Groundwater quality assessment using multivariate statistical technique and hydro-chemical facies in Birbhum District, West Bengal, India

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Abstract

The assessment of quality of groundwater is an important issue in the present era of population growth, massive agricultural development, industrialization and urbanization. As the demand of groundwater increases, the quality becomes deteriorated. In this background, the study of groundwater quality in Birbhum District is very much important as this area has been characterized by diversified rock formations. For the analysis purpose, 14 parameters regarding the hydro-chemical data of groundwater, viz. P^H , electrical conductivity, total hardness, calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, fluoride, silicon dioxide, phosphate and iron, were selected. The present study has been carried out using multivariate statistical method, viz. principle component analysis (PCA) and cluster analysis. In addition, different hydro-chemical facies in terms of hydro-chemical diagrams have been used to show the present status of groundwater quality in the concerned area. The result of PCA, a multivariate statistical technique, reveals that it extracts five major factors accounting for 80% of the total variance. Fluoride has been extracted as first factor. It is because the western part of the district has been characterized by highly fluoride contaminated area where basaltic terrain is present. The study also shows concentration of cation and anion that are present in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+ = Cl^- > HCO_3^- > SO_4^{2-}$. Two clusters have been prepared: one for sample villages and another for chemical components. Sample village-wise cluster reveals that Baidyanath, Muluk, Khayrasole, Md Bazaar, Patel Nagar, etc. bear same chemical characteristics, while chemical component cluster shows the homogeneous grouping among P^H , PO_4 , SiO_2 , Fe. Diagrammatic presentation of chemical parameters is also an important aspect in this study. Here application of Wilcox diagram basically depicts the nature of water for the suitability of irrigation. It shows that about 50% samples out of total sample have been characterized by excellent to good, the rest 25% samples present in good to permissible category, 20% are under the category of permissible to doubtful and 5% belong to the category of doubtful to unsuitable, while Gibbs mechanism displays 68% samples belonging to the category of rock dominance and the rest 32% in precipitation dominance category. This kind of study obviously demand an important space as groundwater quality is directly related to human health. So, for the sustainable development of human health, this type of study opens a new dimension for the betterment of the society and the concerned region.

Keywords Groundwater quality · Multivariate statistical analysis · Hydro-chemical facies

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1 Introduction

Groundwater is an indispensable element for human life and welfare [58, 65]. It meets the essential needs in different economic sectors and daily life, viz. the agricultural, industrial and household requirements [8, 90, 99, 103]. Among all the physio-chemical aspects of groundwater, the quality of it is a very important matter of concern because the sustainable development of groundwater in various fields depends on the availability of good quality of groundwater [66, 80, 83, 91, 94]. In this connection, the assessment of hydro-chemical properties of groundwater is one of the prime tasks in the present-day context [21]. Surface water is normally affected by surface pollutants. But groundwater is highly affected by existing geology, degree of chemical weathering, quality of recharge, level of groundwater, some surface element sources, etc. [54]. So, the quality of groundwater is subjected to the interaction between geological and hydrological processes [1, 11, 12, 25, 33, 51, 60, 88, 93, 102].

With the rapid increase in population, economic demand increases in parallel day by day, leading to industrial and agricultural growth. Consumption of chemical fertilizers and pesticides to enhance more agricultural production has become very common practice. All of these result in the deterioration of water quality. Moreover, large-scale drafting of groundwater for economic and domestic purposes accelerates the depletion rate of groundwater level [20]. This depletion of groundwater table and collapse of water quality is the emerging problem in most of the towns and cities of the country [7, 22, 24, 30, 37–40, 42–46, 48, 53, 64, 69, 73, 82, 98]. The chemical properties of groundwater have been severely affected by geological structure and human harmful activities. Degradation of groundwater cannot be recovered. For example, the fluoride contents in groundwater provides safeguard against dental curiosity specifically for children [54]. If the fluoride concentration is more than 15 mg/L, it leads to the chance of tooth decay and dental fluorosis occurs due to higher concentration [106, 107]. The admissible level of fluoride for drinking water according to World Health Organization is 15 mg/L [113]. If the nitrate concentration is above 45 mg/L, this leads to the risk of methemoglobinemia which usually affects infants [41]. Large accumulation of sulfates causes diarrhea [54]. According to Azizullah et al. [9], high concentration of Fe in groundwater generates some serious diseases like cancer, diabetes, liver- and heart-related problems, etc. The presence of high percentage of arsenic in drinking water leads to the occurrence of skin diseases [17].

Human health largely depends on the quality of groundwater [74, 115]. Therefore, in recent times one

of the major thrusts in research is to analyze the hydro-chemical properties of groundwater, and now, it has become a firm part of regional hydro-chemical studies [104].

For the analysis of groundwater hydro-chemistry, various quantitative techniques have been successfully applied. For example, correlation matrix is an important statistical technique to study relation between various hydro-geochemical data. It helps to identify the association between the groundwater chemical elements [61, 62, 95, 109, 112]. Another important approach to explain the groundwater quality is the multivariate statistical analysis; principal component analysis or PCA is one of these [75, 78]. It is basically applied to reduce the complication of several input variables and extracts the major components from a large volume of data set [27, 29, 62, 76]. Factor analysis (FA), as a technique of PCA, possibly helps to transform correlated sets of variables known as principal components (PCs) [92, 110]. Moreover, if multivariate treatment is successfully applied for the interpretation of environmental data, it will help to manage environmental system in better ways [23].

Four blocks of Birbhum District, namely Muraroi II, Nolhati II, Rampurhut II and Nanor, have been defined as semi-critical stage because of fluctuation of water level during pre- and post-monsoon stages of groundwater development [16]. Except this, fluoride contamination was first identified in the northwestern part of the Birbhum District. Iron is another mineralogical composition present in the groundwater and certain amount of iron is required for the human health [68], though iron may be harmful if its level is above 03 mg/l (milligrams per liter) [13].

For the assessment of groundwater quality, multivariate approach is widely accepted as quantitative technique in modern era [2, 28, 77]. Among various multivariate statistical methods, principal component analysis (PCA) and cluster analysis (CA) are able to extract the relationship between various variables and clearly explain the relation between them [18, 59, 113]. Therefore, PCA has been applied in this work to extract the major chemical components for determining the groundwater quality in the district. Cluster analysis which is the graphical presentation of chemical variables and which depicts the grouping of two or more variables based on the similarity of the chemical components with respect to the special characteristics has also been used here. It also helps in the proper interpretation of groundwater chemistry in a hydro-geochemical context [52, 77, 117].

The main purpose of the study is to identify the hydro-chemical characteristics of groundwater from different wells of Birbhum District and to develop authentic statistical methods for assessing groundwater quality in spatial

Fig. 1 Location map of **a** India, **b** West Bengal and **c** Birbhum District

context. Besides, the use of multivariate statistics to identify the major factors of controlling groundwater quality is not the prime objective of this study, but the analysis and presentation of those factors help to identify the major mineral concentration zones, not only the general minerals but also harmful minerals like fluoride, iron, etc. So, in the present-day context of environmental pollution, this kind of study is utmost relevant.

Except the multivariate statistical techniques, various other indices regarding the parameters of groundwater quality have been studied here like Gibbs ratio, permeability index (PI), percentage of sodium (%Na), etc. [97]. Along with these indices, various graphical presentations have also been provided. Those are Wilcox diagram to show suitability of groundwater for irrigation, Doneen's chart to show permeability index and Gibbs diagrams to

represent the mechanism of controlling the chemistry of groundwater.

2 Materials and methods

2.1 Geographical description of the study area

Spatially, Birbhum District is located between 23°32' 30"N–24°35' 00"N latitude and 87°05' 04"E–88°01' 04"E, covering an area of 4545 sq km, and it consists of 19 community development (CD) blocks (Fig. 1). Administratively, this district is bounded by the Jharkhand state in the west and the north and Murshidabad in the east and Burdwan District in the south.

Fig. 2 Geological units of Birbhum District

Geographically, this region is under “Rarhbanga” area; the soil and landscape are very much similar to that of Murshidabad, Burdwan, Bankura and Midnapore. Geologically, this district comprises many rock formations. For example, dissected plateau composed of granitic gneiss of Archean age is present in the western portion of the district. Eastern part of the district has been formed by sediments of Gondwana period and also formed by laterite

and the alluvium deposit (Fig. 2). The geological succession found in the study area is given in Table 1.

As we see, Birbhum District is a geologically diversified area, where Archaeans are the oldest rock formation, its granitoid and schistose rocks having crystallized at least 900 m.y. ago. These are a continuation to the east of the Peninsular Archaeans of the Chota Nagpur plateau. During upper Gondwana period, the Gondwana land was subjected to marked vulcanicity, which manifested itself into outpouring of Rajmahal lava flows and intrusion of numerous sills and dykes of basic and ultrabasic rocks. The geology of the eastern portion of the district, lie concealed below a capping of Holocene alluvium, was completely unknown until recently, till extensive subsurface investigations were carried out.

A large number of rivers run from west where plateau fringe is present to east with a little bit southeasterly inclination in the Suri subdivision and in the northeasterly inclination in the eastern half of the Rampurhat subdivision [20]. Both the Mayurakshi and Ajoy river valleys are of considerable size when they enter into the district. The river widths vary according to the configuration of the country, from 200 yards to half a mile [63] Expect Mayurakshi and the Ajoy, Kopai, Brahmhani, Dwarka and Bansloi are the main river systems of this district. The position of the major rivers is shown in Fig. 3

This district usually experiences a tropical monsoon climate where the summer temperature hike above 40 °C and winter temperature falls around 10 °C The average annual rainfall is about 14,305 mm [20].

2.2 Data sets used

For the analysis of hydro-chemical characteristics of the groundwater, fourteen parameters have been taken into consideration; namely, P^H, electrical conductivity (EC), total hardness (TH), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonate (HCO₃), chloride (Cl), sulfate

Table 1 Geological framework of Birbhum District

Era	Geological succession
Recent	Alluvium
Tertiary (Miocene)	a. Laterite and lateritic gravels with fossil wood b. Clay beds c. Ferruginous and feldspathic sandstone and clay beds
Middle to upper Jurassic	Rajmahal traps
Upper Gondwana (Middle Triassic to Jurassic)	Grit, ironstone and shale with bed of fire clay and coal seam
Unconformity	
Archaeans	Granite (porphyritic and graphic) gneisses and schists with pegmatite and quartz veins

Fig. 3 Major river networks

(SO_4), fluoride (F), silicon dioxide (SiO_2), phosphate (PO_4) and iron (Fe) have been collected from the Groundwater year book of West Bengal Andaman Nicobar Islands, published by Central Groundwater Board, Government of India, in 2015–2016. The data were collected by CGWB during pre-monsoon season from 108 bore wells, which are randomly present throughout the district.

3 Method

For the proper hydro-chemical analysis of groundwater data, principal component analysis (PCA) has been applied to reduce the dimensionality [4, 32, 104]. PCA has been calculated by using IBM SPSS statistical software version 25. Correlation matrix of Karl Pearson has been prepared to present the association between individual parameters of groundwater chemical and to identify the link between them [5, 112]. The correlation value of > 0.5 represents very high correlation between variables, < 0.5 demarcated poor correlation between variables and 0.5 value of correlation represents moderate relationship between variables [108]. PCA provides the most powerful information about the components of a large data set with minimum loss

of information [35]. In this study, for the proper interpretation of PCA varimax rotation has been used. According to Guttman–Kaiser rule, only those factors which have the eigenvalue greater than 1 have been taken as major factors [14]. Therefore, for the proper extraction of the groundwater quality parameter eigenvalue is taken as > 1 in IBM SPSS software. The graphical presentation of eigenvalue in respect of factors is called Cattle's (1966) scree Test [15]. It is a simple line segment plot that shows the fraction of total variance. It has been shown that when there are substantive factors, the slope of the line will be steep, but when the factors correspond to the error, the slope will be flat.

PCA can be expressed with the help of Eq. 1

$$Z_1 = a_1 \times x_1 + a_2 \times x_2 + \dots + a_{14} \times x_{14} \quad (1)$$

where Z_1 is the first principal component, $x_1, x_2, \dots, x_{14}$ are the original variables (e.g., P^{H} , EC, Ca, Mg, Na, etc.) and $a_1, a_2, \dots, a_{14}$ are the coefficient or weight of each variable for the first principal component Z_1 (Vide Table 5).

From the result of the PCA, we have considered five PCs, i.e., Z_1, Z_2, Z_3, Z_4 and Z_5 . Let n be the number of observations of each of $x_1, x_2, \dots, x_{14}$. Then $Z_1, Z_2, \dots, Z_{14}$ will also have n observation corresponding to n observations of $x_1, x_2, \dots, x_{14}$. To get the coefficient of PCs, we need to find eigenvalues and eigenvector of correlation matrix of the variable $x_1, x_2, \dots, x_{14}$. This procedure has been run here with the help of IBM SPSS version 25 software.

Hierarchical cluster analysis or HCA is another method that has been applied here to classify homogeneous chemical groups as well as sample station-wise homogeneous groups. The most common theme of this method is joining the most similar observations in the data set [31]. Q-mode hierarchical cluster which has been accepted and used by several authors is applied here [36, 55, 57, 79]. The main aim of this method is to group more than one variables into a cluster. The Euclidean distance has been implied here to identify the similarities or differences between two sites i and j which has been calculated by using Eq. 2

$$d_{ij}^2 = \sum_{(k=1)}^m (Z_{(i,k)} - Z_{(j,k)})^2 \quad (2)$$

where d_{ij} is the Euclidean distance, Z_{ik} and Z_{jk} are the variable k for objects i and j , respectively, and m is the number of variables.

The graphical presentation of cluster has been represented by dendrogram, which has been obtained from the Euclidean distance, and Ward's method has been used.

The spatial analysis of 14 groundwater chemical parameters has been carried out using the ArcGIS version 10.5 software. Interpolation of the data has been done using

inverse distance-weighted (IDW) method of spatial analysis tool. Now the question is: Why 14 parameters have been selected to carry out this research? The 14 parameters have been considered by the standard parameters to identify the quality of the groundwater by CGWB [16]. Moreover, these 14 parameters are the ideal parameters for the reorganization of the suitability of the groundwater for irrigation or drinking purposes, so to calculate standard water quality index or WQI, the above-mentioned 14 parameters are very important for the water quality analyzers.

Various hydro-chemical facies like Wilcox diagram, Doneen's chart, USSS diagram and Gibbs diagrams have been plotted using AquaChem version 2011.1 software.

4 Results and discussion

4.1 Spatial pattern of groundwater chemical

Spatial pattern means the distribution of groundwater chemical in different parts of the study area. In all figures of the spatial pattern of groundwater chemical, it can be observed that there are numerous small pockets of chemical concentration, which look like stars. In this connection, it has been explained that interpolation method has been carried out to present spatiality, so on the basis of random data, this kind of spatiality has been shown. Interpolation has been carried out in ArcGIS 10.5 software with the help of IDW tool, which was previously discussed in [method](#) section. In this section, distribution of all chemical components as well as their causes of formations has been analyzed.

The value of P^H varies between 7.5 and 8, which represents that the water is almost neutral in nature. P^H value ranging from neutral to acidic is mainly associated with granitic formation [31, 47]. Therefore, neutral to acidic P^H can be observed in the southwestern side of the study area where granitic gneiss formation is predominant (Figs. 2, 3a). Lower P^H value is the characteristic feature of large quantity of soluble salts, i.e., higher EC and high concentration of acidic ions such as SO_4^{2-} [71]. Figure 3a, b and j shows that the southern and southwestern parts of the district are characterized by lower P^H value because of the presence of highly soluble salts and SO_4^{2-} acidic ions.

Conductivity or the electrical conductivity is frequently used as the parameter to measure salinity in the water [87]. According to the State Water Resources Control Board, the drinking water standard for salinity is 900 $\mu S/cm$ (recommended) and the higher value of EC is 1600 $\mu S/cm$, although the value as higher as 2000 $\mu S/cm$ may be acceptable for irrigation water [96]. According to Rhoades et al. [85], water can be classified into six groups

Table 2 Groups of EC concentration

Type	EC value in $\mu S/cm$	Types of water
I	EC < 700	Non-saline
II	700 and 2000	Slightly saline
III	700 and 2000	Moderately saline
IV	> 2000 and < 10,000	Highly saline
V	10,000 to 25,000	Very highly saline
VI	25,000 to 45,000	Brine water

based on the concentration of EC [86] which is shown in Table 2.

Figures 2 and 4b reveal the fact that electrical conductivity is related to the laterite geological structure. The electrical conductivity in the lateritic geological structure increases when the degree of saturation increases [10]. Therefore, the lateritic patch of western and southwestern parts of the Birbhum District has been characterized by high electrical conductivity concentration. The rest of the study area is about non-saline to slightly saline zone.

The primary cause of the presence of total hardness is the concentration of cations mainly calcium and magnesium which are dissolved in the water and anions like carbonate, bicarbonate, chloride and sulfate [21, 23].

Figure 5a–c reveals the fact that there is a strong positive relationship between total hardness and other cations and anions. The r^2 value of the relationship ranges from 0.6 to 0.9 which clearly describes that total hardness is strongly determined by calcium, magnesium and chloride. The map (Fig. 4c–e, i) strongly displays the relationship between total hardness and other cations and anions. It can be found that high concentration TH is present in the northwestern and southwestern parts of the district where calcium, magnesium and chloride are also highly concentrated.

Calcium bicarbonate ion is highly determined in the southern part of the district (Fig. 4h). This mainly forms due to the reaction of carbon dioxide with water and carbonate rocks like limestone and dolomite [3]. In Birbhum District, HCO_3^- concentrated in hard clay impregnated with caliche nodules geological deposit. So, it is very common to find HCO_3^- in this geological structure.

Initially, sulfate ion has no harmful effect on living organism. It basically influences salinity [21]. WHO-recommended maximum allowance limit of sulfate is 400 mg/l. In this region, sulfate ion varies from 0.01 to 264 mg/l. So, this area has been characterized by optimum amount of sulfate.

Fluoride is a very important hydro-chemical trace element in groundwater. High concentration of fluoride ion may cause fluorosis-related health disorders. The groundwater of the area is characterized by semiarid condition,

Fig. 4 **a** P^H , **b** electrical conductivity, **c** total hardness, **d** calcium, **e** magnesium, **f** sodium, **g** potassium, **h** calcium bicarbonate, **i** chloride, **j** sulfate, **k** fluoride, **l** phosphate, **m** silicon dioxide, **n** iron

Fig. 4 (continued)

Fig. 4 (continued)

Fig. 4 (continued)

Fig. 5 **a** Relationship between total hardness and magnesium, **b** relationship between total hardness and chloride, **c** relationship between total hardness and calcium

Table 3 Correlation coefficient matrix among groundwater hydro-chemical variables

	Correlation matrix														
	p ^H	EC	TH	Ca	Mg	Na	K	HCO3	Cl	SO4	F	PO ₄	Sio2	Fe	
Correlation	p ^H	1.00													
	EC	.082	1.00												
	TH	−.008	.795	1.00											
	Ca	−.060	.703	.952	1.00										
	Mg	.070	.792	.902	.726	1.00									
	Na	.150	.880	.430	.343	.481	1.00								
	K	−.142	.440	.358	.245	.460	.256	1.00							
	HCO ₃	.068	.780	.532	.402	.628	.725	.499	1.00						
	Cl	.070	.897	.815	.766	.747	.742	.317	.498	1.00					
	SO ₄	−.075	.486	.235	.185	.264	.528	.152	.431	.219	1.00				
	F	.079	.247	.475	.458	.420	.049	−.047	.007	.372	.008	1.00			
	PO ₄	.020	.338	.181	.151	.192	.384	.143	.287	.389	−.100	.059	1.00		
	Sio ₂	−.122	.256	.207	.181	.210	.225	.064	.291	.180	.266	−.006	−.096	1.00	
	Fe	−.049	−.064	−.067	−.077	−.045	−.039	−.028	−.012	−.057	−.012	−.045	−.048	.282	1.00

crystalline igneous rocks and alkaline soils which help to generate fluoride [34]. Fluoride above the permissible limit can be observed along the northwestern part of plateau fringe (Fig. 4k). WHO has set 15 mg/l as permissible limit of fluoride. But this part records 143 mg/l fluoride contamination, which has an adverse impact on the human health. Rajmahal trap with semiarid condition is responsible for heavy fluoride contamination in this region (Figs. 2 and 4k).

Iron is of little concern as a health hazard, but still in excessive quantities it is considered as a nuisance [19]. The maximum acceptable limit of iron ranges between 03 mg/l to 10 mg/l. In the study area, iron ranges from 32 to 58 mg/l which is basically above the permissible limit. The major source of iron in this part of study area is the presence of lateritic patch [21]. The maximum concentration of iron in the study is observed in the western and southeastern parts where laterite is predominant. High concentration of iron affects the taste of water and promotes the growth of iron bacteria [21].

4.2 Principal component and factor analysis

Factor analysis (FA) is the technique related to PCA, which helps to generate an unobserved variable which compiles in three or more observed variables. Therefore, factor analysis as statistical tool of principal component analysis has been taken into consideration to extract major chemicals influencing groundwater in Birbhum District.

To calculate factor analysis, the correlation matrix by Pearson has been used here. Based on the result of correlation, the positive and negative relations between

variables can be identified. Table 3 shows the relational matrix between chemical variables of groundwater.

Strong positive correlation can be detected with the total hardness, calcium, magnesium and chloride. This relationship was shown in the previous section with the help of scatter diagram (Fig. 5a–c). Except this, chloride has the strong positive relationship with electrical conductivity, calcium, magnesium and sodium. Total hardness is also significantly related to electrical conductivity. Iron is negatively correlates with almost all the parameters except silicon oxide. Fluoride shares negative relation with potassium.

PCA has been calculated with the aid of Kaiser normalization which is the extract of five main principal components which act as the major factors influencing groundwater in this region. Five principal factors accounted for 7967% of the total variance in the hydro-chemical data.

Factor 1 explains 42% of the total variance, and high positive loading of total hardness, calcium and magnesium is shown in this factor. So, this factor explains the general water quality parameters which are utmost important for the drinking water. The chemical components, viz. Mg, Cl, Na and SO₄, influence rate of evaporation, recharge and anthropogenic sources of the groundwater system [6, 71]. Therefore, it can be concluded that Factor 1 represents the impact of geological variation and human impact on the groundwater chemistry in the concerned area. The study of Jalali [50] has also been reported that the Na and Cl ions are mostly originated from agricultural field mainly from the use of chemical fertilizer, animal waste and industrial pollutants. This factor is also related to the TDS variation [71]. Fluoride (F) concentration is one of the important

Table 4 Varimax rotated factor loading

Variable	1	2	3	4	5
pH	.017	.159	.134	-.125	-. .800
EC	.594	.763	.200	.025	.051
TH	.911	.316	.055	.014	.153
Ca	.894	.203	.016	.012	.138
Mg	.784	.422	.099	.013	.148
Na	.224	.868	.260	.048	-.136
K	.167	.377	.218	-.105	.644
HCO ₃	.250	.800	.195	.069	.175
Cl	.733	.477	.313	.029	-.015
SO ₄	.035	.739	-.450	.043	.028
F	.749	-.206	-.078	-.024	-.240
PO ₄	.098	.176	.860	-.036	.000
SiO ₂	.720	.314	-.260	.688	.105
Fe	-.070	-.102	.116	.874	-.013
Variance (%)	42.009	12.105	10.021	8.087	7.454
Cumulative variable (%)	42.009	54.114	64.135	72.222	79.676

Factor loadings > .7 are marked by bold font

harmful hydro-chemical elements as it has adverse effect on human health [56, 67, 89, 105, 114]. According to the report of CGWB, the villages adjacent to the plateau fringe area of Birbhum District have high concentration of fluoride. So, fluoride has been extracted here as first factor loading with high positive value (Table 4).

EC, Na, SO₄ and HCO₃ have been loaded as second factor which comprises 11.9% of the total variance. There is strong positive correlation between EC and NA ($r=0.88$). This is due to anthropogenic activities which add significant amount of ion to the groundwater. The third factor contributes only 10% of the total variance PO₄ which is positively loaded in this factor. There are two sources of PO₄ where natural sources include deposition of atmospheric, chemical decomposition of rocks and minerals and biomass decay. On the other hand, anthropogenic sources include use of chemical fertilizers and animal wastes, etc. Fe or iron has been loaded as fourth factor which explains only 8% of the total variance. Iron is one of the major constituents of groundwater which basically originated from lateritic geological formation in the study area. Previously it was mentioned that Fe is not harmful to health up to a certain limit, but it may badly affect cloths and utensils. The southeastern part of the study area is affected by high content of iron, so it has been loaded in the fourth factor of the groundwater chemistry. P^H is loaded as the last and fifth factor which accounts for 7.2% among the total variance. Correlation matrix shows that P^H is negatively correlated with most of the analyzed chemical components

Table 5 Weight or coefficient of each components

	Component				
	1	2	3	4	5
pH	.064	-.009	-.628	.218	.479
EC	.978	.146	-.089	.003	-.005
TH	.890	-.357	.179	-.055	.038
Ca	.797	-.429	.183	-.015	.012
Mg	.873	-.197	.142	-.104	.070
Na	.776	.435	-.314	.135	-.010
K	.465	.237	.262	-.466	-.325
HCO ₃	.759	.429	-.006	-.089	-.038
Cl	.900	-.163	-.097	.145	-.129
SO ₄	.559	.456	-.115	-.199	.406
F	.369	-.696	.002	.110	.267
PO ₄	.376	-.046	-.413	.488	-.592
SiO ₂	.280	.328	.560	.381	.255
Fe	-.054	.198	.457	.672	.020

Extraction method: principal component analysis

which are reflected by the negative factor loaded and present in fifth factor.

The weights or coefficients are very important because it help to understand the importance of the variables. Table 5 shows the weight of each components as well as variables.

Table 5 shows that if component 1 is Y_1 , then

$$Y_1 = P^H \times 0.064 + EC \times 0.978 + TH \times 0.890 \dots n$$

In the same way, we can get the weight of each variable for each component.

4.3 Spatial pattern of controlling factors

In this section, the spatial concentration of each factor has been analyzed. This analysis is very important because with the help of this explanation, hydrologist can easily understand the qualitative upgradation and degradation of the groundwater, and also, this analysis helps to make sure what kind of planning and management should be needed for the development of the quality of the groundwater?

Fluoride strongly influences *Factor 1*, as a result in Factor 1 map (Fig. 6a) shows the high concentration of fluoride in the northwestern part of the study area. So, in Birbhum district it has been proved that fluoride concentration is one of the major determinants to control groundwater quality in the northwestern part, where plateau fringe of Jharkhand present.

Factor 2 includes EC, Na, HCO₃ and SO₄, which are mainly concentrated in the southwestern part of the study area. SO₄ is the important chemical components. Sodium

Fig. 6 **a** Factor 1, **b** Factor 2, **c** Factor 3, **d** Factor 4 **e** Factor 5

Fig. 6 (continued)

is very effective in irrigation and drinking purposes. Higher amount of sodium makes the water unsuitable for irrigation purpose, and high sodium content in drinking water causes several health problems like high blood pressure, hypertension, nervous disorder, etc. Higher HCO_3 content may promote the alkalinity level, which may affect human health; high amount of sulfate makes bitter taste and bad odor of water. So, concentration of these chemicals in the southwestern part of the study area must be the prime concern for the hydrologist.

Factor 3 extracts only phosphate. Phosphate is a non-toxic element for the human health until they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate. Phosphate as a third determinant factor is highly concentrated in the southern and northern parts of the study area.

Factor 4 comprises iron, which initially is not harmful for the human health, but high amount of iron, i.e., $> .3 \text{ mg/l}$ in drinking water causes serious health problems like hemochromatosis, digestion problem, diabetes, skin diseases, etc. Figure 6d shows high concentration of iron as fourth factor in the southwestern part of the study area, where lateritic geology is predominant. So, it is also a major

concern to the hydrologist for the optimization of iron content in this part.

Factor 5 helps to extract P^{H} . It is an important chemical component of the drinking water. The limit of P^{H} in the study area is in optimum condition, so it is not the great matter of concern.

The above analysis reveals that the spatiality of the factors makes this study more relevant rather than the implementation of statistical tools.

4.4 Cluster analysis

Cluster analysis is a sort of clustering or grouping technique in which cases or observations can be grouped according to the similarity for the measured variable.

There are various methods for the cluster analysis like two-step clustering, k-means clustering, cluster, etc. But hierarchical cluster analysis is a widely used method for the identification of grouping of chemical variables within groundwater. This method basically helps to group variables into clusters based on similarities in such a way that individual cluster depicts a specific process in a system [71, 116]. Hierarchical clustering is one of these. The level of similarity has been presented through dendrogram. Euclidean distance has been chosen to measure the distance between sample sites, and Ward's method has been chosen as cluster method which has been described in [method](#) section. Except this, Ward's method has been successfully applied to form clusters that are homogeneous and geochemically detachable [23]. Based on standard major cations and other trace elements, cluster analysis has been carried out to split water sample into a number of groups with similar hydro-chemical characteristics.

As we know, the major aim of the cluster analysis is to sort elements into groups or clusters. Therefore, in this study two dendrograms have been prepared. One dendrogram is shown to make grouping or clustering among the sample sites; it means the sample sites having homogeneous chemical composition form a single group (Fig. 6). Based on the sample-wise cluster analysis dendrogram (Fig. 7), it is reported that there are three clusters present in the dendrogram, among which 63.55% sample sites are clustered in cluster 1, 22.897% are in cluster 2 and only 13.55% sample sites are clustered in cluster 3.

On the other hand, another dendrogram (Fig. 8) shows the grouping of chemical components, where P^{H} , PO_4 , SiO_2 and Fe are grouped into cluster 1 and occupy 23.07%. In cluster 2, EC, Na, K, HCO_3 , Cl and SO_4 are grouped and cluster 2 comprises 46.15% of the total grouping. On the other

Fig. 7 Sample-wise cluster shown in dendrogram

Fig. 8 Chemical component-wise cluster shown in dendrogram

hand, TH, Ca, Mg and F are all together grouped into cluster 3 having 30.76% of the total grouping size. From both dendrogram and correlation (Fig. 5a, b), it has been clearly observed that total hardness is strongly associated with calcium and magnesium. EC has strong association with Na, HCO_3 and Cl. Correlation matrix in Table 3 reveals the fact that EC has strong positive correlation with Na, HCO_3 and Cl because the high concentration of potassium and electrical conductivity in water.

4.5 Hydro-chemical facies

In this study, “hydro-chemical facies” is used as a term to signify the analytic chemical characteristics of groundwater solution which occurs in hydrological systems. Facies replicate the response of chemical processes about lithological framework [49, 107]. Wilcox’s diagram, Gibbs mechanism and Doneen’s chart to show permeability index have been used here.

4.6 Wilcox’s diagram

It is used to describe the classification of groundwater for irrigation or the suitability of groundwater for irrigation purpose [70, 96, 101, 111]. In this diagram, EC is plotted against % of Na. Sodium is the best indicator for the use of groundwater in irrigation because sodium has strong impact on soil and influences the blockage of soil particles; therefore, permeability become reduced [31, 72, 100, 106]. % of Na has been calculated in this article with the help of the following formula

Fig. 9 Wilcox's diagram

$$\%Na = \left(\frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + K^+ + Na^+} \right) \times 100$$

where all the ionic concentrations are present in meq per liter

Now, the calculated % Na and electrical conductivity measured in $\mu s/cm$ have been plotted in Wilcox's diagram (Fig. 8).

Figure 9 depicts that about 50% sample are in excellent to good category, while 25% sample present in the good to permissible, 20% samples are under the category of and 5% belongs to the category of doubtful to unsuitable. So, Wilcox's diagram proves that groundwater of the most part of the district is very much suitable for irrigation purpose.

4.7 Gibbs mechanism

The chemical compositions of the groundwater largely depend on the lithological character of the region. Gibbs in 1970 proposed a diagram to represent major anions and cations and set the relationship between water composition and lithology [41, 62, 81, 84]. Gibbs diagram depicts three major mechanisms which regulate the chemical composition of the groundwater, which are a. evaporation dominance, b. precipitation dominance and c. rock dominance. Gibbs ratio can be found out with the help of the following formulas.

$$\text{Gibbs Ratio I (for anions)} = \frac{Cl^-}{(Cl^- + HCO_3^-)}$$

$$\text{Gibbs Ratio II (for cations)} = \frac{Na^+ + K^+}{(Na^+ + K^+ + Ca^{2+})}$$

Figure 10a and b reveals the fact that about 68% samples belong to the category of rock dominance and the rest 32% fall in precipitation dominance category. So, this result indicates that the major portion of the samples of the study area is influenced by weathering of the rocks and resultant mixing of minerals. This phenomenon is basically observed in the western part of the district.

4.8 Permeability index (PI)

Percolation index is the diagrammatic presentation of hydro-chemical facies which helps to identify whether the groundwater of the study area is suitable for irrigation or not. For the formulation of the permeability index, the chemical components such as sodium, calcium, magnesium and bicarbonate are the essential because irrigation water is positively affected by the above-mentioned chemical elements. Therefore, to calculate permeability index, the following formula has been employed.

$$PI = \frac{(Na^+ + \sqrt{HCO_3^-}) \times 100}{Na + Ca^{2+} + Mg^{2+}}$$

Percolation index is represented by Doneen's chart [26, 85], in which three classes have been depicted, where class I and class II are considered as good for irrigation and class III water represents as unsuitable for irrigation.

Figure 11 explains that about 99% samples remain in class I and only 1% present remain in class III. Hence, Doneen's chart depicts that all the samples are suitable for irrigation in the study area.

5 Conclusion

This study helps to reach various conclusions; for example, the implementation of multivariate statistics helps to reduce the dimension of the large data set and extract only few important determinants to control the groundwater quality. As five components account 80% of the total variance, those five components have been taken as major quality controlling factors. In this respect, this study has a separate mathematical or statistical base.

But in geographical point of view, the statistical analysis helps us to find the spatiality of major determinants factors and also helps to formulate whether planning should necessary or not. On the basis of the above analysis, a geographer, an environmentalist and hydrologist can easily take decisions for the optimization of groundwater

Fig. 10 **a** and **b** Mechanism to control the chemistry of groundwater

quality, wherever it necessary. Moreover, different hydrological diagrams help to explain different aspects of groundwater, which is geographically very important and useful.

Therefore, assessment of groundwater quality by using statistical tool and diagrammatic presentation is not just

the general study, but it helps to indentify the most vulnerable zone in terms of groundwater quality which may badly affect the human body and subjected to worse situation. So, this kind of assessment must be helpful to the district planner, hydrologist, geologist and other administrative officers for the betterment and sustainable

Fig. 11 Doneen's chart to classify the irrigation water

development of groundwater resource for the common people. Moreover, the findings of this study may be valuable for government and local authorities.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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