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Assessment of ground water quality of the Golaghat district of Assam, India and its peripheral area using multivariate statistical technique with special reference to the presence of higher levels of fluoride and arsenic

Champa Gogoi[1, 2, 4], Paran Jyoti Kalita[1,3], Pinky Saikia[1, 3], Dipak Sinha [2], Rajib Lochan Goswamee[1,3]*
[1]*Advanced Materials Group,Materials Science and Technology Division, CSIR-North East Institute of Science & Technology*
[2]*Department of Chemistry, Nagaland University, Lumami, Nagaland*
[3]*Academy of Scientific and Innovative Research, CSIR-NEIST Jorhat Campus, India*
[4]*Department of Chemistry CNB College Bokakhat,Golaghat, Assam, India*
Email: goswamirl@neist.res.in

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Abstract

The quality of ground and surface water sources is continuously deteriorating around the world day by day due to various anthropogenic activities. Some of the serious global groundwater quality issues drawing the attention of scientists from different countries of the world. Among them the mixing of either fluoride or arsenic in groundwater is very important. In India one of the highly fluoride and arsenic affected state is the Assam. The Golaghat district of Assam is sandwiched between two known fluoride and arsenic affected areas Jorhat district and Karbi-Anglong district of the state. Accordingly, in the present study it is focused to have a detailed survey of the ground water quality of this district and its peripheral areas with special reference to assessment of arsenic and fluoride level. It has been reaffirmed that six out of eight development blocks of Golaghat district are highly affected by arsenic and two development blocks are affected by fluoride. Besides arsenic and fluoride level, other water quality parameters were also measured and subjected to analyze the groundwater quality parameters by using statistical analytical tools. Statistical analysis showed that the both geogenic and anthropogenic sources are responsible for the groundwater quality variations of Golaghat district of Assam.

Key words: water quality index, fluoride, arsenic, groundwater, statistical analysis.

1. Introduction

Several recent reports describe that, the groundwater sources of various part of Assam state of India are contaminated by arsenic (As) and fluoride (F^-). Groundwater of lower part of Assam covering mainly areas under the districts such as amalgamated Kamrup, Nagaon, Bongaigoan, Kokrajhar, Borpeta, Nalbariare contaminated by both F^- and As (Dutta et al, 2006; Singh, 2004). Ground water of upper part of Assam such as Sibasagar, Dibrugarh, Jorhat, Lakhimpur, Majuli and Tinsukia are contaminated by As (Dutta et al, 2006; Singh, 2004). Karbi-Anglong district of Assam is relatively free from As but is highly affected by F^-. Such an area wise categorization was done by considering the bench mark of lethality of contamination as par the scale recommended by World Health Organization where a maximum permissibility level of 1.5 mg/L is set for F^- (WHO 2017) and 0.01 mg/L for As (WHO 1993), in drinking water. However, in India in the event of absence of alternate source, the maximum permissible limit for As in drinking water is relaxed to 0.05 mg/L (BIS 1991). If the concentration of F^- in drinking water is more than the permissible level, then different health effects like dental and skeletal fluorosis, including other health effects such as cardiovascular effects, neurological effects, endocrine effects, reproductive effects etc are manifested in human body (Verma et al, 2018). Similarly, if the concentration of As in drinking water is more than the permissible limit, then it shows its various health effect such as central nervous system effect, cardiovascular disease, diabetes, renal system effects, enlarged liver, bone marrow depression, high blood pressure, skin diseases and finally different forms of cancer also. Recent publications report that, co-contamination of F^- and As in drinking water can affect the IQ levels leading to the decrease of intellectual functionality among children (Alarcon- Herreraa et al, 2020; Jimenez-Cordova et al, 2019).

Since Golaghat district of Assam is sandwiched between F^- affected Karbi-Anglong district and As affected Jorhat district, so the main objective of our study is to assess the groundwater quality with special reference to these two contaminants of Golaghat district and its peripheral areas in the state of Assam and to identify the root of the pollution that affects the groundwater.

2. Materials and methods

2.1 Study Area

Golaghat is a district with an area of 3,502 km^2, situated in the upper side of state of Assam along the southern bank of river Brahmaputra and forms a part of the vast alluvial plains of the state. The Kakodonga tributary of Brahmaputra is the eastern border of Golaghat district and sharing with Jorhat district. Dhansiri is a southern tributaries of Brahmaputra flowing from south to north in the Golaghat district constitutes the main surface water runoff routes of the district. Dhansiri originate from Laisang peak of nearby Nagaland and falls in the river Brahmaputra near Kaziranga national park. The district has a sub-tropical humid climate. There is a variation in the intensity of rainfall from east to west and from north to south part of the district. During winter season, the average temperature varies from 6^o to 14^o C and during summer season, it varies from 29^o to 36^o C. Golaghat is home of the one-horned rhinoceros which is found exclusively in this part of the world. The district shares the world-famous Kaziranga National Park with Nagaon district. The Nambor Wildlife Sanctuary is also situated in Golaghat.

The district head quarter salso called Golaghat, is a town located at coordinates of 26.0◦ N to 27.1◦ N and 93.0◦ E to 94.18◦ E. It has an average elevation of 95 metres above sea level. There are 8 rural block development areas namely Dergaon, Kathalguri, Podumoni, Kakodonga, Morongi, Gomariguri, Sorupathar and Bokakhat. The maps of relevant rural development blocks with respect to the larger maps of the state and the country are shown in the Figure 1.

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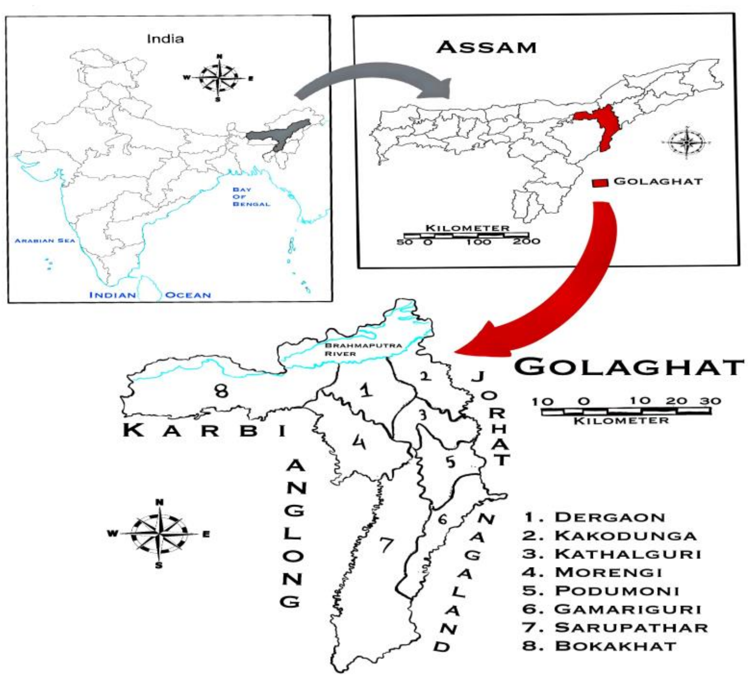

Figure 1: Study sites showing six blocks of Golaghat district, Assam

2.2 Sampling methodology

The groundwater samples were collected from 247numbers of existing tube wells in eight development blocks of Golaghat district just after the flood season mainly during the months of September to November, 2017. At this time of the year water level in most of the wells are comfortably high enough to draw easily by hand or electrical pumps.

During sampling for washing out the stagnant water inside the tube, tube wells were operated 4-5 minutes before collection. Two sets of water samples were collected from each location in poly propylene bottles. The bottles were previously washed by 8 M nitric acid and scrupulously washed by distilled water. At the time of collection of water samples, the bottles were rinsed repeatedly with the sample water (APHA 1998) again. For metal and fluoride analysis the collected water samples were acidified by using 1:1 HNO_3 acid solution to decrease the pH below 2. Among eight development blocks of Golaghat district, 72 samples were collected from Bokakhat, 50 samples from Padumoni, 30 samples from Gamariguri, 27 samples from Morongi, 20 samples from Kakodonga, 19 samples from Kathalguri, 15 samples from Dergaon and 14 samples from Sorupathar block development area.

At the same time, 27 groundwater samples were also collected from the peripheral areas of Golaghat district (Jorhat, Karbi-Anglong and Nagaon districts). Among 27 groundwater samples collected from the peripherial areas, 11 samples were from Jorhat district, 13 samples from Karbi-Anglong district and 3 samples from Nagaon district. The different location of these points of sample collection from the peripherial areas are shown in the Figure. 2 by red spots.

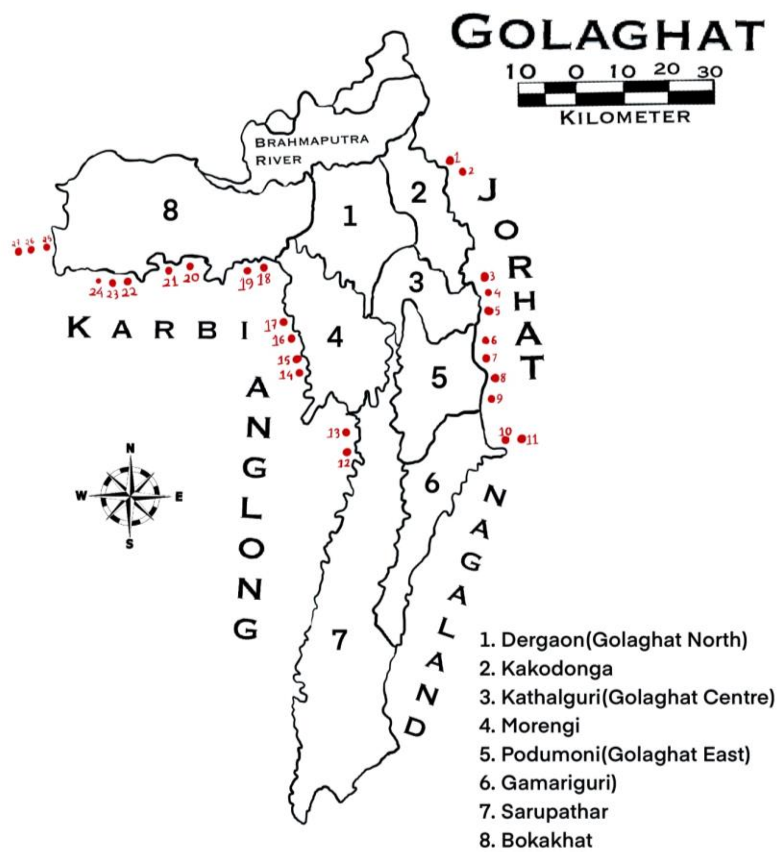

Figure 2: Study sites of Golaghat district with its peripheral areas (1-27), Assam

2.3 Sample analysis

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The groundwater quality parameters such as pH, Total Hardness (TH), Bicarbonate (HCO_3^-), Total Dissolved Solids (TDS), Electrical Conductivity (EC), concentration of various cations and anions with total arsenic and iron were determined. A previously calibrated pocket pH meter (HANNA Co) was used to measure the pH of collected water samples at the spots. Similarly, TDS and EC of water samples were also measured immediately by using pocket TDS meter (HANNA co) and Systonics digital condicitivity meter type 304 which was previously standardized by standard potassium chloride solution. The cations NH_4^+, Na^+, K^+, Ca^{2+},Mg^{2+} were determined by Ion Chrometograph (IC, Metrohm and column Metrosep C4-150). The anions F^-, Cl^-, NO_3^-,SO_4^{2-} and PO_4^{3-} were also determined by Ion Chrometograph (IC, Metrohm and column MetrosepA Supp 5) (Viswanathan, 2015). F^- was measured by both Ion Chrometograph and Ion Selective Electrode (Orion 4 star-pH/ISE). Concentration of arsenic was determined by Atomic Absorption Spectrophotometer (Perkin Elmer, USA). All the required reagents were of analytical grade (Merck, India). For Atomic Absorption Spectrometry (AAS), the standard arsenic solution was procured from Perkin Elmer, USA. In this method, As^{5+} was pre-reduced to As^{3+} using standard potassium iodide solution, ascorbic acid solution and hydrochloric acid solution (Chetia et al, 2011).

To evaluate the relationship among the examined water quality parameters in the studied samples to infer their sources either natural or anthropogenic and to identify the hydrochemistry of collected ground water, Pearson's Correlation Coefficient analysis, Principal Component analysis (PCA), Piper diagram analysis, were performed (Usman et al, 2014; Molla et al, 2015). In this study, the statistical analysis Pearson's correlation coefficient analysis and principal component analysis were carried out by using Statistical Package for Social Science, version: 25. The Piper trilinear diagram (Piper, 1994) was drawn by using the hydrochemical data of collected ground water samples from Golaghat district. The diagram is highly useful to infer the hydro geochemistry of water (Khound et al, 2018). In the Piper diagram, we obtain two lower triangles and one quadrilateral shape. One of these triangles is for the cations (Na^+, K^+, Ca^{2+} and Mg^{2+}); another triangle is for the anions (Cl^-, SO_4^{2-}, CO_3^{2-} and HCO_3^-) and the quadrilateral shape indicates the combined distribution of both cations and anions i.e., the final water type of the sources.

The correlation among the water quality parameters of collected ground water samples were estimated from Pearson correlation coefficient (r) (Molla et al, 2015). Pearson's correlation coefficient analysis provides the values of correlation coefficients that indicate the strength of inter relationship between two chemical parameters. The value of correlation coefficient (r) may be in between +1 and -1. Positive and negative sign of r value indicates the inter-relationship between two parameters positively and negatively. For strong correlation $r > 0.50$, for good correlation $r = 0.50$ and for poor correlation $r < 0.50$ (Kumar et al., 2017).

3. Results and discussion

3.1 Water quality parameters

The analysed water quality parameters of collected groundwater samples from entire Golaghat district and its peripheral areas have been compared with WHO (1993, 2011) and BIS (1991). The water quality data of block wise collected samples along with their minimum, maximum values and standard deviations are given in Table 1, 2 and 3. From the Table 1 and Table 3(a), it is observed that pH of all water samples collected from all eight development block of Golaghat district and its peripheral areas were within the WHO (2017) permissible limit (6.5-8.5).Generally, the acidic (pH<7) character of the water samples are mainly due to the dissolution of carbon dioxide and organic soil and plant humus originated acids like fulvic and humic acids (Garcia et al. 2001). The EC and TDS values were also within the WHO recommended values. Dufor and Becker classified the water to four classes on the basis of TH soft (if TH is 0-60), moderately hard (if TH is 61-120), hard (if TH is 121-180) and very hard (if TH is >180) (Dufor et al., 1964). According to this classification 86.4% water of Podumoni development block; 73.3% of Kakodonga development block; 33.3% of Morangi development block; 16.8% of Gamariguri development block and 12.5% of Sorupathar development block water samples belong to hard type water. In Dergaon, Sorupathar and Podumoni development block 13%, 12% and 5% water samples were found very hard type. Moderately hard type ground water samples were found as 33.3%, 33.4%, 16.6% and 10% of the collected water samples in Kathalguri, Morangi, Gamariguri and Bokakhat development blocks. Similarly, TDS, EC and TH of samples collected from the peripheral areas of Golaghat district are also within the WHO recommended values.

The concentration of other dissolved anions such as Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, and HCO_3^- in ground water of Golaghat district varies from block to block as given in the Table 1. Among the cations in studied samples (in Table 2), except the concentration of Fe (total), the concentration of Na^+, NH_4^+ , K^+, Ca^{2+} and Mg^{2+} were within the ranges of WHO/BIS. The abundance order of Na^+, NH_4^+ , K^+, Ca^{2+} and Mg^{2+} in ground water samples in Golaghat district was $Na^+>Ca^{2+}> Mg^{2+}>K^+>NH_4^+$. Again it is seen that, 97% of water samples of the entire Golaghat district contains

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iron more than WHO/BIS permissible limit (1.0 mg/L) (WHO 1993, BIS 1991). The maximum iron concentration is 4.8 mg/L in Podumoni development block followed by 4.5 mg/L in Sorupathar development block than 4.4 mg/L in Dergaon development block than 4.01 mg/L in Kathalguri development block than 3.8 mg/L in Bokakhat development block than 3.2 mg/L in Gamariguri development block than 2.3 mg/L in Kakodonga development block and finally 1.67 mg/L in Morangi development block.

From the Table 4, it is seen that the concentration of fluoride in groundwater samples of 8 development block namely Dergaon, Kathalguri, Podumoni, Kakodonga, Morangi, Gamariguri, Sorupathar and Bokakhat varied from 0.07-0.45 mg/L, 0.09-0.87 mg/L, 0.16-1.69 mg/L, 0.10-0.54 mg/L, 0.08-0.46 mg/L, 0.25-2.92 mg/L, 0.11-1.83 mg/L and 0.09-0.85 mg/L respectively. Maximum fluoride content recorded was 2.92 mg/Lin a water sample collected from Gamariguri block. 10% samples of Gamariguri block and 4% samples of Podumoni block had fluoride concentration more than WHO/BIS permissible limit (1.5 mg/L). Similarly 14.3% ground water samples of Sorupathar block had fluoride concentration more than 1.5 mg/L. Some ground water samples, 28% of Podumoni development block, 30% of Gamariguri development block and 14.3% of Sorupathar development block were also found to have fluoride contamination in within WHO limit (from 1.0-1.5 mg/L). On the other hand collected ground water samples of Dergaon, Kathalguri, Kakodonga, Morangi and Bokakhat development blocks were not objectionable for drinking purpose in terms of fluoride.

The concentration of arsenic in groundwater samples of 6 blocks are more than that of the permissible limit (WHO/BIS). In Golaghat district, maximum arsenic was found in Gamariguri block (0.460 mg/L). In Podumoni, Kakodonga, Gamariguri, Kathalguri, Sorupathar and Morangi development blocks groundwater samples were found contaminated with arsenic by 68%, 65%, 46.7%, 21.05%, 7.14% and 3.7% with the ranges of (0.001-0.450), (0.001-0.186), (0.001-0.460), (0.001-0.077), (0.001-0.175) and (0.001-0.444) respectively. Many water samples given in Table 5, have As concentration within the range of 0.01-0.05 mg/L. Therefore it is observed that Podumoni, Kakodonga and Gamariguri are highly arsenic affected development block in Golaghat district.

In case of peripheral areas of Golaghat district, the concentration of various cations and anions including fluoride were within the WHO/BIS limit (Table 3(a) and 3(b)); but the concentration of arsenic was greater than the WHO/BIS limit in case of 55% samples collected from Jorhat district (Titabor block development area only) i.e., eastern part of Golaghat district. It is seen that these locations of Jorhat district are adjoining area to arsenic affected development blocks Podumoni and Gamariguri of Golaghat district. Other groundwater samples collected from the adjoining areas of Golaghat district, i.e., Karbi-Anglong and Nagaon districts are not contaminated by arsenic.

3.2 Statistical analysis

In the course of statistical analysis, the correlation among the water quality parameters of groundwater samples collected from Golaghat district of Assam were determined further by using Pearson correlation (Table 6). In this study, It is seen that TDS bears a linear positive correlation with Na^+, HCO_3^-, EC, Mg^{2+}, NH_4^+, PO_4^{3-}, Fe, NO_3^-, F^-, As and Ca^{2+}. Similarly HCO_3^- bears positive correlation with As, Na^+, NH_4^+, K^+, Ca^{2+}, Mg^{2+} and Fe. A significant positive correlation was found between As and F^-, Na^+, Mg^{2+}, Fe, $PO_4^{3-}$and NO_3^-. Positive correlations between Fe and F^-, NO_3^-, TH, PO_4^{3-}, As, Na^+, NH_4^+, K^+, Ca^{2+}, and Mg^{2+} were also found in the collected groundwater samples. Besides these, the Pearson correlation matrices showed significant positive correlation among the various parameters of the collected groundwater samples such as TH-Ca^{2+}, TH-Mg^{2+}, TH-HCO_3^-, TH-$Cl^-$and TH-SO_4^{2-}, which showed that, the groundwater hardness depends on Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^- and SO_4^{2-}.

In case of fluoride it is seen that, although there is no strong positive correlation with other; but some positive correlation was found between F^- and Na^+, K^+, Mg^{2+}, PO_4^{3-} and pH. The positive correlation between F^- and Na^+ in some parts of Nagaon and Karbi-Anglong districts which are the adjoining districts of Golaghat of Assam were also reported (Saikia et al, 2011). A positive correlation between pH and $F^-$was also reported by Gupta and Saikia (Saikia et al, 2011). From the positive correlation between F^- and PO_4^{3-} (0.185), F- might be expected come to contaminate the groundwater from human activities (use of phosphate pesticides) (Navarro et al. 2017) also.

The positive correlation between As and Fe in groundwater of Golaghat district might be expected to come from the dissolution of As-Fe bearing minerals (Singh, 2004; Chetia et al, 2011) and the immediate source material is likely to be ferric arsenate, with or without ferric arsenite, derived from the mineral arsenopyrite that was geologically transported to the Bengal delta and Assam valley (Singh, 2006). Because arsenic originates in Himalayan head waters (Chetia et al, 2008) and the two Himalayan rivers which built the Bengal delta, Ganga and Brahmaputra drain to the Bay of Bengal by carrying the largest sediment load. Similarly, as the Brahmaputra river flows through the heart of Assam to Bengal, thus arsenic occurrence in Assam may be due to heavy deposition of sediments (Singh, 2004).

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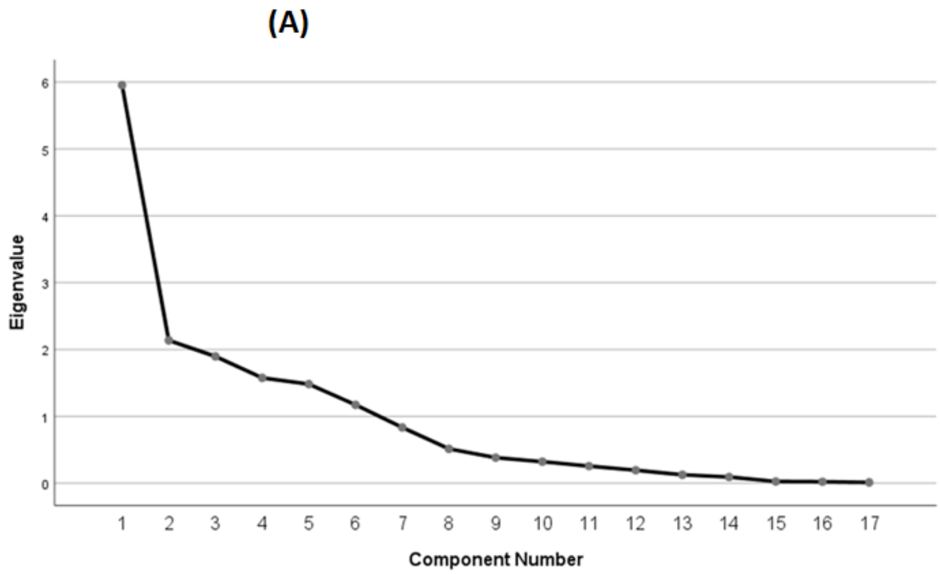
3.2 Principal Component analysis

The Principal Component (PC) Analysis of the collected water samples shows the results of the PC loadings with a varimax rotation, as well as the eigen values, % variance and % cumulative variances. Principal Component Analysis (PCA) was performed on the normalized data set (17 parameters) of ground water of Golaghat district by using varimax with Kaiser normalization rotation method (Kaiser, 1960) to identify the major variables affecting groundwater quality. The Scree plot (Figure 3(A)) indicates the number PCs having the eigen values more than 1 and taken in order to understand the underlying data structure (Khound et al, 2018). Six major PCs were extracted which accounted 83.632% variance of the original data structure. The selected PCs are able to carry more information than a single original variables (Usman et al, 2014). The result of the PCs loading with a varimax rotation as well as eigen values, % of variance and cumulative variance % are given in the Table 6. About 58.747 % variance of the total variance was represented in the first three loading factors in the ground water samples (Figure 3(B)). PC-1 accounts for 35.023% of the total variance, showing strong positive loading (>0.50) on TDS, Na^+, EC, HCO_3^-, Fe, PO_4^{3-},NH_4^+; while moderate positive loading (0.50-0.30) on Mg^{2+} and Fe. Again showing weak positive loading on As and NO_3^-.Since the PC-1 indicated the major contribution for TDS, Na^+, EC, HCO_3^-, Fe, PO_4^{3-} and NH_4^+so these seven parameters of ground water of Golaghat district are correlated and vary together. The high loading factor of TDS and conductivity are due to the active participation of dissolved ions in the groundwater quality. The major variables constituting PC-1 (Mg^{2+}, HCO_3^- and Na^+) is related to the hydro chemical variables originating from mineralization of groundwater. However, due to the absence of industrial activity, the positive loading of TDS, HCO_3^-, Na^+, EC, Mg^{2+},NH_4^+, Fe and PO_4^{3-}accounted PC-1 as geogenic sources of study area. PC-2 accounted 12.568% of the total variance and it is mainly participated by TH, Ca^{2+} and $Mg^{2+}$with strong positive loading; TDS and $HCO_3^-$with moderate positive loading and weak positive loading on EC and NO_3^- . TH, Ca^{2+} and Mg^{2+} presented positive scores, thus PC-2 could be ascribed as geogenic factor (Khound et al, 2018).

Out of the total variance, 11.156% is explained by PC-3 and is mainly carried by NO_3^- and As with strong positive loading; TDS and Mg^{2+} with moderate positive and weak positive loading on Na^+, PO_4^{3-} , EC, Fe and Ca^{2+}. Although the released of As and Fe was reported from the natural source under the reducing groundwater environment (Chapagain et al, 2009); some authors reported that As may be released from human activities like mining (Alarcón-Herreraa et al, 2020); Na^+ and PO_4^{3-}might be come from the fertilizer used in agricultural field, so PC-3 showed mixed sources of both geogenic and anthropogenic of study area. 9.270% of the total variance of water quality is exhibited by K^+ with a strong positive loading under PC-4. Due to weathering of igneous rocklike potassium feldspars, K^+can be increased in natural water (Usman et al, 2014). $Ca^{2+}$and NH_4^+ with moderate and weak positive loading on HCO_3^- and Fe. PC-5 explained 8.717% of the total variance of water quality in groundwater with a high positive loading on Fe and pH; F^- and $Cl^-$with moderate positive loading and EC and TH with weak positive loading. With high positive loading on F^- ; moderate positive loading on Mg^{2+} and Fe; weak positive loading on Na^+, PO_4^{3-}, EC, As and K^+; PC-6 explained 6.898% of the total variance of water quality in ground water. The positive loading of Na^+ and F^-under PC-1, PC-3, PC-4 and PC-5 corroborates with the result of Pearson correlation.



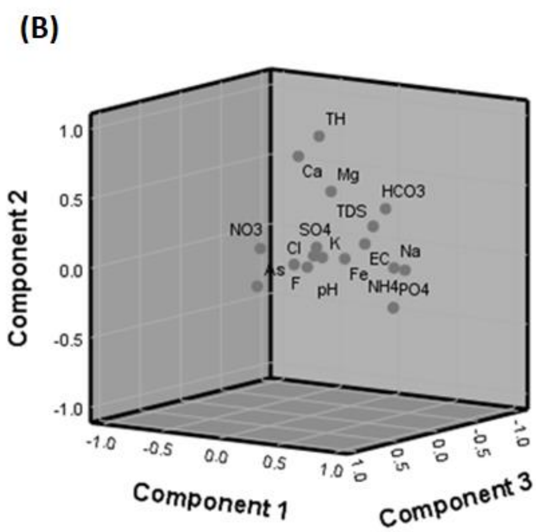


Figure 3: Principal component analysis by (A) Scree plot of the eigenvalues and (B) component plot in rotated space

3.3 Piper classification

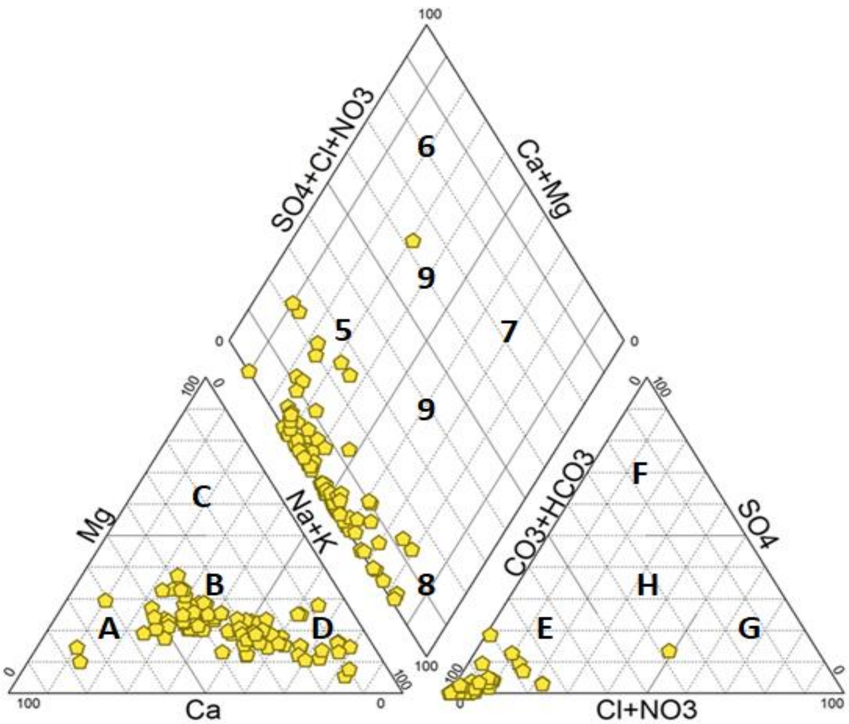


Figure 4: Piper diagram of groundwater samples of Golaghat district

Piper trilinear diagrams (Piper, 1944) (Figure 4) were prepared by using the hydrochemical data of collected groundwater samples from Golaghat district. It is seen that, most of the samples are scattered in zones B and D with respect to cations; only 6% water samples are in zone A of the lower-left triangle, which indicate that some groundwater samples are of calcium type, some of sodium type water and most are of mixed type. From the lower-right triangle of the Figure 4, we can say that, since most groundwater samples are plotted in the zone E, so bicarbonate-type water is predominant. The predominant hydrochemical types are HCO_3^-–Ca^{2+}, HCO_3^-–Na^+ and mixed HCO_3^-–Ca^{2+}–Na^+–Mg^{2+} types. The quadrilateral or diamond shape of the Figure 4, revealed that 49.8% of GW samples fall in the area 5 and another 49.8% fall in the area 8 of the diagram, which suggests that chemical properties of these groundwater samples are significantly dominated by Mg^{2+} and Na^+. The weak acids represented by HCO_3^- exceeds the strong acids represented by $SO_4^{2-}$and Cl^-. Again, 0.4% water samples of the area 9 in the Fig.6, indicates no dominant type of water class i.e., no one cation-anion pair exceeds 50 percent, thereby indicating magnesium and sodium bicarbonate type of water (Khound et al, 2018).

4. Conclusion

The present values of pH, TDS, HCO_3^-, TH, Na^+, NH_4^+, K^+, Ca^{2+} and $Mg^{2+}$of examined groundwater samples of Golaghat district are within the permissible limit; but with respect to fluoride and arsenic groundwater of study area is not fit for drinking at all compared to WHO/BIS safe limit. Six out of eight development blocks of Golaghat district are highly contaminated by As, which is several fold higher than that of WHO/BIS safe limit (0.05mg/L). Highest concentration of As was found in Gamariguri block (0.460 mg/L). In Podumoni, Kakodonga, Gamariguri, Kathalguri, Sorupathar and Morangi development blocks ground water samples were found contaminated with As by 68%, 65%, 46.7%, 21.05%, 7.14% and 3.7% respectively.Groundwater samples of two development blocks (Gamariguri and Sorupathar) are affected by fluoride and Podumoni block is partially fluoride affected area as 28% groundwater samples have concentration more than 1.0 mg/L. Although high level of As and F^- in groundwater is mostly due to natural activities; but it may sometimes be due to some human activities, such as mining (As) and use of phosphate pesticides. In case of groundwater quality of peripheral area of Golaghat district is free from fluoride contamination; but the East-South part of Golaghat district (i.e., Jorhat district) is affected by arsenic. Concentration of Fe is also very high (0.8-4.8 mg/L) in entire Golaghat district and since As and Fe is correlated positively, so As might be come from dissolution of As-Fe bearing minerals (Chetia et al. 2011) and the immediate source mineral is likely to be ferric arsenate (with or without ferric arsenite). From the Piper trilinear diagram analysis, it is found that bicarbonate-type water is predominant. The predominant hydrochemical types are HCO_3^-–Ca^{2+}, HCO_3^-–Na^+ and mixed HCO_3^-–Ca^{2+}–Na^+–Mg^{2+} types.Principal component analysis showed that theboth natural and anthropogenic sources are responsible for the groundwater quality of Golaghat district of Assam.

So, pre-treatment of groundwater of Golaghat district is necessary for the use of it for drinking purpose. Public should be made understand the chronic arsenic and fluoride toxic effects due to long term consumption of such water by arranging awareness camp. Assessment of groundwater quality of these areas at a particular interval of time and implementation of remedial measures is very important however this is beyond the scope of present manuscript therefore would be taken up during future possible studies.

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References

Alarcon-Herreraa, M. T, Martin-Alarconb, D.A, Gutiérrezc, M, Reynoso-Cuevasg, L, Martín-Domínguezd, A, Olmos-Márqueze, M.A, & Bundschuhf, J. (2020). Co-occurrence, possible origin,and health-risk assessment of arsenic and fluoride in drinking water sources in Mexico: Geographical data visualization. Science of the Total Environment, 698-134168, https://doi.org/10.1016/j.scitotenv.2019.134168

APHA 1998, APHA, Awwa (American Public Health Association) (1998) Standardmethods for the examination of water and wastewater. AmericanPublic Health Association, Washington DC

Bureau of Indian Standards (BIS) (1991). 10500:1991, Second Revision ICS No. 13.060.20. http://www.bis. org.in/sf/fad/FAD25(2047)C.pdf.Accessed6Jan2010

Chapagain, S. K, Shrestha, S, Nakamura, T, Pandey, V. P, & Kazama, F. (2009). Arsenic occurrence in Groundwater of Kathmandu Valley, Nepal. Desalination and Water Treatment, 4, 248-254.

Chetia, M, Chatterjee, S, Banerjee, S, Nath, M.J, Singh, L, & Srivastava, R.B. (2011). Groundwater arsenic contamination in Brahmaputra river basin: A water quality assessment in Golaghat (Assam), India. Environ Monit Assess, 173, 371-85

Chetia, M, Singh, S. K, Bora, K, Kalita, H, Saikia, L. B, & Goawami, D. C. (2008). Groundwater arsenic contamination in three blocks of Golaghat district of Assam. Journal of Indian Water Works Association, *40*(2), 150–154.

Dufor, C. N, & Becker, E. (1964). Public Water Supplies of the 100 Largest Cities of the United States. U.S. Govt. Print. Off, 1964.

Dutta, R. K, Saikia, G, Das, B, Bezboruah, C, Das, H. B, & Dube, S. N. (2006). Fluoride contamination in ground water of Central Assam, India. Asian Journal of Water Environment and Pollution, 2(3), 93–100.

Garcia, M.G, Del Hidalgo, V.M, & Blesa, M.A. (2001). Geochemistry of groundwater in the alluvial plain of Tucuman province, Argentina. Hydrogeol J, 9, 597–610

Jimenez-Cordova, M.I, Sanchez-Pena, L.C, Barrera-Hernández, A, Gonzalez-Horta, C, Barbier, O.C., & Del Razo, L.M. (2019). Fluoride exposure is associated with altered metabolism of arsenic in an adult Mexican population. Sci. Total Environ, 684, 621–628.

Kaiser, H. F. (1960). The application of electronic computers to factor analysis. Educ Psychol Meas 20, 141–151.

Khound, N. J, & Bhattacharyya, K. G. (2018). Assessment of water quality in and around Jia Bharali river basin, North Brahmaputra Plain, India, using multivariate statistical technique, Applied Water Science, 8, 221

Kumar, K.S, Babu, S.H, Rao, P.E, Selvakumar, S, Thivya, C, Muralidharan, S, & Jeyabal, G. (2017). Evaluation of water quality and hydrogeochemistry of surface and groundwater, Tiruvallur district, Tamil Nadu, India. Appl Water Sci, 7, 2533–2544. https ://doi. org/10.1007/s1320 1-016-0447-7

Molla, M. A, Saha, N, Salam, S. A, & Rakib-uz-Zaman, M. (2015). Surface and groundwater quality assessment based on multivariate statistical techniques in the vicinity of Mohanpur, Bangladesh. Int J Env Health Eng., 4, 18.

Navarro, O, Gonzalez, J, Junez-Ferreira, H.E, Bautista, C.F, & Cardona, A. (2017). Correlation of arsenic and fluorideinthe groundwater for human consumption in a semiarid region of Mexico. Procedia Eng., 186, 333–340. https://doi.org/10.1016/j. proeng.2017.03.259.

Piper, A. M. (1944). A graphical procedure in the geochemical interpretation of water analysis. Trans Am Geophys Union, 25, 914–923

Saikia, M. M, & Sarma, H. P. (2011). Fluoride geochemistry of Kollong river basin, Assam, India.

Scholars Research Library-Archives of Applied Science Research, 3, 3, 367-372.

Singh, A. K. (2004). Arsenic contamination in groundwater of North eastern India. In Proceedings of 11th national symposium on hydrology with focal theme on water quality (pp. 255–262). Roorkee: National Institute of Hydrology.

Singh, A. K. (2006). Review article-Chemistry of arsenic in groundwater of Gangas–Brahmaputra river basin. Current Science, 91, 599–605.

Usman, U. N, Toriman, M. E, Juahir, H, Abdullahi, M. G, Rabiu, A.A, & Isiyaka, H. (2014). Assessment of Groundwater Quality Using Multivariate Statistical Techniques in Terengganu. Science and Technology, 4, 3, 42-49 DOI:10.5923/j.scit.20140403.02

Verma, K.K, Singh, M, & Verma, C.L. (2018). Fluoride in water: a risk assessment perspective. Asian J. Bot., 1, 1–8. https://doi.org/10.63019/ajb.v1i2.448.

Viswanathan V. C. (2015), Effect of river restoration and hydrological changes on surface water quality – River reach-scale to catchment-scale study. Ph D. Thesis-presented to the Faculty of Science of the University of Neuchâtel to satisfy the requirements of the degree of Doctor of Philosophy in Science

~~WHO (1993). Guidelines for drinking water quality. Geneva: World Health Organization~~ http://www.lenntech.com/WHO's-drinking-water-standards.htm.Accessed 28 Feb 2010.

World Health Organization (WHO), 2017. Guidelines for Drinking-water Quality: Fourth Edition Incorporating the First Addendum.

Table 1. Some water quality parameters of ground water samples of Golaghat district.

Name of the Block Development area (depth of water samples in ft)		pH	TDS (mg/L)	EC (mS/cm)	TH (mg/L)	F^- (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)
Dergaon (4oft-260ft)	Min-Max	6.5-7.8	58-59.5	0.03-0.06	66-240	0.07-0.45	1.27-5.98	0.01-4.75	0.23-0.26	1.72-11.6	54.88-350.42
	Mean	6.97	58.8	0.05	92.71	0.28	3.43	1.58	0.25	3.42	104.1
	Stnd dev	0.38	0.51	0.02	64.96	0.11	1.36	1.47	0.01	3.60	108.9
Kathalguri (40ft-300ft)	Min-Max	6.5-8.5	109-232	0.1-0.28	54-110	0.09-0.87	0.32-4.94	0.53-5.09	0.19-1.71	0.05-0.19	108.4-238.4
	Mean	7.366	165	0.20	81.77	0.47	2.71	1.52	1.71	0.08	179.29
	Stnd dev	0.70	46.88	0.13	23.3	0.21	2.02	1.41	0.8	0.04	38.4
Podumoni (60ft-300ft)	Min-Max	6.7-8.4	164-610	0.02-0.68	90-186	0.16-1.69	0.09-3.19	0.95-32.8	1.11-6.28	0.02-39.83	213.5-528.6
	Mean	7.44	364.52	0.19	151.22	0.76	0.86	14.29	2.52	2.04	338.98
	Stnd dev	0.41	109.69	0.46	29.32	0.40	0.78	7.01	1.52	8.44	114.22
Kakodonga (60ft-220ft)	Min-Max	6.3-8.2	171-262	0.18-0.37	90-170	0.10-0.54	0.11-9.56	0.06-16.44	0.03-1.46	0.11-2.01	220.34-247.28
	Mean	7.64	206.6	0.24	140.80	0.34	2.13	2.73	0.37	0.96	239.79

	Stnd dev	0.50	37.99	0.13	34.11	0.12	2.78	4.39	0.62	0.51	7.71
Morangi (20ft-180ft)	Min-Max	6-7.6	78.4-349	0.01-0.39	44-150	0.08-0.46	0.42-5.31	0.10-32.8	0.2-1.72	0.08-5.21	34.68-54.9
	Mean	6.68	183.33	0.07	90	0.23	2.09	12	0.74	1.83	46.12
	Stnd dev	0.58	145.16	0.26	54.36	0.10	2.79	18.07	0.84	2.92	10.37
Gamariguri (60ft-300ft)	Min-Max	6.3-8.4	222-502	0.04-0.54	50-123	0.25-2.92	0.342-4.407	1.669-16.85	0.402-2.831	0.04-1.50	252.2-457.5
	Mean	7.18	344.66	0.13	96	0.95	1.91	10.11	1.95	0.47	319.5
	Stnd dev	0.60	116.25	0.35	24.93	0.52	1.436	5.472	0.905	0.55	86.86
Sorupathar (40ft-260ft)	Min-Max	6-7.7	210-359	0.003-0.41	100-200	0.11-1.83	0.75-9.97	2.14-4.12	0.40-3.23	0.06-3.23	234.8-323.3
	Mean	7.15	295	0.15	143	0.78	5.75	3.06	1.97	0.76	279.5
	Stnd dev	0.53	5.01	0.29	28.67	0.57	3.13	0.73	0.91	1.03	28.77
Bokakhat (20ft-260ft)	Min-Max	6.1-7.7	47.7-217	0.001-0.31	35-170	0.09-0.85	0.47-43.26	0.16-23.58	0.18-3.68	0.25-42.27	21.25-330.4
	Mean	7.01	120.51	0.07	107.2	0.33	10.68	5.04	0.67	7.99	181.17
	Stnd dev	0.43	51.52	0.22	41.69	0.17	12.14	6.46	1.13	10.99	104.36
WHO/BIS standard Desirable limit		6.5-8.5	500	0.2	200	1.0	250	45	-	200	-
WHO/BIS standard Permissiblelimit			2000	1.5	600	1.5	1000	100	-	400	500

Table 2. Concentration of important cations in ground water samples of Golaghat district.

Name of the Block Development area		Na^+ (mg/L)	NH_4^+ (mg/L)	K^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	As (mg/L)	Fe (mg/L)
Dergaon	Min-Max	4.46-33.42	0.01-2.3	0.04-0.40	0.48-33.98	0.74-12.44	0.001-0.028	3.28-4.4
	Mean	10.96	0.36	0.56	5.65	2.77	0.010	4.15
	Stnd dev	9.97	0.85	1.08	12.49	4.27	0.012	0.4
Kathalguri	Min-Max	12.2-51.6	1.36-6	1.94-25.2	16.44-31.48	4.56-9.66	0.001-0.077	1.4-4.01
	Mean	25.24	3.09	5.9	23.03	6.86	0.017	2.9
	Stnd dev	15.77	1.71	7.41	5.82	1.71	0.029	0.80
Podumoni	Min-Max	11.15-191.64	1.48-4.2	1.98-26.2	18.9-48.5	8.92-17.2	0.001-0.450	0.125-4.8
	Mean	75.28	3.5	5.23	30.71	12.66	0.117	3.92
	Stnd dev	48.94	4.69	4.83	8.47	2.14	0.107	0.72
Kakodonga	Min-Max	16.88-61.38	1.76-2.11	1.35-8.07	19.46-25.69	6.77-12.54	0.001-0.186	1.5-2.3
	Mean	31.9	1.97	3.21	23.72	10.48	0.105	1.86
	Stnd dev	14.08	0.18	2.30	1.90	1.56	0.075	0.40
Morangi	Min-Max	12.84-68.94	1.78-7.41	1.69-3.02	19.14-74.36	5.82-12.96	0.001-0.444	1.1-1.67
	Mean	32.22	3.91	2.31	41.94	9.51	0.026	1.42
	Stnd dev	31.81	3.05	0.66	28.83	3.57	0.084	0.29
Gamariguri	Min-Max	3.14-	2.02-3.43	2.26-6.56	19.94-	6.08-	0.001-	0.1-3.2

		186.76			34.4	11.65	0.460	
	Mean	84.18	2.69	4.35	26.83	9.13	0.082	2.38
	Stnd dev	75.04	0.63	1.60	5.50	1.82	0.121	0.72
Sorupathar	Min-Max	31.18-90	1.48-4.08	2.5-4.14	22.6-35.8	7.3-15.18	0.001-0.175	2.8-4.5
	Mean	65.61	3.34	3.07	28.00	10.59	0.002	3.78
	Stnd dev	18.77	0.54	0.54	4.37	2.26	0.045	0.60
Bokakhat	Min-Max	7.6-21.6	0.64-4.8	1.76-5.92	13.24-59.14	2.66-15.24	0.001-0.024	0.8-3.8
	Mean	13.12	2.08	3.21	24.53	6.89	0.002	1.23
	Stnd dev	4.12	1.10	1.27	12.13	3.7	0.003	0.87
WHO/BIS Standards Desirable limit		200	0.5 mg/L	--	75	30	0.01 mg/L	0.3
WHO/BIS Standards Permissible limit		No relaxation	No relaxation	--	200	100	0.05 mg/L	1.0

Table 3(a) & 3(b): Some ground water quality parameters of the peripheral areas.

Table 3(a):

Name of the Districts and Block Development areas		pH	TDS (mg/L)	EC (mS/cm)	TH (mg/L)	F^- (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)
Jorhat Distric (Jorhat West block & Titabor block)	Min-Max	6.5-7.3	58.4-555	0.01-0.03	78-184	0.4-0.88	0.63-3.36	0.46-12.37	0.1-3.99	0.04-2.14	55.68-262.3
	Mean	6.9	296.08	0.02	130.27	0.58	1.72	3.74	1.3	1.04	239.27
Karbi-Anlong District (Rongmongwe block, Nilip block & Bokajan block)	Min-Max	6.5-7.9	109-232	0.03-0.10	54-110	0.09-0.87	0.32-4.94	0.53-5.09	0.19-1.71	0.05-0.19	108.4-238.4
	Mean	7.2	165	0.06	81.77	0.47	2.71	1.52	1.71	0.08	179.29
Nagaon District(Kaliabor block)	Min-Max	6.8-7.0	164-610	0.04-0.09	90-186	0.34-1.32	0.09-3.19	0.95-32.8	1.11-6.28	0.02-39.83	213.5-528.6
	Mean	6.9	364.5	0.06	151.22	0.70	0.86	14.29	2.52	2.04	338.98

Table 3(b)

Name of the Districts and Block Development areas		Na^+ (mg/L)	NH_4^+ (mg/L)	K^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	As (mg/L)	Fe (mg/L)
Jorhat Distric (Jorhat West block & Titabor block)	Min-Max	7.4-119.64	0.01-3.43	0.04-6.56	0.51-35.8	0.74-17.44	0.02-0.11	0.94-4.2
	Mean	56.73	1.83	2.83	21.76	10.625	0.058	1.85
Karbi-Anlong District (Rongmongwe block, Nilip block & Bokajan block)	Min-Max	8.26-45.67	1.84-7.41	1.6-4.58	16.2-25.07	3.3-9.77	0.001-0.01	0.86-1.5
	Mean	15.54	3.09	2.33	17.34	5.13	0.003	0.95
Nagaon District(Kaliabor	Min-Max	11.06-15.06	0.64-2.46	2.5-3.9	24.56-29.66	5.06-13.12	0.001-0.005	0.9-1.5

block)	Mean	12.4	1.26	3.06	26.44	7.79	0.002	1.1

Table 4: Concentration of fluoride in ground water samples

Block	Range (mg/L)	Mean (mg/L)	Below desirable limit (%)	Within WHO limit (%)	Above permissible limit (%)
Dergaon	0.07-0.45	0.28	100	0	0
Kathalguri	0.09-0.87	0.47	100	0	0
Podumoni	0.16-1.69	0.76	68	28	4
Kakodonga	0.10-0.54	0.34	100	0	0
Morangi	0.08-0.46	0.23	100	0	0
Gamariguri	0.25-2.92	0.95	60	30	10
Sorupathar	0.11-1.83	0.78	71.4	14.3	14.3
Bokakhat	0.09-0.85	0.33	100	0	0

Table 5: Concentration of arsenic in ground water samples

Block	Range (mg/L)	Mean (mg/L)	Below desirable limit (%)	Within WHO limit (%)	Above permissible limit (%)
Dergaon	0.001-0.028	0.0107	60	40	0
Kathalguri	0.001-0.077	0.0175	78.95	0	21.05
Podumoni	0.001-0.450	0.1177	16	16	68
Kakodonga	0.001-0.186	0.105	20	15	65
Morangi	0.001-0.444	0.0268	77.8	18.5	3.7
Gamariguri	0.001-0.460	0.0823	30	23.33	46.7
Sorupathar	0.001-0.175	0.00195	64.29	28.57	7.14
Bokakhat	0.001-0.024	0.00236	72	28	0

Table 6: Pearson correlation between chemical parameters of groundwater samples

	TH	pH	HCO_3^-	TDS	EC	F^-	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	As	Na^+	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Fe
TH	1.00																
pH	.098	1.00															
HCO_3^-	.308	-.057	1.00														
TDS	.316	-.034	.793	1.00													
EC	.370	.070	.477	.754	1.00												
F^-	.100	.157	-.077	.133	.248	1.00											
Cl^-	.031	.181	-.152	-.257	-.101	-.344	1.00										
NO_3^-	.196	-.262	.236	.513	.432	-.055	-.065	1.00									
PO_4^{3-}	-.133	-.145	.394	.608	.479	.185	-.372	.204	1.00								

SO_4^{2-}	.048	-.175	-.336	-.521	-.249	-.315	.091	-.376	-.244	1.00							
As	-0.06	-.148	.151	.406	.391	.232	-.232	.615	.262	-.324	1.00						
Na^+	.154	-.06	.632	.841	.892	.172	-.190	.354	.724	-.360	.337	1.00					
NH_4^+	.034	-.093	.516	.618	.353	.079	-.103	.097	.547	-.351	.059	.547	1.00				
K^+	-.192	.027	.182	-.013	-.330	.270	-.158	-.231	-.142	-.282	-.167	-.235	.310	1.00			
Ca^{2+}	.540	-.036	.475	.440	-.035	-.188	-.182	.317	-.086	-.227	.034	-.012	.148	.120	1.00		
Mg^{2+}	.512	-.204	.550	.728	.652	.298	-.146	.438	.277	-.260	.449	.590	.279	.059	.385	1.00	
Fe	.104	.469	.421	.607	.478	.546	-.183	.139	.408	-.604	.288	.506	.342	.258	.138	.419	1.00

Table 7: Rotated component matrix for data of groundwater samples

Variables	Components					
	1	2	3	4	5	6
Na^+	.894	.077	.229	-.274	.095	.126
TDS	.814	.389	.373	.064	.090	.074
PO_4^{3-}	.807	-.235	.114	-.082	-.122	.232
NH_4^+	.786	.008	-.061	.350	-.020	-.040
HCO_3	.714	.462	.076	.241	-.004	-.103
EC	.680	.237	.283	-.481	.231	.183
TH	.034	.894	-.074	-.266	.123	.066
Ca^{2+}	.039	.788	.190	.396	-.101	-.161
Mg^{2+}	.437	.599	.355	-.088	-.012	.306
NO_3^-	.172	.233	.849	-.103	-.133	-.113
As	.135	-.044	.836	-.119	-.043	.259
SO_4^{2-}	-.314	-.008	-.540	-.485	-.424	-.050
K^+	-.009	.003	-.174	.850	.075	.239
pH	-.086	.006	-.179	-.009	.876	-.037
Fe	.464	.099	.222	.220	.649	.372
F^-	.038	-.025	.078	.054	.352	.856
Cl^-	-.178	-.050	-.068	-.193	.363	-.689
% of variance	35.023	12.568	11.156	9.270	8.717	6.898
Cumulative %	35.023	47.591	58.747	68.017	76.734	83.632