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Spatial variation on hydrogeochemical parameter in the Hetauda Valley, central Nepal

Devaki Kafle[1], Urusha Gautam[1], Dinesh Pathak*[1], Rewant K. Rawat[2]

[1] Central Department of Geology, Tribhuvan University, Kirtipur, Nepal
[2] Department of Environmental Science, Kathmandu University, Dhulikhel, Nepal
dpathaktu@gmail.com

* Corresponding Author

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Abstract: *Water is a requisite source for human survival, facing increasing issues and challenges in terms of both quantity and quality due to exacerbated global populations and urbanization trends. This increased demand has caused a decline in the overall availability and quality of water resources. Hetauda, serving as the administrative center of Bagmati Province, has emerged as a key destination for employment services along with a good potential zone for geotourism closely connected to its diverse geological features and water resources. However, excessive utilization, depletion, and extensive pollution of surface water sources in the region have underscored the importance of exploring groundwater for agricultural, and domestic needs along with decreasing the possibilities for geotourism. As the study area lies in the Hetauda Valley, to address this concern, water samples from 34 different sources such as dug wells, boreholes, and springs were collected. A thorough analysis of physicochemical parameters was conducted to evaluate water quality, revealing notable variations across locations, including the presence of iron and arsenic traces in specific samples. The Weighted Arithmetic Index Method was used to calculate the Water Quality Index (WQI) showing that certain water sources had very good quality while few weren't appropriate for human consumption. The Piper diagram indicates the dominancy of calcium ions in cations and chloride in anions. The stiff diagram shows that the ions Na + K > Ca > Mg dominate the composition of the cations, whilst* HCO_3^- *>* Cl^- *>* SO_4^{2-} *dominates the anions. Besides, the multivariate statistical analysis through Principal Component Analysis was executed to support these hydrochemical findings. In conclusion, this research underscores the critical necessity for sustainable water management strategies in the study area, advocating for the prudent exploration of groundwater while addressing the challenges posed by contaminants, thus ensuring the availability of safe and sufficient water resources in the region.*

Keywords: *hydrogeology, water quality analysis, multivariate analysis, geotourism, Hetauda Valley*

Introduction

Groundwater is an essential global water resource, playing a fundamental role in the Earth's hydrological processes. The process begins when precipitation enters the Earth's surface and descends to generate groundwater (Todd & Mays, 2004). Water plays a significant role in shaping geological features and is intricately associated with the formation of unique landscapes (Zierler *et al.*, 2023). It is an indispensable source of drinking water globally, particularly in developing nations, and has become a primary water resource, and ensuring its quality is essential for use. Water resources are becoming rapidly scarce in different parts of the world. The quality of groundwater is a crucial factor for human health as well as for social development (Thomas, 2023). The decline in groundwater quality resulting from anthropogenic activities has emerged as a significant issue that causes a consequence in uncontrolled withdrawal of groundwater at a higher rate than the recharge rate (Gulgundi & Shetty, 2018; Li Y. *et al.*, 2022). The pollution in the water not only affects the quality of water but also increases threats to human health, economic development, and social prosperity (Tiwari *et al.*, 2017).

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The groundwater quantity and quality are both equally important factors in the context of modern water management (Kumar *et al.*, 2013), so the study was conducted to assess the water chemistry of the groundwater concerning its suitability for drinking and irrigation purposes. Beyond the challenges posed by the water quality, geotourism has emerged in the form of nature-based tourism that holds significant potential in highlighting and educating about the geological and geomorphological features or landscapes while creating a valuable connection to water resources (Sumanapala & Wolfs, 2022). The involvement of geotourism in the study area can have a great impact on its economic development. The study area located in the Hetauda Valley is surrounded by mesmerizing green forests, natural springs, and rivers that can be a great source for the touristic destination. For the sustainable management of these resources, the local authorities should prepare a strategy based on geotourism and how it can be preserved for upcoming generations by providing economic benefit to the local communities.

Hydrogeological studies cover a wide range of topics, such as recharge and discharge of groundwater, subsurface flow, and interactions with surrounding rocks and soil which delves into diverse factors such as the conditions prevailing in different regions, the chemical composition of water, and the physical properties of rocks, including porosity, permeability, fracturing, and the outcomes of pumping tests (Diédhiou *et al.*, 2023). The interaction between the groundwater and the aquifer materials is considered an important tool of hydrogeochemical studies. The quality of groundwater is influenced by the interaction of the rocks or soils with the water passing through and how long it accumulates there (Abdelshafy *et al.*, 2019). The leaching, dissolution, ion exchange process, etc. also affect the groundwater chemistry. Water quality encompasses the evaluation of various physiochemical parameter that determines the suitability of water for its intended uses. These parameters include pH, turbidity, temperature, alkalinity, hardness, calcium, magnesium, iron, sodium, chloride, nitrate, and so on. Consequently, the main purpose of conducting this study was to evaluate the groundwater chemistry, understand the rock-water interaction and its importance in groundwater chemistry, and studying the feasibility of groundwater usage for different purposes like drinking, irrigation, and domestic.

Location map of the study area

The research area is located in Hetauda, the capital of the Bagmati province and part of Makwanpur District. It is a well-known location for cemeteries, historical and religious places, and geological formations. It can be easily accessible through two main highways, the Tribhuvan Highway and the Mahendra Highway, with distances of 132 km via Daman and 22 km via Narayangadh, covering a total area of 77 km^2. Hetauda is precisely positioned at 27.429071 latitude and 85.029716 longitude. The area is situated in the dun valley surrounded by hills; Mahabharata ranges in the North and Siwalik in the South (Fig. 1).

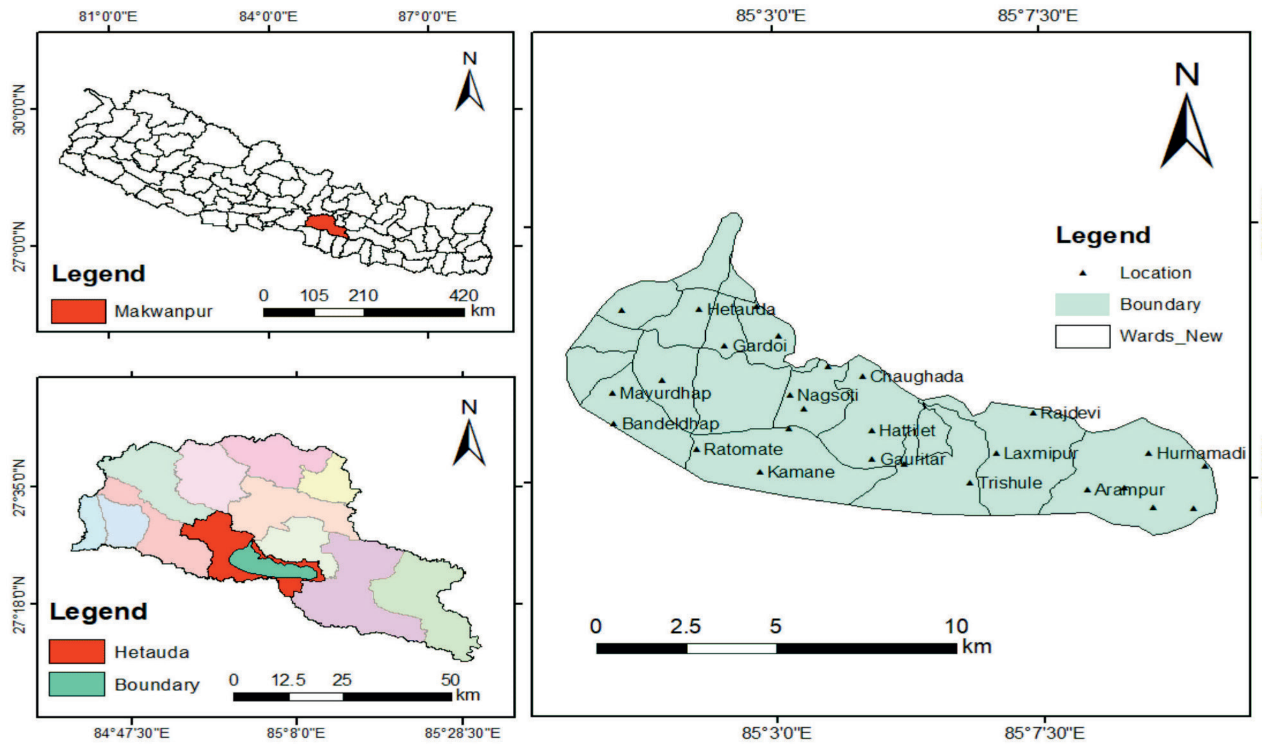

Fig. 1. Location map of the research region

Geology of the study area

The understanding of geology is quite important to know the impacts of soils, rocks, and their structures on groundwater hydrogeochemistry. The interaction between the soils and water helps to know what kind of water is available in the area. Hetauda lies in the Siwalik group which comprises three significant divisions; Lower Siwalik, Middle Siwalik, and Upper Siwalik which dominantly constitutes sedimentary deposits (mudstone, shales, fine-grained sandstone, salt and pepper sandstone, conglomerates) (Tamrakar & Subedi, 2020). The study area consists of coarsening upward sequence sediment from the middle Miocene to the Early Pleistocene period (Schelling *et al.*, 1991). The hydrogeology of the study area is characterized by the presence of multilayers aquifers as unconfined aquifers, confined aquifers, aquitard comprising lithology as sand, silt, clay, and gravel similar to Chitwan Dun Valley (Bhandari, 2019). The study area situated in Quaternary deposits is dominantly composed of sand and gravel, an excellent source of groundwater, while also containing lithologies like clay, silt, gravels, pebbles, and cobbles.

Materials and research methods

The flowchart below provides a visual representation of the sequential steps involved in the research study for water quality assessment, starting from the preliminary study, and fieldwork to laboratory analysis, data interpretation, and presentation of results (Fig. 2).

During the study, various materials were used to proceed with the study such as topographic maps, sampling bottles, bucket, *in-situ* test kit, and water level indicator.

Sampling methods and techniques

The surface and subsurface samples were obtained at 34 different spots comprising shallow and deep wells, springs, river and reservoirs of pre-monsoon seasons. The locations of the research region are depicted in Figure 3. The samples of the water were collected in 500 ml of polythene sample bottles that were rinsed with distilled water. The initial *in-situ* parameters (pH, EC, TDS) were tested in the field using an *in-situ* test kit, and the remaining chemical tests were done by bringing the water samples to the laboratory of the Water/Waste Water Quality Assurance Division, Mahankalchaur-KUKL, for the analysis of different parameters. The analytical methods used in the determination of the hydrochemical parameters are under the World Health Organization standards which is also followed by Nepal Drinking Water Quality Standards (NDWQS). Different standard methods and models were used to analyze the concentration of the water samples like ultraviolet-visible spectrophotometer for iron, phosphate, sulphate, and nitrate, a flame photometer for sodium and potassium, a turbidimeter for turbidity, and so on.

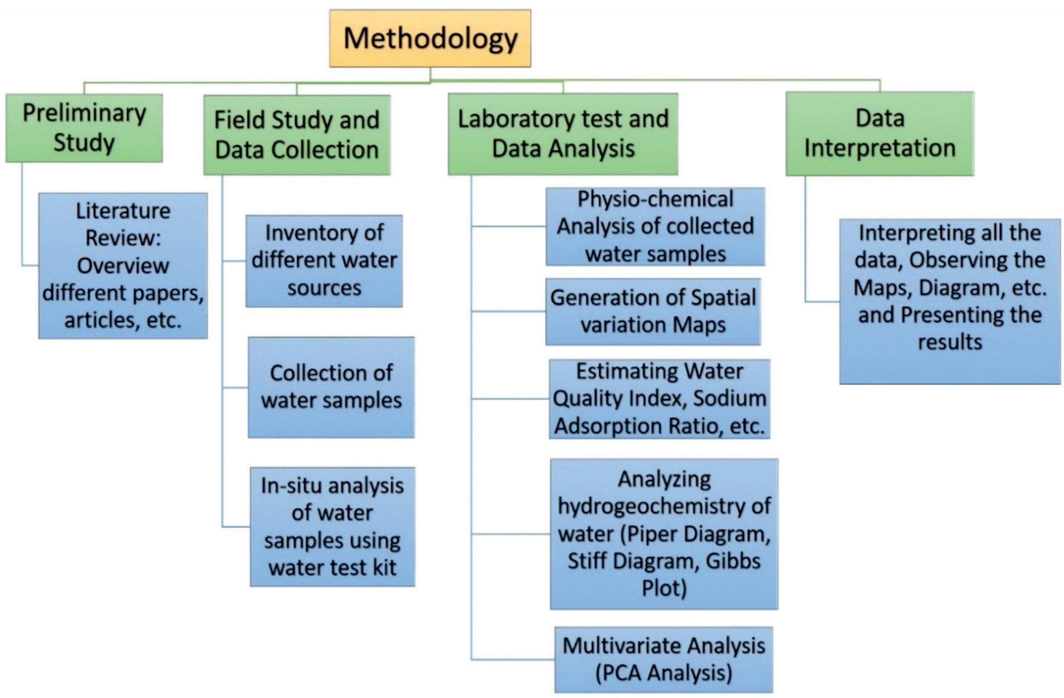

Fig. 2. Flowchart representing the overall process of the study

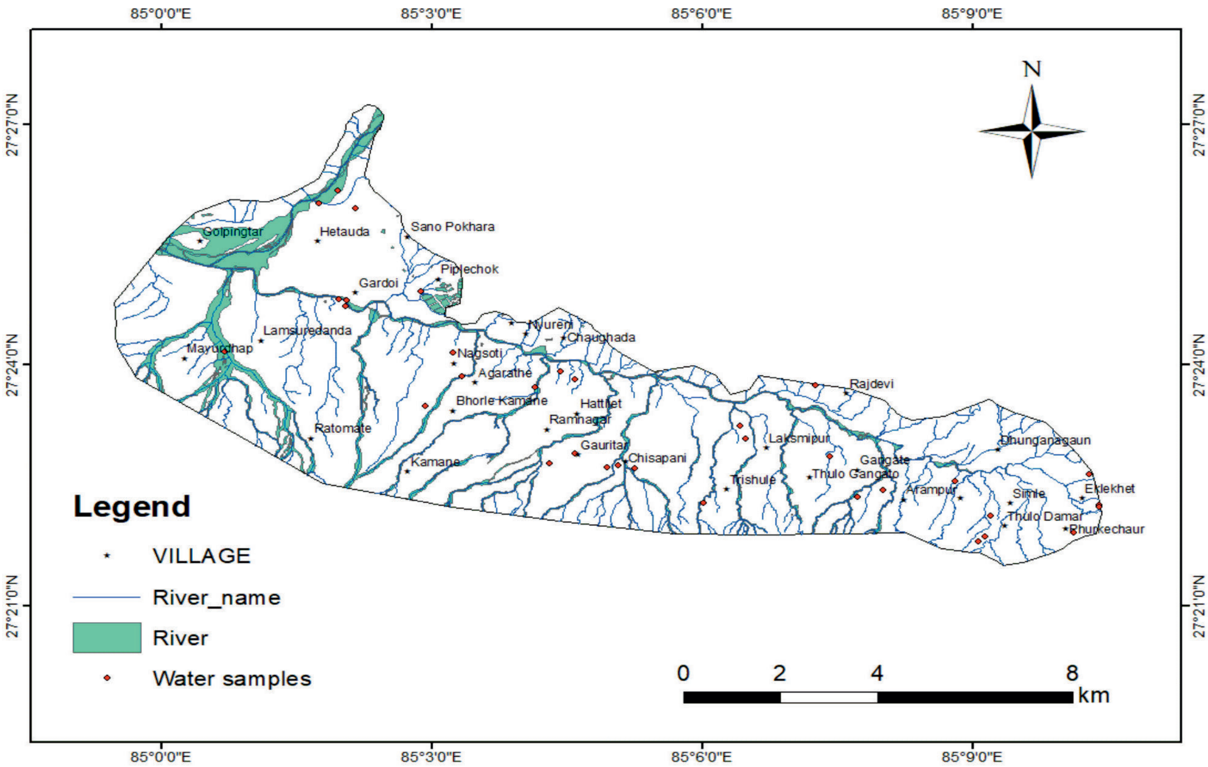

Fig. 3. Sample collected areas along with drainage systems

Analytical techniques

The maps depicting location, drainage, and so on, were prepared using the ArcGIS software. GIS serves as a potent tool in addressing groundwater resource challenges, evaluating quality, assessing availability, and managing resources at a national or international scale, particularly in the context of geographical variations (El Tahlawi *et al.*, 2016). The fundamental digitization tasks, such as delineating boundaries and designating sample collection areas, were carried out using the Google Earth application. The statistical analysis and the creation of geochemical plots were undertaken using Microsoft Excel, SPSS software, and Origin Pro software.

Results

The hydrogeochemical investigation comprises the measurement of the *in-situ* physiochemical parameters i.e. EC, pH, TDS, alongside the other chemical parameters with major cations and anions (Silwal *et al.*, 2022). During the research in the study area, the water samples from the 34 various sources like dug wells, deep boring, shallow borings, tube wells, and springs were collected and the physical and chemical parameter was analyzed. The selection of sampling locations was done based on specific criteria, including population density, areas with industrial or human-related activities, as well as proximity to river catchment areas.

Hydrogen ion concentration (pH)

pH serves as a gauge of water's acidity or alkalinity, primarily relying on the concentration of hydrogen ions (H^+). The guideline for pH level in drinking water is 6.5–7.1. In the study area, the value of pH ranges from 5.39 to 8.03 with an average temperature of 6.53 (Fig. 4). The pH value differs according to the different water resources.

Electrical Conductivity (EC)

Electrical Conductivity (EC), an indicator of a water sample's electrical current conduction ability is closely associated with the water's salinity level. According to the Nepal Drinking Water Quality Standard (NDWQS), the maximum limit for Electrical Conductivity is 1,500 µS/cm. So in the study area minimum value begins from 31.6 µS/cm to 770 µS/cm at maximum (Fig. 5). Hydrogeologically, low EC means presence of very low dissolved ions and salts and higher EC means presence of more saline water. If the concentration of the EC is higher than the permissible limit then the proper treatment of the water should be done.

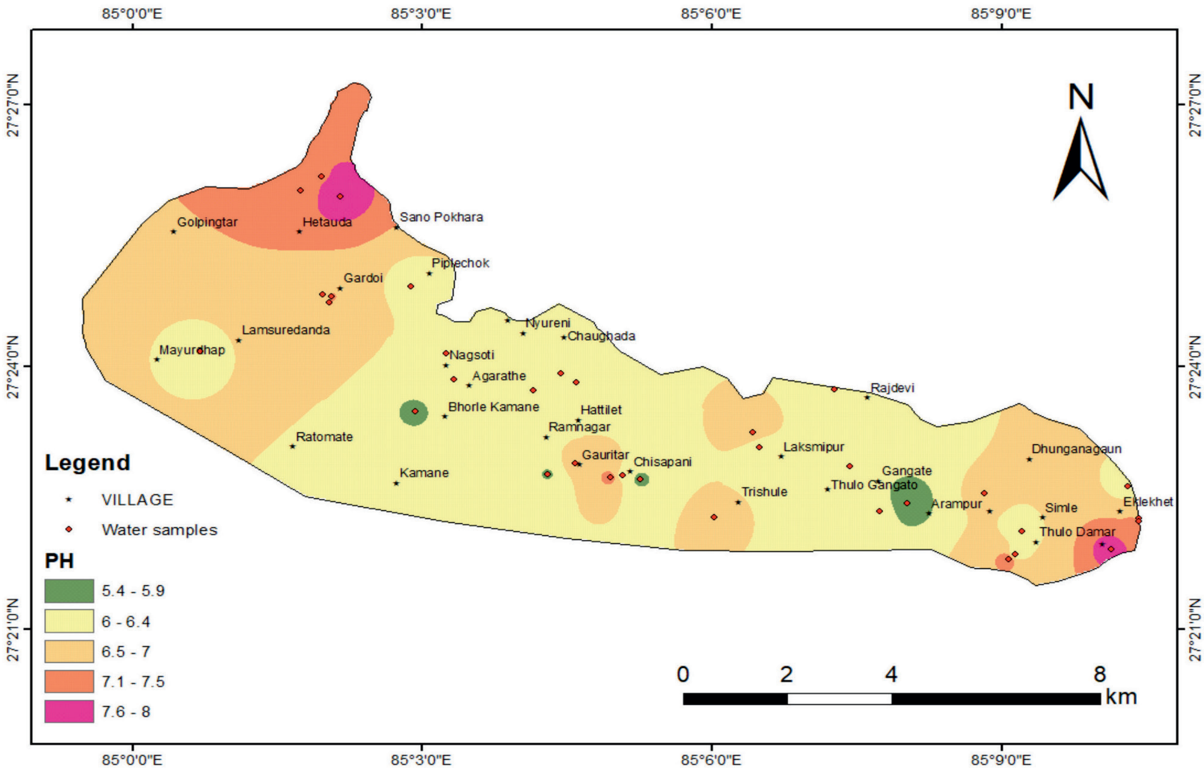

Fig. 4. Spatial distribution maps of pH of water samples

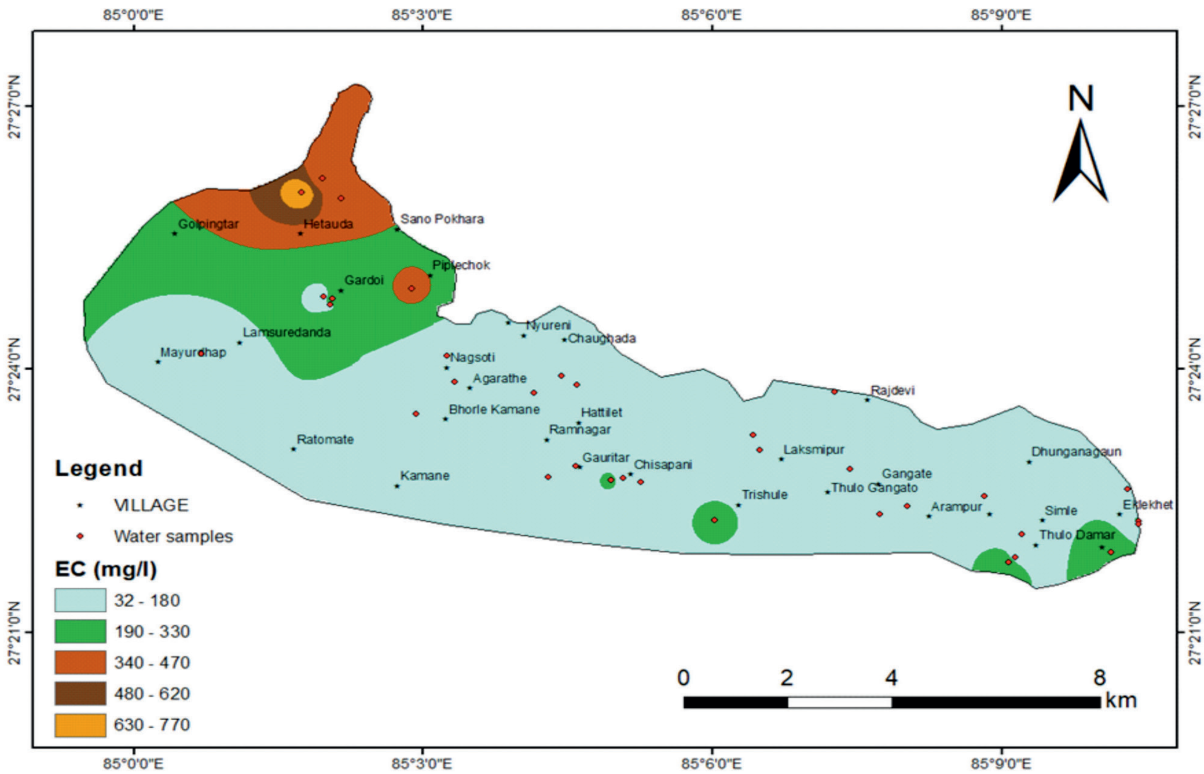

Fig. 5. Spatial distribution maps of Electrical Conductivity of water samples

Total Dissolved Solids (TDS)

The Total Dissolved Solids (TDS) content in groundwater varies between 20.54 mg/l and 500.50 mg/l, with an average concentration of 104.89 mg/l. Notably, the highest recorded TDS value of 500.50 mg/l is associated with tube well water (Fig. 6). Consuming higher amount of TDS containing water may increase the sodium intake later causing severe health conditions like hypertension and other health problems.

Total alkalinity

The standard value of the alkalinity according to NDWQS (2079) is 200 mg/l. Usually, the alkalinity of the water may vary according to the geological and environmental characteristics and are influenced by the presence of minerals and ions that can buffer against change in pH. In the study area, the minimum total alkalinity of the water sample is found to be 4 mg/l while the maximum value is found to be 284 mg/l which is above the permissible limit (Fig. 7).

Total hardness

Total hardness in water refers to the amount of dissolved minerals present. The recommended limit for total hardness is 500 mg/l. In the study area, the lowest total hardness recorded is 6 mg/l, while the highest is 310 mg/l, both falling within the permissible standard value (Fig. 8).

Calcium

The minimum concentration for calcium is 0.80 mg/l and the maximum temperature is 100.90 mg/l. The NDWQS (2079) standard for concentration of Calcium is 200 mg/l which shows that the overall concentration of calcium is under limit. Figure 9 shows the concentration of calcium in the study area.

Magnesium

The minimum concentration of the magnesium is 0.97 mg/l and the peak concentration is 16.03 mg/l. In terms of hydrogeology, if the concentration level of the water exceeds, taste of water changes and slowly it affects the health. The standard value given by NDWQS (2079) for the magnesium is 30 mg/l which shows that the sample are under the permissible limit. Figure 10 shows the concentration of magnesium in the study area.

Chloride

The chloride test demonstrates the precipitation of insoluble salts in water. The presence of too much chloride in the sample may result in an odd taste in the water that is considered unsafe. The average chloride concentration in the study region is 11.76 mg/l, with a minimum of 4 mg/l in Gauritar Rangashala and a maximum of 46 mg/l in the hospital road tubewell in Hetauda (Fig. 11). According to the NDWQS (2079) standard value of chloride is 250 mg/l, the water samples tested in the locations are below the allowable range.

Total iron

Total iron is found in the water primarily due to the leaching of iron-rich rocks. Another source can be the corrosion of steel or iron pipes in plumbing systems. In the study area, total iron was detected at a limited number of sites, notably in the deep borehole at Bhorle, where it reached a maximum concentration of 3.2 mg/l. Additionally, iron was identified in the Piple region, with a concentration of 1 mg/l, and a concentration of 0.8 mg/l was observed in the flowing water of the Karra River (Fig. 12). Generally, the maximum limit for total iron as per NDWQS (2079) is 0.3 mg/l which means the sample whose concentration is higher should not be consumed and treatment should be proceed.

Sodium

A maximum concentration of 20 mg/l sodium (Fig. 13) is present in the research area, which is less than the NDWQS (2079) permitted limit. If the water sample has too much sodium, the taste will turn salty and may cause a number of chronic ailments.

Potassium

The minimum value of potassium is 0.25 mg/l while the maximum value is 10 mg/l with an average value of 1.77 mg/l (Fig. 14). According to the NDWQS (2079) guidelines, the standard value ranges up to 15 mg/l which means the observed water samples were under the permitted limits.

Nitrate

The contamination of nitrates in surface water or groundwater may be caused due to the leaching of chemical fertilizers, pesticides, and other chemicals from the soil. The presence of high amounts of nitrates in water may cause problems in the respiratory organs, reproductive organs, kidneys, etc. In the study area, the bottom concentration of nitrates is 0.1 mg/l while the peak concentration is 4.8 mg/l (Fig. 15). The NDWQS (2079) standard for nitrate is 50 mg/l which means the water samples are feasible for consumption.

Sulphate

The minimum concentration of sulphate in the study area is 0.7 mg/l while the maximum concentration is 23.7 mg/l (Fig. 16). The standard value for Sulphate is 250 mg/l which means the presence of sulphate was also under the permissible limits.

The overall summary of the analytical results of physicochemical parameters of water samples collected from different sampling sites are shown in Table 1. In general, the concentration of water samples across various areas displays variability influenced by factors such as lithology, human intervention, and other anthropogenic activities. The concentration of pollutants in shallow wells, deep wells, and surface wells varies accordingly. While certain water samples fall within acceptable limits, others exceed these thresholds.

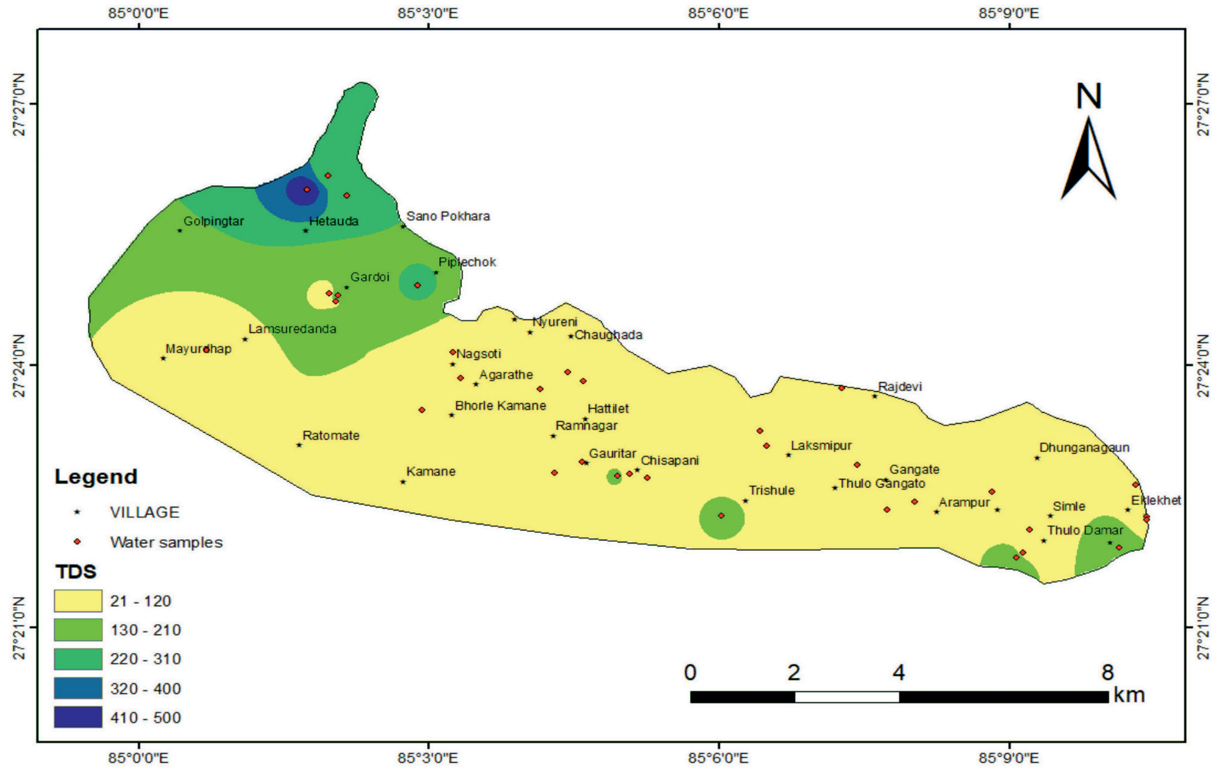

Fig. 6. Spatial distribution map of the TDS of water samples

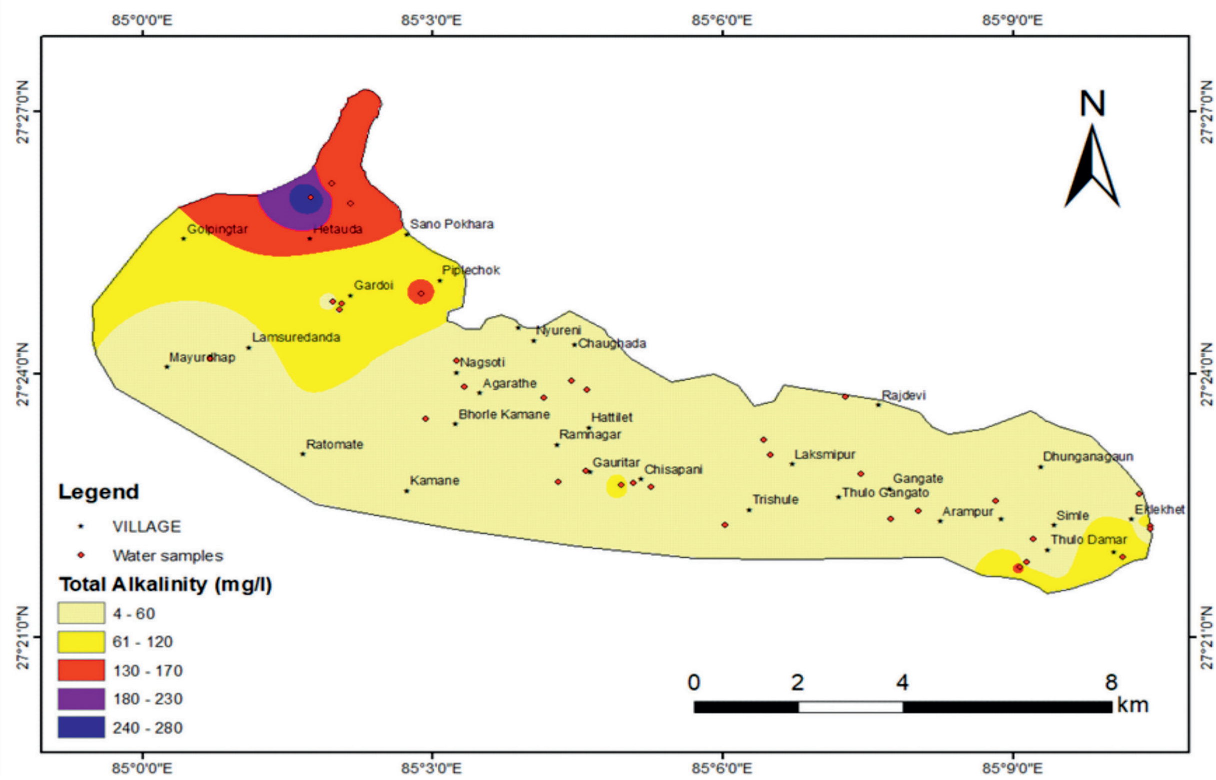

Fig. 7. Spatial distribution map of the Total Alkalinity of water samples

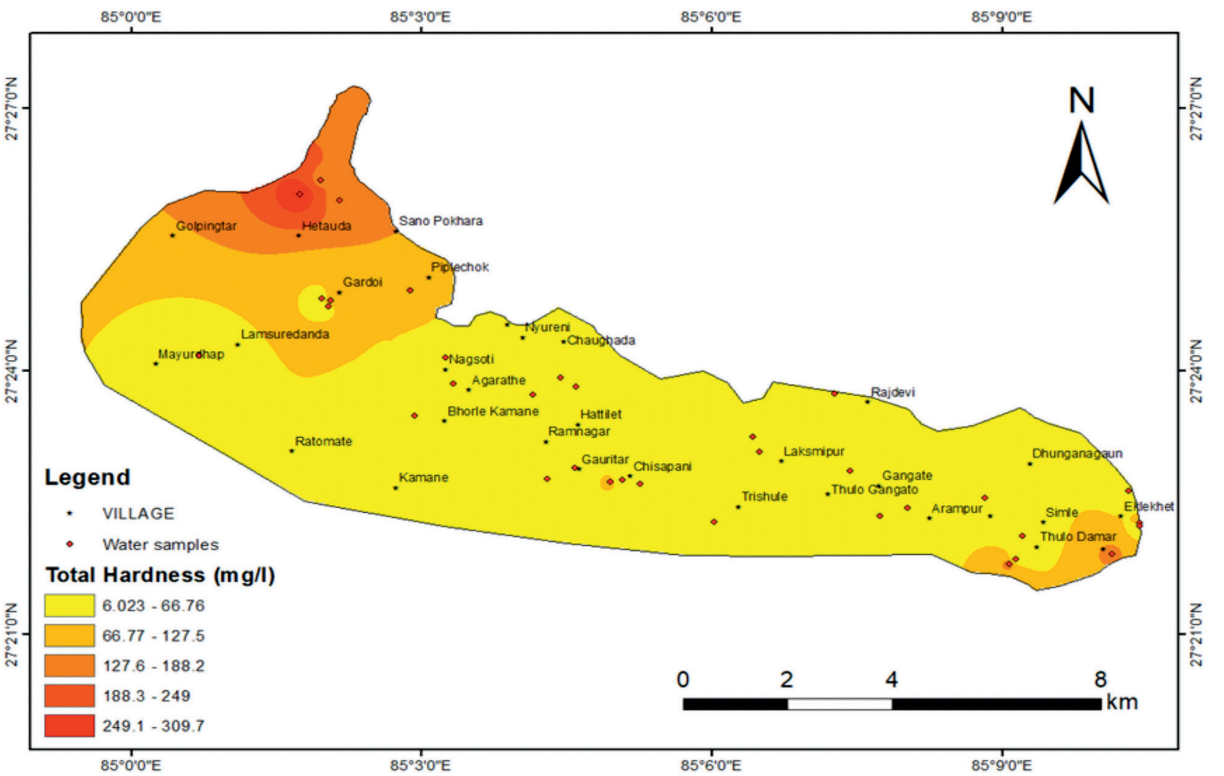

Fig. 8. Spatial distribution map of total hardness of water samples

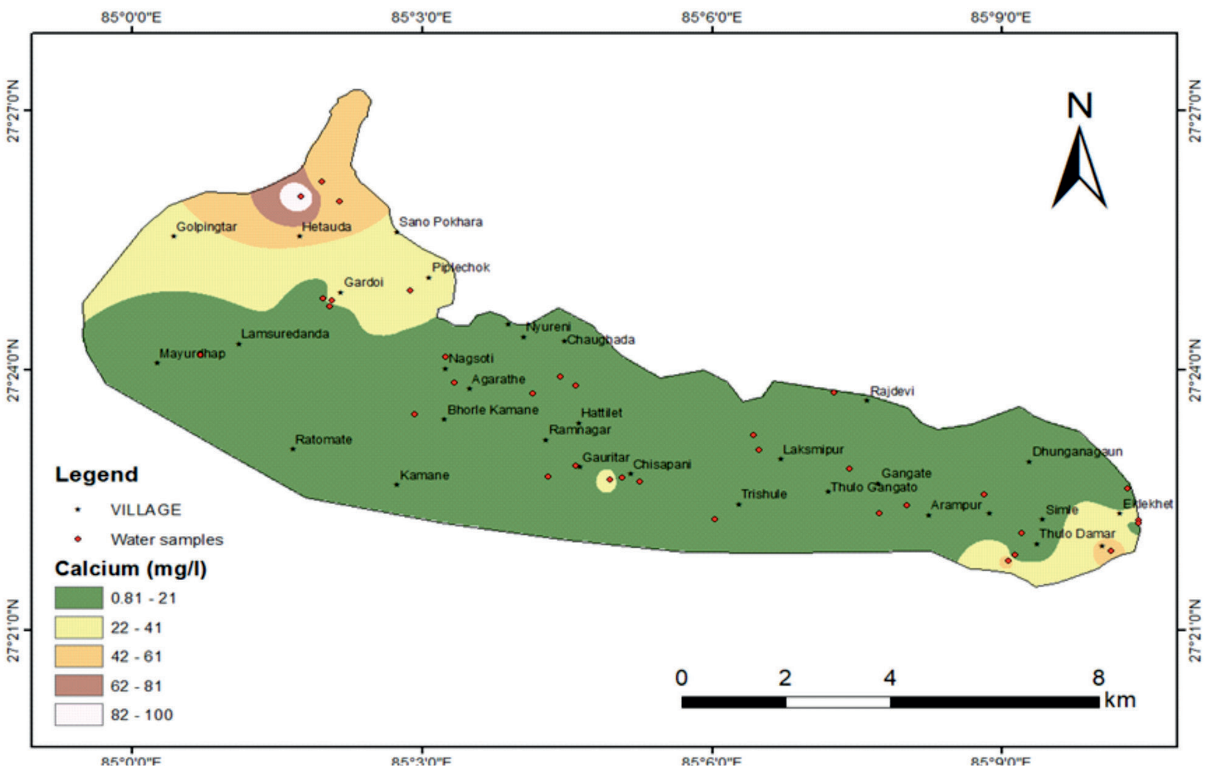

Fig. 9. Spatial distribution map of calcium of water samples

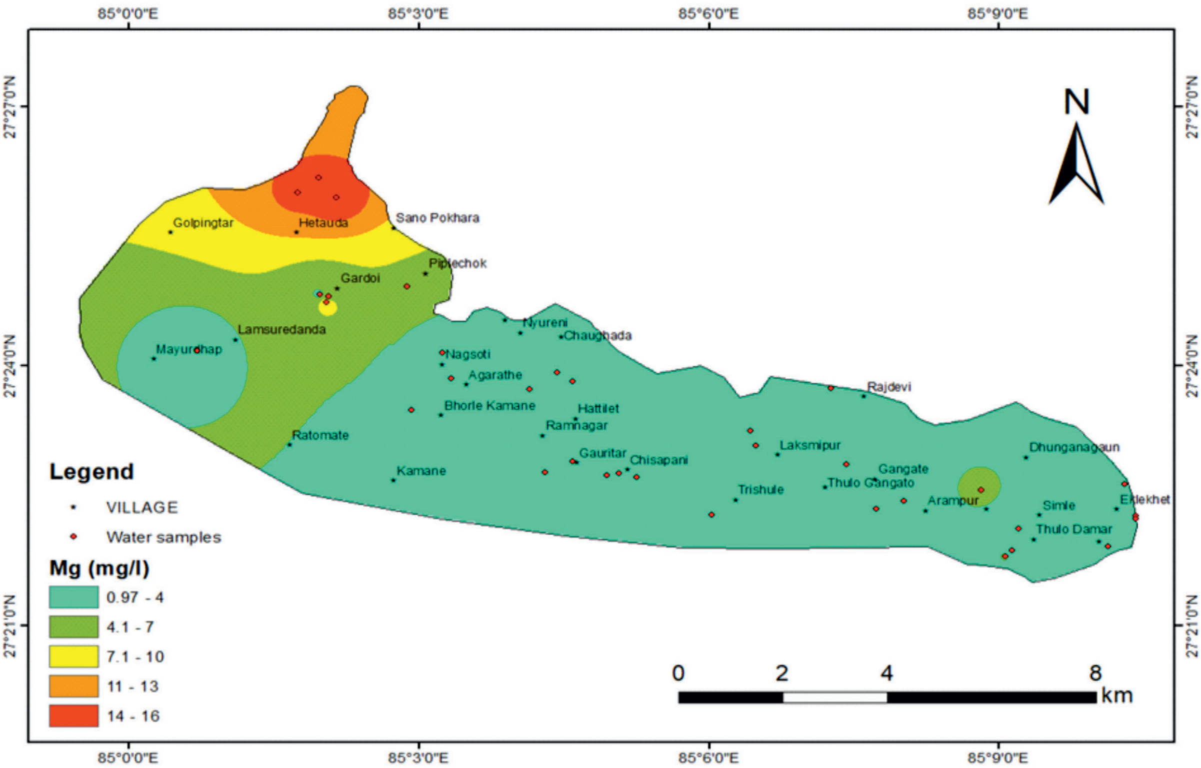

Fig. 10. Spatial distribution map of the magnesium of water samples

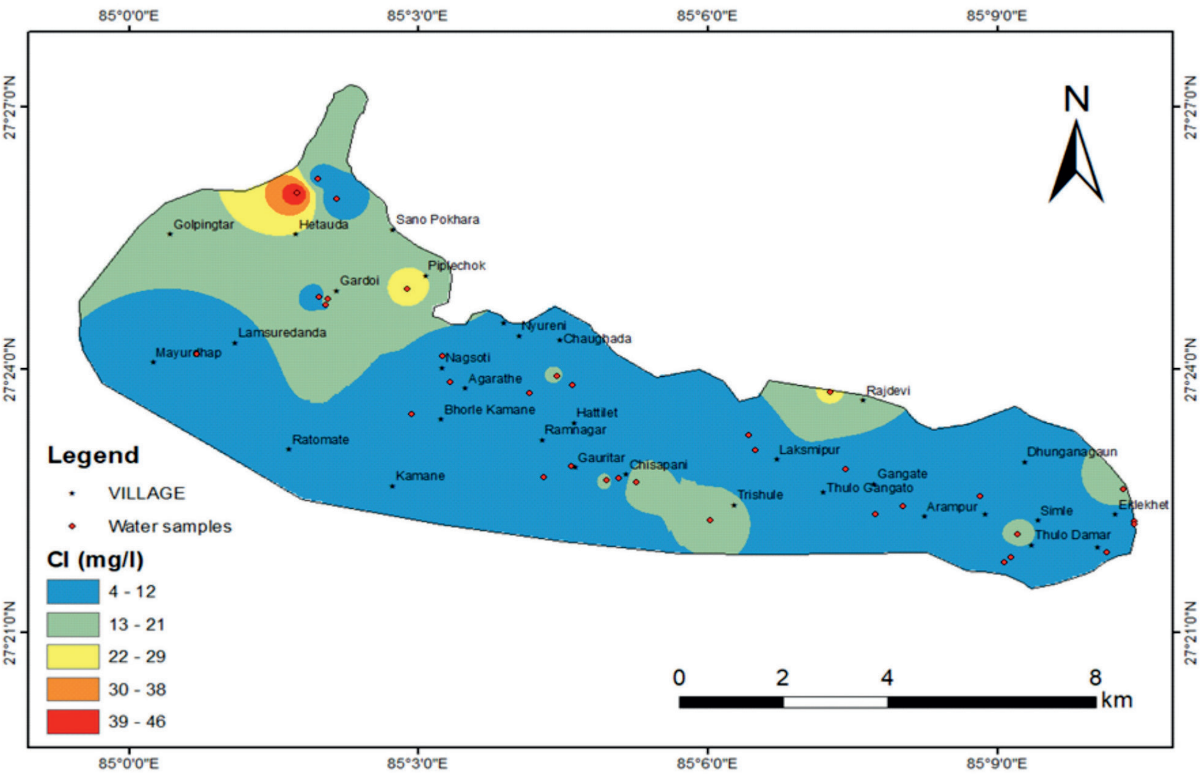

Fig. 11. Spatial distribution map of the chloride of water samples

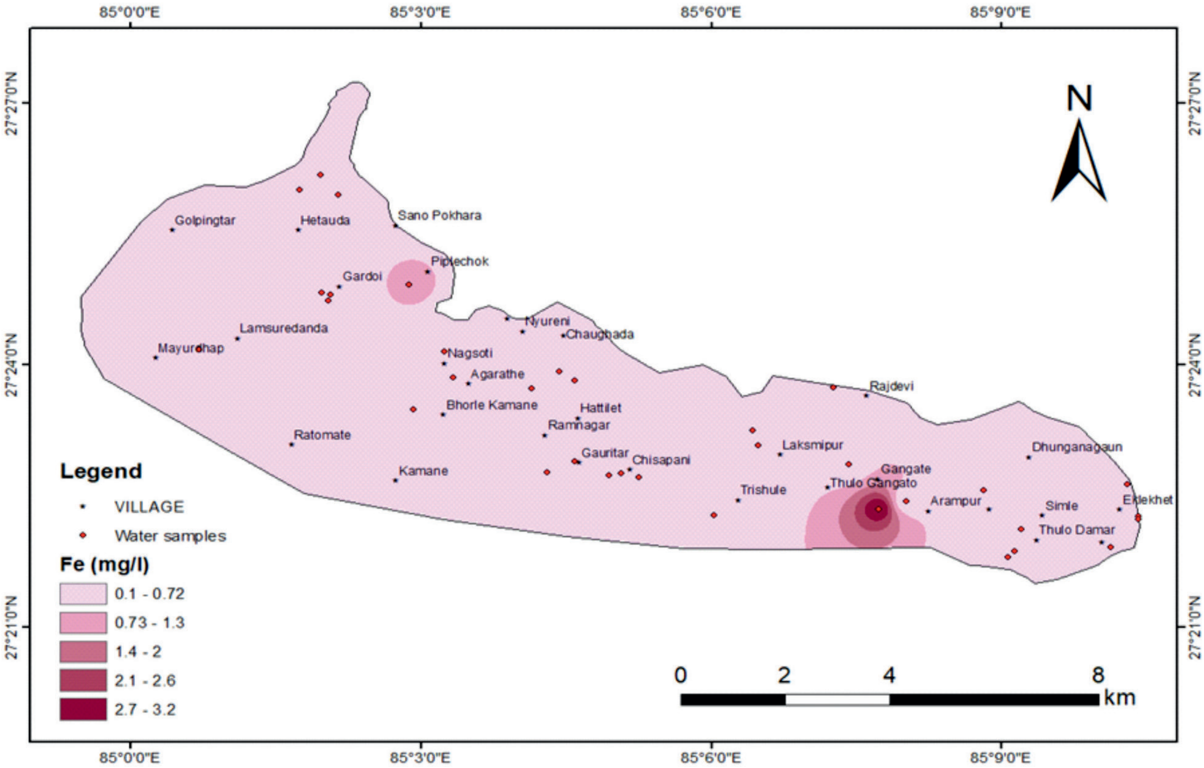

Fig. 12. Spatial distribution map of the total iron of water samples

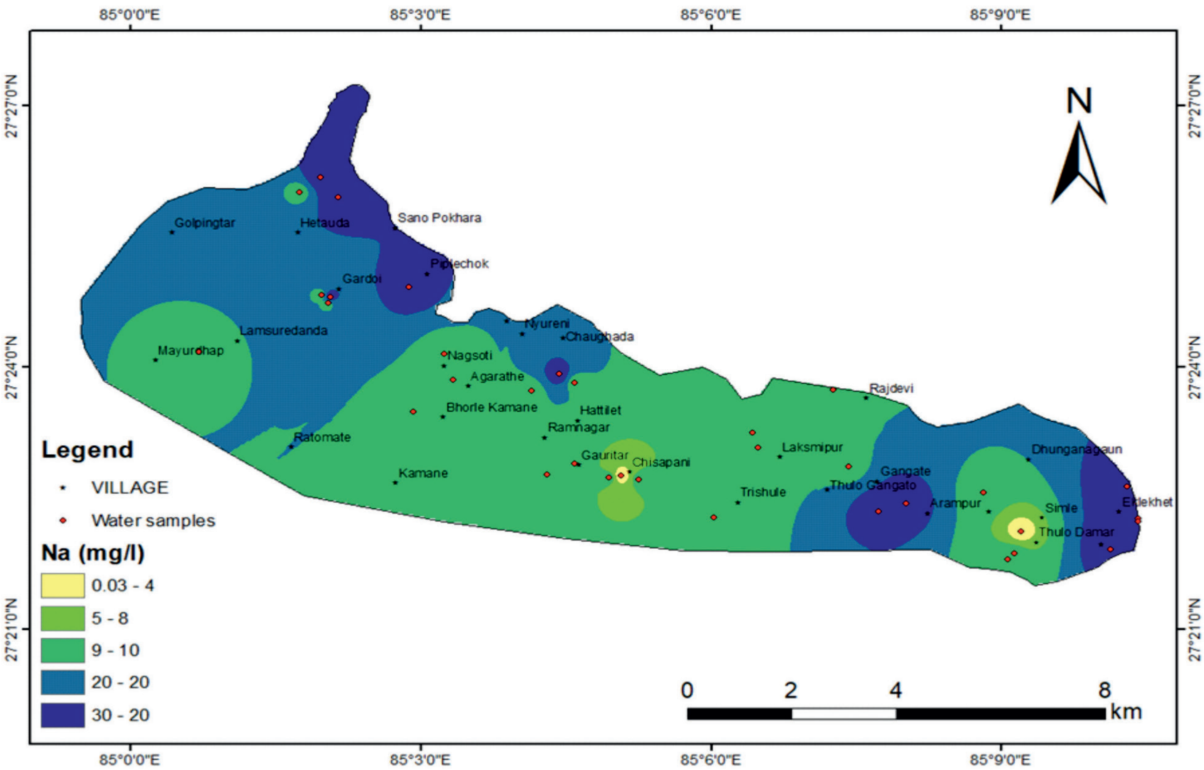

Fig. 13. Spatial distribution map of sodium of the water samples

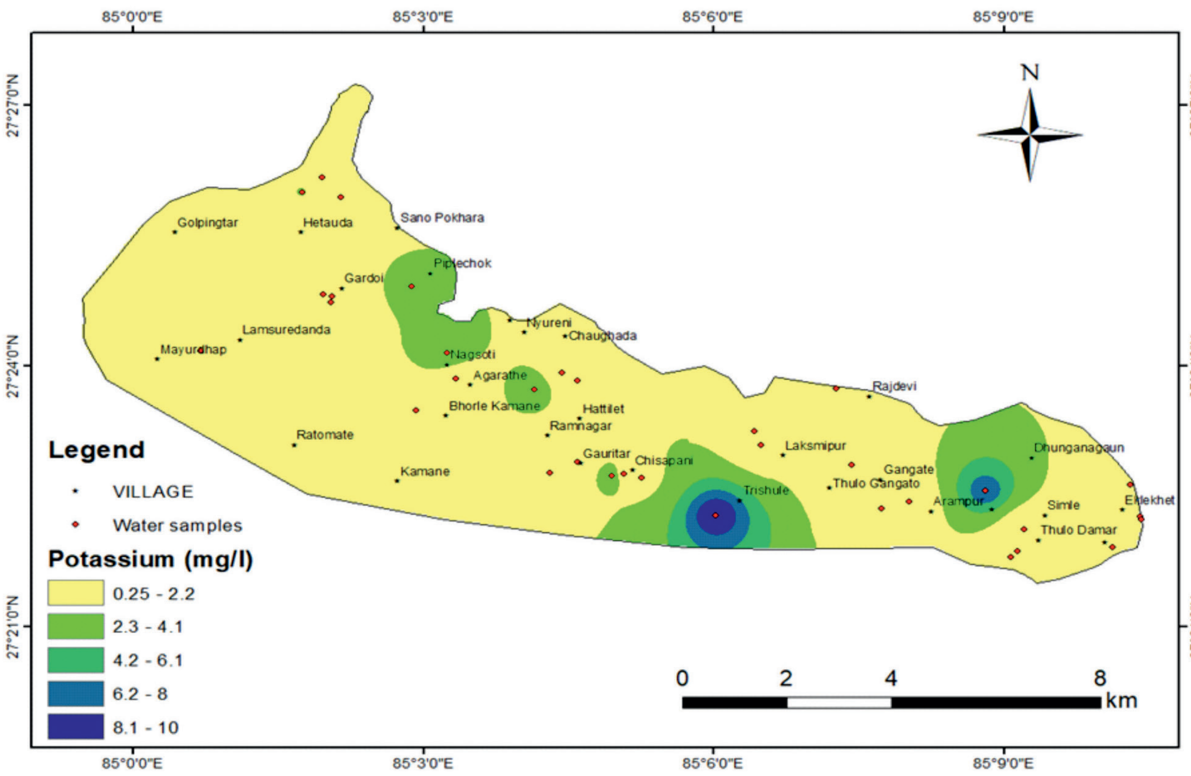

Fig. 14. Spatial distribution of potassium of water samples

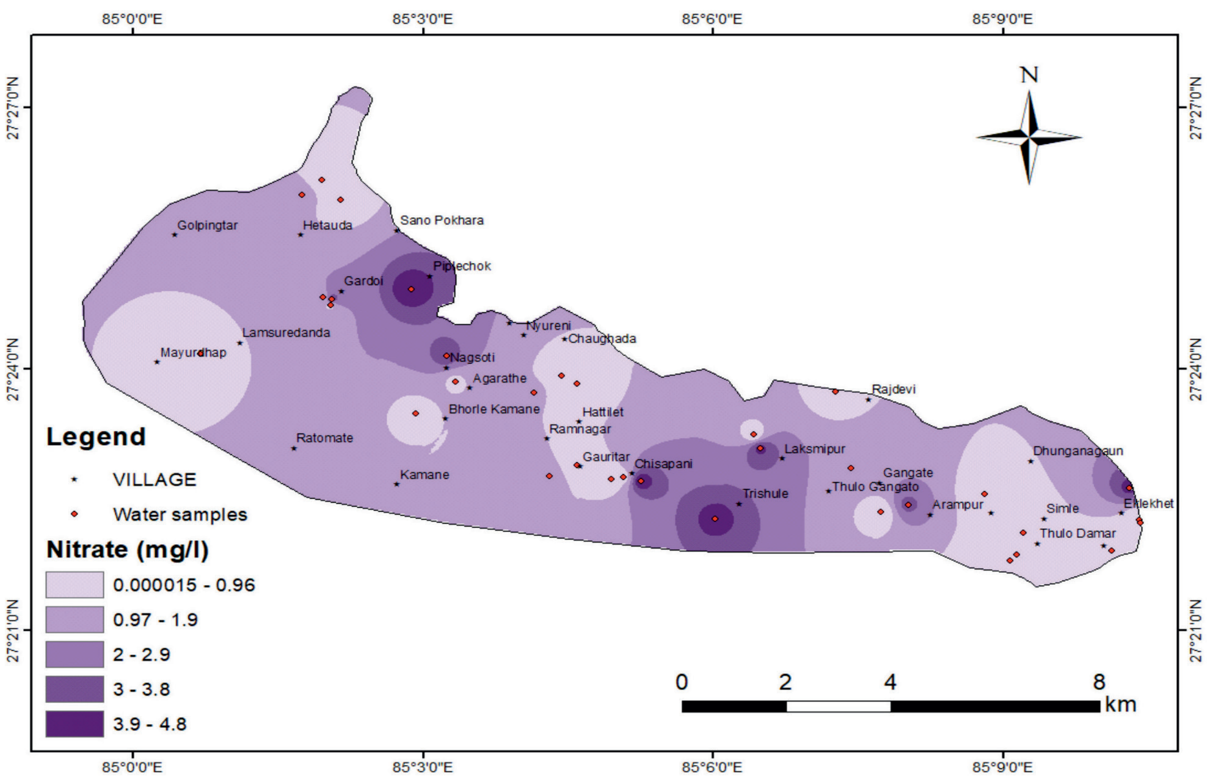

Fig. 15. Spatial distribution map of nitrate of water samples

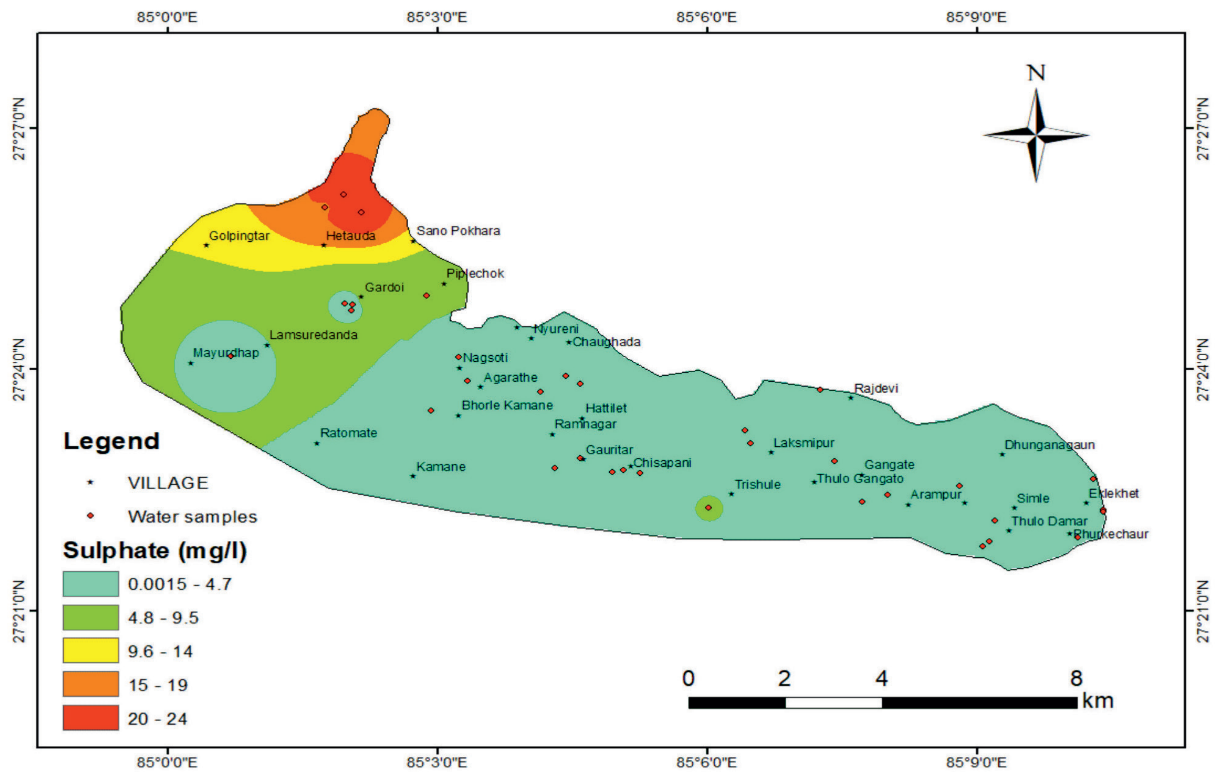

Fig. 16. Spatial distribution map of sulphate of water samples

Table 1. Summary of some physico-chemical parameters of groundwater and surface water samples from the study site

Value/ parameter	EC	TDS	pH	TA	TH	Ca^{2+}	Mg^{2+}	Cl^{-}	Fe^{++}	Na^{+}	K^{+}	NO_3^{-}	SO_4^{-}
Min.	31.60	20.54	5.39	4.00	6.00	0.80	0.97	4.00	0.10	0.00	0.25	0.00	0.00
Max.	770.00	500.50	8.03	284.00	310.00	100.90	16.03	46.00	3.20	20.00	10.00	4.80	23.70
Avg.	161.36	104.89	6.53	52.50	60.60	17.90	3.86	11.76	0.25	12.60	1.70	1.34	4.34

Water Quality Index

The Water Quality Index (WQI) is a parameter that assures the safety of water bodies to the users such as water for irrigation and domestic purposes, for the aquatic purposes. The WQI map has been prepared using ArcGIS 10.8 software. This mapping process involves the selective consideration of specific water quality parameters. Its main aim is to delineate distinct quality classes of the water samples, such as excellent, good, poor, very poor, and unsuitable (Tab. 2) by providing a complete representation of the water quality across the area.

Table 2. Ratings of water quality as per Weighted Arithmetic Water Quality Index method (Tyagi *et al*., 2013)

WQI value	Water Quality Rating	Grading
0–25	excellent water quality	A
26–50	good water quality	B
51–75	poor water quality	C
76–90	very poor water quality	D
91–100	unsuitable for drinking purpose	E

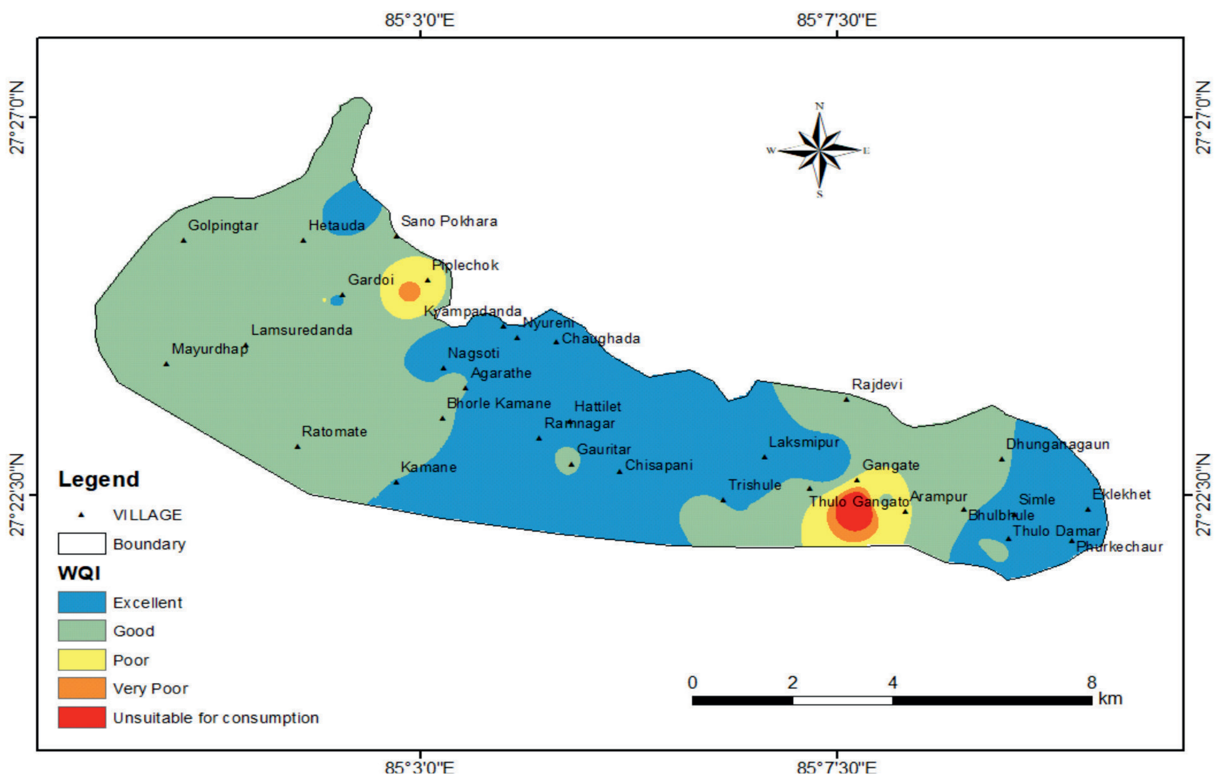

Fig. 17. Water Quality Index map of the water samples

The result obtained from the analysis shows that dominant water samples falls under excellent category while few areas have samples whose condition is not suitable for the drinking purposes (DW12, DTW4, DTW8) which is shown in the Figure 17. Despite falling into the excellent category, it is advisable to treat the water before consumption for safety and better quality.

Sodium Adsorption Ratio (SAR)

The quality of the water sample was also evaluated in order to determine its appropriateness for irrigation. To determine the quality status, the sodium adsorption ratio was calculated using Equation (1):

$$SAR = \frac{Na^{+}}{\left(\sqrt{Ca^{2+} + Mg^{2+}}\right)/2} \tag{1}$$

SAR is renowned as an indication of water suitability for agricultural irrigation since it determines the concentration of sodium in relation to calcium and magnesium. The accepted value for SAR in Nepal is below 10 for irrigation. So from the analysis it is concluded that the sample collected are excellent for the agricultural purposes (Fig. 18).

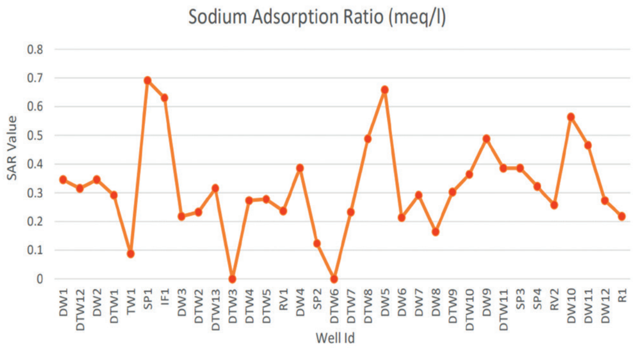

Fig. 18. Graphical representation of sodium adsorption ratio

Hydrochemical analysis

Piper diagram

The visual representation of the major ions presents in the water samples which includes three triangular plots representing the concentration of cations and anions is shown in the Piper diagram. There is dominancy of Ca^{++} in the water samples followed by the $Na^+ + K^+$. In the anions, there is dominancy of Cl^- followed by the HCO_3^-. The investigation shows the content of alkaline earths metals (Ca^{++} and Mg^{++}) are greater than the alkali metals (Na^+) while strong acids (Cl^-) are higher than the weak acids (HCO_3^-). The intersection of the ions in the diagram reveals that most of them falls under magnesium-bicarbonate class followed by sodium-bicarbonate class and few under mixed type (Fig. 19).

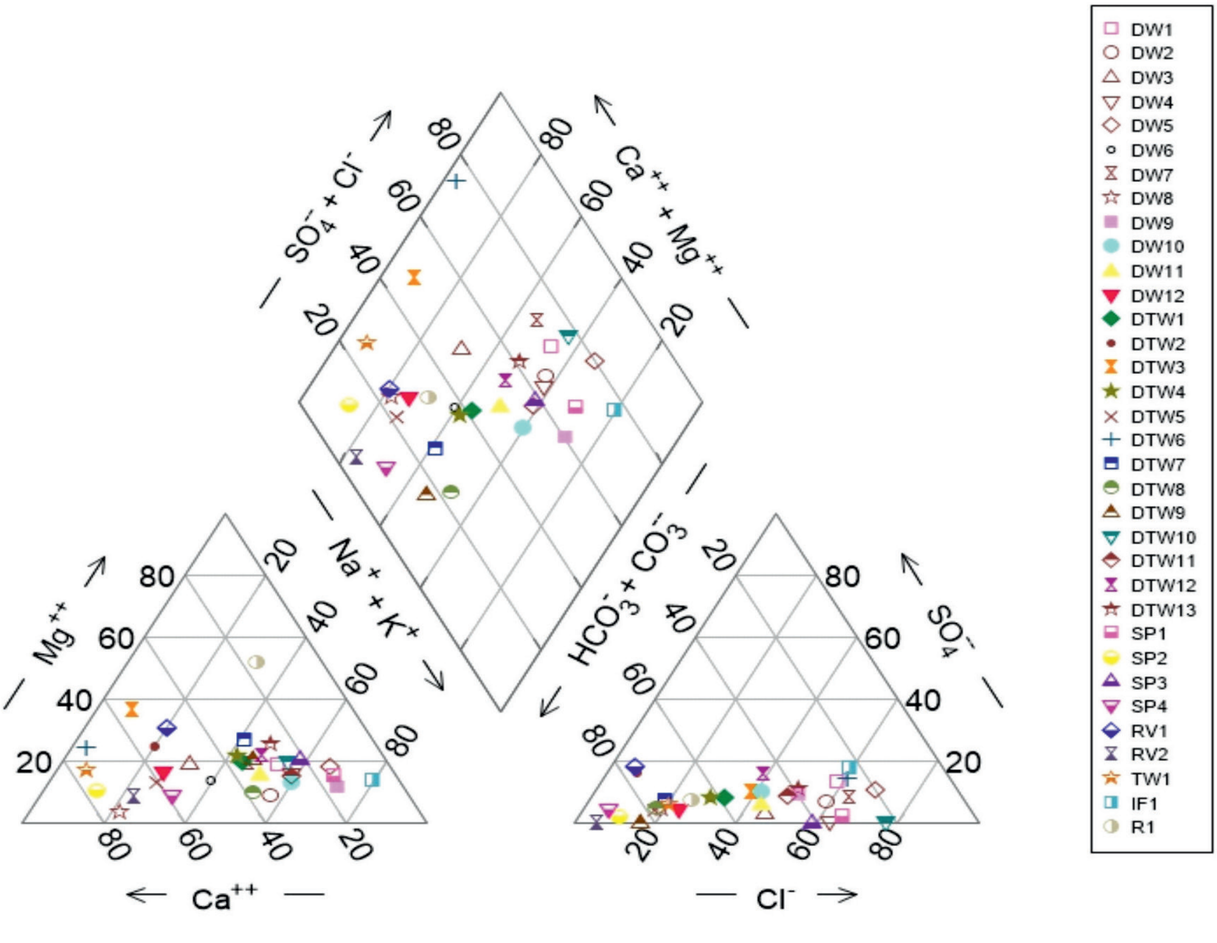

Fig. 19. Plotting of dominant ions in the Piper diagram

Stiff diagram

Stiff diagrams typically display the concentrations of major ions, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-), and chloride (Cl^-), on a polygonal graph providing a standardized way to visualize and compare the chemical composition of water samples, making proper insights about the water's source, geochemical processes, and its suitability for various purposes (Lorenz, 2016). Here, the stiff diagram illustrates that the composition of cation is dominated by the ions Na + K > Ca > Mg while in the anions there is dominant $HCO_3^- > Cl^- > SO_4^{2-}$ (Fig. 20). The diagrams similar to each other have the same kind of hydrogeological and hydrochemical properties and also the similar origin. The concentration among the minerals are very much alike giving same structure.

Gibbs plot

Gibbs diagrams usually examine the natural factors that influence the mechanisms of groundwater formation (Li P. *et al.*, 2016). From the obtained results (Fig. 21), it can be said that the groundwater chemistry of the water sample is strongly influenced by other factors rather than geology as major samples from outside the rock dominance areas. It may be caused due to the anthropogenic activities or industrial discharges that have been released to water without proper analysis or any other different factors. It may exhibit the complex geochemical characteristics that may not fit into the rock dominance areas. Few sample that falls under rock dominance area indicates that the chemical composition of water is predominantly influenced by the geological processes and hydrogeochemical processes.

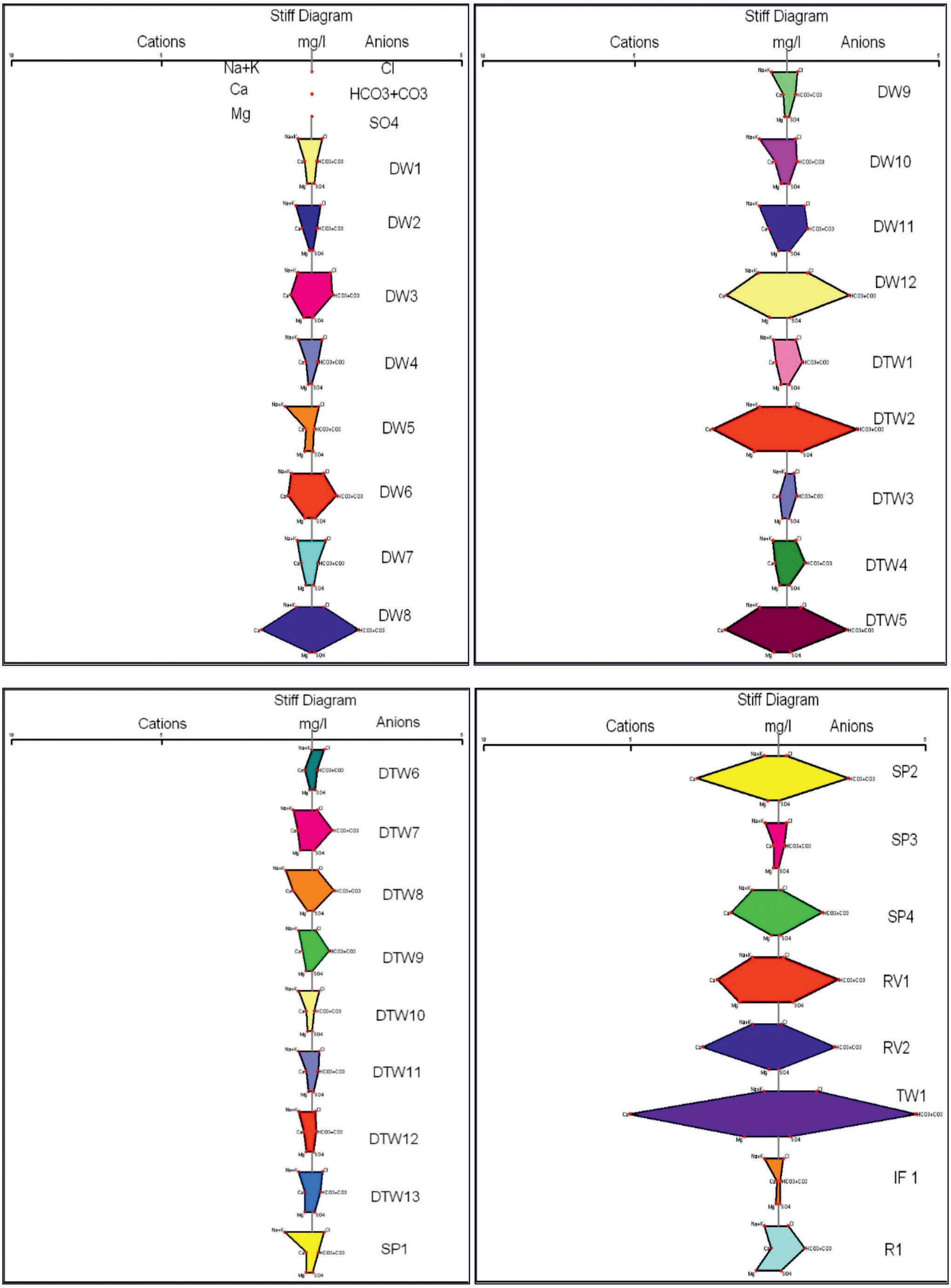

Fig. 20. Stiff plots of the water sample of the study area

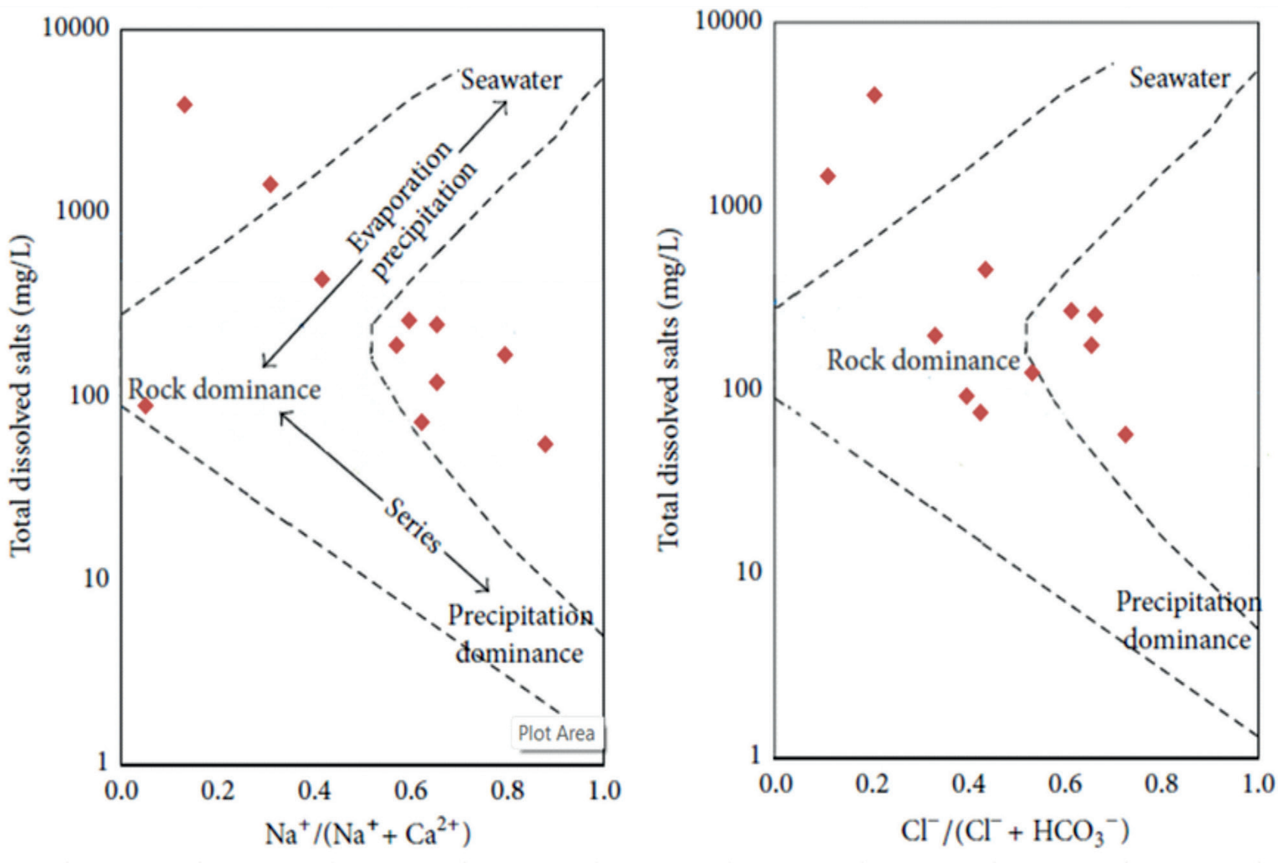

Fig. 21. Gibbs plot of water samples of the study area

Table 3. Statistical correlation of physiochemical parameters

	EC	TDS	pH	Temp.	Tur-bid.	TA	TH	Ca^{++}	Mg^{++}	Cl^-	Fe	NH_3	Na^+	K^+	NO_3	SO_4^-
EC	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
TDS	1.00	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–
pH	0.62	0.62	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–
Temp.	0.06	0.06	0.15	1.00	–	–	–	–	–	–	–	–	–	–	–	–
Turbid.	0.00	0.00	0.03	−0.09	1.00	–	–	–	–	–	–	–	–	–	–	–
TA	0.98	0.98	0.69	0.06	0.04	1.00	–	–	–	–	–	–	–	–	–	–
TH	0.98	0.98	0.70	0.08	0.00	0.99	1.00	–	–	–	–	–	–	–	–	–
Ca^{++}	0.97	0.97	0.68	0.07	0.00	0.98	0.99	1.00	–	–	–	–	–	–	–	–
Mg^{++}	0.78	0.78	0.60	0.10	0.01	0.75	0.80	0.69	1.00	–	–	–	–	–	–	–
Cl^-	0.64	0.64	−0.01	0.03	−0.06	0.56	0.52	0.53	0.36	1.00	–	–	–	–	–	–
Fe	0.11	0.11	−0.01	−0.13	0.97	0.14	0.09	0.09	0.08	0.07	1.00	–	–	–	–	–
NH_3	−0.15	−0.15	−0.17	0.00	0.26	−0.15	−0.18	−0.15	−0.24	−0.01	0.28	1.00	–	–	–	–
Na^+	0.30	0.30	0.29	0.36	0.23	0.29	0.33	0.30	0.33	−0.05	0.25	−0.04	1.00	–	–	–
K^+	0.12	0.12	0.00	−0.13	−0.11	0.05	0.02	0.03	−0.02	0.15	−0.08	0.10	−0.15	1.00	–	–
NO_3	0.10	0.10	−0.43	0.08	−0.14	−0.04	−0.03	−0.02	−0.06	0.39	−0.05	0.26	0.13	0.34	1.00	–
SO_4^-	0.69	0.69	0.55	0.08	−0.04	0.66	0.72	0.62	0.89	0.31	0.02	−0.15	0.24	0.01	−0.07	1.00

Statistical analysis of water samples

The pairs of concerned ions showing positive inter-relationships suggest that they originated from a common source whereas negative inter-relationships suggest different origin. In Table 3, the correlation matrix between EC shows a negative relation with the ammonia (−0.15). The EC and the TDS show a linear correlation between each other (1) which is very perfect. Similarly, the pH shows a positive correlation with the alkalinity. The calcium shows a negative correlation with the ammonia and nitrate (−0.024). The total hardness also shows a negative correlation with nitrate and ammonia.

Multivariate analysis

Principal Component Analysis (PCA)

Principal Component Analysis (PCA), a multivariate statistical method, effectively reduces the dimensionality of the initial dataset, extracting information regarding the correlation among variables in water samples while minimizing the loss of the actual data (Sun *et al.*, 2019; Chakraborty *et al.*, 2022). It was performed to identify the influencing variables that govern groundwater quality. In the Principal Component Analysis, three factors were extracted which is shown in Table 4. The factor loading has been divided into three categories: strong (>0.75), moderate (0.75–0.5), and weak (0.5–0.3) (Liu *et al.*, 2003). So from the result obtained it can be assured that TH, EC, Ca^{2+}, Mg^{2+}, and SO^{4-} have strong positive loading and the remaining factors such as K, turbidity, Na, and Fe have weak loadings. The strength between the original variables and the principal component is indicated by factor loading. Positive factor loading indicates a positive correlation between the parameter and component and *vice versa*.

Table 4. Factor loading data of Principal Component Analysis

	Component		
	factor 1	**factor 2**	**factor 3**
TH	0.99	−0.02	0.02
EC	0.97	−0.04	0.18
TA	0.97	0.01	0.06
Ca^{2+}	0.95	−0.02	0.05
Mg^{2+}	0.87	−0.02	−0.11
SO_4^{2-}	0.79	−0.07	−0.10
PH	0.72	0.02	−0.46
Na	0.37	0.36	−0.08
Turbidity	0.03	0.96	0.04
Fe	0.12	0.95	0.15
NO_3^-	−0.04	−0.14	0.85
Cl^-	0.53	−0.14	0.62
K	0.04	−0.23	0.52
NH_3	−0.20	0.39	0.45

Extraction method: Principal Component Analysis

Scree plot

A scree plot in PCA analysis depicts the proportion of total variation represented by individual components in the data (Thomas, 2023). In the scree plot, the point where the change takes place is the “point of inflection” or the “elbow point”. The four extracted values consist of an eigenvalue greater than 1 which means they retain more variability of the original dataset while the remaining ten factors have an eigenvalue less than 1 means they have less impact in retaining the original datasets (Fig. 22).

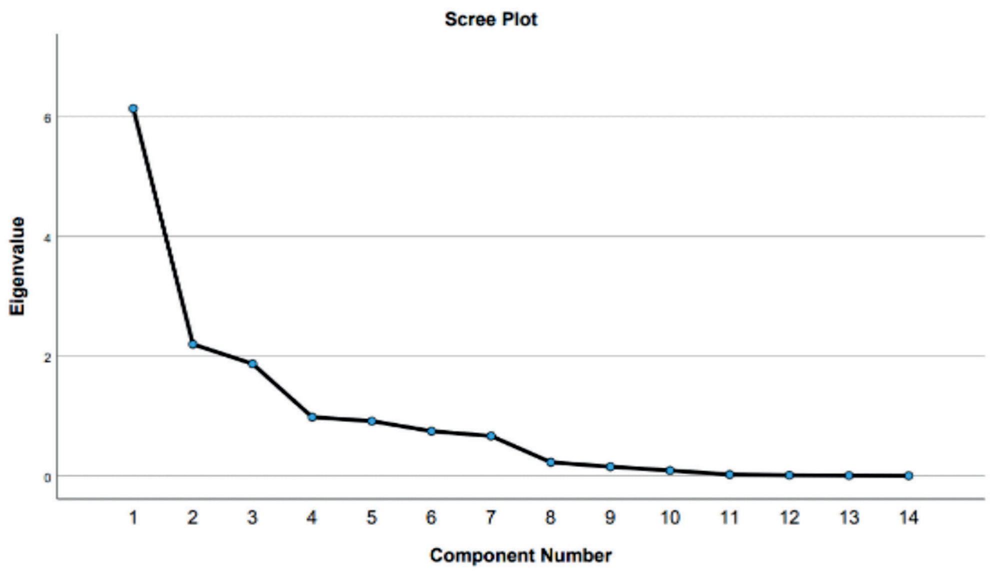

Fig. 22. Scree plot of the Principal Component Analysis

Potentiality of water resources for geotourism

Geotourism is seen as a viable approach to promote economic activities as well as the sustainable development as it benefits local communities by preserving natural resources, culture, heritage, and traditions, celebrating the essence of a place while supporting conservation principles (Yuliawati *et al.*, 2016). Hetauda stands out as a promising geotourism and water tourism destination that offers a unique blend of geological landscapes and abundant water resources. The valley has diverse geological features, including hills, valleys, and distinctive rock formations which provide an intriguing landscape for geotourists (Gilbert & Landsem, 2023). Simultaneously, its water resources, comprising rivers, wells and natural springs, add another layer of appeal for water tourism enthusiasts. Also, the intersection of geological formations and water sources creates a dynamic environment that furnish to both geological exploration and water-based recreational activities. Figure 23 is the natural spring in the study area which serves as a great touristic destination in term of geological, ecological and hydrological significance. The groundwater discharge can be observed that have been arise from different geological formation providing insight to the sub-surface geology. In terms of ecology, different water plant and animal survive in those water bodies which attract geotourists to learn more about those flora and fauna. Besides, the agricultural land can also be one of the best for the scenic view.

Fig. 23. Natural spring behind Aangareswor Mahadev temple

Discussion

The physio-chemical examination of water was carried out via *in-situ* and the laboratory method, with 34 samples obtained from various water resources and physio-chemical parameters were analyzed, including EC, pH, temperature, total hardness, total alkalinity, chloride, calcium, magnesium, sulphate, nitrate, etc.

In the study, the variations in water quality parameters was observed. The pH of groundwater ranged from 6.39 to 8.03, while surface water pH fell between 6.1 and 7.5. The pH values above 7.5 indicated slower groundwater recharge in certain areas (Mahamat *et al.*, 2017). These findings highlight the diversity of water quality characteristics in the study area. Water temperature also varied, with temperatures ranging from 21.9°C to 30.8°C. Electrical Conductivity values in the study area ranged from 31.6 µS/cm to 770 µS/cm which means they are under the permissible limit provided by NDWQS and the salinity level of the water was maintained. Total Dissolved Solids in the field exhibited a range of 20.54 mg/l to 500.50 mg/l making it appropriate to use for the domestic and agricultural purposes.

Furthermore, water hardness displayed fluctuations, with the minimum observed hardness concentration at 6 mg/l and the maximum at 310 mg/l. According to Durfor & Becker (1964), water with hardness up to 75 mg/l is considered soft, 76 mg/l to 150 mg/l is moderately soft, and 151 mg/l to 300 mg/l is considered hard. Some samples in our study area exceeded 300 mg/l, indicating hard water, while others were below this threshold, suggesting softer or moderately soft water. Excessive hardness may not pose severe health risks but can affect taste and usability. In terms of nitrate levels, they remained within an acceptable range, with the highest observed value being 4.8 mg/l, well below the 50 mg/l threshold. Sulphate values in the field ranged up to a maximum of 23.7 mg/l. This data provides valuable insights into the diverse water quality characteristics in our study region, encompassing pH, temperature, EC, TDS, hardness, nitrate, and sulphate levels. Those samples whose value have been greater than the limit should undergo the effective treatment before suppling or using for the personal uses.

The Principal Component Analysis conducted in this study aimed to identify key factors influencing groundwater quality revealing the three main factors and their associations with different water parameters. Such as parameters like total hardness, Electrical Conductivity, calcium, magnesium, and sulfate showed a strong positive relationship with these factors, while others like potassium, turbidity, sodium, and iron displayed weaker connections. For example, high factor loadings for total hardness indicate a strong correlation with the identified factors. On the other hand, weaker loadings for parameters like potassium and turbidity suggest less influence on these principal components. The WQI in the study area shows that dominant water samples fall under excellent category and only few areas have samples whose condition is not suitable for the drinking purposes. The suitability of water for the agricultural aspect was analyzed through SAR which seen to be excellent. The Hydrochemical analysis such as Piper plot, Stiff diagram and Gibbs plot showed the chemical composition of water along with its interaction with surroundings geology.

Geotourism has both pros and cons, it can be best destination for tourists for various purposes such as to observe the wide agricultural land, land surrounded by green forest along with water flowing in river. The ancient water wells provide the hydrological history of the area, the natural spring and its diversity also attracts the tourists. Beside if these sector are not properly managed then it can be threat to the environments and loses its charm for geotourism. These findings provide insights for targeted interventions to maintain and improve groundwater quality in the study area, enhancing our ability to make informed decisions about water resource management and environmental protection.

Conclusion

Groundwater plays a vital role in sustaining ecosystems, meeting water demands, and supporting various economic activities, including industry and agriculture. Our study focused on Hetauda city in the Makwanpur district, which has become a hub for people seeking different opportunities, resulting in increased water demand. To assess the water quality in Hetauda valley, samples were collected from surface and subsurface sources for physiochemical analysis.

In Bhorle area, elevated levels of iron were detected, rendering the water unsuitable for human consumption. The Water Quality Index (WQI) for the water samples were calculated, revealing that water quality ranged from excellent to good in most places. The same area where iron was detected, the quality of water seems to be poor for both domestic as well as for agricultural purpose. On the positive side, the sodium adsorption ratio of the water samples was predominantly excellent. The Sodium Adsorption Ratio (SAR) indicates that the condition of water in the study area for the irrigational purposes. In this study, the Principal Component Analysis identified three main factors influencing groundwater quality. Parameters like total hardness, Electrical Conductivity, calcium, magnesium, and sulfate strongly correlated with these factors, while potassium, turbidity, sodium, and iron showed weaker connections. For instance, total hardness has a significant impact, while potassium and turbidity have less influence. The geotourism in the area is quite impressive and can help in the economic development of the area if conserved the important sites like jungles, rivers, etc. and managed well from the local authorities with cooperative collaboration with the public.

Overall, the condition of groundwater in Hetauda valley appears to be satisfactory, with a few exceptions that require careful planning, management and recommendations to enhance the water quality standards in the region.

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