sodium type (Zone D) and 1 sample in (Zone C). In terms of anions, the majority of groundwater samples, totaling 58, exhibit characteristics of the bicarbonate type (Zone E). Meanwhile, 1 samples lack a clear dominant type (Zone B), and only 1 samples conform to the chloride type (Zone G).

The position of anions and cations is represented in a diamond shape within the Piper plot. Notably, a substantial number of groundwater samples, specifically 37, fall within the HCO3-Ca type (Zone 4). Moreover, 2 samples exhibit traits of both SO4 Cl-Na type (Zone 2) and 21 samples in HCO3-Na type (Zone 3). These observations underline the complex composition of groundwater samples and the coexistence of various chemical characteristics.

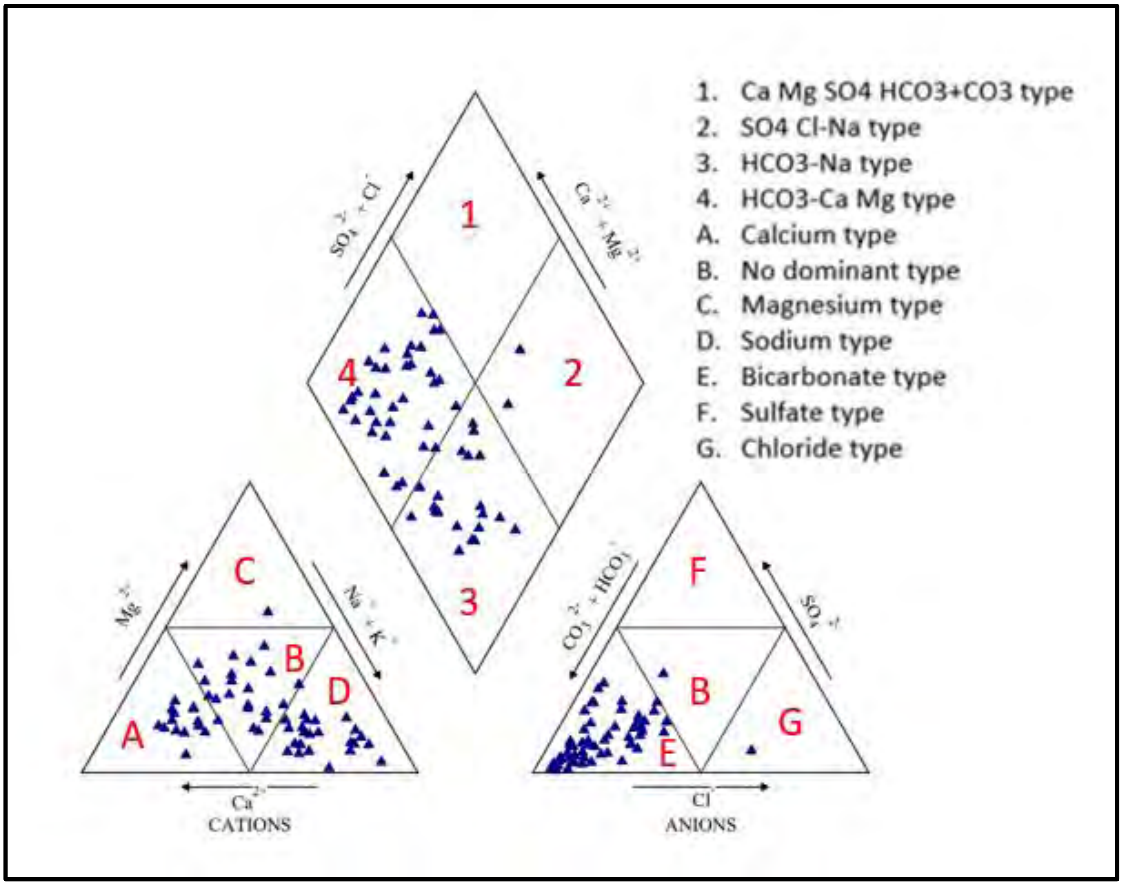


Figure 5.5 Showing Piper diagram of Tehsil Gujrat

5.5. Gibbs Diagram:

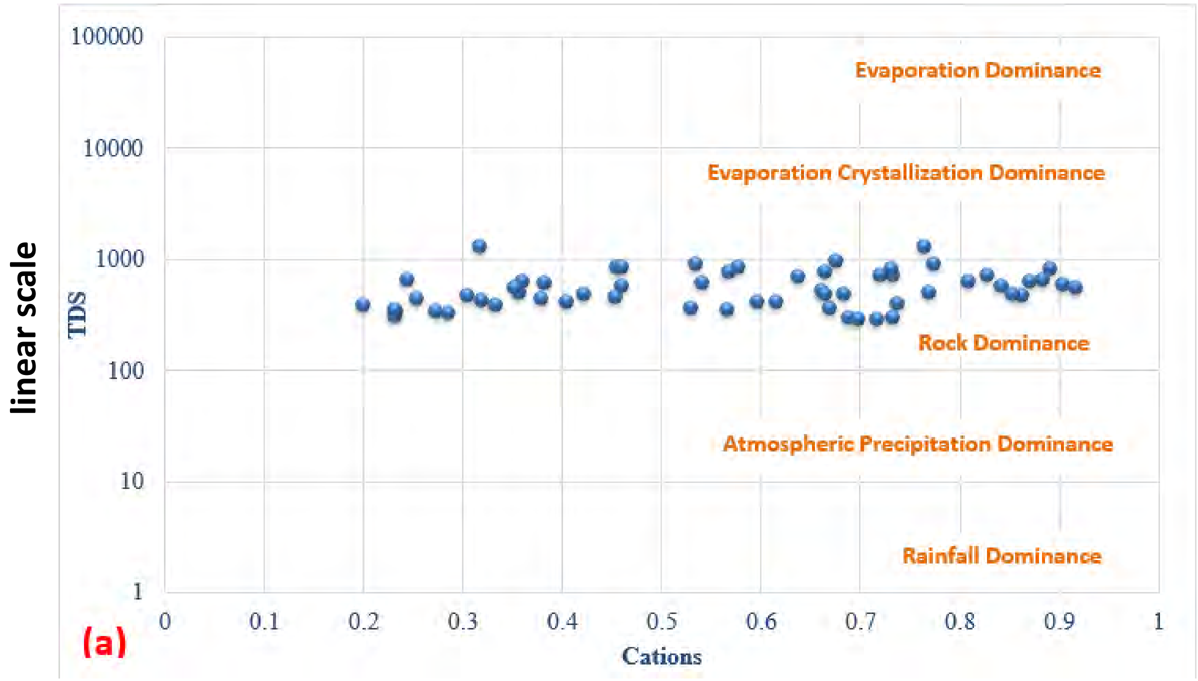
The Gibbs plot serves as a valuable tool to decipher the governing factors of groundwater chemistry in Tehsil Gujrat. Various factors, such as weathered conditions and the mineralogy of the aquifer, contribute to shaping groundwater chemistry. The plot consists of two segments, one for cations and another for anions. These diagrams shed light on pivotal processes, including evaporation dominance, evaporation crystallization dominance, rock dominance, atmospheric precipitation dominance, and rainfall dominance. In particular, the cation and anion plots both distinctly place all the study area samples within the evaporation crystallization dominance and rock dominance zones. This observation highlights the significant influence of these two factors on the groundwater chemistry.

Examining the Gibbs plots closely reveals that a majority of the samples are situated within the TDS range of 100 to 1000, signifying a rock dominance zone. Additionally, a smaller subset of samples falls within the TDS range of 1000 to 10000, representing the evaporation crystallization dominance zone. Notably, approximately 90% of the samples are attributed to the rock dominance zone, while the remaining 10% belong to the evaporation crystallization zone.

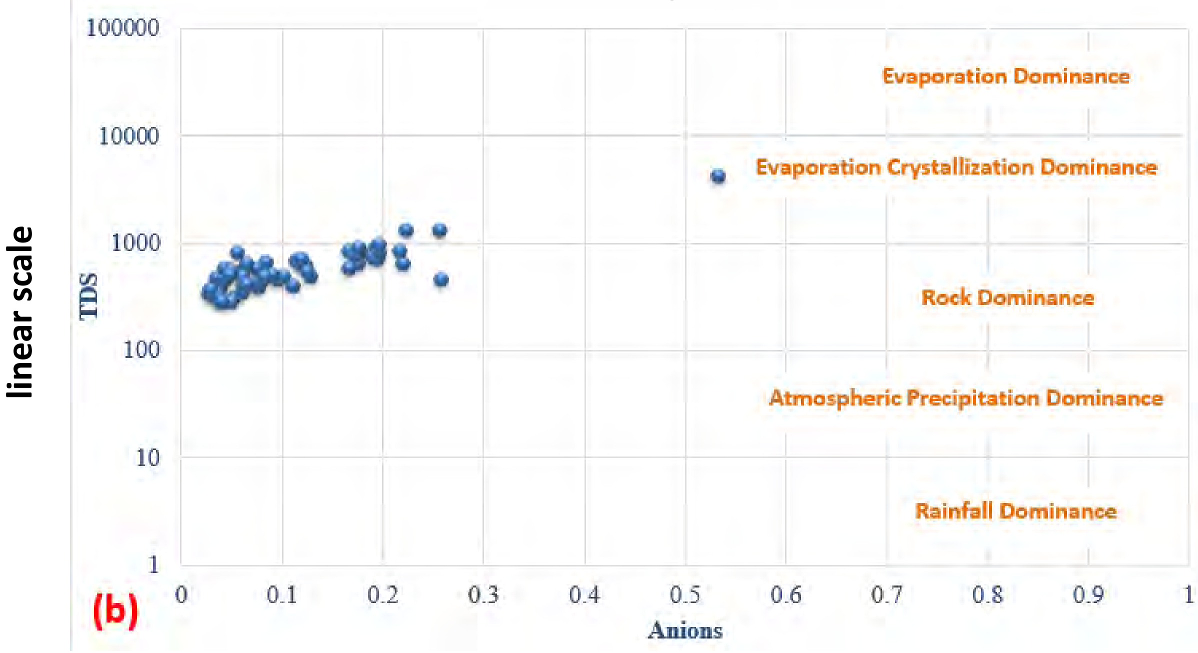
In the context of Gibbs plots, the "Rock Dominance Zone" signifies an area where the chemical composition of rocks can be deduced solely from their elemental composition. This characteristic is intrinsic to the minerals constituting the rocks, rather than being influenced by external factors like mineralogy or texture. This zone, hence, indicates samples where the chemical composition aligns predominantly with the rock-forming minerals. Ascertaining a sample's placement in this zone allows for insights into its probable rock type.

On the other hand, the "Evaporation-Crystallization Dominance Zone" within Gibbs plots points to samples whose chemical composition is chiefly molded by processes of evaporation and subsequent crystallization. These samples mirror the ratios of elements present in the original solution and are shaped by the specific conditions under which evaporation and crystallization occurred. Geological environments such as salt pans, evaporite deposits, and hot springs typically yield samples within this zone. These environments offer a unique glimpse into the past chemical compositions and formation conditions, which can be deduced from the crystallized minerals.

Effectively utilizing Gibbs plots involves determining whether a sample aligns with the Rock Dominance Zone or the Evaporation-Crystallization Dominance Zone, which provides insights into the geological history and conditions of formation. This information holds value across diverse geological applications, ranging from understanding sedimentary basin evolution and climate reconstruction to resource exploration and mineral assessments.



Semi-log Scale



Semi-log Scale

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

5.6. Water Quality Index Calculations

The analysis of the water quality index in Gujrat tehsil, focusing on groundwater samples, reveals interesting findings. Specifically, the breakdown of groundwater sample results indicates that:

- An impressive 34% of the samples fall within the "excellent" water quality category.
- A significant majority, constituting 36% of the samples, demonstrate "good" water quality.
- A smaller proportion, 20% of the samples, fall into the "poor" category.
- Another 10% of the samples are classified as "very poor."
- Encouragingly, none of the samples fall into the "worse" category.

This analysis underscores that the overall water quality in Gujrat is notably favorable, with the majority of samples falling within the "good" quality range

Table 5.3 Showing Water quality Index Calculations of Tehsil Gujrat

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

Table 5.4 showing the Calculations of Area of Gujrat WQI

Area		
1	Excellent Water Quality	170 sq.km
2	Good Water Quality	302 sq.km
3	Poor Water Quality	428 sq.km
4	Very Poor Water Quality	563 sq.km

5.7. Saturation Index:

The dataset encompasses measurements associated with six different minerals: anhydrite, aragonite, calcite, dolomite, gypsum, and halite.

Starting with "Anhydrite," the numeric measurements range from -0.99 to 0.85, and notably, all values in this column are negative, denoted by a distinctive blue color in the dataset. Moving on to "Aragonite," values span from 0.33 to 1.89 represented by red color, reflecting a positive range, while "Calcite" measurements vary from 0.48 to 2.03 represented by green color. Similarly, "Dolomite" displays values between 0.68 and 3.62 represented by yellow color .

In contrast, "Gypsum" features measurements ranging from 0.06 to 1.14 represented by dark blue color, while "Halite" encompasses values that fall between -5.55 and -3.29 represented by gray color. It's worth noting that "Halite" values are predominantly negative, possibly signifying a distinct characteristic of this mineral.

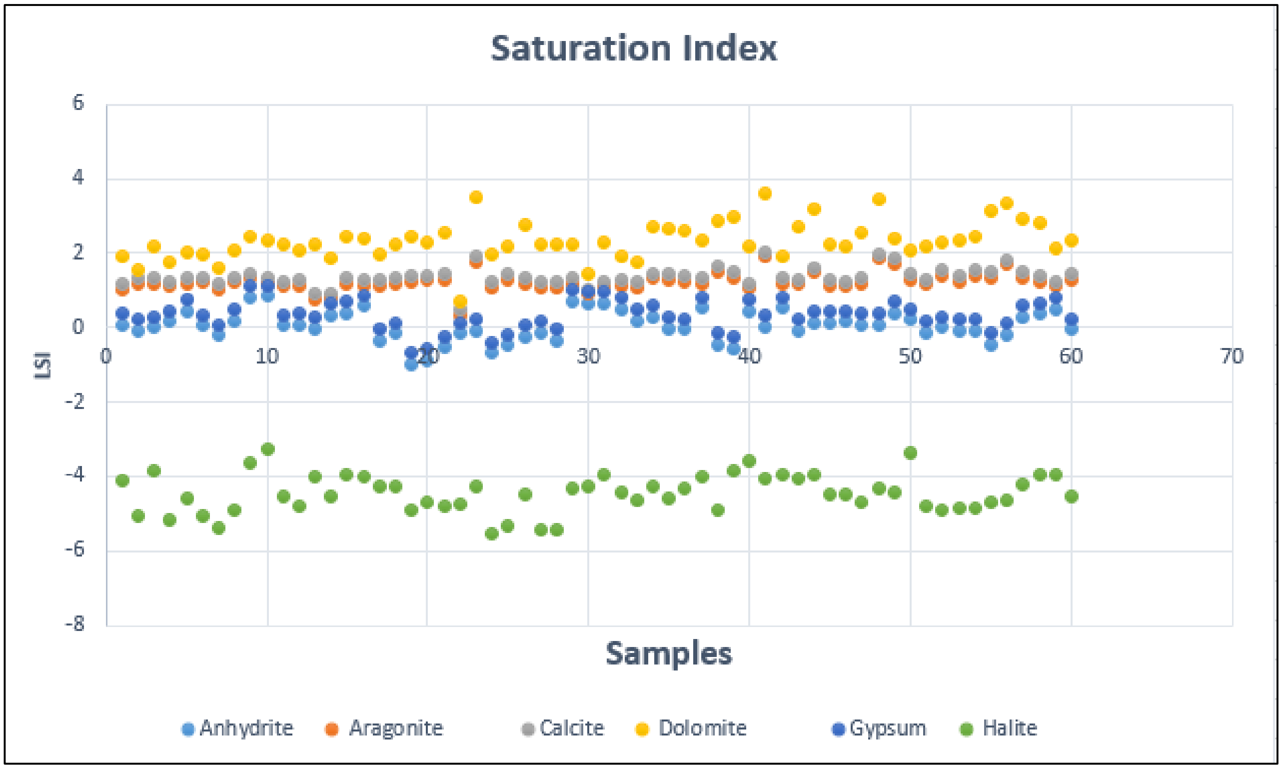


Figure 5.7 Saturation Index of Tehsil Gujrat (Different Minerals)

The provided dataset consists of Langelier Saturation Index (LSI) values for various samples. In the context of water chemistry, the LSI is used to assess the saturation state of water with respect to calcium carbonate. A LSI value of 0 indicates that the water is in a saturated state, meaning it is in equilibrium with calcium carbonate and is not prone to either scaling (precipitation of calcium carbonate) or corrosion (dissolution of calcium carbonate).

LSI values greater than 0 indicate a super-saturated condition, where the water has the potential to form scale deposits if conditions allow. This suggests that the water contains more calcium carbonate than it can hold in equilibrium, and scaling may occur over time.

Conversely, LSI values smaller than 0 indicate an under-saturated condition, where the water has the potential to dissolve calcium carbonate. Water with negative LSI values is corrosive and can lead to the erosion of materials like pipes and fixtures.

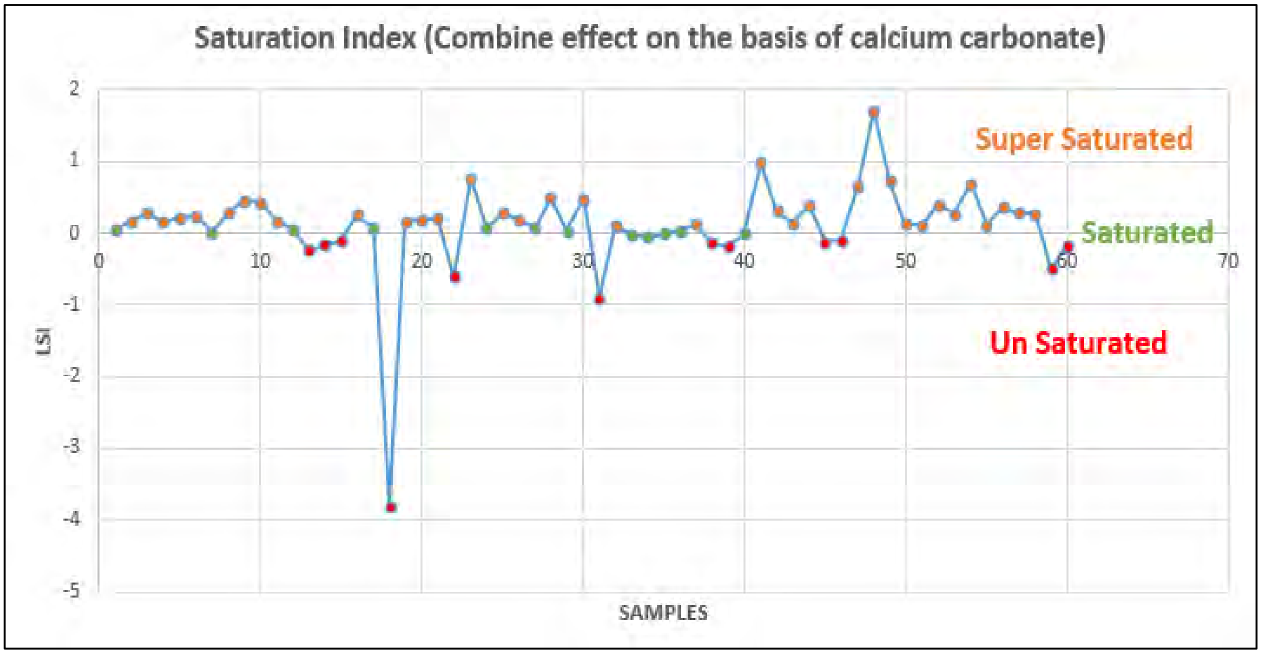


Figure 5.8 Saturation index combine effect on the basis of calcium carbonate of Tehsil Gujrat

5.8. Source rock deduction:

The objective of the method outlined here is to provide insights into the potential source of a water analysis. This method serves a dual purpose, serving as both a valuable analytical validation tool and an investigative procedure when the source of the water is unidentified.

Table 5.5 showing source rock deduction of tehsil Gujrat

Parameters	Range	Samples	Weathering
Na+k-Cl/Na+k-Cl+Ca	i) >0.2,<0.8 ii)<0.2, >0.8	i) 19 ii) 1	i) plagioclase weathering possible ii) plagioclase weathering unlikely
Na/Na+Cl	>0.5	20	Sodium source other than halite
Mg/Mg+Ca	i)<0.5 ii)>0.5	i) 17 ii) 3	i) limesrone-dolomite weathering ii) dolomite dissolution or seawater
Ca/Ca+SO4	i)<0.5 > 0.5	i)3 ii) 17	i) pyrite oxidation ii) calcium source other than gypsum
Ca+Mg/SO4	i)>0.2,<1.2	2	dedolomization
TDS	i)>500 ii) <500	i)9 ii) 11	i) carbonate weathering ii) silicate weathering
Cl/∑Anions	i)>0.8,TDS>500 ii)>0.8,TDS<100 iii)<0.8	i)0 ii)0 iii) 20	i) evaporations ii) Rainwater iii) Rock weathering
HCO3/∑Anions	i)>0.8 ii) <0.8	i)7 ii) 13	i) silicate or carbonate weathering ii) gypsum dissolution

- The ratio Na+k-Cl/Na+k-Cl+Ca suggests the possibility of plagioclase weathering occurring in the Tehsil Gujrat .
- The Na/Na+Cl ratio implies the presence of a sodium source other than halite (rock salt) in the Tehsil of Gujrat.
- The Mg/Mg+Ca ratio points to weathering processes consistent with limestones and dolomites in the Tehsil Gujrat.
- An elevated Ca/Ca+SO4 ratio indicates the existence of a source of calcium other than gypsum.
- The TDS value reflects both carbonate and silicate weathering in the area.

- A high Cl/∑Anions ratio suggests that rock weathering is occurring in the region, rather than processes related to evaporation and precipitation.
- The HCO3/∑Anions ratio signifies a combination of carbonate weathering, silicate weathering, and potential gypsum dissolution in the Tehsil Gujrat.

5.9. Agriculture Analysis:

The salinity index range provides insight into the suitability of electrical conductivity (EC) values for irrigation purposes. Based on this assessment, it is determined that EC values less than 750 µS/cm are considered optimal for irrigation. Through calculations, it is revealed that 32% of the samples fall into class 2, signifying a favorable irrigation quality. Furthermore, 67% of the samples are categorized as class 3, indicating permissible levels of salinity for irrigation despite being moderately high. The remaining 1% of samples fall within class 4, characterized by very high saline content, which is less suitable for irrigation.

Table 5.6 Showing Salinity Hazard calculations for tehsil Gujrat (Doneen, 1964).

S. No	EC	Water Salinity	Classification	Percentage (%)
1	0-250	Low (Excellent Quality)	Class-1	NIL
2	251-750	Medium (Good)	Class-2	32%
3	751-2250	High (Permissible)	Class-3	67%
4	2251-6000	Very high	Class-4	1%
5	6001-10,000	Extensively High	Class-5	NIL
6	10,001-20,000	Brines Week 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

The analysis of sodium adsorption ratio (SAR) results indicates that an impressive 97% of the water samples fall within the excellent water quality category. Additionally, 3% of the water samples are classified as belonging to the good water quality class, and a mere 0% are categorized as doubtful (table).

In terms of sodium percentage analysis, the results reveal that 12% of the samples demonstrate excellent water quality, while a substantial 44.6% fall within the good category. Furthermore, 17% of samples are classified as permissible, 23.4% as doubtful, and a minimal 3% as unsuitable (table).

Turning to the classification based on magnesium hazard, it is noteworthy that a significant 75% of water samples showcase suitable water quality, while the remaining 25% are placed in the harmful category (table).

Kelly's ratio results exhibit that 67% of samples fit into the suitable water quality category, whereas 17% are classified as marginally suitable. The remaining 16% unfortunately fall into the unsuitable category (table).

Table 5.7 Showing agriculture potential calculation (SAR, Na%, KR, MH%,) of Tehsil Gujrat

S.NO	Sodium Adsorption Ratio (SAR)	Water Quality	Percentage (%)
1	<10	Excellent	97%
2	10 – 18	Good	3%
3	19 – 20	Doubtful	0%
4	>20	Unsuitable	NIL
S. NO	Sodium Percentage (Na%)	Water Quality	Percentage (%)
1	<20	Excellent	12%
2	20 – 40	Good	44.6%
3	40 – 60	Permissible	17%
4	60 – 80	Doubtful	23.4%
5	>80	Unsuitable	3%
S. No	Magnesium Hazard (MH%)	Water Quality	Percentage (%)
1	<50	Suitable	75%
2	>50	Harmful	25%
S. No	Kelly's Ratio	Water Quality	Percentage (%)
1	<1	Suitable	67%
2	1 – 2	Marginal Suitable	17%
3	>2	Unsuitable	16%

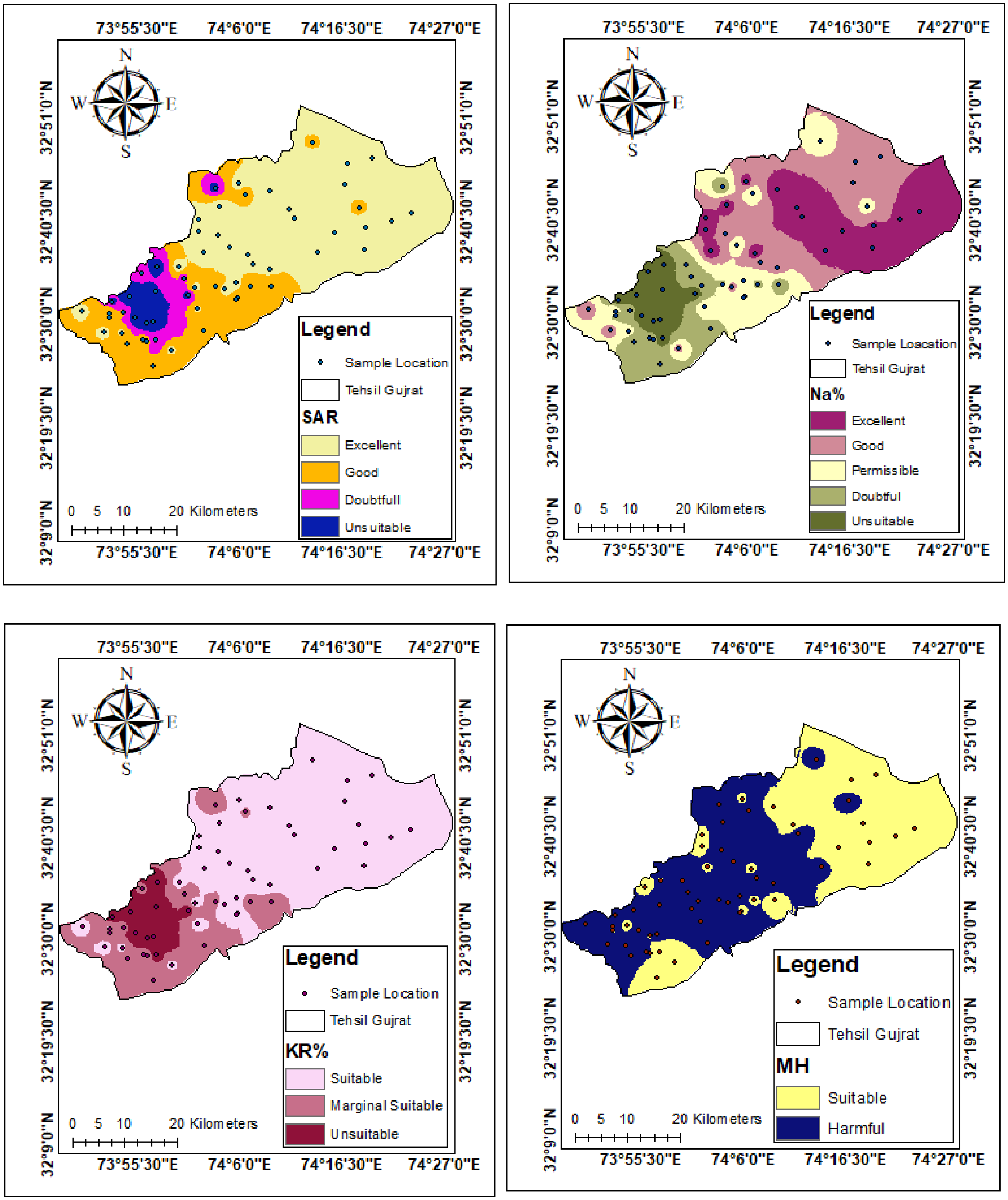


Figure 5.9 Showing Agriculture potential maps (SAR, Na%, KR and MH)

Table 5.8 Showing the table of area of agriculture analysis.

<table>
<tr><td colspan="3">Area (SAR)</td></tr>
<tr><td>1</td><td>Excellent Water Quality</td><td>1,239 sq.km</td></tr>
<tr><td>2</td><td>Good Water Quality</td><td>224 sq.km</td></tr>
<tr><td>3</td><td>Doubtful Quality</td><td>-</td></tr>
<tr><td>4</td><td>Unsuitable Water Quality</td><td>-</td></tr>
<tr><td colspan="3">Area (Sodium Percentage)</td></tr>
<tr><td>1</td><td>Excellent Water Quality</td><td>196 sq.km</td></tr>
<tr><td>2</td><td>Good Water Quality</td><td>568 sq.km</td></tr>
<tr><td>3</td><td>Permissible Water Quality</td><td>233 sq.km</td></tr>
<tr><td>4</td><td>Doubtful Water Quality</td><td>363 sq.km</td></tr>
<tr><td>5</td><td>Unsuitable Water Quality</td><td>103 sq.km</td></tr>
<tr><td colspan="3">Area (Magnesium Hazard)</td></tr>
<tr><td>1</td><td>Suitable</td><td>986 sq.km</td></tr>
<tr><td>2</td><td>Harmful</td><td>477 sq.km</td></tr>
<tr><td colspan="3">Area (Kelly’s Ratio)</td></tr>
<tr><td>1</td><td>Suitable</td><td>868 sq.km</td></tr>
<tr><td>2</td><td>Marginal Suitable</td><td>339 sq.km</td></tr>
<tr><td>3</td><td>Unsuitable</td><td>256 sq.km</td></tr>
</table>

5.10. Arsenic Concentration:

A spatial distribution map detailing the prevalence of arsenic across the Tehsil Gujrat has been created . Adhering to the World Health Organization's (WHO) arsenic limit of 10 µg/L, the map utilizes color gradations to signify varying concentrations. Light pink is indicative of arsenic levels ranging from 0 to 10 µg/L, representing low concentration, while dark pink color indicate concentrations surpassing 10 µg/L and the red color indicating the arsenic values ranging from 16 to 25, reflecting high levels of arsenic. In the Tehsil Gujrat the arsenic concentration is noted to span from 11 to 25 µg/L, with an average reading of 8.78 µg/L. Alarmingly, a considerable 43% of sampled values exceed the maximum permissible limit for safe drinking water.

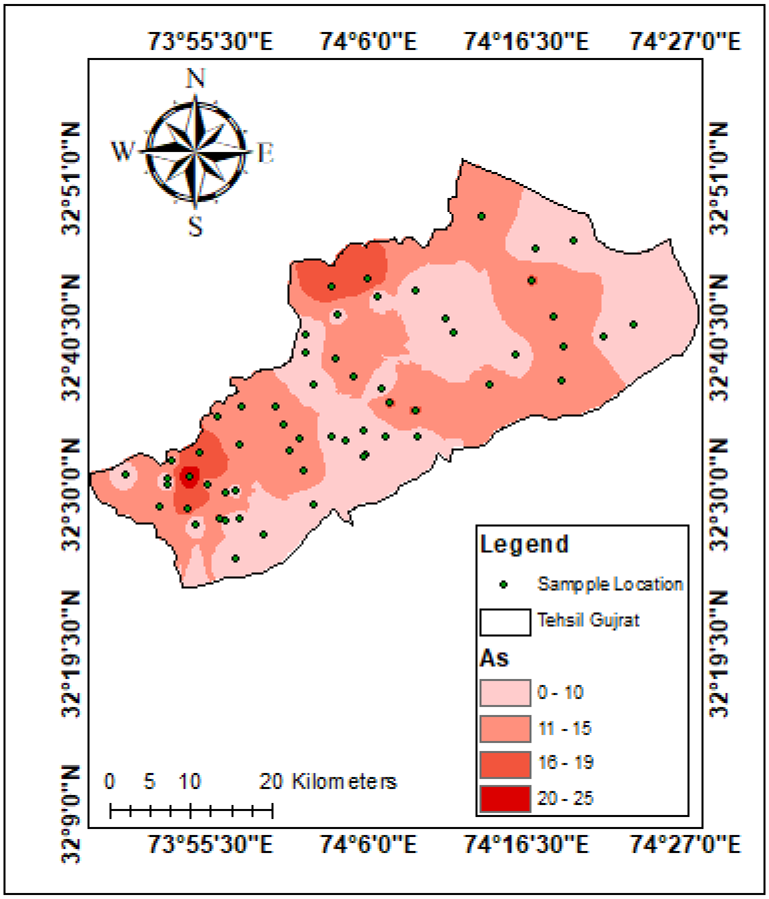


Figure 5.10 showing Arsenic concentration map of Gujrat

5.11. Fluoride Concentration:

A spatial distribution map detailing the prevalence of fluoride across the Tehsil Gujrat has been created . Adhering to the World Health Organization's (WHO) arsenic limit of 1.5 mg/L, the map utilizes color gradations to signify varying concentrations. Light purple is indicative of fluoride levels ranging from 0.01 to 0.93 mg/L, representing low concentration, while medium purple color indicate concentrations surpassing 0.94 to 1.87 mg/L and the dark purple color indicating the fluoride values ranging from 1.88 to 2.8 mg/L , reflecting high levels of fluoride. In the Tehsil Gujrat the fluoride concentration is noted to span from 0.01 to 2.8 mg/L, with an average reading of 0.3 mg/L. Alarmingly, a considerable 29% of sampled values exceed the maximum permissible limit for safe drinking water.

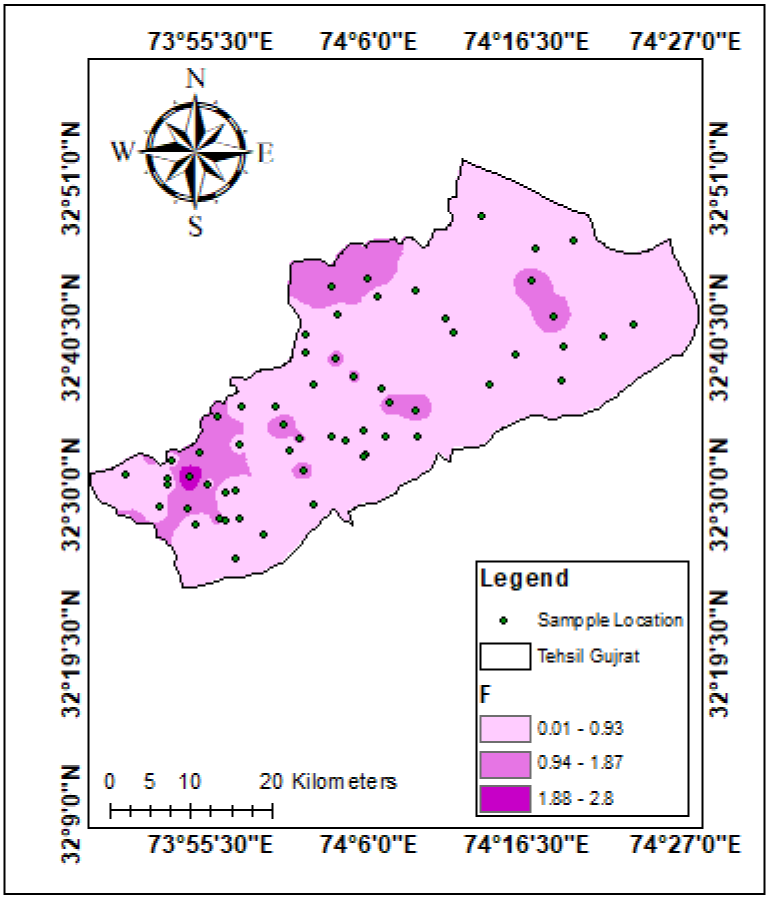


Figure 5.11 Showing fluoride concentration map of Fluoride

5.12. Hazard Quotient Analysis:

A Hazard Quotient map is a specialized visual representation that illustrates the comparative risk of encountering a specific environmental hazard, such as harmful chemicals, within a defined geographic area. The Hazard Quotient is computed by dividing the estimated exposure level to a substance by its reference dose, a recognized safe exposure threshold. The resulting ratio serves as an indicator of the potential risk associated with coming into contact with that substance. Hazard Quotient maps find common application in environmental health assessments and the planning of risk mitigation strategies, helping to pinpoint regions where individuals might face an elevated risk due to exposure to hazardous agents.

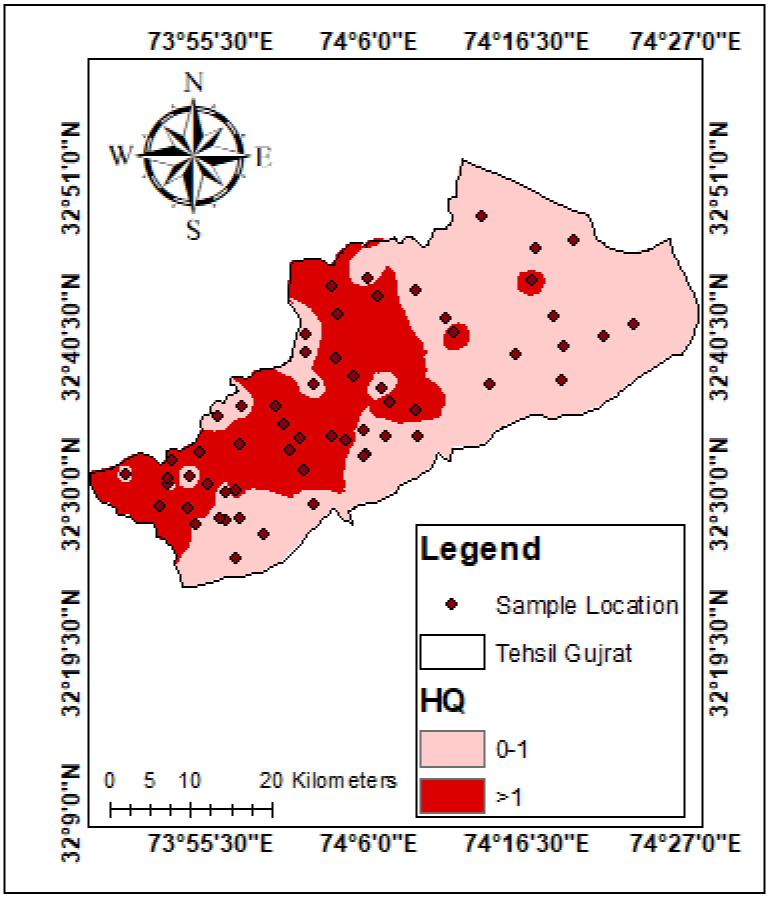


Figure 5.12 Showing Hazard Quotient Map

The map reveals that approximately 43% of groundwater samples surpass the prescribed Hazard Quotient threshold (HQ>1), signifying heightened potential risks. Conversely, only 57% of groundwater samples fall within the established Hazard Quotient limit (HQ<1), indicating a lower risk of exposure within this subset.

5.13. Ingestion Pathway

The ingestion pathway of arsenic in groundwater pertains to how humans or animals are exposed to arsenic by consuming water that contains this contaminant. This exposure usually happens when individuals or animals drink water from wells or other water sources that have been tainted by naturally-occurring arsenic. Over time, such exposure can result in severe health issues, including but not limited to skin problems, various types of cancer, and cardiovascular diseases.

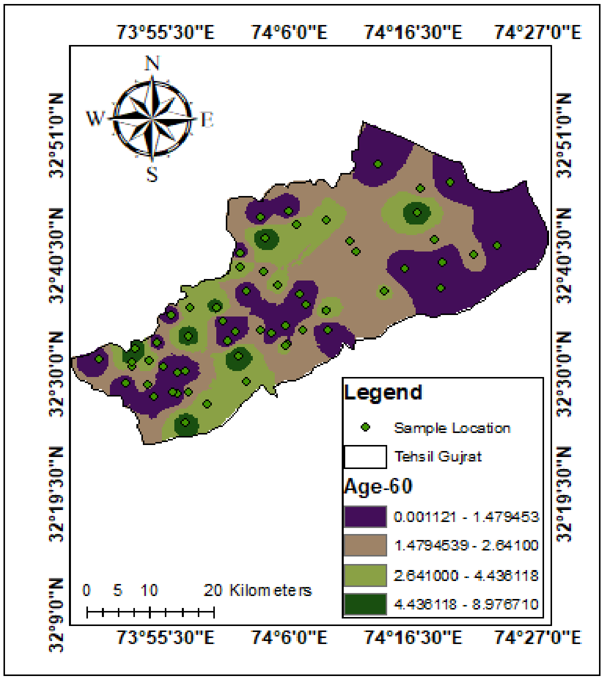
Table 5.9 Showing table of Ingestion pathway.

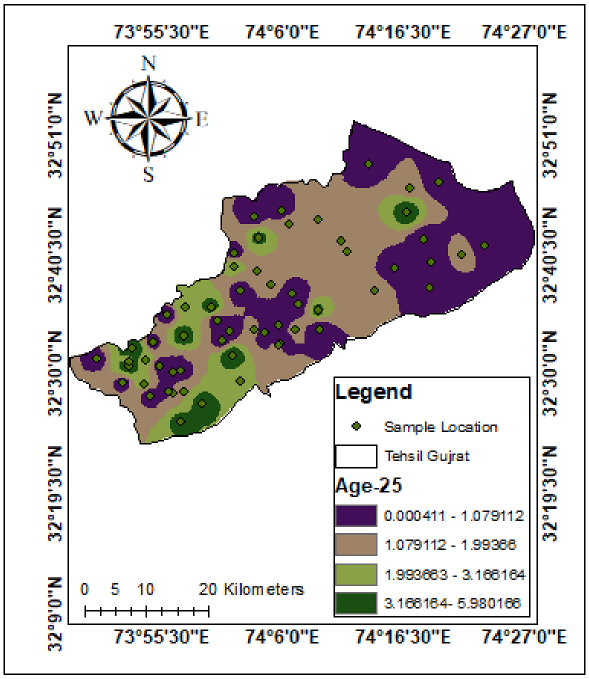
Age 60	Age 25	Age 6	Age 2
0.023707	0.005690	0.003225	0.001897
2.018433	1.304424	0.025079	1.101475
2.015540	0.003730	1.202114	1.101243
0.028152	0.006756	0.003830	0.002252
0.216240	0.003898	0.002210	1.201299
0.012530	0.003007	0.001705	0.001002
2.012717	2.003052	2.001730	1.401017
3.323543	2.005650	2.003203	1.101883
0.013778	0.003307	0.001875	0.001102
0.012145	0.002915	0.001652	2.000972
8.012378	4.002971	3.001684	2.000990
0.012215	0.002932	0.001662	0.000977
2.217967	2.004312	2.002444	1.201437
0.012985	0.003116	0.001767	2.001039
0.013382	0.003212	0.001821	0.001071
5.012507	4.003002	3.301702	2.001001
0.007163	0.001719	0.000975	0.000573
2.011958	1.602870	1.401627	1.100957
0.015050	0.003612	0.002048	1.401204
0.003103	0.000745	0.000422	0.000248

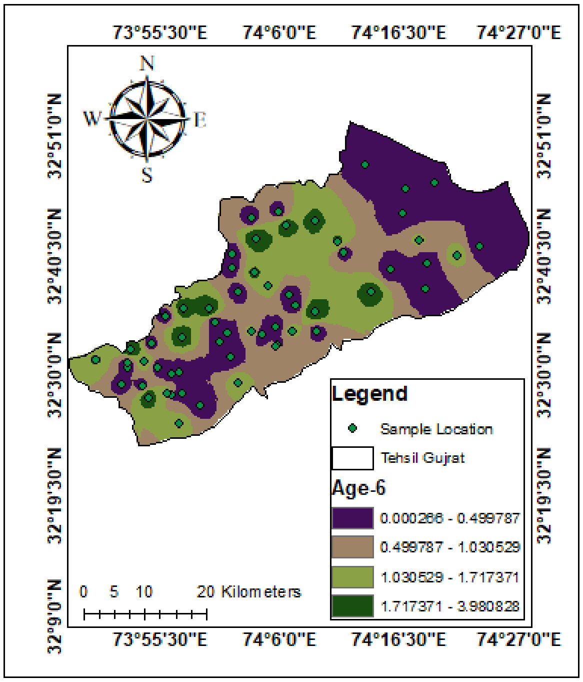
5.220720	2.004973	1.202819	1.101658
0.004935	0.001184	0.000671	0.000395
2.011935	1.702864	1.401624	1.300955
0.000257	0.000062	0.000035	0.000021
4.301365	3.000328	0.000186	1.300109
3.524733	2.005936	2.203365	1.301979
0.001097	0.000263	0.000149	0.000088
2.012448	1.602988	0.001694	1.100996
3.012833	2.003080	2.301746	1.501027
0.001318	0.000316	0.000179	0.000105
7.001085	5.000260	0.000148	2.000087
2.310978	2.002635	1.501494	1.200878
0.006405	0.001537	0.000871	0.000512
4.001575	2.000378	1.700214	1.400126
6.001855	4.400445	3.000252	2.000148
0.000642	0.000154	0.000087	0.000051
9.010022	6.002405	0.001363	2.000802
3.001867	2.000448	1.800254	1.200149
0.000443	0.000106	0.000060	0.000035
0.002298	0.000552	0.000313	0.000184
4.204445	3.001067	2.200605	2.000356
0.000525	0.000126	0.000071	0.000042

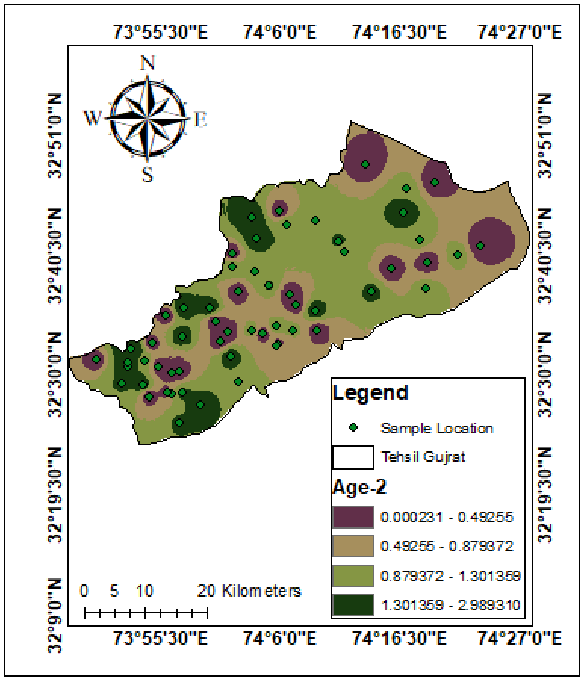
7.016135	5.003872	3.002195	2.001291
0.004363	0.001047	0.000594	0.000349
0.000735	0.000176	0.000100	0.000059
8.001178	6.000283	4.000160	3.000094
0.000618	0.000148	0.000084	0.000049
0.011690	0.002806	0.001590	0.000935
3.002135	2.000512	0.000290	1.700171
5.001482	3.000356	2.000202	1.100119

The findings regarding the ingestion pathway of arsenic in the groundwater of Tehsil Gujrat indicate that the Hazard Quotient (HQ) values vary across different age groups. Specifically, for individuals aged 60, the HQ ranges from 0.000257 to 9.010022. For those aged 25, the HQ ranges from 0.000062 to 6.002405, while individuals aged 6 show HQ values ranging from 0.000035 to 4.000160, and those aged 2 exhibit HQ values ranging from 0.000021 to 3.000094.









Regarding the Acceptable Daily Dose (ADD) intake, it is observed that 58% of the samples for individuals aged 6 exceed the prescribed limit of HQ>1. Similarly, 30% of the samples for individuals aged 25 and 28% of the samples for individuals aged 6 also surpassed the specified HQ>1 limit.

5.18. Dermal Pathway

The dermal pathway of exposure to arsenic-contaminated groundwater pertains to the absorption of arsenic through the skin. Arsenic, naturally occurring in rocks and soils, can seep into groundwater in certain regions. Prolonged consumption of arsenic-contaminated drinking water has been linked to various health issues, including skin problems, cancer, and cardiovascular diseases.

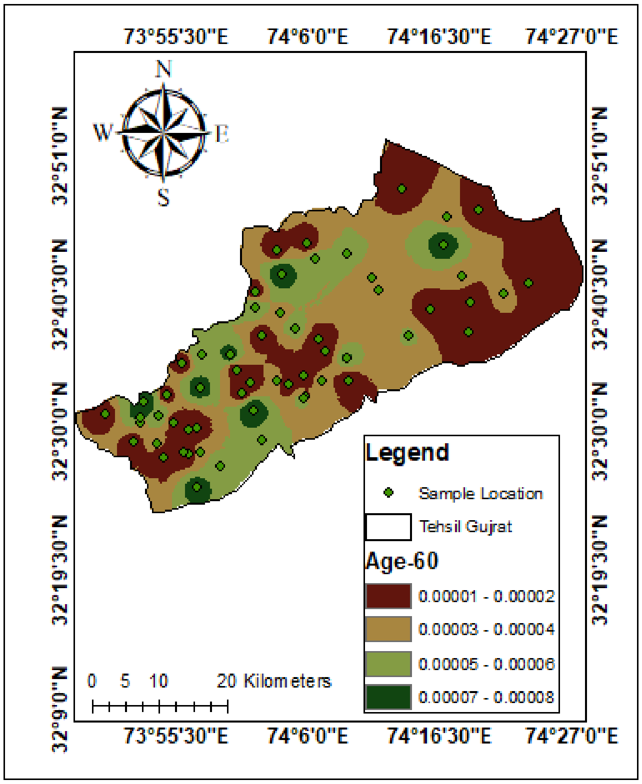
When an individual encounters arsenic-contaminated groundwater, their skin can absorb a portion of the arsenic, subsequently entering the bloodstream. The degree of dermal absorption depends on several factors, such as the concentration of arsenic in the water, the duration and frequency of exposure, the condition of the skin's protective barrier, and the presence of other substances that may enhance or inhibit absorption.

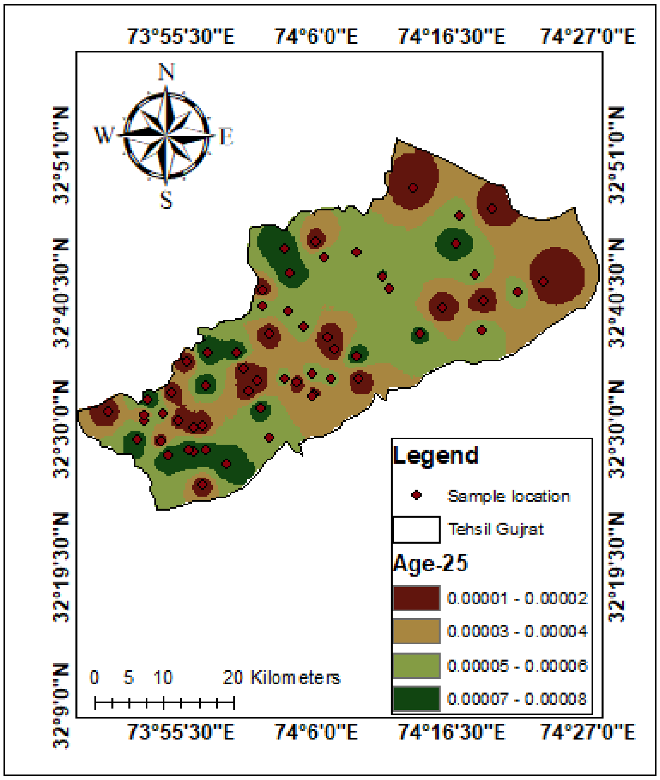
To mitigate the risk of dermal exposure to arsenic, it is advisable to minimize contact with contaminated water, particularly over extended periods. The use of protective clothing and gloves can help reduce skin contact. Furthermore, routine monitoring of groundwater quality and the treatment of contaminated water sources can play a vital role in preventing exposure to arsenic and other hazardous substances.

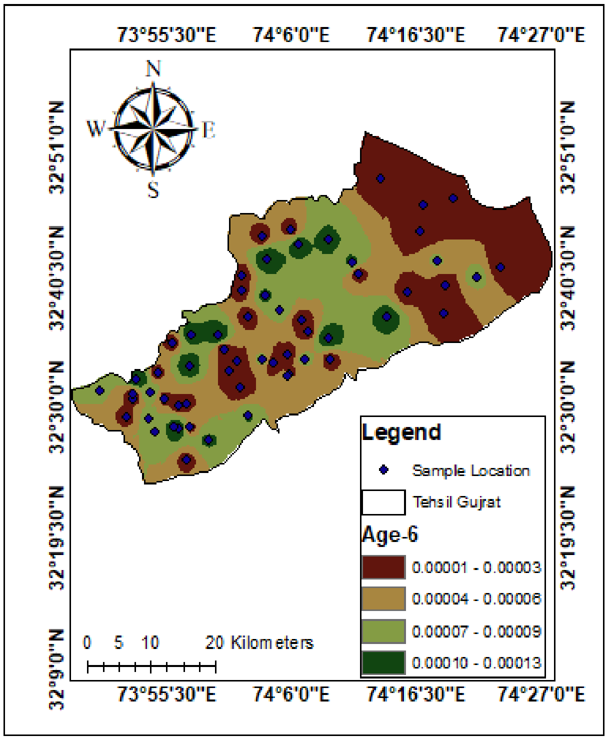
Table 5.10 Showing table of Dermal pathway

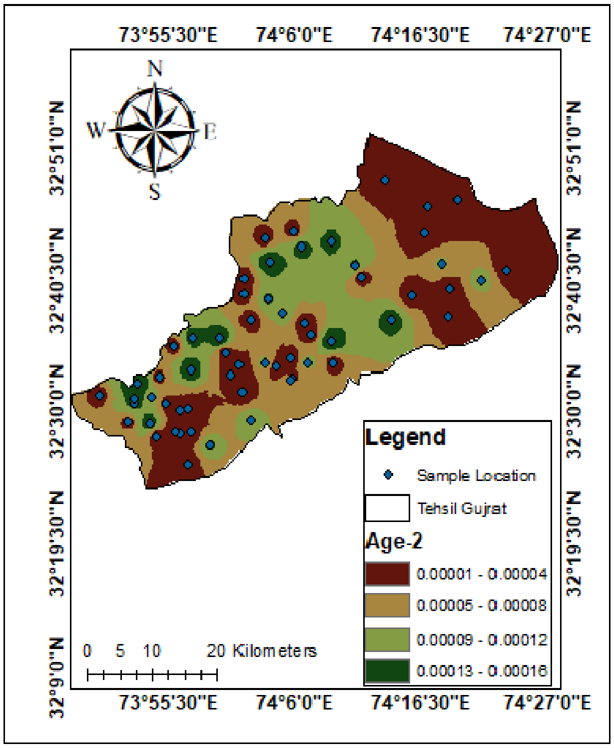
Age 60	Age 25	Age 6	Age 2
0.00002	0.00003	0.00005	0.00009
0.00001	0.00001	0.00003	0.00004
0.00002	0.00004	0.00005	0.00008
0.00002	0.00002	0.00003	0.00005
0.00002	0.00004	0.00005	0.00009
0.00003	0.00003	0.00005	0.00007
0.00003	0.00003	0.00005	0.00006
0.00002	0.00002	0.00004	0.00007
0.00001	0.00001	0.00003	0.00005
0.00003	0.00003	0.00006	0.00009
0.00003	0.00003	0.00005	0.00007
0.00002	0.00002	0.00005	0.00006
0.00003	0.00003	0.00004	0.00007
0.00001	0.00001	0.00005	0.00007
0.00001	0.00001	0.00003	0.00005
0.00003	0.00003	0.00004	0.00005
0.00002	0.00003	0.00006	0.00008
0.00003	0.00003	0.00004	0.00005
0.00002	0.00002	0.00005	0.00009
0.00003	0.00003	0.00004	0.00005
0.00003	0.00003	0.00005	0.00007
0.00004	0.00004	0.00006	0.00011
0.00002	0.00002	0.00005	0.0001
0.00004	0.00004	0.00007	0.00008
0.00001	0.00001	0.00006	0.00013
0.00002	0.00002	0.00005	0.00007
0.00001	0.00001	0.00004	0.00008

0.00002	0.00002	0.00007	0.00011
0.00004	0.00004	0.00007	0.00009
0.00001	0.00002	0.00005	0.00007
0.00003	0.00003	0.00005	0.00006
0.00001	0.00003	0.00003	0.00004
0.00002	0.00002	0.00007	0.0001
0.00003	0.00003	0.00005	0.00007
0.00002	0.00002	0.00005	0.00006
0.00003	0.00003	0.00005	0.00007
0.00002	0.00002	0.00007	0.00009
0.00004	0.00004	0.00006	0.00007
0.00003	0.00003	0.00004	0.00005
0.00002	0.00003	0.00006	0.00009
0.00007	0.00007	0.00009	0.00011









The outcomes of the assessment regarding the dermal pathway of exposure to arsenic in groundwater within Tehsil Gujrat reveal a Hazard Quotient (HQ) range of 0.00002 to 0.00007 for individuals at the age of 60, 0.00003 to 0.00007 for those aged 25, 0.00005 to 0.00009 for individuals aged 6, and 0.00009 to 0.00011 for those at the age of 2. The Assessment of Daily Dermal Intake (ADD intake) indicates that 42% of the samples surpass the prescribed limit (HQ>1) for individuals aged 6, 36% of the samples exceed the limit for those aged 25, and 22% of the samples go beyond the limit for individuals aged 60.

6. **Conclusion:**

In conclusion, the integrated approach to hydrogeochemical appraisal and quality assessment of groundwater in Gujrat Tehsil, District Gujrat 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 Gujrat Tehsil is predominantly of the calcium-bicarbonate type, with elevated levels of sodium, chloride, and sulfate in some wells. 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.

In this study 60 different samples are collected from different locations of tehsil Gujrat but only 40 water schemes are working then these samples are sent into lab and different methods are applied for their analysis then the statistical analysis are done for all the physiochemical parameters and correlation is calculated. The result of agricultural potential calculation shows that the groundwater of tehsil Gujrat 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 .

7. References:

1. Abbas, M., Shen, S.-L., Lyu, H.-M., Zhou, A., Rashid, S., 2021. Evaluation of the hydrochemistry of groundwater at Jhelum Basin, Punjab, Pakistan. Environmental Earth Sciences 80, 1-17.

2. Adebayo, T.B., Abegunrin, T.P., Awe, G.O., Are, K.S., Guo, H., Onofua, O.E., Adegbola, G.A., Ojediran, J.O., 2021. Geospatial mapping and suitability classification of groundwater quality for agriculture and domestic uses in a Precambrian basement complex. Groundwater for Sustainable Development 12, 100497.

3. Adeloju, S.B., Khan, S., Patti, A.F., 2021. Arsenic contamination of groundwater and its implications for drinking water quality and human health in under-developed countries and remote communities—a review. Applied Sciences 11, 1926.

4. Ahada, C.P., Suthar, S., 2019. Assessment of human health risk associated with high groundwater fluoride intake in southern districts of Punjab, India. Exposure and health 11, 267-275.

5. Abbas, M. and K. Cheema (2015). "Arsenic levels in drinking water and associated health risk in district Sheikhupura, Pakistan." Journal of Animal and Plant Sciences **25**(3): 719-724.

6. Abbas, M. T. "Analysis of Groundwater Quality and its Impact on Human Health: A Review."

7. Bibi, I., Shahid, M., Niazi, N.K., Younas, F., Naqvi, S.R., Shaheen, S.M., Imran, M., Wang, H., Hussaini, K.M., Zhang, H., 2021. Hydrogeochemical and health risk evaluation of arsenic in shallow and deep aquifers along the different floodplains of Punjab, Pakistan. Journal of Hazardous Materials 402, 124074.

8. B. N. Tandel, Dr. J. Macwan and C. K. Soni - "Assessment of Water Quality Index of Small Lake in South Gujarat Region, India."

9. Doneen, L., 1964. Water quality for agriculture. Department of Irrigation, University of California, California 48.

10. Dr. M. K. Mahesh, B. R. Sushmitha, H. R. Uma - "Assessment of Water Quality for Hebbal Lake of Mysore", ISSN No. 2277 - 8160, Volume: 2, Issue: 2, Feb 2013.

11. Flörke, M., Kynast, E., Bärlund, I., Eisner, S., Wimmer, F., Alcamo, J., 2013. Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study. Global Environmental Change 23, 144-156.

12. Gibbs, R. J. (1970). "Mechanisms controlling world water chemistry." Science **170**(3962): 1088-1090.

13. Hassan, J. (2014). "A Geostatistical approach for mapping groundwater quality (Case Study: Tehsil Sheikhupura)." Int J Sci Res **3**(4): 239-245.

14. Jiang, Y., Wu, Y., Groves, C., Yuan, D., Kambesis, P., 2009. Natural and anthropogenic factors affecting the groundwater quality in the Nandong karst underground river system in Yunan, China. Journal of contaminant hydrology 109, 49-61

15. Javeda, Z., et al. (2021). "Spatial statistical analysis of groundwater quality based on inverse distance weighting and ordinary kriging in District Sheikhupura, Pakistan." DESALINATION AND WATER TREATMENT **235**: 324-332.

16. Jiang, J.-Q., et al. (2013). "Arsenic contaminated groundwater and its treatment options in Bangladesh." International journal of environmental research and public health **10**(1): 18-46.

17. Kumar, S.K., Rammohan, V., Sahayam, J.D., Jeevanandam, M., 2009. Assessment of groundwater quality and hydrogeochemistry of Manimuktha River basin, Tamil Nadu, India. Environmental Monitoring and Assessment 159, 341-351.

18. Mandal, B. K. and K. T. Suzuki (2002). "Arsenic round the world: a review." Talanta **58**(1): 201-235.

19. M. S. Islam, B. S. Ismail, G. M. Barzani, A. R. Sahibin and T. M. Ekhwan - " Hydrological Assessment and Water Quality Characteristics of Chini Lake, Pahang, Malaysia", American-Eurasian J. Agric. & Environ. Sci., 12 (6): 737-749, 2012.

20. M. Pejaver, M. Gurav - "Study of Water Quality of Jail and Kalwa Lake, Thane, Maharashtra", J. Aqua. Biol. Vol. 23(2), 44 -50, 2008.

21. Nabi, G., et al. (2019). "The crisis of water shortage and pollution in Pakistan: risk to public health, biodiversity, and ecosystem." Environmental science and pollution research **26**(11): 10443-10445.

22. Ötleş, S. and Ö. Çağındı (2010). "Health importance of arsenic in drinking water and food." Environmental Geochemistry and Health **32**(4): 367-371.

23. Peeters, L. (2014). "A background color scheme for piper plots to spatially visualize hydrochemical patterns." Groundwater **52**(1): 2-6.

24. Piper, A. M. (1944). "A graphic procedure in the geochemical interpretation of water-analyses." Eos, Transactions American Geophysical Union **25**(6): 914-928.

25. P. J. Puri, M. K. N. Yenkie, S. P. Sangal, N. V. Gandhare, G. B. Sarote and D. B. Dhanorkar - "Surface water (Lakes) quality assessment in Nagpur city (India) based on Water quality index (WQI)", Vol.4, No.1, 43-48 (2011).

26. Qureshi, A.S., McCornick, P.G., Sarwar, A., Sharma, B.R., 2010. Challenges and prospects of sustainable groundwater management in the Indus Basin, Pakistan. Water resources management 24, 1551-1569.

27. Qazi, M. A., et al. (2014). "Spatial distribution of heavy metals in ground water of Sheikhupura District Punjab, Pakistan.

28. Rasheed, H., Iqbal, N., Ashraf, M., ul Hasan, F., 2022. Groundwater quality and availability assessment: A case study of District Jhelum in the Upper Indus, Pakistan. Environmental Advances 7, 100148.

29. Rather, M.I., Rashid, I., Shahi, N., Murtaza, K.O., Hassan, K., Yousuf, A.R., Romshoo, S.A., Shah, I.Y., 2016. Massive land system changes impact water quality of the Jhelum River in Kashmir Himalaya. Environmental Monitoring and Assessment 188, 1-20.

30. Ravikumar, P., Somashekar, R., Angami, M., 2011. Hydrochemistry and evaluation of groundwater suitability for irrigation and drinking purposes in the Markandeya River basin, Belgaum District, Karnataka State, India. Environmental Monitoring and Assessment 173, 459-487.

31. Rehman, F., Cheema, T., 2016. Effects of sewage waste disposal on the groundwater quality and agricultural potential of a floodplain near Jeddah, Saudi Arabia. Arabian Journal of Geosciences 9, 1-10.

32. Rehman, F., Siddique, J., Shahab, A., Azeem, T., Bangash, A.A., Naseem, A.A., Riaz, O., ur Rehman, Q., 2022. Hydrochemical appraisal of fluoride contamination in groundwater and human health risk assessment at Isa Khel, Punjab, Pakistan. Environmental Technology & Innovation 27, 102445.

33. Rishi, M.S., Kaur, L., Sharma, S., 2020. Groundwater quality appraisal for non-carcinogenic human health risks and irrigation purposes in a part of Yamuna sub-basin, India. Human and Ecological Risk Assessment: An International Journal 26, 2716-2736.

34. R. W. Gaikwad, V. V. Sasane - "Assessment of ground water quality in and around Lonar lake and possible water treatment", International Journal of Environmental Sciences, Volume 3, No 4, 2013.

35. R. M. Khan, M. J. Jadhav, I. R. Ustad - "Physicochemical Analysis of Triveni Lake Water of Amravati District in (M.S.) India. Bioscience Discovery, 3(1):64-66, Jan. 2012.

36. Sarfraz, M., Sultana, N., Tariq, M.I., 2019. Hazardous pollutants in potable groundwater sources of public schools, southern Punjab (Pakistan). Revista internacional de contaminación ambiental 35, 797-805.

37. Sheikhy Narany, T., Ramli, M.F., Aris, A.Z., Sulaiman, W.N.A., Fakharian, K., 2015. Groundwater irrigation quality mapping using geostatistical techniques in Amol–Babol Plain, Iran. Arabian Journal of Geosciences 8, 961-976.

38. Shahid, M., et al. (2018). "Arsenic level and risk assessment of groundwater in Vehari, Punjab Province, Pakistan." Exposure and Health **10**(4): 229-239.

39. Shahid, M., et al. (2018). "A meta-analysis of the distribution, sources and health risks of arsenic-contaminated groundwater in Pakistan." Environmental pollution **242**: 307-319.

40. Sridharan, M. and D. Senthil Nathan (2017). "Groundwater quality assessment for domestic and agriculture purposes in Puducherry region." Applied water science **7**(7): 4037-4053.

41. S. Chandra, A. Singh and P. K. Tomar - "Assessment of Water Quality Values in Porur Lake Chennai, Hussain Sagar Hyderabad and Vihar Lake Mumbai, India", Chem Sci Trans., 1(3), 508-515, 2012.

42. S. Hussaina, V. Maneb, S. Takdea, A. Pathanc, M. Farooquic - " Comparison between Treated and Untreated water so as to study water treatment plant of Ahmadpur Dist. Latur," International Journal of Modern Engineering Research (IJMER) www.ijmer.com, Vol.1, Issue2, pp- 564-569, ISSN: 2249-6645.

43. S. N. Thitame and G. M. Pondhe, - "Assessment of seasonal variation in physico-chemical characteristics and quality of Pravara River water for irrigation use in Sangamner, Dist Ahmednagar, Maharashtra", Journal of Chemical and Pharmaceutical Research, J. Chem. Pharm. Res., 2(2): 316-320, 2010.

44. Tabassum, R.A., Shahid, M., Dumat, C., Niazi, N.K., Khalid, S., Shah, N.S., Imran, M., Khalid, S., 2019. Health risk assessment of drinking arsenic-containing groundwater in Hasilpur, Pakistan: effect of sampling area, depth, and source. Environmental Science and Pollution Research 26, 20018-20029.

45. Tropea, E., Hynds, P., McDermott, K., Brown, R.S., Majury, A., 2021. Environmental adaptation of E. coli within private groundwater sources in southeastern Ontario: Implications for groundwater quality monitoring and human health. Environmental Pollution 285, 117263.

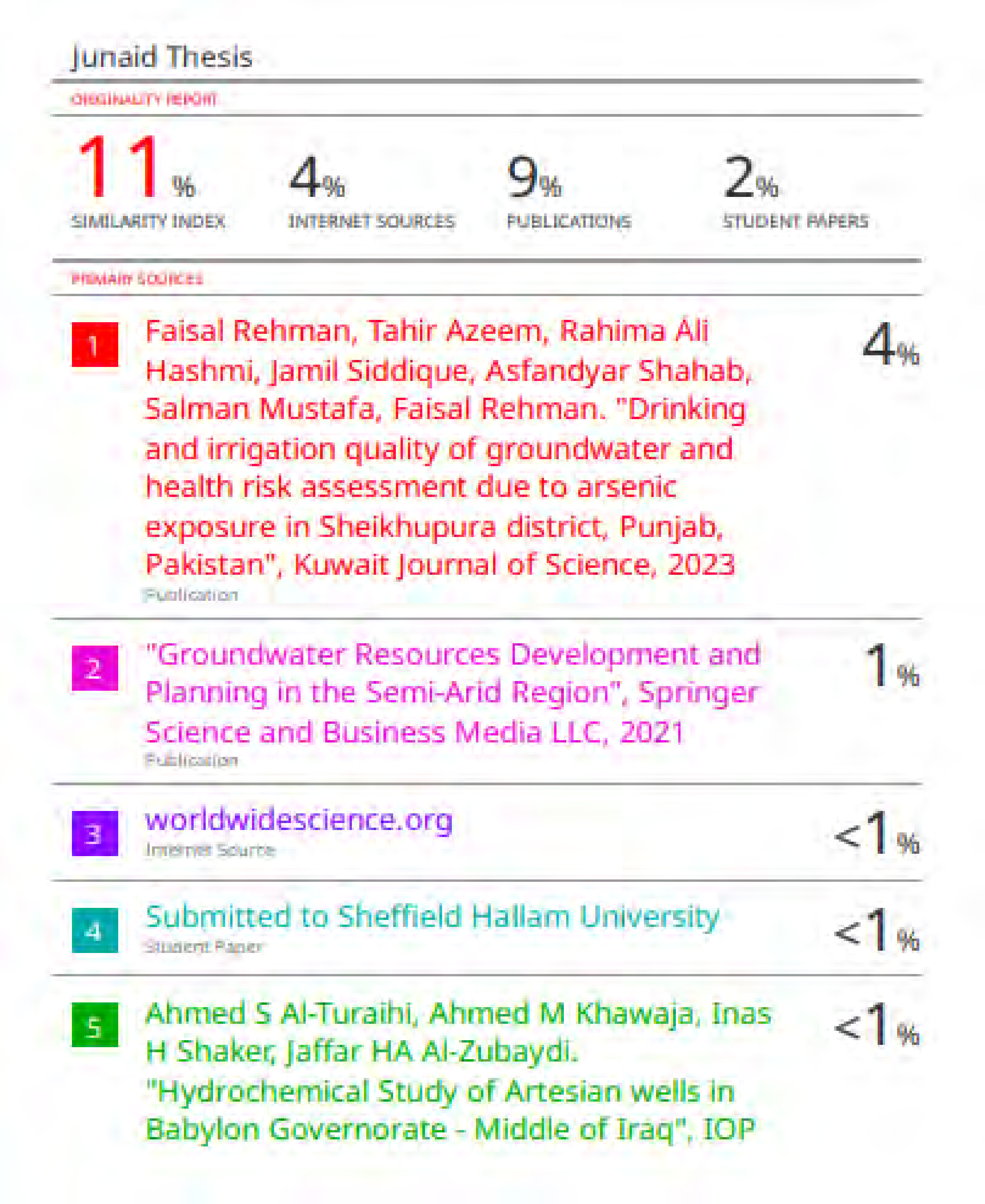
46. Ullah, Z., Rashid, A., Ghani, J., Talib, M.A., Shahab, A., Lun, L., 2022. Arsenic Contamination, Water Toxicity, Source Apportionment, and Potential Health Risk in Groundwater of Jhelum Basin, Punjab, Pakistan. Biological Trace Element Research.

47. V. Pradhan, M. Mohsin, B. H. Gaikwad - "Assessment of physico chemical parameters of Chilika Lake water", International Journal of Research in Environmental Science and Technology, 2(4): 101-103, 2012.

48. V. B. Y. Sheikh, P. R. Bhosale, B. N. Nagargoje - "Water Quality Assessment of Nagzari Dam of Maharashtra." Journal of Applied Technology in Environmental Sanitation, Volume 3, Number 3: 111-116, October 2013.

49. Wu-Seng Lung, A. M. Asce - "Lake Acidification Model: Practical tool", J. Environ. Eng.113:900-915, 1987.

50. Zheng, N., Liu, J., Wang, Q., Liang, Z., 2010. Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. Science of the total environment 408, 726-733.



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