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Research Article

Groundwater Quality and Suitability Assessment in Tirupur Region, Tamil Nadu, India

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The study aims to understand the hydrochemical characteristics and groundwater suitability for agricultural and drinking purposes. For this purpose, 21 groundwater samples were collected, and major physicochemical parameters such as pH, EC, TDS, temp, salinity, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, and SO_4^{2-} were analyzed, followed by the standard analytical procedures. Different groundwater quality graphical representations were constructed by using Aqua Chem software. The results indicate groundwater samples were alkaline with fresh to moderate saline in nature, sixty-eight percent of the samples were suitable for drinking in accordance with WHO, and thirty-two percent of the samples were unsuitable due to the excess amount of different ionic concentrations derived from natural and various anthropogenic sources. Irrigation water quality parameters such as SAR, EC, PI, Na %, RSBC, MR, and KR were used to understand the irrigation suitability. The US salinity diagram exemplifies that most groundwater samples fall in the C3S1 category with high salinity hazard and low alkali hazard. The Wilcox plot reveals that 80% of the samples were found under very good to permissible limits, and few samples fall with doubtful to unsuitable quality due to the excess amount of alkali and salinity. Permeability index values show that groundwater is suitable for irrigation. Three major hydrochemical facies were identified with the dominance order of mixed CaMgCl, NaCl, and CaCl. Gibb's plot suggests that evaporation and rock-water interaction are the dominant natural mechanisms controlling the groundwater chemistry in the present study area.

1. Introduction

Groundwater has developed into the most significant source of water used for drinking, domestic, irrigation, and various industrial uses. The increasing population, industrial growth, urbanization, and unplanned management are enforcing huge stress on the surface and groundwater resources, which highly induce contamination and are unfit for various uses [1, 2]. Generally, the groundwater quality is conditional on the residence of a variety of major and minor chemical dissolve ionic concentration and their physical characteristics, which are predominantly associated with natural resources, particularly in the presence of surface soils, landforms, and subsurface surrounding rocks [3–6]. Mineral ions dissolved from soil particles and rocks are naturally present in groundwater. Human activities may alter the natural composition of groundwater by dumping or dispersing different harmful chemicals and microbiological matter on the land surface and into soils or by injecting trash directly into groundwater [7]. Groundwater contamination is described as an undesirable change in natural groundwater properties caused by the addition of solid, liquid, or gaseous waste, as well as physical, chemical, or biological pollutants, or by the addition of sewage or industrial wastes. The four types of groundwater pollution are physical, chemical, biological, and physiological activity [8–12].

The quality of water is a utility of evenly natural and anthropogenic pressures. Apart from the natural contamination of groundwater with the weathering, and interaction of parent rock and minerals, numerous toxic chemical contaminants and infectious microbes are further due to different anthropogenic activities in the name of development [13–17]. Phosphate, nitrate, sulphate, oxalate, and chloride, and in addition, certain pesticides, oils, detergents, phenols, biphenyls, and dangerous bacteria, fungi, algae, plankton, amoeba, viruses, and worms can have harmful effects. Many types of major diseases such as cholera, typhoid, digestive disturbance, hepatitis, diarrhea, viral fever, carcinogenic problems, dental fluorosis, kidney problems, poisonous, hepatitis, gastroenteritis, and dehydration are caused by toxic pollutants and bad quality water [18–20]. Since 2010, there has been a drastic increase in groundwater contamination in India due to over-extraction of subsurface water, improper conjunctive use of water resources, untreated industrial effluents, continuous domestic sewages, and irrigation return flow. A proper understanding of the groundwater condition is important to meet this increasing demand and formulate future development and management strategies [21–23].

In India, many factories are generating synthetic chemicals, and various dyes, producing wastes that are induced in groundwater contamination. Apart from this, the contamination of such sources and the increasing use of pesticides and fertilizers resulted in the nonpoint pollution of different drinking water sources [24]. In this current scenario, human activities are regularly adding industrial, agricultural, and domestic wastes to groundwater reservoirs at an alarming rate [25]. The factors affecting groundwater pollution include (i) pattern of rainfall, water table depth (ii), and contamination of source from the distance (iii). Properties of soil such as structure, texture, and filtration rate are also affected [26–28]. With respect to the geochemical studies, water usage provides an understanding of changes in quality as development progresses, which in turn provides limited information about total development, or can allow the planning for appropriate treatment that provides the quality of water supply in the future [29–32]. Water quality evaluation has become inevitable in water resource management as a result of the increased degradation of water quality in connection to human activities [33]. Several researchers have attempted and carried out a groundwater quality assessment [34–38] and contamination studies at national and regional levels during the recent decades [39–47]. However, no detailed groundwater suitability study has been reported so far in the present study region. Hence, this present study aims to assess the groundwater quality and its suitability for drinking and irrigation by identifying the sources of contamination.

1.1. Study Area. The study area is situated in the part of Tirupur district of Tamil Nadu (Figure 1). The present study area lies between 77°26′E to 77°40′E longitude and 11°05′N to 11°18′N latitudes. The southern part of the Tirupur district is covered by hills of Western Ghats (Anamalai, Sirumugai Malai, Nilgiris, Boluvampatti, Janakal, and Velliangiri), and the rest of the district consists of undulating plain sloping gradually from west to east. Palladam taluk surrounds the study area in the west, Avinashi taluk to the north and northwest, Perundurai taluk in the east and northeast, and Dharapuram in the south. The Noyyal River passes across the study site, almost cutting it in half. The river has been associated with water quality problems, and the practice of discharging untreated waste from the industrial into the river course has been alarming. The Tirupur district is dominated by Archaean to Late Proterozoic crystalline rocks and granulitic topography. Ground water occurs under the phreatic condition wherever deep-seated fractures occur under semiconfined to confined conditions. The depth of a well in hard rock generally ranges between 8 and 15 m below ground level. Generally, the yield in open wells ranges from 30 to 250 m^3/day and between 260 and 430 m^3/day in bore wells. The maximum temperature ranges from 36°C to 43°C, and the temperature maximum varies from 14°C to 31°C. According to the 2011 census, the taluk of Tirupur had a population of 980851, with 499648 males and 481203 females, and a literacy rate of 76.36. Industrial activities such as dying, bleaching, and spinning mills and, to some extent, agricultural activities are the main important roles of the present research site.

The groundwater sample has been collected from 21 respective locations in the Tirupur region and distributed over the study during the month of April 2022 from bore wells and dug wells. The samples were collected in polythene bottles with 250 and 100 ml capacities. Prior to collection, both bottles were properly rinsed with distilled water, and the 100 ml bottle was rinsed with diluted HNO_3 acid in the laboratory before filling the bottle with the sample. The polythene bottles were rinsed in the field with the respective water samples before filling and labeled accordingly. The detailed analysis and calculation methods adopted in major drinking water quality parameters [48] and irrigation suitability index are given in Table 1. After the analysis of major chemical parameters, the analytical error was calculated and checked using the Aqua Chem software package. The result shows that all groundwater samples did not exceed a maximum of 5%. The Piper trilinear diagram [49] was plotted using AquaChem Scientific v4.0 software.

2. Results and Discussion

The major ion concentrations for drinking groundwater quality were compared with the standard guideline values suggested by the World Health Organization [50] and the national standard guideline of the Bureau of Indian Standards [51] for drinking and public health standards. The chemical parameters of groundwater, as well as pH, electrical conductivity, TDS, and salinity, were statistically analyzed, and the results were contrasted to drinking water acceptance criteria, as shown in Table 2.

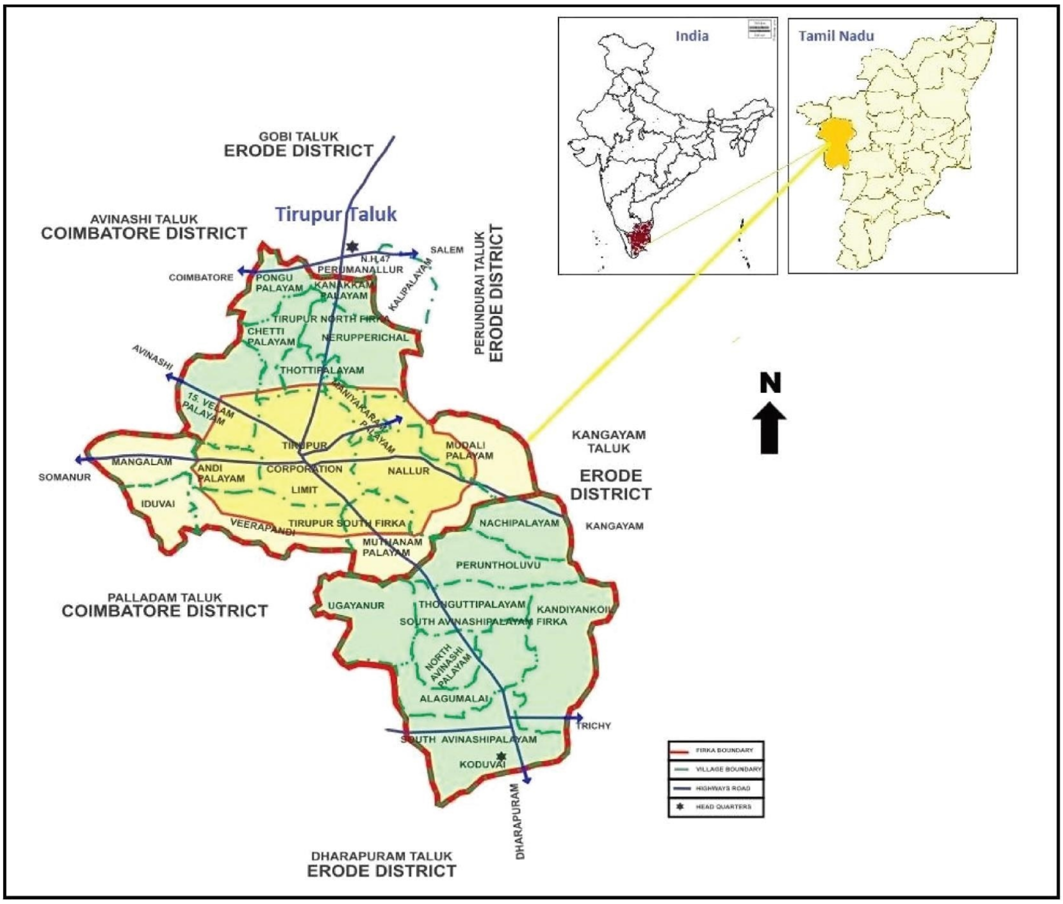

FIGURE 1: Location map of the study area materials and methods.

TABLE 1: Methodology adopted to analyze for physicochemical parameters and irrigation water quality.

Parameters	Unit	Analytical methods/instruments and formula adopted
pH	Range	HANNA portable water quality meter (HI-9828, USA)
Electrical conductivity (EC)	μS/cm	
Temperature	°C	
Total dissolved solids (TDS)	mg/L	
Calcium (Ca^{2+})	mg/L	EDTA titrimetric
Magnesium (Mg^{2+})		
Sodium (Na^{+})		Digital flame photometer (Deep Vision. Model.381)
Potassium (K^{+})		
Carbonate (CO_3^{-})	mg/L	H_2SO_4 titrimetric
Bicarbonate (HCO_3^{-})		
Chloride (Cl^{-})		$AgNO_3$ titrimetric
Sulphate (SO_4^{2-})		UV-visible spectrophotometer
Total hardness (TH)		EDTA titrimetric
Sodium adsorption ratio (SAR)	meq/L	$SAR = Na/\sqrt{(Ca+Mg)/2}$
Residual sodium bicarbonate (RSBC)		$RSBC = (HCO3 - Ca)$
Sodium percentage (Na %)	%	$Na\% = (Na+K)/Ca+Mg+Na+K \times 100$
Permeability index (PI)		$PI = (Na + \sqrt{HCO3})/(Ca + Mg + Na) \times 100$
Soluble sodium percentage (SSP)		$SSP = Na/(Na + Ca + Mg) \times 100$
Magnesium hazard (MH)		$MH = (Mg)/(Ca + Mg) \times 100$
Kelly index (KI)	Range	$KI = ((Na)/(Ca + Mg))$

Table 2: Physicochemical characteristics of groundwater in the study region.

S. no	Ions	Unit	Min	Max	Average	WHO [50]	ISI (1983)	BIS [51]
1	pH	Range	6.95	8.35	7.88	6.5–8.5	6.5–9.2	6.5–8.5
2	EC	μS/cm	360.94	3689.1	1758.6	1500	—	—
3	TDS	mg/l	231	2361	1125.5	1500	1500	1500
4	Temp	˚C	25.11	36.63	30.232	—	—	—
5	Salinity	mg/l	0.17	1.93	0.88	—	—	—
6	Ca^{2+}	mg/l	31.05	202.4	105.6	200	200	200
7	Mg^{2+}	mg/l	21	194.7	87.1	150	100	100
8	Na^{+}	mg/l	41	435	172.8	200	150	150
9	K^{+}	mg/l	4	102	28.1	12	—	—
10	HCO_3^{-}	mg/l	113.8	619	352.5	500	400	400
11	Cl^{-}	mg/l	71	805.8	338.4	600	1000	1000
12	SO_4^{2-}	mg/l	34	390	181.6	250	400	400

2.1. Evaluation of Groundwater Quality for Drinking

2.1.1. pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Salinity. pH is a measure of the activity and presence of the hydrogen ion. The measurement of pH is needed to determine the acidity, alkalinity, and corrosiveness of the groundwater. The pH of the groundwater in the present study area ranges from 6.95 to 8.35, with an average value of 7.88, indicating an alkaline in nature, and all samples are suitable for drinking WHO [50]. The observed EC values vary from 360.94 to 3689.17 μS/cm, with a mean value of 1125.5 μS/cm. TDS and salinity are directly related to EC levels. TDS is the total amount of organic and inorganic dissolved materials in a watery solution. TDS levels varied from 231 to 2361 mg/l, with an average of 1758.6 mg/l, while salinity levels ranged from 0.17 to 1.93 mg/l (Table 2). Groundwater containing less than 1000 mg/l might be considered as freshwater and good enough for drinking and domestic purposes. Elevated TDS and salinity levels in groundwater can have a negative economic impact on drinking and domestic use; they can pose numerous health risks, reduce surface water infiltration, result in fallow land that ruins agricultural activities, and cause a variety of other environmental issues [52]. There are four main groundwater suitability classifications for drinking and irrigation, according to Davis & Dewiest. According to this classification, 19% of the samples have suitable TDS of <500 mg/l, 24% have admissible TDS of 500–1000 mg/l for drinking, 52% of the samples (1000–3000 mg/l) are only useable for cultivation, and 5% of the sample is unsuited for both consumption and irrigation. The economic consequences of elevated TDS and salinity values in groundwater can cause it to be unsuitable for potable and domestic uses, it can cause many health hazards, it can reduce infiltration of surface water, which can result in fallowed land and disrupt farming practices, and it can cause many other environmental concerns.

2.2. Major Cations and Anions. The dominant major ions' contents were present in decreasing order of $HCO_3^{-} > Cl^{-} > Ca^{2+} > Na^{+} > Mg^{2+} > SO_4^{2-} > K^{+}$ (Figure 2).

Calcium and magnesium are significant chemical constituents commonly found in the groundwater aquifer and are mainly associated with many types of minerals and rocks. The calcium ion concentration varies from 31.05 to 202.4 mg/l with an average value of 105.6 mg/l, and magnesium values vary between 21 and 194.7 mg/l with an average value of 87.1 mg/l. According to WHO [50] and BIS [51], the preponderance of the groundwater samples was safe for drinking. Naturally, both calcium and magnesium concentrations are important to human health. The increasing magnesium and calcium values are directly related to the total hardness of the water. The very excessive amount of calcium (202 mg/l) and magnesium (94 mg/l was found in near-dye industries with the sources of dyeing and bleaching effluents and several small-scale industries, use of excessive lime to the soil in farming uses, and municipal wastes.

Sodium is an extremely soluble chemical constituent naturally established in groundwater because most soils have abundant sodium-rich mineral deposits and rocks. The sodium ion content ranges between 41 and 435 mg/l, with an average of 172.8 mg/l. The sodium ion content in groundwater in this investigation surpasses the maximum allowable limit of 200 mg/l in four sites. Increased sodium intake in drinking water can cause high blood pressure, hypertension, kidney, and heart diseases [53]. The potassium-carrying rocks weather at a slower pace than sodium-bearing rocks; the potassium contents are lower. The potassium ion content ranges between 4 and 102 mg/l, with an average of 28.1 mg/l. According to WHO [50], seventeen groundwater samples surpassed the permitted level of 12 mg/l.

Bicarbonate concentrations in the study region range from 113.8 mg/l to 619 mg/l, with an average of 352.5 mg/l. According to the drinking appropriateness index, seven groundwater samples surpassed the allowed limit (400 mg/L) and are thus unsuitable for drinking. The content of chloride varies from 71 mg/l to 805.8 mg/l, with an average of 338.4 mg/l. More consumption of bicarbonate-rich groundwater can induce changes in acid-base balance as well as blood pH, high acidity in the body (indigestion), blood pressure, and skin diseases. According to WHO standards, the maximum allowable value of Cl^{-} for drinking

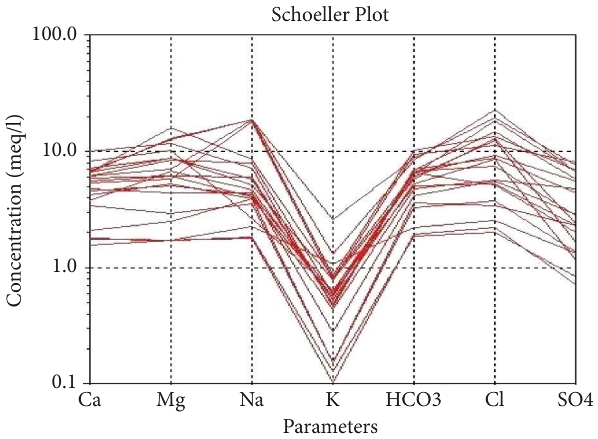

Figure 2: Schoeller plot represents the major ion level.

is 600 mg/l. In the research region, three groundwater samples exceeded this limit and were unfit for drinking under normal circumstances. The increasing chloride concentration results from human-caused, mainly municipal solid waste, landfill leachate, domestic sewages, fertilizers, agricultural runoff, and industrial effluents [54–56]. The sulphate concentration is varied between 34 mg/l and 390 mg/l, with a mean value of 181.6 mg/l. In terms of the sulphate value, six groundwater samples are unfit for drinking according to the WHO maximum allowed level (250 mg/l). Sulphate is found in water from both natural and man-made sources (mining, fertilizers, and metallurgical refineries). Generally, sulphate is not as toxic, but higher concentrations in drinking water can cause cathartic effects, dehydration, and diarrhea.

2.3. Evaluation of Groundwater Quality for Irrigation.

Irrigation operations in the current study region are also a key utility that relies on groundwater and surface water in the neighboring regions of the Noyyal River and tributaries. As a consequence, it is critical to comprehend the parameters responsible for the quality of irrigation water [46]. Therefore, it is essential to understand the parameters accountable for irrigation water quality. The irrigation water quality indices such as electrical conductivity/salinity, SAR, Na%, SSP, PI, RSBC, MH, and KI were used (Table 3).

The U.S. Regional Salinity Laboratory has conducted the diagram (Figure 3) for the classification of irrigation water [57], defining sixteen classes with reference to sodium absorption ratio as an index for hazards in sodium and EC as an index for salinity hazard. The correlation among EC (salinity hazard) and SAR (sodium hazard) plots (Figure 3) shows that the maximum amount of the groundwater samples is suitable for irrigation to contain low to moderate salinity hazard with low sodium hazard (C3S1 and C2S1); thus, they can be used for irrigation on almost all types of soil with little danger of exchangeable sodium. On the other hand, few samples fall under medium sodium hazard with very high salinity hazard (C4S1 and C4S2); these samples will be suitable for plants having good salt tolerance and hence restricted suitability for irrigation, especially in soils with limited drainage, and some samples are inappropriate for agricultural uses due to an excess amount of salinity hazard that affects the plants which can lead to the condition of saline soil and affect the sodium hazard affects in soils which can lead to conditions of sodic soil.

The sodium percentage (Na %) in groundwater is a crucially significant factor for determining irrigation appropriateness. The range of Na% values was 15.029% to 62.49%, with a mean value of 37.649%. The Wilcox [57] plot reveals (Figure 4) that the irrigation appropriateness in the research regions samples is classified as follows: excellent to permitted (11), very good to good (4), inappropriate (4), doubtful to unsuitable (4), and unsuitable (2). The value of the PI of the study differs from 14.227 to 28.831, with an average of 22.075. The classification of permeability index values is shown in Table 3. Based on PI value, all samples were found suitable for the purpose of irrigation. The magnesium ratio in the study region ranges from 6.25 to 64.71, with an average of 36.43. According to the magnesium ratio classification, 76% of samples are appropriate for farming purposes, whereas 24% of samples are unsuitable for cultivation. According to the Kelly ratio, soluble sodium percentage, and residual sodium bicarbonate values, the preponderance of the groundwater samples was appropriate for agricultural uses.

2.4. Evaluation of Hydrochemical Facies Using Piper Plot.

In the present study, the majority of groundwater samples fall under the no dominant type in the cation and anion triangle, and only a few samples are under the sodium type dominance in the cation triangle and chloride type in the anion triangle [49]. Three major hydrochemical facies were identified with the dominant order of mixed CaMgCl, NaCl, and CaCl (Figure 5). The 12 samples of groundwater fall under the mixed composition of Ca-Mg-Cl. This indicates that calcium and magnesium were the major dominant cations, and chloride was the major anion dominance. These major hydrochemical facies for Na-Cl indicate that the increasing range of salinization is due to the result of climate change with rising evaporation and anthropogenic contamination from various types of industrial developments

Table 3: Classification of groundwater on the basis of EC, SAR, Na%, PI, MR, and Kelly's ratio.

Parameters	Range	Groundwater class	Samples ($n = 49$) In. no	Samples ($n = 49$) In%
Electrical conductivity (EC)	<250	Excellent	0	0
	250–750	Good	3	14
	750–2250	Permissible	13	62
	>2250	Unsuitable	5	24
Sodium adsorption ratio	<6	No problem	21	100
	6–9	Increasing problem	0	0
	>9	Severe problem	0	0
Sodium percentage (Na %)	<20	Excellent	1	4
	20–40	Good	16	76
	40–60	Permissible	4	20
	60–80	Doubtful	1	4
	>80	Unsuitable	0	0
Soluble sodium percentage (SSP)	<50	Suitable	19	90
	>50	Unsuitable	2	10
Residual sodium bicarbonate (RSBC)	<1.25	Suitable	16	76
	1.25–2.5	Marginal	2	10
	>2.5	Unsuitable	3	14
Permeability index (PI)	<60	Suitable	21	100
	>60	Unsuitable	0	0
Magnesium hazard (MH)	<50	Suitable	16	79
	>50	Unsuitable	5	24
Kelly's index (KI)	<1	Suitable	18	86
	>1	Unsuitable	3	14

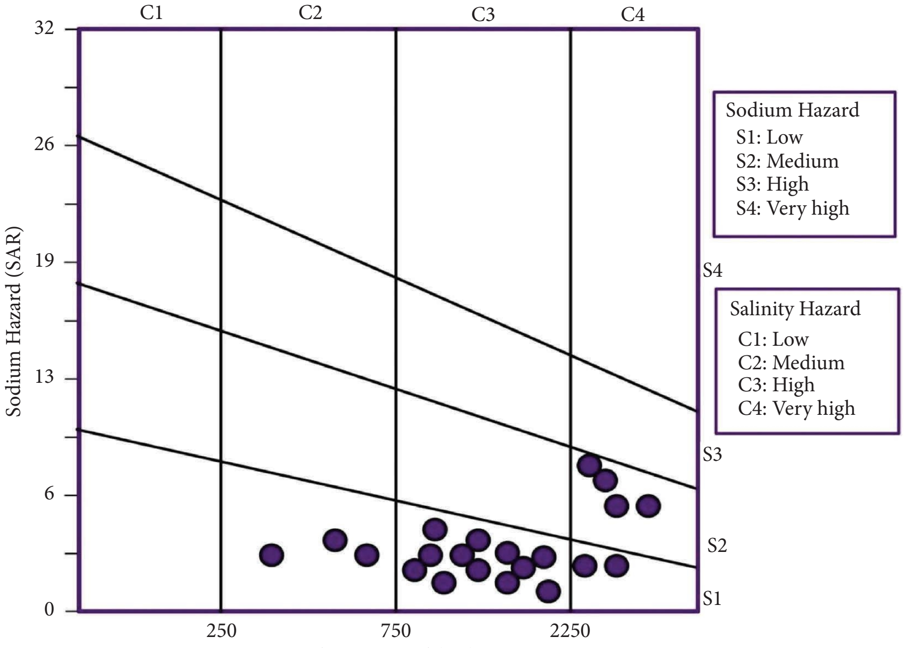

Figure 3: Diagram of sodium adsorption ratio and salinity for the classification of groundwater for irrigation purposes using USSL plot.

and domestic sewages. The Ca-HCO_3 facies represent the dominance of carbonate weathering from limestones. The Ca-Cl type suggests an interaction between soil-water-rock and the dissolution of calcium-rich minerals.

2.5. Mechanisms Controlling Groundwater Chemistry Using Gibb's Plot. Gibbs [58] proposed two diagrams for identifying the natural mechanisms and controlling the hydrogeochemistry based on the ratio of cations ((Na + K)/

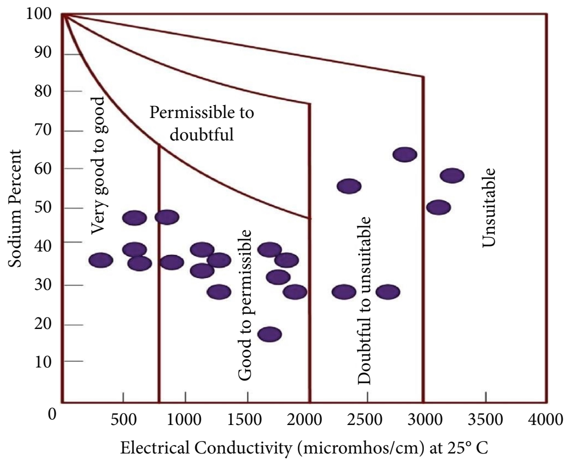

Figure 4: Wilcox plot for irrigation suitability assessment.

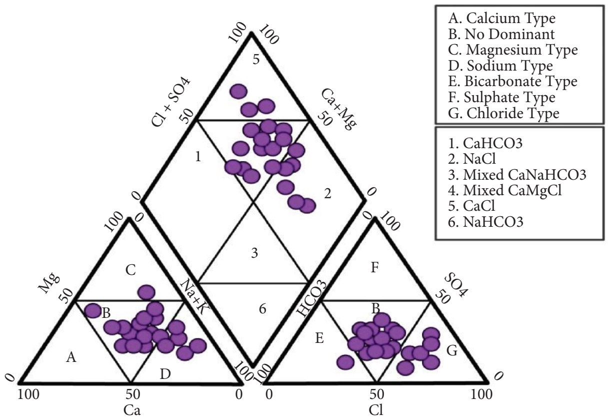

Figure 5: The Piper trilinear diagram represents the relationship between major ions' chemistry.

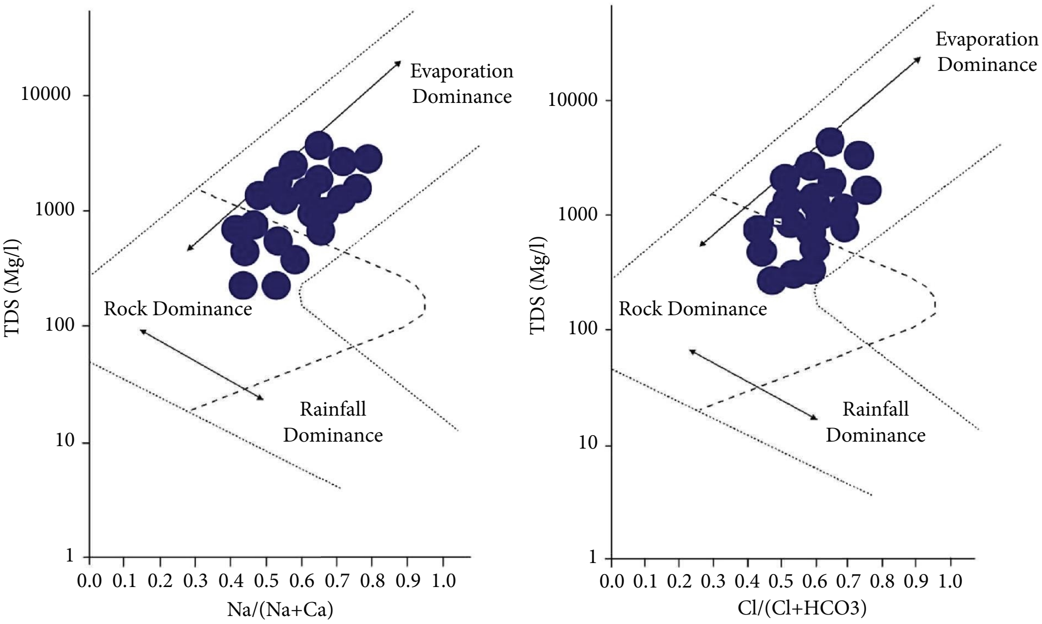

Figure 6: Gibb's plot.

(Na + K + Ca)) and anions (Cl/Cl + HCO_3) against TDS. Gibb represented that almost all global groundwater fell within limits and conjectured the three most important mechanisms controlling the groundwater chemistry including evaporation, rock-water interaction, and rainfall dominance. Gibb's plot also can be used for the functional source's appraisal of dissolved chemical constituents of groundwater. Figure 6 indicates that few samples are under the dominant rock zone, and the maximum of the samples fall under the evaporation dominance zone. The result reveals that the evaporation process is dominant because of arid and dry conditions in this region. Evaporation and concentration refer to the process of concentrating dissolved substances in groundwater under evaporation, though evaporation is also an important dominant mechanism controlling factor owing to the semiarid environment with increasing temperature and depletion of precipitation in addition to the role of the anthropogenic sources. It mainly occurs in arid climates and semiarid climates. Evaporation and concentration will not only increase the salinity of groundwater but also change the chemical type of groundwater.

3. Conclusion

The extensive physicochemical characteristics and groundwater suitability assessment studies for drinking and irrigation analysis revealed that the groundwater in the studied region is alkaline with fresh to moderately saline qualities. The predominance of significant ions is as follows: $HCO_3^- > Cl^- > Ca^{2+} > Na^+ > Mg^{2+} > SO_4^{2-} > K^+$. The increasing amount of calcium, magnesium, and bicarbonate ions was primarily due to the geological characteristics of the aquifer, limestone mining, processing of dolomites by several small-scale industries, and excessive use of lime to the soil in agricultural uses, municipal wastes, and industrial effluents. The suitability of drinking and irrigation water assessment study shows that 68% of the sampling stations' groundwater is found to be suitable for drinking according to world and national level standard limits as well as irrigation purposes, and also, 85% of the groundwater samples were found to be suitable for only irrigation purpose and 18% of the groundwater samples are unsuitable for both drinking and irrigation purposes. The USSL plot and Wilcox plot suggest that the majority of the samples have moderate alkalinity with salinity content of very good to permissible limit, and few samples have high alkalinity with increasing salinity and are doubtful to unsuitable for irrigation purposes. This study has demonstrated that the chemical composition of groundwater differs according to water type. Three major hydrochemical facies Ca-Mg-Cl, Na-Cl, and Ca-Cl were identified. Gibb's plot reveals that evaporation and rock-water interaction are the dominant natural mechanisms controlling groundwater chemistry. In the present study area, the groundwater quality has deteriorated due to mainly anthropogenic activities such as domestic sewages, municipal wastes, and discharge of effluent from dyeing and bleaching industries. However, the leaching and evaporation affect groundwater quality due to the natural processes of the chemical weathering in rock-forming minerals. Possibly, this study can be used by the concerned authorities in water resource planning and management sectors.

Data Availability

All data are included in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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