Application of Water Quality Index and Multivariate Statistical Method To Determine Groundwater Quality In Raigarh District Chhattisgarh

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Abstract

In the present study we have analyzed the groundwater profile of Dharamjaigarh, Tamnar and Kharsia tehsils of Raigarh, district of Chhattisgarh, India is carried out by using water quality index and multivariate statistics. The water quality index is a number that gives us an idea about the overall quality of drinking water. Groundwater samples were collected from 15 villages and physicochemical parameters like pH, TDS, alkalinity, hardness, calcium, magnesium, sulphate, nitrate, chloride fluoride along with dissolved oxygen, BOD and COD were analyzed. A multivariate statistical technique like principal component analysis and cluster analysis was performed to get summarize the idea of water quality pattern in the study area and the result shows only four sampling locations have a good quality of water out of 15. High fluoride concentration is specifically prevalent in this area which a major concern in this analysis. The overall analysis suggests a large number of the rural population is at risk and groundwater in this area needs adequate treatment before consumption.

Key Words: Groundwater, Water Quality Index, Physicochemical Parameters, Fluoride, Multivariate Statistical Analysis

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Introduction

Water is the most important asset to the living world. Increasing the demand for water has caused a shortage for drinking purpose. People are now paying for drinking water even in the rural area where it was readily available before [1].Seeing the present scenario of water crisis quantity as well as quality of water both is equally important, whether it is surface or groundwater ([2],[3]. Water scarcity itself may lead to poor water quality due to improper disposal and the consequent accumulation of domestic wastewater and industrial wastes in different water bodies ([4], [5]. Moreover it is majorly affected by urbanization, industrialization, agricultural practices, in the past few decades groundwater pollution has emerged as a serious issue throughout the world [6]. Raigarh district is soil of mineral deposits which mainly comprises coal and iron, industry based on coal and iron are the main power of this district which greatly influences the quality of water in both surface and ground [7]. Sturdy degradation in groundwater quality of India and rural parts of Chhattisgarh is seen due to geological formation and anthropogenic activeties. Major health issues due to inadequate and contaminated water have been faced throughout the world however it is more distressful in developing countries like India and their rural

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backward areas where proper treatment methods are not employed [8]. The physical and chemical content of groundwater plays an important role in determining its use for domestic, agriculture or industrial purposes [9], [10]. The accurate idea of water chemistry is important to evaluate the groundwater quality in any area in which the groundwater is used for both irrigation and drinking purpose [11]

The physicochemical assessment of water gives clear information regarding the underground geological environments in which the water is present [12], [13]. Water quality index (WQI) calculation gives a single number that represents the overall water quality of specific location and time based on numerous physico-chemical water quality parameters [14], [15]. WQI is mainly used to evaluate and detect the Pollution level of water in different sources [16], [13]. It characterizes the influence of different physicochemical parameters altogether. Multivariate statistical methods have been used as a valuable tool in reducing large data obtained from the physicochemical analysis of water to get summarized ideas about the variables i.e. parameters and sampling locations [11]. These techniques remove the effect of different measurement units and thus give the dimensionless data. Multivariate statistical techniques, along with hierarchical cluster analysis (HCA), principal component analysis (PCA), discriminate analysis (DA), and principal factor analysis (PFA) are frequently applied methods for water quality investigations [17], [18]. The main objective of this study is to monitor the groundwater quality of Dharmajaigarh, Kharsia and Tamnar tehsil of Raigarh district of Chhattisgarh state of India by using water quality index and multivariate statistical analysis. All studies were performed using the data obtained during the observation period of November 2018 to February 2019.

Study Area

Raigarh district falls in the easternmost part of Chhattisgarh state and surrounded by surguja and jashpur districts in the north, Orissa state in the east, mahasamund district in the south and korba and janjgir-champa districts in the west. It consists of nine tehsils and covers a total area of 7086 square kilometers. Kharsia, Raigarh, Dharmajaigarh, sarangarh, Tamnar are major towns in the district [19]. Study area is located in the central part of mahanadi gond-wana master basin that mostly cover Mand - Raigarh Coalfield. These lands are classified into Talchir, Barakar and Kamthi formations. The soil geology has a great influence in the chemistry of ground water due to continue infiltration/ recharge minerals mixing in the groundwater [20]. Around 33% of the geographical area is covered by forest and Annual rainfall in the district is around 1240 mm and the rainfall increases slightly from south to north 90 % of the rainfall occurs in monsoon season between mid of June to September. Site map of the location is shown in Figure No. 01 drawn with the help of Google maps maker and Raigarh government Site.

Materials and Methods

For the analysis of groundwater fifteen sampling locations of Kharsia and Tamnar tehsil of Raigarh district were identified and samples were collected every month from November 2018 to February during the post monsoon season. Water samples were collected in washed and clean plastic bottles and kept in cool environment. A total fifteen physico-chemical parameters were selected for the analysis of groundwater and standard procedures were applied to determine physicochemical parameters procedure according to the American Public Health Association [21]. Total alkalinity was analyzed by the neutralization titration method with the help of 0.02 N HCL as an intermediate solution. Total hardness, calcium and magnesium were tested by complex-metric titration using EDTA solution, and Eriochrome black T. whereas chloride by argentometric titration [22]. Temperature, TDS, specific conductivity, pH and dissolved Oxygen and BOD were analyzed by using a pre-calibrated portable water analyzer kit. Sulphate and nitrate were analyzed by using turbidity and UV spectrophotometer respectively. Fluoride was determined using the ion-selective electrode. After analysis of samples on monthly basis mean value was calculated and single data for every parameter was generated for one season and later water quality index and Multivariate statistical techniques were applied to get the insight of water quality. Detailed analysis report of all the characteristic parameters are given in the table number – 01 along with their units of measurement. Standard permissible value recommended by the Indian council of medical research and bureau of Indian standard is given in table number – 0 2 with unit weight calculated by using weight arithmetic method given by [16]

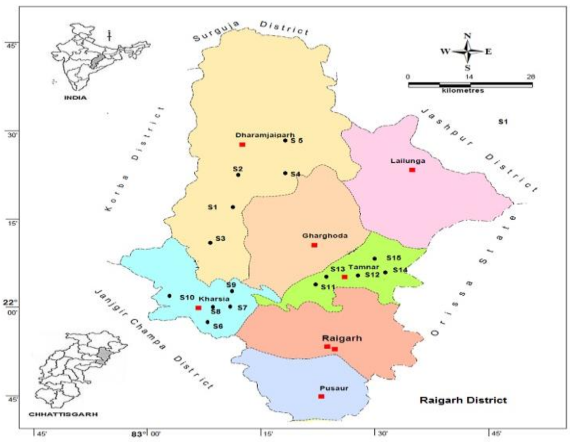


Figure No. -01 Location map of the Raigarh district with study area

Table No – 1 physicochemical parameters of groundwater in different sampling sites of Raigarh district.

Sampling Location	Turbidity	pH	Total Alkalinity	EC	TDS	TH	Ca^{2+}	Mg^{2+}	SO_4^{2-}	NO_3^{2-}	F^-	Cl^-	DO	COD	BOD
WS1 Chhal	0.9	7.6	264.45	697.34	485	254.1	28.5	43.8	12.8	5.98	1.48	51.2	5.2	6.4	2.4
WS2 Hati	3.0	7.6	56.2	106.2	85.2	55.4	13.6	6.8	3.58	26.4	0.22	16.2	4.2	5.3	2.9
WS3 Amapali	3.8	7.5	30.9	155.2	106.5	98.25	9.7	7.8	6.84	5.6	0.42	26.8	4.8	4.6	2.1
WS4 Kudumekela	200.0	7.3	187.6	415.2	247.32	168.3	178.6	24.5	8.6	0.4	1.62	16.4	4.9	4.3	3.4
WS5 Pathalgaon	2.9	8.2	96.37	465.3	357.2	142.6	35.2	15.6	4.5	19.6	0.62	20.13	4.3	5.7	1.2
WS6 Anjoripali	0.7	7.43	271.64	915.45	417.30	240.73	27.87	50.93	11.24	6.13	1.23	89.65	5.1	6.4	3.7
WS7 Kharsia	1.1	7.73	112.37	315.83	210.40	127.27	28.87	14.90	11.78	8.60	0.53	20.52	4.1	4.7	1.3
WS8 Kharsia	0.5	7.60	225.97	839.93	535.90	277.73	74.63	26.40	56.65	9.30	1.72	64.27	4.9	5.3	3.5
WS9 Chodha	8.4	7.50	246.90	556.97	369.20	233.50	44.43	27.10	37.47	0.04	1.67	31.10	4.9	4.9	3.6
WS10 Makri	0.6	7.70	273.57	937.93	502.36	410.17	75.77	52.93	70.80	30.03	1.53	100.93	5.2	6.3	3.9
WS11 Devgarh	3.0	7.83	190.48	432.96	282.23	164.43	36.38	15.08	2.23	0.68	1.61	35.52	5.0	6.4	2.3
WS12 Tamnar	2.3	7.73	174.13	431.76	276.55	152.43	26.47	21.35	2.20	0.13	1.29	28.69	5.9	5.7	3.8
WS13 Amaghat	163.9	7.28	118.73	503.14	324.6	82.66	12.83	11.87	5.60	0.15	0.38	14.06	5.3	6.2	2.1
WS 14 Libara	2.1	6.8	237.15	332.21	194.44	89.14	18.3	10.58	25.6	0.53	2.84	12.3	5.4	6.1	2.9
WS 15 Saraitola	0.5	6.95	109.65	349.63	197.50	105.33	19.43	9.63	25.82	1.27	5.15	14.59	5.2	6.1	3.8

All parameters are expressed in mg/l except pH, turbidity (NTU) and spec EC (S/cm).

Table No - 02 Statistical summary of quantitative groundwater quality data (n = 15) along with standard permissible values by [23] and ICMR

Parameters ^{a}	**Minimum**	**Maximum**	**Mean**	**SD**	**BIS 2009 / ICMR Maximum Permissible limit**	**Unit weight**
Turbidity	0.45	200.00	26.24	63.61	10	0.070
pH	6.80	8.20	7.51	0.34	6.5-8.5	0.082
Total Alkalinity	30.90	273.56	173.07	80.82	120	0.006
Electronic Conductivity	106.20	937.93	497.00	253.29	300	0.002
TDS	85.20	535.90	306.11	138.76	500	0.001
Total Hardness	55.40	410.16	173.46	94.40	300	0.002
Calcium	9.70	178.60	42.03	42.69	75	0.009
Magnesium	6.80	52.93	22.61	15.29	30	0.023
Sulphate	2.19	70.80	19.04	20.92	150	0.005
Nitrate	0.04	30.03	7.65	9.89	45	0.016
Fluoride	0.22	5.15	1.48	1.22	1.5	0.466
Chloride	12.30	100.93	36.15	28.10	250	0.003
DO	4.13	5.900	4.958	0.474	5	0.140
COD	4.30	6.400	5.633	0.733	20	0.035
BOD	1.24	3.900	2.860	0.906	5	0.140
					Unit weight ∑	**1.00**

all parameters are expressed in mg/l except pH, turbidity (NTU) and spec EC (S/cm)

Results and Discussion

Understanding of groundwater quality is essential as it is the main factor that determines whether water is suitable for drinking and agricultural purpose or not. In the current study water quality assessment has been carried out by using physicochemical data gained from laboratory analysis and then water quality index has been calculated by involving weight arithmetic method [24]. Water quality index for all the sampling location is described in the Table No - 03. Results indicate that there is variation in water quality from place to place in the district. Table No - 02 shows the statistical summary of quantitative ground-water quality data along with standard per-missible values by IS [23] and ICMR which has been used for calculation of Water quality index calculation of ground water samples.

Water Quality Index [WQI : [16], [25]

WQI indexing is employed for an easy understanding of water quality by layman kee-ping in mind the suitability of water for human consumption [24], [8] . Water quality Index is calculated by using method given by [25]. In the present study calculation of WQI is done by using the weight arithmetic method. Quality parameters were taken and quality rating was assigned to each parameter, which corresponds to the nth parameter. Quality scale (Q), relative unit weight (Wn) given in table no 02 and WQI were calculated for each factor using the formula given by [25]. Quality of groundwater is rated based on water quality index range. Given by [16] that gives insight of the overall quality of water so when WQI ranges from 0-25 water is said to be excellent in quality and when it between 26-50 water is good to moderate quality and when the values is in range of 51 to 75 it shows poor quality of water, from 76 -100 water quality is supposed to be very bad or poor quality and if water quality index range is above 100 then water quality is reported as unfit for drinking purpose. Among all fifteen water sampling locations only two samples are found good whereas nine water samples are ranging from moderate to poor and very poor quality and four samples water are found unfit for drinking purpose. The major reason for high WQI value in the water samples are High TDS, Turbidity and excessive fluoride levels in groundwater of the selected region. Iron ore mines and various industries are situated in this region which affects the underground and surface water by slow movement of minerals and their chemical interactions.

Table No – 03 Water Quality Indexes of all water samples with the Quality rating.

Samples	WQI Values	Overall Water Quality
WS1	77.38	Poor Quality
WS2	38.30	Good
WS 3	40.94	Good Quality
WS 4	221.73	Water not suitable for drinking purpose
WS 5	50.82	Moderate Quality
WS 6	73.44	Poor Quality
WS 7	43.71	Moderate Quality
WS 8	85.90	Poor Quality
WS 9	90.23	Very Poor Quality
WS 10	86.54	Very Poor Quality
WS 11	81.51	Poor Quality
WS 12	73.20	Poor Quality
WS 13	150.62	Water not suitable for drinking purpose
WS 14	113.85	Water not suitable for drinking purpose
WS 15	187.41	Water not suitable for drinking purpose

Groundwater chemistry

pH shows the hydrogen ion concentration in water and gives the idea of whether water is acidic neutral or basic. pH in the study area ranges from 6.8 to 8.2 are within the desirable limits prescribed by (BIS 2009 and WHO) however overall groundwater is slightly alkali-ne in the region. Measurement of specific cond-uctivity provides an indication of ion concen-tration EC (μs/cm) its value ranges from 106.2 0 – 937.93 (mean 497.0). TDS is total dissolved solid present in water it ranges from 85.20 – 535.90 (mean 306.11) low TDS is could be due to its residence time as TDS in ground water is dependent on residence time with under-ground water or the rate of weathering of granitic gneiss terrain [26]. Alkalinity is the measure of basicity present in water [27], it is due to the presence of three types of ions OH-, HCO3- and CO32-groundwater in this region is slightly alkaline and most of the samples have alkalinity above the permissible limit. It ranges from 273. 56 mg/ L to 30.90 mg/L in the study area high alkalinity in water gives it a bitter taste, highly alkaline water may cause drying and itching of skin while using for washing [28]. Nitrate in ground water is an anthropogenic pollutant added by seepage of irrigation water from agriculture field where nitrogenous fertilizers are used.

Fluoride

Fluoride is represented as F^- it has a significant role in water quality [29]. Fluoride is present in almost all water resources ranging from its concentration in traces to high. Fluoride is a substance whose upper and lower concentration both are important, its lower limit is 0.6 mg/l and upper permissible limit in drinking water is 1.5 mg/l, at very low concentration fluoride cause tooth and bone decay , it is essential for bones and teeth [30] but when it is consumed in a higher concentration for longer time causes serious health issues and is responsible for causing specific disease called *Fluorosis* that damage teeth and bones [31], [32], [33] In this analysis fluoride ranges from 0.22 mg/l to 5. 15 mg/l. highest concentration is recorded in S15 Saraitola which above prescribed limit of BIS / WHO, total seven locations were identified with very high concentration. High fluoride concentration in groundwater is seen in areas where rocks include fluoride-bearing minerals. The main reason for fluoride contamination in groundwater of this area is coal-bearing Barakar formation in the groundwater subgroup. Fluoride can enter in ground water or it is found in ground water due to decomposition and dissociation also it can be enriched by the dissolution of fluoride bearing minerals [34] . Low visibility or no clarity of water due to the presence of suspended particles or colloidal particles is called turbidity there is huge variation turbidity throughout the study area turbidity ranges from 0.2 to 200. At two sampling locations water is highly turbid and not suitable for drinking purposes.

Multivariate Statistical Techniques

Multivariate statistical analysis is used in this study are Principal Component Analysis (PCA) and Agglomerative Hierarchical Cluster Analysis (AHCA) to acquire the relationships between different parameters and sampling sites. MSA is used to classify groundwater that allows grouping of water samples based on similar physicochemical characteristics and also to show the correlation between chemical parameters and ground water samples [35] [36]. PCA and HCA, were used to quantitatively investigate the relationships among the dataset of the spring samples (15 chemical variables in the 15 samples).

Agglomerative Hierarchical Cluster Analysis (AHCA)

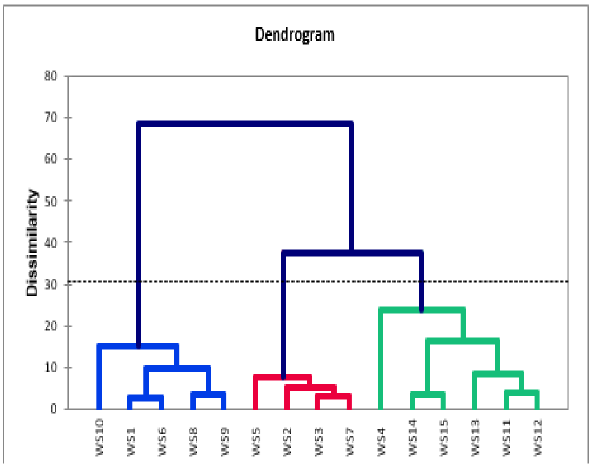


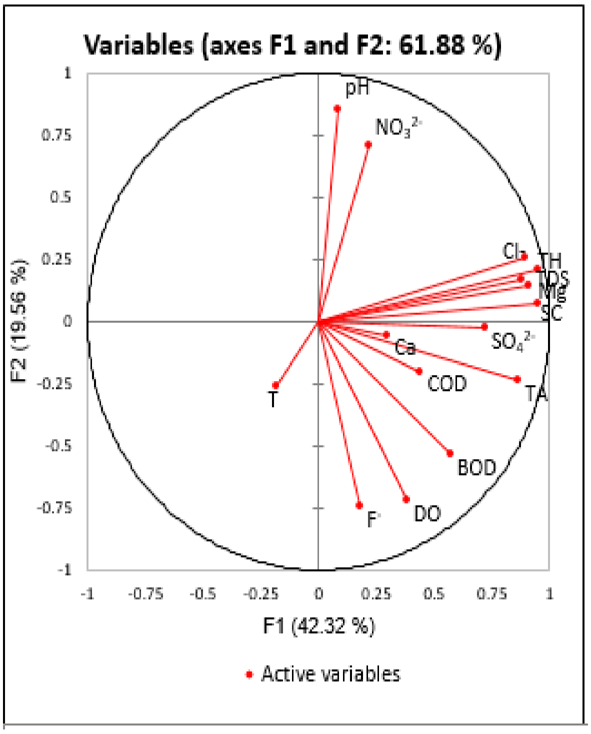
Figure 2 Agglomerative Hierarchical clustering analysis (AHCA) results of sampling sites according to water quality parameters

Agglomerative Hierarchical clustering analysis (AHCA) was performed on the samples WS1 – WS15 based on the dis-similarities in water quality parameters. With the application of hierarchical cluster analysis groundwater samples are grouped into different clusters so that sampling stations within cluster are similar to each other with respect to their chemical and physical properties but are different from other clusters. Process of clustering is done in sequence starting from most similar pair of objects and forming higher cluster in step by step process till a single cluster formed containing all the samples [37], [36]. The result is illustrated in Figure 2. For linkage and distance measurements, the Euclidean distance with Ward's method was used to get the best possible results. Based on 15 parameters (Variables), the dendrogram was able to group the 15 samples into three clusters. Cluster 1 contains WS1, WS6, WS8, WS9, &WS 10 this cluster depicts the poor quality of water is the respective locations.

Whereas cluster 2 contains WS2, WS3, WS5 &WS7 in this cluster the quality of water is good and can be used for drinking purposes directly. The third cluster has remaining samples i.e., WS4, WS11, WS12, WS13, WS14 &WS15 water samples in this cluster are of worst quality and not suitable for drinking unless proper treatment is done Cluster 1 and cluster 2 water samples are acceptable in absence of other sources compared to cluster 3. AHCA implied that there were three separate water qualities in the studied region.

The Principal Component Analysis (PCA)

Principal component analysis was carried out using XLSTAT 2019 1.2 and Microsoft excel 2010. The Principal Component Analysis (PCA) is the process of reduction in the number of components and explanation of variance with a reduced number of components without sacrificing too much of the information. Eigen values greater that one, are considered the most significant component. The component with higher variance gives more information of the data. Rotations are performed to maximize the variables and it creates new sets of factors from the original variables [24]



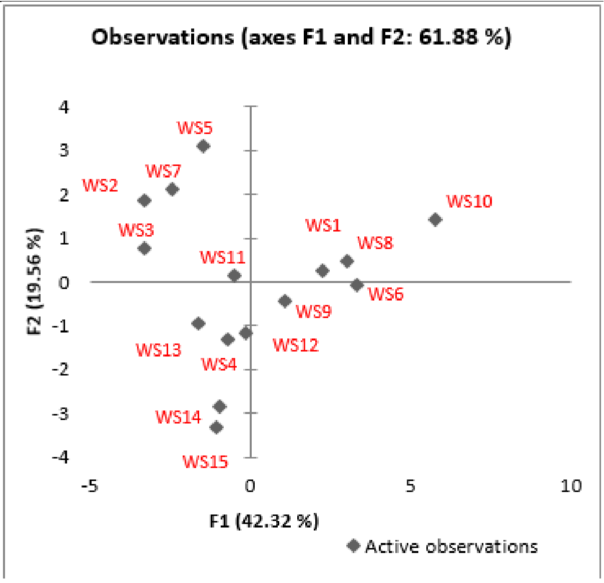


Figure 3 Correlation Circle for F 1 and F2 for variables and observations.

XLSTAT 2019 was used for dimensionality reduction in this article. Figure Number 3 is the correlation circle. This circle examines the relationships between the variables (parameters). The horizontal axis is the first PCA dimension, represents 42.32% of the initial information. The vertical axis is the second PCA dimension and represents 19.56% of initial data. In all these two PCA dimensions carry 61.88% information of initial data. Red vectors are the investigating variables (parameters). In correlation circle, interpretation is done in terms of angles between two variables or PCA dimensions. Narrow angles represent positively linked variables, thus Chloride, Total Hardness, Total Dissolve solids, Magnesium, and Specific conductivity are positively and strongly correlated. Total Alkalinity and Nitrate are at a right angle to each other hence there is no correlation between them. There is an obtuse angle between many variables such as pH and Fluoride and many more. These obtuse angles represent the negative correlation between the variables. If the vector lengths are small in selected PCA dimensions then it can be better represented in other PCA dimensions. We have selected the dimensions F1 and F2 which provided maximum possible length of vectors.
The chart shown in the figure number 03 relates the sample site to the variable (physicochemical parameters) and one another. Here also we have selected two PCA dimensions selected. The PCA dimensions are

again selected in such a way that it carries the maximum percentage of initial information. Water samples located on the right have greater values of the variables (parameters) but the smaller value of Turbidity whereas the samples located on the left side have the opposite characteristics. Water samples in the upper left part have lesser values of fluoride and turbidity, the water quality of the lower left is very poor as compared to the upper-left coordinate of the chart.

Conclusion

Groundwater in the selected area is deteriorated and the reason is soil chemistry in the particular geographical region as it falls in an ore mining area with high mineral content so the possibility of mineral contamination and their interaction is very high in the selected region. Among three tehsil water quality of Dharmajaigarh is found better as compared to Tamnar and Kharsia The overall study of water quality in the area shows high fluoride concentration. Around 50 % samples are reported with high fluoride, here TDS concentration is also playing important role in water quality degradation which is affecting the residents of this region to a great extent. Immediate action towards the application of Suitable remediation method for treating drinking water is suggested and recommended with proactive approach in the study area.

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