Evaluation of Groundwater Quality Using GIS Techniques in Part of Udupi District, Karnataka, Southern India

Vignesh Akshitha, Keshava Balakrishna, and Harikripa Narayana Udayashankar

Abstract Groundwater is a major source for drinking and agricultural purposes to most of the population in Udupi district, southern India. The objective of the current study is to evaluate the spatial distribution of major ions and drinking water quality index in the study area. Groundwater samples ($N = 100$) were collected during pre-monsoon season. The collected samples were analyzed for major cations and anions. Based on electrical conductivity, 90 open wells were classified as fresh (<1500 µS/cm), four open wells as brackish (1500–3000 µS/cm) and six open wells as saline (>3000 µS/cm). The evaluation of drinking water quality index identified that seven groundwater samples are good, four are poor, two are very poor, three are considered to be unsuitable for drinking and 84 groundwater samples are excellent for drinking purposes. Human health risk assessment revealed that infants were more vulnerable to health risk than other age groups. The concentrations of nitrate in the two open wells were above the prescribed limit (>45) which could cause human health risk for all the age groups. Water management plan in the study area should prioritize to reduce the nitrate contamination in the study area.

Keywords Saltwater intrusion · Human health risk assessment · Nitrate contamination · Water quality index

1 Introduction

The demand for groundwater is increasing in recent years because of increase in the global population, urbanization, industrialization and irrigation. The quality of groundwater relies on various factors such as the capacity of recharge, quality of recharged water, subsurface geochemical process overlying land use/land cover pattern and anthropogenic process [1]. The critical issue with groundwater is that quality is difficult to restore once it is contaminated. Thus, it is essential to preserve

V. Akshitha · K. Balakrishna (✉) · H. N. Udayashankar
Department of Civil Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal 576104, India
e-mail: k.balakrishna@manipal.edu

A. K. Dikshit et al. (eds.), *Innovative Trends in Hydrological and Environmental Systems*, Lecture Notes in Civil Engineering 234,
https://doi.org/10.1007/978-981-19-0304-5_28

the quality of groundwater for its sustainable development and management. Groundwater quality is evaluated by calculating drinking water quality indices from physical and chemical water quality parameters [2]. Geographical Information System (GIS) is an effective tool for assessing the spatial variability of physico-chemical parameters and groundwater quality [3, 4]. The spatial variability maps enable to identify the polluted areas and extent of pollution. Water quality index (WQI) is a useful tool for decision makers in order to develop new strategies for water resource management [5, 6]. Agricultural activities and discharge of domestic sewage lead to increased concentration of nitrate in the groundwater environment [7, 8]. The human health risk evaluation is essential to understand the impact of nitrate contamination on human health. Nitrates easily dissolve in water and commonly present in groundwater through leaching process [8, 9]. Increased concentration of nitrate in the groundwater can be hazardous to human health. Continuous monitoring of drinking water quality is necessary for determining the areas requiring water management plans. The main objective of the present study is to evaluate the ground water quality and human health risk of nitrate contamination in parts of Udupi district. There is no in-depth study that is carried out in the study area to evaluate drinking water quality and human health risk associated with consumption.

2 Materials and Methods

2.1 Study Area

The selected study area is a part of Udyavara river basin. The Udyavara river basin has 25 micro-watersheds from which nine micro-watersheds are selected for the present study. Udyavara River originates in the foothills of the Western Ghats, Karkala Taluk. It flows in Udupi and Karkala taluk. It flows parallel to the sea shore for about 10 km before it meets the Arabian Sea near Malpe. The climate is tropical, hot and humid with 4500 mm annual rainfall. The average atmospheric temperatures ranged from 22 to 33 °C. Geologically the river basin is composed of granite gneiss, laterite, migmatite gneiss and fine sand. Groundwater is present in weathered zone of granite and coastal alluvial sediments. The study area lies between longitudes 74°41′ and 74°48′ E and latitudes 13°12′ and 13°22′ N (Fig. 1) and covers an area of ~130 km^2 [10].

2.2 Sampling and Analytical Techniques

In the present study, 100 monitoring wells within the study area were chosen for ground water sampling during pre-monsoon season, 2019 (Fig. 2). The geographic

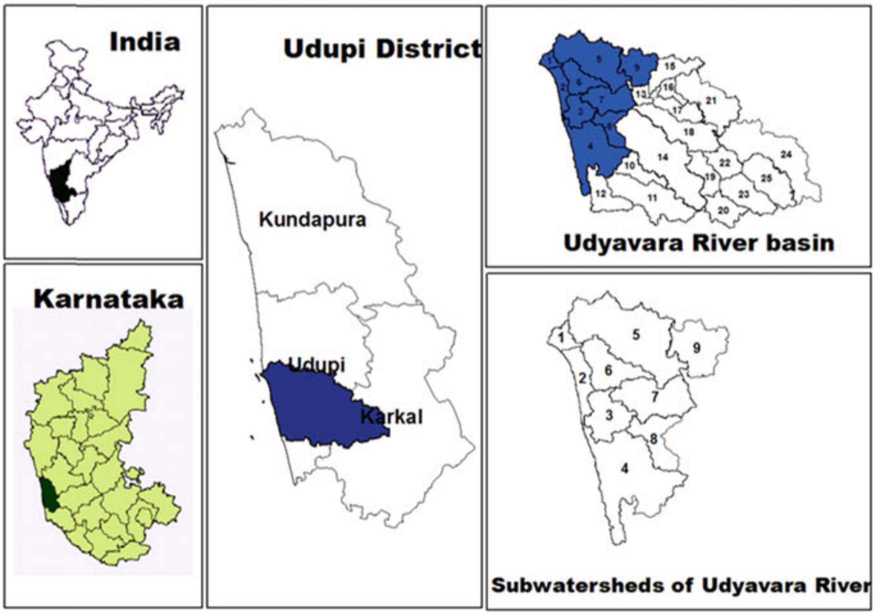

Fig. 1 Location map of the study area

coordinates of the well was recorded using Global Positioning System (GPS—Garmin make) and loaded to the GIS platform. Monitoring well location map was created using ArcGIS version 10.1. The collected samples were filled to 1000 ml pre-cleaned polypropylene bottles. The sample collected bottles were transported and stored at 4 °C cold room to avoid any significant chemical alteration [11]. The parameters total dissolved solids (TDS), electrical conductivity (EC) and pH were determined onsite using HACH multiparameter probes. Ion chromatography (IC, Dionex™ ICS1100) was used to analyze major cations (Na^+, Ca^{2+}, Mg^{2+}, K^+) and anions (Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}). Bicarbonate was measured using Metrohm auto-titrator. The accuracy of the analysis was assessed by calculating the charge balance error (CBE). CBE values of the analyzed groundwater data were within 10%.

2.3 Water Quality Index Calculation

WQI is calculated using weighted arithmetic formula [12]. Many researchers across the globe calculated WQI and identified polluted and unpolluted groundwater [13–16]. The overall results of WQI are interpolated and spatial variability map of groundwater quality is prepared. WQI calculation has four steps. The steps include various water quality parameter measurements and its conversion into dimensionless number. Next, weight assignment is done depending on their significance and aggregation of

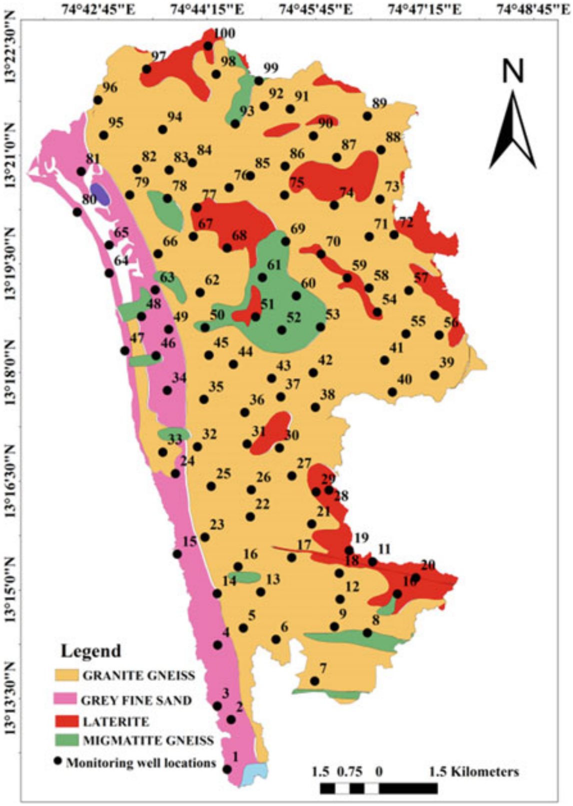

Fig. 2 Monitoring well locations in the study area

quality rating based on the final WQI values. The WQI is calculated using Eq. 1,

$$\text{WQI} = \sum_{i=1}^{n} W_i \times Q_i \tag{1}$$

where W_i is the relative weight of each water quality parameters and Q_i is the quality rating. The W_i is calculated using the Eq. 2,

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{2}$$

where w_i is the weight of each water quality parameter and n is the number of parameters. The Qi is calculated using the Eq. 3.

$$Q_i = 100 \times \frac{C_i}{S_i} \tag{3}$$

Table 1 Weight and relative weight of groundwater quality parameters used in the computation of WQI

Parameters	Weight (w_i)	Prescribed standard (S_i) as per WHO	Relative weight (W_i)
pH	4	6.5–8.5	0.11
TDS	5	500	0.13
Na^+ (mg/l)	4	200	0.11
K^+ (mg/l)	3	20	0.08
Mg^{2+} (mg/l)	3	30	0.08
Ca^{2+} (mg/l)	3	75	0.08
Cl^- (mg/l)	4	250	0.11
NO_3^- (mg/l)	5	45	0.13
SO_4^{2-} (mg/l)	2	200	0.05
HCO_3^- (mg/l)	3	200	0.08
	36		1

where C_i is the measured concentrations and S_i is the standard value of water quality parameters as per World Health Organization [17] drinking water quality standard. Weight for each parameter is assigned between 1 and 5 (Table 1).

2.4 Assessment of Human Health Risk

The present study used USEPA (United States Environmental Protection Agency) method to assess human health risk associated with consumption of groundwater contaminated with . Increased concentration of NO_3^- in drinking water lead to non-carcinogenic human health risk [18]. Human health risk is calculated for different age groups such as infants (0–1 years), kids (1–7 years), children (8–12 years), teens (13–20 years), adults (21–60 years) and aged people (61–69 years). The hazard quotient (HQ) due to ingestion through drinking water is calculated using the Eq. 4 [19].

$$\mathrm{HQ} = \frac{\mathrm{ADI}}{\mathrm{RfD}} \tag{4}$$

where ADI is average daily ingestion (mg/kg/day). RfD is reference dosage of the nitrate, which is 1.6 mg/kg/day based on USEPA [18] guideline. The ADI is calculated using the Eq. 5.

$$\mathrm{ADI} = \frac{\mathrm{CPW} \times \mathrm{IR} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{Bw} \times \mathrm{AT}} \tag{5}$$

CPW is measured concentration of nitrate in groundwater sample (mg/l). IR is average ingestion rate (in liters) which were considered as 0.8 (infants), 1.35 (kids), 1.9 (children), 2.2 (teens), 2.94 (adults) and 2.6 (aged people). ED is exposure duration (in years) which were taken as 0.75 (infants), 8 (kids), 13 (children), 40 (adults) and 64 (aged people). EF is exposure frequency which is 365 days. BW is body weight (in kg) which were noted as 11 (infants), 25 (kids), 35 (children), 55 (teens), 76 (adults) and 65 (aged people). AT is average life expectancy (in days) 274 (infants), 2920 (kids), 4745 (children), 6570 (teens), 14,600 (adults) and 23,360 (aged people).

2.5 Data Analysis in GIS

Geo-statistical interpolation method in ArcGIS is useful to identify the suitable and unsuitable zones for drinking water. In this study, Inverse Distance Weighted (IDW) analysis is used to examine the spatial variation of analyzed groundwater quality parameters, drinking water quality and human health risk in different age groups. IDW interpolates unknown values using weighted average of two nearest known points. The weight is determined based on the distance between known and unknown points.

3 Results and Discussions

3.1 General Hydrogeochemistry

The mean pH value in the pre-monsoon was 7.4 indicating slightly alkaline pH in the study area. pH of 32 groundwater samples were not within the prescribed drinking water standard limit (Fig. 3a). The spatial distribution of electrical conductivity (EC) during pre-monsoon season in collected groundwater samples ranged from 44.5 to 44000 μS/cm. Based on the EC values during pre-monsoon season, groundwater samples varied between fresh, brackish and saline water in nature. High EC was observed in the north-western part of the coastline indicating saline water intrusion. TDS ranged from 30 to 29,828 mg/l with mean value of 630 mg/l (Fig. 3b). Based on the TDS values, groundwater in the study area is classified into four groups [20]. Table 2 shows groundwater classification for the suitability of drinking purpose. The dominance of major anions and cations in the pre-monsoon season was $Na^+ > Ca^{2+} > Mg^{2+} > K^+ = Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$.

Cations: Sodium and calcium were dominant cations in pre-monsoon season (Fig. 4a, d). This is due to the presence of plagioclase feldspar minerals in the granitic rock. The maximum potassium values were 208 mg/l during pre-monsoon season (Fig. 4b). Potassium concentration was high in groundwater in coastal wells due to salinity

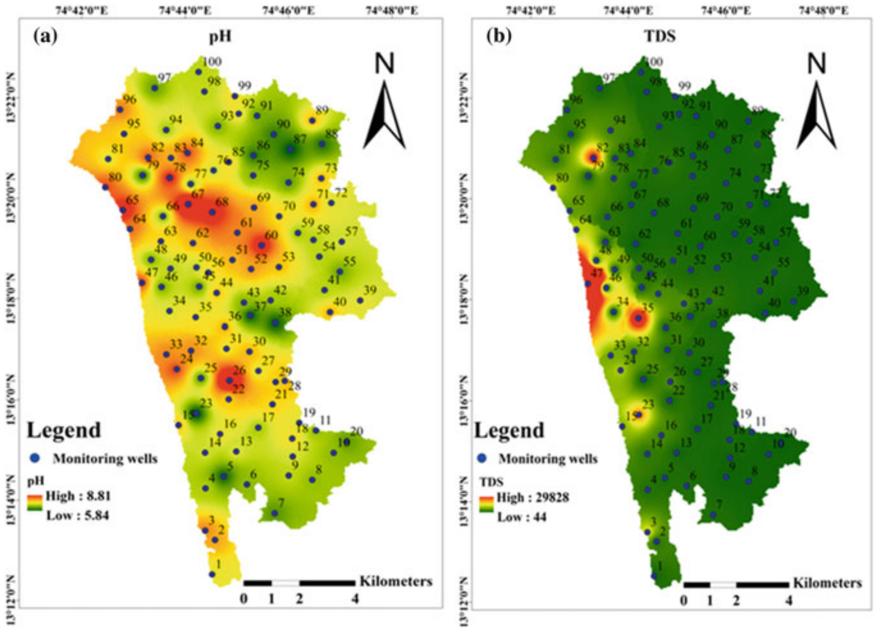

Fig. 3 Spatial distribution of **a** pH, **b** TDS in pre-monsoon

Table 2 Groundwater classification in the study area based on TDS values

TDS (mg/l)	Groundwater classification	Percentage of samples
<500	Desirable for drinking purposes	88
500–1000	Permissible for drinking purposes	3
1000–3000	Desirable for irrigation purposes	6
>3000	Unfit for drinking and irrigation	3

content [21]. The magnesium concentration ranged from 0.44 to 957 mg/l during pre-monsoon monsoon (Fig. 4c). The magnesium concentration was high in coastal wells and low in inland wells. The low concentration was because of the lack of carbonate rocks in the study area. Saltwater intrusion process resulted in high concentration of magnesium and potassium in groundwater present in coastal region.

Anions: Chloride was the dominant anion and ranged from 4.3 to 17,402 mg/l (Fig. 4e). Saltwater mixing led to the high chloride concentrations in the coastal wells [22]. Chloride may also contribute from wet atmospheric deposition through precipitation. The nitrate concentration ranged between 0.31 and 171 mg/l (Fig. 4f). The nitrate source in the groundwater is considered to be non-lithological [23]. Anthropogenic activities such as agricultural run-off and percolation from the soak pit are identified as causes of nitrate in the study area. Phosphate was below the detection limit (BDL) in the study area. Sulfate concentration varied between 0.43 and

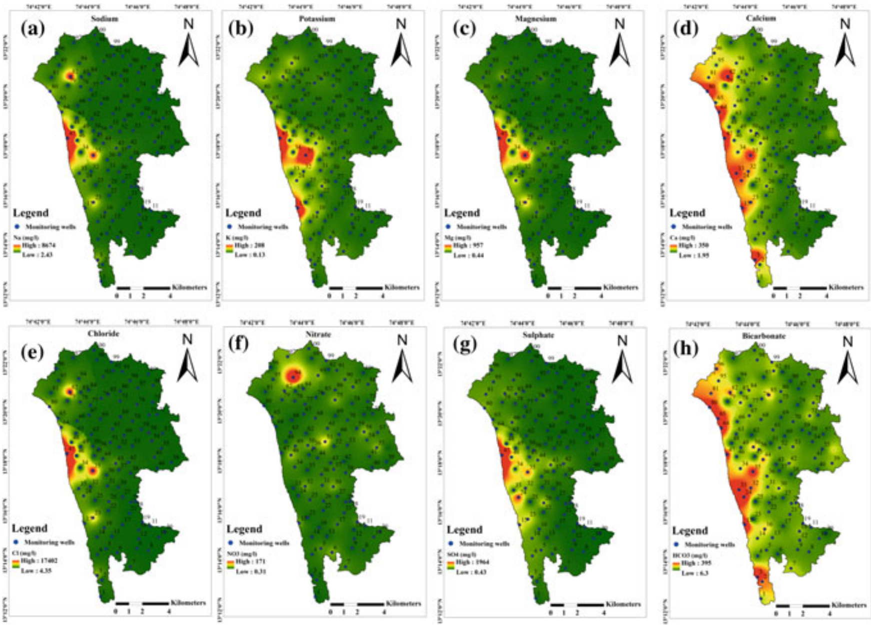

Fig. 4 Spatial distribution of **a** Na, **b** K, **c** Mg ,**d** Ca, **e** Cl, **f** NO_3, **g** SO_4 and **h** HCO_3 in pre-monsoon

1963 mg/l (Fig. 4g). Sulfate concentrations were high in the coastal wells were due to saltwater mixing process. Most of the inland wells showed very low concentrations of sulfate due to the absence of sulfate minerals bearing host rock. The maximum bicarbonate concentration was 395 mg/l. Bicarbonate concentration in the open wells near the coastal part was higher than the inland wells because of the impact of marine environment (Fig. 4h) [24].

3.2 *Groundwater Quality Index*

The five categories of water quality index are (i) water unsuitable for drinking (>300), (ii) very poor water (200–300), (iii) poor water (100–200), (iv) good water (50–100), (v) excellent water (0–50). The results of WQI estimated ranged from 13.9 to 2554. Based on the classification, 84 groundwater samples were excellent for drinking purposes. Whereas, seven were good, four were poor, two were very poor and three were considered to be unsuitable for drinking. The western part of study area near the coast is considered to be contaminated due the influence of saltwater. The increased concentration of major anions and cations lead to change in the quality of groundwater. The inland water samples posed excellent water quality and suitable for drinking. Figure 5 shows spatial distribution of water quality index in the study area.

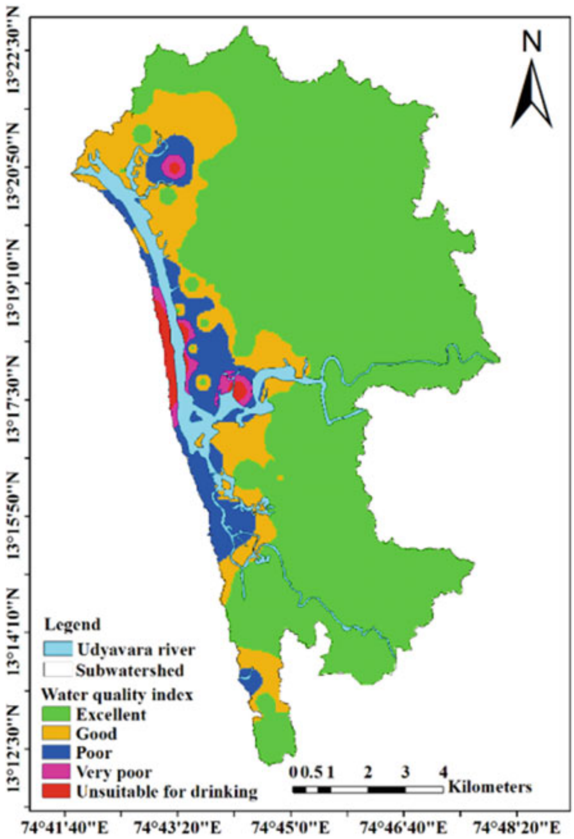

Fig. 5 Map showing spatial variability of WQI

3.3 Human Health Risk of Nitrate

Hazard quotient value >1 in the human health risk evaluation indicates potential non-carcinogenic health risk for humans and <1 indicates no potential health risk. Nitrate concentration >45 mg/l in groundwater can lead to health hazards [25]. The hazard quotient for infants, kids, children, teens, adults and aged people ranged from 0.01–7.78, 0.01–5.78, 0.01–5.81, 0.01–4.28, 0.01–4.14 and 0.01–4.28 respectively. The assessment result showed that 11%, 4%, 4%, 2%, 2% and 2% of the samples pose potential health risk (HQ > 1) for infants, kids, children, teens, adults and aged people respectively (Fig. 6). The infants were more vulnerable to health risk among other age groups. The open wells with high potential risk are present in residential area and nitrate contaminated due to leakage of soak pit in the study area. Nitrate concentration in two open wells (S94 and S51) were exceeding the prescribed drinking water standard. These two open wells pose high potential health risk for all the age groups. Therefore two open wells require attention in order to control the nitrate contamination.

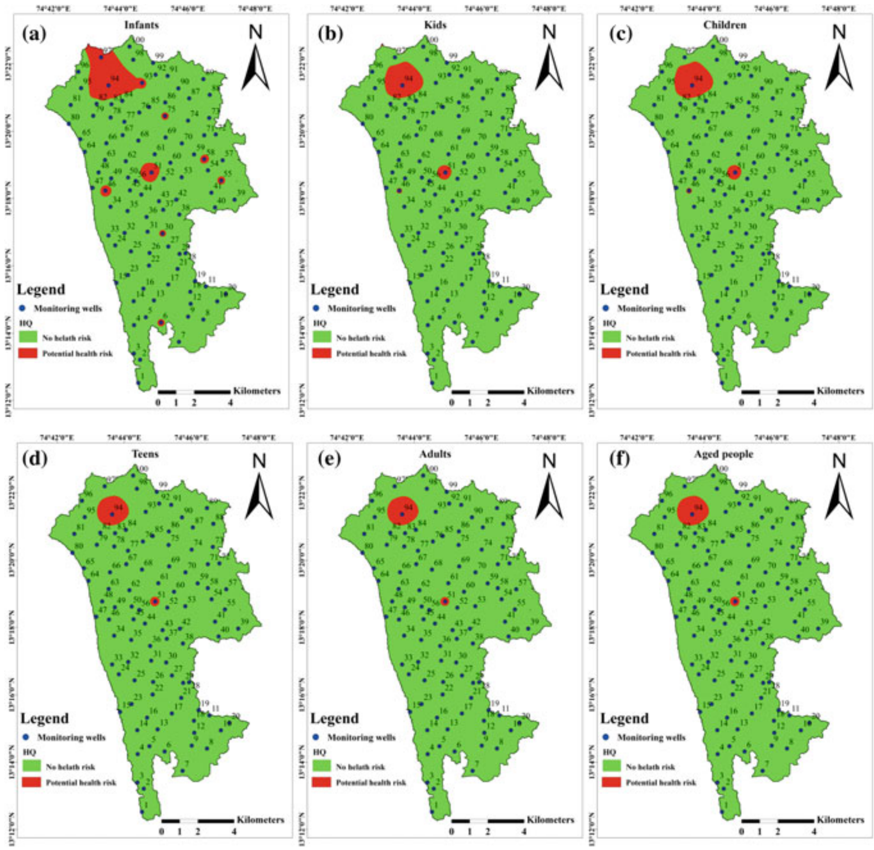

Fig. 6 Spatial distribution of HQ **a** infants, **b** kids, **c** children, **d** teens, **e** adults and **f** aged people in pre-monsoon

4 Conclusions

The present study evaluates the drinking water quality and nitrate contamination in the study area. WQI estimation revealed that 84 groundwater samples are excellent for drinking purposes, seven are good, four are poor, two are very poor and three are considered to be unsuitable for drinking. The western part of study area is considered to be contaminated due the influence of saltwater. Nitrate concentrations in two open wells exceeded the prescribed drinking water standard and pose high potential health risk for all the human age groups. Evaluation of groundwater quality using spatial interpolation of WQI delineates coastal and north-west region of study area need remedial measures to improve the drinking water quality. The findings of the study will be useful for the policy makers to make appropriate water quality management measures in the study area.

Acknowledgements The first author would like to acknowledge the support of Manipal Academy of Higher Education for providing Dr. T.M.A. Pai scholarship.

References

1. Vasanthavigar, M., Srinivasamoorthy, K., & Vijayaragavan, K. (2010). Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environmental Monitoring and Assessment, 171*, 595–609. https://doi.org/10.1007/s10661-009-1302-1
2. Saeedi, M., Abessi, O., Sharifi, F., & Meraji, H. (2010). Development of groundwater quality index. *Environmental Monitoring and Assessment, 163*(1–4), 327–335. https://doi.org/10.1007/s10661-009-0837-5
3. Klimas, A. A. (1996). Methodology for mapping shallow groundwater quality in urbanized areas: A case study from Lithuania. *Environmental Geology, 27*(4), 320–328. https://doi.org/10.1007/BF00766701
4. Vaiphei, S. P., Kurakalva, R. M., & Sahadevan, D. K. (2020). Water quality index and GIS-based technique for assessment of groundwater quality in Wanaparthy watershed, Telangana India. *Environmental Science and Pollution Research, 27*(36), 45041–45062. https://doi.org/10.1007/s11356-020-10345-7
5. Ketata, M., Gueddari, M., & Bouhlila, R. (2012). Use of geographical information system and water quality index to assess groundwater quality in El Khairat deep aquifer (Enfidha, Central East Tunisia). *Arabian Journal of Geosciences, 5*, 1379–1390. https://doi.org/10.1007/s12517-011-0292-9
6. Rawat, K., Pradhan, S., Tripathi, V., Jeyakumar, L., & Singh, S. K. (2019) Statistical approach to evaluate groundwater contamination for drinking and irrigation suitability. *Groundwater for Sustainable Development, 9*, 100251.https://doi.org/10.1016/j.gsd.2019.100251
7. Kim, H., Yu, S., Oh, J., Kim, K., Lee, J., Moniruzzaman, M., Kim, H.K., & Yun, S. (2019). Nitrate contamination and subsequent hydrogeochemical processes of shallow groundwater in agro-livestock farming districts in South Korea. *Agriculture, Ecosystems & Environment, 273*, 50e61. https://doi.org/10.1016/j.agee.2018.12.010
8. Liu, J., Peng, Y., Li, C., Gao, Z., & Chen, S. (2021). Characterization of the hydrochemistry of water resources of the Weibei Plain, Northern China, as well as an assessment of the risk of high groundwater nitrate levels to human health. *Environmental Pollution, 268*, 115947.https://doi.org/10.1016/j.envpol.2020.115947
9. Chen, J., Wu, H., & Qian, H. (2016). Groundwater nitrate contamination and associated health risk for the rural communities in an agricultural area of ningxia, northwest China. *Exposure Health, 8*(3), 349–359. https://doi.org/10.1007/s12403-016-0208-8
10. Akshitha, V., Balakrishna, K., & Udayashankar, H. N. (2021). Assessment of hydrogeochemical characteristics and saltwater intrusion in selected coastal aquifers of southwestern India. *Marine Pollution Bulletin, 173*, 112989.https://doi.org/10.1016/j.marpolbul.2021
11. APHA. (2012). *Standard methods for the examination of water and wastewater*, (twenty-second ed.). American Public Health Association, American Water Works Association, Water Environment Federation.
12. Horton, R. K. (1965). An index number system for rating water quality. *Journal of the Water Pollution Control Federation, 37*, 300–306. https://doi.org/10.12691/ajwr-1-3-3
13. Loh, Y. S. A., Akurugu, B. A., Manu, E., & Aliou, A. S. (2020). Assessment of groundwater quality and the main controls on its hydrochemistry in some Voltaian and basement aquifers, northern Ghana. *Groundwater for Sustainable Development, 10*, 100296.https://doi.org/10.1016/j.gsd.2019.100296

14. Mallick, J., Kumar, A., Almesfer, M. K., Alsubih, M., Singh, C. K., Ahmed, M., & Khan, R. A. (2021). An index-based approach to assess groundwater quality for drinking and irrigation in Asir region of Saudi Arabia. *Arabian Journal of Geosciences, 14*(3), 1–17. https://doi.org/10.1007/s12517-021-06506-8
15. Singaraja, C. (2017). Relevance of water quality index for groundwater quality evaluation: Thoothukudi District, Tamil Nadu India. *Appl Water Sci, 7*(5), 2157–2173. https://doi.org/10.1007/s13201-017-0594-5
16. Singh, C. K., Shashtri, S., Mukherjee, S., Kumari, R., Avatar, R., Singh, A., & Singh, R. P. (2011). Application of GWQI to assess effect of land use change on groundwater quality in lower Shiwaliks of Punjab: Remote sensing and GIS based approach. *Water Resources Management, 25*(7), 1881–1898. https://doi.org/10.1007/s11269-011-9779-0
17. World Health Organization. (2011). *Guidelines for drinking-water quality* (4th ed.). World Health Organization. https://apps.who.int/iris/handle/10665/4458
18. USEPA (United States Environmental Protection Agency). (1989). Superfund Public Health Evaluation Manual (Washington, DC).
19. USEPA (US Environmental Protection Agency). (2001). Baseline Human Health Risk Assessment Vasquez Boulevard and I-70 Superfund Site. Denver CO. http://www.epa.gov/region8/superfund/sites/VB-170-Risk.pdf
20. Davis, S. N., & DeWiest, R. J. (1966). *Hydrogeology*. Wiley.
21. El Ghandour, M. F. M., Khalil, J. B., & Atta, S. A. (1983). Distribution of sodium and potassium in the groundwater of the Nile Delta region (Egypt). *CATENA, 10*(1–2), 175–187. https://doi.org/10.1016/S0341-8162(83)80015-0
22. Howard, K. W. F., & Lloyd, J. W. (1983). Major ion characterization of coastal saline ground waters. *Groundwater, 21*(4), 429–437. https://doi.org/10.1111/j.1745-6584.1983.tb00744.x
23. Ritzi, R. W., Wright, S. L., Mann, B., & Chen, M. (1993). Analysis of temporal variability in hydrogeochemical data used for multivariate analyses. *Ground Water, 31*, 221–222. https://doi.org/10.1111/j.1745-6584.1993.tb01814.x
24. Subba Rao, N., Saroja Nirmala, I., & Suryanarayana, K. (2005). Groundwater Quality in a Coastal Area: A Case Study from Andhra Pradesh India. *Environmental Geology, 48*(4–5), 543–550. https://doi.org/10.1007/s00254-005-1306-2
25. World Health Organization. (2017). Guidelines for drinking-water quality: Fourth edition incorporating the first addendum. ISBN978-92-4-154995-0.