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Appraisal of Physico-chemical Quality of Groundwater in Ganga-Sone Divide Region of Bihar Using Statistical and Multivariate Techniques

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Abstract: This study examines the relationship between groundwater deterioration and agricultural development in Ganga-Sone divide region of Bihar, where agriculture is the main source of livelihood and population is completely dependent on groundwater for their basic needs. Physico-chemical properties of groundwater samples have been collected. The higher values of most of the parameters were found in the agriculturally developed areas. The statistical analysis of data suggests that most of the elements exceed the general acceptable limit and significant relationship exists among most of the parameters. This indicates the impact of excess use of chemical fertilizer/pesticides on agricultural land. Results of analysis identified the problem areas in respect of high sodium, electrical conductivity, potassium, nitrate and fluoride.

Key words: Groundwater, deterioration, agricultural development, land-use/cover, Ganga-Sone divide, Bihar.

Introduction

Increasing over-use of chemical fertilizers and pesticides in the agricultural fields coupled with heavy pressure of human and animal population has led to increased seepage of chemicals and bio-chemicals into groundwater.

Groundwater is used for irrigating nearly half of the area in the research region. Along with this almost whole of the population is dependent on groundwater for their basic needs. The availability of water both in terms of quality and quantity is essential for the very existence of mankind (Datta, 2005; Datta et al., 2009; Rai and Kumari, 2012). Adequate and reliable water supplies are insufficient to support agricultural, industrial, and domestic uses, and future water use demands are predicted to increase as developing countries seek new levels of economic growth and prosperity (Jury and Vaux, 2005). It is evident that water quality is highly variable over time and space due to natural and human factors. Due to these spatial and temporal variations in water, continuous monitoring will provide a reliable estimation of the quality of groundwater. To assess the degree of pollution, several water quality parameters have been measured. This research is focused on assessing the relationship between levels of agricultural development and degree of pollution of groundwater quality in selected stations of region.

Study Area

The southern part of Ganga-Sone Divide is the most important region of Bihar. The tract is a great alluvial crescent stretching from the Sone River in Rohtas to river Karmanasa in Kaimur districts. These two districts of Rohtas and Kaimur located in the southern part of Bihar, are selected as representative districts for detailed study. It lies between the grid of 83°12′14″ and

84º20′16″E and 24º18′9″ and 25º21′32″N (Figure 1) and known as “rice bowl of India”. Geologically the area is broken into two different physiographic divisions. The first one is an extensive flat country fertile tract of tertiary and alluvial origin, which is spread over about 65% of the total area. It is for the most part very fertile, highly cultivated and densely populated. The second region is the hilly, called the Kaimur hills and Rohtas plateau, which comprises about 1768 km^2 and extends along the southern boundary of the district in an undulating table-land and is incapable of cultivation (Sinha et al., 2013). The normal annual rainfall is 300 mm. May is usually the hottest month of the year, with a mean daily maximum temperature of 35ºC and mean daily minimum of 27 ºC. In the given study area total 26 monitoring stations have been set up by CGWB for measuring the physico-chemical quality of groundwater (Figure 1).

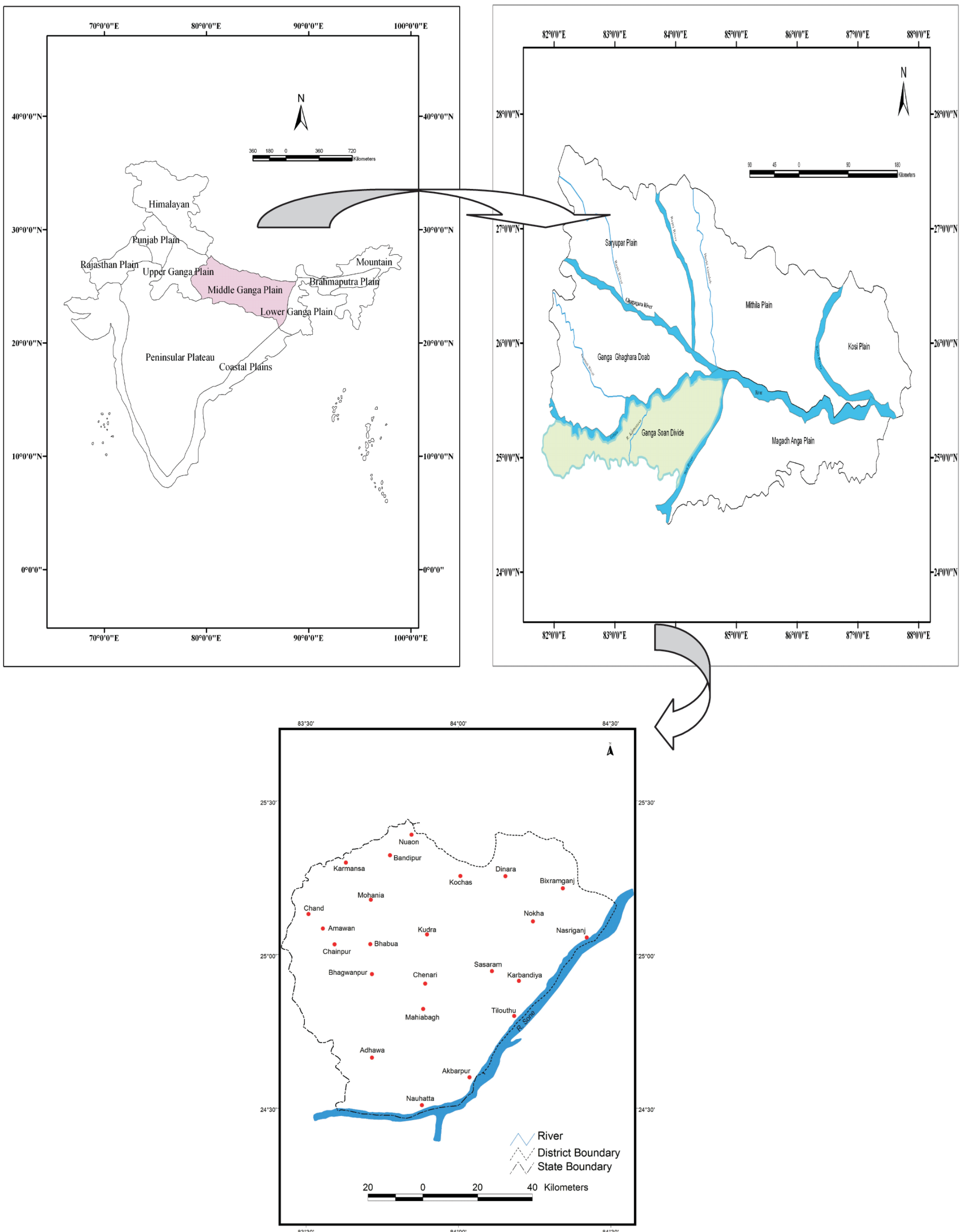

Figure 1: Location map of study area and groundwater monitoring stations.

Materials and Methods

The data for selected parameters of agricultural development have been collected and analyzed for two time periods (2001 and 2012). Data for physico-chemical parameters of water quality are collected from the office of Central Ground Water Board, Faridabad. For calculating agriculture development 'z-score' is calculated. The multivariate data of water quality parameters is statistically analyzed using SPSS 16.0 software package (version 16.0). The methods of bivariate correlation analysis (with the Pearson's correlation coefficient (*r*) at two tailed significance level) has been used. Along with correlation the logic is supported and verified by Factor analysis also. It also helps to understand the correlation structure of collected data and identified most important factors contributing the data structure. For factor analysis Varimax and Kaiser Normalization rotation method was used and also used to find association between parameters so that the number of measured variables can be reduced.

After obtaining correlation matrix and Eigen values, factor loading were used to measure the correlation between variables and factors. These variables were then rotated by varimax rotation technique to obtain new variability which is easy to interpret. Cluster analysis is also another data reduction method that was used to classify entities with similar properties. Multivariate statistical method encompassing cluster analysis, factor analysis, principal component analysis and discriminate analysis has been successfully used in hydrochemistry for many years (Praus, 2005; Alberto et al., 2001). Factor analysis was also used to find association between parameters so that the number of measured parameters can be reduced. The method divides a large number of homogeneous groups on the basis of their co-relation structure. For cluster analysis single linkage method was used. In this method the distance between clusters was determined using the distance of two closest objects (nearest neighbour) in the different clusters (Pathak et al., 2008).

Results and Discussion

Spatial Pattern of Agricultural Development

The analysis of spatial pattern of agricultural development in different blocks based on development index (*Z* value) is very much needed in the region where it is the main stay of more than 70% of the population. There is significant level of spatial development disparity. On this basis all blocks are grouped into five categories viz., very high developed, high developed, moderate, low and very low developed.

The pattern of agriculture development in the study area shows that north-west tract of the region is well developed. The blocks which lie in this zone, are Bhabua (15.94), Sasaram (15.24), Chainpur (10.89) and Mohania (10.05) in 2012 and only three blocks, Bhabua (14.81), Sasaram (13.59) and Karakat (8.12) were in 2001. It is perceptible that Chainpur and Mohania have increased their agricultural output and come in very highly developed category.

In the next category of high developed, blocks placed in eastern and northern parts of the region occupy this place. They are Karaghar (5.98), Seosagar (5.87), Karakat (5.12) and Kochas (4.87) in 2012 and in 2001

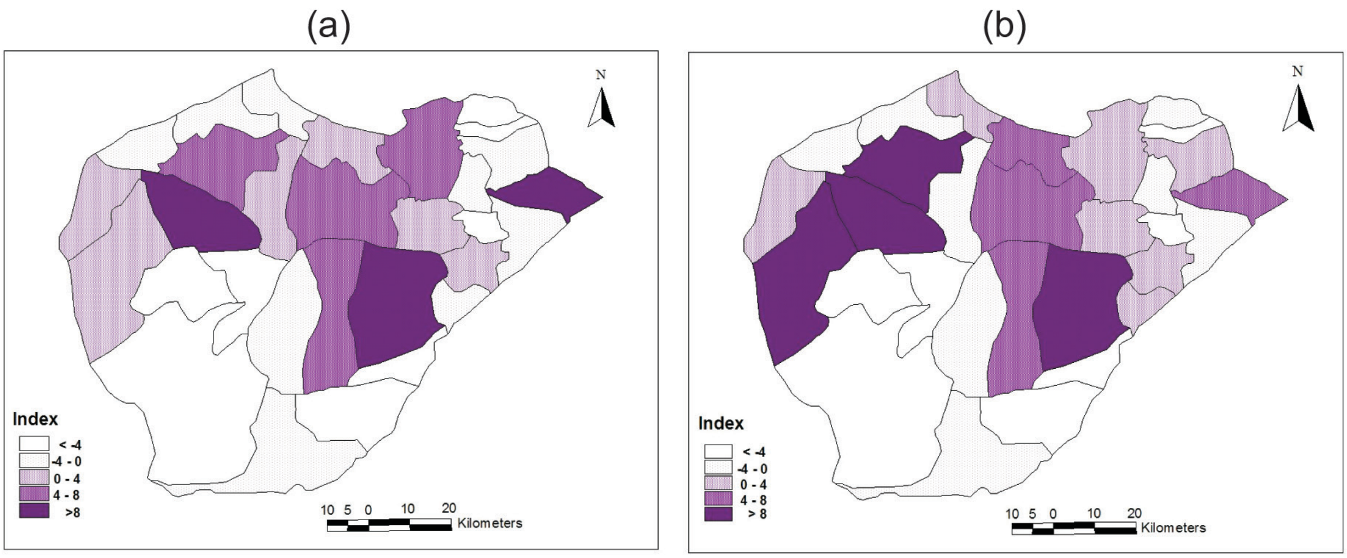

Figure 2: Pattern of agricultural development in the Ganga-Sone divide, 2001 (a) and 2012 (b).

only three blocks Mohania, Karaghar and Sivsagar were placed in this category. They are comparatively less privileged in agricultural infrastructure. The spatial pattern of moderately developed blocks is as such that they lie in the surrounding of above category of developed blocks. In 2012 as such, here seven blocks fall in this group. They are Nokha (3.87), Dinara (3.74), Dehri (2.45), Akhori Gola (2.01), Nuon (1.63), Bikramgang (1.25) and Chand (0.66). While in 2001 number is same as seven but blocks were different.

The spatial pattern of low developed category, blocks are scattered in nature, which is the result of less fertile, undulating land with less irrigation facility and network connectivity including Chenari (-0.12), Durgawati (-0.95), Nauhatta (-1.21), Kudra (-1.26), Ramgarh (-1.45), Nasrigang (-2.45), Sanjhauli (-2.84) and Dawath (-3.41) in 2012 appear to be in low developed category. In 2001 they were Chenari (-0.10), Nuon (-0.76), Bikramgang (-1.13), Durgawati (-1.19), Dehri (-1.29), Nauhatta (-1.30), Nasrigang (-2.13), Sanjhauli (-3.83), Ramgarh (-3.85) and Dawath (-4.76). Another reason for their low level of development is low level of connectivity link of this region with the main market.

The southern section of the region, which is less fertile, undulating land with less irrigation facility and network connectivity included, Rajpur (-4.12), Rohtas (-4.15), Tilauthu (-5.78), Surajpura (-5.98), Adhaura (-7.87), Bhagwanpur (-10.66) and Rampur (-10.87) in 2012. For 2001 they were Rohtas (-5.39), Tilauthu (-5.68), Surajpura (-6.37), Rajpur (-7.20), Rampur (-7.34), Bhagwanpur (-8.54) and Adhaura (-10.06). This is again co-terminous with user soil and no irrigation facility available there.

Temporal Change in Level of Agricultural Development

During the period of 11-years, major change in level of agricultural development is expansion of agriculturally very high developed area, which is about 114% increase in areal coverage as a result of more expansion in irrigated area, reduction in area prone to flood, increasing level of agricultural infrastructure such as more availability as well as accessibility of agriculture credits to farmers through commercial banks, co-operative banks and regional rural banks etc. The number of banks in the region has increased from 165 in 2001 to 219 in 2012 and the number of credit societies has increased tremendously from 42 in 2001 to 270 in 2012.

There is natural break in the next category of high level of development which is only about 5% increase in areal expansion in the same period because, two blocks, Karaghar and Karakat, maintained their position and only Mohania is replaced by Seosagar.

In the next hierarchy of category of development the decrease in areal coverage of moderate level of development is about 28%. This is because of shifting of few blocks from this category to higher level of category such as Chainpur, and Seosagar.

In the next category of low level of development there is expansion in areal coverage of about 9%. The reason being few blocks have improved their status and shifted from very low category of development to the category of low level of development.

In the last category of very low level of development, there is reduction in areal coverage of near about 19% in the 11-year period. Rohtas and Rajpur have increased their position and have been shifted in the next higher category. In Rohtas most of the forested area is converted into agricultural fields as a result of increasing the pressure of population growth. In Rajpur, now population is more inclined and serious in agriculture sector because more fertilizer depots and banks are opened in last few years and personnel from Krishi Vigyan Kendra are giving training to local people for adopting scientific agriculture practices.

In conclusion, it is stated that spatio-temporal changes in agricultural development do occur due to changes in irrigation, yield, land-use and other infrastructural facilities. It is noticed that out of total 30 blocks nine blocks have deteriorated their position and 15 blocks have improved and rest blocks could not show any significant change.

Groundwater Quality

State of Pollution

The descriptive statistics of the analysed water quality parameters are depicted in Table 1. The groundwater of the study area is slightly alkaline (7.87). But, it comes under the acceptable limit of 6.8 to 8.7. The pH varies from 6.94 to 8.80. Reading of pH reveals that 8% of the total samples investigated have hydrogen ion concentrations above the threshold limit. In general, groundwater pH is slightly alkaline due to influx of bicarbonates (HCO_3) ions in the groundwater aquifer, which is due to percolation of rain water and irrigation water through soils (Mor et al., 2008).

The Electrical Conductivity is an indicator of salinity and also signifies the amount of Total Dissolved Solids. Electrical Conductivity of collected water samples ranges from 371 to 2256 millimhos/cm. The highest (2256) Electrical Conductivity has been found in Chand

and lowest (371) in Nasrigang (Table 2). More than 75% of the samples are having EC level below the threshold limit. TDS indicates the inorganic pollution load (Mor et al., 2008). It ranges between 216 and 1411, out of which Nasrigang experiencing minimum and Chand lies at maximum end of TDS reading.

The observed calcium contents in sample water ranged from 4.0 to 58.0 mg/l. The highest concentration is recorded in Mohania, while lowest in Chand and Adhaura. The concentration of Ca is not only under acceptable limit of BIS and WHO standards (Table 3) but also it is under the minimum threshold level. Magnesium content varies from 10.90 to 93.60 mg/l. As regards magnesium, 100% of the observations were found to be under the minimum level of acceptance of drinking water. Chlorine concentration in the study area varied from 14.2 to 535 mg/l. Sulphate is a major contributor to total hardness. All the water samples of selected sites have SO_4 content under the acceptable limit.

Table 1: Descriptive statistics of groundwater

Parameters	*Units*	*No. of samples*	*Minimum*	*Maximum*	*Mean*	*St. error*	*SD*	*Variance*
pH	-	26	6.94	8.91	7.88	0.092	0.47	0.22
EC	µS/cm	26	371	2256	972.27	100.00	509.90	2.60
TDS	mg/L	26	216	1411	612.08	72.24	368.40	1.35
TH	mg/L	26	90	530	238.46	22.828	116.40	1.35
Ca	mg/L	26	4	58	24.50	2.96	15.10	228.26
Mg	mg/L	26	10.9	93.6	3.55	3.89	19.84	393.65
Na	mg/L	26	34.7	283.2	1.17	1.53	78.19	6.11
K	mg/L	26	0.9	101.7	2.32	6.04	30.80	949.15
CO_3	mg/L	26	0	18	1.96	1.09	5.56	30.91
HCO_3	mg/L	26	140.3	530.7	2.61	1.83	93.54	8.75
Cl	mg/L	26	14.2	535.3	1.33	2.65	135.16	1.82
NO_3	mg/L	26	2.2	354	7.30	1.74	88.92	7.90
SO_4	mg/L	26	0	123.3	1.96	4.94	25.21	635.85
F	mg/L	26	0.08	2.0	0.85	0.11	0.57	0.33

Table 2: Comparison of groundwater quality parameters of Ganga-Sone divide area with drinking water quality standards (India and WHO)

Parameters	*Samples range*	*BIS standards*		*WHO limit*
		Acceptable limit	*Maximum limit*	
pH	6.94-8.91	7.0-8.5	6.5-9.2	6.5-9.2
EC	371-2256	1625-2228	-	-
TDS	216-1411	300	1500	500
TH	90-530	300	600	300
Ca	4-58	75	200	105
Mg	10.9-93.6	30	100	50
Na	34.7-283.2	50	50	200
K	0.9-101.7	50	-	200
CO_3	0-18	75	200	75
HCO_3	140.3-530.7	30	-	150
Cl	14.2-535.3	250	1000	250
NO_3	2.2-354	45	45	45
SO_4	0-123.3	250	400	200
F	0.08-2	1.0	1.5	0.5

Units of all the parameters are in mg/l except EC (mS) and pH

Table 3: Groundwater quality at different locations in the Ganga-Sone divide

Sites	*pH*	*EC*	*TDS*	*TH*	*Ca*	*Mg*	*Na*	*K*	CO_3	HCO_3	*Cl*	NO_3	SO_4	*F*
Adhaura	8.78	616	282	390	4.0	19.4	68.9	16.4	18.0	153.0	31.9	22.6	0.0	0.64
Bhabua	8.91	1450	904	235	28.0	40.1	177.5	93.8	18.0	237.9	223.3	154.3	19.7	1.54
Bhagwanpur	7.98	1652	992	435	48.0	76.5	189.2	21.0	0.0	530.7	226.9	50.4	39.4	0.83
Chainpur	8.29	640	391	250	49.0	31.0	41.7	1.7	0.0	274.5	42.5	11.0	32.1	0.50
Chand	6.94	2256	1411	395	4.0	93.6	283.2	99.9	0.0	176.9	535.3	252.5	21.5	1.05
Durgawati	7.30	1202	742	255	28.0	45.0	178.0	2.6	0.0	140.3	336.8	51.1	3.2	0.23
Kudra	7.37	1534	882	260	18.0	52.2	197.5	32.8	0.0	414.8	237.5	48.1	24.5	0.81
Mohania	7.60	1259	773	530	58.0	20.7	176.2	52.9	0.0	353.8	216.2	71.7	13.4	2.0
Nuaon	7.47	1781	1369	365	38.0	65.6	267.9	15.8	0.0	207.4	273.0	354.0	10.4	1.09
Ramgarh	7.99	1347	789	220	12.0	46.2	157.9	41.7	0.0	207.4	205.6	151.0	31.1	0.38
Rampur	7.39	778	425	235	46.0	29.2	54.7	2.3	0.0	329.4	28.4	5.3	43.9	0.72
Akhorigola	7.92	700	397	105	12.0	18.2	98.2	11.2	0.0	244.0	31.9	15.7	0.0	0.26
Bikramgang	7.59	754	436	150	14.0	27.9	94.2	1.7	0.0	317.2	78.0	49.1	38.2	0.38
Chenari	8.07	628	407	175	32.0	23.1	64.4	21.4	0.0	219.6	42.5	90.7	1.1	1.86
Dawath	7.50	1147	808	155	16.0	27.9	135.2	101.7	0.0	158.6	106.4	250.5	30.6	0.35
Dehri	8.17	516	312	145	18.0	24.3	51.6	4.4	0.0	225.7	35.5	7.4	0.0	1.36
Dinara	7.73	1621	1378	265	20.0	52.2	236.7	6.1	0.0	219.6	358.0	35.5	20.7	1.52
Karahghar	8.80	502	302	140	26.0	18.2	60.8	3.2	15.0	189.1	24.8	2.2	4.2	1.46
Karakat	8.17	440	267	150	18.0	25.5	40.1	1.3	0.0	225.7	17.7	8.0	2.4	1.71
Kochas	7.89	1110	646	335	52.0	47.8	101.6	21.4	0.0	201.3	173.7	51.1	8.4	0.51
Nasrigang	8.03	371	216	90	18.0	10.9	35.0	21.0	0.0	401.7	14.2	44.9	0.0	0.25
Nauhatta	8.09	456	264	140	18.0	23.1	46.7	1.0	0.0	366.0	21.3	46.0	6.3	0.19
Nokha	7.79	928	605	95	12.0	15.8	179.3	3.0	0.0	274.7	88.6	67.8	123.3	0.98
Rohtas	7.84	572	333	145	18.0	24.3	40.6	21.1	0.0	317.2	53.2	24.9	17.5	0.35
Sasaram	7.52	514	282	355	14.0	29.2	37.6	3.0	0.0	213.5	35.5	14.1	4.5	1.27
Tilauthu	7.93	505	301	185	16.0	35.2	34.7	0.9	0.0	195.2	28.4	20.1	13.5	0.08

TH – Total Hardness as $CaCO_3$; TDS – Total Dissolved Solids; EC – Electrical Conductivity; All parameters are in mg/L except pH and EC (µS/cm).

Sodium content of groundwater of the study area varied from 34.7 to 283.2 mg/l, which is far beyond the maximum desirable limit of WHO and BIS. More than 70% of the samples have reading above the threshold limit. Potassium is an important cation and plays a vital role in intermediate metabolism. Potassium content varies from 0.9 to 101.7 mg/l. More than 50% of the samples have reading above the threshold limit. The TDS content of groundwater of the study area varied from 216 to 1169 mg/l. The highest level of concentration of TDS was found in Nuaon and lowest in Nasrigang.

The main source of nitrate and fluoride in the groundwater is high consumption of fertilizers, pesticides, herbicides, weedicides etc. The concentration of nitrate varies from 4.2 to 354.0 mg/l. The observation above the permissible limit NO_3/l are found to be more than 30%. Nuawan, Chand. Ramgarh, Dawath and Nokha are the blocks where nitrate concentration is even more than 150 mg/l.

The status of fluoride concentration is also not good, the ranges varies between 0.1 and 2.5. The distributed data for fluoride shows that 45% of the observations are more than the allowable limit. The groundwater is showing high concentration of fluoride and is more than WHO prescribed maximum permissible concentration in drinking water i.e. 1.5 mg/l.

It is interesting to note that higher values of all the parameters were found in the agriculturally developed areas, while lower values were observed in the agriculturally low developed areas. This shows the clear impact of higher use of chemical fertilizer and pesticides in the agriculture.

Table 4 represents the initial eigen value, percent of variance and cumulative percent of total variance of groundwater data. From Table 4, it is perceptible that the first four components together account for 77.66% of the total variance in which the first component accounts for 43.36% of the total variance.

The second component explains 14.45%, the third component 12.01% and the fourth component exhibit 7.82% of the total variance. For interpreting of the data the method of Kaiser Criterion is followed which retains only those factors having eigen values greater than 1. The first four factors having an eigen value greater than 1 has been used for further interpretation. The extracted components explain nearly 77.66% of the variability in the 14 variables. The number of eigen values can be estimated from a scree plot demonstrated in Figure 3. As shown in this figure, the eigen values

Table 4: Rotated component matrix, eigen value, percentage of total variance and cumulative percentage of groundwater

Variables	*Factors*			
	1	*2*	*3*	*4*
pH	-0.537	0.655	0.207	0.285
EC	0.984	0.022	0.023	0.090
TDS	0.966	0.027	-0.001	0.069
TH	0.605	0.128	0.56	-0.234
Ca	0.141	-0.163	0.812	-0.031
Mg	0.862	-0.084	0.042	-0.152
Na	0.941	0.022	-0.045	0.176
K	0.599	0.378	-0.223	0.140
CO_3	-0.142	0.865	0.075	0.271
HCO_3	-0.039	-0.530	0.484	0.369
Cl	0.939	0.320	-0.030	-0.089
NO_3	0.732	0.178	-0.330	0.006
SO_4	0.172	-0.393	-0.135	0.803
F	0.196	0.429	0.493	0.101
Eigen value	6.07	2.02	1.68	1.09
% Total variance	43.36	14.45	12.01	7.82
Cumulative %	43.36	57.81	69.83	77.66

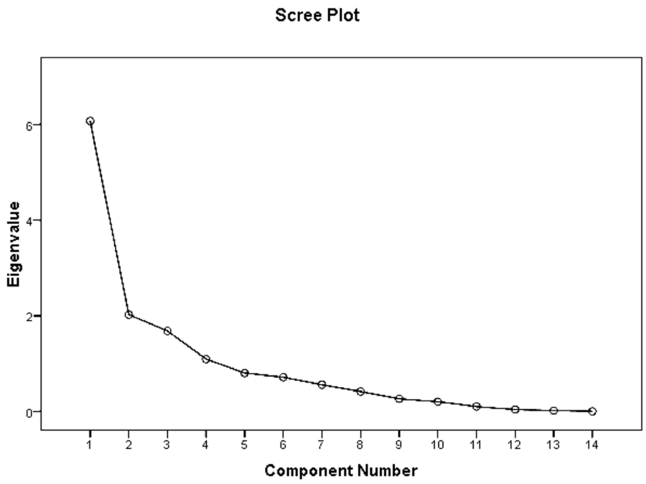

Figure 3: Scree plot of groundwater.

sharply decrease within the first four components and then slowly stabilize for the remaining ones.

The correlation analysis of pH was found to be negatively correlated with Mg (r = -0.447*), Na (r = -0.443*), HCO_3 (r = -0.068), Cl (r = -0.497**) and NO_3 (r = -0.336). It showed a high degree of positive correlation with CO_3 (r = 0.736**) and correlation was significant at the 0.01 level. EC or TDS is mainly contributed by salts of Na, SO_4 and Cl. TDS is highly correlated with Na (r = 0.0.957), Cl (r = 0.914) and Mg (r = 0.820). Table 5 shows a moderate degree of correlation of Na with K (r = 0.488*), NO_3 (r = 0.669**), SO_4 (r = 0.286) and F (r = 0.218). Na is highly correlated with Cl (r = 0.906). Total Hardness is moderately correlated with Ca (r = 0.449*), Mg (r = 0.557**), Na (r = 0.480*), Cl (r = 0.545**), NO_3 (r = 0.254) and F (r = 0.313). Cl was found to be significantly correlated with EC (r = 0.935**), TDS (r = 0.914**), Mg (r = 0.841**) and Na (r = 0.906**), indicating the presence of chloride salts of Ca and Mg. SO_4 was significantly correlated with Na, indicating the presence of Na-SO_4 salt (Table 5). Cursory examination of the data reveals that the majority of the groundwater samples in this region are dominated by Mg hardness as compared to Ca hardness.

Table 4 represents the factor loading which were used to measure the correlation between variable and factors. The components with larger variance are more desirable since they give more information about the data. The highest factor loading of EC and TDS is 0.98 and 0.96, respectively indicating the strong relationship between these two variables (Table 4), which is further supported by regression analysis as r = 0.97 and cluster analysis (Dendrogram) as shown in Figure 4.

The concentration of EC, TDS, Na and Cl show high positive loading (0.984-0.939) and the concentration of NO_3 and TH have moderate positive loading (0.732-0.605) in the first component. The second component contains high positive loading of CO_3 (0.865). The third component is governed by Ca (0.812) whereas fourth component exhibit only SO_4 (0.803) ions. On the basis of the factor loading the first component can be designated as "salt factor" as it contains EC along with inorganic salts. The first component is associated with a combination of various hydro-geochemical processes that contribute to enrich more mineralized water (high value of TDS). The enrichment of Na and Cl ions in groundwater is due to the interaction of water with rocks and secondly the association of TDS with higher concentration of Na and Cl ions. This indicates anthropogenic activities such as discharge of sewage in open unlined earthen pits, runoff from agricultural fields, which support the water to percolate into soil and mixes with groundwater. Component first supports the contamination in groundwater from animal and animal wastes. The concentration of HCO_3 in the groundwater is the result of the reaction of soil CO_2 with the dissolution of silicate minerals. Minerals of the bed rock are subjected to weathering and subsequently affected by leaching, which contribute dissolved salts to groundwater, resulting in an increase in TDS and EC, and hence water salinity. Second component shows high positive loading of CO_3. High loading of CO_3 is mainly due to the weathering of limestone rocks. Third component controlled by Ca relates to again limestone and dolomite rocks. Fourth component shows dominance of SO_4.

The dendrogram of sampling stations produced three major groupings (Figure 4). The dendrogram shows that the association between cases 16-19; 22-26-12; 21-24; and 4-11 is more significant. The first cluster group shows that the close association between cases (sampling stations) 16, 19 with bonds to stations 25, 14 to a lesser degree. Second group of association is between 22-26 and 12 resembles with 21-24 together bound with each other with lesser degree. The second group has further affinity with group first.

There is a close association between 4-11 which bounds with 13 on lesser degree of association and this cluster constitutes third group. This third group has again association with first and second groups on lesser degree. Sampling stations 5, 15, 9, 23, 1 and 18 show

*Correlation is significant at 0.05 level (2-tailed). ** Correlation is significant at 0.01 level (2-tailed).

Table 5: Correlation co-efficient matrix of physico-chemical data of groundwater in the Ganga-Sone divide

	pH	*EC*	*TDS*	*TH*	*Ca*	*Mg*	*Na*	*K*	*CO_3*	*HCO_3*	*Cl*	*NO_3*	*SO_4*	*F*
pH	1	-0.455*	-0.446*	-0.235	-0.003	-0.447*	-0.443*	-0.137	0.736**	-0.68	-0.497**	-0.336	-0.199	0.162
EC		1	0.970**	0.577**	0.139	0.865**	0.955**	0.584**	-0.069**	0.017	0.935**	0.671**	0.208	0.174
TDS			1	0.509**	0.132	0.820**	0.957**	0.513**	-0.104	-0.046	0.914**	0.697**	0.192	0.225
TH				1	0.449*	0.557**	0.480*	0.267	0.073	0.076	0.545**	0.254	-0.122	0.313
Ca					1	0.133	0.052	-0.077	-0.135	0.329	0.057	-0.039	-0.005	0.240
Mg						1	0.742**	0.372	-0.169	0.034	0.841**	0.532**	0.040	0.032
Na							1	0.488	-0.058	-0.025	0.906**	0.669**	0.286	0.218
K								1	0.198	-0.131	0.505**	0.661**	0.022	0.134
CO_3									1	-0.266	-0.098	-0.041	-0.166	0.217
HCO_3										1	-0.106	-0.258	0.228	-0.072
Cl											1	0.558**	0.074	0.164
NO_3												1	0.084	0.059
SO_4													1	-0.071
F														1

*Correlation is significant at 0.05 level (2-tailed); **Correlation is significant at 0.01 level (2-tailed).

Rescaled Distance Cluster Combine

```
?
* * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L  C
L U S T E R   A N A L Y S I S * * * * * * * * * * * * * * * * * *
 *


 Dendrogram using Single Linkage

                          Rescaled Distance Cluster Combine

   C A S E    0         5        10        15        20        25
  Label  Num  +---------+---------+---------+---------+---------+

         16    -+
         18    -¦
         26    -¦
         19    -+-+
         24    -+ ¦
         21    ---¦
         22    -+ +-+
         11    ---¦ ¦
         13    ---¦ ¦
         12    ---¦ +-------+
          4    ---¦ ¦       ¦
         14    ---+ ¦       +-----+
          1    -----+       ¦     ¦
         25    ---+         ¦     ¦
         23    -------------+     ¦
          2    ---------+         ¦
         10    -----+   ¦         +---------------------------+
          7    ---------¦         ¦                           ¦
          6    ---------+-+       ¦                           ¦
         20    ---------+ ¦       ¦                           +-+
         15    -----------+-----+ ¦                           ¦ ¦
          3    -----------+     +-+                           ¦ ¦
          8    -----------------+                             ¦ ¦
          9    -----------------------------------------------+ ¦
         17    -----------------------+                         ¦
          5    -------------------------------------------------+
```

Figure 4: Dendrogram of the location of 26 cases using single linkage.

Linkages Distance

```
?
* * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L  C L
 U S T E R   A N A L Y S I S * * * * * * * * * * * * * * * * * * *


 Dendrogram using Single Linkage

                            Rescaled Distance Cluster Combine

   C A S E      0         5        10        15        20
25
  Label     Num  +---------+---------+---------+---------+--------
-+

  CO3         9   -+
  F          14   -¦
  pH          1   -¦
  Ca          5   -¦
  Mg          6   -¦
  SO4        13   -¦
  K           8   -+---+
  Na          7   -¦   ¦
  Cl         11   -¦   +------------------------------------------
-+
  NO3        12   -+   ¦
 ¦
  TH          4   -----¦
 ¦
  HCO3       10   -----+
 ¦
  EC          2   ------------------------------------------------
-+
  TDS         3   ---------------------------------+
```

Figure 5: Dendrogram of the 14 chemical parameters of 26 cases.

associations with rest of the sampling stations at lesser degree as linkages distances is from 12 to 25.

Another dendrogram of the 14 indexes based on cluster analysis is depicted in Figure 5. On the basis of dendrogram of all 14 indexes can be grouped into three main clusters. First cluster group shows close association between CO_3, F, pH, SO_4, Ca, Mg and K. This group is further associated with group second to a lesser degree, having NO_3, Na, Cl and TH indexes. Group third shows the close association between HCO_3 and EC. These findings corroborates with the result of correlation analysis and factor analysis.

Conclusions

The water quality assessment study carried out in the representative sites, has identified the problem areas in respect of high nitrate, fluoride, bicarbonate and pH in the region. Generally the groundwater falls in the hard category and only about 50% of the samples are within the permissible limit of WHO for TDS. The concentration of TDS, TH, HCO_3, Na, NO_3 and F at most of the sampling stations exceeds the safety limits for drinking water. Computational analysis of the data set of hydrochemical constituents in the groundwater suggests that the aquifer is mainly controlled by hardness, HCO_3, Na and NO_3. There is a strong positive relationship between EC-TDS; EC-Na; EC-Cl; TDS-Cl etc. About 30% samples are contaminated by NO_3 and more than 60% samples have higher concentration of F than the WHO limit. It poses the risk of dental caries for the populace of the region. The problem seems mainly enhanced by rainfall and irrigation together with poor quality of water.

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