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SEASONAL VARIATION IN GROUNDWATER QUALITY AND DETERMINATION OF WATER QUALITY INDEX IN RAIGARH DISTRICT CHHATTISGARH INDIA

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ABSTRACT

The study analyzed groundwater quality across three Tehsils in Raigarh, Chhattisgarh, India, during both the rainy and summer seasons, using the Water Quality Index (WQI) and multivariate statistical methods. Groundwater samples were collected from 15 villages and assessed for various physicochemical parameters. Seasonal variation was evident in the quality of groundwater, with notable differences between the two periods. Overall, only four of the 15 sampling locations were found to have good quality water in both seasons. High fluoride concentration emerged as a major concern, particularly during the summer season, posing potential health risks. The findings indicate that the rural population in the region is at risk, and adequate treatment of groundwater is essential before consumption, especially during the summer season when contamination levels tend to rise.

Keywords: *Ground Water, Water Quality Index, Physicochemical Parameters, Fluoride, Multivariate statistical Analysis*

INTRODUCTION

Fresh air and pure water are essential resources for living systems, including humans. On average, a person needs about 2 liters of clean water per day to stay hydrated and avoid contamination. Groundwater is a crucial resource for drinking and agriculture, especially in developing countries like India [1]. Continuous environmental changes and unsustainable human activities are causing degradation of water quality and creating water crises, along with other environmental issues [2], [3]. The demand for groundwater is increasing in urban and semi-urban areas, and areas of high population density are particularly vulnerable to groundwater contamination due to excessive use of fertilizers and pesticides, as well as overexploitation of groundwater resources. Groundwater quality assessments have been conducted in urban and semi-urban areas worldwide [4], [5]. Over 1.5 billion people depend on groundwater for basic needs such as drinking and irrigation. Mismanagement, unplanned urbanization, and economic factors governing water supply have led to water scarcity, while anthropogenic activities and overexploitation have caused drastic alteration and contamination/degradation of water quality [6]. There has been significant emphasis on the study of water quality in the past few decades due to the severe health issues caused by inadequate and contaminated water, particularly in developing countries where appropriate sanitation services are often lacking [5], [7], [8].

Globally, various guidelines and policies have been adopted to control and prevent environmental degradation, with the aim of promoting sustainable use of the earth's resources. Studies such as [9] have discussed the effectiveness of these policies in addressing environmental issues. 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 [10] [11] WQI is mainly used to evaluate and detect the Pollution level of water in different sources [12][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 [14]. These techniques remove the effect of different measurement units and thus give the dimensionless data. The use of multivariate statistical techniques, such as hierarchical cluster analysis (HCA), principal component analysis (PCA), discriminate analysis (DA), and principal factor analysis (PFA), is common in water quality investigations [15][16]. The aim of this study is to monitor the groundwater quality of Dharamjaigarh, Kharsia, and Tamnar tehsils in Raigarh district, Chhattisgarh, India, using water quality index and multivariate statistical analysis. The study utilized data obtained between March to September 2019 in pre and monsoon season.

METHODOLOGY

Study Area

Raigarh district is located in the easternmost part of Chhattisgarh state and is bordered by Surguja and Jashpur districts to the north, Orissa state to the east, Mahasamund district to the south, and Korba and Janjgir-Champa districts to the west. The district consists of nine tehsils and covers an area of 7086 square kilometers, with major towns including Kharsia, Raigarh, Dharmajaigarh, Sarangarh, and Tamnar [17]. Groundwater samples were collected from 15 villages in Dharamjaigarh, Kharsia, and Tamnar Tehsils on a monthly basis from March to May 2019 pre monsoon and June to August 2019 post monsoon. A map of sampling locations was drawn using Google Maps, as shown in Figure 01.

Around 90 water samples were collected from 15 different villages in the study area. Pre-cleaned and sanitized plastic bottles were used to collect water samples from tube wells, boreholes, and hand pumps.

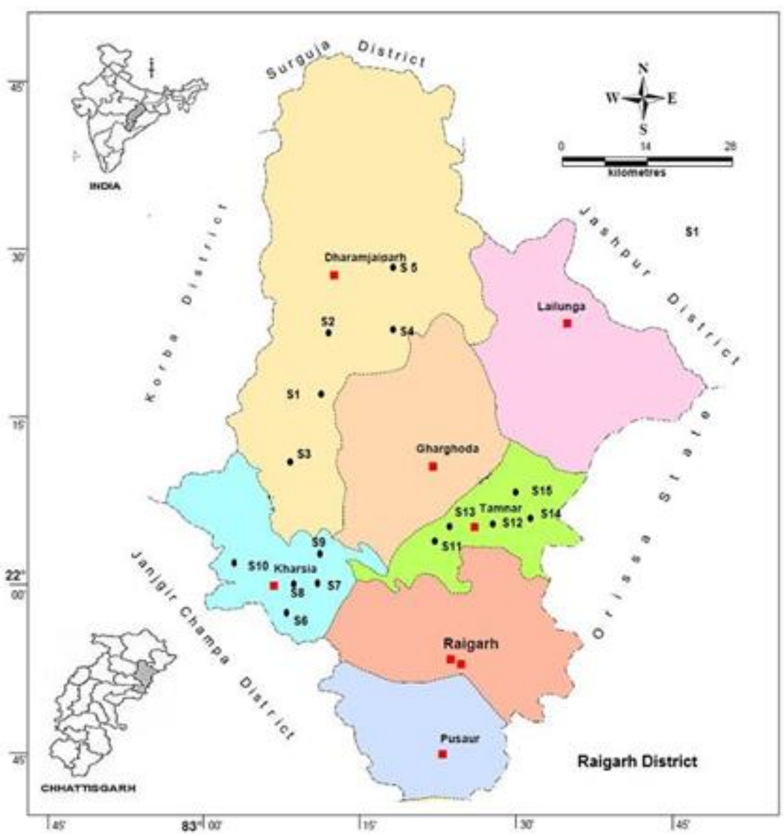

Figure No – 1 List of Sampling Locations

MATERIALS AND METHODS

Total fifteen physicochemical parameters were used to analyze groundwater and standard procedures were applied to determine physicochemical parameters procedure according to the American Public Health Association [18]. Total alkalinity was analyzed by using 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 [19]. 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 [2]

Table No – 1 Statistical summary of all fifteen parameters along with their unit weight.

SI No	Parameters	Units	Standard Value	Recommending Agencies	Minimum	Maximum	Minimum	Maximum	Weight
					Rainy	Summer			
1	Turbidity	NTU	10	ICMR / BIS	0.21	187	0.2	200	0.070
2	pH	Scale	6.5- 8.5	ICMR/ BIS	5.9	7.7	7.1	8.9	0.082
3	Total Alkalinity	mg/L	120	ICMR	21.39	269.35	37.21	287.60	0.006
4	Specific Conductivity	µS/cm	300	ICMR	101.92	898.48	120.7	967.20	0.002
5	TDS	mg/L	500	ICMR/ BIS	80.13	523.83	99.43	547.75	0.001
6	Total Hardness	mg/L	300	ICMR / BIS	34.78	404.55	59.74	422.63	0.002
7	Calcium	mg/L	75	ICMR/ BIS	176.23	7.84	10.2	198.2	0.009
8	Magnesium	mg/L	30	ICMR/ BIS	4.12	50.85	7.36	57.30	0.023
9	Sulphate	mg/L	150	ICMR / BIS	2.14	70.53	2.76	76.30	0.005
10	Nitrate	mg/L	45	ICMR	0.00	30.08	0.40	35.40	0.016
11	Chloride	mg/L	250	ICMR	10.54	94.4	18.66	105.30	0.466
12	Fluoride	mg/L	1.5	WHO/ BIS	0.12	5.11	0.431	6.373	0.003
13	DO	mg/L	5	ICMR	3.9	5.7	4.6	6.1	0.140
14	COD	mg/L	20	ICMR / BIS	4.1	6.1	4.6	6.8	0.035
15	BOD	mg/L	5	ICMR	1.9	4.2	1.5	4.1	0.140
				Unit weight ∑					1.00

RESULTS AND DISCUSSION

Water Quality Index

A water quality index (WQI) is a tool that is used to summarize water quality data into a single value that can be easily understood by the public or decision-makers. The index is based on measurements of various water quality parameters, such as pH, dissolved oxygen, temperature, total dissolved solids, turbidity, and levels of various pollutants such as nitrates, phosphates, heavy metals, and pathogens. Which expressed in Table No - 1 where the unit weight is assigned to all the parameters.

The WQI provides a quick and easy way to assess the overall quality of a body of water and to compare the water quality at different locations or over time. The index is typically based on a scoring system, where each parameter is assigned, a score based on its measured value, and the scores are then weighted and combined into a single value that represents the overall water quality [12], [21]. The specific formula for calculating a WQI can vary depending on the regulatory guidelines like BIS ICMR or methodology used, but the final result is typically expressed as a single value on a scale from 0 to 100, with lower values indicating better water quality. As standard range is shown in table no – 2 given by BIS.

Water quality indices can be useful for a wide range of applications, including monitoring and managing drinking water supplies, assessing the health of aquatic ecosystems, and evaluating the effectiveness of pollution control measures. However, it is important to note that the specific parameters and weights used in a WQI can vary depending on the context, and the index should be interpreted with caution and in conjunction with other data and information about the water system. Water Quality Index and their status is clearly mentioned in the table no -3 for both the seasons.

Table No – 2 Water Quality Index and their range

Water Quality Index Range	Status of water quality
0 – 25	Excellent Quality of water
26 – 50	Good to moderate Quality of water
51- 75	Poor quality of water
76 – 100	Very Poor Quality of water
Above 100	Water not suitable for drinking purpose

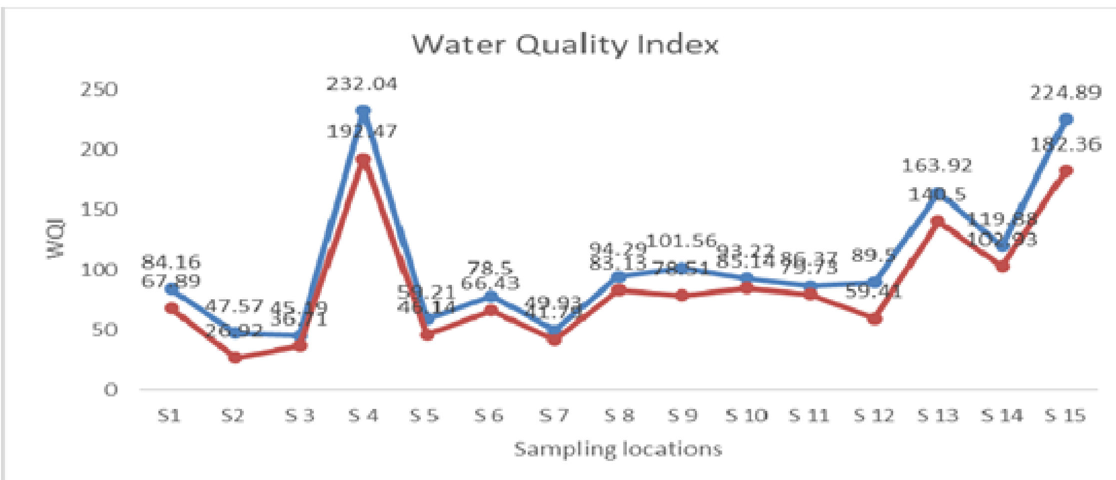

Figure No – 2 Graph between WQI and Sampling Locations

IMPORTANT SPECIFIC PARAMETERS

Electrical Conductivity

Electrical conductivity (EC) is a measure of a water sample's ability to conduct an electrical current, which is influenced by the presence of dissolved salts, minerals, and other ionic substances in the water. The World Health Organization (WHO) recommends a maximum limit of 1500 micro siemens per centimeter (µS/cm) for drinking water. This limit helps to ensure that the water is safe for consumption and does not have a high concentration of dissolved salts, which can affect the taste of the water and potentially cause health problems if consumed in excess. High levels of electrical conductivity can also indicate the presence of other pollutants or contaminants in the water, such as industrial or agricultural runoff, sewage, or other types of waste. Therefore, measuring electrical conductivity is an important part of water quality testing and can help to identify potential sources of contamination and ensure that the water is safe for human consumption.

pH

The pH value in the study area ranges from 5.9 to 7.7 during the rainy season. pH is a measure of the acidity or basicity of a solution, with a value of 7 considered neutral. pH values below 7 indicate acidity, while pH values above 7 indicate basicity. The pH range observed in the study area suggests that the water in this region is slightly acidic to slightly basic, which is within the range that is considered suitable for drinking water. However, it is important to note that even slight changes in pH can have a significant impact on water quality and can affect the solubility of minerals and the presence of microorganisms. Therefore, regular monitoring of pH levels in the water is essential to ensure its safety and quality for consumption.

Table No – 3 Water Quality Index of All the Sampling Locations Along with Their Interpretation for Both Seasons

Pre - Monsoon				**Monsoon**	
Locations	**WQI**	**Overall Water Quality**	**Locations**	**WQI**	**Water Quality satus**
S1	84.16	Very Poor Quality	S1	67.89	Poor Quality
S2	47.57	Moderate quality	S2	26.92	Very good quality
S 3	45.19	Good Quality	S 3	36.71	Good Quality
S 4	232.04	Unfit for drinking	S 4	192.47	Unfit for drinking
S 5	59.21	Poor quality	S 5	46.14	Good Quality
S 6	78.50	Very poor Quality	S 6	66.43	Poor Quality
S 7	49.93	Moderate Quality	S 7	41.79	Good Quality
S 8	94.29	Poor Quality	S 8	83.13	Poor Quality
S 9	101.56	Very Poor Quality	S 9	78.51	Poor Quality
S 10	93.22	Very Poor Quality	S 10	85.14	Poor Quality
S 11	86.37	Poor Quality	S 11	79.73	Poor Quality
S 12	89.50	Poor Quality	S 12	59.41	Poor Quality
S 13	163.92	Unfit for drinking	S 13	140.50	Unfit for drinking
S 14	119.88	Unfit for drinking	S 14	102.93	Unfit for drinking
S 15	224.89	Unfit for drinking	S 15	182.36	Unfit for drinking

TURBIDITY

Turbidity is a measure of the cloudiness or haziness of a liquid caused by the presence of suspended particles, such as sediment, algae, or other organic or inorganic matter. The World Health Organization (WHO) recommends a maximum level of 5 Nephelometric Turbidity Units (NTU) for drinking water, and an optimal level of 1 NTU. This is because high turbidity can interfere with disinfection processes, provide a habitat for bacteria and other microorganisms, and affect the aesthetic quality of the water.

Measuring turbidity is an important aspect of water quality testing, as it can help to indicate potential sources of contamination and the overall quality of the water. Treatment methods such as filtration, coagulation, and sedimentation can be used to reduce turbidity and improve the quality of drinking water.

FLUORIDE

Long-term exposure to elevated levels of fluoride in drinking water can cause various health issues. One such effect is dental fluorosis, characterized by discoloration and weakening of tooth enamel. Another is skeletal fluorosis, where excess fluoride accumulates in bones and joints, resulting in pain, stiffness, and reduced mobility. [14], [22]– [24]. In severe cases, skeletal fluorosis can also cause bone deformities and fractures. Prolonged exposure to high levels of fluoride have also been associated with an increased risk of other health problems, including thyroid dysfunction, neurological effects, and developmental issues in children. Therefore, it is essential to ensure that the fluoride content in drinking water is within safe limits to prevent such health impacts. [16], [23], [25] The World Health Organization (WHO) recommends that the optimal level of fluoride in drinking water should be 0.5-1.5 mg/L, and levels above 1.5 mg/L should be avoided to prevent adverse health effects. In this study locations fluoride content is very high and have severe health impacts. It ranges between 0.12 mg/L to 6.37 mg/L.

CHLORIDE

Chloride ion is the most common natural form of chlorine and is highly stable in water. In groundwater, chloride can come from various sources, including weathering, leaching of sedimentary rocks and soil, as well as domestic and municipal effluents, as noted by [26], [27]. The presence of chloride in groundwater can indicate contamination from various sources, such as wastewater discharge, road salt runoff, or agricultural activities. Monitoring chloride levels in groundwater is important for assessing water quality and identifying potential sources of contamination, as high levels of chloride can affect the taste and odor of the water and may also pose health risks if consumed in large quantities.

DO COD AND BOD

Dissolved oxygen (DO), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) are all important parameters to measure in groundwater studies as they provide information on the water's quality and the level of pollution in the groundwater system. Overall, monitoring DO, COD, and BOD in groundwater is important for assessing the water's quality, identifying potential sources of pollution, and developing strategies for protecting and improving the groundwater system [11]. In this study BOD, COD, and DO levels in groundwater are within an acceptable range, it is an indication that the water is of good quality and safe for various uses, such as drinking, irrigation, and other purposes

MULTIVARIATE STATISTICAL TECHNIQUES

The Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a multivariate statistical technique that can be used in ground water analysis to identify patterns and relationships in large datasets. PCA can be used to reduce the dimensionality of a dataset by identifying the most important variables that contribute to the variation in the data. In the context of ground water analysis, PCA can be used to identify the key factors that contribute to water quality, such as levels of dissolved minerals or contaminants, and to identify sources of contamination [28]. By reducing the number of variables, PCA can help simplify the interpretation of complex datasets and aid in decision-making processes [29]. PCA can also be used to identify outliers in the data, which may indicate anomalous water quality measurements or contamination events. Overall, PCA is a powerful tool for exploring and understanding patterns and relationships in ground water quality data [20].

XLSTAT 2019 was utilized for dimensionality reduction. Figure Number 3 and Figure Number 4 in the article shows the correlation circle biplot which examines the relationships between the variables or parameters. The horizontal axis in the circle represents the first PCA dimension, which accounts for 42.32% and 23.72% of the initial information, while the vertical axis represents the second PCA dimension, which represents 24.6% % of the initial data. Together, these two dimensions carry 57.25 % and 76.32% of the initial data respectively for pre-monsoon and monsoon season the red vectors in the circle indicate the investigating variables or parameters. In the correlation circle, the interpretation is done in terms of angles between the two variables or PCA dimensions. The angle between two vectors in the circle indicates the strength of their correlation or association. Overall, the correlation circle is a useful tool for visualizing the relationships between the variables and understanding their relative importance in the dataset.

Narrow angles in the correlation circle indicate strong positive correlations between the variables, such as Chloride, Total Hardness, Total Dissolved Solids, Magnesium, and Specific Conductivity. In contrast, when tw variables are at a right angle to each other, there is no correlation between them, as seen with Total Alkalinity and Nitrate. Obtuse angles in the correlation circle represent negative correlations between the variables, such as pH and Fluoride. If the vector lengths are small in the selected PCA dimensions, it can be better represented in other

PCA dimensions. In this study, the authors selected dimensions F1 and F2, which provided the maximum possible length of vectors, allowing for a clearer representation of the relationships between the variables. Overall, the correlation circle provides valuable insights into the interrelationships between different variables in the dataset, which can aid in the interpretation of the results

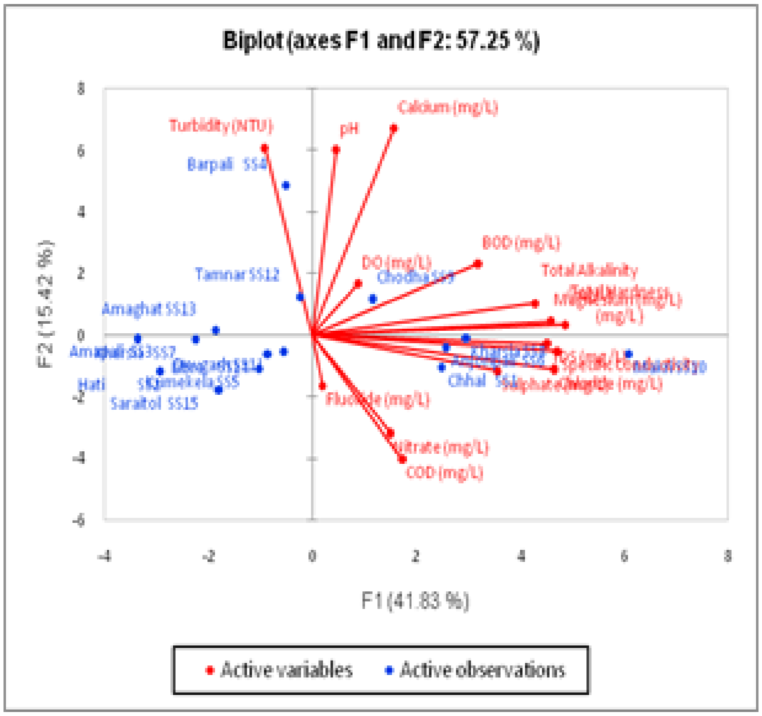

Figure No – 3 Pre - monsoon Correlation Circle Biplot

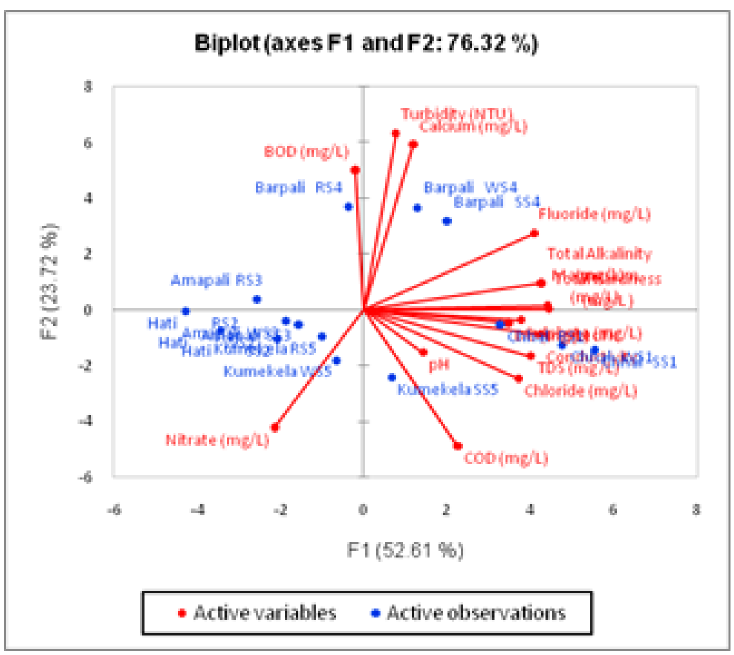

Figure No – 4 Correlation Circle Biplot

CONCLUSION

The groundwater quality in the studied area has deteriorated due to high mineral content in the soil, primarily caused by ongoing ore mining activities. The study reveals that water quality remains largely consistent between the monsoon and pre-monsoon seasons, showing no significant seasonal variation. This consistency suggests a persistent risk of mineral contamination, particularly elevated levels of fluoride and total dissolved solids (tds). Among the locations assessed, dharmajaigarh shows relatively better water quality compared to tamnar and kharsia. However, approximately 50% of the samples across all areas exhibit high fluoride concentrations in both seasons. These elevated levels of fluoride and tds are having a considerable impact on the health of local residents. There is an urgent need to implement effective water treatment and remediation strategies. A proactive and timely response is essential to mitigate the contamination and ensure access to safe drinking water for the community.

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