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Hydrogeochemical Evaluation of Groundwater Quality in an Arid Region of Alsisar Block, Jhunjhunun District, Rajasthan, India

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Abstract:

Groundwater is the primary source of drinking water in the arid and semi-arid regions of Rajasthan due to scanty and irregular rainfall. However, its quality is significantly influenced by climatic conditions, geological formations, and anthropogenic activities. The present study evaluates the seasonal variation and hydrochemical characteristics of groundwater in the Alsisar block of Jhunjhunu District. Representative groundwater samples were collected from various villages during pre-monsoon (summer) and post-monsoon (winter) seasons and analysed for major physicochemical parameters, including pH, total dissolved solids (TDS), chloride (Cl^-), and fluoride (F^-), using standard analytical techniques. The results reveal that the groundwater is alkaline in nature, with high electrical conductivity, TDS, and hardness. Higher concentrations of dissolved constituents were observed during the pre-monsoon season, primarily due to increased evaporation and limited groundwater recharge. While some samples fall within the permissible limits prescribed by the World Health Organization, elevated levels of TDS, chloride, hardness, and nitrate render certain samples unsuitable for drinking purposes. Most groundwater samples are, however, suitable for irrigation with some limitations. Geologically, the region is characterized by extensive sandy plains, undulating sand dunes, poor drainage conditions, and alluvial deposits of sand, clay, and kankar extending below the saturation zone. The study underscores the necessity for continuous groundwater quality monitoring and the implementation of sustainable management practices to ensure safe water supply in arid regions.

Keywords: Alsisar, Jhunjhunun, Groundwater Quality, Water quality parameters.

1. Introduction:

Groundwater constitutes a crucial component of freshwater resources and plays a significant role in sustaining domestic, agricultural, and industrial water demands, particularly in arid and semi-arid regions of India. In areas where surface water availability is limited and rainfall is scarce and irregular, groundwater often serves as the primary and most reliable source of water supply. The increasing dependence on groundwater, coupled with climatic variability and anthropogenic pressures, has intensified concerns regarding its quality and long-term sustainability. Rajasthan, one of the largest states in India, is predominantly characterized by arid and semi-arid climatic conditions. The state experiences low and erratic rainfall, high evapotranspiration rates, and limited surface water resources, leading to substantial reliance on groundwater for drinking and irrigation purposes. In such environments, groundwater quality is significantly influenced by natural processes such as evaporation, limited recharge, and prolonged water–rock interaction. These processes often result in elevated concentrations of dissolved salts, hardness, and other chemical constituents. Deterioration of groundwater quality poses serious challenges to public health, agricultural productivity, and sustainable water resource management. The presence of excessive total dissolved solids (TDS), fluoride, nitrate, and other ions can render groundwater unsuitable for drinking and may contribute to water-borne diseases and other health issues. Therefore, systematic assessment and monitoring of groundwater quality are essential to ensure a safe water supply and to formulate appropriate management strategies. The present study focuses on Alsisar, an arid region of Rajasthan, where groundwater serves as the principal source of water for domestic and agricultural needs. The study aims to evaluate the hydro-chemical characteristics and seasonal variations in groundwater quality, thereby contributing to a better understanding of its suitability for drinking and irrigation purposes and supporting sustainable water resource management in arid regions.

2. Study Area:

Rajasthan can be broadly classified into three major rainfall zones: arid, semi-arid, and sub-humid, reflecting significant spatial variability in precipitation across the state. Jhunjhunu District is situated in the northern part of Rajasthan and represents a predominantly semi-arid to arid climatic setting. Geographically, Jhunjhunu district extends between 27°38′13.88″ to 28°31′11.09″ North latitudes and 75°01′30.74″ to 76°06′01.47″ East longitudes, covering an approximate area of 5,911.1 square kilometres. The district is bounded by Churu District to the northwest, the state of Haryana to the east, and Sikar District to the southwest. This strategic location places the district within the transitional climatic belt of northern Rajasthan. From a geomorphological and hydrological perspective, the district lacks a well-developed and systematic drainage network. A narrow central strip of the district, trending from northwest to southeast, forms part of the Shekhawati River Basin. However, the remaining eastern and western portions of the district fall within what is locally referred to as the “Outside Basin,” characterized by the absence of integrated surface drainage. Consequently, surface runoff is limited and often results in ephemeral streams or localized depressions rather than organized river systems. The lack of a structured drainage system, combined with low and erratic rainfall, significantly influences groundwater recharge patterns and overall water resource availability in the district. These physiographic and climatic characteristics make the Jhunjhunu district particularly vulnerable to water scarcity, thereby necessitating careful planning and sustainable management of available water resources.

The study area, Alsisar, is located between 75°25′00″ to 75°30′00″ East longitudes and 26°58′00″ to 27°05′00″ North latitudes in the arid climatic zone of Rajasthan. The region is characterized by low and erratic rainfall, sandy terrain, and limited surface water resources. Physiographically, it comprises extensive sandy plains and undulating dunes, accompanied by a poorly developed drainage system. Geologically, the area is dominated by alluvial deposits consisting of sand, clay, and kankar, extending below the zone of saturation. The principal aquifer-bearing formations are composed of granite, quartz, feldspar, and sandstone, which significantly influence the hydrogeological characteristics of the region. Due to scarce and irregular rainfall, groundwater serves as the primary source of water for domestic and agricultural purposes in Alsisar. The local population largely depends on groundwater for drinking and other daily needs. Therefore, systematic evaluation of groundwater quality is essential to ensure safe water supply, safeguard public health, and prevent water-borne diseases in this arid region.

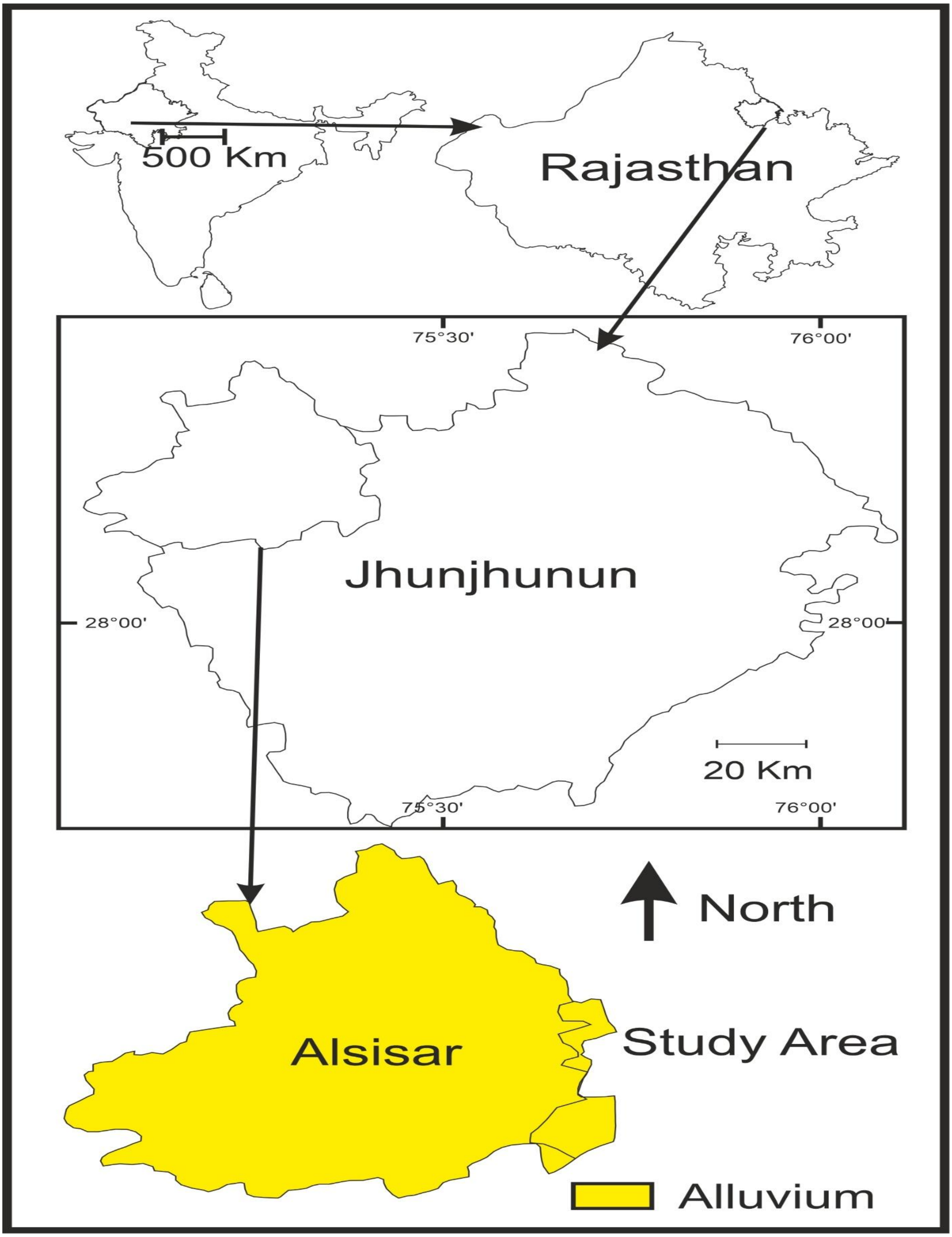

Figure 1: Location map of the Study Area

3. Objectives of the Study:

The present study was undertaken with the following objectives:

To assess the physicochemical characteristics of groundwater in the study area.

To determine the suitability of groundwater for drinking purposes with reference to standard guidelines.

To understand the influence of lithology and arid climatic conditions on groundwater quality.

4. Materials and Methods:

Groundwater samples were collected from selected dug wells and hand pumps within the study area during two distinct seasons, namely pre-monsoon (summer) and post-monsoon (winter), to assess seasonal variations in water quality. The selection of sampling locations was based on their spatial distribution and their use for domestic and agricultural purposes. Samples were collected in clean polyethylene bottles of one-litre capacity. Before sampling, the bottles were thoroughly washed with distilled water and subsequently rinsed with the respective groundwater sample to minimize the risk of contamination. During collection, appropriate precautions were taken to ensure that the samples were representative of the aquifer conditions. The collected samples were properly labelled, preserved, and transported to the laboratory for further physicochemical analysis using standard analytical procedures.

5. Analytical Methods

The collected groundwater samples were analysed for major physicochemical parameters to evaluate their quality and suitability for domestic and agricultural use. The parameters determined included pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl^-). All analyses were carried out using standard analytical techniques in accordance with the protocols recommended by the American Public Health Association (APHA). Appropriate quality control measures were maintained throughout the analytical process to ensure accuracy and reliability of the results.

6. Results and Discussion

The analytical results were compared with the WHO and BIS drinking water standards to evaluate the suitability of groundwater for human consumption**.** Groundwater quality data from Alsisar reveal significant seasonal variation between the pre-monsoon and post-monsoon periods, reflecting the combined influence of arid climatic conditions, local lithology, and limited natural recharge. Most physicochemical parameters showed higher concentrations during the pre-monsoon season. This increase can be attributed to intense evaporation, reduced dilution, and prolonged water–rock interaction under dry conditions. In contrast, post-monsoon samples exhibited comparatively lower concentrations of dissolved constituents due to recharge from rainfall, which provides partial dilution of groundwater. However, the reduction in concentration is limited because recharge in the region is relatively low and irregular. The study area lacks a well-developed floodplain and perennial river system. Consequently, groundwater recharge primarily occurs through direct rainfall infiltration rather than through river or canal seepage. The absence of significant surface water flow further restricts natural dilution mechanisms, leading to the accumulation of dissolved salts and other chemical constituents, particularly during the dry pre-monsoon period. These hydrogeological conditions play a crucial role in controlling the seasonal dynamics of groundwater quality in the region.

pH

The pH of groundwater samples collected from the study area ranged between 7.8 and 8.7 during both the pre-monsoon and post-monsoon seasons, indicating slightly to moderately alkaline conditions. The observed alkalinity can be attributed to the predominance of bicarbonate (HCO_3^-) ions and the weathering of silicate minerals in granitic and sandstone formations, which influence the geochemical composition of groundwater. All analysed samples fall within the permissible limits for drinking water as recommended by standard guidelines. Therefore, pH does not appear to pose a significant constraint for potable use in the study area.

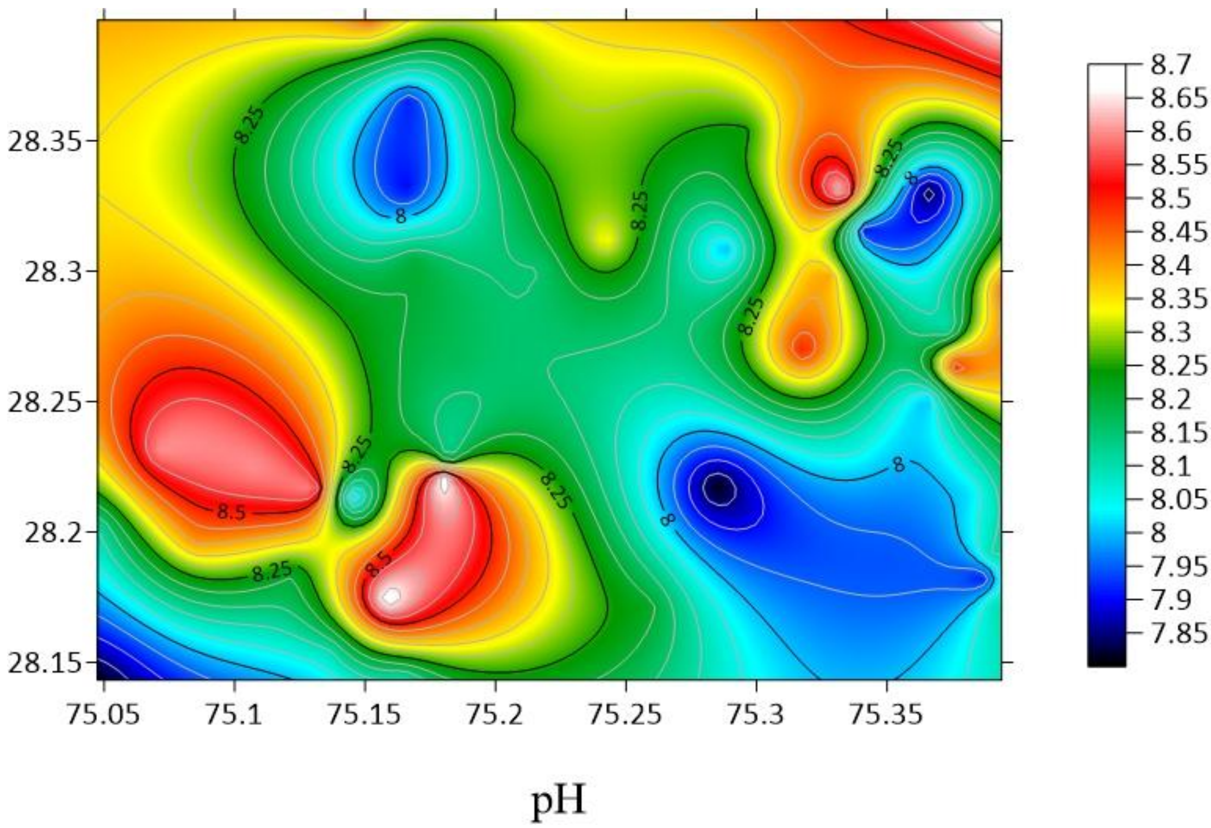

Figure 2: Spatial Distribution of pH Values of Groundwater in the Study Area

Alkalinity

The spatial distribution of alkalinity in groundwater across the study area. Alkalinity values range approximately from 200 mg/L to 850 mg/L, as indicated by the colour scale. Lower alkalinity concentrations are represented by dark blue shades, while higher concentrations are shown in yellow to red tones.

The map demonstrates noticeable spatial variation in alkalinity levels. Higher alkalinity zones (≥650 mg/L) are predominantly observed in the northern, southwestern, and central parts of the study area. In contrast, relatively lower alkalinity values (≤400 mg/L) are concentrated in localized pockets, particularly in the northwestern and southeastern regions.

The contour lines represent iso-alkalinity levels and highlight the gradient and distribution pattern of bicarbonate-rich groundwater. Elevated alkalinity in the region can be attributed to the dominance of bicarbonate ions and the dissolution of carbonate and silicate minerals under arid climatic conditions. Limited recharge and prolonged water–rock interaction further enhance alkalinity levels.

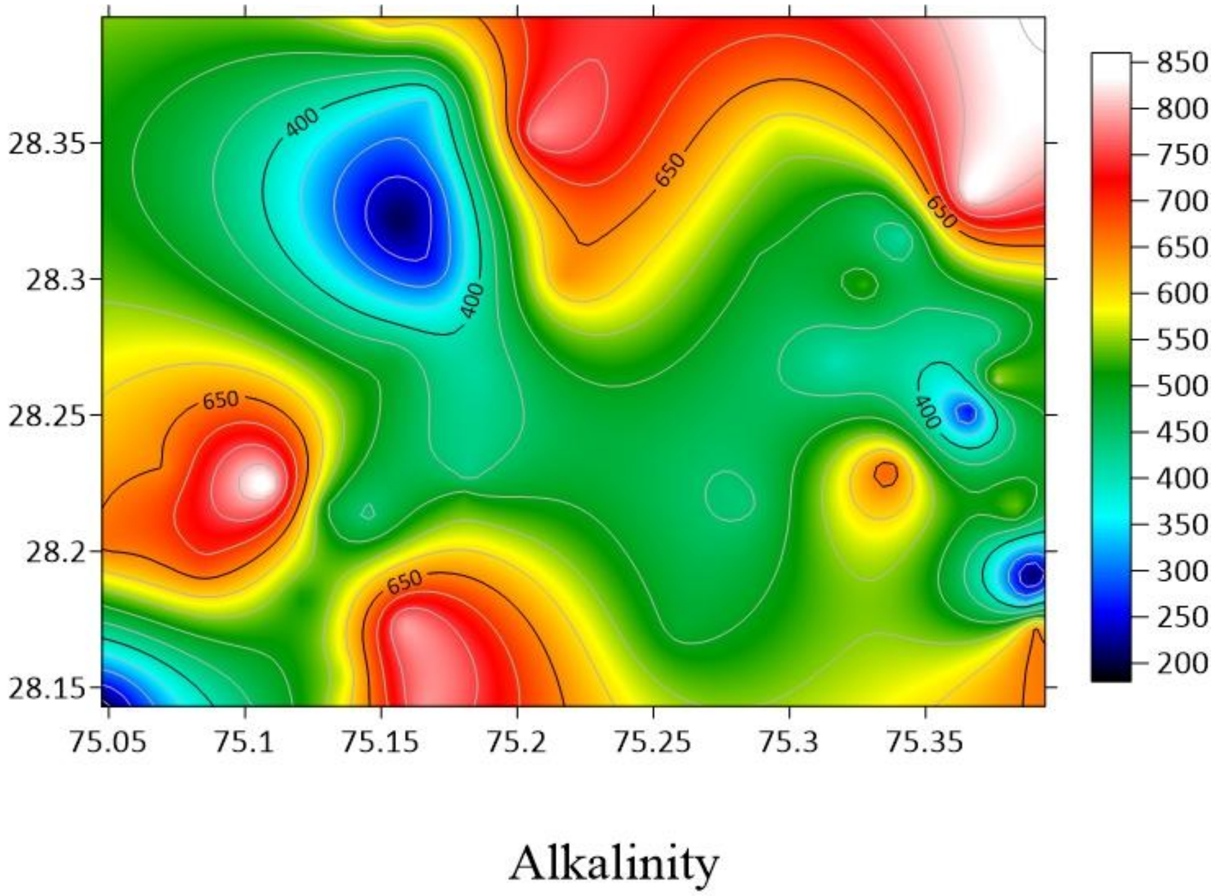

Figure 3: Spatial Distribution of Alkalinity in Groundwater Samples of the Alsisar Block.

Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

Electrical Conductivity (EC) and Total Dissolved Solids (TDS) values of groundwater samples were found to be relatively high, particularly during the pre-monsoon season, indicating increased mineralization. The EC values ranged from 206.25 to 1750 µS/cm, while TDS concentrations varied between 1320 mg/L and 11,200 mg/L across the study area. The elevated EC and TDS levels can be attributed to arid climatic conditions, high evaporation rates, limited groundwater recharge, and prolonged water–rock interaction within the aquifer system. These processes enhance the dissolution of minerals, leading to the accumulation of dissolved salts in groundwater. A number of groundwater samples exceeded the desirable limits prescribed for drinking water, suggesting salinity-related concerns and potential limitations for potable use. However, suitability may vary depending on the degree of salinity and intended usage.

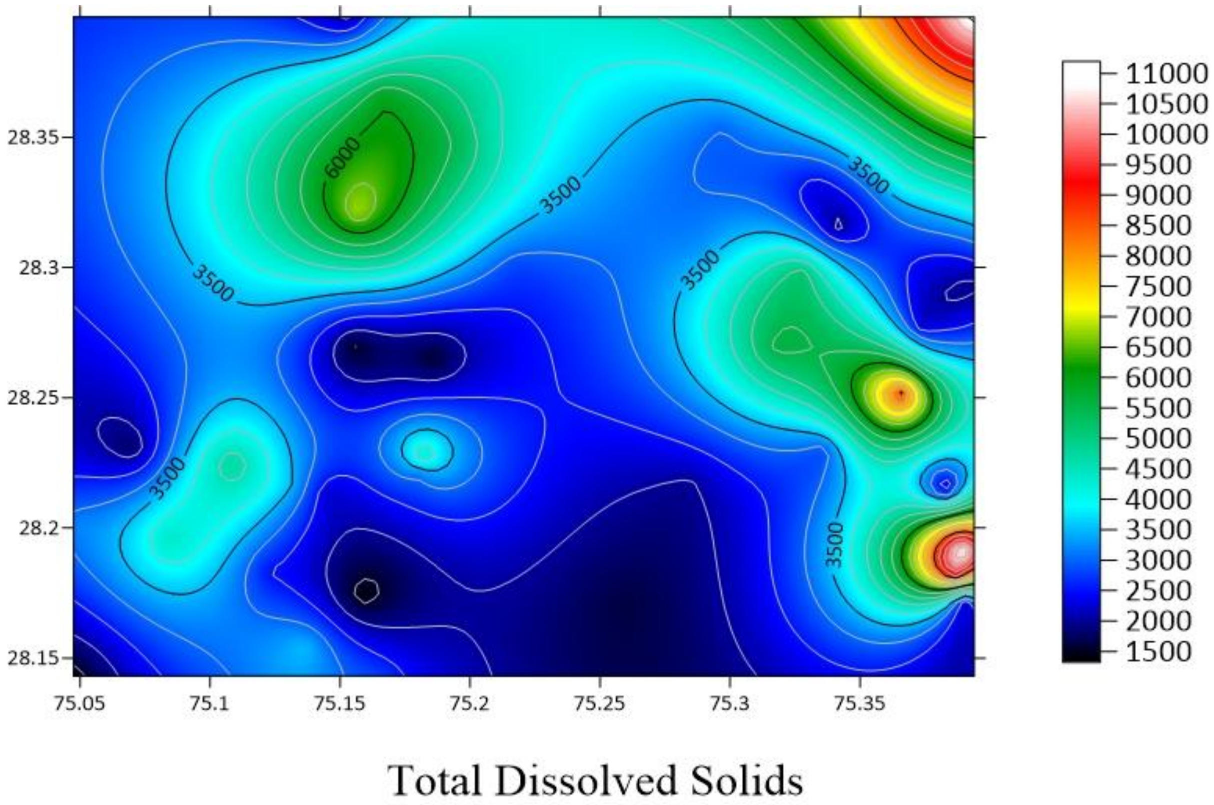

Figure 4: Spatial Distribution of Total Dissolved Solids in Ground Water of the Samples

Total Hardness (TH)

Total hardness is caused mainly by calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. These ions react with **EDTA** (Ethylenediaminetetraacetic acid) during titration. Total Hardness (TH) values of groundwater samples ranged from 180 to 850 mg/L (as $CaCO_3$), indicating that the water varies from moderately hard to very hard in nature, with a majority of samples falling under the very hard category. The elevated hardness is primarily attributed to the presence of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, which are derived from the dissolution of carbonate and silicate minerals within the aquifer formations. Calcium concentrations ranged from 40 to 220 mg/L, while magnesium concentrations varied between 30 and 160 mg/L. These ions significantly contribute to the overall hardness of groundwater in the study area.

Chloride (Cl^-)

Chloride (Cl^-) concentrations in the analysed groundwater samples varied from 290 to 3400 mg/L, indicating significant spatial variability and wide differences in salinity across the study area. The elevated chloride content can be attributed to arid climatic conditions characterized by high evaporation rates, limited recharge, and dissolution of chloride-bearing minerals within the aquifer matrix. Additionally, localized anthropogenic activities such as agricultural return flow and domestic waste disposal may contribute to increased chloride levels at certain locations.

A comparison with established drinking water standards reveals that chloride concentrations in several samples exceed the permissible limits, thereby rendering the water unsuitable for potable use in those areas. High chloride content not only affects the taste of water but also indicates salinity-related issues, which may pose constraints for both domestic consumption and agricultural applications.

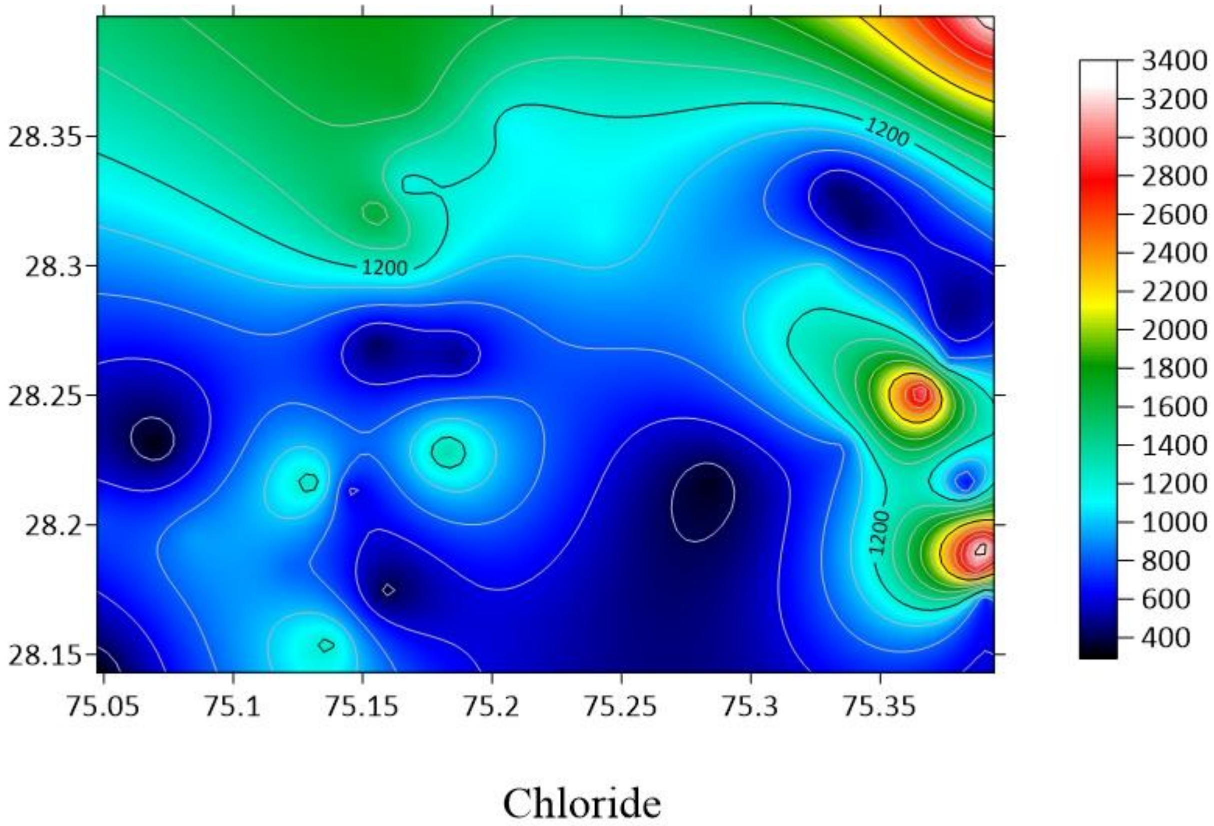

Figure 5: Spatial Distribution of Chloride Value in the Groundwater Samples

Fluoride (F^-)

The spatial distribution of fluoride concentration in groundwater across the Alsisar Block is illustrated in the fluoride concentration map. Areas exhibiting low fluoride concentrations (≤1.5 mg/L), which fall within the permissible limits for drinking water, are represented in blue. These areas cover approximately 5.7% of the total study area and are considered suitable for domestic consumption.

Regions with moderately elevated fluoride concentrations (1.5–3.0 mg/L) are depicted in green/yellow and account for nearly 61.2% of the area. Areas with fluoride concentrations exceeding 3.0 mg/L constitute approximately 33.1% of the study area represented by the color Red/yellow, Overall, fluoride concentrations in the block range from 0.3 to 4.2 mg/L.

The high-fluoride zones (>3.0 mg/L) are primarily concentrated around Patoda, Kaliyasar, Sonasar, and Kamalsar villages in the Alsisar Block. Groundwater in these areas exceeds the permissible limits for drinking water and is therefore unsuitable for domestic use without appropriate treatment measures.

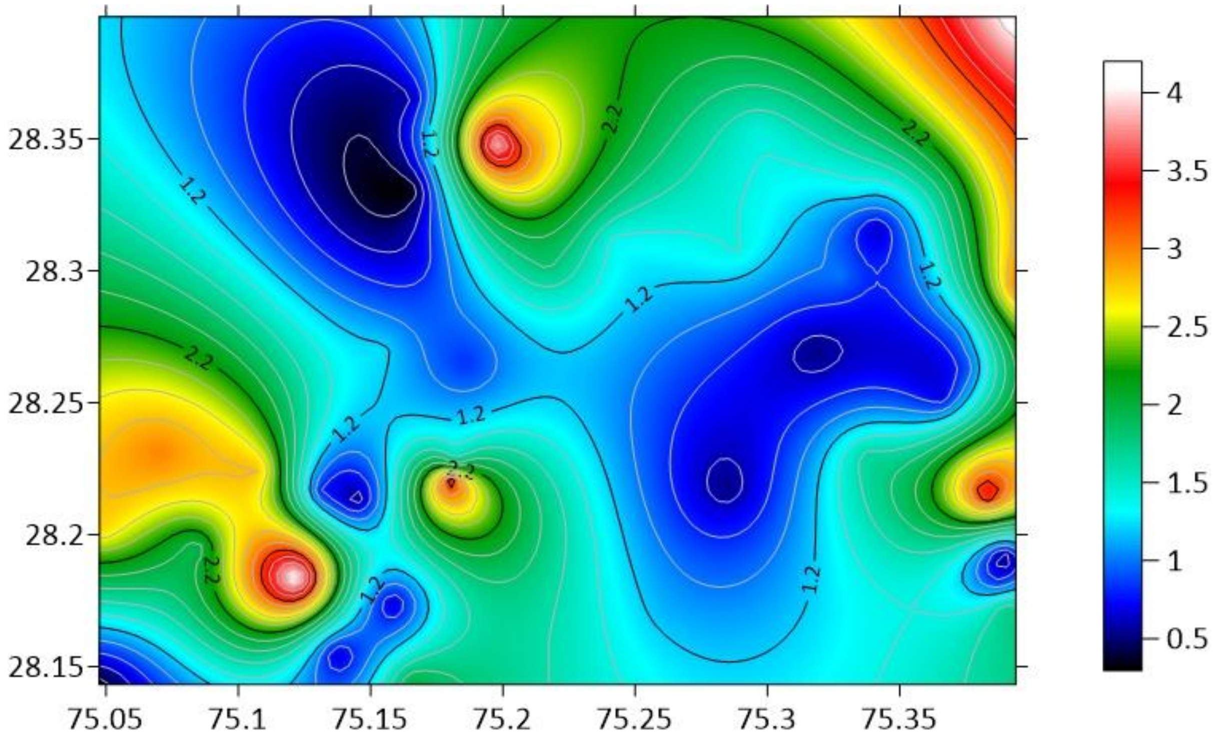

Figure 6: Spatial Distribution of Fluoride (F^-) in Alsisar Block

Conclusion

The present study evaluated the hydrochemical characteristics and seasonal variations of groundwater quality in the Alsisar Block. The analytical results, when compared with WHO and BIS drinking water standards, reveal considerable spatial and seasonal variability influenced by arid climatic conditions, lithological characteristics, and limited natural recharge. Groundwater in the study area is generally slightly to moderately alkaline, with pH values within permissible limits. However, elevated concentrations of electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), chloride (Cl^-), and fluoride (F^-) were observed in several locations. The higher concentration of dissolved constituents during the pre-monsoon season reflects the impact of intense evaporation, reduced dilution, and prolonged water–rock interaction. Although post-monsoon recharge results in partial dilution, the improvement in water quality is marginal due to low and irregular rainfall and the absence of a well-developed surface drainage system. Total hardness indicates that groundwater ranges from moderately hard to very hard, primarily due to elevated calcium and magnesium concentrations derived from carbonate and silicate mineral dissolution. High chloride and TDS values in many samples suggest salinity-related concerns, limiting the suitability of groundwater for drinking without treatment. Elevated nitrate concentrations at certain locations indicate possible anthropogenic contamination from agricultural and domestic sources. Fluoride contamination emerges as a significant concern in the Alsisar Block. A substantial portion of the area exhibits fluoride concentrations above the permissible limit, particularly in villages such as Patoda, Kaliyasar, Sonasar, and Kamalsar. Groundwater in these zones is unsuitable for drinking without appropriate defluoridation measures. Overall, the study highlights that while groundwater remains the primary source of water for domestic and agricultural purposes in the region, its quality is compromised in several areas due to both geogenic and anthropogenic factors. Continuous monitoring, implementation of appropriate treatment technologies, artificial recharge measures, and sustainable groundwater management practices are essential to ensure safe and reliable water supply in this arid region.

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