Groundwater Quality Assessment Based on a Statistical Approach in Gaya District, Bihar

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ABSTRACT

India is one of the countries that face the serious problem of groundwater contamination. The current study's main objective is to evaluate the quality of the groundwater in the Serghati and its surrounding region of the Gaya district and its suitability for drinking purposes. To achieve this aim, 75 groundwater samples from the 15 sampling sites were collected during the period from March to May 2022. We measured and analyzed the major physicochemical characteristics of the water and compared them to the World Health Organization (WHO) standards. With the help of the Water Quality Index (WQI), groundwater quality was assessed. According to the study results, 3 sites have a WQI value of more than 100, which is unsuitable for drinking. Correlation matrices were used to assess groundwater quality and the extent of the interdependencies of the various parameters. Principal Component Analysis (PCA) reduces the number of significant variables. Three principal components with a total variance of 73.53% were identified and used in the analysis. Overall, the result indicates that most areas' water quality is good and safe for drinking.

Keywords-drinking water; physiochemical parameters; statistical analysis; Pearson's correlation; principal component analysis

I. INTRODUCTION

Water resources play a critical role in the growth and development of civilization [1]. Nowadays, water resources have inevitably become one of the most important factors that determine economic growth. It is necessary to assess whether water resources are sufficient and sustainable, particularly in countries like India, where water often plays a multiple-faceted role in terms of economics as well as social aspects [2]. Maintaining access to safe drinking water has become an urgent requirement, even though 30% of the urban population and 90% of the rural population are still wholly dependent on contaminated surface and ground water to meet their daily needs. The availability and quality of clean drinking water are among the most important factors for promoting agricultural production and providing health care services to the general population [3]. Many states, including Andhra Pradesh, Bihar, Rajasthan, West Bengal, Jharkhand, Orissa, and Punjab, are experiencing severe water scarcity, due to factors such as the lack of environmental awareness and indiscriminate waste disposal from agriculture, mining, and anthropology, resulting in one of the most dangerous situations for development in their areas [4]. The use of fertilizers and agrochemicals and the overexploitation of groundwater, result in the contamination of water resources [5]. Residents of arid and semi-arid regions rely heavily on groundwater [6]. Agricultural lands are also getting deteriorated due to the contamination of groundwater by excess fluoride [7, 8]. Fluoride-contaminated groundwater slowly accumulates the excess fluoride and produces adverse effects [8, 9]. Large quantities of fluoride are stored in various parts of the body due to the use of contaminated water [10]. Crippling skeletal fluorosis has become common across the globe [2]. The immune system also gets affected by the intake of excess fluoride [11]. Chronic kidney diseases may attack at a faster rate due to the intake of excess fluoride through food [12]. To remove the excess fluoride, various techniques have been developed. Among them, adsorption is found to be more effective in both removal and cost. Various materials have been developed as defluorination adsorbents, such as nanomaterials [13], clay [14], chitosan [15], industrial waste [16], carbonaceous [17], alumina [18], calcium [19], and metal oxides [20].

II. MATERIALS AND METHODS

A. Study Area

Gaya district stretches over 4976km^2 and lies between 24°30' and 25°06' latitude and 84°24' and 85°30' longitude The entire research region has a hostile environment caused by the continental monsoon. Mountains surround Gaya on three sides, with a river on the other side, resulting in seasonal temperature variations in the region. Higher temperatures up to 45°C can be found during the summer months (May-July). The city receives about 214cm of rainfall in July and October. The winter months are known for their cold temperatures ranging from -4°C to 28°C. The study was conducted in the surrounding area of Sherghati, located in the Gaya district of Bihar.

B. Water Sampling and Analysis

A total of 75 groundwater samples, 5 from each of the 15 sites, were taken across the research region from underground sources (maximum bore wells and hand pumps). The sampling site and geo-positions (latitude and longitude) were located with Global Positioning System (GPS). The concentrations of each individual parameter at each sampling site were determined by averaging the concentrations of each parameter. Between March and May 2022, fresh groundwater samples were collected from shallow bore wells and tube wells. The water samples were collected using pre-cleaned high-density 500mL polythene bottles. The bottles were handled with gloves to prevent sample contamination. Before sampling the water from a bore well, it was drained for 5 minutes. The samples were sealed tightly so contaminants were not able to enter the bottles. As soon as the samples were transported to the laboratory, they were encased in iceboxes and were preserved at 4°C for further chemical analysis. All steps were carefully monitored throughout the sampling process to ensure that the samples were not contaminated or agitated during the collection, transportation, and analysis. The fluoride concentration in the water was determined using the SPADNS method described in APHA1994 [21]. The chemicals and distilled water used to prepare the solution (or dilution) were analytical grades and the highest purity Millipore water, respectively. Thermo Scientific Multi-Parameter Kit measured in situ parameters like pH immediately after sampling. The anions chloride, sulphate, and phosphate were quantified using the usual $AgNO_3$ titration with a UV spectrophotometer, turbid metric, and colorimetric methods. Authors in [3] used a technique to assess water samples' nitrate (NO_3) content. Calcium and magnesium were determined using the conventional EDTA titration technique. All the processes used in the investigation were conventional methods for examining water and wastewater [22].

C. Estimation of Water Quality Index (WQI)

WQI was estimated according to a three step process:

- Step-1. The weight (Wn) characteristics of each specification are calculated to utilize the given equation:

$$Wn = K/Sn \tag{1}$$

where $K = \frac{1}{\frac{1}{S1}+\frac{1}{S2}+\frac{1}{S3}+...+\frac{1}{Sn}} = \frac{1}{\sum \frac{1}{Sn}}$, where Sn is the standard desirable value of the *n*th specification.

- Step-2. The Sub-Index (*Qn*) is calculated to utilize the given equation:

$$Qn = \frac{Vn - V0}{Sn - V0} \times 100 \tag{2}$$

where *Vn* is the mean concentration of the *n*th specification, *Sn* is the standard desirable value of the *n*th specification, and *Vo* represents the real values of the specifications in pure water (Generally, $Vo = 0$, for most specifications except for pH, that has a *V0* of 7).

- Step-3. WQI was calculated by the summation of *Wn* and *Qn:*

$$WQI = \sum_{QnWn} / \sum_{Wn} \tag{3}$$

and since $\sum_{Wn} = 1$, we have:

$$WQI = \sum_{QnWn} \tag{4}$$

D. Correlation

An evaluation of the correlation between two variables can be measured by the coefficient of correlation (*r*), which can be defined as a measure of the degree to which the two variables are associated. As far as the range of *r* is concerned, it spans from -1 to +1 [23]. As a general rule, the correlation between different water quality parameters is obtained to determine their interrelationship, which helps visualizing the most effective parameters [24]. This ultimately contributes to the decision-making process related to monitoring water quality. However, a high or low value of *r* (for example, close to +1) is typically indicative of a strong correlation [25].

E. Principal Component Analysis (PCA)

The PCA method of multivariate statistics is usually used to reduce the dimension of a dataset [26]. PCA produces eigenvalues and eigenvectors when applied to the covariance matrix of the initially correlated variables [27]. Several coefficients make up the eigenvector, also referred to as the loading. To obtain the Principal Components (PCs) [28], one has to multiply all the loadings by the original set of variables. PCA is a linear combination of initially correlated variables that forms a new set of orthogonal uncorrelated variables. In 1933, Hoteling developed this method and had been widely adopted in studies regarding water quality assessment [29].

III. RESULTS AND DISCUSSION

The physicochemical parameters of the groundwater samples are presented in Table I. The pH of the drinking water at the 15 sites has been found to range between 6.78 and 7.20. Over the study area, it is evident that the water is slightly acidic to slightly basic. There is no site where the pH values exceed the permissible limit of 8.5. As far as chloride is concerned, the minimum value is 43.23mg/L and the maximum value is 203.49mg/L and all samples are within the maximum allowable limit of 1000mg/L. Sulphate concentration ranges from 15.67 to 95.18mg/L, with a mean value of 39.09mg/L and a standard deviation of 24.90mg/L. The sulphate levels do not exceed the permissible limit of 400mg/L. There is a wide range of nitrate concentrations in the samples, ranging from 3.54 to 43.23mg/L with a mean and standard deviation of 15.54 and 10.49mg/L, respectively. The nitrate levels did not exceed the permissible limit of 45mg/L. Likewise, the minimum fluoride concentration was 0.37mg/L, the maximum fluoride concentration was

2.70mg/L, with 6 locations crossing the permissible limit of 1.5mg/L. Total Hardness (TH) ranged between 92 and 332 mg/L, with an average and standard deviation of 228.93mg/L and 58.39mg/L, respectively. No sites had TH values crossing the permissible limit of 600mg/L. At some sites, the concentrations of parameters that describe the water quality were higher than those recommended by the Bureau of Standards (2012) for drinking water. Combinations of different natural factors, such as soil salinization, mineral dissolution, prolonged residence time for water-rock interactions may be responsible. However, it should be noted that anthropogenic activities also play a significant role in the degradation of groundwater quality. There is a great concern regarding the concentration of nitrate and fluoride in groundwater since their increased value adversely affects human health.

TABLE I. STATISTICAL ANALYSIS OF PHYSICOCHEMICAL PARAMETERS

	Minimum	Maximum	Mean	Std. deviation
pH	6.78	7.20	7.05	0.12
TDS	290	426.60	331.02	33.98
F^-	0.37	2.70	1.378	0.7
Cl^-	43.23	203.49	108.84	44.89
NO_3^-	3.54	43.23	15.54	10.5
SO_4^{2-}	15.67	95.18	39.09	24.91
TH	92	332	228.93	58.4
Total alkalinity	21.40	40.50	31.36	6.59

TABLE II. GROUNDWATER WQI VALUES

Sampling location	WQI
S1	81.25
S2	39.61
S3	43.6
S4	76.52
S5	90.9
S6	119.78
S7	149.15
S8	97.43
S9	20.85
S10	37.45
S11	36.26
S12	128.94
S13	47.3
S14	24.54
S15	70.32

We employed the WQI to investigate the groundwater's condition and assess whether it is suitable for drinking based on its overall quality. As WQI uses a weighted sum approach to calculate its score, it makes it easy for the data to be communicated to a broad audience because it combines all the parameters into one numerical value that can be used to convey information. Table II presents the WQI of each site. There is no doubt that 3 out of 15 sites have WQI above 100, as shown in Figure 1. The groundwater at these sites is not suitable for drinking. It was found that the groundwater had the highest WQI according to this study (149.14), which indicates that the groundwater is the most polluted. However, the lowest WQI at the least polluted site is 24.53. Generally, the groundwater quality in the study area is acceptable for most areas, but it is of very poor quality in some regions and shouldn't be used for drinking. We assessed the inter-dependencies among different parameters by establishing the correlations between their values. The analysis outcome is shown in Table III.

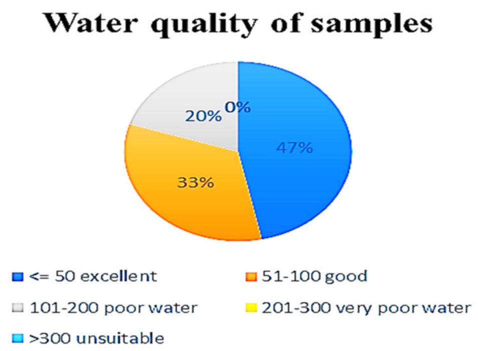

Fig. 1. Water quality based on WQI value.

TABLE III. PEARSON'S CORRELATION MATRIX

	pH	TDS	F^-	Cl^-	NO_3^-	SO_4^{2-}	TH	TA
pH	1.000							
TDS	-0.351	1.000						
F^-	0.565	-0.214	1.000					
Cl^-	0.315	0.340	0.242	1.000				
NO^{3-}	-0.0022	0.361	-0.096	0.396	1.000			
SO_4^{2-}	-0.370	0.776	-0.192	0.527	0.584	1.000		
TH	0.347	-0.430	0.047	0.205	-0.094	-0.225	1.000	
TA	0.126	0.150	0.097	0.376	0.331	0.111	0.592	1.000

TABLE IV. TOTAL VARIANCE ANALYSIS

Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	3.058	33.974	33.974	3.058	33.974	33.974
2	2.294	25.485	59.458	2.294	25.485	59.458
3	1.266	14.072	73.530	1.266	14.072	73.530
4	0.956	10.627	84.157			
5	0.626	6.957	91.114			
6	0.364	4.050	95.164			
7	0.227	2.525	97.689			
8	0.178	1.981	99.670			
9	0.030	0.330	100.000			

Extraction Method: PCA.

An increase in positive or negative values of *r* is usually indicative of a strong correlation between two variables. It can be seen that most of the parameters demonstrate a positive correlation with one another. Generally, the parameters from a common origin are strong correlated and vice versa. Despite this, some of these parameters show a negative correlation and some a very small correlation, indicating that these components' sources may differ.

PCA was also conducted on each of the water quality parameters, and the results are shown in Table IV. The variances for each PC are individually and cumulatively based on the data collected. There is no doubt that PC1, PC2, PC3 are responsible for the majority of the Variance (73.53%), while the rest of the PCs are responsible for a much lower percentage of the Variance. Most of the time, it is recommended that the PCs capable of explaining 70% of the Variance are used to reduce dimensionality while losing the least amount of information [30]. To determine the leading PCs from the original variables in the study, PCA was carried out using the SPSS 16.0 software. The first factor accounts for about 33.974% of the variance, corresponding to the largest eigenvalue (3.058). In the total variance calculation, the second factor, which corresponds to the second eigenvalue (2.294), is responsible for approximately 25.485% of the variance. The third factor accounts for 14.072 % of the total variance with an eigenvalue of 1.266. Among the remaining 9 factors, no one has an eigenvalue greater than 1. The significance of any factor is determined by its eigenvalue, which must be greater than 1. There appears to be a relatively higher loading for PC1 for the parameters TDS and sulphate compared to the others, as shown in Table V. Meanwhile, hardness, alkalinity, chloride, and pH loadings are found to be more in PC2, and in PC3, loading is more in fluoride.

TABLE V. COMPONENT MATRIX

	Component		
	1	2	3
pH	-0.589	0.564	0.359
TDS	0.878	0.090	0.146
F- (ppm)	-0.379	0.406	0.558
Cl- (ppm)	0.272	0.810	0.260
$NO3^-$ (mg/l)	0.595	0.453	0.006
SO_4^{2-} (mg/L)	0.849	0.283	0.149
TH (mg/l)	-0.467	0.568	-0.601
Total alkalinity (mg/l)	0.124	0.699	-0.567

Extraction Method: PCA

IV. CONCLUSION

Generally, there is a groundwater contamination issue in Sherghati, Gaya district. The purpose of this study is to investigate the quality of grounwater and its suitability for drinking. The available water in the region lies between slightly acidic to slightly alkaline. To analyze the status, we calculated the water quality index for each site of the sampling area. The physicochemical parameters are almost within the permissible range except for fluoride, which crosses the permissible limit at some sampling sites. WQI was accurately predicted for the groundwater samples, something that can be of great importance for analyzing and reducing environmental impacts and, ultimately, ensuring public health. We used the PCA methodology to analyze the water quality measurements, and we extracted 3 components with a total variance of 73.53%. Most of the 15 samples have WQI value below 100 and only 3 cross the value of 100. Hence, there is good quality drinking water available in the area.

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