



# Groundwater quality evaluation for drinking and irrigation using analytical hierarchy process with GIS in semi critical block of Chhattisgarh, India

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## Abstract

Groundwater plays a crucial role in achieving sustainable development across various dimensions. Groundwater resources comprise of two integral aspects namely quality and quantity which are interconnected and important to comprehend and manage efficiently. The groundwater quality in the semi critical blocks of Chhattisgarh State is deteriorating, creating a health risk for the local population. In current study, ten representative groundwater samples were obtained and analyzed physiochemical parameters such as pH, EC, TDS, TH with major anions and cations for both pre and post monsoon period of 2020 for Patan block of Chhattisgarh. Fluoride and Nitrate concentration at some location has been found beyond permissible limit of BIS. Hydrochemical evaluation of groundwater samples were carried out by Piper and Gibbs diagrams. Groundwater quality index (GWQI) and irrigation water quality index (IWQI) were prepared based on a combination of Geographical Information System (GIS) and Analytic Hierarchical Process (AHP) for drinking and irrigation uses, respectively. AHP is known for handling quantitative and qualitative criteria, providing a structured framework and allowing for expert knowledge and subjective judgments. To assess maps of WQI with regards to their applicability for drinking and irrigation uses, six parameters/indices were selected and their weights were calculated using the AHP. The GWQI and IWQI maps were prepared using a weighted overlay technique in GIS. This shows that 6.11%, 85%, and 8.89% of total area falling into “good”, “moderate” and “poor” classification for groundwater for drinking purposes, respectively. Similarly, the IWQI shows that 96.53% and 3.47% of the area fall into the categories of suitable and doubtful, respectively. The preponderance of groundwater within the region is drinkable and appropriate for agriculture.

**Keywords** AHP · GIS · GWQI · IWQI · Gibbs diagram · Piper diagram

## Introduction

Groundwater holds immense importance due to its numerous benefits and contributions to both natural ecosystems and human activities. In order to effectively utilize groundwater

for the purpose of sustainable development, it is imperative to adopt tactics that are deemed necessary and methods that encourage its sustainable employment, safeguard its quality and impartial access. Water quality control is among the most urgent challenges of the twenty-first century for

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environmental resilience of groundwater resources, as the demand of groundwater is high (Mittal et al. 2021; Li et al. 2021). In developing nations, groundwater serves predominantly as a vital resource for household, manufacturing and agricultural operations. Furthermore, these nations encounter the quandary of inadequate management of subterranean water resources, with regard to both their quality and quantity. The National Ground Water Association (2020) estimates that over 75% of annual groundwater extraction occurs in India, Mexico, China, the United States, Pakistan, Saudi Arabia, and Iran. India is widely recognized as one of the foremost agricultural nations across the globe, owing to its vast land area and significant agricultural production, withdraws most groundwater and has a real problem with sustainable groundwater management. Aquifer, which is geological formation or structure that contain and transmit sufficient water, are of utmost importance as they serve as crucial water resources. The management of these aquifers poses a range of qualitative and quantitative challenges, which require immediate attention (Rahman 2008; Jha et al. 2019). Rapid growth of urbanization and industrialization reduces groundwater recharge zones. It increases residential, commercial and industrial wastes ultimately leading to water quality conflicts and changing lifestyles (Ram et al. 2021). Nitrate and bacteriological contamination of shallow aquifers has been caused by landfill leachate, effluent from unregulated wastewater disposal facilities, over-fertilization and sometimes inadequate drainage techniques (Ramaroson et al. 2020). Groundwater quality is also influenced by hydro-geochemical processes (evaporation, mixing, and dissolution) in aquifers (Chung et al. 2020). The increase in groundwater abstraction and demand necessitates regular inspection of water sources as the concentrations of groundwater physicochemical parameters fluctuate due to natural and human interventions (Nigam and Tripathi 2020; Adamo et al. 2018). The situation becomes even more problematic during the dry season due to low groundwater levels. Groundwater contamination is a major problem, especially when people directly consume untreated water as drinking water. Groundwater quality should be tested and preserved before using various treatment alternatives, such as physical–chemical approaches and membrane technologies for purification. Contact with contaminated water can hurt health and this has been extensively researched worldwide (Chowdhury et al. 2016; Wu et al. 2019). Overusing polluted groundwater negatively impacts soil sustainability and presence of pollutants in irrigation water can stress plants, impair their growth and development ultimate overall crop productivity (Eliopoulos et al. 2021). Health complications and financial losses may result from consuming poor-quality groundwater (Banerjee et al. 2018). Because a healthy environment requires good water quality, groundwater assessment and monitoring are critical to water supply management (Germolec et al. 1989).

As a result, we need to regularly adopt rules and regulations developed by national policymakers to stop human-induced water pollution (Vasanthavigar et al. 2010).

Groundwater contamination issues in different countries addressed with a range of measures, techniques and policies. Several techniques for groundwater remediation have been evaluated in the past, including membrane technology, chemical precipitation, coagulation (Ge et al. 2020), adsorption (Hao et al. 2018), ion-exchange (Chen et al. 2021), bioremediation (Hubadillah et al. 2020) and biological methods. With the rapid technological development, many novel techniques have been developed to study groundwater contamination, including geophysical and geoinformatics techniques. Geographical information systems (GIS) and remote sensing have accelerated the development of groundwater (Megahed 2020).

Various researchers have used a range of conventional tools and techniques, including graphical and statistical methods to interpret groundwater quality (Sara and Gibbons 1991). However, more recent research has emphasized the need for modern techniques such as GIS and groundwater modelling to accurately characterize and manage groundwater resources (Machiwal and Jha 2015). The emergence of GIS technology particularly during the 1990s has substantially improved the visualization, interpretation and presentation of groundwater quality evaluations and making it a valuable tool for analyzing and mapping contaminated zone that ultimately help in decision-making (Jha et al. 2007; Yetis et al. 2021).

WQI is a powerful numerical tool which is extensively used worldwide to assess the water quality (Dandge and Patil 2022; Kumar et al. 2020; Uddin et al. 2021). It produce comprehensive quality of water based on the parameters, which can be helpful for the decision analysis. Despite the provision of simulation approaches and conceptual models for water quality evaluation, widespread use of WQI remains essential in this regard (Mukate et al. 2019; Nong et al. 2020). The technique ascertains WQI metrics by allotting weights to particular parameters based on their significance. Water quality evaluation is often carried out using this method as it facilitates the assignment of weights to the individual criteria that ultimately determine the quality of the area in question. This approach is widely used due to its effectiveness (Adimalla 2021; Chaurasia et al. 2018).

On the other hand, MCDA approaches including AHP have been used to individually change the weighting of each criterion for quality analysis (Prasad et al. 2019; Sutadian et al. 2017). AHP recognizes all qualitative data as it generates a specific weight for selected parameters that depend on pairwise comparison matrices (PCMs) developed by decision-makers (Kumar et al. 2014; Ying et al. 2007; Jhariya et al. 2017). Value obtained through employment of MCDA technique provides insight into the relative impact of varying

concentrations of distinct study region parameters. The Pearson correlation approach is a statistical methodology that is utilized for gauging the intensity and orientation of the linear bond that exists between two uninterrupted variables. This technique can be employed to evaluate interrelationship among diverse water quality parameters, with aim of comprehending their interconnections and the likelihood of any associations between them (Kumar and Krishna 2021). The utilization of aforementioned technique has been employed by diverse scholars in their respective studies (Awomeso et al. 2020; Nath et al. 2021).

This project was conducted within confines of Patan block, situated geographically in Durg district of Chhattisgarh, India. Recently published report of Central Ground Water Board (CGWB) for year 2017 has made an estimation that groundwater resources in patan is 8009.08 Ha-m. The potential for further groundwater development in this region is limited. The study area primarily relies on groundwater for both domestic and agricultural purposes, due limited availability of surface water resources. The demand for groundwater has been on the rise particularly due to the adoption of a double cropping pattern in the area where a significant number of farmers opt to cultivate paddy crops during the rabi season. Therefore, more attention should be paid to sustainable groundwater use and recharge. There is an acute situation of groundwater contamination in this study area. Some anions (nitrate ( $\text{NO}_3^-$ ), sulfate ( $\text{SO}_4^{2-}$ ), fluoride ( $\text{F}^-$ )) and heavy metals (arsenic and lead) were observed originating from both geogenic and man-made activities (Acharya et al. 2005; Yadav et al. 2020; Singha et al. 2019). Various locations throughout the state have exhibited elevated levels of these contaminant within the groundwater. However, some areas in Chhattisgarh are still unexplored and need detailed investigation. Ghosh et al. (2016) reported physicochemical analysis in this area but did not address the hydrogeological characteristics of the groundwater. They found a higher concentration of fluoride, which seriously threatens human health. Prior research has similarly discovered that in certain regions of the Patan block, the appropriateness of groundwater for potable utilization is lacking (Sar et al. 2017; Shrivastava et al. 2014; Giri et al. 2013; Jhariya et al. 2017). Patan is prone to several diseases caused by contaminated water, including fluorosis, dysentery, typhoid, diarrhea, dengue, hepatitis, cancer, skinning, gastroenteritis, malaria, intestinal and liver infections, which have been detected in the block (Ghosh et al. 2016). Furthermore, there has been insufficient studies for the appropriateness of groundwater to irrigate crops. Therefore, it is imperative to conduct a thorough investigation in this particular scenario.

Thus, it is of utmost importance to implement requisite actions to safeguard the present state of groundwater resources. The primary aim of the current investigation was

to (1) characterize hydrochemistry of the groundwater, (2) evaluate quality of the groundwater using the WQI, and (3) make suitability map of groundwater for both drinking and irrigation. The outcome of this study can help policymakers to implement meaningful plans and proactive steps to regulate groundwater availability.

## Framework of the study

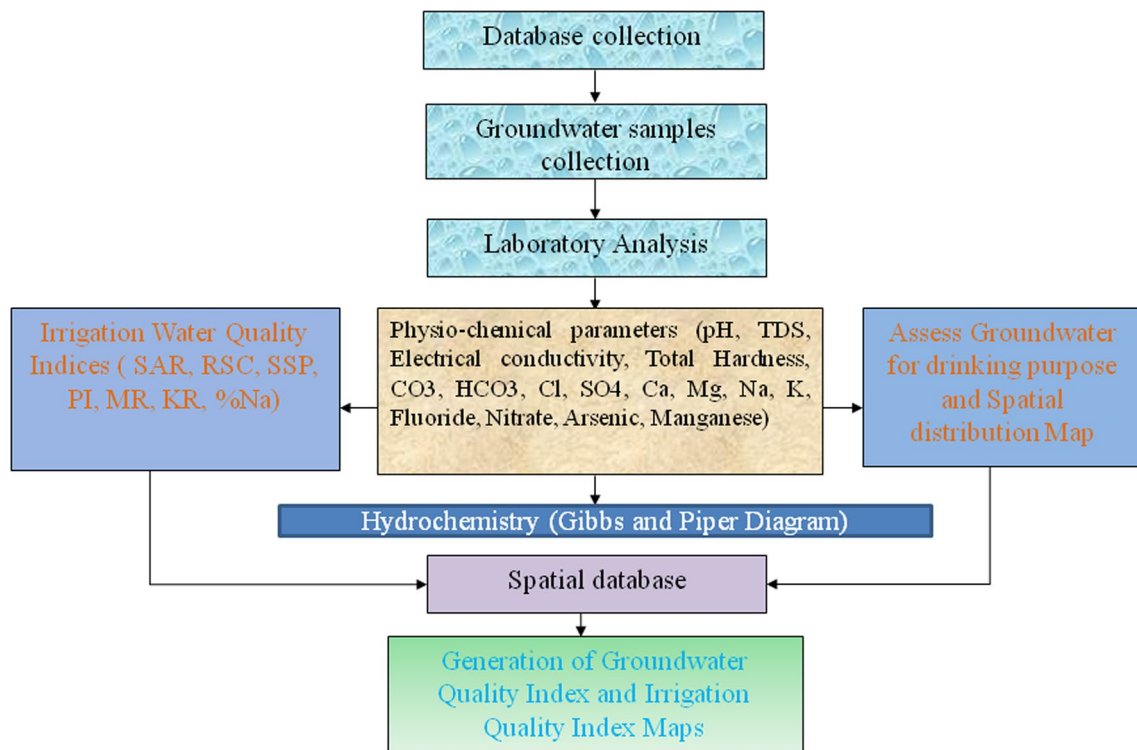
Groundwater samples were obtained and subjected to an evaluation of their physicochemical properties encompassing major anions and cations. The application of AHP and GIS enabled the creation of WQI maps, providing valuable information for both drinking and irrigation purposes. Furthermore, the examination of groundwater chemistry was conducted through the utilization of Piper and Gibb's diagram. The estimation of groundwater contamination sources was facilitated through the application of correlation analysis. Figure 1 shows the flowchart for the details of the methodology.

## Study area

The investigation has performed in Patan block which can be found in Durg district of Chhattisgarh state, India as shown in Fig. 2. The river Kharun forms its eastern edge boundary. The area is located between  $20^{\circ}5'40''$  to  $21^{\circ}31'48''$  N latitudes and  $81^{\circ}22'48''$  to  $81^{\circ}36'0''$  E longitudes and encompasses a  $750 \text{ km}^2$  area, which represents about 36% of the overall area of the Durg district, Chhattisgarh. Its elevation above mean sea level ranges from 290 to 311 m. The Patan block gets most of its rainfall from southwest monsoon, with an average of 1207.48 mm per year. Groundwater development of study region is 78% which comes under the semi-critical category as per CGWB. The abstraction structures of groundwater are usually dug wells, borewells/tubewells. Paddy, Wheat and Gram are the major crops and double cropping is also practiced in this area.

## Lithological characteristics of Patan

The geological composition of the studied region is composed of lithological formations that include limestone, sandstone, and shale. Most of the area of  $621.85 \text{ km}^2$  is covered by limestone (Charmuriya formation), followed by shale (Gunderdehi Formation) covering  $95.70 \text{ km}^2$  in phreatic and fractured form (CGWB 2017). Figure 3 depicts the study block's geology. In limestone formation, groundwater movement is regulated by the solution's fractures, joints, and cavities. In the area, the average depth of the weathered rock is about 13.5 m, with discharge ranging from 0.1 to 4.0 L per second. The drawdown of the area varies between 7.4 and



**Fig. 1** Structure and methodology of the study

32.29 m, with a fracture thickness of about 0.36 m (CGWB 2017). Dug and drilled wells/tube wells access most of these formations. The groundwater in the Gunderdehi shale is found in two different conditions. In the weathered portion, it occurs under phreatic or water table conditions, while in the deeper part consisting of fractures, it is semi-confined to confined conditions. Fractures are rarely encountered in the study, although they are less potent from a groundwater perspective. The Seonath, Hanp, Kharun, and Tandula rivers form the floodplain where most of the alluvial deposits in the region are concentrated. The alluvial deposits range from 5 to 15 m in depth. They mostly comprise clay, silt, coarse to fine sand, and gravel. Sand and gravel is good aquifers due to their high porosity and permeability compared to clay and silt (Thakur et al. 2016).

### Groundwater level fluctuation

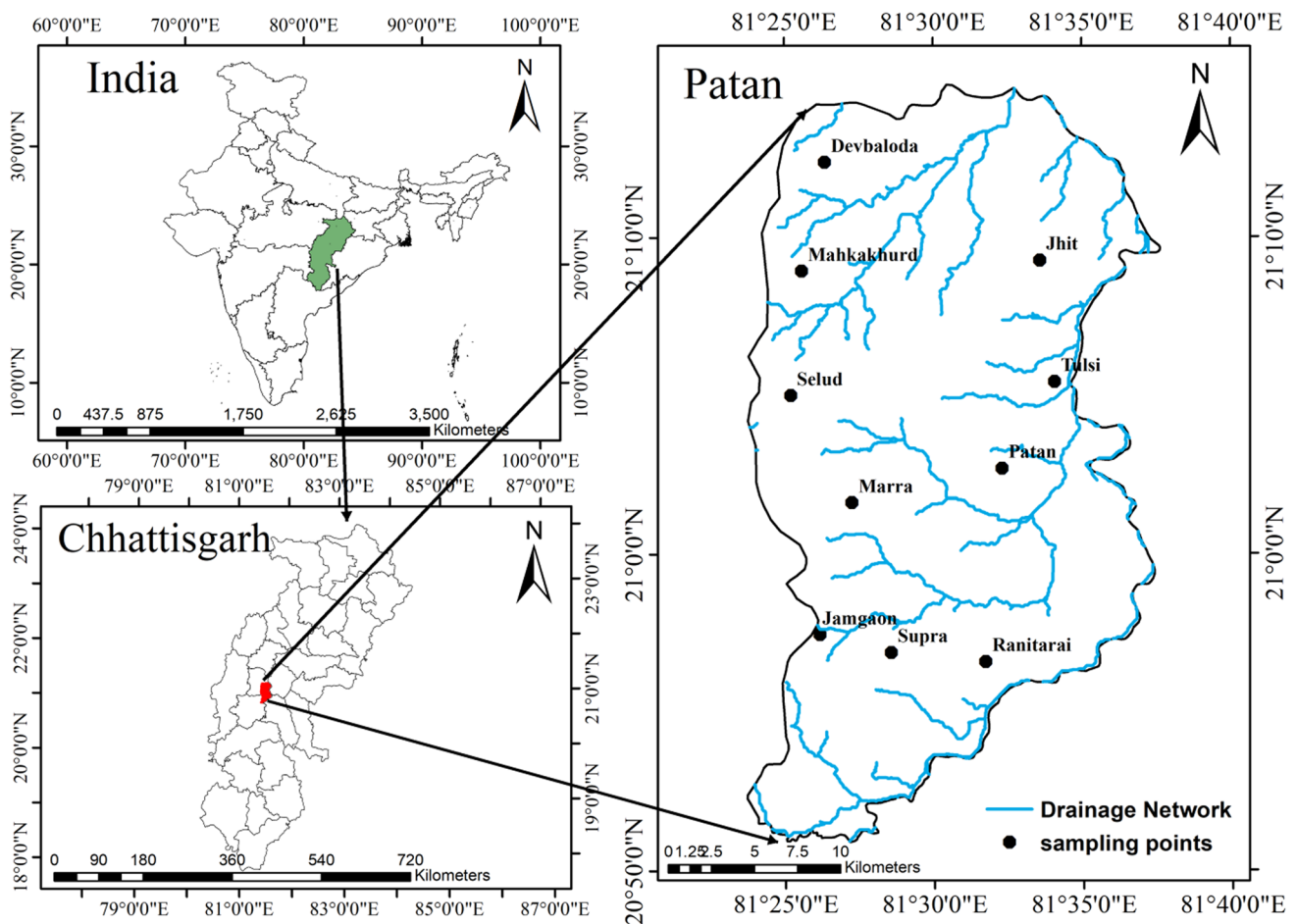
The levels of groundwater are subject to the equilibrium between the recharge and discharge of water. In the event that withdrawal rate surpasses recharge rate, it is known as an overdraft, there may be a protracted reduction of water table. The hydrogeological traits of an area can have an effect on the oscillations in groundwater levels. The depth of water-table below the earth's surface ranges between 4.2–12 and 1.8–3.29 m during pre and post monsoon season respectively. In patan block, the depth of groundwater table is

subject to fluctuations ranging from 1.75 to 10 m, with a mean variation of 4.14 m. Figure 4 shows groundwater fluctuation in Patan block.

## Methodology

### Groundwater analysis

Groundwater samples for this study was collected from all available wells and hand pumps at the ten representative sites of Patan block during both pre and post monsoon period (2020). The obtained groundwater sample were analyzed at CGWB North Central Chhattisgarh Region (NCCR) laboratory in raipur. An extensive evaluation of physico-chemical parameters, encompassing total hardness (TH), total dissolved solids (TDS), electrical conductivity (EC), pH, magnesium ( $Mg^{2+}$ ), calcium ( $Ca^{2+}$ ), potassium ( $K^{2+}$ ), sodium ( $Na^{+}$ ), fluoride ( $F^{-}$ ), nitrate ( $NO_3^{-}$ ), chloride ( $Cl^{-}$ ), sulfate ( $SO_4^{2-}$ ), arsenic ( $As^{+5}$ ), and manganese (Mn), was conducted. Standard procedures proposed by American Public Health Association (APHA 1992) were incorporated to determine the above mentioned parameter (Table 1). Pre-calibration was performed on each instrument in accordance with standards of practise before starting tests. Inverse Distance Weighted (IDW) interpolation technique is broadly utilized to assess values at unfamiliar locations by relying



**Fig. 2** Geographical locations of sampling sites of groundwater in Patan block

on the available data points in the vicinity. It is a popular choice in the fields of spatial analysis and geostatistics to interpolate data points on a smooth surface. This approach operates on the assumption that data points in close proximity to target position exert a significant impact on predicted value than those that are far away. IDW has demonstrated superior performance in comparison to alternative methods that generate interpolation for the designated points with greater variability (Natesan et al. 2021; Gong et al. 2014).

### AHP

The AHP is decision-making tool that permits us to divide a problem into different criteria, organize them into a hierarchy, make decisions about the appropriate value of combinations of components, and synthesize the results (Karakus 2019). This particular procedure can be delineated into multiple phases, commencing with the (1) formation of hierarchy structures (2) developing a PCM using the Satty scale (3) normalizing the eigenvalue (4) checking the consistency of matrix. In the current investigation, six

parameters comprising  $\text{NO}_3^-$ ,  $\text{F}^-$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , TDS, and pH for drinking purposes and residual sodium carbonate (RSC), permeability index (PI), soluble sodium percentatge (SSP), Kelly ratio (KR), magnesium ratio (MR), and percentage sodium (%Na) for irrigation were carefully chosen to determine the appropriate weights.

The respective importance of the selected parameter values is calculated using the Saaty scale (Table 2), with the scale ranging from one to nine. In the realm of pairwise comparison, a value of one signifies an equitable degree of significance between two elements, while value of nine denotes a profound degree of importance for one element in comparison to the others. Within comparison matrix, all chosen parameters are pitted against each other, and the diagonal element of the PCM is consistently equivalent to one (Table 3). Then, the normalized eigenvector was calculated using the comparison matrix, which is useful for the consistency measure. The consistency index (CI), the degree of consistency often referred to as the variance of the priority ratio, was calculated using this equation,

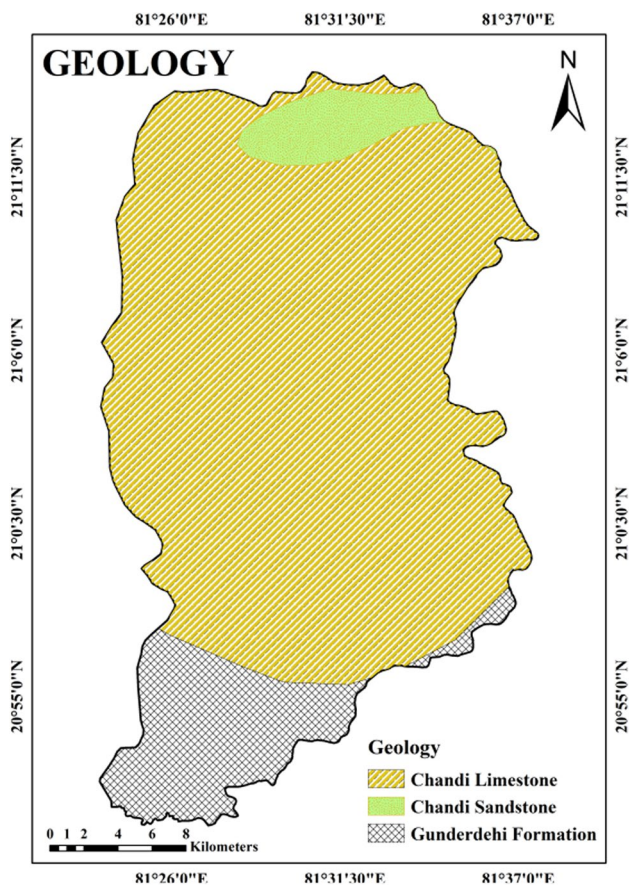


Fig. 3 Geology map of study area

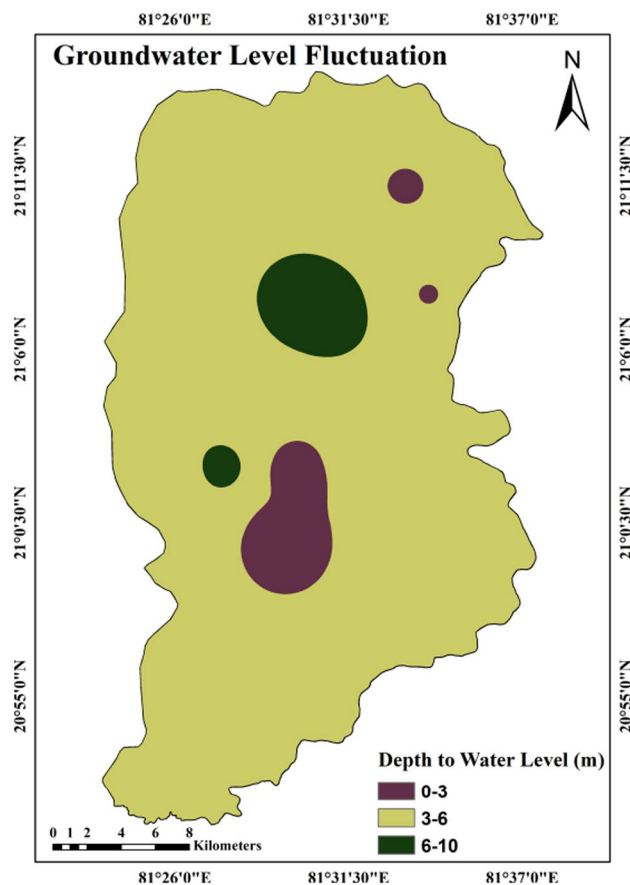


Fig. 4 Groundwater level fluctuation map of the study area

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

where,  $\lambda_{max}$  & n denotes average eigen value, number of selected parameters/indices, respectively (i.e., 6). After determination of CI, Consistency Ratio (CR) is estimated; it measures accuracy of PCM using this equation:

$$CR = \frac{CI}{RI} \tag{2}$$

where, RI denotes random index, and values of RI are given for n parameters of Saaty (Table 4). In this study, the consistency ratio is calculated as 0.009, less than 0.01, indicating that PCM has a reasonable degree of consistency. We must check the subjective decision if CR is greater than 10 percent (Dalalah et al. 2010).

Table 5 shows the weights of each parameter and their CR. The calculated weights are 0.40, 0.27, 0.11, 0.10, 0.06 and 0.06 for  $NO_3^-/RSC$ ,  $F^-/SSP$ ,  $Ca^{2+}/PI$ ,  $Mg^{2+}/KR$ ,  $TDS/MR$ , and  $pH/\%Na$ , respectively, used in the GIS.

Table 1 Standards methods used for the analysis of groundwater samples

Parameters	Methods
Electrical conductivity (EC)	EC meter
Calcium ( $Ca^{2+}$ ), Magnesium ( $Mg^{2+}$ ), Total Hardness (TH)	EDTA titration
Sodium ( $Na^+$ ), Potassium ( $K^+$ )	Flame photometer
Bicarbonate ( $HCO_3^-$ )	Titration method
Nitrate ( $NO_3^-$ ), Sulphate ( $SO_4^{2-}$ )	UV-VIS spectrophotometer
Fluoride ( $F^-$ )	ECR dye method
Chloride ( $Cl^-$ )	Argentometric Mohr method
Arsenic (As), Manganese (Mn)	Atomic absorption spectroscopy (AAS)

### Suitability map

The WQI have been extensively considered as dependable methodology for assessing quality of groundwater. It is noteworthy that physical and chemical parameters of groundwater quality have been employed to formulate a singular indicator value. Numerous scholars from diverse countries have proffered divergent WQIs that are premised on distinct

**Table 2** The comparison scale of AHP (Saaty 1980)

Scale value	Importance
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

ground water quality parameters, and these classifications of indices have gained widespread acceptance and adoption (Nath et al. 2021; Roy et al. 2021; Chabuk et al. 2020; Hilali et al. 2021; Ahmed et al. 2021). The proposition of the GWQI map, intended for drinking activities, is rooted in the amalgamation of six distinct parameters pertaining to ground water quality. Correspondingly, the IWQI map, devised for irrigation activities, is made on the basis of integration of six indices relating to irrigation water quality. These groundwater quality parameters and indices have been selected based on their influences in selected region. Weightage of sepecific parameter/indices were estimated incorporating AHP methodology as described earlier. Afterward, the final GWQI and IWQI maps were generated through six thematic layers and

their weights using weighted overlay techniques which is available in spatial analyst tool of ArcGIS.

### Irrigation water quality

The quality of water applied to crop can hold considerable implications for plant growth, soil health, and overall agricultural productivity. Nevertheless, higher levels of specific nutrients may lead to disbalance or salt accumulation in soil, which can have detrimental effects on plant health. Furthermore, the occurrence of pollutants such as heavy metals, pesticides, or industrial contaminants in irrigation water can pose hazards to both crops and human health (Malakar et al. 2019). To asses appropriateness of groundwater for employment in irrigation, a variety of indices, namely SAR, RSC, SSP, PI, KR, MR and %Na, as delineated by Eqs. (3–9), were employed.

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{3}$$

$$RSC = (CO_3^{2-} + HCO_3) - (Ca^{2+} + Mg^{2+}) \tag{4}$$

**Table 3** Pairwise comparison matrix

Suitability criterion	NO <sub>3</sub> /RSC	F/SSP	Ca/PI	Mg/KR	TDS/MR	pH/%Na
NO <sub>3</sub> /RSC	1.000	2.000	4.000	4.000	6.000	6.000
F/SSP	0.500	1.000	3.000	3.000	5.000	5.000
Ca/PI	0.250	0.333	1.000	1.000	2.000	2.000
Mg/KR	0.250	0.333	1.000	1.000	2.000	2.000
TDS/MR	0.167	0.200	0.500	0.500	1.000	1.000
pH/%Na	0.167	0.200	0.500	0.500	1.000	1.000
Total	2.333	4.067	10.000	10.000	17.000	17.000

**Table 4** Random index (RI) value (Saaty 1980)

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

**Table 5** Computation of weights of selected parameters

Parameters	NO <sub>3</sub> /RSC	F/SSP	Ca/PI	Mg/KR	TDS/MR	pH/%Na	Weights	(CR)
NO <sub>3</sub> /RSC	0.429	0.492	0.400	0.400	0.353	0.353	0.404	6.003
F/SSP	0.214	0.246	0.300	0.300	0.294	0.294	0.275	6.004
Ca/PI	0.107	0.082	0.100	0.100	0.118	0.118	0.104	6.004
Mg/KR	0.107	0.082	0.100	0.100	0.118	0.118	0.104	6.004
TDS/MR	0.071	0.049	0.050	0.050	0.059	0.059	0.056	6.003
pH/%Na	0.071	0.049	0.050	0.050	0.059	0.059	0.056	6.004

$$SSP = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \quad (5)$$

$$PI = \frac{(Na^+ + K^+) + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \quad (6)$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (7)$$

$$MR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (8)$$

$$Na\% = \frac{(Na^+ + K^+)}{Na^+ + K^+ + Mg^{2+} + Ca^{2+}} \times 100 \quad (9)$$

The concentrations of each variable used in irrigational indices in Eqs. (3) through (9) are reported in meq/l.

### Hydrochemical facies

The Piper diagram serves as a graphical aid in comprehending the prevalent water chemistry classifications and interconnections among assorted ions that exist within the water (Piper 1944). Because samples with similar results cluster together on the diagram, it highlights contrasts and similarities within groundwater samples (Todd 2001). It is especially useful for comparing hydrochemistry of water in various geographical locations, tracing alterations over time, and detecting water quality problems (Walton 1970). Piper's trilinear diagram is generated using Aqua software (Rockware). The commonly utilized tool to illustrate the connection between lithologic properties of an aquifer and its water composition is the Gibbs chart (Gibbs 1970). It enables the evaluation of the principal mechanisms that govern water chemistry while also identifying the geological features of water sources. It serves as a valuable tool in comprehending the hydrogeochemical progression of groundwater systems and their respective mixing ratios, and gauging the impact of water–rock interactions on groundwater quality (Zhou et al. 2020). Gibbs chart exhibits three domains wherein evaporation, rockwater interaction & precipitation are dominant influencers. Gibbs ratio- I & II can be computed by employing the subsequent equations.

$$\text{Gibbs ratio - I (for anion)} = \frac{Cl^-}{Cl^- + HCO_3^-} \quad (10)$$

$$\text{Gibbs ratio - II (for cation)} = \frac{Na^+ + Ca^{2+}}{Na^+ + Ca^{2+} + K^+} \quad (11)$$

## Results and discussion

Table 6 provides a summary of analyzed parameters and their general features in Patan. It includes the parameter's maximum, minimum, mean, and standard deviation values. pH concentration of total samples ranges from 7.2 and 8.1, with a standard deviation of 0.319. The observed pH value (Fig. 5f) in the groundwater is relatively alkaline, which can be found in the literature (Ahmed et al. 2020). The EC value is between 292 and 1078  $\mu\text{S}/\text{cm}$ , having a median value of 709.7  $\mu\text{S}/\text{cm}$ , a standard deviation of 294.387  $\mu\text{S}/\text{cm}$ . The EC value signifies the salinity proportion of the project area because high EC can harm crop productivity and soil characteristics. High EC values are caused by different geochemical mechanism, encompassing rock water interaction, weathering, dissolution and excessive evaporation (Alfaifi et al. 2020). The cation values in the samples such as  $Na^+$ ,  $K^+$ ,  $Ca^{2+}$ , and  $Mg^{2+}$  ions vary from 9.35 to 90.48 mg/l, 0.12 to 25.85 mg/l, 28 to 120 mg/l, and 1.2 to 45.6 mg/l, respectively, and having an average value of 33.803 mg/l, 4.265 mg/l, 64.4 mg/l, and 16.56 mg/l, respectively. The primary dominant anions  $Cl^-$ ,  $SO_4^{2-}$  and  $HCO_3^-$  were detected in the groundwater sample at concentrations ranging from 10.65 to 124.25 mg/l, 4.4 to 57.6 mg/l, and 128.1 to 341.6 mg/l, respectively, having an average concentration of 64.255 mg/l, 20.645 mg/l, and 76.862 mg/l. Patan exhibits a consecutive progression of cations and anions, which are identified in declarative ranges as  $Ca^{2+} > Na^+ > Mg^{2+} > K^+$  and  $HCO_3^- > Cl^- > SO_4^{2-}$ , respectively.

**Table 6** Statistic of groundwater quality parameter of the study area

Parameters	Minimum	Maximum	Mean	SD
pH	7.2	8.1	7.52	0.319
EC	292	1078	709.7	294.387
TDS	193	707	467.6	193.222
$Na^+$	9.35	90.48	33.803	23.591
$K^+$	0.12	25.85	4.265	8.000
$Ca^{2+}$	28	120	64.4	29.178
$Mg^{2+}$	1.2	45.6	16.56	12.235
$HCO_3^-$	128.1	341.6	231.19	76.862
$F^-$	0.63	2.92	1.311	0.682
$Cl^-$	10.65	124.25	64.255	46.571
$NO_3^-$	1.88	86.3	23.025	27.807
$SO_4^{2-}$	4.4	57.6	27.39	20.645
TH	100	385	211.5	90.800
As	0.0010	0.0025	0.0015	0.000
Mn	0.002	0.108	0.015	0.033



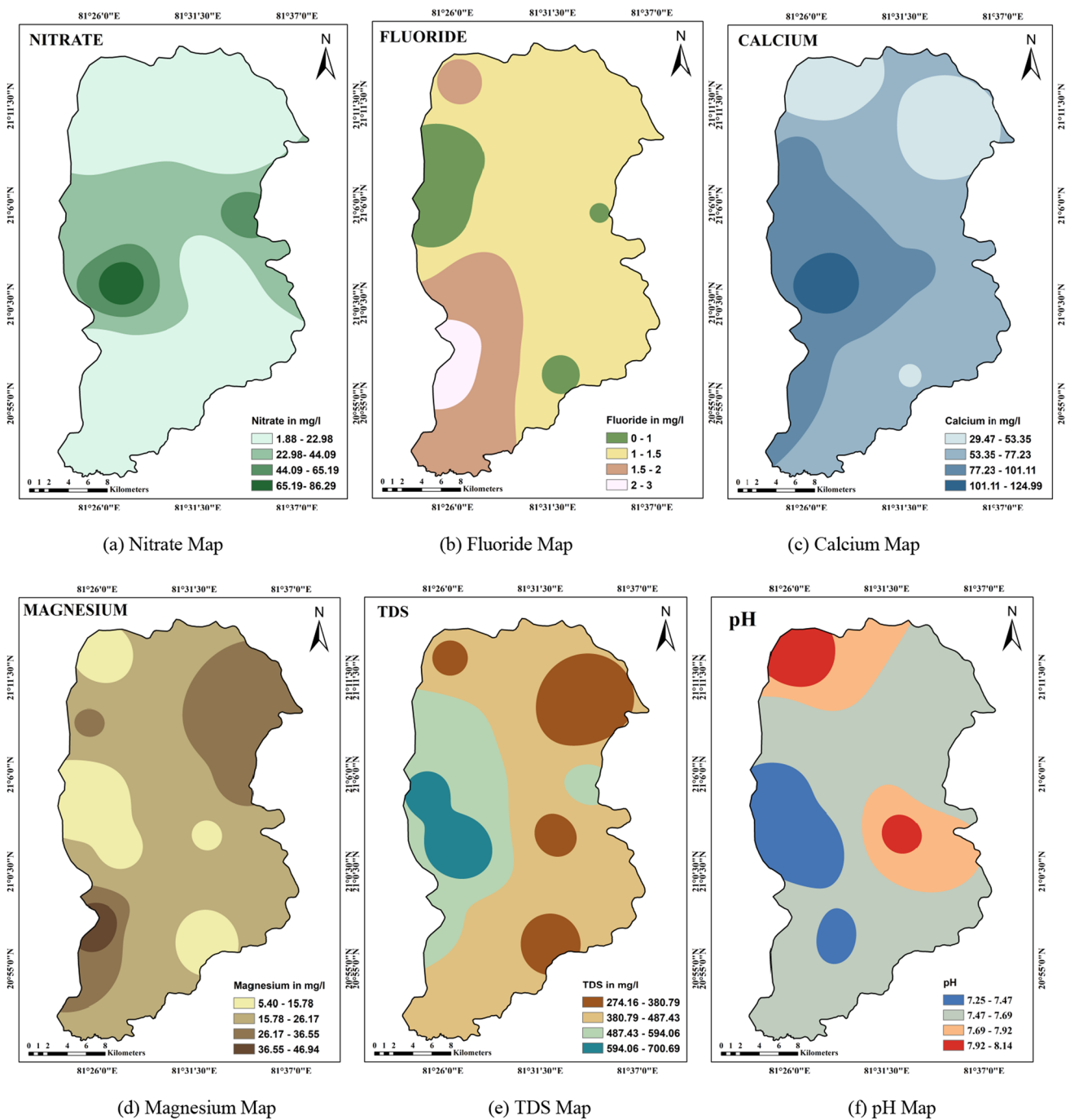
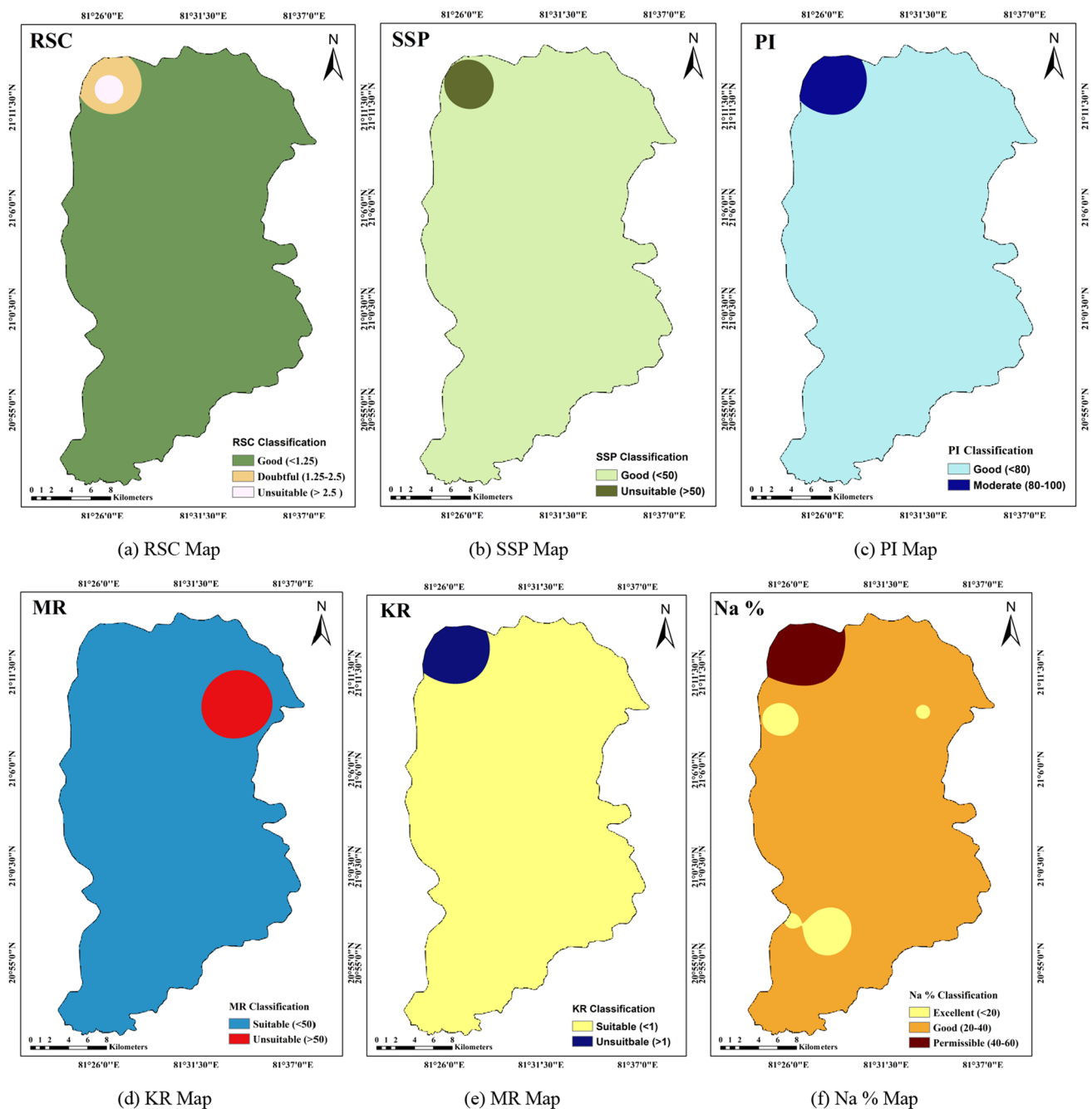


Fig. 5 a–f Spatial distribution maps of different parameters of groundwater

**Spatial distribution maps of groundwater quality parameters and irrigation indices**

Geographic maps depicting distribution of specific parameters or indices were created using the spatial analysis tool integrated into the ArcGIS platform. The resulting maps are shown in Figs. 5a–f and 6a–f. The evaluation of results indicate that level of fluoride and nitrate exceed the allowable

threshold. The geographically distribution and concentration of nitrate are depicted in Fig. 5a. The available nitrate in patan has been classified into two classes based on the BIS limit, namely the acceptable limit (less than 45 mg/l) and the limit exceeding category (greater than 45 mg/l), where nitrate concentration in study area is good, with the exception of two distinct locations, namely Marra and Patan. Consequently, 56.73 km<sup>2</sup> (7.51%) of the entire block



**Fig. 6** a-f Spatial distribution maps of different indices for irrigation water quality

is beyond the limit zone. Most of the nitrate in groundwater comes from human sources (Jayarajan and Kuriachan 2021; Su et al 2021; Solgi and Jalili, 2021). The primary cause of this phenomenon can be attributed to excessive fertilization resulting from implementation of high-intensity agricultural practices experienced in contaminated zone. As per BIS 2012 recommendation, the acceptable level of fluoride in groundwater for drinking is limited to 1.5 mg/l. While concentration of 1.0 mg/l is deemed suitable for dental health, surpassing

the allowable limit may result in health issues. The recommended fluoride level in drinking water must be maintained to avoid adverse effects on human health (WHO 2011). The sources of fluoride are widely considered to be geogenic, and no human-caused sources are assumed. According to the map of the spatial distribution of fluoride (Fig. 5b), 82.95 km<sup>2</sup> area is below the acceptable limit, 500.49 km<sup>2</sup> area is below the allowable limit, and 166.56 km<sup>2</sup> area is above the limit. All other parameters are within acceptable

limits per the BIS 2012 guidelines. The  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  content and spatial distribution are depicted in Fig. 5c and d, respectively. Figure 5c illustrates that calcium concentration in majority of the study areas falls below the acceptable limit. Groundwater containing calcium and magnesium in groundwater results from decomposition of alumina silicates from calcium and magnesium at higher concentrations (Kozisek 2003). The availability of magnesium in groundwater is generally low compared to calcium because it exhibits a greater tendency to form chemical bonds with other elements, which in turn facilitates its integration into minerals, thereby leading to its prevalence in greater quantities. TDS concentration and their spatial variation map are displayed in Fig. 5e. Higher TDS content makes drinking water taste salty, bitter, and brackish, which can harm aquatic life in the water (Adimalla et al. 2018). TDS concentration increases along with salinity mixing. This phenomenon causes the freshwater to change to an inappropriate level. TDS and EC are closely related, with a higher EC content indicating a higher TDS content.

### Groundwater quality for irrigation

Table 7 provides an overview of various indices utilized for assess groundwater quality intended for irrigation

purposes. According to categorization of SAR, most groundwater samples were excellent ( $< 10$ ), indicating that there is indeed no alkali risk to crops. The results from SAR also indicate that patan is unaffected by exchangeable sodium (Sharma et al. 2021). According to the RSC classification, it has been determined that a significant majority of the samples, specifically 90%, belong to the category of good while the remaining 10% are classified as doubtful. The SSP has a range of 9.68 to 66.35, with 90% of samples falling into good category during post-monsoon, while 10% fall into unsuitable category. During pre-monsoon, all samples are categorized as suitable. Almost all sites had a PI value greater than 75% permeability, demonstrate that groundwater is deemed appropriate for purposes of irrigation. The values of KR and MR demonstrate that irrigation can be successfully carried out with a high degree of efficacy in as much as 90% of the analyzed samples. Based on the Wilcox (%Na), during post-monsoon, the recorded values fall within the range of 9.75–66.48, with 50% of samples categorized as “excellent”, 30% as “good”, 10% as “permissible” and 10% as “doubtful.” Conversely, in pre-monsoon period, 90% of the samples were classified as “good” whereas 10% were labeled as “permissible.”

**Table 7** Suitability of groundwater for irrigation purposes

Irrigation water quality indices	Range	Groundwater classification	Patan	
			Post-monsoon Samples (%)	Pre-monsoon samples (%)
Sodium adsorption ratio (SAR; Richards 1954),	0–10	Excellent	100	100
	10–18	Good	0	0
	18–26	Doubtful	0	0
	> 26	Unsuitable	0	0
Residual sodium carbonate (RSC; Richards 1954)	< 1.25	Good	90	90
	1.25–2.5	Doubtful	10	10
	> 2.5	Unsuitable	0	0
Soluble sodium percentage (SSP, Wilcox 1955)	< 50	Good	90	100
	> 50	Unsuitable	10	0
Permeability Index (PI; Doneen 1964),	< 80, Class I > 75% permeability	Good	90	90
	80–100, Class II 25–75% permeability	Moderate	10	10
	100–120, Class III < 25% permeability	Poor	0	0
Kelly Ratio (KR; Kelly 1940)	< 1	Suitable	90	100
	> 1	Unsuitable	10	0
Magnesium Ratio (MR; Raghunath 1987)	< 50	Suitable	90	100
	> 50	Unsuitable	10	0
Percent sodium (%Na; Wilcox 1955)	< 20	Excellent	50	0
	20–40	Good	30	90
	40–60	Permissible	10	10
	60–80	Doubtful	10	0
	> 80	Unsuitable	0	0

## Groundwater quality index mapping

The GWQI and IWQI maps were created via the weighted overlay technique of several characteristics of the spatial distribution map. The AHP approach supports the importance of different thematic starata of quality variables and their identical groups affecting groundwater quality. Six parameters were used to measure the groundwater quality index:  $\text{NO}_3^-$ ,  $\text{F}^-$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , TDS, and pH. Similarly, six indices measure irrigation water quality: RSC, SSP, PI, KR, MR, and %Na. Table 5 gave the weights for these six elements and indices, and a PCM was created, depicted in Table 3. GWQI map (Fig. 7) is divided into three categories: good, moderate, and poor, covering 6.11%, 85%, and 8.89% of the region, respectively. The GWQI is a recognized approach that indicates suitability for use as drinking water. The IWQI map (Fig. 8) is divided into three categories: suitable, doubtful, and unsuitable. The suitable category covers 96.53% of the area, while the doubtful category covers 3.47%.

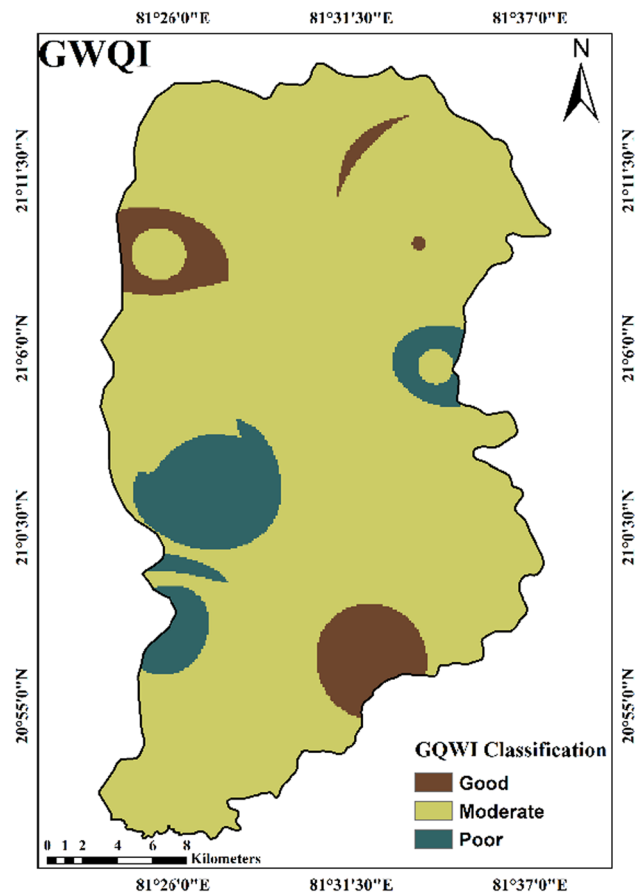


Fig. 7 GWQI map of Patan block

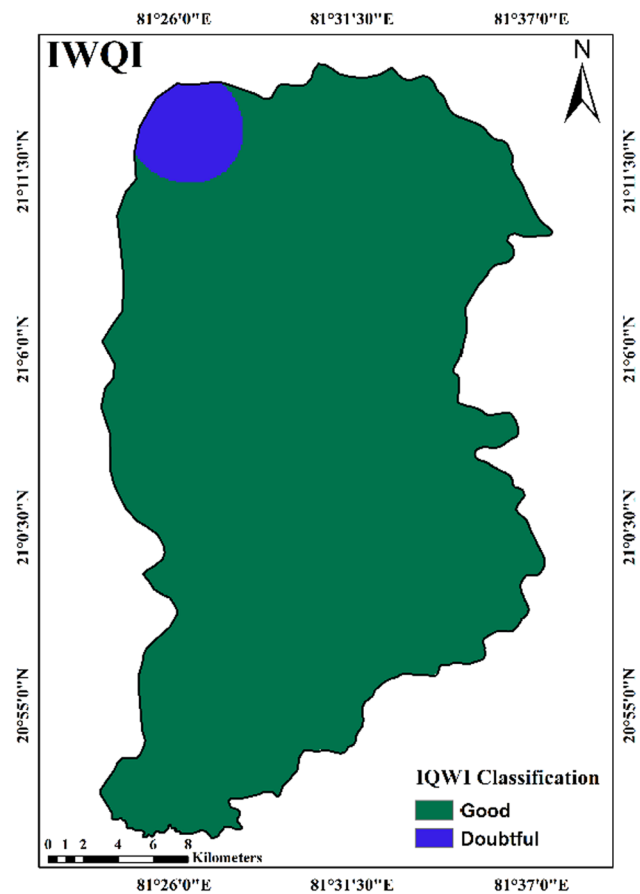
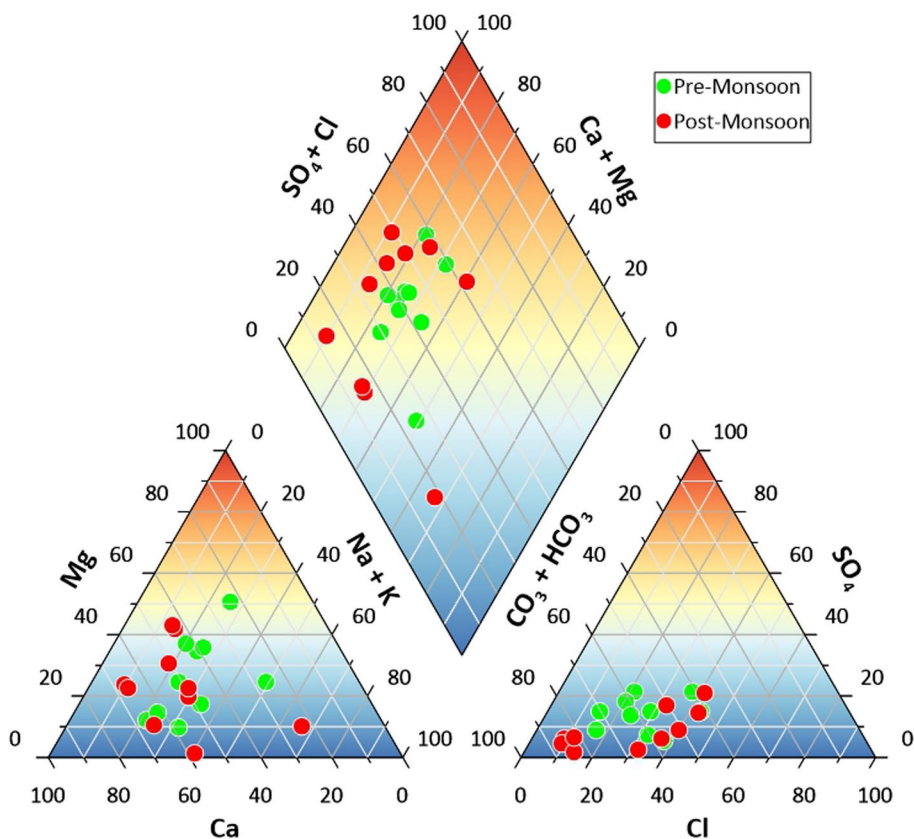


Fig. 8 IWQI map of Patan block

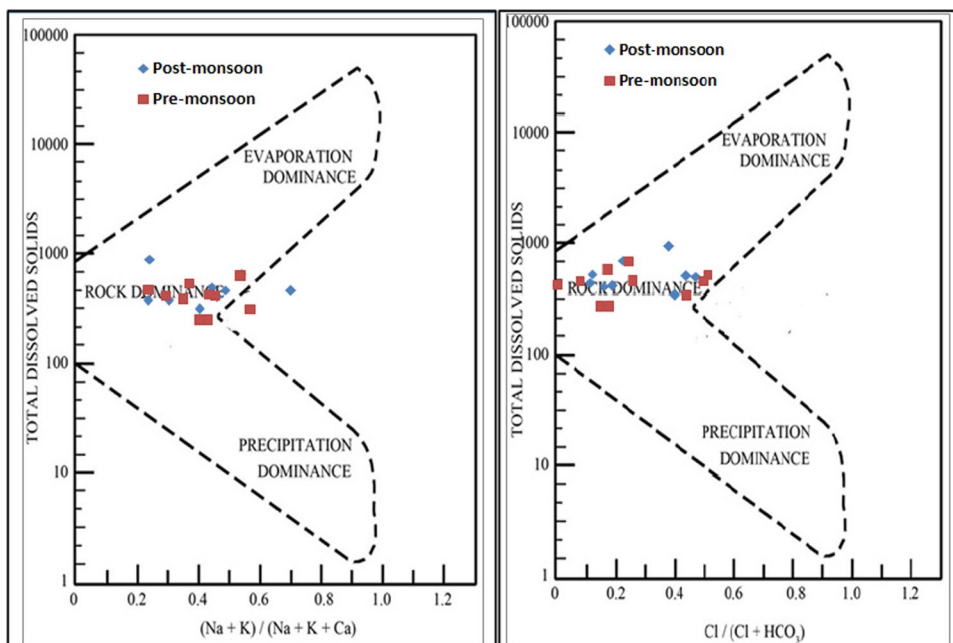
## Hydrochemical characteristic

The trilinear Piper diagram was employed in the present investigation to gauge the hydrochemical attributes of groundwater (Fig. 9). In Piper diagram, main anions and cations are arranged in right and left triangles of the diagrams, which show the dominance of bicarbonate in the anion triangle, indicating the hard nature of groundwater. As for the cation triangle, most of the sample falls in the zone of no dominance. The diamond-shaped diagram divides into different sub-zones showing comprehensive characteristics of groundwater chemistry (Singh et al. 2011). It shows the control of  $\text{Ca}^{2+}$  -  $\text{Mg}^{2+}$  -  $\text{HCO}_3^-$  kind of water subsequently  $\text{Ca}^{2+}$  -  $\text{Mg}^{2+}$  -  $\text{Cl}^-$  -  $\text{SO}_4^{2-}$  and  $\text{Na}^+$  -  $\text{K}^+$  -  $\text{HCO}_3^-$ . It shows that groundwater hydrochemistry is limited by mineralization, interaction with rocks, and human interference (Selvam et al. 2015). In patan block, most groundwater collapses in rock water connection region in Gibbs diagram as depicted in Fig. 10. Predominant area of rock water connections shows the relation between geological formation(rock) and the subsurface water.

**Fig. 9** Piper diagram of the study area (Pre and Post-Monsoon 2020)



**Fig. 10** Gibbs diagram of the study area



**Correlation matrix**

The scrutiny of interrelations and connections amongst variables in a dataset is facilitated by correlation coefficient. The correlation matrix contains correlation coefficients between

variable pairs, with each cell signifying the potency and orientation of their linear association. This method calculates a set of parameters for the pairwise associations. It presents the results in the form of a matrix. This is useful for assessing the significance of the interaction of the parameters

under study. The 'r' values between different parameters are displayed in Table 8. It exhibits notable association between EC and TDS/ $\text{Ca}^{2+}/\text{Cl}^-/\text{SO}_4^{2-}$ ;  $\text{Cl}^-$  with EC / $\text{Ca}^{2+}/\text{TH}$  and TDS with  $\text{Ca}^{2+}$  in available groundwater.

## Conclusions

The current study seeks to propose a new water quality index based on AHP to monitor quality of groundwater in a semi-critical block. The article presented a combined approach of GIS and AHP towards the appraisal of groundwater quality with an interpretation of the cation–anion distribution in groundwater and the identification of distinguishing parameters of groundwater in study block for both drinking and irrigation uses. Groundwater in Patan is predominantly of  $\text{Ca}^+ - \text{Mg}^+ - \text{HCO}_3^-$  type. Fluoride and nitrate content in some places exceed the standard BIS. Both man-made and natural activities contribute to cations and anions in groundwater. After a thorough examination, it has been ascertained that groundwater's quality is appropriate not only for the purpose of irrigation but also for drinking. The groundwater quality index map that has been constructed displays that certain areas located within eastern and western sectors of study block are found to exhibit poor groundwater quality.

Similarly, IWQI map illustrated northern sector of Patan is under doubtful conditions for irrigation use. Pearson correlation coefficient was also calculated in matrix form to determine the correlation between different parameters. Some positive and negative correlations were found between the parameters, with EC and TDS having the highest positive correlation. The utilization of AHP enabled the evaluation of effectiveness of discriminant water quality parameters pertaining to their interaction with other variables affecting water quality. Furthermore, it is imperative to think about characteristics of the water quality variables that are causing interference, in addition water quality gradient in region, AHP assessments of the appropriate individuals were combined to ultimately reveal the extent of the water quality problem and promote the optimization of control strategies for groundwater resource management in an area. The current study highlights the effectiveness and capabilities of GIS and AHP to classify groundwater quality index. This provides a more accurate and realistic map of groundwater quality for better interpretation of the study region and aids in groundwater management and environmental sustainability. The comprehensive assessment indicates that the groundwater quality in Patan is reasonably safe. Moreover, the exceedance of Fluoride and Nitrate levels in groundwater is an alarm signal for coming decades.

**Table 8** Correlation matrix of the study area

	pH	EC	TDS	Na	K	Ca	Mg	HCO <sub>3</sub>	F	Cl	NO <sub>3</sub>	SO <sub>4</sub>	TH
pH	1.00												
EC	-0.62	1.00											
TDS	-0.62	1.00	1.00										
Na	0.50	0.05	0.05	1.00									
K	-0.39	0.46	0.46	0.14	1.00								
Ca	-0.59	0.82	0.82	-0.16	0.31	1.00							
Mg	0.02	-0.05	-0.05	-0.30	-0.46	-0.08	1.00						
HCO <sub>3</sub>	0.56	-0.14	-0.14	0.33	-0.55	-0.04	0.44	1.00					
F	0.06	0.12	0.12	0.35	-0.35	0.24	0.47	0.66	1.00				
Cl	-0.32	0.78	0.78	0.07	0.21	0.78	0.38	0.24	0.48	1.00			
NO <sub>3</sub>	-0.59	0.73	0.73	-0.07	0.16	0.63	-0.12	-0.39	0.00	0.46	1.00		
SO <sub>4</sub>	-0.74	0.85	0.85	-0.03	0.68	0.58	-0.25	-0.61	-0.24	0.47	0.74	1.00	
TH	-0.47	0.70	0.70	-0.03	0.08	0.79	0.43	0.25	0.66	0.93	0.44	0.39	1.00

The proposed framework in this study can be applied in other areas to assess groundwater quality for domestic and agricultural purposes and based on the result of this study it is recommended that water planners and decision-makers develop strategies for managing effluents and preventing groundwater contamination from anthropogenic sources, as prevention is more cost-effective than remediation of contaminated groundwater. In contaminated area, alternative water sources should be identified and promoted. Groundwater monitoring networks with real-time data capabilities are essential, as well as awareness campaigns and collaborative efforts between various stakeholders. Therefore, continuous groundwater quality monitoring and proper groundwater management with strict rules are required to ensure groundwater sustainability.

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## Declarations

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