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# A statistical evaluation for the groundwater quality of Jharia coalfield, India

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**Abstract:** Jharia is the most extensively explored and exploited coalfield and sole repository of much needed prime coking coal in India. It is a part of the Gondwana coalfields and lies in the heart of the Damodar valley at south of the Dhanbad city. Detail investigation of groundwater chemistry for the suitability of drinking and domestic uses in the Jharia coalfield. For this purpose, 29 samples from coalfield were collected and analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS) , major cations ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$) and major anions ($HCO_3^-$ $F^-$, $Cl^-$, $NO_3^-$, $SO_4^{2-}$). $HCO_3^-$ and $SO_4^{2-}$ are dominant anions and $Ca^{2+}$and $Mg^{2+}$ as the dominant cation in the water chemistry. In majority of the samples, the analyzed parameters are well within the desirable limits and water is potable for drinking purposes with few exceptions. Pearson correlation analysis shows perfect cor-relation EC and TDS, revels that EC is a measure of dissolved solids in the groundwater. Pearson correlation matrix has been applied to a total number of 29 groundwater samples. Statistical data analysis suggest that there is positive correlation between $Ca^{2+}$-$Mg^{2+}$, $K^{+}$-$Na^{+}$ are observed.
**Keywords:** Groundwater chemistry, Pearson correlation, Multivariate statistical method, Frequency distribution, Jharia coalfield.

## Introduction:

Water is renewable natural resource of earth and is essential for all living organism for their existence and metabolic processes in the world [2]. Water quality is based on the physical and chemical constituents due to weathering of parent rocks and anthropogenic indispensable source of our life. Particularly, in rural areas it accounts for 88% of the drinking water [1, 23]. Groundwater is the major source for drinking and domestic purposes in both rural and urban areas [26]. Drinking water quality is affected by the presence of different soluble salts [3]. The major problem with the groundwater activities [6]. Groundwater is the principal source of drinking water in our country and is that once contaminated, it is difficult to restore its quality. Hence, there is a need and concern for the protection and management of groundwater quality. It is well known that no straightforward reasons can be advanced for the deterioration of water quality, as it is dependent on several water quality constituents [4]. Anthropogenic activities and improper management of natural resources also led to unequal distribution of major and minor elements in nature [8]. Water pollution in mining areas is mainly due to overburden (OB) dumps, surface impoundments, mine water, industrial effluents, acid mine drainage, tailing ponds etc. [24].The quality of the groundwater varies from place to place with the depth of water table. The classification, modeling and interpretations of monitoring data are the most important steps in the assessment of water quality. To define the resource water quality many researchers treated water quality parameters individually by describing the seasonal variability and their causes. It is a very difficult and laborious task to regularly monitor all the parameters even if adequate manpower and laboratory facilities are available. For this reason, in recent years an easier and simpler approach based on statistical correlation, has been developed using mathematical relationship for comparison of physicochemical parameters

[11,12]. Access to drinking water in India has increased over the past few decades with the tremendous adverse impact of unsafe water for health [22]. Scarcity of clean and potable drinking water has emerged in recent years as one of the most serious developmental issues in many parts of West Bengal, Jharkhand, Orissa, Western Uttar Pradesh, Andhra Pradesh, Rajasthan and Punjab [25]. Correlation and regression analysis is widely used in geochemistry; it is useful for interpreting commonly collected groundwater quality data and relating them to specific hydro-geological processes. The basic purpose of such an analysis to the study of the hydro-geochemistry of an aquifer is to find a set of factors, few in number, which can explain a large amount of the variance of the analytical data [7]. The statistical regression analysis has been found to be a highly useful tool for correlating different parameters. Correlation analysis measures the closeness of the relationship between chosen independent and dependent variables. If the correlation coefficient is nearer to +1 or –1, it shows the probability of linear relationship between the variables x and y. This way analysis attempts to establish the nature of the relationship between the variables and thereby provides a mechanism for prediction or forecasting [4]. In general, the quality of groundwater depends on the composition of recharge water, the interaction between the water and the soil, the soil–gas, the rock with which it and other domestic purposes. The correlation coefficient is a helpful tool for the promotion of research in water pollution problems. Groundwater quality is analyzed for its physical, chemical and biological parameters which are closely interlinked. All the research so far completed on the groundwater quality of different areas of Jharia coalfield is based on physicochemical analyses. No attempt has yet been made to predict the groundwater quality of the study area with precision using the correlation coefficients of different water quality parameters. In the present study, an attempt has been made to study the interactions between different components of groundwater and their relationship with total dissolved solids, using Pearson correlation matrix and multiple linear regression technique. This paper comprising of statistical analysis of groundwater quality parameters is the first exploration in the study area of Jharia Coalfield of Jharkhand, India.

## Materials and Methods

### Study area

Jharia Coal mining areas is one of the most important Coal mining areas in India. It is roughly elliptical or sickles – shaped, located in Dhanbad district of Jharkhand lies between latitude 23°39′ N and 23°48′ N and longitudes 86°11′ E and 86°27′ E. It stretches from Chandanpura on the west to Sindri on the east. The main component of the natural drainage in JCF is the Damodar River. There are eight major streams, a few perennials and the rest intermittent, which drains the JCF from north to south to join the Damodar River. The Gondwana sequence in the Jharia basin begins with Talchir Formation which is followed stratigraphically upwards by Barakar Formation, Barren Measures and Raniganj Formation. The oldest rocks are exposed along the northern margin and youngest formations are out-cropped towards south in the western part of the basin [14] (Fig 1).

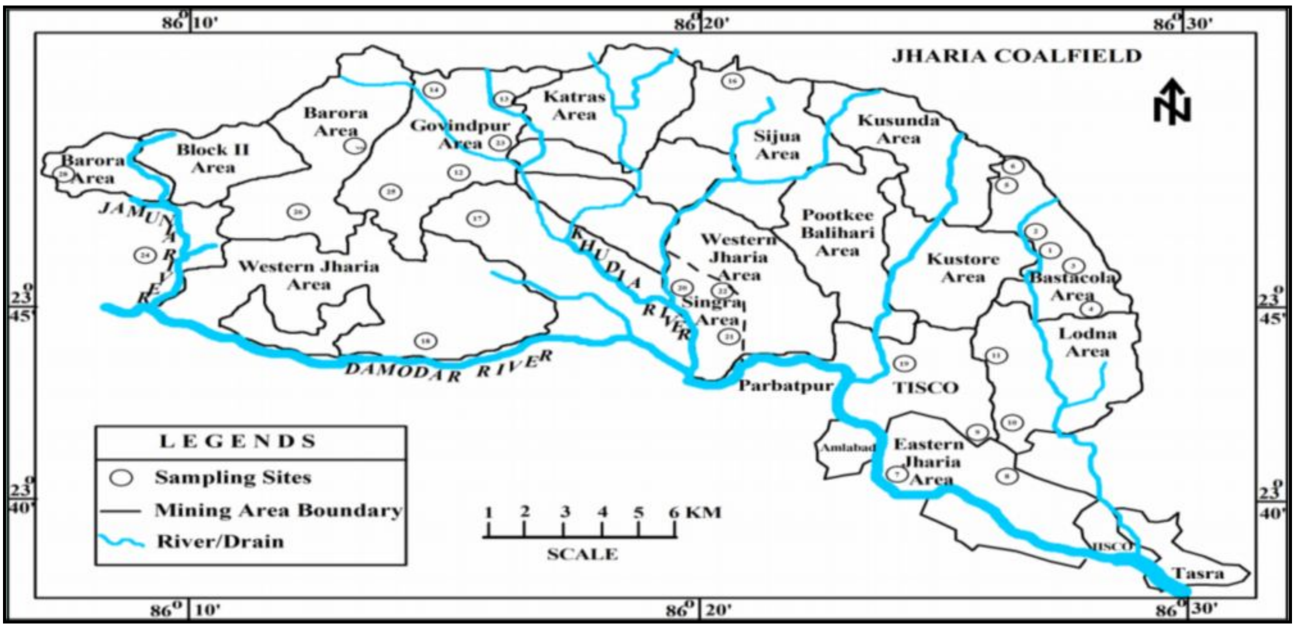



**Fig 1: Sampling Sites in the study area**

## Result and Discussion:

### Hydrogeology:

Geology, the major feature is the great coal basin of this region with intervening areas of crystalline rocks. The ancient rock types of Dharwar and post Dharwars period from the basement rock which the lower-Gondwana group of sedimentary strata consisting of coal seams and patches of sandstone are formed. Damodar is the main river in the state as well as in the region. It is the main sources of water supply. Due to hilly characteristic, the river is not navigable. Jaumina River is the major tributary, meeting Damodar nearly two km west of Telmuchu Bridge. It is fed by a number of hilly streams and seasonal nalas. Jaumina Rivers is also not navigable. Rivers of the region have the region have the usual characteristics of the hill streams. Following the natural slope of the region have as easterly or south- easterly course. Katri nadi dissects the Jharia coalfield north-south through a number of tributraies, such as khudiya Nadi, Bans Jhor, Kumari Jhor etc. meeting katri at different levels.(fig 2)

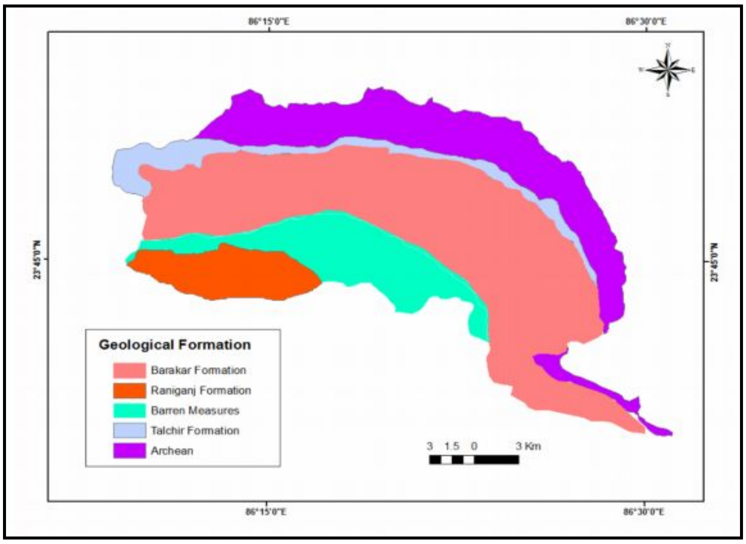



**Fig 2: Geology map of the Jharia Coalfield**

### Drainage density:

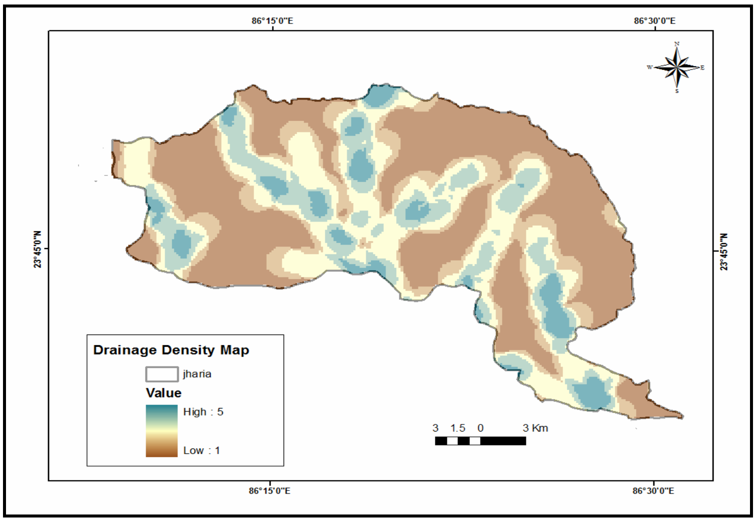



**Fig 3: Drainage density map of the study area**

Drainage density (Dd), is regarded as the most important aerial measure network of surface streams, in that it expresses the degree of basin dissection by surface streams and hence links the form attributes of the basin to underlying processes and is defined by:

Dd = ∑L/Ad
Where ∑L is the total channel length in the basin of area Ad or is also written as,
Drainage density = Total lengths of streams (milies)/Area (square miles)

Two sets of factors determine drainage density those which govern the amount and quality of water received at the surface, and those which control the subsequent distribution of that water, its availability for channel cutting, and erodibility. The first is climatic, while the second includes a complex mix of lithological, vegetation and edaphic and topographic influences. Drainage density is broadly correlated with mean annual precipitation. There are various factors that control the drainage density. One important control is rock type. Hard resistant rocks such intrusive granitic rock, gneiss, sandstone, and quartzite, tend to give low density (Course texture).

**Major ion chemistry**

Among major cations calcium was the dominant ions representing on average 46% of total cations. Magnesium and sodium ions were of secondary importance, representing on average 26% and 23% of total cations, respectively. Potassium was least dominant cation and representing 5% of the total cations. The order of cation abundance for post monsoon was $Ca^{2+}$> $Na^{+}$>$Mg^{2+}$>$K^{+}$ (fig 4a). Among the major anions, bicarbonate was generally dominant and representing on average 43% of the total anions. Sulphate is the second dominant anion, representing on an average 39% of the total anions. Chlorides were less dominant ions and contributing 17% to the total anions respectively. Nitrate and fluoride is least dominant anion contributing 0.7% and 0.3 % of the total anions. The order of anions abundance in the surface was found as $HCO_3^-$> $SO_4^{2-}$ > $Cl^-$>$NO_3$>$F^-$ (fig 4b).

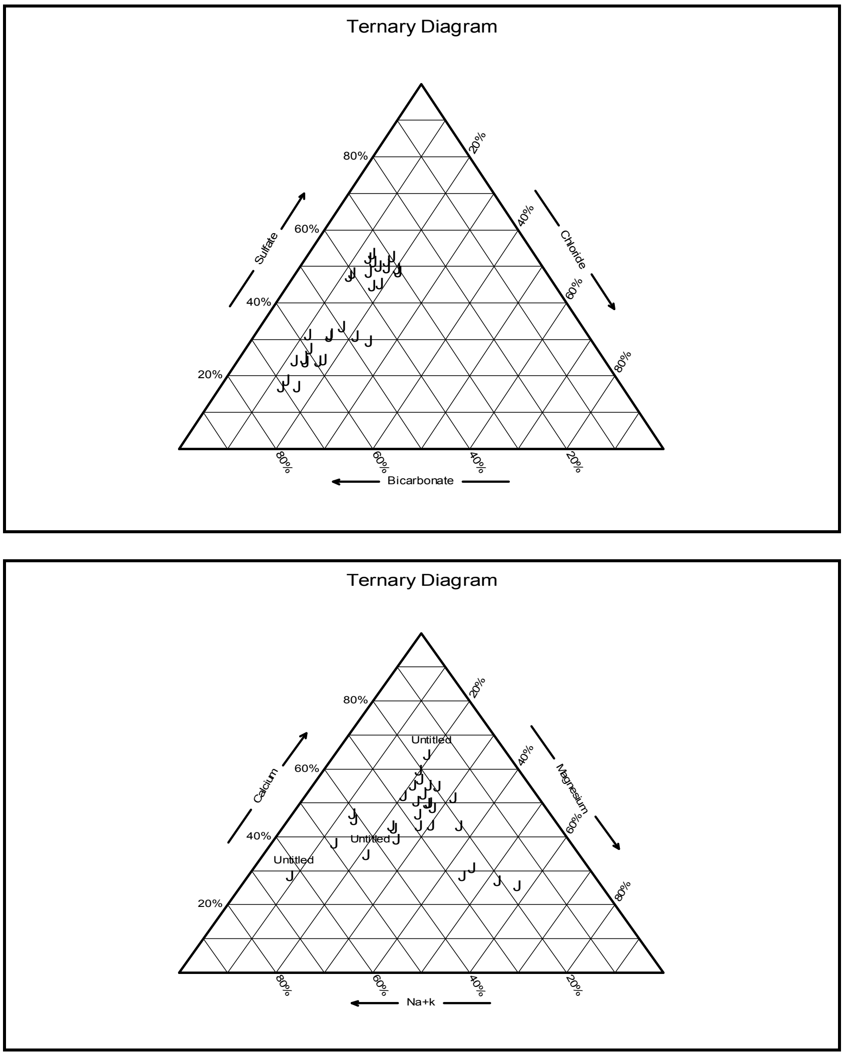
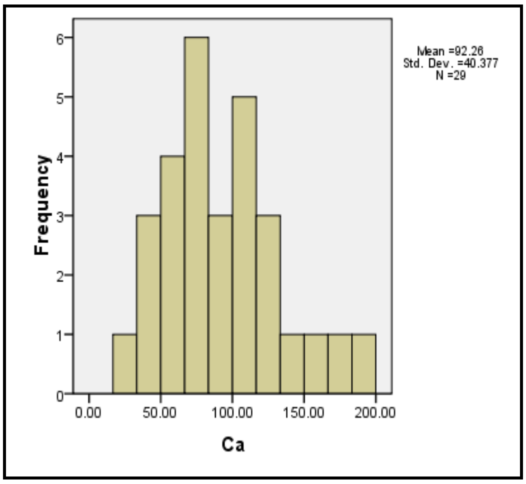


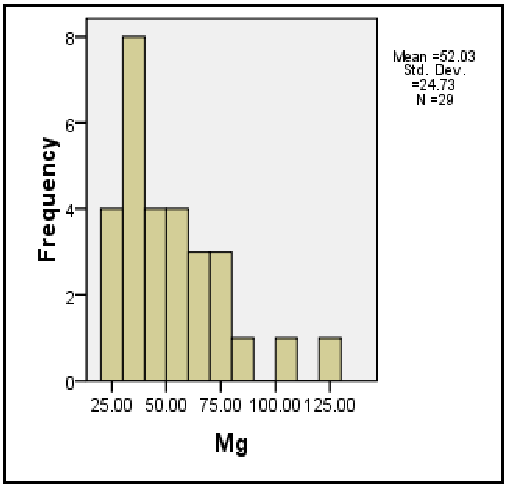

**Fig. 4: Ternary (a) anion and (b) cation diagrams showing contribution of individual ions towards the anionic and cationic mass balance**

**Groundwater Quality**

The pH of the groundwater samples was found to be ranging from6.5 to 8.2 and with mean of 7.2. However, the accepted concentration of pH in drinking water given by WHO is 7-8.5. The overall conductivity ranges from 480 µS/cm to 1300 µS/cm and mean 862.3. The TDS were varied from 350 mg/L to 1150 mg/L. The differences in TDS values may be attributed to the variation in geological formations, hydrological processes and prevailing mining conditions in the region. The chloride content in the study area varies from 39.4 mg/L to 198.0 mg/L in the groundwater. On an average, chloride is contributing about 17% of the total anionic balance in the groundwater. It is assumed that bulk of the chloride in water is derived primarily from halite, sea spray, brines and hot springs. Abnormal concentration of chloride may result from anthropogenic sources including agricultural runoff, domestic and industrial wastes and leaching of saline. The Nitrate content in the groundwater samples varied from 1.12 mg/L to 29.7 mg/L. The sulphate in the water samples ranged from 46.7 mg/L to 357.0 mg/L. According the BIS limit is 400 mg/L. low concentration is physiologically harmless. The overall concentration of sulphate in the study area is within the safe limit. Sulphates in the groundwater are usually derived from the oxidative weathering of sulphide-bearing minerals such as pyrite ($FeS_2$), gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$). Jharia coals are poor in sulphur; usually contain less than 1% sulphur. However, mineral pyrite ($FeS_2$) is reported to occur as a secondary mineral in these coals and associated sediments [14]. The range of calcium ions was 28.2 mg/L to 192 mg/L. Weathering and dissolution of calcium carbonate (limestone and dolomite) and calc-silicate min-erals (amphiboles, pyroxenes, olivine, biotite, etc.) are the most common source of calcium in water. Concentration of $NO_3^-$ ranged from 1.12 to 29.7 mg $L^{-1}$ and average concentration value was 8.0 mg $L^{-1}$, contributing about 0.7% the total anions. The chief sources of the nitrate are—biological fixation, atmospheric precipitation and the application of fertilizers and industrial sewage [15]. The magnesium ranged from 23.7 mg/L to 129.0 mg/L weathering of ferromagnesian minerals as a possible source of $Mg^{2+}$ in this water [16, 17]. The sodium concentration in the water samples was found between 14.2 g/L to 142.7 mg/L. The desirable limit for sodium is given as 200 mg/L according to WHO guidelines. In the study area potassium did found 1.3 mg/L to 35.2 mg /L. constitute 23% of the total cations. $Na^+$ and $K^+$ in the aquatic system are mainly derived from the atmospheric deposition; evaporate disso-lution and silicate weathering [18] Weathering of $Na^+$ and $K^+$ silicates such as albite, anorthite and orthoclase are the possible source minerals for the Na and K in the present study area [19, 20]. The evaporate encrustations of Na/K salts developed due to cyclic wetting and drying periods of Damodar River cause the formation of alkaline/saline soils, which may also serve as a source of Na and K [21]. The total hardness (TH) of the analyzed water samples of the study area varies between 210.5 mg/L to 752.7 mg/L and (Avg. 144.5 mg/L) respectively indicating hard to very hard types of water.

**Statistical analysis:**



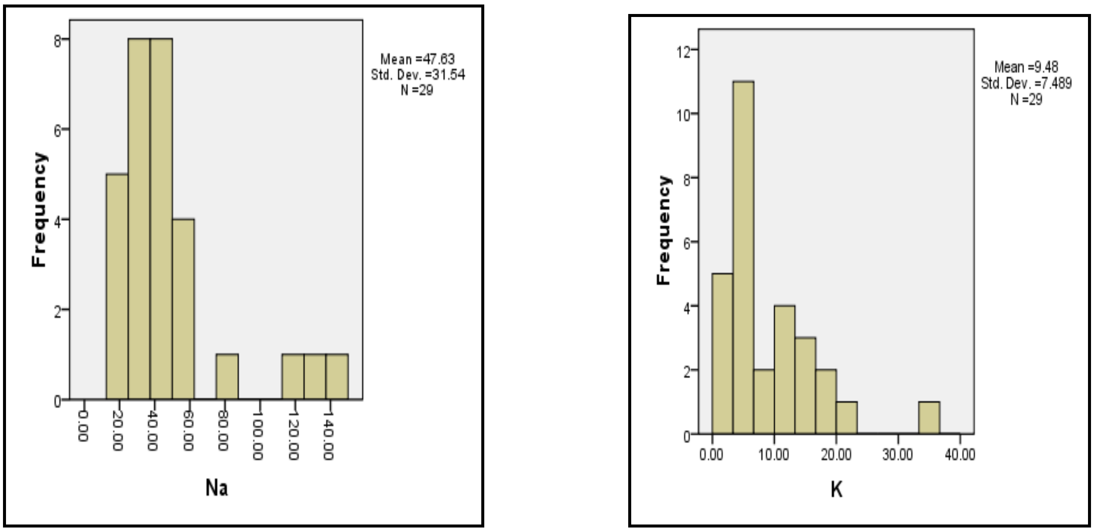



**Fig 5: Percentage frequency distribution of major cation concentration in mg/L**

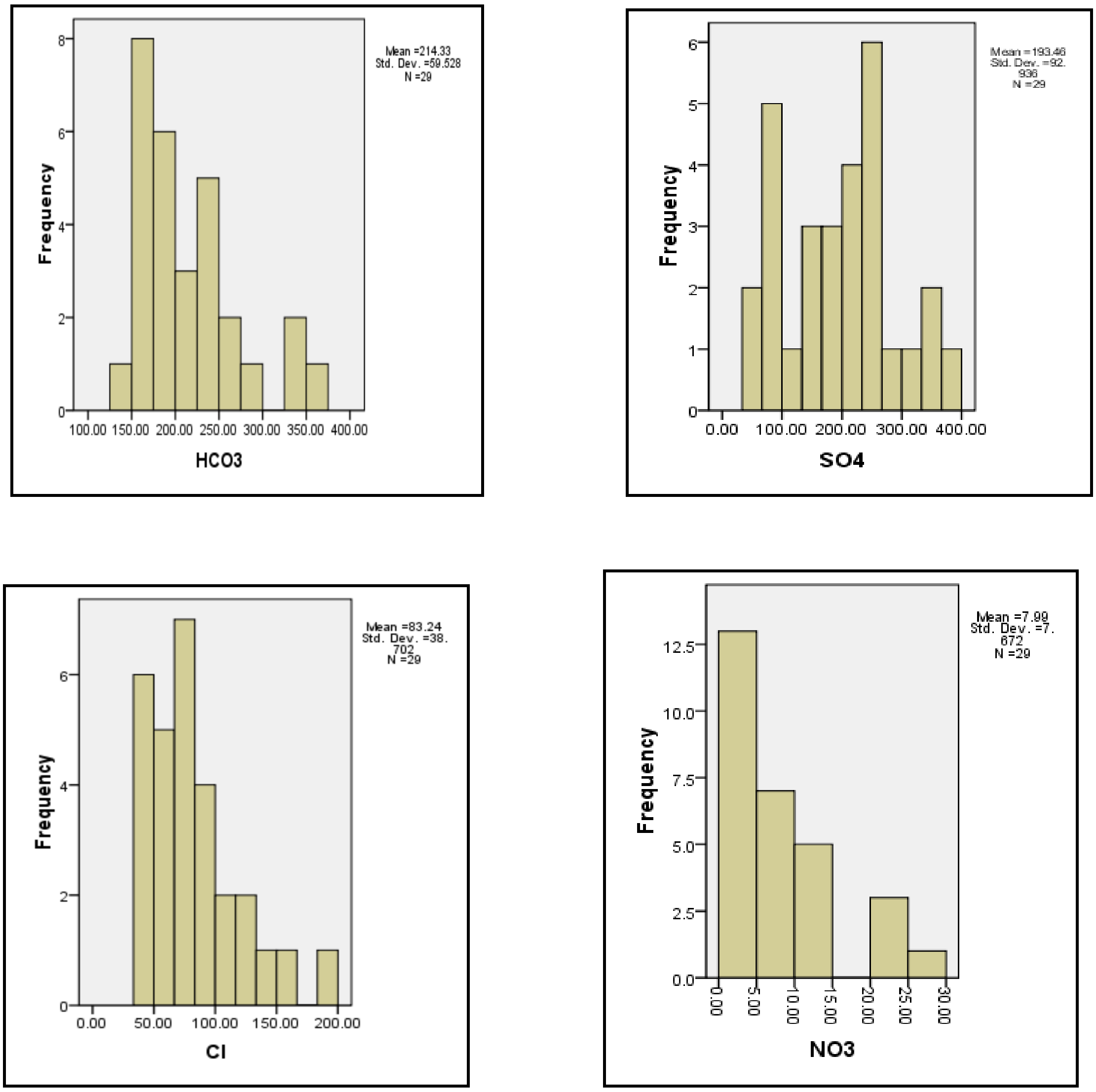



**Fig 6: Percentage frequency distribution of major Anion concentration in mg/L**

The major ions are plotted in frequency versus percentage milli- equivalent of the total cations and anion is provided in the Fig.5 and defined content of the cation and anion as the percentage of the milli- equivalent per liters (mg/L) in Pie diagram shown in Fig 6. Statistical analysis of the hydro-chemical parameters is shown in Table 1. Correlation between major cations and anions were carried out using Pearson correlation (Table 3). A cor-relation analysis is a bivariate method applied to describe the degree of relation between two hydro-chemical parameter. Table 2 show perfect cor-relation between EC and TDS, which indicates that EC measure of dissolved solids in the groundwater. The good cor-relation is also shows $Mg^{2+}$ and $Ca^{2+}$. The good cor-relation is also shows $K^+$ and $Na^+$ which indicates originate from common source. $Mg^{2+}$ and total hardness and calcium and total hardness also show good relation in the groundwater of the study area.

**Table 1: Sampling location of Jharia Coal field**

| S.No. | Location | Latitude | Longitude | Elevation |
|---|---|---|---|---|
| W1 | Near Bararee Colliery | 23°43'26" | 86°24'35" | 623 |
| W2 | Bhoolan Bararee | 23°43'27" | 86°24'36" | 642 |
| W3 | Jealgora-7 No. | 23°47'42" | 86°19'40" | 731 |
| W4 | Bhowrah South | 23°40'41" | 86°24'26" | 526 |
| W5 | Digwadih Campus | 23°41'46" | 86°25'19" | 552 |
| W6 | Bararee | 23°43'25" | 86°24'34" | 622 |
| W7 | Bhagamor | 23°47'37" | 86°18'07" | 599 |
| W8 | South Tisra | 23°47'38" | 86°19'08" | 613 |
| W9 | Joyrampur | 23°47'40" | 86°19'20" | 588 |
| W10 | Ghanudih 4-No | 23°44’47” | 86°26’14” | 667 |
| W11 | Ghanudih 4-No | 23°44’48” | 86°26’25” | 665 |
| W12 | Ghanudih 4-No | 23°44’47” | 86°26’24” | 661 |
| W13 | Bera Colliery | 23°46’06” | 86°25’53” | 656 |
| W14 | Chandmari Colliery | 23°45’38” | 86°25’15” | 784 |
| W15 | Bengali Kothi | 23°45’38” | 86°25’15” | 645 |
| W16 | Victory | 23°45’50” | 86°24’44” | 690 |
| W17 | Goluckhdih | 23°44’80” | 86°26’33” | 637 |
| W18 | Dobari | 23°45’20” | 86°25’57” | 638 |
| W19 | Khas Kusunda | 23°44’82” | 86°26’37” | 642 |
| W20 | East-Basseria | 23°45’30” | 86°26’41” | 650 |
| W21 | Bhalgora | 23°47’37” | 86°18’07” | 584 |
| W22 | Tetulmari Road | 23°48’5.8” | 86°20’07” | 675 |
| W23 | Akashkinari | 23°47’48” | 86°16’11” | 640 |
| W24 | Sonardih | 23°46’37” | 86°14’21” | 794 |
| W26 | Phulawartar | 23°46’37” | 86°14’12” | 690 |
| W27 | Loyabad | 23°47’49” | 86°16’13” | 698 |
| W28 | Mooraidih | 23°48’16” | 86°13’59” | 330 |
| W29 | Baghmara | 23°47’37” | 86°18’07” | 590 |

**Table 2: Statistical parameter of ground water (Post- Monsoon)**

| Sl.No | Constituents | Min | Max | Mean | SD |
|---|---|---|---|---|---|
| 1 | pH | 6.5 | 8.2 | 7.2 | 0.4 |
| 2 | EC | 480.0 | 1300 | 862.3 | 254.7 |
| 3 | TDS | 350 | 1150 | 705.3 | 209.3 |
| 4 | $Cl^-$ | 39.4 | 198.0 | 83.2 | 38.7 |
| 5 | $F^-$ | 0.23 | 1.5 | 0.7 | 0.3 |
| 6 | $NO_3^-$ | 1.12 | 29.7 | 8.0 | 7.7 |
| 7 | $SO_4^{2-}$ | 46.7 | 369.3 | 193 | 92.9 |
| 8 | $HCO_3^-$ | 144.23 | 357.0 | 214.3 | 59.5 |
| 9 | $Na^+$ | 14.2 | 142.7 | 47.6 | 31.5 |
| 10 | $K^+$ | 1.3 | 35.2 | 9.5 | 7.5 |
| 11 | $Ca^{2+}$ | 28.2 | 192.4 | 92.3 | 40.4 |

| | | | | | |
|---|---|---|---|---|---|
| 12 | $Mg^{2+}$ | 23.7 | 129.0 | 52.0 | 29.22 |
| 13 | TH | 210.5 | 752.7 | 444.5 | 159.8 |

**Table: 3: Linear Correlation of the different hydro chemical parameters of the Area**

| | pH | EC | TDS | $F^-$ | $Cl^-$ | $HCO_3^-$ | $SO_4^{2-}$ | $NO_{3-}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^+$ | $K^+$ | TH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | .120 | .149 | .134 | .352 | .287 | -.019 | $-.376^{*}$ | -.029 | .287 | -.086 | .247 | .164 |
| EC | | 1 | $.968^{**}$ | $.781^{**}$ | $.889^{**}$ | $.402^{*}$ | $.785^{**}$ | .326 | $.798^{**}$ | $.520^{**}$ | $.591^{**}$ | $.677^{**}$ | $.835^{**}$ |
| TDS | | | 1 | $.742^{**}$ | $.923^{**}$ | $.435^{*}$ | $.800^{**}$ | .300 | $.787^{**}$ | $.587^{**}$ | $.616^{**}$ | $.718^{**}$ | $.871^{**}$ |
| $F^-$ | | | | 1 | $.689^{**}$ | .274 | $.591^{**}$ | .320 | $.639^{**}$ | .320 | $.532^{**}$ | $.561^{**}$ | $.608^{**}$ |
| $Cl^-$ | | | | | 1 | $.435^{*}$ | $.673^{**}$ | .133 | $.674^{**}$ | $.618^{**}$ | $.514^{**}$ | $.774^{**}$ | $.819^{**}$ |
| $HCO_3^-$ | | | | | | 1 | -.160 | .284 | .131 | .313 | .296 | $.518^{**}$ | .282 |
| $SO_4^{2-}$ | | | | | | | 1 | .093 | $.749^{**}$ | $.493^{**}$ | $.422^{*}$ | $.370^{*}$ | $.786^{**}$ |
| $NO_{3-}$ | | | | | | | | 1 | .306 | -.085 | $.395^{*}$ | .218 | .139 |
| $Ca^{2+}$ | | | | | | | | | 1 | $.912^{**}$ | .331 | .362 | $.787^{**}$ |
| $Mg^{2+}$ | | | | | | | | | | 1 | .048 | .348 | $.791^{**}$ |
| $Na^+$ | | | | | | | | | | | 1 | $.700^{**}$ | .179 |
| $K^+$ | | | | | | | | | | | | 1 | $.451^{*}$ |
| TH | | | | | | | | | | | | | 1 |

## Conclusion:

Multivariate statistical method used in this study Pearson correlation coefficients help to find statistically important factors in data variability and thus improve conclusions in environmental impact studies. Pearson correlation matrix was applied to all the collected water samples for identifying the possible statistical relationship between different pairs of groundwater quality parameters. A highly strong correlation was observed between EC and TDS. The good correlation is also shows $Mg^{2+}$ and $Ca^{2+}$, $K^+$ and $Na^+$.Based on the correlation regression study, it can be concluded that all the parameters are more or less correlated with each other. The linear correlation is very useful to get fairly accurate idea of quality of the groundwater by determining a few parameters experimentally. The chemistry of groundwater is dominated by $Ca^{2+}$ and $Mg^{2+}$ in the cationic and $HCO_3^-$ and $Cl^-$ in anionic abundances. In majority of the samples, the analyzed parameters are well within the desirable limits and water is potable for drinking purposes. However, concentrations of EC, TDS, $SO_4^{2-}$ TH, $Ca^{2+}$, $Na^+$ and $Mg^{2+}$ exceed the desirable limit at few sites.

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