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Evaluating the Suitability of Groundwater for Drinking Purposes by the Use of Statistical Techniques and the Utilization of a Water Quality Index

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Abstract- Groundwater is an important source of drinking water and, its quality directly affects human health. 24 groundwater samples were taken from Nalanda, Bihar, to evaluate the quality of the drinking water. Residents rely on groundwater as their main source of drinking water, so it is imperative to assess its condition in the research area. Physiochemical characteristics namely pH, Temperature, Total Dissolved Solids, Turbidity, Alkalinity, Hardness, Calcium, Magnesium, Nitrate, Sulphate, Chloride, Electrical Conductivity, and Dissolved Oxygen were determined and compared with World Health Organization (WHO) & Bureau of Indian Standard (BIS10500:2012). Their measurements were conducted using standard methods. To assess the factors influencing the distribution of groundwater quality, several statistical approaches such as correlation analysis were employed, along with the usage of a water quality index. Several physiochemical measurements exceeded the specified BIS restrictions. Principal Component Analysis (PCA) reduced the initial set of 12 variables to 4 significant components, which collectively account for 82.864% of the total variance in the data. Principal Component Analysis (PCA) demonstrates that groundwater quality is impacted by the interaction between rocks and water, the redox environment, weathering, leaching, and human activities. The Water Quality Index (WQI) indicates that 63% of the samples are deemed appropriate for drinking, while the remaining 27% are classified as poor and unsuitable. This study emphasizes the patterns of groundwater pollution. Overall Groundwater quality is suitable for drinking purposes. Comprehensive regulation and integrated groundwater management is essential to prevent future degradation of groundwater quality.

Keywords- Groundwater, Water quality index (WQI), Correlation, statistical methods,

Introduction

One of the most significant difficulties facing the water sector across the globe is the inherent limitation of water resources (Harun et al., 2021; A. Kumar et al., 2023). In many regions with limited surface water resources and insufficient precipitation, groundwater is used to meet demand, generally without treatment (Mohammadi et al., 2020). Groundwater is one of the world's most important natural water resources, with extensive use for drinking, agriculture, and industrial particularly in arid and semi-arid climates (D. Kumar et al., 2019). Furthermore, in many geological terrains that have seen large population increases, rapid industrial and urbanization, significant agricultural development, biomedical waste, excessive fertilizer use, high evaporation, and low rainfall, groundwater contamination has increased dramatically. (Prasun et al., 2023; Adimalla & Qian, 2019). The widely used WQI method is a straightforward yet effective technique for assessing the water quality in aquatic environments. The primary benefit of the WQI is its ability to condense several chemical and physical factors into a single numerical value, therefore offering valuable information. (Alam & Kumar, 2023). Utilizing multivariate statistical techniques, such as factor analysis (FA) and principal component analysis (PCA), is an effective approach to examining water quality datasets while retaining crucial information. These approaches can assist in determining the correlation between water quality variables, identifying identical parameters, and grouping water quality parameters (Abdelaziz et al., 2020; Islam et al., 2018; Krishan et al., 2023; Teixeira de Souza et al., 2021)

.The current study used 24 examined samples that were taken from tube/pumping wells in the study region to assess and identify the quality of the groundwater in Nalanda, Bihar. The first step involves doing a correlation analysis to determine the relationship between the water quality variables. Additionally, a comprehensive method is used, which combines a water quality index based on principle components analysis (PCA), to improve the categorization and mapping of the water quality index within the research region. The initial step towards reaching SDG-6, enhancing water quality, and mitigating pollution would involve identifying the sources of pollution in the research region.

Study area & its details

The Nalanda district is situated in the southern part of the Gangetic plains, specifically within the Mid-Ganga basin. The district has 20 administrative block and 2,355 km^2 of land. The district shares its northern boundary with the district of Patna, its southern border with the districts of Nawada and Gaya, its western border with Jehanabad, and its eastern border with the districts of Sheikhpura and Lakhisarai. The Nalanda district is situated on the globe map among the geographical coordinates of 24°57' and 25°27' North latitude, and 85°18' and 85°56' East longitude. The district primarily encompasses a flat alluvial landscape, with the exception of Rajgir Hill located in the southern region. The majority of the area, except the southern region, consists primarily of alluvium. A small portion in the northern region of the Harnaut block and the eastern region of the Sarmera block consists of older alluvium, while the remaining part is composed of younger alluvium, which was formed by rivers moving from the southern to the northern/northeastern direction in the districts. Pediplanes are present at the confluence of younger alluvium and a mountainous terrain. The region is characterised by a collection of inselbergs, which are bordered by Indo-Gangetic alluvium that dates back to the Pleistocene era. The inselbergs demarcate the northernmost limit of the Precambrian peninsular shield.

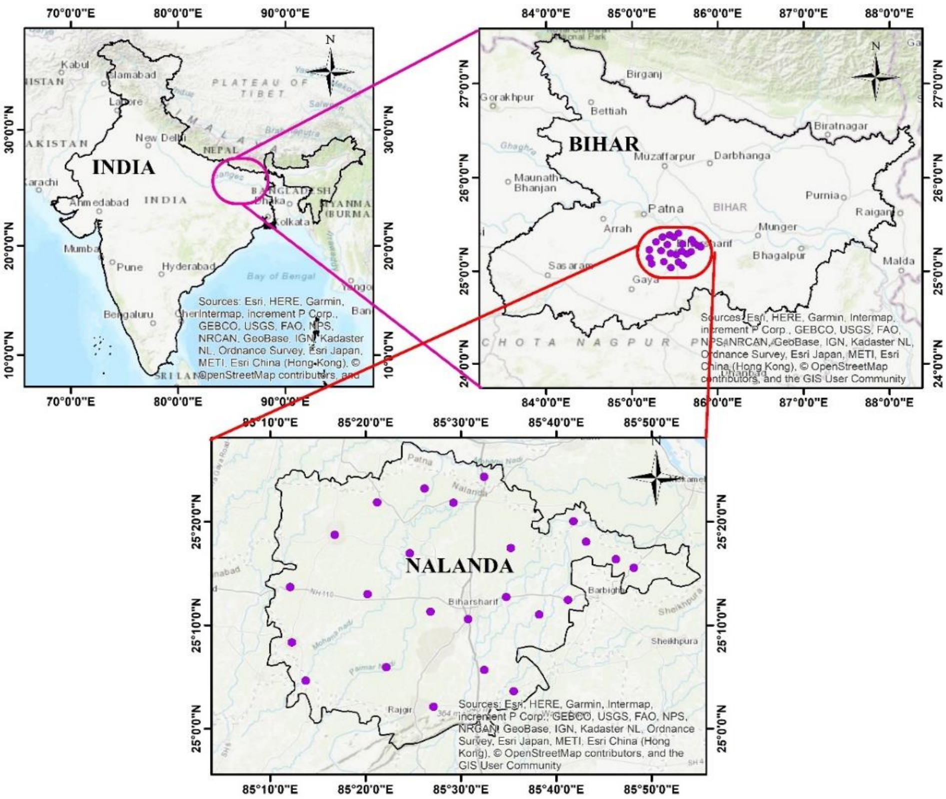

Figure 1. sample location map of study area

The Nalnada district is located inside the Harohar Basin. The overall gradient of the region is oriented towards the northeast. The main rivers are Harohar, Lokain, Mohana, Nonain, Panchane, and Sakri river. All rivers in the region flow in a northeasterly direction and converge with the Ganges River in the northern part. The majority of

Nalanda district is comprised of Quarternary sediments, with the exception of a tiny area in the south which is inhabited by metasediments of the Munger group, dating back to the middle Proterozoic era. Groundwater is present in both alluvium and metasediments. In alluvium, groundwater exists in an unconfined state, but in metasediments, groundwater is found inside the formation owing to secondary porosity, namely between faults and fractures within rocks.

Methodology

The groundwater samples were collected in polythene bottles that were pre-washed and had a high thickness. These bottles were thermetically sealed to prevent any leakage. Before collecting the samples, the bore wells/hand pumps were operated for a sufficient duration to extract water from the aquifer. The pH and EC of the hydrogen ionic concentration were determined in the field using portable meters immediately after collecting the samples. The laboratory assessed the concentration of bicarbonate and sulfate ions in groundwater samples using titrimetric methods. The chloride content in the samples was determined using a solution of silver nitrate. The process of EDTA titration was conducted to determine the concentrations of calcium and magnesium ions in all 24 groundwater samples obtained in the field (fig. 1). Nitrate concentrations were assessed using a UV spectrometer. The concentration of the main ions in the groundwater samples of the research region was determined using the recommended analytical approach outlined in the American Public Health Association (APHA, 2005) guideline.

Hydrological investigations frequently employ multivariate statistical analysis to comprehend multi-dimensional challenges. The primary use of statistical analysis techniques has been in the monitoring of groundwater quality, with some limited research also conducted on drinking water. Typically, these studies involve a wide range of physico-chemical variables and observations. By employing Principal Component Analysis (PCA), the dataset's dimensionality was effectively decreased, allowing for the clustering of drinking water samples based on their respective sources of groundwater. In their study, (Alam & Singh, 2023) utilized principal component analysis to examine the multivariate correlation between chemical data. The parameters were then clustered together based on their similarity in terms of water quality features. Principal Component Analysis (PCA) was employed to consolidate the information and distinguish the distinct causes of variability. This study conducted a combined examination of the physico-chemical parameters of groundwater samples for the purpose of principal component analysis (PCA). The data sets underwent log transformation to accommodate a broad spectrum of parameters.

Water Quality Index

The weighted arithmetic water quality index (WQI) method, which was initially introduced by (Horton, 1965) and further developed by (Brown et al., 1970), was used to assess the WQI of each sampling site in Nalanda. The WQI calculation was carried out using a weighted arithmetic index as shown below.

The numerical value of the Water Quality Index (WQI) was computed using eq. (1).

$$\mathrm{WQI} = \Sigma\, Q_n * W_n \qquad \text{Equation 1}$$

The term "WQI" refers to the water quality index, which is a measure of the overall quality of water. "Qi" represents the water quality rating, while "Wi" represents the unit weight assigned to each particular water quality indicator.

In order to obtain a dimensionless numeric constant (k), the reciprocals of all the standard values are put together, as each parameter has its own unit of measurement.

$$W_n = k/S_n \qquad \text{Equation 2}$$

where,

$$k(\text{constant}) = 1/(1/V_{s1} + 1/V_{s2} + 1/V_{s3} \ldots.. + 1/V_{sn}) \qquad \text{Equation 3}$$

Sn represents the numerical value assigned to the standard for water quality characteristics. Additionally, the rating for water quality is determined using equation (4).

$$Q_n = 100 * \left[\frac{(Vn - Vi)}{(Sn - Vi)}\right] \qquad \text{Equation 4}$$

The variables in discussion are Vn, which represents the actual concentration of the water sample, Vi, which represents the ideal value (0 for all water quality indicators except pH (7.0) and DO (14.6 mg. l-1), and Vs, which represents the standard value. If the value of Qi is zero, it indicates the absence of individual pollutants. A value between 0 and 100 signifies that the pollutant is present within the specified level, while a value more than 100 indicates that the pollutants exceed the acceptable limit. The final statistics representing the state of water quality are then classified into many categories to provide a clear and comprehensible interpretation for the general public. If the values are below 50, the water is classified as excellent. If the values range from 50 to 100, the water quality is considered good. Values between 100 and 200 indicate poor water quality. Values ranging from 200 to 300 indicate very poor water quality. If the values exceed 300 mg/L, the water is not suitable for drinking.

Result and Discussion-

Descriptive statistics

Comprehending the quality of groundwater is essential, since it is the main factor that determines whether it is suitable for drinking, residential, agricultural, and industrial uses. Table 1 presents the physical and chemical characteristics of a substance, including statistical measurements such as the lowest concentration, highest concentration, average concentration, standard deviation, skewness, and kurtosis..

Table 1. Descriptive statistics of water quality parameters of Nalanda

	Minimum	Maximum	Mean	Std. Dev.	Variance	Skewness	Kurtosis
pH	6.65	7.65	7.265	0.2047	0.042	-0.803	0.846
TDS	45.4	3810	888.12	739.51	546875.4	2.988	10.707
EC	231.2	1864	472.16	348.09	121166.4	3.174	11.303
DO	1.29	7.74	2.6021	1.2797	1.638	2.952	11.476
F-	0.18	1.6	0.4388	0.2698	0.073	2.887	10.429
Cl-	12.01	120.09	42.83	26.087	680.526	2.029	4.597
NO3-	0.15	50.77	14.633	17.045	290.532	1.095	-0.133
SO4	16.74	116.5	50.243	23.908	571.582	1.15	1.264
TA	24.5	70.46	39.154	10.199	104.029	1.468	2.769
TH	148	778	353.21	137.67	18953.04	1.509	3.428
Ca^{2+}	60	419	174.38	81.532	6647.462	1.371	2.713
Mg^{2+}	5	410	178.83	97.242	9456.058	0.73	0.288

The descriptive statistics for 24 groundwater samples of Nalanda Districts are given in Table 1. The pH of water varied from 6.74 to 7.65 an average of 7.26 which represent neutral nature of groundwater. The EC varied from 231.2 to 1864 µs/cm. Higher EC indicate the salinity of water and has significant influence of ion exchange and dissolution process on groundwater (Azhdarpoor et al., 2019). The Total dissolved solid ranged in groundwater from 101.14 to 1470 mgl^{-1}. Higher TDS can cause gastrointestinal irritation, heart illness, sand kidney stones to people (M. Kumar & Kumar, 2013) . The concentration of ca^{2+} in groundwater varied between 60 to 419 mg L^{-1} with an average of 174.38 mg L^{-1}. The range of magnesium ion concentration was from 5 to 410 mg/L. Maximum groundwater samples had calcium and magnesium concentrations exceeded the (BIS, 2012) allowed limits of 75 and 50 mg/L, respectively. The lack of ca^{2+} in consumption of water can lead to kidney stones, stroke, hypertension. Chloride levels in the groundwater varied from 12.01 mg/L to 120.09 mg/L. The highest value of fluoride 1.6 mg l^{-1} and lowest value of fluoride is 0.18 mgl^{-1}. The World Health Organization (WHO) recommends an acceptable limit of 1.5 mg per liter (1.5 mg/l) for fluoride levels in drinking water. Due to intake of higher fluoride concentration in drinking water more than 200 million people suffered with fluorosis (Alam et al., 2024). The highest value of sulphate in groundwater is 116.5 mg L^{-1} and lowest value of sulphate is 16.74 mg L^{-1}. High concentrations of nitrates in drinking water pose an increased possibility of stomach cancer in infants and expectant mothers, along with other possible hazards (Karunanidhi et al., 2021). The nitrate concentration in the research region ranges from 0.15 to 50.775 mg L^{-1}.

Pearson's Correlation matrix

The correlation matrix may be examined in comprehensive manner, which is beneficial since it reveals the specific roles and influences of each parameter in the hydrochemistry process. In the Pearson's correlation matrix, if the values of r are '+1' or '-1', they are considered to have a high correlation coefficient value, indicating a full correlation or functional dependency between two variables. If the values approach zero, it signifies the absence of a statistically significant link between two variables at a significance threshold of $P < 0.05$. If the value of r is more than 0.7, it indicates a significant correlation between the parameters. If the value of r falls between 0.5 and 0.7, it suggests a moderate correlation between the parameters (Alam & Singh, 2022). The correlation matrix is utilized to analyze the relationship between the experimentally recorded data, allowing for a discussion of the factor loadings using PCA. (B Patil et al., 2020). Based on the studied geochemical data, this study has found a poor link ($r < 0.50$) between fluoride, chloride, dissolved oxygen (DO), nitrate, and sulphate, as well as other water quality parameters. The data indicate a significant association ($r > 0.50$) between the parameters TDS with EC, F, alkalinity, and magnesium. The statistically significant correlation ($p < 0.05$, $r = 0.52$) between nitrate and sulphate indicates that these contaminants have entered the environment due to human activities, such as the use of fertilisers, the seepage of domestic sewage, or the application of irrigation water rich in nutrients. The correlation between sulphate and calcium and magnesium (table 2) is statistically insignificant ($p < 0.05$, $r = 0.33$, 0.48).

Table 2. Correlation matrix of parameters.

	pH	TDS	EC	DO	F^-	Cl^-	NO_3^-	SO_4^{2-}	Total Alkalinity	Total hardness	Calcium	Magnesium
pH	1.00											
TDS	0.13	1.00										
EC	-0.02	0.93	1.00									
DO	-0.15	0.12	0.07	1.00								
F^-	0.38	0.72	0.69	0.08	1.00							
Cl^-	0.09	0.16	0.07	0.16	0.02	1.00						
NO_3-	-0.53	0.18	0.33	0.15	-0.14	0.29	1.00					

SO_4^{2-}	-0.38	0.25	0.34	-0.09	0.04	0.10	0.52	1.00				
Total Alkalinity	0.02	0.66	0.66	0.03	0.51	0.09	0.14	0.32	1.00			
Total hardness	-0.57	0.49	0.62	0.09	-0.04	0.04	0.69	0.54	0.29	1.00		
Calcium	-0.66	0.01	0.13	-0.09	-0.44	-0.35	0.39	0.33	0.00	0.72	1.00	
Magnesium	-0.25	0.69	0.77	0.20	0.31	0.35	0.65	0.48	0.41	0.81	0.18	1.00

The principal component analysis (PCA) produced four significant factors, also known as varifactors or VFs, which have eigenvalues greater than one. This information is displayed in the scree plot. The combined contribution of these four variables accounted for 82.864% of the overall variability observed in the sample. Table 3 contains comprehensive data on the eigenvalues of the varifactors and the related percentages of explained variances. Loadings in PCA indicate the degree of correlation between variables and factors.

Table 3. Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.595	38.294	38.294	4.595	38.294	38.294
2	2.922	24.352	62.646	2.922	24.352	62.646
3	1.421	11.841	74.487	1.421	11.841	74.487
4	1.005	8.377	82.864	1.005	8.377	82.864
5	.643	5.359	88.223			
6	.485	4.041	92.264			
7	.363	3.023	95.287			
8	.301	2.504	97.791			
9	.173	1.440	99.231			
10	.062	.516	99.747			
11	.030	.253	100.000			
12	2.703E-006	2.253E-005	100.000			

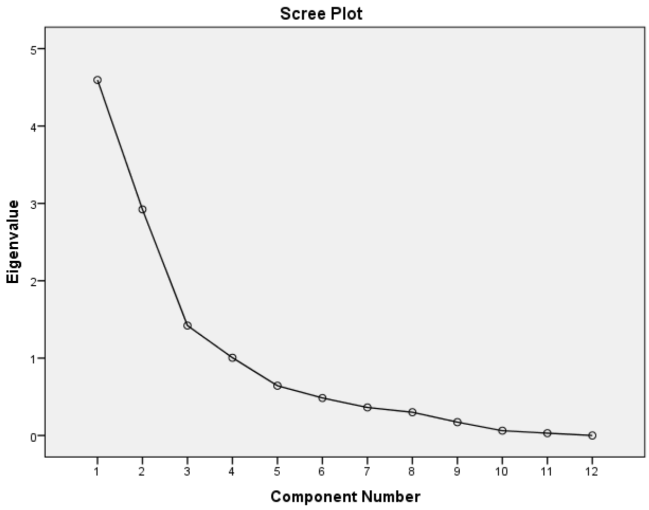

Figure 2. Scree plot diagrams

The Scree Plot provides a visual representation of the eigenvalues for all elements. When selecting factors, it is beneficial to employ the principles of principal component analysis to determine the optimal number of principal component factors. Only eigenvalues with a magnitude larger than one are considered, as seen in figure 2.

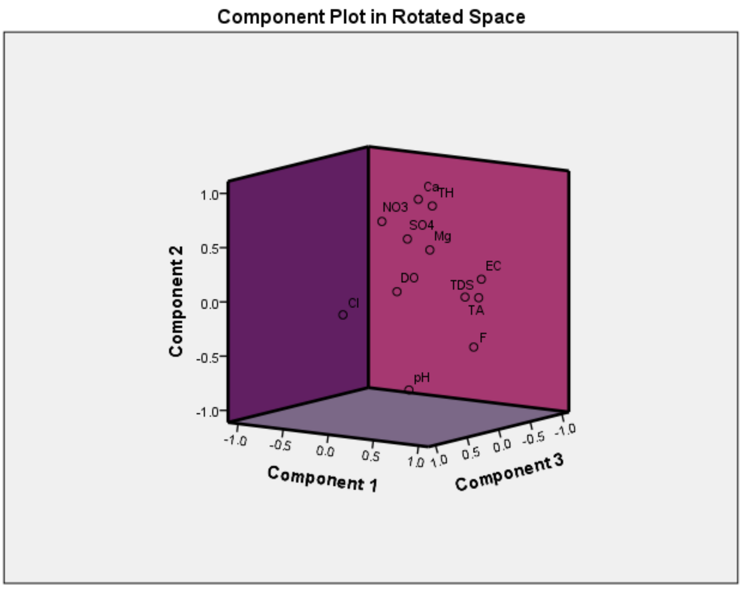

Figure 3. Diagram illustrating the plot of components in a rotating space

The allocation of variables on derived varifactors is depicted in Table 4, while the factor component plot for this allocation is displayed in Figure 3 and will be addressed in this section. VF1, having eigenvalue 4.595, explained 38.294% of the total variance and holds a positive robust loading for, TDS (0.946), EC (0.941), F^- (0.837) and Mg^{2+} (0.632). VF2, with eigenvalue 2.922, explained 24.352% of the total variance and held robust positive loadings for pH (-0.824) Ca^{2+}(0.806), NO_3^-(0.764), SO_4^{2-}(0.593). and VF3 with eigen value 1.421, explain 11.841% with a major loading of Cl^- (0.933) and VF3 with eigen value 1.005, explain 8.377% held positive loadings for DO (0.943).

Table 4. Rotated Component Matrix[a]

	Component			
	1	2	3	4
pH	.197	**-.824**	.116	-.155
TDS (ppm)	**.946**	.098	.081	.072
EC (µS/cm)	**.941**	.261	.031	.020
DO (ppm)	.065	.069	.116	**.943**
F- (ppm)	**.837**	-.379	.004	.065
Cl- (ppm)	.038	-.029	**.933**	.074
NO3- (mg/l)	.108	**.764**	.417	.079
SO42- (mg/L	.265	**.593**	.236	-.359
Total Alkalinity (mg/l)	**.759**	.077	.029	-.105
Total hardness (mg/l)	.395	**.880**	.028	.032
Calcium hardness (mg/l)	-.086	**.826**	-.437	-.089
Magnesium hardness (mg/l)	**.632**	.553	.405	.118

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]
a. Rotation converged in 6 iterations.

Water quality index

In the present study, the water quality index obtained, for the groundwater samples ranged from 21.35 to 130.67. The WQI was calculated using 12 physio-chemical parameters at each sampling site. Based on the obtained WQI, the water quality at each site may be classified as Excellent, Good, Poor, very poor, and unsuitable, depending upon their respective WQI values (BROWN et al., 1973; Mishra & Lal, 2023 and Ram et al., 2021). The WQI value and water categorization is summarized in **Table 5**. Based on WQI values, 14 samples out of 24 (59% of total samples) fall under class 'B' i.e., good water quality; 6 samples out of 24 (35% of the total samples) fall under class 'C' i.e., poor water quality; 2 samples out of 24 (6% of the total samples) fall under class 'D' i.e., very poor water quality; and one-one samples fall under class 'A' (Excellent water quality) or class 'E' (unsuitable water quality). The spatial distribution of the WQI in the study area is shown in (**Fig. 4**). The spatial map was generated using the IDW tool in Arc-GIS 10.8 software. The IDW (inverse distance weightage) is a type of deterministic technique for multivariate interpolation using a pre-available dataset of scattered points.

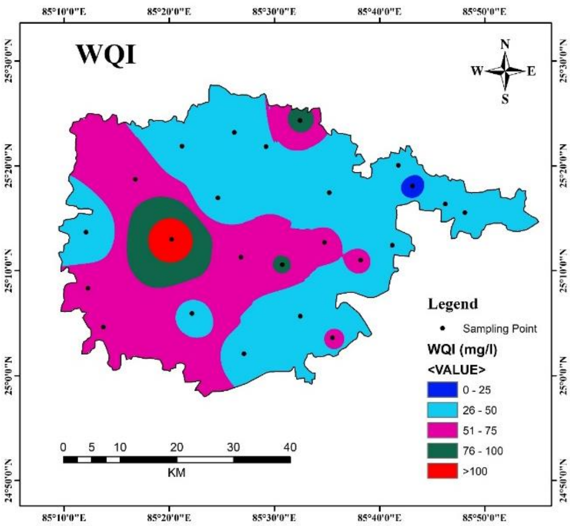

Figure 4 Map displaying the geographical distribution of various water categories determined by the Water Quality Index (WQI) value.

Table 5 Water quality categorization determined by the Water Quality Index (WQI) value.

Sr. No.	WQI value	Water Quality	% of Sample
1	0-25	excellent	4.16
2	25-50	good	58.33
3	50-75	poor water	25
4	75-100	very poor water	8.33
5	>100	unsuitable	4.16

Conclusion

An evaluation has been conducted to know the suitability of Nalanda groundwater in Bihar for drinking purposes. Based on the findings of the hydro-chemical analysis, the physicochemical parameters, including TDS, F^{-}, Cl^{-}, Ca^{2+}, Mg^{2+}, NO_3^{-} were discovered to exceed the permissible limits for drinking water set by the Bureau of Indian Standards (BIS 2012). The correlation analysis shows a significant link between TDS and EC, F, alkalinity, and magnesium. There is a notable link between nitrate and sulphate, hardness, and magnesium. The correlation study indicates that both natural (geogenic) and human-induced (anthropogenic) activities have significant influences on the pollution of groundwater.

The multivariate statistical analysis demonstrated that the four identified components explained 82.864% of the total variation. A total of 12 physicochemical variables were assessed and subsequently condensed into 4 major factors. The Water Quality Index (WQI) of the groundwater samples varied between 21.35 and 130.67. The derived Water Quality Index (WQI) suggests that 63% of the samples exhibit favorable water quality and are deemed suitable for consumption. 25% of the samples exhibit poor water quality, while the remaining 12% fall into either the extremely bad water quality category or the unsuitable category, both of which need treatment before consumption. Awareness of local communities regarding the appropriate usage of groundwater and prevent untreated domestic sewage to join groundwater may provide an effective tool to manage the water resources from future contamination. Thus, this study demonstrated that Multivariate statistical techniques (MSTs) and WQI are effective approaches to assess Groundwater quality of the city. The study's findings will assist policymakers in making informed decisions on groundwater resource management and sustainable design in the foreseeable future.

References

[1] Abdelaziz, S., Gad, M. I., & El Tahan, A. H. M. H. (2020). Groundwater quality index based on PCA: Wadi El-Natrun, Egypt. *Journal of African Earth Sciences*, *172*(October 2019), 103964. https://doi.org/10.1016/j.jafrearsci.2020.103964

[2] Adimalla, N., & Qian, H. (2019). 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. *Ecotoxicology and Environmental Safety*, *176*(126), 153–161. https://doi.org/10.1016/j.ecoenv.2019.03.066

[3] Alam, A., Kumar, A., & Singh, A. (2024). A GIS approach for groundwater quality evaluation with entropy method and fluoride exposure with health risk assessment. *Environmental Geochemistry and Health*, *46*(January), 1–23. https://doi.org/10.1007/s10653-023-01822-2

[4] Alam, A., & Kumar, S. (2023). Groundwater Quality Assessment and Evaluation of Scaling and Corrosiveness Potential of Drinking Water Samples †. *Environmental Sciences Proceedings*, *25*(1), 1–7. https://doi.org/10.3390/ECWS-7-14316

[5] Alam, A., & Singh, A. (2022). GROUNDWATER QUALITY EVALUATION USING STATISTICAL APPROACH AND WATER QUALITY INDEX IN. *Rasayan J. Chem*, *188*, 180–188. http://doi.org/10.31788/RJC.2022.1558191

[6] Alam, A., & Singh, A. (2023). Groundwater quality assessment using SPSS based on multivariate statistics and water quality index of Gaya, Bihar (India). *Environmental Monitoring and Assessment*, *195*(6), 0–23.

https://doi.org/10.1007/s10661-023-11294-7

[7] APHA. (2005). *APHA (2005) Standard methods for the examination of water and waste-water. American Public Health Association (APHA), Washington, DC*.

[8] Azhdarpoor, A., Radfard, M., Pakdel, M., Abbasnia, A., Badeenezhad, A., Mohammadi, A. A., & Yousefi, M. (2019). Assessing fluoride and nitrate contaminants in drinking water resources and their health risk assessment in a Semiarid region of Southwest Iran. *Desalination and Water Treatment*, *149*(April), 43–51. https://doi.org/10.5004/dwt.2019.23865

[9] B Patil, V. B., Pinto, S. M., Govindaraju, T., Hebbalu, V. S., Bhat, V., & Kannanur, L. N. (2020). Multivariate statistics and water quality index (WQI) approach for geochemical assessment of groundwater quality—a case study of Kanavi Halla Sub-Basin, Belagavi, India. *Environmental Geochemistry and Health*, *42*(9), 2667–2684. https://doi.org/10.1007/s10653-019-00500-6

[10] BIS. (2012). Indian Standard Drinking Water Specification (Second Revision). *Bureau of Indian Standards*, *IS 10500*(May), 1–11.

[11] BROWN, R. M., McCLELLAND, N. I., DEININGER, R. A., & O'CONNOR, M. F. (1973). a Water Quality Index – Crashing the Psychological Barrier. *Advances in Water Pollution Research*, 787–797. https://doi.org/10.1016/b978-0-08-017005-3.50067-0

[12] Brown, R., McClelland, N., Deininger, R., & Tozer, R. (1970). A water quality index—do we dare? *Proceedings, National Symposium on Data and Instrumentation for Water Quality Management*, *117*, 339–343.

[13] Harun, H. H., Kasim, M. R. M., Nurhidayu, S., Ash'aari, Z. H., Kusin, F. M., & Karim, M. K. A. (2021). Association of physicochemical characteristics, aggregate indices, major ions, and trace elements in developing groundwater quality index (Gwqi) in agricultural area. *International Journal of Environmental Research and Public Health*, *18*(9). https://doi.org/10.3390/ijerph18094562

[14] Horton, R. K. (1965). An index number system for rating water quality. *J Water Pollut Control Fed*, *(3)*(37), 300-306.

[15] Islam, A. R. M. T., Shen, S., Haque, M. A., Bodrud-Doza, M., Maw, K. W., & Habib, M. A. (2018). Assessing groundwater quality and its sustainability in Joypurhat district of Bangladesh using GIS and multivariate statistical approaches. *Environment, Development and Sustainability*, *20*(5), 1935–1959. https://doi.org/10.1007/s10668-017-9971-3

[16] Karunanidhi, D., Aravinthasamy, P., Subramani, T., Kumar, D., & Setia, R. (2021). Investigation of health risks related with multipath entry of groundwater nitrate using Sobol sensitivity indicators in an urban-industrial sector of south India. *Environmental Research*, *200*(July), 111726. https://doi.org/10.1016/j.envres.2021.111726

[17] Krishan, G., Bhagwat, A., Sejwal, P., Yadav, B. K., Kansal, M. L., Bradley, A., Singh, S., Kumar, M., Sharma, L. M., & Muste, M. (2023). Assessment of groundwater salinity using principal component analysis (PCA): a case study from Mewat (Nuh), Haryana, India. *Environmental Monitoring and Assessment*, *195*(1), 1–15. https://doi.org/10.1007/s10661-022-10555-1

[18] Kumar, A., Alam, A., & Singh, A. (2023). Simulation of One-Dimensional Solute Transport with Equilibrium-Controlled Non-Linear Sorption Using Modular Three-Dimensional Multispecies Transport Model. *ECP 2023*, 28. https://doi.org/10.3390/ECP2023-14741

[19] Kumar, D., Singh, A., Jha, R. K., Sahoo, B. B., & Sahoo, S. K. (2019). *Source characterization and human health risk assessment of nitrate in groundwater of middle Gangetic Plain , India*. *2*.

[20] Kumar, M., & Kumar, R. (2013). Assessment of Physico-Chemical Properties of Ground Water in Granite Mining Areas in Goramachia, Jhansi, UP, India. *International Research Journal of Environment Sciences_ISSN*, *2*(1), 19–24.

[21] Mishra, A., & Lal, B. (2023). Assessment of groundwater quality in Ranchi district , Jharkhand , India , using water evaluation indices and multivariate statistics. *Environmental Monitoring and Assessment*. https://doi.org/10.1007/s10661-023-11101-3

[22] Mohammadi, A. A., Morovati, M., Saleh, H. N., Askari, S. G., Ghaderpoori, M., Shams, M., Kalteh, S., & Sadeghi, S. (2020). Groundwater quality evaluation for drinking and industrial purposes . A case study. *International Journal of Environmental Analytical Chemistry*, *00*(00), 1–11.

https://doi.org/10.1080/03067319.2020.1807533

[23] Prasun, A., Singh, A., Kumar, P. A., Alam, A., & Kumar, A. (2023). Removal of Phenol from Biomedical Waste via an Adsorption Process. *Engineering Proceedings*, *June*, 30. https://doi.org/10.3390/ecp2023-14663

[24] Ram, A., Tiwari, S. K., Pandey, H. K., Chaurasia, A. K., Singh, S., & Singh, Y. V. (2021). Groundwater quality assessment using water quality index (WQI) under GIS framework. *Applied Water Science*, *11*(2), 1–20. https://doi.org/10.1007/s13201-021-01376-7

[25] Teixeira de Souza, A., Carneiro, L. A. T. X., da Silva Junior, O. P., de Carvalho, S. L., & Américo-Pinheiro, J. H. P. (2021). Assessment of water quality using principal component analysis: a case study of the Marrecas stream basin in Brazil. *Environmental Technology (United Kingdom)*, *42*(27), 4286–4295. https://doi.org/10.1080/09593330.2020.1754922