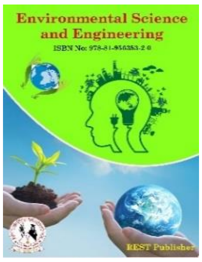
Environmental Science and Engineering
Vol: 2(3), 2023
REST Publisher; ISBN: 978-81-956353-2-0
Website: http://restpublisher.com/book- series/environmental-science-and-engineering/
DOI: https://doi.org/10.46632/ese/2/3/2



Studies on Groundwater Pollution: A Case Study of Beenaganj-Chachura Block

Sanjeev Kumar Ahirwar, *Yogesh Iyer Murthy
Jaypee University of Engineering & Technology, Guna, India.
*Corresponding author Email: yogesh.murthy@juet.ac.in

Abstract: *The present research work investigates the impact of natural and anthropogenic inputs on the chemistry and quality of the groundwater in the Beenaganj-Chachura block of Madhya Pradesh, India. A total of 50 groundwater samples were examined for Nitrates, Fluoride, chlorides, TDS, Calcium, Magnesium, pH, total hardness and conductivity and their impact on Entropy Weighted Water Quality Index (EWQI) and pollution index of groundwater (PIG) was investigated. According to analytical findings, Ca, Mg, Cl-, SO42-, and NO3- exceed the desired limit (DL) and permitted limit (PL) set by the Bureau of Indian Standards (BIS) and the World Health Organization (WHO). According to PIG findings, 76%, 16%, and 8% of groundwater samples, respectively, fell into the insignificant, low, and moderate pollution categories*.

1. INTRODUCTION

Groundwater is the primary source of water for drinking and agriculture in the world's arid and semi-arid regions. Because surface water supplies are largely insufficient in those areas, reliance on groundwater has grown considerably in recent years [1, 2]. Contamination of groundwater, on the other hand, is a pervasive and visible concern on both regional and global dimensions [3, 4]. Many studies have been conducted in recent years to examine groundwater quality, the variables influencing water quality, and the impact of geogenic and anthropogenic sources of pollution. Subba Rao et al. [2], for example, evaluated groundwater quality standards utilizing ionic spatial distribution, entropy water quality index, and principal component analysis. Rao et al. [5] used a pollution index of groundwater (PIG) to analyze groundwater quality in the rural region of Wanaparthy in Telangana state, India, and discovered that the PIG approach gives significant information on the appropriateness of groundwater for household uses. Li et al. [6] assessed the geochemical parameters influencing water quality in Guizhou, China, and discovered that carbonate dissolution is a critical contributor. Adimalla et al. [7] assessed the acceptability of groundwater for drinking in a rural area in Telangana state, India, and concluded that geological weathering and anthropogenic activities influence groundwater quality. These investigations show that fluctuations in groundwater quality are caused by geochemical variables such as rock water interactions, dissolution processes, and ion exchange, as well as anthropogenic activities [8-12]. In particular, irregular rainfall, fast urbanization, extensive irrigation activity, excessive fertilizer use, unplanned industrialisation, population increase, man-made/anthropogenic and geogenic pollution all contribute to significant groundwater contamination [13-15]. As a result, drinking dirty water is a major concern to people, causing a variety of health issues in many parts of the world [16]. In India, groundwater is more commonly used for home purposes than surface water. According to a recent research by Rao et al. [5], groundwater is used for drinking by 80% of the rural population and 50% of the urban population in India. However, just a few reports on groundwater quality from rural India have been published [5]. As a result, in the current study, the Beenaganj-Chachura block was chosen from a rural region of the Guna district in Madhya Pradesh, India. Geochemistry, groundwater quality, groundwater contamination sources, and related health risks have all been widely researched in recent decades. Karunanidhi et al. [17], for example, evaluated groundwater quality and its associated geo-medical health risk in the western part of Tamil Nadu, India, and discovered that continuous ingestion of highly unsafe drinking water causes health risk, with children being more vulnerable than adults. Adimalla and Qian [12] investigated two alternative approaches in the evaluation of human health risk in an agricultural region of Nanganur, south India, whereas Wu et al. [14] investigated groundwater chemistry and groundwater quality index integrating health risk in northwest China. In terms of overall chemical quality of groundwater assessment, Gao et al. [3] used the integrated-weight water quality index method to compute groundwater quality in the Guanzhong basin in northwest China, whereas Rao et al. [5]; Egbueri [18]; Subba Rao and Chaudhary [19] used the pollution index of groundwater method to assess the relative impact of each physico-chemical parameter on overall chemical quality of groundwater and discovered that the Sunkari and Abu [20] explored hydrochemistry, geographical distribution, and multivariate analysis to analyze groundwater in the Bongo area of

Ghana, with a focus on fluoride pollution. They observed that rock water interaction is a prominent natural/geogenic source that has a considerable effect on groundwater quality in the central and southern parts of Bongo, Ghana. A number of studies have highlighted the need of employing diverse approaches not only to estimate groundwater quality but also to assess pollution sources and susceptible distribution [21]. Based on previous investigations, the current research aims to: Determine the quality of groundwater for drinking reasons using EWQI and PIG; and Create distribution maps to identify groundwater quality zones for various uses using EWQI and PIG. To compare the findings of PIG and EWQI to the standard values of the WHO and BIS limits after being performed at a standard temperature and under a standard set of conditions according to Alpha's standard protocols. To identify the major elements influencing the EWQI and PIG of the Beenaganj-Chachura block.

Study area:

This research site is in Guna district, India, and is located in the NE of the Malwa Plateau along the Parbati River. The coordinates are N 24° 1756′-N 25° 06′ and E 76° 9996′-E 78° 16′) (Fig. 1). According to the 2011 Census of the Government of India, this area has a population of 21860 people with a population density of 1850 people per square kilometer. Groundwater is used for all operations in the communities, including irrigation and household and commercial needs. The annual rainfall was 108.72 cm, with the SW monsoon (from June to September) receiving the most rain (86%). According to the Indian Meteorological Department (IMD) data (2011-2020), the air temperature varied from 4.8 °C (winter) to 46 °C (summer).

FIGURE 1. Study area Beenaganj-Chachura in Guna district, Madhya Pradesh

In the Beenaganj-Chachura block, a total of 50 ground water samples were taken from the 50 different villages using a variety of hand pumps, tube wells, bore wells, and other sources. These samples were then taken to the labs where they were tested for various ions such as calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), as well as carbonate (CO_3^-), bicarbonate (HCO_3^-), sulphate (SO_4^{2-}), nitrate (NO_3^-), and chloride (Cl^-), were determined. Using a factor of 0.65, total dissolved solids (TDS) were calculated from EC.

2. ENTROPY WEIGHTED WATER QUALITY INDEX

The entropy weighted water quality index (EWQI) can be used to integrate all of the physicochemical data into a representative value that reflects the water quality. The algorithm to compute the EWQI is according to the following steps [2, 5, 13]:

Step 1: An entropy weight is most important which is generally associated with "m" groundwater samples and each sample has "n" hydro-chemical parameters (Su et al. 2018; Wu et al. 2018). In this first step, the calculation of eigenvalue matrix "X," which is associated with all hydro-chemical parameters and estimated by the following equation (Eq. 1):

$$X = [x_{11}\ x_{12}\ \dots\dots\dots x_{1n}\ x_{21}\ x_{22}\ \dots\dots..x_{2n}\ x_{m1}\ x_{m2}\ \dots\dots..x_{mn}] \qquad (1)$$

where, "m" (i=1, 2, 3, 4, …, m) represents the groundwater samples; n (j=1, 2, 3, 4, ……., n) signifies the number of hydrochemical parameters of each sample.

Step 2: The standardization process "y_{ij}" can be evaluated and then standard evaluation matrix "Y" can be obtained following Eqs. (2) and (3), respectively.

$$y_{ij} = \frac{x_{ij} - x_{ijmin}}{x_{ijmax} - x_{ijmin}} \qquad (2)$$

$$Y = [y_{11}\ y_{12}\ \dots\dots\dots y_{1n}\ y_{21}\ y_{22}\ \dots\dots..y_{2n}\ y_{m1}\ y_{m2}\ \dots\dots..yx_{mn}] \quad (3)$$

where, x_{ij} is the initial matrix; x_{ijmin} and x_{ijmax} are the minimum and maximum values of the hydrochemical parameters of the samples, respectively.

Step 3: The third step is to compute the entropy "e_j" and entropy weight "w_j" by the following equations:

$$e_j = -\frac{1}{lnln\,(m)}\sum_{i=1}^{m} P_{ij}\ln(P_{ij}) \quad (4)$$

$$P_{ij} = \frac{1+y_{ij}}{\sum_{i=1}^{m} 1+y_{ij}} \quad (5)$$

$$w_j = \frac{1-e_j}{\sum_{i=1}^{m} 1-e_j} \quad (6)$$

Step 4: The fourth step is to compute the quality rating scale "q_j" of the "j" parameter by the following formula (7):

$$q_j = \frac{\frac{c_j}{s_j}}{(C_{pH}-7)/(S_{pH}-7)} X\ 100 \quad (7)$$

where, "C_j" is the concentration of chemical parameters "j" (mg/L); "S_j" is the permissible limit of World Health Organizations (WHO) standards of parameter "j" (mg/L); "C_{pH}" represents the value of pH; "S_{pH}" is the permissible limit of pH (6.5 to 8.5), if the measured pH is larger than 7, "S_{pH}" is to be taken 8.5, while the pH is smaller than 7, "S_{pH}" is equal to 6.5 to confirm the value of "q_j" is positive.

Step 5: Finally, EWQI is calculated by using the Eq. (8):

$$\text{EWQI} = \sum_{j=1}^{m} w_j\,q_j \quad (8)$$

The EWQI has been classified as excellent quality if < 25 good quality between 25 and 50, medium quality from 50 to 100, poor quality from 100 to 150, and extremely poor quality if>150. Moreover, groundwater quality and EWQI classification and ranks are presented in Table 1 [19, 22].

TABLE 1. Classification standards of groundwater quality according to Entropy Weighted Water Quality Index (EWQI)

EWQI	Rank	Quality of Water
<25	1	Excellent
25-50	2	Good
50-100	3	Medium
100-150	4	Poor
>150	5	Very Poor

Index of Groundwater Pollution:

Subba Rao (2012) proposed the pollution index of groundwater (PIG) approach as a tool for assessing the status of many individual chemical variables (such as pH, EC, TDS, TH, Ca2+, Mg2+, Na+, K+, Cl, SO42, NO3 and F) to assess the general quality of groundwater for drinking. To compute the PIG, the general methodology outlined by [19] was used, as follows:

Step 1: Each chemical characteristic is given a relative weight (RW) value between 1 and 5, depending on how much of an impact they have on the overall quality of water suitable for drinking. The parameters with the highest RW ("5"), which naturally have the most effects (NO3, F, SO42, and Cl), and the parameters with the lowest RW ("1"), which have fewer impacts (K+ and HCO3), are allocated. Additionally, RW "2" is allocated to Ca2+ and Mg2+ whereas "4" is assigned to pH, TDS, Na+, and TH. (Table 2)

Step 2: The weight parameter (WP) is the ratio of each chemical water quality measure's relative weight to the total number of relative weights. Equation (Eq. 9) estimates the WP as follows:

$$\text{WP} = \frac{RW}{\Sigma\ (RW)}$$

Step 3: The drinking water quality standards (DWQS) limitations are collected from the World Health Organization (WHO 2017) and Bureau of Indian standards [23] and used to calculate the status of concentration (SOC) of each groundwater sample. The equation (Eq. 10) is displayed below.

$$\text{SOC} = \frac{C_i^n}{DWQS}$$

Step 4: The following equation (Eq. 11) computes the overall quality of groundwater (OQG) for drinking purposes: where WP denotes the weight parameter and SOC denotes the status of concentration.

$$\text{OQG} = \text{WP} \times \text{SOC}$$

Step 5: PIG is calculated by adding together all OQG values to determine the impact of contaminants on groundwater quality (Eq. 12).

$$\text{PIG} = \sum\ OQG$$

Insignificant pollution (PIG 2.5) is one of five categories under which the PIG is categorized [19]. Table 3 displays the categorisation in detail.

TABLE 2. Relative weight, weight parameters and drinking water standards used for PIG calculation

Chemical parameter	Relative weight (Rw)	Units	Weight parameters (Wp)	Drinking water standards (Ds)
pH	5	-	0.094	7.5
EC	2	mg/l	0.038	500
TDS	5	mg/l	0.094	500
TH	5	mg/l	0.094	300
Ca	2	mg/l	0.038	75
Mg	5	mg/l	0.094	30
Na	4	mg/l	0.075	200
K	1	mg/l	0.019	10
Cl^-	4	mg/l	0.075	250
F^-	5	mg/l	0.094	1.5
HCO_3^-	3	mg/l	0.057	300
SO_4^{2-}	5	mg/l	0.094	150
NO_3^-	5	mg/l	0.094	45
Sum (Σ)	53		1	

TABLE 3. Classification standards of groundwater quality according to pollution index of groundwater (PIG)

PIG	Level of Pollution
<1	Insignificant
1-1.5	Low
1.5-2.0	Moderate
2.0-2.5	High
>2.5	Very High

3. Results and Discussion

In this section, analysis of the results obtained from EWQI and PIG are discussed first. Next, deliberations on the distribution of ground water quality based on EWQI and PIG are presented.

TABLE 4. the physicochemical characteristics and their comparability to drinking standards set by the Bureau of Indian Standards (BIS).

Parameter	WHO limit (DL-PL)*	BIS limit (DL-PL)	Range	Avg.	% of sample above DL	% of samples above PL
pH	6.5–8.5	6.5–8.5	7.1-8.9	7.82	100	8
EC	500–1,500	–	261-1819	822.735	–	–
TDS	500–1,500	500–2,000	170-1576	543.58	44	0
Ca	75–200	75–200	24-291.2	69.864	22	2
Mg	50–100	30–100	7.2-110	27.62	28	2
Na	200–600	200	36.2–501.4	111.2	0	15
K	10	12	0.3–8.3	2.49	0	0
Cl	250–500	250–1,000	19.5-549	87.68	6	2
SO_4	200–250	200–400	31.54–261.41	111.9	10	0
NO_3	45	45	2–51	9.5	0	2
F	1–1.5	1–1.5	0.3-1.8	0.6483	8	4
TH	100–500	300–600	90-528	271.22	96	6

*DL = Desired Limit PL = Permissible Limit

Table 4 lists the chemical compositions of the groundwater in different Beenaganj-Chachura block villages. The average pH of the groundwater was 7.82, with a range of 7.1 to 8.9 (Table 3). According to WHO and BIS criteria, the groundwater in this block is generally alkaline and usually potable. According to WHO, the ideal and allowable ranges for electrical conductivity (EC) in drinkable water are 500 and 1500, respectively, however Beenaganj-Chachura has values of 261 and 1819, with an average value of 822.73. As a result, while the value lies substantially lower in certain villages than the DL, the EC is greater in some villages than the PL, indicating a higher concentration of dissolved and charged particles. charged compounds (often referred to as salts) in the water. TDS typically only contains trace amounts of organic materials and inorganic salts.

TABLE 5. Location-wise EWQI, water quality and EWQI rank

S.No.	Village	EWQI	Water Quality	EWQI rank
1	KHEKHEH	84.10	Medium	3
2	BORDA	54.59	Medium	3
3	FAKNEHRU	98.31	Medium	3
4	NAVALPURA	68.44	Medium	3
5	LAKHORI	67.92	Medium	3
6	KAKRUAA	141.16	Poor	4
7	DEHRI	64.39	Medium	3
8	BITAKHEDI	57.85	Medium	3
9	BAPCHA LAHARIYA	73.91	Medium	3
10	RAMTEDI	86.24	Medium	3
11	DOKRIYAKEDI	118.11	Poor	4
12	PAKHARIYAPURA	103.84	Poor	4
13	TELIGAV	71.31	Medium	3
14	PURABKANYA	59.43	Medium	3
15	BOR KA KEDA	83.40	Medium	3
16	KALI KARAR	73.93	Medium	3
17	MOHMMDPUR	52.60	Medium	3
18	FULUKHDI	45.18	Good	2
19	GULWADA	56.50	Medium	3
20	KHEDIKLA	116.70	Poor	4
21	PECHI	63.72	Medium	3
22	KIKHADA	81.40	Medium	3
23	KOTRA	64.11	Medium	3
24	KHATOLI	141.26	Poor	4
25	TODI	72.27	Medium	3
26	SAGAR	100.20	Poor	4
27	KEKRIYA	61.56	Medium	3
28	BATAWDA	49.51	Good	2
29	KUDHAMPURA	67.44	Medium	3
30	BADHAGAV	58.72	Medium	3
31	GOLYIAKHEDI	123.44	Poor	4
32	MOIYA	94.64	Medium	3
33	SAGODI	80.01	Medium	3
34	GUNJARI	91.14	Medium	3
35	JAMONIYA KLA	63.38	Medium	3
36	BARKHEDA KHURD	139.00	Poor	4
37	PIPLIYA MOTI	57.62	Medium	3
38	KHANPUR	52.14	Medium	3
39	PATONDI	123.52	Medium	3
40	TLAVLI	99.24	Medium	3
41	JUKHARA	167.93	Extremely Poor	5
42	UMARTHANA	71.79	Medium	3
43	DEDLA	53.89	Medium	3
44	MAHESHPURA	47.51	Good	2
45	BARKHEDI MAFI	125.58	Poor	4
46	AMASER	71.89	Medium	3
47	KHEJRA KLA RANI	76.26	Medium	3
48	KEKADHIYA	137.81	Poor	4
49	BASAHEDHA	77.21	Medium	3

50	BETHDA	67.93	Medium	3

TDS thus plays a significant role in determining the salinity of water and whether it is suitable for home use [24, 25]. The TDS values for the different villages in the Beenaganj-Chachura block were well within the BIS and WHO guidelines. Table 5 also lists the average concentrations of different significant ions. In groundwater, the average concentrations of Ca2+, Mg2+, Na+, K+, Cl, SO42, NO3, and F were respectively 69.864 mg/l, 27.62 mg/l, 111.2 mg/l, 2.49 mg/l, 87.68 mg/l, 111.9 mg/l, 9.5 mg/l, and 0.6483 mg/l. Therefore, the ions can be grouped in the following ascending order based on the average concentrations: SO42 > Na + Cl > Ca 2 + Mg 2 + NO3 > K > F. The total hydrogen content (TH) of the samples, measured as the sum of Ca2+ and Mg2+ dissolved in groundwater samples, ranged from 90 to 528 mg/L CaCO3. The PL is 500 but in this case the number is comfortably within BIS criteria but somewhat outside of WHO norms, as the PL is 500 while in this case the value for the village Barkheda Khurd was 528. In general, the concentrations of most of the villages for all the parameters were within the recommendations of WHO and BIS.

EWQI based quality assessment of groundwater:

One of the most objective, straightforward, and thorough methods for assessing the quality of potable drinking water is the EWQI [26–28]. The village, EWQI score, water quality, and EWQI rank for the Beenaganj-Chachura block are shown in Table 6. The village of Jukhara, which had an EQUI value of 176.93 and was ranked number five, is indicated as having extremely poor water quality.

Pig Based Quality Assessment of Groundwater:

The PIG was created to combine the wide range of physicochemical data into a single numerical number that adequately describes the general quality of the groundwater. Additionally, the classification of groundwater using PIG aids in the assessment of the chemical suitability of water that is consumed for drinking. The predicted PIG values ranged between 0.426 to 1.67 (Fig. 4), with 0.750 serving as the average (Table 5). The groundwater in the area under consideration can be categorized into one of three categories of water contamination based on the results of this study: negligible contamination, low contamination, or considerable contamination. 63 percent of the groundwater tests, according to PIG's findings, show "insignificant pollution." The samples were examined to ascertain this. As a result, the groundwater in these communities has been assessed and determined to be of adequate drinking quality (Table 5). As seen in Figure 4 and Table 5, approximately 27% of groundwater samples fall into the "low pollution" category, whereas 10% go into the "moderate pollution" group. The groundwater in the research region is only moderately suitable for drinking, according to the results of the analysis that used the PIG method. Fig. 5 presents the various groundwater quality classifications that were identified using the PIG technique and displays how they were distributed throughout the study area. Be aware that the study area's locations that the EWQI classification methodology identifies as having extremely low water quality are also those that the PIG classification method identifies as having intermediate water quality. This is so because to identify whether places have moderate or poor water quality, both categorization techniques use the same criteria. Ten villages have water that is of low quality, compared to 38 that have water that is of medium grade. According to EWQI, the villages of Fulukhedi, Batawda, and Maheshpura are ranked two and are considered good. There was no area of the village with excellent water quality. Figure 2 displays the Beenaganj-Chachura block's EWQI-based groundwater quality distribution map.

4. CONCLUSION

The hydrochemical data suggested that groundwater is alkaline in nature and has persistent hardness in this investigation. pH, TDS, TH, SO4-2, Mg, Na, Cl, Ca, NO3-, K, and F ions surpass the drinking limit in a few groundwater samples, according to BIS drinking guidelines. Because of excessive fertilizer use in agriculture, elevated nitrate concentrations were discovered in 4% of samples. The increased EC is due to salt dissolution and the inorganic pollution load in the water. According to PIG data, 76%, 16%, and 8% of groundwater samples are negligible, low, moderate, and none are high. Ten villages have bad water quality, while 38 villages have medium water quality. According to EWQI, the villages of Fulukhedi, Batawda, and Maheshpura rank second and are classified as excellent. None of the villages' water quality could be described as outstanding. The interpretation of PIG reveals that groundwater samples collected near intensive agricultural areas were problematic, necessitating specific remedial actions. Prior knowledge of the findings of any experimental procedure is typically advantageous in moving theory towards practical applications. The graphs demonstrate that variations in nitrite, fluoride, overall hardness, and magnesium have a greater influence on the PIG than changes in the other variables.

REFERENCES

[1]. Zhou, Y., Li, P., Chen, M., Dong, Z., Lu, C., 2020. Groundwater quality for potable and irrigation uses and associated health risk in southern part of Gu'an County, North China Plain. Environ. Geochem. Health. https://doi.org/10.1007/s10653-020- 00553-y.

[2]. Subba Rao, N., Sunitha, B., Adimalla, N., Chaudhary, M., 2020. Quality criteria for groundwater use from a rural part of Wanaparthy District, Telangana State, India, through ionic spatial distribution (ISD), entropy

water quality index (EWQI) and principal component analysis (PCA). Environ. Geochem. Health 42 (2), 579–599.

[3]. Gao, Y., Qian, H., Ren, W., Wang, H., Liu, F., Yang, F., 2020. Hydrogeochemical characterization and quality assessment of groundwater based on integrated-weight water quality index in a concentrated urban area. J. Clean. Prod. 260, 121006.

[4]. He, X., Li, P., Wu, J., Wei, M., Ren, X., Wang, D., 2020. Poor groundwater quality and high potential health risks in the Datong Basin, northern China: research from published data. Environ. Geochem. Health.

[5]. Rao, N.S., Sunitha, B., Rambabu, R., Rao, P.V.N., Rao, P.S., Spandana, B.D., Sravanthi, M., Marghade, D., 2018. Quality and degree of pollution of groundwater, using PIG from a rural part of Telangana State, India. Applied Water Science 8 (8), 227.

[6]. Li, P., He, S., He, X., Tian, R., 2018. Seasonal hydrochemical characterization and groundwater quality delineation based on matter element extension analysis in a paper wastewater irrigation area, northwest China. Exposure and Health 10 (4), 241–258.

[7]. Adimalla, N., Li, P., 2019. Occurrence, health risks, and geochemical mechanisms of fluoride and nitrate in groundwater of the rock-dominant semi-arid region, Telangana State, India. Hum. Ecol. Risk Assess. 25 (1–2), 81–103. https://doi.org/ 10.1080/10807039.2018.1480353.

[8]. Adimalla, N., Marsetty, S.K., Xu, P., 2019. Assessing groundwater quality and health risks of fluoride pollution in the Shasler Vagu (SV) watershed of Nalgonda, India. Hum. Ecol. Risk Assess. 1–20.

[9]. Adimalla, N., Qian, H., 2019. Hydrogeochemistry and fluoride contamination in the hard rock terrain of central Telangana, India: analyses of its spatial distribution and health risk. SN Applied Sciences 1 (3), 202.

[10]. Adimalla, N., Qian, H., 2019b. Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. Ecotoxicol. Environ. Saf. 176, 153–161.

[11]. Adimalla, N., Venkatayogi, S., 2017. Mechanism of fluoride enrichment in groundwater of hard rock aquifers in Medak, Telangana State, South India. Environ Earth Sci 76 (1).

[12]. Adimalla, N., Li, P., Qian, H., 2019. Evaluation of groundwater contamination for fluoride and nitrate in semi-arid region of Nirmal Province, South India: a special emphasis on human health risk assessment (HHRA). Hum. Ecol. Risk Assess. 25 (5), 1107–1124.

[13]. Kumar, R., Mittal, S., Sahoo, P.K., Sahoo, S.K., 2020. Source apportionment, chemometric pattern recognition and health risk assessment of groundwater from southwestern Punjab, India. Environ. Geochem. Health.

[14]. Wu, J., Zhou, H., He, S., Zhang, Y., 2019. Comprehensive understanding of groundwater quality for domestic and agricultural purposes in terms of health risks in a coal mine area of the Ordos basin, north of the Chinese Loess Plateau. Environ Earth Sci 78 (15), 446.

[15]. Wu, J., Zhang, Y., Zhou, H., 2020. Groundwater chemistry and groundwater quality index incorporating health risk weighting in Dingbian County, Ordos basin of northwest China. Geochemistry 125607.

[16]. Yadav, K.K., Kumar, V., Gupta, N., Kumar, S., Rezania, S., Singh, N., 2019. Human health risk assessment: study of a population exposed to fluoride through groundwater of Agra city, India. Regul. Toxicol. Pharmacol. 106, 68–80.

[17]. Karunanidhi, D., Aravinthasamy, P., Kumar, D., Subramani, T., Roy, P.D., 2020. Sobol sensitivity approach for the appraisal of geomedical health risks associated with oral intake and dermal pathways of groundwater fluoride in a semi-arid region of south India. Ecotoxicol. Environ. Saf. 194, 110438.

[18]. Egbueri, J.C., 2020. Groundwater quality assessment using pollution index of groundwater (PIG), ecological risk index (ERI) and hierarchical cluster analysis (HCA): a case study. Groundwater for Sustainable Development 10, 100292.

[19]. Subba Rao, N., Chaudhary, M., 2019. Hydrogeochemical processes regulating the spatial distribution of groundwater contamination, using pollution index of groundwater (PIG) and hierarchical cluster analysis (HCA): a case study. Groundwater for Sustainable Development 9, 100238.

[20]. Sunkari, E.D., Abu, M., 2019. Hydrochemistry with special reference to fluoride contamination in groundwater of the Bongo district, Upper East Region, Ghana. Sustainable Water Resources Management 5, 1803–1814.

[21]. Badeenezhad, A., Radfard, M., Passalari, H., Parseh, I., Abbasi, F., Rostami, S., 2019. Factors affecting the nitrate concentration and its health risk assessment in drinking groundwater by application of Monte Carlo simulation and geographic information system. Hum. Ecol. Risk Assess. 1–14.

[22]. Shafiullah, G., Al-Ruwaih, F.M., 2019. Spatial-multivariate statistical analyses to assess water quality for irrigation of the central part of Kuwait. Bull. Eng. Geol. Environ. 79, 27–37.

[23]. BIS, 2012. Drinking water-specification. Bureau of Indian standards, New Delhi IS: 10500. Bureau of Indian Standards Manak Bhavan, 9 Bahadur Shah Zafar Marg New Delhi 110002.

[24]. Li, P., He, X., Li, Y., Xiang, G., 2019a. Occurrence and health implication of fluoride in groundwater of loess aquifer in the Chinese loess plateau: a case study of tongchuan, northwest China. Exposure and Health 11 (2), 95–107.

[25]. Li, P., Tian, R., Liu, R., 2019b. Solute geochemistry and multivariate analysis of water quality in the guohua phosphorite mine, guizhou province, China. Exposure and Health 11 (2), 81–94.

[26]. Ukah, B. U., Ameh, P. D., Egbueri, J. C., Unigwe, C. O., & Ubido, O. E. (2020). Impact of effluent-derived heavy metals on the groundwater quality in Ajao industrial area, Nigeria: an assessment using entropy water quality index (EWQI). International Journal of Energy and Water Resources, 4(3), 231-244.
[27]. Yang, Y., Li, P., Elumalai, V., Ning, J., Xu, F., & Mu, D. (2022). Groundwater quality assessment using EWQI with updated water quality classification criteria: a case study in and around Zhouzhi County, Guanzhong Basin (China). Exposure and Health, 1-16.
[28]. Wang, L., Dong, Y., Xu, Z., Qiao, X., 2017. Hydrochemical and isotopic characteristics of groundwater in the northeastern Tennger Desert, northern China. Hydrogeol. J. 25 (8), 2363–2375.