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Assessment of groundwater quality using GIS and CCME WQI techniques: a case study of Thiruthuraipoondi city in Cauvery deltaic region, Tamil Nadu, India

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ABSTRACT

This research evaluated the groundwater quality of Thiruthuraipoondi city in the southern part of Tamil Nadu, India during summer and monsoon seasons in 2011. Eighteen groundwater samples were collected throughout Thiruthuraipoondi city and its surroundings. This case study represented that the combined analysis of ordinary kriging and CCME WQI in GIS was effective to evaluate the groundwater pollution sources, as well as for the spatial interpolation and assessment of groundwater quality. Groundwater samples evaluated by CCME WQI values belonged to good quality sectors in summer and monsoon, but to poor quality sectors at small patches of south and southeast directions in both seasons. Moreover, the higher concentration of Na and Cl was designated as irrigation waste and also seawater incursion. Based on the Piper plot, most of groundwater samples belong to Ca–Mg–Cl_2 type and followed by Ca–Cl_2 and Na–Cl types in summer season. In case of monsoon season, most of the groundwater samples dropped in Na–Cl type and followed by Ca–Mg–Cl_2 and Ca–Cl_2 water types. In Wilcox diagram, most of groundwater samples in both seasons occupied S2 and C4 categories of medium sodium hazard and very high salinity hazard, respectively. This research represented that higher concentration Na and Cl resulted from anthropogenic activities and seawater incursion due to overpumping of groundwater. An effective groundwater management plan of artificial recharge is necessary to conserve valuable groundwater resources in Thiruthuraipoondi city.

Keywords: Groundwater quality; GIS; Ordinary kriging; CCME WQI; Piper plot; Wilcox diagram

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1. Introduction

The quality of groundwater resources in the world is increasingly despoiled as a consequence of overexploitation [1,2]. Groundwater quality has noticeably been deteriorated in many countries during the past few years [3–9]. The overexploitation of groundwater has affected groundwater quality as well as quantity. The portability of groundwater is essentially based on the kinds and concentrations of ionic constituents in groundwater. Groundwater chemistry is determined as the results of various chemical variations of meteoric water in geological systems. Groundwater quality is naturally influenced by geochemical compositions of the rocks along with various hydrodynamic factors. Groundwater resources play a vital role to continually increasing demands of agriculture, industry, and domestic parts of India [10–16]. Groundwater quality is also influenced by human activities that induce pollutants into our environment. Groundwater overexploitation causes harmful effects in quality and quantity aspects. Uncountable large cities and many new megacities in India have developed a major component of their domestic, agricultural, and industrial water supply from groundwater, both from civic well fields and many private bore wells. India has been confronted with severe water scarcity in several parts of the country, particularly in arid and semi-arid regions. The overdependence on groundwater in domestic, irrigation, and industry sectors has resulted in overexploitation of groundwater resources in several states of India such as Tamil Nadu, Gujarat, Rajasthan, Punjab, Haryana, and Uttar Pradesh among others [17–20].

Geographic information system (GIS) has been developed as a great tool for loading, evaluating, and presenting spatial data and used as a decision-making technique in numerous research areas including engineering and environmental fields [21–23]. This technique can make rapid organization, quantification, and elucidation of a large volume of spatial data. It has been efficiently used for various purposes related to groundwater quality assessment in the last decade. Groundwater quality map is very important for drinking and agricultural purposes, and as a preventive suggestion for environmental or health problems. The concept of the water quality index (WQI) was first introduced more than 150 years ago in Germany, where the presence or absence of certain organisms in water was used as an indicator of the fitness of a water source [24–26]. WQI was treated as a management tool that summarized large amount of complex data into a single number that yielded easily interpretable information for reporting to policy-makers and the public. It is a dimensionless quantity that helps to relate the overall water quality at a specific location and time, thereby determining the suitability of water [27–29]. Keeping in this view, Canadian council of ministers of environmental water quality index (CCME WQI) which is a well-established and universally accepted model for the calculation of WQI has been followed [30,31].

This case study carries out some important things such as: (1) identification of groundwater quality deterioration based on the physicochemical constituents of groundwater in summer and monsoon seasons; (2) evaluation of the possible contamination sources associated with human activities, agricultural wastes, and seawater incursion due to the groundwater overexploitation; and (3) establishment of drinking water quality zones based on WHO [32] standards. In order to achieve these objectives, the integration of geostatistical spatial interpolation (ordinary kriging) and CCME WQI was proposed as a result of this case study based on a GIS platform.

2. Materials and methods

2.1. Study area

Thiruthuraipoondi city is located at the southern part of Thiruvarur district of Tamil Nadu, India. Its area is 452.34 Km^2 (Fig. 1(a)). It is an agricultural city with more than 25 villages. Rice and bean are cultivated here. This area is a plain terrain with gentle slope from the southeast direction. The maximum topographic elevation is 30 m at the western part of the study area. Geology (Fig. 1(b)) of this region is covered by alluvium and sandy clay of recent marine sediments. It is delineated as alluvial plain deposits and marine coastal plain deposits (Fig. 1(c)). Fluvial-marine deposits comprise natural levee, beach and marsh of the Quaternary period. The climate of the region is semi-arid and subtropical type with a temperature from 28 to 35˚C. The average annual rainfall is 918 mm. Rainy season continues from October to December. Study area composes mainly of alluvial deposits with sand, silt, and clay. The soils are imperfectly drained and mottled throughout the area. The land use map represented 90% of agricultural area and 10% of settlement area (Fig. 1(d)).

Groundwater occurs in the forms of semi-confined and confined conditions. Shallow unconfined aquifers and medium to deep confined aquifers were formed from quaternary formations. The thickness of medium to deep confined aquifer ranges from 30 to 70 m, and shallow aquifer ranges between 5 and 25 m. Aquifers are composed of sand intercalated with clay, sand and

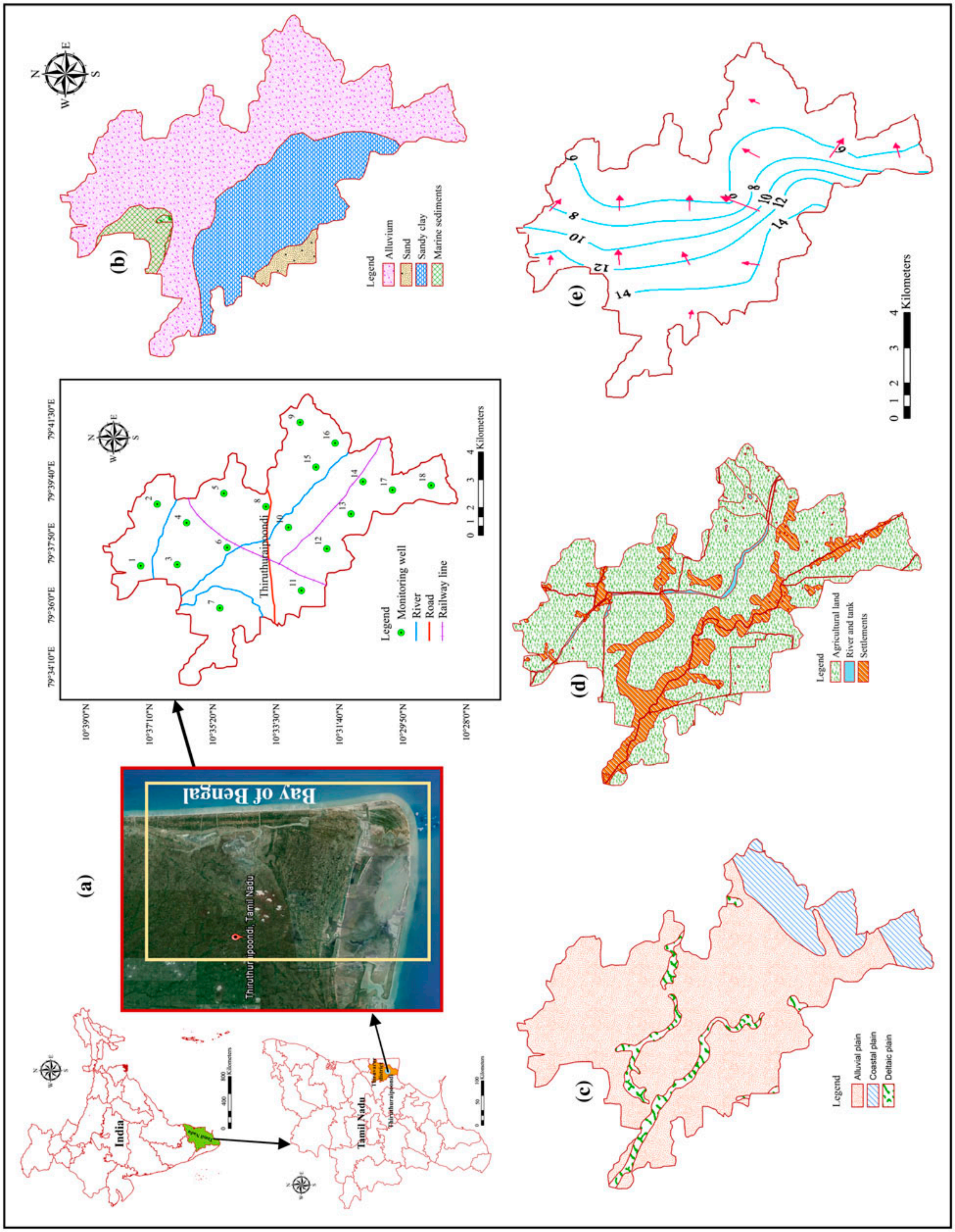

Fig. 1. Map showing Thiruthuraipoondi city, Tamil Nadu, India, (a) sampling location, (b) geology, (c) geomorphology, (d) land cover, and (e) groundwater flow direction.

silt showing lateral and vertical grain size variations. These aquifers are developed by dug and bore wells. Groundwater occurs under phreatic conditions in the shallow zones of sedimentary formations. Groundwater table ranges from 0.56 to 2.76 m (−GL) during winter and from 2.06 to 4.60 m (−GL) during summer. Groundwater flows from the west to the east in the upper part, and from the southwest to the northeast in the lower part (Fig. 1(e)). Moreover, the study area flow Mulliyar, Adappar, Pottiayar, Marakkakoraiyar, and Harichandaranadi Rivers play a major role for saline nature of this land [33].

2.2. Groundwater sampling

Groundwater samples were collected from dug (nos. 12) and bore (nos. 6) wells of 18 predetermined locations in the city during summer (May) and monsoon (November) in 2011. Samples were gathered by 1,000-ml acid-washed polyethylene HDPF bottle, and were stored at a temperature below 4℃ in the laboratory. Samples were analyzed for major physicochemical parameters adopting standard procedures of [34]. EC, TDS, and pH were measured in the field using portable water quality analyzers. Major cations (Ca, Mg, and K) and anions (Cl, HCO_3, SO_4, and NO_3) were determined using multiparameter photometer (Hanna, HI83099). Na was measured by flame photometer (ELCO-CL378). Total hardness (TH) was calculated as [35]:

$$\mathrm{TH(CaCO_3)\ mg/L} = (2.497)\mathrm{Ca} + (4.115)\mathrm{Mg} \tag{1}$$

All concentrations were expressed in milligrams per liter (mg/L), except pH and EC (μS/cm). The results were appraised in accordance with the drinking water quality standards given by the World Health Organization [32]. Piper trilinear and Wilcox diagrams were produced using Aquachem software (ver. 4).

2.3. GIS analysis

Study area base map was digitized from an Indian topographical sheet (58 N/10 and N/11) using ArcGIS 10.2 software. Location of sampling points were also determined in the field by using global positioning system (GARMAN 76CSx), and the precise longitudes and latitudes of sampling points were imported from GIS platform. Ordinary kriging interpolation technique was used to develop spatial maps for all physicochemical parameters according to WHO [32] standard of drinking water quality. The ordinary kriging is a local estimation technique which provides the best linear unbiased estimator (BLUE) of the unknown characteristics. The kriging can be expressed as

$$Z_K^* = \sum_{i=1}^{n} \lambda_i Z_i \tag{2}$$

where Z_K^* is an estimator by kriging, λ_i is a weight that is apportioned to Z_i, and Z_i is a value of spatial variable. The weight of kriging is calculated to ensure that the estimator is unbiased, and the estimation variance is minimal [36].

The non-bias condition of kriging can be expressed as

$$E\left[Z_V - Z_K^*\right] = 0 \tag{3}$$

where Z_V is actual value and Z_K^* is estimated value. The sum of weights is

$$\sum_{i=1}^{n} \lambda_i = 1.0 \tag{4}$$

The estimation variance or kriging variance can be expressed as

$$\sigma_K^2 = E\left\{\left[Z_V - Z_K^*\right]^2\right\} = \bar{C}(V,V) + \mu - \sum_{i=1}^{n} \lambda_i \bar{C}(v_i, V) \tag{5}$$

where $\bar{C}(V,V)$covariance of between spatial variable, μ is Lagrange parameter, and $\bar{C}(v_i, V)$ is covariance of between spatial variable and estimator. In ordinary kriging method, a semivariogram evaluates the characteristics for the spatial distribution of sample data. From the analysis of the experimental variogram, a suitable semivariogram model is fitted by weighted least squares, and the parameters (e.g. range, nugget, and sill) are determined. The parameters are used to produce an estimator at the proposed point [37–39].

2.4. Water quality index (CCME WQI)

CCME WQI was originally established by Canadian water quality index [40]. It is divided into three factors of Factor 1 (Scope), Factor 2 (Frequency), and Factor 3 (Amplitude).

Factor 1 (Scope)

It assess the proportion by which the variables deviate from their objectives. It is expressed as:

$$F1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) \times 100 \tag{6}$$

Factor 2 (Frequency)

It is the percentage of failed tests, and is represented as:

$$F2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of variables}}\right) \times 100 \quad (7)$$

Factor 3 (Amplitude)

It represents the amount by which failed test values deviate from their objectives. It is calculated in three steps such as (i) the first excursion is defined by the number of an individual concentration greater than or less than the objective. It is calculated as:

$$\text{Excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_j}\right) - 1 \quad (8)$$

In case the test value exceeds the objective, we can use the following equation:

$$\text{Excursion}_i = \left(\frac{\text{Objective}_j}{\text{Failed test value}_i}\right) - 1 \quad (9)$$

(ii) It is usually calculated by dividing the summation of all excursions by the total number of tests. This is known as the normalized sum of excursion (NSE) and is calculated as:

$$\text{NSE} = \left(\frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Number of tests}}\right) \quad (10)$$

(iii) Factor 3 (amplitude) is calculated with the help of an asymptotic function by scaling of the normalized sum of the excursions from the objectives within 0 ~ 100.

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) \quad (11)$$

The factor value of 1.732 is introduced to scale index ranged from 0 to 100. The groundwater quality based on the CCME WQI values are ranked in the following five categories: excellent (95–100), good (80–94), fair (60–79), marginal (45–59), and poor (0–44). CCME WQIs for all chemical components are computed at the individual sample points, and contrived to classify the groundwater quality using ordinary kriging spatial interpolation by GIS.

3. Results and discussion

Box and Whisker plots for physicochemical parameters of the groundwater samples in summer and monsoon seasons were represented in Fig. 2. Ordinary kriging spatial interpolation maps for summer and monsoon seasons and the physicochemical concentrations were classified according to WHO standard [32] for drinking water (Figs. 3a and 3b). A detailed percentage comparison of groundwater quality with WHO standard [32] in both seasons were given in Table 1.

3.1. Physical groundwater components

pH value of the groundwater samples ranged from 7.8 to 8.2 during the summer and in monsoon it ranged from 8.2 to 8.9. This shows that groundwater samples were in alkaline condition. A higher value of pH was observed during monsoon when compared with the summer season. The alkalinity of groundwater samples may be attributed to the presence of bicarbonate ions. These ions created by the free mixture of CO_2 with water to form carbonic acid affected the pH of the groundwater [41].

Electrical conductivity is the most important parameter to determine salinity hazard and fitness of groundwater for agricultural purpose. EC varied from 1,632 to 5,818 μS/cm and from 1,500 to 4,878 μS/cm in summer and monsoon seasons, respectively. Spatial distribution map (Fig. 3a) of EC in summer exhibits "not permissible zone" and covered north, south, and central parts. In monsoon, the map (Fig. 3b) shows S and SE directions, patches of NW (station 2, 3, and 7) and central portion (station 10) of the study area. Classifications of groundwater samples based on EC and TDS value [42] are represented in Table 1. TDS values varied from 1,106 to 4,001 mg/L in summer and, from 992 to 3,170 mg/L in monsoon, respectively. Spatial map of higher concentration of TDS are seen in all the portion in both seasons, except station 13 in summer and station 6 in monsoon. Higher concentration of EC and TDS of irrigation and domestic wastes may percolate into the groundwater and seawater intrusion [43–45].

TH varied from 476 to 2,822 mg/L and from 529 to 1,325 mg/L during summer and monsoon seasons, respectively. Most of TH fell at "not permissible zone" based on the WHO [32] classification in both seasons, except station 16 and station 17 of summer and station 4 and station 13 of monsoon. According to Sawyer and Mccarthy [46] classification of TH, all samples belong to very hard nature, in both seasons. It suggests that groundwater in the study area practices

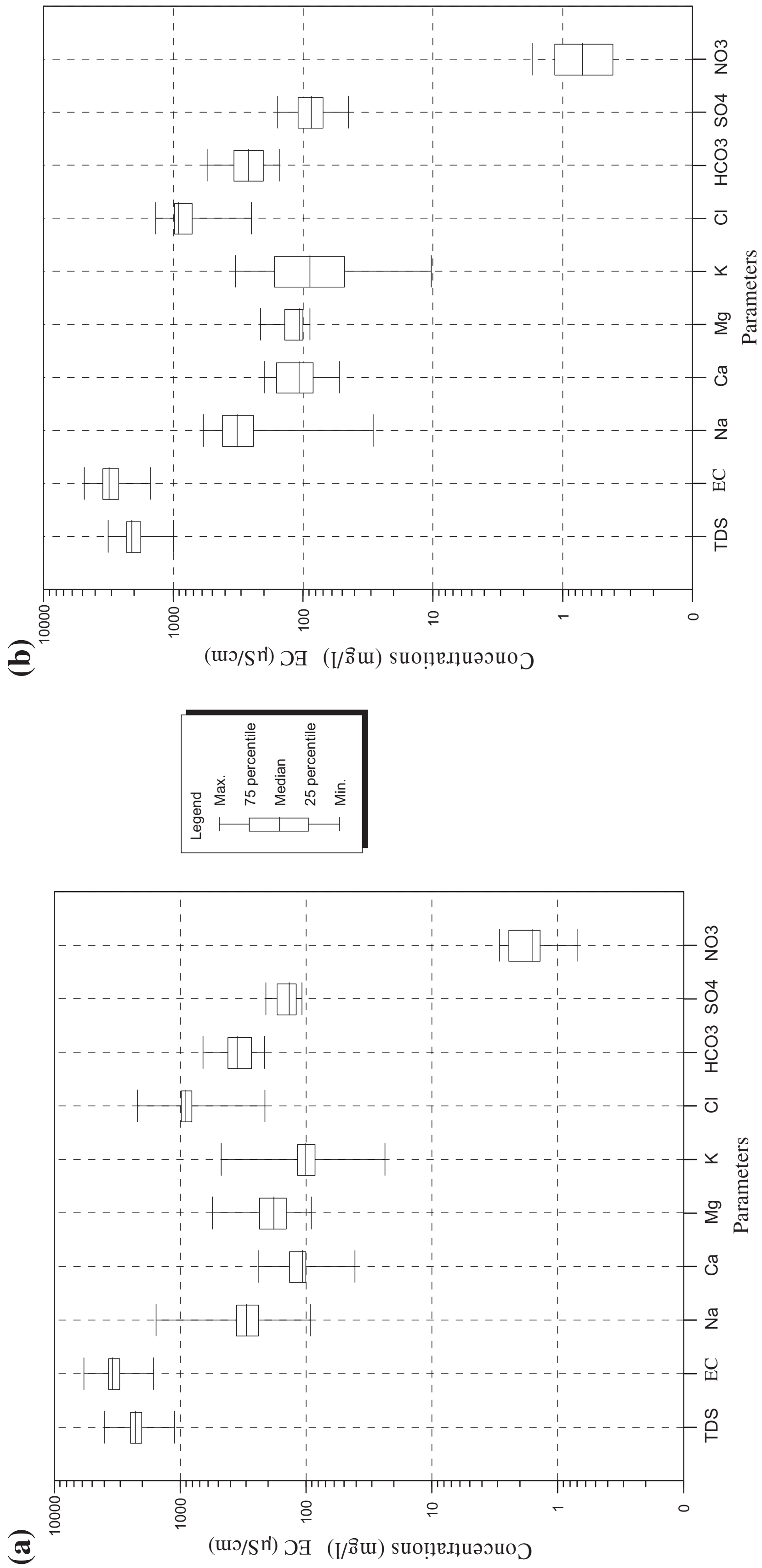

Fig. 2. Box and Whisker plot of the chemical components for (a) summer and (b) monsoon.

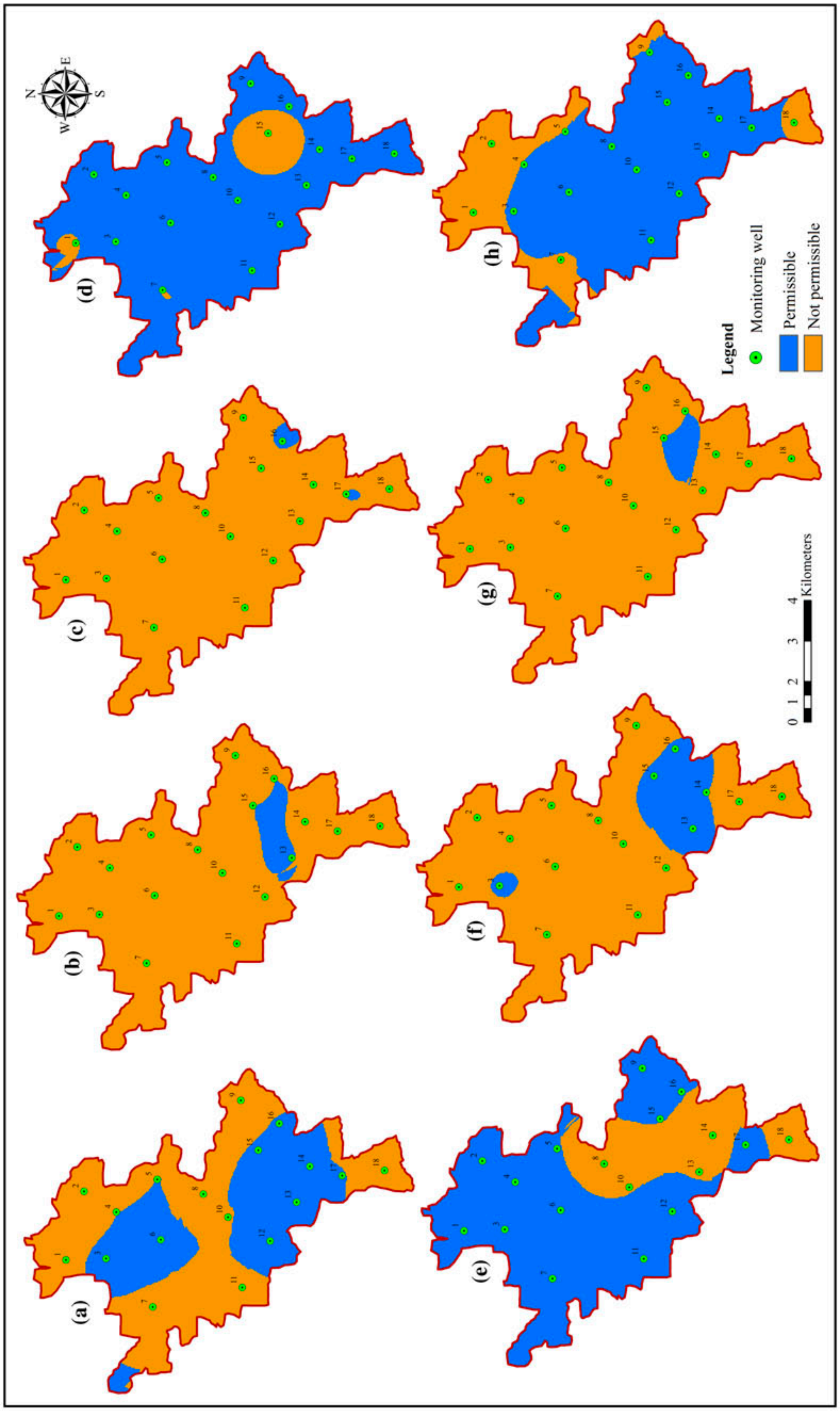

Fig. 3a. Groundwater quality parameter maps in summer season based on spatial ordinary kriging interpolation method (a) EC, (b) TDS, (c) TH, (d) Ca, (e) Mg, (f) Na, (g) Cl, and (h) HCO_3.

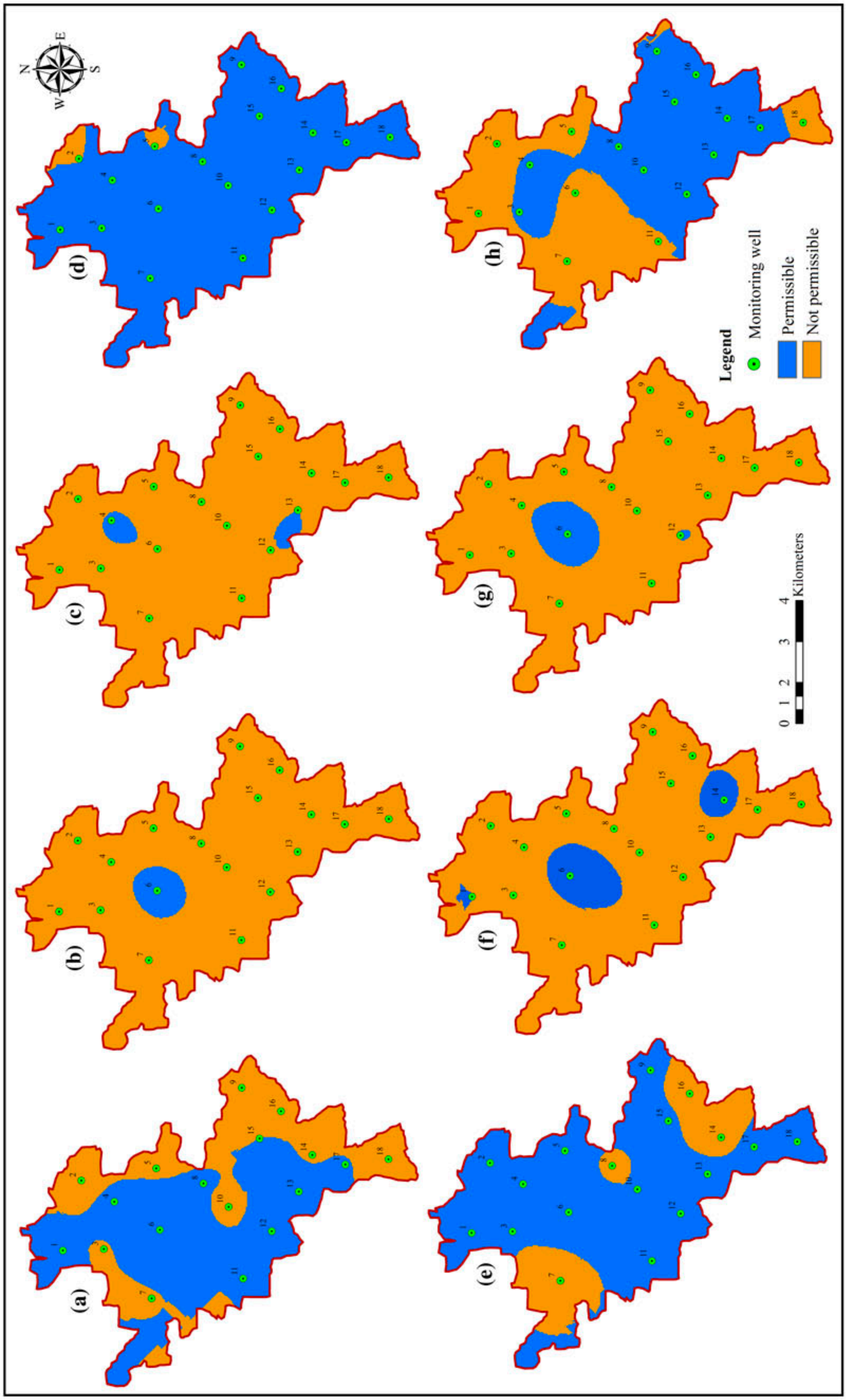

Fig. 3b. Groundwater quality parameter maps in monsoon season based on spatial ordinary kriging interpolation method (a) EC, (b) TDS, (c) TH, (d) Ca, (e) Mg, (f) Na, (g) Cl, and (h) HCO_3.

Table 1
Classifications of groundwater quality according to WHO [32], Handa EC [42], and Davis & Dewiest [44] TDS Standards

Parameters	Units	WHO [32] Most desirable limits	WHO [32] Maximum allowable limits	Percentage of samples exceeding allowable limits in summer	Percentage of samples exceeding allowable limits in monsoon
pH	–	6.5	8.5	–	77
EC	μS/cm	780	3,125	61	56
TDS	mg/L	500	1,500	95	95
TH	mg/L	300	600	95	95
Ca	mg/L	75	200	11	95
Mg	mg/L	30	150	67	17
Na	mg/L	–	200	89	83
K	mg/L	–	10	95	95
Cl	mg/L	200	600	95	89
HCO_3	mg/L	–	300	67	45
SO_4	mg/L	200	400	–	–
NO_3	mg/L	–	50	–	–
Handa [42] EC classification					
EC (μS/cm)	Water salinity	Summer Number of sample		Monsoon Number of sample	
0–250	Low (excellent)	–		–	
251–750	Medium (good)	–		–	
751–2,250	High (permissible)	–		3 (17%)	
2,251–6,000	Very high	18 (100%)		15 (83%)	
6,001–10,000	Extensively high	–		–	
10,001–20,000	Brines weakly conc.	–		–	
20,001–50,000	Brines moderately conc.	–		–	
50,001–100,000	Brines highly conc.	–		–	
>100,000	Brines extremely highly conc.	–		–	
Davis and Dewiest [44] TDS classification					
Total dissolved solids (TDS, mg/L)	Classification	Summer Number of sample		Monsoon Number of sample	
<500	Desirable for drinking	–		–	
500–1,000	Permissible for drinking	–		1 (5%)	
1,000–3,000	Useful for irrigation	17 (95%)		15 (84%)	
>3,000	Useful for drinking and irrigation	1 (5%)		2 (11%)	
Freeze and Cherrey [45] TDS classification					
<1,000	Freshwater type	–		1 (5%)	
1,000–10,000	Brackish water type	18 (100%)		17 (95%)	
10,000–100,000	Saline water type	–		–	
>100,000	Brine water type	–		–	

very high level of hardness in both seasons. High level of hardness may affect water supply system and normal soap consumption, and also human health such as arteriosclerosis, urolith, and stomach disorder [47].

3.2. Chemical groundwater components

3.2.1. Major cations

The order of dominant cations are as Na > Mg > K > Ca in summer and Na > K > Mg > Ca in monsoon. Among major cations, sodium played a dominant role in both seasons. Potassium was dominant ion in monsoon compared to the summer season. The concentrations of Ca and K are relatively low when compared to other major cations.

Calcium (Ca) concentration in groundwater samples varied from 41 to 241 mg/L in summer, and from 52 to 201 mg/L in monsoon season. In summer, calcium was detected to the impermissible limit at small patches of stations 1, 7, and 15, but in monsoon, it was shifted to two patches, stations 2 and 5 of northern part due to the influence of monsoonal rainfall. Eighty-nine percent of the groundwater samples fell at the maximum allowable limit, and 11% of groundwater samples exceeded the permissible limit in summer. Ninety-five percent of groundwater samples fell at the maximum allowable limit, and 5% of samples exceeded the permissible limit in monsoon. Magnesium (Mg) concentration ranged from 91 to 552 mg/L in summer, and from 88 to 213 mg/L in monsoon, 17% of groundwater samples fell at the maximum allowable limit, and 83% of groundwater samples exceeded the permissible limits in summer. Sixty-seven percent of samples fell at the maximum allowable limit, and 33% of samples exceeded the impermissible limit due to the fertilizer and domestic wastes.

The concentration of sodium (Na) in groundwater samples ranged from 93 to 1,554 mg/L in summer, and from 29 to 588 mg/L in monsoon season. The impermissible limit of sodium (>200 mg/L) in summer was observed at all study area except at small patches of stations 3, 13, 14, 15, and 16. However, the impermissible limit was decreased at stations 14, 6, and 1 in monsoon season. Eleven percent of groundwater samples fell at the maximum allowable limit and 89% of samples exceeded the permissible limit in summer. Seventeen percent of samples fell at the maximum allowable limit, and 83% of samples exceeded the permissible limit in monsoon. The higher concentration of Na was caused by water–rock interaction, seawater intrusion, and anthropogenic contamination. Sodium concentration played a vital role in groundwater for irrigation, and it caused the increase in hardness as well as the reduction in permeability of soil [48]. Potassium (K) concentration of groundwater samples varied from 9 to 472 mg/L in summer, and from 8 to 331 mg/L in monsoon. Potassium concentrations were slightly higher in summer than in monsoon season. The higher concentration of potassium may be originated from seawater intrusion and fertilizer [33].

3.2.2. Major anions

The dominant order of anions was $Cl > HCO_3 > SO_4 > NO_3$ in both seasons. Chloride and bicarbonate played a dominant role in both seasons. SO_4 and NO_3 showed relatively low concentrations compared to other major anions.

Chloride (Cl) concentration ranged from 213 to 2,180 mg/L in summer, and from 250 to 1,365 mg/L in monsoon season. The maximum allowable limit of WHO [32] for Cl is 600 mg/L. The permissible limit of Cl was observed only at small patch of stations 15 and 16 in summer, and it was observed only at stations 6 and 12 in monsoon. Ninety-five percent of groundwater samples exceeded the permissible limit of Cl, and 5% of samples fell at the permissible limit in summer. Eighty-nine percent of samples exceeded the permissible limit, and 11% of samples fell at the maximum allowable limit in monsoon season. Higher concentrations of Na and Cl ions in groundwater may point out the significant influences of seawater intrusion and fertilizer waste. High concentration of Cl may be harmful to human health such as heart, kidney, indigestion, and palatability [47].

Bicarbonate (HCO_3) concentrations of groundwater samples varied from 214 to 658 mg/L in summer, and from 153 to 549 mg/L in monsoon. Its concentration was slightly higher in summer than monsoon, but their distribution patterns were quite similar to each other. The permissible limit of HCO_3 is 500 mg/L. The increase in HCO_3 concentration may be attributed to the dissolution of CO_2 gas in the air or soil into water, and the irrigation return flow containing carbonate minerals precipitated in the soil. This is a common process in arid and semi-arid agricultural region.

Sulfate (SO_4) concentrations ranged from 108 to 209 mg/L in summer, and from 44.5 to 157 mg/L in monsoon. Sulfate concentrations were present within the permissible limit in both seasons. The slightly higher concentration of SO_4 was observed in summer compared to monsoon period. SO_4 may be originated from multiple ways, i.e. dissolution of sulfate minerals, oxidation of sulfide minerals, seawater intrusion, and anthropogenic sources. Nitrate (NO_3) concentration varied from 0.73 to 2.89 mg/L in summer and from 0.12 to 1.74 mg/L in monsoon. NO_3 concentration of groundwater sample also fell within the permissible limit in both seasons [49].

3.3. CCME water quality index

CCME WQI was used to rate overall water quality in spatial comparisons of location (Fig. 4).

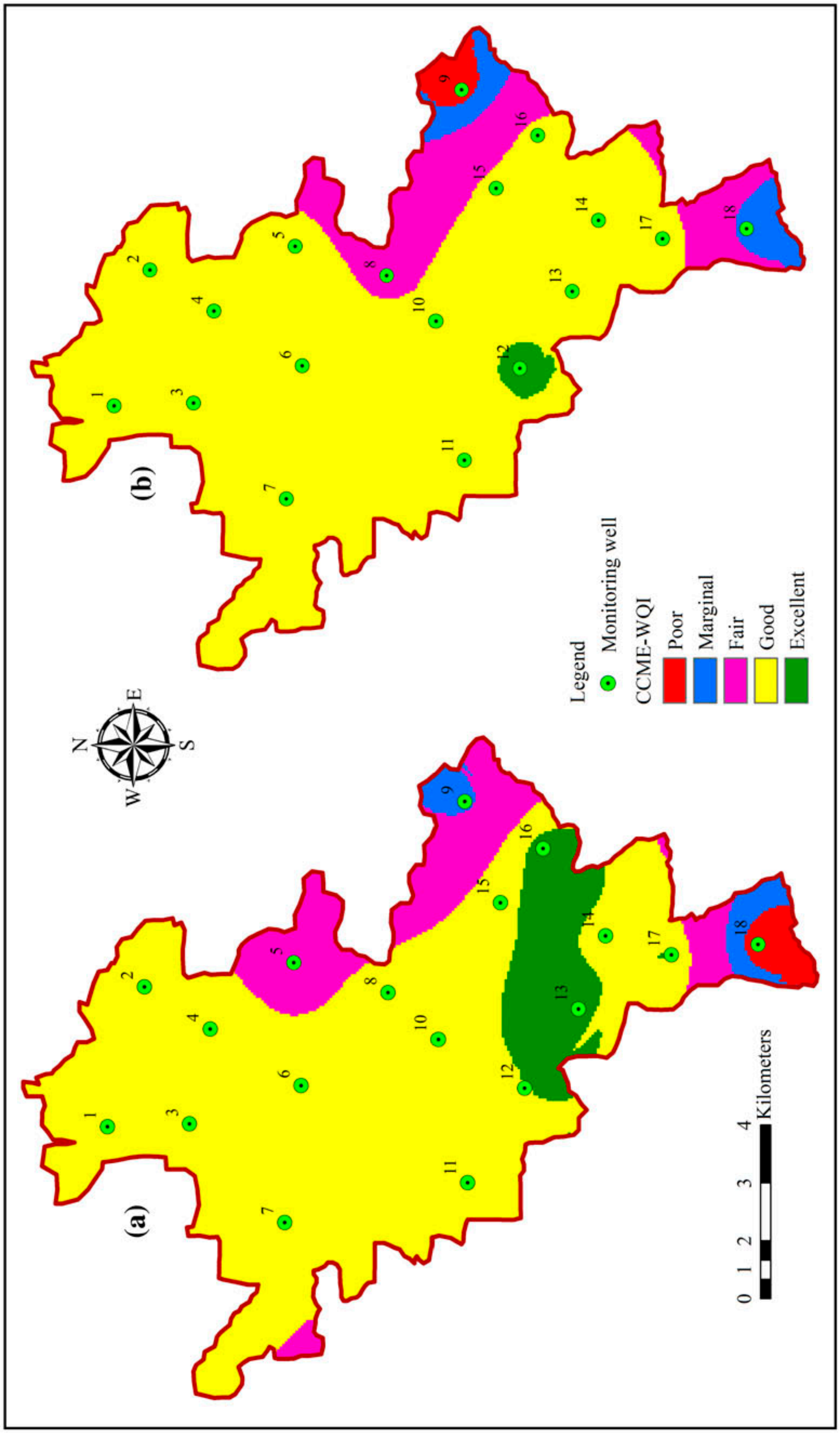

Fig. 4. Spatial interpolation maps of ordinary kriging based on CCME WQI of groundwater samples for (a) summer and (b) monsoon.

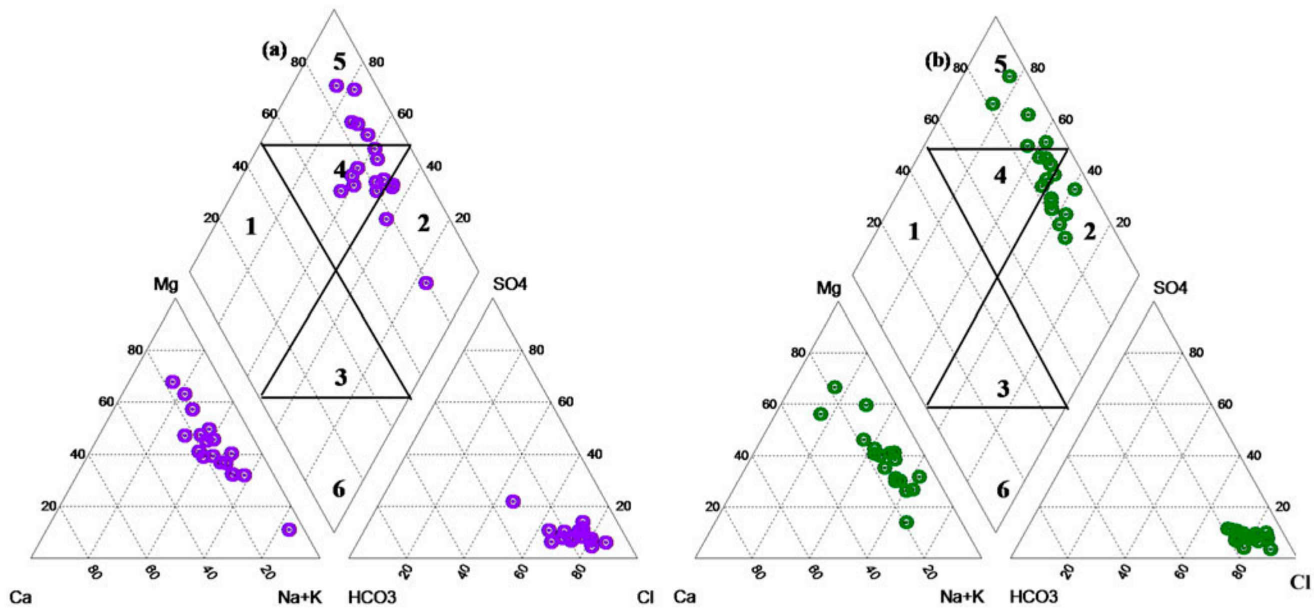

Fig. 5. Piper trilinear diagram showing groundwater samples for (a) summer and (b) monsoon.

The application of the CCME WQI was a worthy guideline for the assessment of absolute water quality. This research evaluated water quality aspect for the bionetwork initiatives, and used newly developed CCME WQI that can be simply understood by the public, water distributors, planners, managers, and policy-makers. It assessed spatial and temporal changes in water quality. Its absolute index scores ranged from 0 to 100, with values from 95 to 100 indicating best overall condition relative to the protection of aquatic life [40]. GIS-based spatial analysis and ordinary kriging interpolation techniques were proved as a potent tool to represent the distribution of major ions in the study area. The categories of groundwater quality evaluated by CCME WQI values revealed that most of the study area belonged to good sectors in both seasons. The spatial distribution map clearly showed that the small patches of poor groundwater quality were observed at the south and the southeast directions (stations 9 and 18) in both seasons. It suggests that the groundwater contamination sources of this area were related with irrigation wastes and seawater intrusion due to the overpumping of groundwater.

3.4. Groundwater classification

Analytical data obtained from groundwater samples are plotted on a Piper trilinear diagram [50] to understand the hydrogeochemical regime in both seasons (Fig. 5). Piper trilinear diagram is divided into six water types such as: (1) Ca–HCO_3, (2) Na–Cl, (3) mixed Ca–Na–HCO_3, (4) mixed Ca–Mg–Cl, (5) Ca–Cl, and (6) Na-HCO_3. Most of groundwater samples fall

Table 2
Hydrogeochemical facies of groundwater quality based on Piper trilinear diagram

Field no.	Summer Percentage of sample	Monsoon Percentage of sample	Interpretation result
1	–	–	Alkaline earths exceed alkalis
2	22%	39%	Alkalis exceed alkaline earths
3	–	–	Weak acids exceed strong acids
4	50%	34%	Strong acids exceed weak acids
5	28%	27%	Carbonate hardness (secondary alkalinity) exceeds 50% that is by alkaline earths and weak acids
6	–	–	Non-carbonate hardness (secondary salinity) exceeds 50%

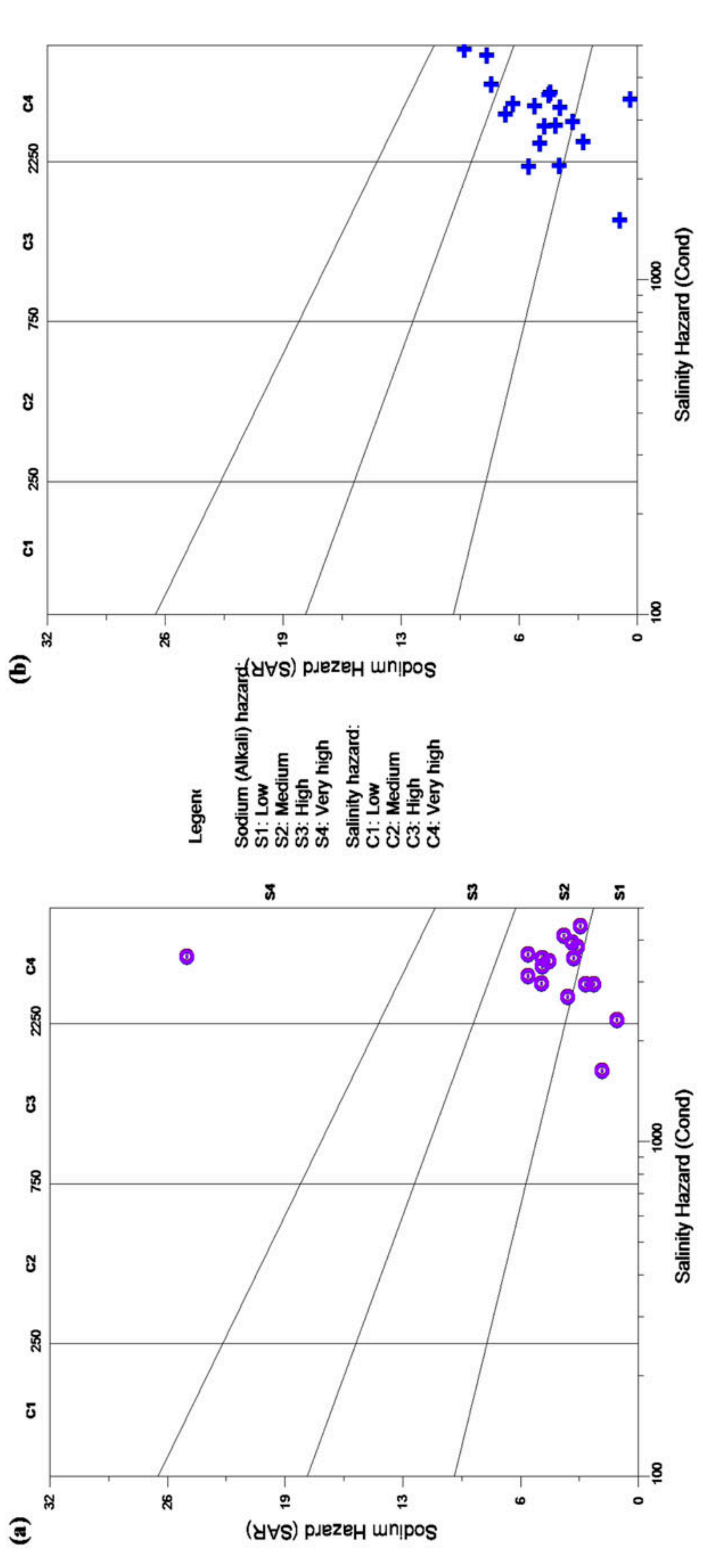

Fig. 6. Wilcox diagram showing groundwater samples for (a) summer and (b) monsoon.

at Ca–Mg-Cl and followed by Ca–Cl and Na–Cl types in summer season. In monsoon season, most of groundwater samples fall at Na–Cl and followed by Ca–Mg–Cl and Ca–Cl types. In cations, it is observed that alkalis exceed alkaline earths, and strong acids exceed weak acids. In anions, strong acid control over weak acid, and HCO_3 and Cl have influenced almost equal to Na, which denotes seawater intrusion into the freshwater aquifer system of this region (Table 2).

3.5. Irrigation classification

The suitability of groundwater in agricultural purpose was evaluated by Wilcox diagram [51]. Excessive Na and Cl makes water unsuitable for soils that contain exchangeable Ca and Mg ions. The total content of soluble salts such as Na, Ca, and Mg affect the suitability of groundwater for irrigation. The irrigation water containing a high proportion of Na and Cl will increase the exchange of Na content with the soil, and affect the soil permeability. Soil texture is changed and soil becomes hard to plow and unsuitable for seedling emergence [52]. According to Wilcox diagram (Fig. 6), the groundwater samples ranged between moderate to unsuitable for irrigation uses in both seasons. The primary effect of high EC reduces the osmotic activity of plants, and interferes with the absorption of water and nutrients from the soil. By Wilcox classification, most of groundwater samples in S2 and C4 category indicate medium sodium hazard and very high salinity hazard in both seasons.

4. Conclusion

Groundwater quality evaluation of GIS and CCME WQI methods was useful to visualize the spatial distribution of groundwater quality. The abundance sequence of cations was in the following order: $Na > Mg > K > Ca$ in summer and $Na > K > Mg > Ca$ in monsoon. Anions represented the following order: $Cl > HCO_3 > SO_4 > NO_3$ in both seasons. CCME WQI values indicated that most of the city fell at good water quality type in both seasons. Small patches in south and southeast directions (stations 9 and 18) showed poor groundwater quality. It suggests that the groundwater contamination sources of this area were related with irrigation wastes and seawater intrusion due to the overpumping of groundwater. Hydrogeochemical facies suggest that majority of groundwater samples fall at Ca–Mg–Cl and followed by Ca–Cl and Na–Cl water types in summer. In monsoon, Na–Cl and followed by Ca–Mg–Cl and Ca–Cl types were predominated in this region. According to Wilcox classification, most of groundwater samples fell at S2 and C4 category indicating medium sodium hazard and very high salinity hazard. Groundwater quality can be improved in the study area by implementing the groundwater management scheme of artificial recharge that ensures sustainable and non-hazardous groundwater resources for drinking, agriculture, and domestic purposes.

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