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ORIGINAL ARTICLE

Geoenvironmental appraisal of groundwater quality in Bengal alluvial tract, India: a geochemical and statistical approach

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Abstract Groundwater is an essential natural resource which has enormous use throughout the world, but with the enhanced population pressure, its quality and quantity gets affected. Consequently, assessment and categorization of groundwater quality is necessary and the availability of safe water for utilization is to be ensured. The present study was based on groundwater samples, collected over 5,324 km^2 from the alluvial tract of Bengal plain, India. Ten geochemical parameters viz. *arsenic, pH, total dissolved solids, electrical conductivity, iron, total hardness as calcium carbonate, sulphate, nitrite* and *depth* were analysed, and multivariate statistical analyses were performed on the data set. Factor analysis depicted four factors, which explained 66.57 % of total variability of data. Factor 1 represented high positive loadings on *total dissolved solids* and *electrical conductivity*. Factor 2 was associated with *depth, arsenic* and *iron* and indicated process of reduction in groundwater. Over extraction of groundwater showed probable relationship with arsenic concentration in groundwater. Parameters of Factor 3 and 4 had been related with agricultural activities and local geological conditions. Further, four clusters observed from hierarchical cluster analysis, assisted in grouping groundwater geochemistry of the region. The results coupled with GIS facilitated in categorizing and mapping the groundwater quality.

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Introduction

The rapid increase of population is a cause of concern because it enhances the pressure on all natural resources. Groundwater is one of such indispensable natural resource which has vast uses. Globally, it is being exploited for agriculture, industries, irrigation and drinking purpose. It is widely known that the human interferences such as industrial and domestic waste disposal and excessive use of fertilizers contribute in contaminating the water. Rahim et al. (2010) discussed the impact of anthropogenic effects such as solid waste disposal and its effects on the shallow groundwater in west Malaysia. Elevated concentration of different elements as well as considerable ionic balance error was found in the groundwater. Hosono et al. (2009) studied the human impacts on groundwater flow as well as the contamination in South Korea. Multiple isotopes were used in the study to demonstrate the human-induced degradation of groundwater. Khalil et al. (2008) studied the heavy metal contamination and metal content in soil runoff and groundwater in the mining sites of South Morocco, while Takamatsu et al. (2010) worked on the similar aspect of heavy metal contamination in Kanto, Japan. Simeonov et al. (2003) and Kanchan and Ghosh (2012) discussed the impact of excessive withdrawal of groundwater and associated problems of lowering of water table, poorer quality of water and restricted availability of uncontaminated water. On the other hand, natural factors of leaching of minerals and chemical reactions of surface and subsurface rocks with water were studied by Oinam et al. (2011) in Bishnupur district of Manipur, India.

Harvey et al. (2005) studied the health effects of groundwater arsenic contamination in the Ganges delta, while Mukherjee and Bhattacharya (2001) reported the high health risk of millions of people in Bangladesh due to groundwater arsenic contamination. According to the study by Kanchan and Ghosh (2011), presence of different elements, ions and minerals are valuable for human health, but at the same time if the presence of ion and minerals exceeds the permissible limit and is consumed for longer period of time then it may create serious health issues. The vital parameters of the groundwater are interdependent; hence, with the increase in the number of variables, their complexity also increases. Use of appropriate statistical techniques is one of the ways of reaching to probable generalization. Multivariate statistical analyses such as factor analysis (FA) and cluster analysis (CA) are some of the statistical tools, which are adopted to deal with large amount of data and number of parameters. According to the study of Simeonov et al. (2003), the multivariate statistical analyses helped in interpreting the underlying variable structure by deriving much simpler groups. Liu et al. (2003) performed a study in blackfoot diseased area of Taiwan and applied multivariate statistical analyses for the assessment of groundwater quality. Stüben et al. (2003) discussed about the geochemical characteristics of groundwater of Murshidabad district of West Bengal incorporating factor analysis. Oinam et al. (2011) studied spatio-temporal pattern of groundwater quality using cluster analysis in Bishnupur district of Manipur state, India, taking arsenic, iron and other parameters into considerations. Yammani et al. (2008) discussed the seasonal variability of different parameters and factors that controlled the groundwater quality in the hard terrain of Andhra Pradesh, India, using factor analysis. Giridharan et al. (2008) also worked on the similar line, and studied the seasonal pattern of geochemical parameters of groundwater quality in Chennai, India. Spatio-temporal pattern of Dianchi Lake basin water pollution was studied by Yang et al. (2010) using multivariate statistical analyses. Güler et al. (2002) examined the advantages and disadvantages of different types of clustering techniques along with the principal component analysis in parts of Southwestern USA. Yidana and Yidana (2010) have also applied factor analysis technique for the formulation of water quality indexing in Voltaian sedimentary aquifers of Ghana, while Singh et al. (2011) and Lake et al. (2003) attempted spatial distribution of groundwater quality using the statistical technique associated with the mapping technique for interpretation of groundwater quality. Techniques of quality index using statistical method, as well as conventional graphical scheme for the analysis of groundwater quality in the Volta region of Ghana was discussed by Yakubo et al. (2009).

Groundwater is one of the major sources of consumption for drinking as well as other purposes, in countries like India. Therefore, a detailed study is necessary to demarcate the zones of groundwater according to the level of contamination. The present study was carried in the central alluvial tract of Bengal plain, India, based on the analysis of ten geochemical groundwater parameters viz. *arsenic* (As), *pH*, *total dissolved solids* (TDS), *electrical conductivity* (EC), *iron* (Fe), *chloride* (Cl^-), *sulphate* (SO_4^{-2}), *total hardness as calcium carbonate* (will be used in the rest of the text as *total hardness* only), *nitrite* (NO_2^-) and *depth*. In association with the understanding of geochemical characteristics, geology and hydrological setup, synthesis of multivariate statistical analyses such as factor and cluster analysis provided better opportunity to analyse these multifaceted relationship.

Materials and method

Study area

The study area extends between 23°43′30″ N to 24°50′20″ N latitude and 87°46′17″ E to 88°46′00″ E longitude with areal coverage of about 5,324 km^2 in the central Bengal alluvial tract covering the entire Murshidabad district of West Bengal, India (District Census Hand Book 2001). Northeast and east of the study area shares the international boundary with Bangladesh, whereas, northern, western and southern boundaries are shared with Malda, Birbhum, Bardhaman and Nadia districts of West Bengal, respectively (Fig. 1). Northwestern region of the study area is demarcated by the state boundary between West Bengal and Jharkhand. Geomorphologically, the terrain is almost flat having elevation varying between 10 and 50 m above the mean sea level. (District Resource Map 2008)

Hydrogeological setup

The study area falls in central alluvial tract of Bengal plain, India, and it comprises of unconsolidated sediments of Late Pleistocene to Late Holocene times. Stratigraphically, the area is mainly comprised of quaternary sediments belonging to Rampurhat, Kandi and Bhagirathi formations, whereas older basaltic rock occurs in the northwestern region covering a small patch of Rajmahal trap (District Resource Map 2008). The western part of the study area is dominated by the sandy and silty clay of Rampurhat formations and Kandi formations, which show the alternate layering of sand, silt and clayey sediments, extensively spread over the study region (Fig. 2). The Bhagirathi formation denoting the present day flood plain deposits and marked by the fine-grained sediments mainly silt and clay.

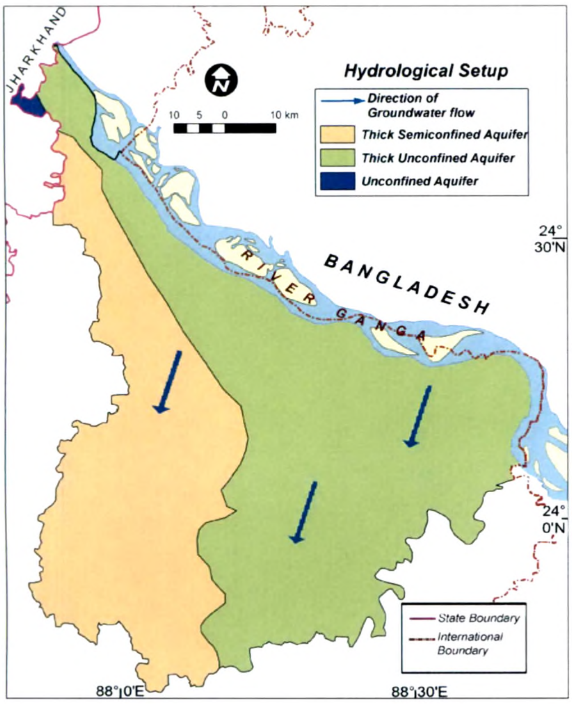

Fig. 3 Hydrological setup of the study area (Source: Groundwater Information Booklet 2007)

depended upon these parameters (Mathes and Rasmussen 2006). The parameters such as *arsenic* and *nitrite* are very hazardous, as a minute concentration above the permissible limit can create serious health issues (Oinam et al. 2011; Mishima et al. 2010).

Concentration of *pH*, *total dissolved solids* and *electrical conductivity* was examined on field using digital pH metre (Hanna, Model No. HI-9827), TDS tester (Hanna, Dist 1, Model No. HI 98300) and digital EC metre (Hanna, Dist 4, Model No. HI 98303). Before collection of samples, hand pumps were mechanically pumped continuously for 10 min to flush out the water in the upper part of the pipe of the hand pumps. Samples were collected in 500-ml PET (Polyethylene terephthalate) bottles, and pH level of water was maintained below 2 using HCl. The samples were stored at low temperature (4° C) until further chemical analyses were undertaken.

Concentration of *arsenic, iron* and *nitrite* was analysed through spectrophotometric techniques using Molybdenum Blue Complex method (Jeffery et al. 1989), 1/10 Phenanthroline method (APHA 1989) and Cadmium Reduction technique (APHA 1989), respectively, by Elico Double Beam UV–Vis Spectrophotometer (Model sl-210). *Total Hardness* was determined through EDTA Titration (APHA 1989), *chloride* by Argentometric method using silver nitrate (APHA 1989), and *sulphate* by Iodometric titration method (APHA 1989), respectively. The results from the analyses were tabulated in Table 1.

Data treatment

All data were subjected to statistical analysis using statistical package SPSS 19. Shapiro–Wilk (W) test showed that data set had a positive skewness, which indicated non-normal distribution of data. To ensure normality, standardization had been done by 'z-score' (Liu et al. 2003). Standardized data set was further used for factor analysis (FA). Ward's linkage method was applied for hierarchal cluster analysis (HCA) using squared euclidian distance.

Spatial interpolation and mapping

Arc GIS 10® software was used for mapping of groundwater parameters and different factors. All 78 GPS locations were plotted on the base map of the study area. Factor scores collected from the statistical analysis were tabulated with respect to their locations in the attribute table. Inverse Distance Weighting (IDW) method was applied for generation of isolines. Class interval of 1, both positive and negative, was used to identify the high as well as low potential contamination zones. Graded shades were applied to indicate the values of the factors wherein, lighter shades were used to indicate lower concentration and darker shades for higher concentration of parameters. These maps were superimposed and final composite picture was drawn. For each of the factors, individual maps were generated. Cluster numbers of each variable analysed from cluster analysis were tabulated according to their respective locations and applied for mapping of different clusters. For comparison with the factor distribution in GIS environment, individual parameters were also taken into considerations and interpolated maps were prepared using IDW technique.

Results and discussions

General geochemical properties and spatial distribution

The *arsenic* concentration in the groundwater in the study area varied between Below Detection Limit (BDL) and 0.98 mg/L (Table 1) with mean value 0.10 mg/L indicating a critical condition according to the permissible limit (0.05 mg/L), set by Bureau of Indian Standard (BIS). Although standard deviation was as low as 0.19, but the skewness and kurtosis both are highly positive (Table 2). The concentration of arsenic in the eastern segment of river Bhagirathi showed higher values exceeding the permissible limit of BIS. In the western segment of the region,

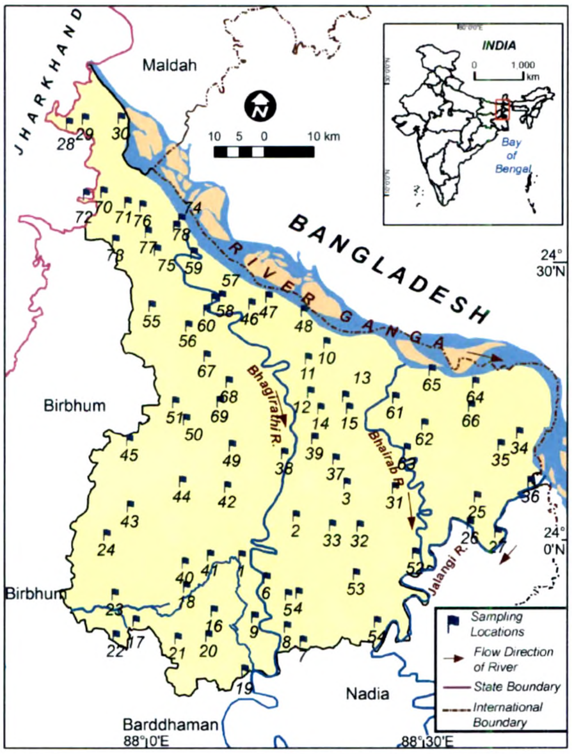

Fig. 1 Location map of the study area

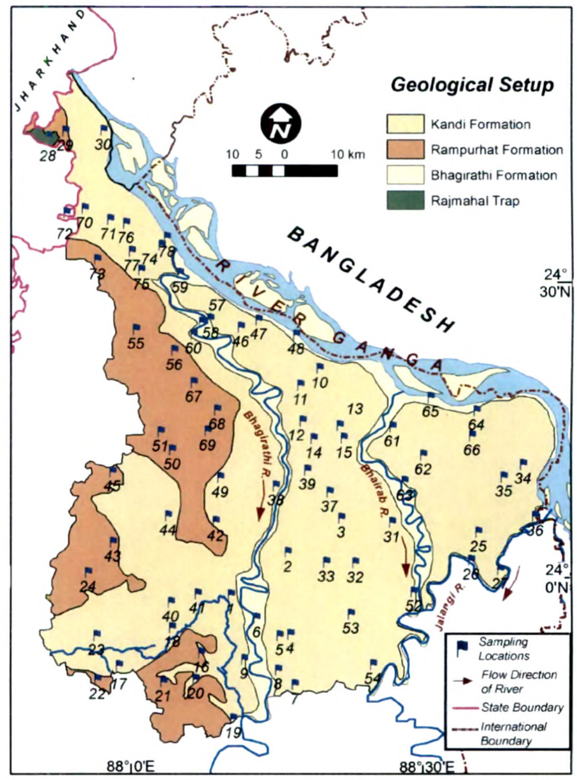

Fig. 2 Geological setup of the study area (Source: District Resource Map 2008)

Hydrological framework of the region is mainly controlled by river Ganga and its two distributaries, river Bhagirathi and river Bhairab. The river Ganga flows in northwest to southeast direction along the northwestern periphery of the Murshidabad district through Bhagirathi formation, while river Bhagirathi, which is draining in north–south direction, roughly midway of the region. River Bhairab also follows north–south direction in a highly meandered path on the east of river Bhagirathi. The river Ganga shows development of large bars and meandering in upper reach, whereas the lower reach is characterized by large meandering pattern with narrowed channel close to eastern part. As a part of Bengal plain, the study area comprises of three major aquifer systems. East of river Bhagirathi is associated with the thick unconfined aquifer, while the western tract is related to thick semi-confined aquifer (Fig. 3). Lithologically, eastern segment of river Bhagirathi is associated with recent alluvium, whereas older alluvium of Upper Tertiary period is found in the western segment of the region (Groundwater Information Booklet 2007). Only a small patch of unconfined aquifer consisting of basaltic rock of Upper Cretaceous period is situated in the northwestern part of the study area. Saturated groundwater zone is found as far down as 150 m in the eastern part of the region due to lack of any significant impermeable layer. Water table is generally found within 2–5 m below the surface. Groundwater potential is greater than 42 yield (L/s) in the eastern and southern part. (District Planning Map Series 2002; Deshmukh and Goswami 1973).

Sample collection and geochemical analysis

78 groundwater samples were collected from the Bengal alluvial tract during the pre-monsoon period of May 2011. Sampling locations were marked using GPS of Garmin e-Trex Vista make. Later, the data from GPS were downloaded to computer, using "Mapsource" software. Depths of the hand pumps were known with the help of local authorities as well as Public Health Engineering Departments (PHED). Parameters of the water quality were chosen on the basis of their significance for attaining groundwater condition. *pH* value is a measure of acidity or alkalinity of water, and changes in level convey the geochemical reactions, which may change the characteristics of groundwater (Yammani et al. 2008). *TDS, EC, iron, total hardness, chloride* and *sulphate* are the natural constituents of water and needed to be monitored, as the primary portability in terms of drinking and for other purposes

Table 1 Values of geochemical parameters

Block name	Location code	Latitude	Longitude	Depth (m)	Arsenic (As) (mg/L)	pH	TDS (mg/L)	Electrical conductivity EC (S/cm^{-1} × 10^{-3})	Iron (Fe) (mg/L)	Chloride (Cl^-) (mg/L)	Sulphate (SO_4^{-2}) (mg/L)	Total hardness as $CaCO_3$ (mg/L)	Nitrite (NO_2^-) (mg/L)
Baharampur	1	23.97250	88.16940	30	0.05	7.2	894.3	1.41	8.1	30.5	1000.2	702.3	16.96
Baharampur	2	24.04490	88.26700	60	B.D.L	7.4	451.3	0.71	7.4	30.3	451.2	452.4	15.17
Baharampur	3	24.10330	88.35820	45	0.03	8.2	556.4	0.86	7.5	25.8	906.5	503.2	12.50
Beldanga-1	4	23.90530	88.27190	20	0.02	7.1	502.2	0.78	14.3	55.4	72.3	53.4	22.32
Beldanga-1	5	23.90260	88.25310	40	0.04	8.1	610.1	0.93	25.0	60.7	181.2	45.4	17.85
Beldanga-1	6	23.93280	88.21410	24	0.06	8.0	552.5	0.86	18.3	45.2	201.4	52.3	17.85
Beldanga-2	7	23.81930	88.27970	75	0.06	8.0	607.2	0.93	7.2	65.5	505.4	63.4	31.25
Beldanga-2	8	23.84450	88.25100	60	0.05	7.5	509.1	0.78	4.1	40.7	300.2	63.4	31.35
Beldanga-2	9	23.86260	88.19270	35	0.06	8.1	511.4	0.78	2.1	50.2	320.2	68.5	19.64
Bhagwangola-1	10	24.35630	88.32170	60	0.06	7.2	753.4	1.17	6.2	21.5	706.5	325.4	56.25
Bhagwangola-1	11	24.32810	88.28870	60	0.03	7.1	652.4	1.02	4.0	40.1	600.3	470.5	55.35
Bhagwangola-1	12	24.26780	88.29250	90	B.D.L	7.0	855.2	1.33	5.3	90.8	610.5	475.3	60.17
Bhagwangola-2	13	24.26000	88.35580	75	0.04	7.4	504.2	0.78	5.4	120.5	702.4	504.5	56.25
Bhagwangola-2	14	24.23810	88.31110	18	0.01	7.3	512.4	0.78	9.0	120.6	710.3	403.4	55.35
Bhagwangola-2	15	24.23870	88.36260	45	0.05	7.5	601.2	0.93	4.2	120.4	705.3	433.4	69.64
Bharatpur-1	16	23.87330	88.11900	30	0.04	8.2	510.2	0.78	5.6	125.0	155.3	702.4	22.32
Bharatpur-1	17	23.84470	87.97790	55	B.D.L	7.3	405.4	0.63	3.2	110.4	103.2	762.3	52.67
Bharatpur-1	18	23.91690	88.06910	20	0.02	7.4	430.2	0.63	3.6	30.3	123.2	601.2	18.75
Bharatpur-2	19	23.76140	88.17410	30	B.D.L	7.5	402.3	0.62	4.0	25.5	20.0	642.5	6.25
Bharatpur-2	20	23.82860	88.10960	30	0.04	7.2	310.2	0.46	2.2	10.0	42.1	782.3	8.92
Bharatpur-2	21	23.82430	88.05380	15	0.02	7.4	348.4	0.55	3.2	20.5	32.1	722.3	18.75
Burwan	22	23.82830	87.94130	25	0.02	7.1	452.1	0.73	3.9	15.7	62.3	472.3	25.00
Burwan	23	23.90300	87.93940	30	B.D.L	7.5	520.1	0.78	2.5	15.3	41.2	401.2	25.00
Burwan	24	24.01060	87.92490	15	0.02	8.5	402.2	0.62	1.9	10.5	41.6	432.3	14.28
Domkal	25	24.07910	88.59360	10	0.73	7.0	552.1	0.86	4.3	16.3	402.3	46.3	17.85
Domkal	26	24.03160	88.58080	20	0.12	7.5	602.2	0.93	38.0	110.6	254.3	40.3	13.39
Domkal	27	24.01560	88.63050	18	0.98	8.5	403.2	0.81	36.5	40.7	810.3	52.4	14.28
Farakka	28	24.74110	87.85590	55	0.09	8.5	510.2	0.78	3.1	20.4	44.3	321.2	34.82
Farakka	29	24.75870	87.88490	20	0.08	8.0	452.3	0.71	5.5	15.7	81.5	42.3	18.75
Farakka	30	24.76010	87.95010	15	0.09	8.1	420.1	0.63	5.2	20.3	72.6	812.3	16.96
Hariharpara	31	24.09570	88.44560	60	0.16	7.1	451.2	0.72	3.6	46.5	602.5	203.4	19.64
Hariharpara	32	24.02670	88.38240	25	0.07	7.5	301.2	0.46	3.1	50.1	506.3	162.3	13.39
Hariharpara	33	24.02780	88.33250	60	0.09	8.2	452.1	0.75	5.2	42.7	751.4	204.3	16.96
Jalangi	34	24.19410	88.66980	35	0.06	7.5	450.6	0.71	2.8	25.4	203.6	212.3	27.67

Table 1 continued

Block name	Location code	Latitude	Longitude	Depth (m)	Arsenic (As) (mg/L)	pH	TDS (mg/L)	Electrical conductivity EC (S/cm^{-1} × 10^{-3})	Iron (Fe) (mg/L)	Chloride (Cl^-) (mg/L)	Sulphate (SO_4^{-2}) (mg/L)	Total hardness as $CaCO_3$ (mg/L)	Nitrite (NO_2^-) (mg/L)
Jalangi	35	24.17250	88.63680	30	0.81	7.6	601.2	0.93	4.3	12.6	207.4	322.3	27.67
Jalangi	36	24.10620	88.69060	12	0.41	7.8	600.4	0.93	3.2	30.7	252.5	403.5	26.78
Jiaganj	37	24.14720	88.33820	60	0.01	8.1	802.3	1.25	1.3	120.4	702.5	321.1	71.42
Jiaganj	38	24.15760	88.24610	75	0.02	7.2	900.0	1.41	1.1	100.2	603.4	183.4	35.71
Jiaganj	39	24.18460	88.30030	30	0.03	7.5	403.2	0.62	1.7	100.5	551.4	352.3	59.82
Kandi	40	23.95990	88.06670	45	0.03	7.0	452.5	0.76	4.2	27.6	172.5	850.0	25.89
Kandi	41	23.97400	88.11280	30	0.04	7.8	502.5	0.78	30.2	35.3	142.5	706.3	26.78
Kandi	42	24.09730	88.14330	12	0.04	7.5	601.2	0.93	18.3	28.4	82.4	742.3	33.03
Khargram	43	24.06200	87.96730	90	0.01	6.4	255.4	0.39	1.4	30.6	35.6	601.3	26.78
Khargram	44	24.10680	88.06160	35	0.03	6.0	253.4	0.39	2.1	31.3	71.5	545.7	25.00
Khargram	45	24.18150	87.96620	15	0.02	7.3	302.3	0.46	3.6	30.2	45.8	512.3	25.89
Lalgola	46	24.42640	88.18650	30	0.05	7.1	410.2	0.62	2.1	110.6	552.0	55.7	19.64
Lalgola	47	24.43910	88.21730	45	0.05	7.5	900.0	1.41	2.6	95.7	1000.0	62.3	25.89
Lalgola	48	24.41370	88.28130	60	0.07	8.5	402.3	0.61	1.4	30.4	603.6	46.3	25.89
Nabagram	49	24.17150	88.15150	30	0.02	8.4	255.4	0.39	5.5	20.5	1,100.0	61.2	36.60
Nabagram	50	24.21870	88.06880	35	0.04	8.0	302.3	0.46	3.1	24.7	702.3	163.4	19.64
Nabagram	51	24.24950	88.04900	55	0.01	7.1	255.4	0.39	2.1	18.3	1,005.4	182.3	10.71
Nawada	52	23.97740	88.48240	30	0.04	6.5	262.3	0.93	2.05	74.5	60.3	632.3	15.17
Nawada	53	23.93980	88.37520	25	0.03	8.1	400.3	0.68	5.42	90.4	142.3	401.4	9.82
Nawada	54	23.85390	88.41310	18	0.04	6.1	502.4	0.78	4.2	120.6	310.4	669.7	17.85
Raghunathganj-1	55	24.42260	88.00630	30	0.04	7.5	550.0	0.86	4.2	60.3	52.3	122.3	26.78
Raghunathganj-1	56	24.38680	88.07220	45	0.04	6.2	600.7	0.93	9.4	21.4	202.3	104.3	25.89
Raghunathganj-1	57	24.43520	88.11950	35	0.02	6.5	354.2	0.53	4.2	50.7	112.4	52.4	18.75
Raghunathganj-2	58	24.44090	88.13380	45	0.05	7.1	602.3	0.93	7.3	65.3	1,100.0	708.6	18.75
Raghunathganj-2	59	24.51850	88.08200	35	0.08	7.6	615.3	0.93	2.5	52.5	752.3	82.3	25.00
Raghunathganj-2	60	24.41470	88.10520	90	0.05	7.6	505.3	0.93	7.3	65.3	1,100	703.5	18.75
Raninagar-1	61	24.25780	88.44630	25	0.05	7.5	500.2	0.78	2.7	50.5	204.3	62.6	33.03
Raninagar-1	62	24.21000	88.49880	09	0.04	7.1	452.3	0.75	3.8	55.4	143.4	35.2	50.00
Raninagar-1	63	24.16590	88.46690	18	B.D.L	8.2	459.2	0.74	4.4	100.3	122.3	30.0	19.64
Raninagar-2	64	24.28520	88.59030	25	0.80	7.9	502.3	0.78	6.5	26.6	62.3	122.3	34.82
Raninagar-2	65	24.30760	88.51180	18	0.09	7.2	610.2	0.93	0.4	65.3	403.5	102.4	39.28
Raninagar-2	66	24.24270	88.58260	21	0.05	7.8	601.2	0.93	5.0	15.6	32.3	352.3	18.75
Sagardighi	67	24.33240	88.10560	12	0.06	7.6	555.3	0.86	1.9	95.5	104.5	217.5	50.89
Sagardighi	68	24.28630	88.14580	18	0.04	8.0	652.3	1.02	5.3	100.4	82.3	410.4	28.57

Table 1 continued

Block name	Location code	Latitude	Longitude	Depth (m)	Arsenic (As) (mg/L)	pH	TDS (mg/L)	Electrical conductivity EC (S/cm^{-1} × 10^{-3})	Iron (Fe) (mg/L)	Chloride (Cl^-) (mg/L)	Sulphate (SO_4^{2-}) (mg/L)	Total hardness as $CaCO_3$ (mg/L)	Nitrite (NO_2^-) (mg/L)
Sagardighi	69	24.25090	88.12940	12	B.D.L	6.1	610.2	0.93	5.0	65.2	66.3	520.0	26.78
Samsheganj	70	24.62750	87.91830	45	0.04	7.1	801.2	1.25	3.2	30.8	252.3	730.5	20.53
Samsheganj	71	24.60910	87.96200	25	0.07	7.5	700.2	1.09	3.3	20.2	304.3	620.0	26.78
Samsheganj	72	24.60921	87.88336	60	0.04	8.0	700.2	1.09	4.3	36.4	603.2	645.0	27.67
Suti-I	73	24.54110	87.93980	90	B.D.L	7.5	610.1	0.93	2.1	95.6	105.4	540.0	21.67
Suti-I	74	24.56600	88.05050	30	0.04	7.4	508.6	0.78	1.3	86.4	73.6	750.3	21.67
Suti-I	75	24.52360	88.01580	22	0.03	7.9	600.2	0.93	5.3	100.3	752.3	600.3	25.89
Suti-2	76	24.60280	87.98920	12	0.07	7.1	452.2	0.73	3.2	80.4	66.5	502.3	19.64
Suti-2	77	24.55550	87.99910	22	0.06	8.0	304.2	0.60	4.1	100.2	202.3	400.0	25.00
Suti-2	78	24.57890	88.05960	22	0.02	7.2	503.4	0.78	4.3	85.5	120.5	430.0	26.78

B.D.L. below detection level

concentration of *arsenic* was considerably low and in most of the places, it was even below permissible limit. Patches of higher concentration were also observed in the north-western tip of the region (Fig. 4a).

The *pH* value of the groundwater varied between the minimum and maximum value of 6 and 8.5 with a mean value of 7.49 and low standard deviation of 0.57 indicating slightly alkaline condition. The skewness of *pH* was moderately negative (−0.47), and kurtosis was positive with a value (+0.33). The *pH* value of the groundwater in the north-central region was found between 7 and 7.5 except for one continuous patch from south central to east where *pH* value was between 7.5 and 8 (Fig. 4b).

The *total dissolved solids* were in the range from 253.40 to 900 mg/L with a mean of 514.95 mg/L, and standard deviation of 152.01 indicated a considerable variability in concentration of throughout the region. Both skewness (+0.53) and kurtosis (+0.41) were slightly positive. The higher concentration of *total dissolved solids* was observed along the river Bhagirathi (Fig. 4c). With the increasing distance from the river, the concentration of *total dissolved solids* decreased considerably and reached to its minimum level in the western end.

The *electrical conductivity* showed a similar pattern of total dissolved solids ranging from 0.39×10^{-3} to 1.41×10^{-3} S/cm^{-1} having a mean value of 0.81×10^{-3} S/cm^{-1} with standard deviation of 0.23 (Fig. 4d).

Figure 4e revealed the concentration of *iron* and varied between 0.40 and 38.0 mg/L with a standard deviation of 7.04 and mean value of 5.98 mg/L. Both values of skewness and kurtosis were high and positive, i.e. +3.25 and +10.92, indicating a wide variation in the concentration in the study area. The major concentration of *iron* was observed in the eastern and southern segment of the studied region. Concentration of *iron* was found below 5 mg/L in rest of the region.

The concentration of *chloride* has been shown in Fig. 4f. The variation was from 10 to 125 mg/L with standard deviation of 35.12 and mean value 55.51 mg/L indicating substantial variation of concentration throughout the region. Skewness showed a moderate value of +0.85, while the kurtosis indicated −0.49. The concentration of *chloride* was observed in a continuous patch from north-west to south-central portion of the study area. In the western segment of the region, the concentration of the *chloride* was relatively less. Similarly, the *sulphate* concentration widely varied between 20 and 1,100 mg/L with a mean value of 354.18 mg/L and standard deviation 321.17. The skewness was observed positive (+0.85) and kurtosis was having a value of −0.49. *Sulphate* concentration was extended spatially from the central portion to the western region of the area (Fig. 4g).

Total Hardness was determined by EDTA titration and the its value was observed in the range from 30 to 850 mg/L

Table 2 Summery statistics of the 78 groundwater samples

Parameters	Mean	Min	Max	SD	Skewness	Kurtosis
Depth (m)	36.32	9.00	90.00	21.09	1.00	0.29
Arsenic (mg/L)	0.10	0.01	0.98	0.19	3.63	12.43
pH	7.49	6.00	8.50	0.57	−0.47	0.33
TDS (mg/L)	514.95	253.40	900.00	152.01	0.53	0.41
Electrical conductivity (S/cm^{-1} × 10^{-3})	0.81	0.39	1.41	0.23	0.53	0.67
Iron (mg/L)	5.98	0.40	38.00	7.04	3.25	10.92
Chloride (mg/L)	55.51	10.00	125.00	35.12	0.57	−1.06
Sulphate (mg/L)	354.98	20.00	1,100.00	321.17	0.85	−0.49
Total hardness of $CaCO_3$ (mg/L)	370.41	30.00	850.00	255.61	0.12	−1.35
Nitrite (mg/L)	27.45	6.25	71.42	14.28	1.40	1.48

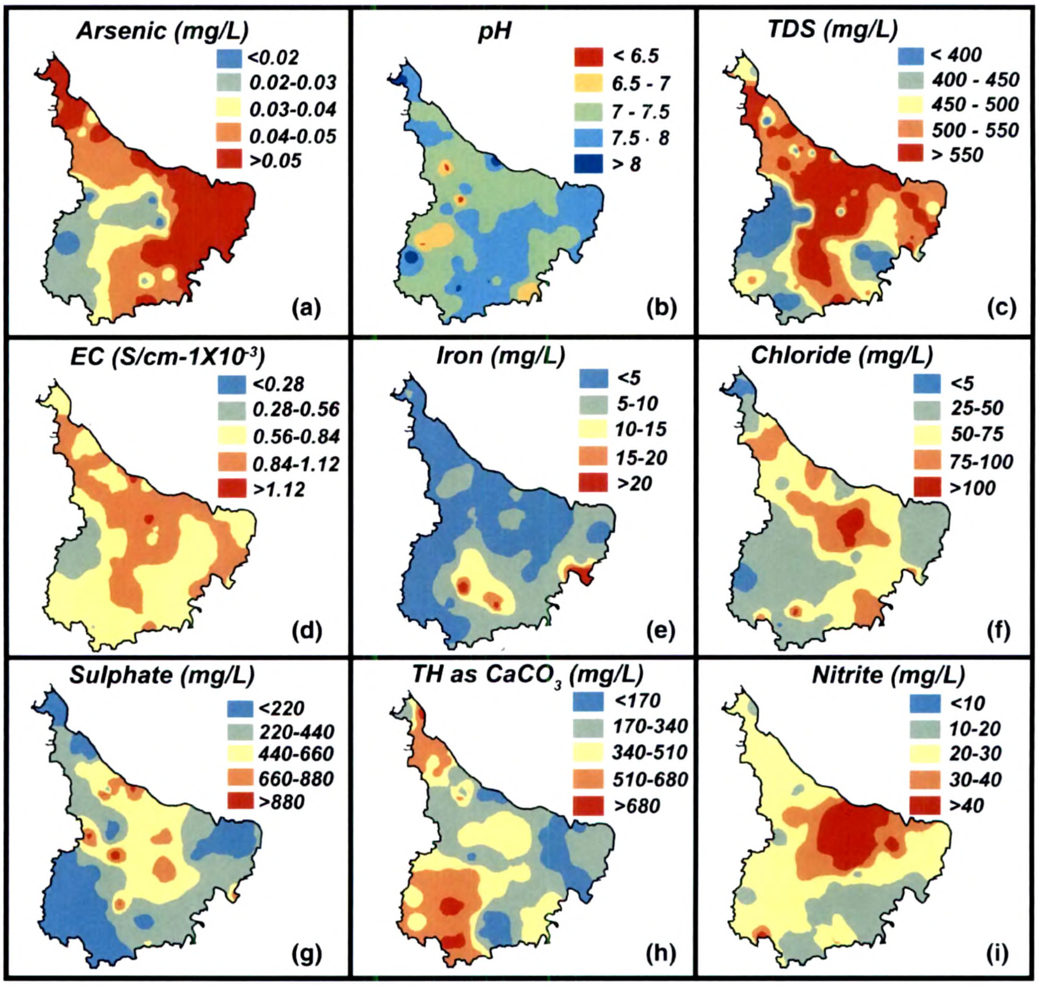

Fig. 4 Spatial distribution of parameters **a** arsenic, **b** pH, **c** TDS, **d** EC, **e** iron, **f** chloride, **g** sulphate, **h** TH as $CaCO_3$, **i** nitrite

and mean value of 370.41 mg/L. Very high standard deviation of 255.61 and skewness of +0.12 and kurtosis −1.35 were observed. The hardness was widely spread in the western end and in the northwestern tip of the region with considerably higher value, while the rest of the area revealed the low concentration values of *total hardness* (Fig. 4h).

Table 3 Factor analysis

Components	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	2.622	26.222	26.222	2.622	26.222	26.222	2.203	22.030	22.030
2	1.681	16.808	43.029	1.681	16.808	43.029	1.551	15.513	37.542
3	1.284	12.841	55.870	1.284	12.841	55.870	1.462	14.623	52.165
4	1.071	10.706	66.576	1.071	10.706	66.576	1.441	14.411	66.576
5	0.874	8.744	75.321						
6	0.809	8.088	83.408						
7	0.647	6.468	89.877						
8	0.532	5.323	95.200						
9	0.473	4.732	99.932						
10	0.007	0.068	100.000						

Table 4 Rotated component matrix

	Components			
	PC1	PC2	PC3	PC4
Depth	0.395	**−0.609**	−0.024	0.393
Arsenic	0.074	**0.668**	−0.210	0.228
pH	−0.082	0.116	−0.141	**0.609**
Total dissolved solids	**0.955**	0.052	0.162	−0.019
Electrical conductivity	**0.957**	0.093	0.181	0.002
Iron	0.150	**0.685**	−0.058	0.063
Chloride	0.096	−0.019	**0.855**	−0.044
Sulphate	0.324	−0.208	0.166	**0.669**
Total hardness as calcium carbonate	0.153	−0.402	−0.177	**−0.634**
Nitrite	0.213	−0.187	**0.739**	0.093

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization. Rotation converged in six iterations

Significant loadings are boldface

cluster. Fourth cluster showed higher amount of *total dissolved solids* (636.12 mg/L), *nitrite* (49.59 mg/L) and *electrical conductivity* (1.01 $S/cm^{-1} \times 10^{-3}$) while the *sulphate* (615.28 mg/L) concentration was moderately present.

Categorization of groundwater quality

Factor 1 score distribution map is associated with high positive loadings on *total dissolved solids* and *electrical conductivity* (Fig. 8a). Therefore, this factor can be assigned as the turbidity factor, which might be originated from the point sources such as agricultural wastes and runoff water with high load of solids that mixed with the groundwater through percolation. High scores of factor 1 are mostly associated with the thick unconfined aquifer situated in the eastern part of the study area. Influence of river Ganga on *total dissolved solids* and *EC* concentration is clearly confirmed in Fig. 8a by the continuous stretch throughout the northern peripheral region. The factor scores were substantially higher along a narrow trail extended from north to south and followed the path of river Bhagirathi. Groundwater mixing with the river water might be one of the controlling factors in this respect. The increased concentration of solids was observed at the confluence of river Bhagirathi with river Ganga. The scores were decreasing gradually towards western part where the tributaries of river Ganga were scanty. The hand pump no. 1, 12, 38 and 47, which are located along the river, had higher *total dissolved solids* as well as *EC*.

Figure 8b represents factor 2, which is associated with variables of *depth*, *arsenic* and *iron*. The higher positive scores of *arsenic* and *iron* and negative loading on *depth* were observed in the eastern end and southern segment. The presence of higher concentration of *arsenic* and *iron* in the shallower depth depicted a typical redox condition largely because of reduction dissolution (Chapagain et al. 2010). In this region, the factor score showed more than 1 which indicated an elevated concentration of the parameters. Over pumping of groundwater might be the governing factor as it is the major source of drinking water as well as irrigation in that region. Over extraction introduces excess amount of oxygen, which helps in greater amount of oxidation of the minerals and release of *arsenic* in the groundwater (Liu et al. 2003). The eastern side of the river Bhagirathi is composed of thick unconfined aquifer. There is no significant intervening layer between the surface and subsurface, and this leads to percolate the water directly into the aquifers through these surface and subsurface layer. This might be the governing factor of arsenic release into the groundwater (Ghosh and Kanchan 2011). The hand

Nitrite concentration, which is responsible for the 'Blue Babies syndrome' (Mishima et al. 2010), was also analysed and found to be in the range from 6.25 to 71.42 mg/L with an average of 27.45 mg/L and standard deviation of 14.28 with skewness and kurtosis as +1.40 and +1.48, respectively. Higher concentration of nitrite in the central part of the study area gradually decreased in all directions (Fig. 4i).

Factor analysis (FA)

Factor analysis is a multivariate statistical analysis, which helps in detecting the similarity among the variables. The major aim of this analysis is to reduce the dimensionality of the data and reproduce set of related variables without losing any information (Farnham et al. 2002). This statistical approach had been adopted by Helena et al. (2000) to interpret the interrelated complex processes, which were controlling the general water chemistry. Factor analysis technique was used in the present study to extract the factors using "Kaiser Criterion" where *eigenvalues* greater than the unity (1) were taken into consideration (Davis 1986). *Scree* test was applied though decreasing order of the *eigenvalues* in respect to the factors. Break in the *scree* plot represented the number of factors to be considered. To ensure the maximum variability, "varimax rotation" was applied. With extracted factors, the interrelationships among the variables were analysed in much efficient way as the number of variables was grouped into lesser number.

In the present analysis, four significant factors were extracted using varimax rotation with *eigenvalues* more than 1 explaining 66.57 % of the total variability of the data (Table 3). Higher factor loading value for factor 1 showed that *total dissolved solids* (+0.955) and *electrical conductivity* (+0.957) accounted for 26.22 % of the total variation among the sample. Factor 2 had 16.80 % of variance with higher positive loadings on *arsenic* (+0.668) and *iron* (+0.685), while negative loadings on *depth* (−0.609) parameter. Third and fourth factors had been observed having 12.84 and 10.70 % variability, respectively. The third factor depicted positive loadings on *chloride* (+0.855) and *nitrite* (+0.739). The fourth factors showed higher positive loadings on *pH* (+0.609) and *sulphate* while negative loading on *total hardness* (−0.634). The last two factors depicted relatively lower percentage of variance, which indicated more local effects than the first two factors. Factor loadings of the four factors of the data set are listed in the Table 4.

Interdependence between the factors

Inter-factorial relationship can be better interpreted through the scatter plot of factors, which is essential for understanding the importance of each factor and also the interdependence between the factors. High positive loadings were observed in all the parameters of factor 1, i.e. *total dissolved solids* and *electrical conductivity* and factor 2 having *iron* and *arsenic* excluding *depth* as shown in Fig. 5a. Positive loadings of *iron* and *arsenic* showed a relationship with *total dissolved solids* and *electrical conductivity*. The negative loading on *depth* indicated an inverse relationship which controls the concentration of *arsenic* and *iron*. A high positive loading of *iron* in both unconfined and semi-confined aquifer is a better indication of dissolution of iron oxides under reducing conditions (Akai et al. 2004; Ravenscroft et al. 2001). Fig. 5b showed that the *iron* and *arsenic* are mostly concentrated in the shallow aquifer with higher *total dissolved solids* and *electrical conductivity*. Positive loadings on both factor 1 (*total dissolved solids* and *electrical conductivity*) and factor 3 (*chloride* and *nitrite*) showed strong control on both the factors (Fig. 5b). Control of *arsenic*, *iron* and *depth* on *pH* is indicated by high positive loadings and determined through interrelationship between factor 2 and factor 4 (Fig. 5c). Inverse relation was noticed between *arsenic*, *iron* (Factor 2) and *sulphate*, *total hardness* and *pH* (factor 4).

Hierarchical cluster analysis (HCA)

Among several clustering techniques, HCA is widely applied in earth science studies (Davis 1986). It is one of the key techniques, which is widely used for grouping of hydrochemical data having similar characteristics and applied by several workers (Mencio and Mas-Pla 2008; Forina et al. 2002). The grouping of variables was done by the Euclidian distance method and linking up on the basis of overall similarity. The data set can be classified easily by HCA and direct way with representation through dendrogram (Davis 1986). In the present study, Ward's linkage agglomeration schedule coefficient was applied for the identification of number of classes. Dendrogram represented the actual pattern of data (Fig. 6), and 78 samples were clustered into four groups (Table 5). As per Table 5, cluster 1 was distinguished from others on the basis of presence of higher *electrical conductivity* (0.75 $S/cm^{-1} \times 10^{-3}$), *chloride* (52.83 mg/L) and *total hardness* with 55 % of the total sampling locations. Figure 7 showed the cluster 2 in the central and southern part of the district with alkaline condition (7.61), moderate *total dissolved solids* (405.68 mg/L) and high *sulphate* (714.78 mg/L) concentration. Cluster 3, though observed in only 6 % locations, but is problematic because of very high concentration of *arsenic* (0.75 mg/L) and *iron* (10.96 mg/L) in shallow aquifers. The amount of *sulphate* (342 mg/L) was moderate and that of *chloride* (24.80 mg/L) was low in this

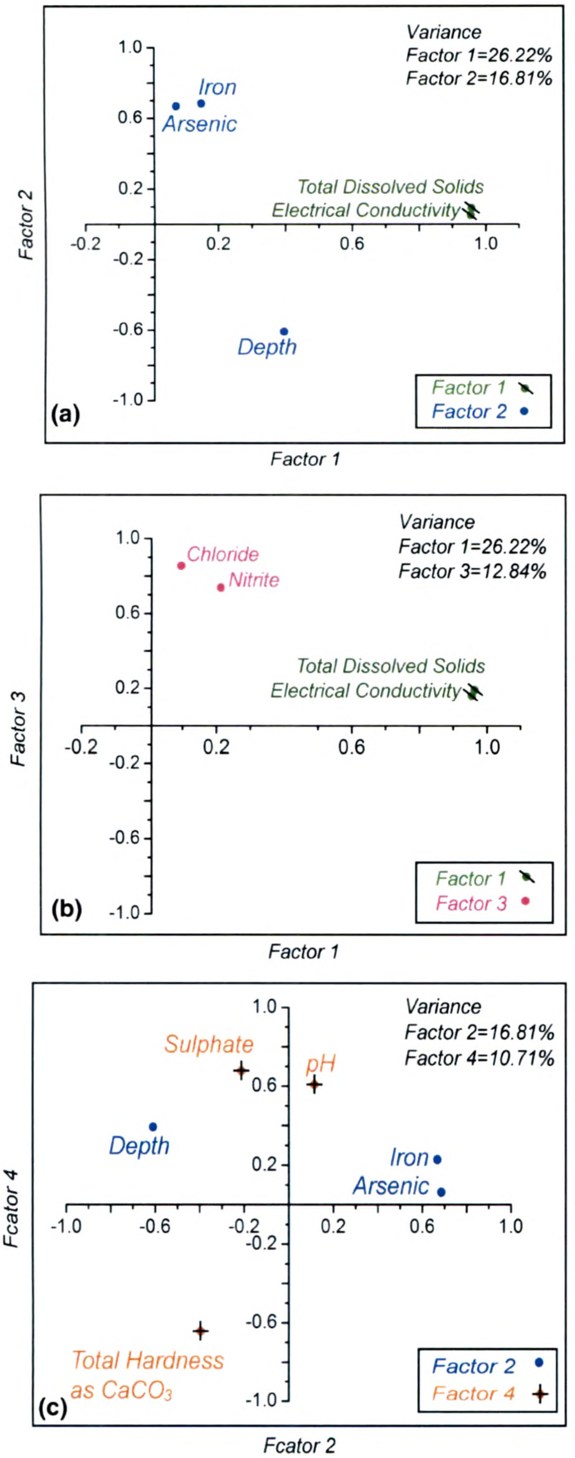

Fig. 5 Interfactoral relationship. **a** factor 1 and factor 2, **b** factor 1 and factor 3, **c** factor 2 and factor 4

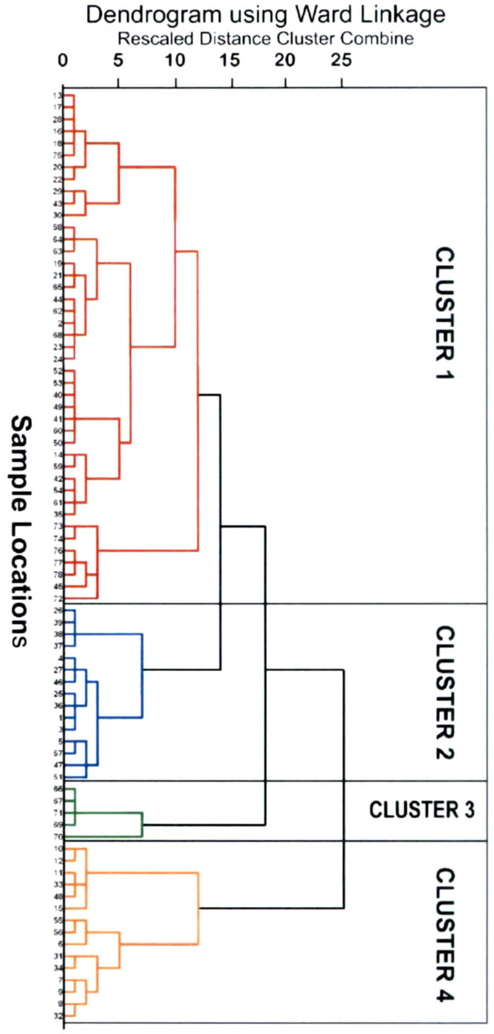

Fig. 6 Cluster dendrogram

pumps no. 25, 26 and 27 are some of the locations located in the eastern part of the region, with very high concentration of *arsenic* in the shallower depth with considerably high concentration of *iron*. On the other hand, location no. 40, 41 and 43 showed considerably low *arsenic* concentration below permissible limit in the higher *depth* with low *iron* concentration. The result indicated a definite relationship between the parameters.

Whole of the northern region showed dominance of factor 3. Higher positive loading on both *chloride* and *nitrite* is observed in the north-central part of the study area (Fig. 8c) with factor score more than 1. The origin of *chloride* from local natural sources has moderate concentration, while, nitrite is one of the important components of

Table 5 Mean of clusters of parameters

Cluster	Depth (ft.)	Arsenic (mg/l)	pH	TDS (mg/l)	Electrical conductivity ($S/cm^{-1} \times 10^{-3}$)	Iron (mg/l)	Chloride (mg/l)	Sulphate (mg/l)	Total hardness of $CaCO_3$(mg/l)	Nitrite (mg/l)	n^x
1	89.19	0.04	7.17	479.69	0.75	8.06	52.83	142.68	376.51	23.36	43
2	163.07	0.05	7.61	405.68	0.63	4.10	37.91	714.78	227.96	21.18	15
3	62.00	0.75	7.30	530.00	0.86	10.96	24.80	342.00	187.60	24.28	5
4	154.72	0.03	7.11	636.12	1.01	4.33	84.84	615.28	454.72	49.59	15

n^x total number of sampling locations in each clusters

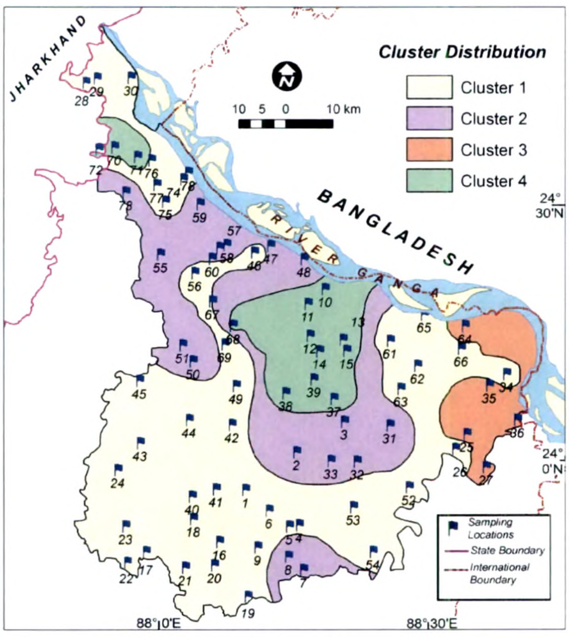

Fig. 7 Cluster distribution map

fertilizers. Excessive use of fertilizers and untreated sewage contamination might have caused the concentration of nitrogen bearing elements in the groundwater (Chanakya and Sharathandra 2008; Schmoll et al. 2006). *Nitrite*, having a positive relationship with the wastewater discharge and pesticides, excessively used in agriculture, contributed to anthropogenic local pollution (Kumazawa 2002; Gupta et al. 2008). Higher concentration of *chloride* and *nitrite* had been observed from hand pump no. 14, 15 and 16. On the other hand, the hand pump nos. 1, 19 and 20, which are considerably away from the river, had shown a low amount of *chloride* and *nitrite*. This is an indication of a probable relation with the river water.

Fourth factor is associated with high positive loadings on *pH*, *sulphate* and high negative loadings on *total hardness* (Fig. 8d). Variation in *pH* of water was considered to be a critical parameter as it triggers hydrochemical reactions in groundwater. Throughout the region, *pH* value varied between 6 and 8.5. *Total hardness* showed a range from 30 to 850 mg/L, which was considerably high. According to Sawyer and McCarthy (1967), this might be due to the weathering of sedimentary rocks, calcium bearing elements and use of excessive lime in agricultural land. Hand pump nos. 1, 14, 15 and 16 are some of the locations, which also follow the above said conditions. Moreover, factor 3 and factor 4 are showed the influence of agricultural activities.

Composite results after superimposition of the analysed factors, groundwater zones were categorized. Major contaminated zones were identified in the north central and in the eastern part of the study area where factor score showed very high value of more than 2. However, the higher factor scores were extended from central part to the eastern end of the region (Fig. 8e). The contact zone between thick unconfined and semi-confined aquifer has an important role to play in this regard. As per the results, the entire thick unconfined aquifer situated in the eastern part of river Bhagirathi is a matter of concern in terms of groundwater contamination. Hand pump nos. 35, 34, 13, 14 and 15 showed the higher scores, which indicated the highest contaminated zones. Entire region of the eastern part had positive composite factor score seemed to be the most problematic zone because of the highest composite factor of more than 2 in the eastern end region. Gradual decrease in factor scores was observed from east to western part. Here the factor scores are negative indicating the less contaminated groundwater regions.

Conclusion

In the present study, geochemical analysis of different parameters coupled with statistical analysis ascribed the contamination zones of groundwater in the central alluvial tract of Bengal plain of India. Result showed that the rivers are playing an important role in controlling the geochemical properties of groundwater of the region. In areas closer to the recharge zones of river Ganga, its tributaries and distributaries, higher concentration of *total dissolved solids* and *electrical conductivity* was observed. Higher

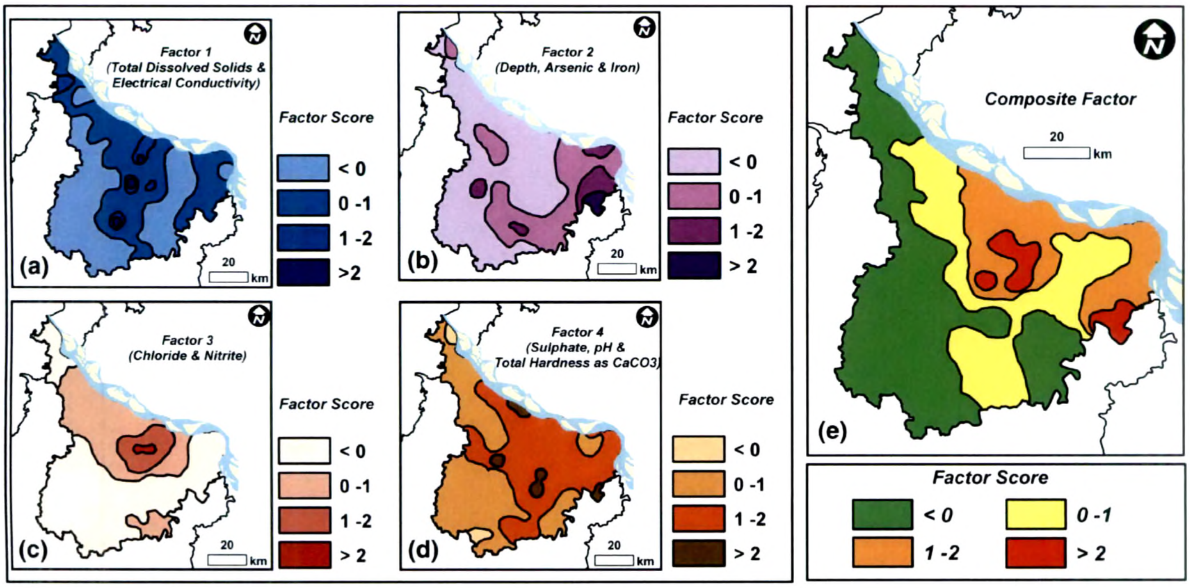

Fig. 8 Factor score distribution maps. **a** factor 1 (TDS and EC), **b** factor 2 (depth, arsenic and iron), **c** factor 3 (chloride and nitrite), **d** factor 4 (sulphate, pH and TH as $CaCO_3$), **e** composite factor

concentration of *arsenic* and *iron* in shallower aquifer was found in the eastern end, while it decreased considerably in the western segment. Southern part showed higher values of *pH* in the water samples, while the groundwater in the central part extended up to the southern end of the studied area that had higher concentration of *Chloride*. The concentration of *sulphate* was spread from the central to the western part. However, *hardness* of groundwater was noted in the entire region of the central alluvial tract except eastern part and *nitrite* concentration in the north-central portion of the region.

The factor scores ascribed the abundance of higher scores from eastern segment of river Bhagirathi to the western segment in a gradually decreasing trend. Turbidity factor related to *TDS* and *EC* showed higher concentration along the path of river Bhagirathi. It was observed that the eastern most segment of the studied area had hazardous elements viz., *arsenic* and *iron* in the shallower *depth* and agricultural factor i.e. *nitrite* and *chloride* was concentrated in the north-central portion. *Hardness* factor comprising of *total hardness, pH* and *sulphate* was spread over almost whole eastern segment of river Bhagirathi. Cluster analysis also confirmed the presence of *arsenic* and *iron* in the eastern most part in the shallower *depth* and higher concentration of *TDS* and *total hardness* at the confluence of river Bhagirathi and river Ganga in the north-central part. The present results concluded the need of the groundwater quality categorization to ensure availability of groundwater that can be used for drinking and other purposes. Further, characterization of groundwater quality in different seasons may depict the seasonal pattern of groundwater processes. For the identification of subsurface hydrological characteristics, subsurface lithological modelling accompanied by the geochemical data and statistical analysis may be useful.

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Identification of Groundwater Arsenic Contaminated Vulnerability Zones in Alluvial Tract of West Bengal, India

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ABSTRACT

Underground water is regarded to be free from all types of pollutants hence it is considered to be safe for drinking. Consequentially, it is a predominant source of drinking water in several parts of the world particularly in the developing countries. Regrettably, empirical studies have also been conducted in other parts of the World and it is found that in twenty countries the subsurface water is contaminated with arsenic. Serious arsenic contamination is reported along the River Bhagirathi in Ganga–Brahmaputra delta in the linear tract of 470 km. The occurrence of arsenic in groundwater is mainly in the shallow and intermediate aquifer, the deeper aquifers are free from contamination. Arsenic mobilization in water is favoured by desorption of arsenic from iron and other metals oxides. In Bengal Plains such conditions tend to occur in shallow aquifers in quaternary strata underlying the regions large alluvial and deltaic plains. The occurrence of arsenic in groundwater is influenced by local geology, geo-chemistry and hydrology of the alluvial aquifers. The present study envisages studying the spatial pattern of groundwater contamination in West Bengal and identifies the arsenic contaminated vulnerability zones. Spatial variation in respect to the depth and proximity to river Bhagirathi is noticed in the alluvial tract.

Keywords: *Alluvial tract, Arsenic contamination, Intermediate aquifer, West Bengal, Vulnerability zones*

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1. INTRODUCTION

Underground water is regarded to be free from all types of pollutants hence it is considered to be safe for drinking [1]. Consequentially, it is a predominant source of drinking water in several parts of the world particularly in the developing countries. Taking into account its purity, it is a major source of drinking water even in the areas where fresh river water is available like in the Bengal Plains of India and Bangladesh. The safety of underground water was put at risk when the epidemiological studies conducted in 1980s found that the groundwater in the Bengal Plains was contaminated (above 0.05 mg/L as per the WHO recommendations) with arsenic [2–4]. Regrettably, empirical studies have also been conducted in other parts of the World and it is found that in 20 countries of the World the subsurface water is contaminated with arsenic [5]. The major incidences of the high level of the element are noted in Taiwan, China, Chile, Argentina, Mexico, United States, India, Bangladesh, Nepal, Vietnam, Cambodia and Mongolia [6–8]. In India, it was first detected in some localized pockets of West Bengal. Later, serious arsenic contamination was reported throughout the linear tract of 470 km along River Bhagirathi in Ganga–Brahmaputra delta covering an area of about 37, 500 sq. km. in the districts of Malda, Murshidabad, Nadia, North and South 24 Parganas, part of Kolkata (on the left bank of the river), Barddhaman and Hugli on the right Bank [9–13]. Arsenic is now even noticed in the states of Bihar, Chattisgarh, Uttar Pradesh and Assam (Department of Health & Family Welfare) and the occurrence of this element in the states of Bihar and Uttar Pradesh is also in alluvium [14–16]. Arsenic mobilization in water is favoured by desorption of arsenic from iron and other metals oxides. In Bengal Plains such conditions tend to occur in shallow aquifers in quaternary strata underlying the large alluvial and deltaic plains [17, 18]. The occurrence of arsenic in groundwater is influenced by local geology, geochemistry and hydrology of the alluvial aquifers [19–22].

2. WHAT IS ARSENIC AND HOW DOES IT GET INTO DRINKING WATER?

Arsenic is a naturally occurring element found in earth's crusts which is found almost everywhere. It occurs naturally in rocks, soil, water, air, plants and animals. There are trace amounts of it in all living matter. In general, it depends on hydrochemical characteristics of groundwater aquifers, presence of oxidized / reduced mineral phases and arsenic rich solid phases. The processes of arsenic mobilization from its source to groundwater are mainly either natural or anthropogenic. As stated earlier it is widely distributed in nature and principally occurs in the form of inorganic and organic compounds. Inorganic compounds in the most toxic form consists of arsenite. The main anthropogenic sources are industrial waste, phosphate, fertilizers, coal, oil, cement, ore processing, metal extraction and purification, glass, chemicals, leather, textiles, alkali, petroleum refineries, insecticides and catalysts [23]. Natural contamination is generally regarded as the main mechanism causing high levels in the entire Gangetic Plains Bhagirathi and Ganga–Padma interfluves.

Problem of the Arsenic contamination in West Bengal is a natural phenomenon. Here, arsenic sorbed in Fe-oxyhydroxide was preferentially captured in argillaceous, organic rich, mid Holocene deltaic sediments. It is released to groundwater by bio-mediated reductive dissolution of Fe-oxyhydroxide. In West Bengal, extensive pumping triggered the reduction process by inducing and enhancing movement of groundwater having highly reducing degraded organic products. There are two contending schools on arsenic contamination in Bengal Basin:

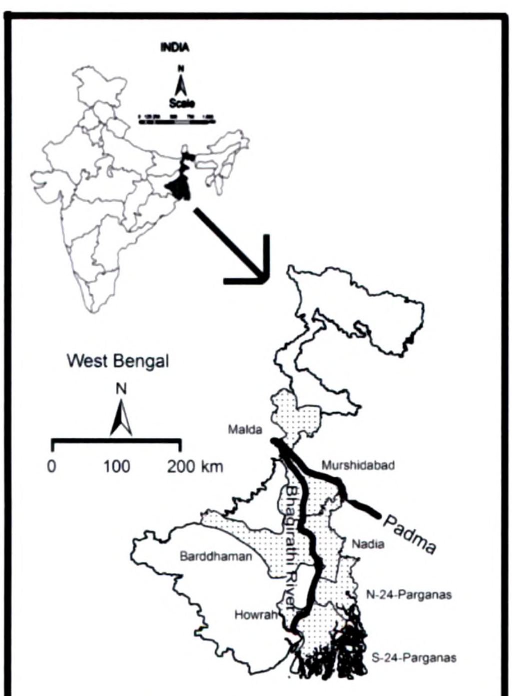
(i) It is caused by oxidation of pyrite and arseno-pyrite that are present in aquifer sediments by atmospheric oxygen which enters the groundwater due to lowering of the water table caused by excessive groundwater abstraction.

(ii) It is caused by reductive dissolution of ferric oxyhydroxide that contains sorbed arsenic [24].

Most arsenic in drinking water comes from natural rock formations. Water that encounters rock formations can dissolve arsenic and carry it into underground aquifers that may be used as drinking water supplies. When dissolved in water, arsenic has no smell, taste or colour even at high concentrations. Due to these characteristics the element is not traceable in water easily and hence it is fatal.

3. EXTENT OF PROBLEM IN WEST BENGAL

High levels of arsenic in groundwater in deltaic environments are common and wide reported from the entire Gangetic Plain which embraces the districts of Malda, Murshidabad, Nadia, North 24 Parganas, South 24 Parganas Howrah, Hooghly, Cooch Behar, North Dinajpur, South Dinajpur, Kolkata and Barddhaman [25, 26, 27]. The region is restricted between 22^{0}N and 25^{0}N latitude and 87^{0}E and 89^{0}E longitude. The arsenic infested zone covers an area of around 35 000 km^2 representing nearly 40% of the total area of the State. 50% of the total population of the State is in the high vulnerability zone (Table I). The current findings are based on 50 villages spread over 7 districts (Figure 1)— Malda, Nadia, Murshidabad, North 24 Parganas, South 24 Parganas, Howrah and Barddhaman.



Source: Modified after Das et al(1995)

Figure 1

Table I West Bengal: Arsenic Affected Areas

District	Number of Block	Number of Village	Area (Km^2)	Population 2011
Malda	07	229	3,733	3,997,970
Murshidabad	18	354	5,324	7,102,430
Nadia	17	541	3,927	5,168,488
N 24 Parganas	19	472	4,094	10,082,852
S 24 Parganas	09	409	9,960	8,153,176
Howrah	02	4	1,467	4,841,638
Barddhaman	02	38	7,024	7,723,663
Total	74	2,047	35,529 (40%)	47,070,217 (51.5%)
West Bengal Total			88,752	91,347,736

Source : Department of Health & Family Welfare, Government of West Bengal

4. GEOLOGICAL, SEDIMENTOLOGICAL, GEOMORPHOLOGICAL AND HYDROLOGICAL CHARACTERISTICS OF WEST BENGAL

The Bengal Basin is a large asymmetrical basin in the north-eastern part of the Indian Sub-continent. It comprises of a thick pile of fluvial sediments pertaining from Mesozoic to Recent age. The Ganges - Brahmaputra river system contributed to the building up of the Bengal delta. Ever since the tertiary period these rivers have carried enormous volume of sediments from the Himalayas to the north and north-eastern mountain chains [28].

Based on geomorphic features, the Bengal delta can be divided into upper and lower part. The upper delta plain, located in the northern part of the area is characterized by the Padma–Bhagirathi (Ganges) meander belt. The groundwater in the upper delta plain primarily in the area of meander belts is mostly affected by arsenic enrichment. The lower delta plain is located in the southern part of the area. Geomorphologically, this area is composed of several tidal creeks; tidal mud flats, distributary levees and other inter distributary marsh complexes. Sedimentlogically, the area is characterized by thick (50–250 feet) clay layer. In many places silt sand and gravel deposits overlie the clay layer [29].

The upper part of the Bengal alluvial plain is composed of three interconnected aquifer system. The shallowest aquifer extends up to 40–50 feet below the surface and is largely unconfined accept in the southern part where it is partly confined. Shallow and Intermediate aquifers are located at lower depths in the districts of Malda, Murshidabad, Nadia, Barddhaman, North 24 Parganas whereas in the South 24 Parganas they occur at greater depth. The groundwater level gradient is sub-parallel to the general slope of the area, dipping towards southeast (Figure 4).

5. OBJECTIVES

The present study envisages to study the spatial pattern of groundwater contamination in West Bengal and to identify the arsenic contaminated vulnerability zones.

6. METHODOLOGY

6.1. Data Collection and Sample Analysis

To fulfill the above objectives both primary and secondary data have been collected. The secondary data have been procured from the offices of the Central Groundwater Board, Government of India; Ministry of Water Resources, Eastern Region, Kolkata; Public Health Engineering Department, Government of India, West Bengal; District Census Handbook & Statistical Abstract of West Bengal.

Primary data base is used for the measurement and identification of the magnitude of the

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problem as well as for identification of vulnerability zones. This has been collected through the following steps:

Stepwise stratified random sampling has been applied in the selection of the spot wells. Fifty villages spread over seven blocks in the same number of districts have been identified on the basis of the reported arsenic in groundwater (Table II). As the belt of the Ganga–Meghna and Brahmaputra Plain is badly affected [30] hence, seven districts lying in this belt have been selected for the detailed analysis. Five of them viz. Nadia, Malda, Murshidabad and North and South 24 Parganas have arsenic level of more than the permissible limit (Figure 2). Two more districts viz. Howrah and Barddhaman adjoining this contaminated belt are also taken into consideration. Later, is almost arsenic free and only the eastern part of it is in the alluvial plain region.

Ninety two water samples were collected at varying depths between July 2009 and March 2010. All of these are positioned in alluvial plains. Considering, the hypothesis that the level of contamination is higher at lower depths [31] water samples were largely collected from shallow depths (<200 feet). However, few samples were even gathered from deeper depths (up to 1000 feet).

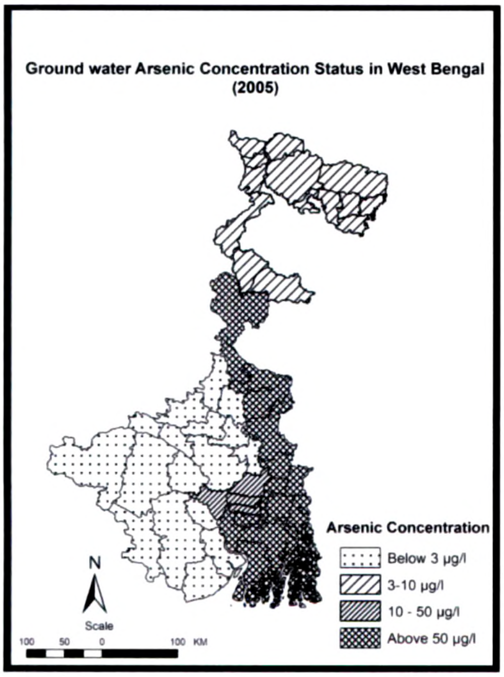

Figure 2

Table II West Bengal: Arsenic Affected Districts

% of Arsenic	Name of District
Above 0.05 mg/l	Most parts of **Murshidabad*, Nadia*, Malda*, N & S 24 Parganas***, Kolkata and parts of Howrah
0.05 to 0.03 mg/l	**Howrah***, Kolkata and parts of Barddhaman, Hooghly, Darjeeling, CoochBehar, Uttar & Dakshin-Dinapur, Jalpaiguri
Below 0.03 mg/l	Birbhum, Purulia, E & W Midnapore, Bankura & parts of **Bardhaman***

* *Selected for Detailed Study*

Source: Public Health Engineering Department, Government of India, West Bengal

Garmin E-trex Vista HCx® handheld GPS was used for marking the location of tube wells and data were tripped through Mapsource Software® in Computer. Groundwater of the selected spot tube wells was collected in 250 ml capped Polyethylene bottles and acidified with HNO_3. Further, samples were analysed.

6.2. Instrumentation, Glassware and Regents

Elico Double Beam UV–VIS Spectrophotometer Model S1-210 is used in the detection of arsenic concentration. Pyrex evolution vessel is used for arsenic extraction from the water samples.

All the reagents in the experiment are of analytical grade and double distilled water (Aquapure) has been used. Standard Molybdenum Blue method for arsenic detection is employed for detection of trace arsenic in water samples [32].

Stock solutions of arsenic (1000 mg/l) are prepared from arsenic trioxide (As_2O_3), Loba Chemical Pvt. Mumbai, India, with proper dilution. Highly pure Hydrochloric Acid (35%–38%) (SD Fine Chemical Limited, Mumbai, India) is used at different levels of the experiment. Further, Potassium Iodide (KI), Tin (II) Chloride ($SnCl_2.2H_2O$), Zinc granules (Zn), Iodine (I), Sodium Bisulphite (SO_2), Sodium Hydrogen Carbonate ($NaHCO_3$), Hydrazinium Sulphate ($NH_2.NH_2.H_2SO_4$) and Ammonium Molybdate ($(NH_4)_6Mo_7O_{24}.4H_2O$) were obtained from Mark India Limited, Mumbai, India.

7. SPATIAL PATTERN OF ARSENIC LEVEL

Spatial variation both in respect to the depth and proximity to river Bhagirathi is noticed in the alluvial tract. It is generally observed that at greater depth water is arsenic free [33–39]. In Nadia, Murshidabad and 24 Parganas districts the tube wells with a depth of >85 feet are mostly contaminated (Figure 3).

Murshidabd has the highest level of contamination where even at 200 feet most of the wells show arsenic above permissible limit (Table III). Here, the water in seven out of eight wells (78%) is unsafe for drinking. The peripheral belt comprising of Barddhaman and Howrah Districts are free from pollution (Table III). In Rajapur villages of Domkal Block and Katlamari village of Raninagar II Block (Murshidabad District) 0.352mg/l and 0.210 mg/l arsenic is observed at a depth of 85 feet respectively.

In North 24 Parganas, six out of seven tube wells are noted to have unsafe drinking water at <200 feet depth. Surprisingly, although at deeper depths water is considered safe for drinking. In Chandalati (Deganga Block) 0.524 mg/l of arsenic is recorded at 250 feet. In Malda and South 24 Parganas only two points confirmed unsafe drinking water at <100 feet. In Malda, at Ratua I Block, Sahapur

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village the water is safe even at 25 feet. In the same district, at the same depth (25 feet) and at 50 feet in Kamalpur village (Manikchowk Block) and Dariapur village (Kaliachowk Block), respectively, 0.392 and 0.434 mg/l of contamination is detected.

Lower level of arsenic is observed in South 24 Parganas. The highest level is at Baniara village where 0.191 mg/l arsenic is noted at 200 feet depth. Here, even at 500 feet the contamination is high (1.015 mg/l) (Table IV). This level is below the permissible limits in Howrah and Barddhaman Districts. In the former, only at Basudevpur village (Uluberia II Block) the amount is 0.98 mg/l. In the later district (Barddhaman), five of the seven spot wells are arsenic free. The highest level of 0.159 mg/l is recorded at Champhati village of Purbasthali I Block. Most of the wells between the depths of 100 and 300 feet are free from this element.

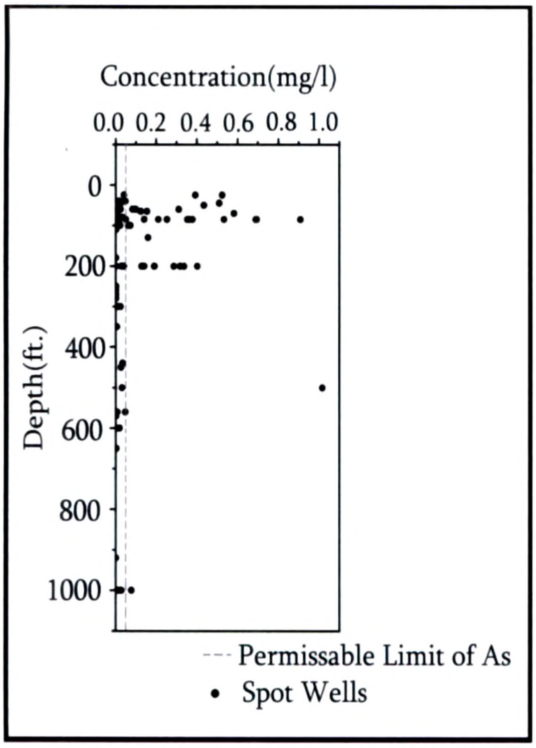

Figure 3

Table: III % Of Safe Spot Tube Wells with Arsenic Content

District	Depth in Feet						
	> 50	50-100	100-200	200-300	300-500	500-1000	Total
Malda	-	28	-	-	-	-	28
Murshidabad	-	14	12	-	-	-	13
Nadia	75	25	85	-	-	-	64
N-24 Parganas	0	20	-	0	100	75	43
S-24 Parganas	100	75	-	100	0	85	78
Howrah	-	0	-	100	100	100	93
Bardhaman	100	100	80	100	-	-	93
Total	57	50	55	91	80	88	61

- No Spot Tube Well Surveyed

Source: Computed

The depth of maximum arsenic concentration increases from north to south. On the north of the river, in Malda district the highest level of contamination is observed at 50 and 70 feet. In Murshidabad and Nadia highest level of arsenic concentration is found at 85 feet. In North and South Parganas it is at a depth of <200 feet. In the former, fluctuations are observed where the maximum concentrations are noted either at 45 or at 500 feet depths.

Both the slope and the water table of the aquifers are responsible for this phenomenon. The general slope of the land is towards south-east and also the water table is shallower in the similar direction (Figure 4).

The entire eastern part of the state has a shallow water table of >25 feet. The yield prospects are also high in this area [40]. Malda is on the northern bank of River Bhagirathi, and as the flow of the subsurface water is southeast wards, hence, it has a lower content of arsenic. The level is highest immediately south i.e., in Murshidabad and Nadia Districts.

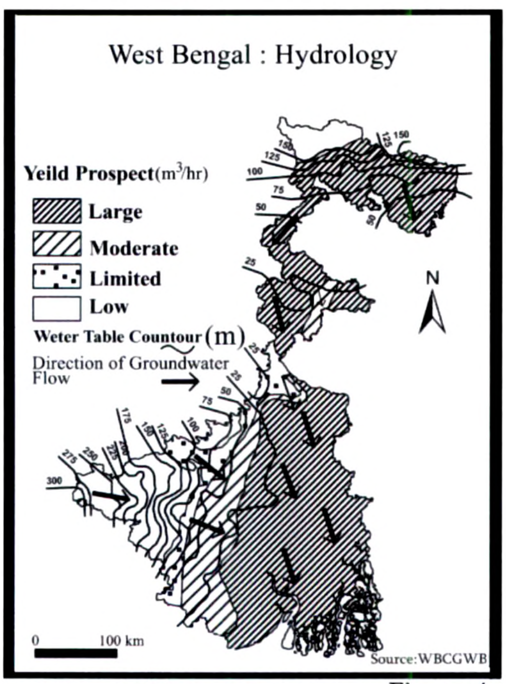

Figure 4

It lowers southwards with moderately high in North and South 24 Parganas whereas Howrah is almost element free. Barddhaman District on the western flank is also considered free from contamination.

The western part of this district comprises of sandstone, shale, grit, conglomerate and some crystalline rocks (Figure 5) whereas sand and fine particles are said to be rich in arsenic [1, 14, 16, 41].

Table IV Maximum Identified Arsenic Content

District	Block	Village	Max As Content	Depth (in Feet)
Malda	Kaliachwak- III	Dariapur	0.434	50
			0.582	70
Murshidabad	Beldanga-I	Mokrampur	0.907	85
Nadia	Tehatta-I	Betai-Jitpur	0.693	85
	Karimpur-I	Andhar-Kotha	0.693	
	Karimpur-II	Mahisbathan	0.689	
N-24 Parganas	Baduria	Tegharia	0.509	45
	Deganga	Chandalati	0.524	250
S-24 Parganas	Bhangar-II	Baniara	0.191	200
			1.015	500
Howrah	Uluberia-II	Basudevpur	0.098	60
Bardhaman	Purbasthali I	Champhati	0.159	130

Source: Computed

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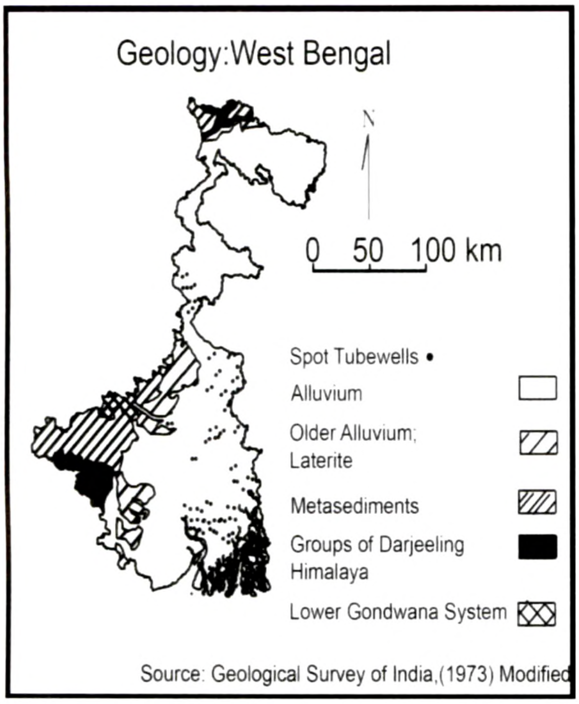

Figure 5

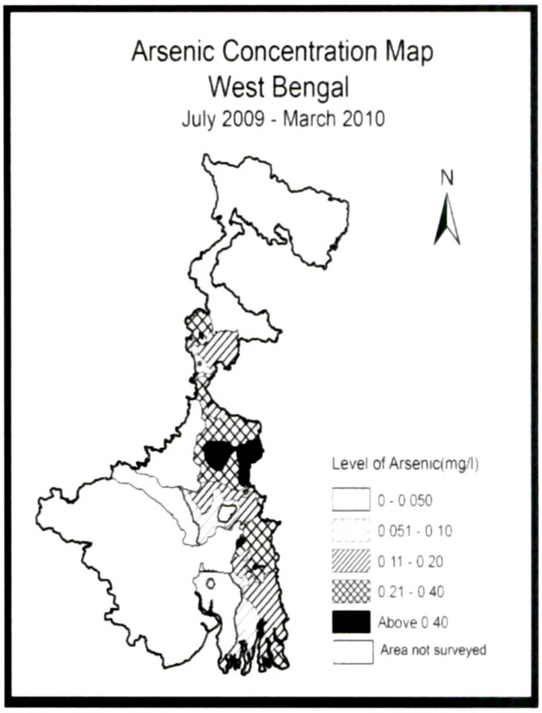

Figure 6

8. ARSENIC VULNERABILITY ZONES

The level arsenic was noted down to identify the vulnerability zones. The pocket of highest concentration stretches from 87°57'44" to 88°42'35" E longitude and 23°36'34" N to 24°4'35" N latitude largely covering southern Murshidabad and northern Nadia districts (Figure 6).

Adjoining this high risk zone is the belt of high concentration between 0.21 and 0.40 mg/l.

A large part of these two districts are covered and thus are highly vulnerable. Three isolated pockets with 0.11–0.20 mg/l arsenic level are intermittently noted (Table V). The two belts which are below the prescribed norms are in (i) the south western part and (ii) western corridor of central West Bengal.

A small pocket in the central part situated in the district of Barddhaman is also free from this element.

Thus overall, the drinking water in 73.6% of the total surveyed area is unsafe for drinking and only one-fourth (26.4%) is safe. Amongst the unsafe zones 7.9%, 31.3%, 16.6% and 17.6% areas have concentration >0.41 mg/L, 0.21–0.40 mg/L, 0.11–0.20 mg/L and 0.05–0.01 mg/L, respectively.

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Table V Vulnerability Zones

	As Level Mg/l.	Area^2 Km.	Area
1	>0.41	**2080.76**	Southern Murshidabad & Northern Nadia
2	0.21 to 0.40	863.03	North Western Malda
		4,638.80	Murshidabad except Southern Part
		2,741.49	Southern Nadia & Northern & Central N 24 Paraganas
		8,243.32	
3	0.11 to 0.20	2157.73	Central & Southern Malda
		2281.95	Central Nadia & North Eastern Barddhamann
		4,439.68	
4	0.05 to 0.10	2015.16	Eastern Barddhamann
		2612.37	Western S-24 Parganas
		4,627.53	

Source: Computed

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Open Access **Research Article**

Spatio-Temporal Pattern of Groundwater Arsenic Concentration in Thick Unconfined Aquifer of Murshidabad District, West Bengal, India

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Abstract:

Groundwater is one of the major sources of drinking water in several parts of the world. At the same time it is associated with contamination and health issues. Arsenic contamination of groundwater is one of the major concerns among them. In India, many parts of West Bengal plain are severely affected by Arsenic concentration. From the severity of the problem the utmost priority is to identify the major hot spots of the arsenic concentration. To evaluate the behavior of arsenic in groundwater both in terms of spatial and temporal aspect, samples are collected from the unconfined aquifer of Murshidabad district of West Bengal, for three following years in different seasons. An important relationship is found between the arsenic concentration, rainfall intensity and the subsurface lithology.

Keywords: Arsenic, Subsurface lithology, Unconfined Aquifer

1.0 Introduction:

Beginning of late twentieth century marks the rapid increase of groundwater consumption throughout world (Ravenscroft *et al.,* 2009). With the increasing intensity of extraction, the quality of groundwater can deteriorate to some extent. Several parts of the world experiences groundwater contamination due to mixing of different minerals both naturally and due to human activities (Onodera *et al.,* 2008). Although minerals in groundwater are necessary for human health, but to a certain limit. Above the permissible limit it may create health problem which may range from mild to severe depending on the duration and exposure (Kanchan and Roy, 2009, Hung *et al.,* 2004). Among these minerals arsenic is considered as the problematic, even when consumed in lower quantities. World Health Organisation has set 0.05mg/l as the permissible limit in water for drinking (Chakraborti *et al.,* 2008). The first case of arsenic poisoning was reported from Poland in 1898 (Mandal and Suzuki, 2002). The arsenic contamination cases were even reported from Canada (Wyllie, 1937) and New-Zealand in mid-twentieth century (Grimmett and McIntosh, 1937). Taiwan also attracts the attention of several countries in respect of arsenic contamination. Bangladesh, located in the Padma-Meghna-Brahmaputra plain, shows that in 41 of 64 districts (1998) arsenic level in groundwater was above 0.05mg/l (WHO, 1993). In Indian subcontinent Bengal plain have the highest concentration where almost 50% of total area is contaminated.

Several parts of Jharkhand, Uttar Pradesh, Assam valley experience the occurrence of arsenic in groundwater (Chakraborti *et al.,* 2004). The recent studies shows nine districts of West Bengal namely Malda, Murshidabad, Budwan, Nadia, Hoogly, Howrah, Kolkata, North 24 Parganas and South 24 Parganas, among 19 districts are severely affected by arsenic concentration (SOES). Long term exposure to arsenic may creates different health effects like melanosis, keratosis, black and white pigmentation, gangrene and in the most harsh cases cancer of lungs and bladders (Smith, Lingas and Rahman, 2000; Hossain *et al.,* 2004, Cavar *et al.,* 2005;Sun et *al.,* 2006, Ahamed *et al.,* 2006, Villaescusa *et al.,* 2008, Roychowdhury *et al.,* 2010). In the last two decades thousand of water samples were collected from different parts of India and many showed the presence of arsenic above permissible limit. (Chakraborti *et al.,* 2002). From the severity of the problem the utmost priority is to identify the major hot spots of the arsenic concentration and also spot out the risk free zones. In this context variation of arsenic concentration in groundwater is one of the major concerns of among different scholars. (McArthur *et al.,* 2001, 2004; Kinniburgh and Smedley, 2001; Cheng *et al.,* 2005; Wagner *et al.,* 2005; Gonçalves *et al.* 2007; Savarimuthu *et al.* 2006) Present paper restricted to find the spatial and temporal variation of arsenic in groundwater in Murshidabad district, west Bengal, India.

1.1 Source and Mechanism of Arsenic Mobilization in Bengal Basin and Ganges Delta:

Major four types of mechanism through which arsenic mobilized into the groundwater are recognised. These four mechanisms are more or less dependent upon the geological and climatic setting and both of them are inseparably associated with each other. Reductive dissolution, alkali desorption, Sulphide oxidation, geothermal are major for mechanism of natural arsenic concentration in groundwater (Ravenscroft *et al.,* 2009). Several studies illustrate the arsenic in Ganges delta is originated from sulphide mineral (Harvey *et al.,* 2005). Workers like Mallick and Rajgopal (1996), Das *et al.,*(1996), Mandal *et al.*(1998) hold the hypothesis of oxidation of pyrite that is released in to the groundwater due to excessive withdrawal of water. On the other hand researcher like Acharyya *et al.* (1999, 2000, 2005) support the concept of comparative ion exchange with phosphate from fertilizers. At the same time other researchers argued that the source of dissolved phosphate is not from the fertilizers (McArthur *et al.,* 2001). Reductive dissolution of iron mechanism was first documented by Bhattacharya, Chatterjee and Jacks (1997) and further accepted by others (McArthur *et al.,* 2001, Harvey *et al.,* 2005). The main mechanism of reductive dissolution is mobilization of arsenic sorbed to iron(oxy)(hydr) oxides. (Nickson *et al.,* 2000). Scholar like Zheng *et al.,* (2004) combine Oxidation of pyrite and Reductive Dissolution, and proposed new mechanism of Reduction and oxidation. The concept was accepted and elaborated by Mukherjee and Fryar (2008).

2.0 Materials and Methods:

2.1 Study Area:

Murshidabad district is situated in the flank of River Ganga. One of the major distributary, Bhagirathi passes through the heart of the district. The geographical extent of the district is 24^0 50' 20" to 23^0 43' 30" N and $87^0$46' 17" and $88^0$46' 00" E (Fig. 1). The eastern part of Bhagirathi exhibits younger alluvium where as the western part is associated with older alluvium mainly lateritic. The study area in the present study is confined to the eastern part of river Bhagirathi. Only thick unconfined aquifer is taken into account to investigate any relationship between the source of water from the surface in the form of rainfall and variation in the level of arsenic concentration.

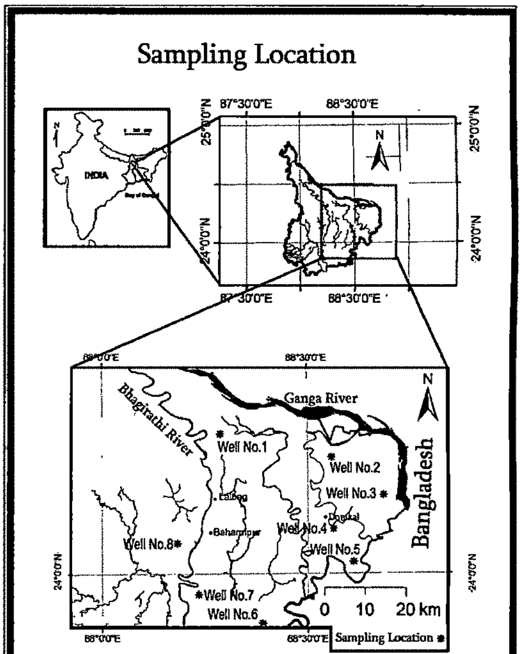

Fig. 1

2.2 Hydrogeological Setup:

The West Bengal part of Bengal Basin has sedimentary deposition from Mesozoic to Recent age. Ganga- Brahmaputra river system contributes in building up the Bengal delta. Even in the Tertiary these rivers carries a considerable amount of sediments from Himalaya (Stüben *et al.,* 2003). The study area experience the recent alluvium deposition resulted by the extensive fluvial processes (Morgan and McIntire, 1959). Sedimentologically the Bengal Delta is characterized by thick accumulation of clay layer which is in some places overlain by silt sand and gravel deposits (Deshmukh and Goswami 1973). The upper part of the Bengal plain reveals three inter connected aquifer system. The shallowest aquifer extends upto the depth of 12-15 m, typically made of sub angular, fine to medium grained sands and clay lenses. The shallow aquifer shows mixed igneous and metamorphic provinces for the eroded deposited minerals. The intermediate aquifer extends from 35-46 m and mainly metamorphic type of minerals can be observed where as the lower aquifer extended from 70 to 150 m with magmatic province. (Stüben *et al.,* 2003). The eastern part of Bhagirathi River is composed of thick unconfined aquifer.

Table 1: Location of Sample Wells

Well ID.	Block	Location Name	Depth (ft.)	Longitude	Latitude
Well No.1	Bhagwangola-1	Shyampur	85	88°17'05"	24°20'10"
Well No.2	Raninagar-2	Kadamtala	85	88°52'29"	22°43'08"
Well No.3	Jalangi	Khayramari	85	88°38'50"	24°11'52"
Well No.4	Domkal	Harurpara	85	88°38'12"	24°03'16"
Well No.5	Domkal	Rajapur	85	88°38'12"	24°03'16"
Well No.6	Nowda	Chandalati	85	88°27'32"	24°52'55"
Well No.7	Beldanga-1	Mokrampur	85	88°15'32"	23°56'22"
Well No.8	Baharampur	Beuchitala	85	88°22'46"	24°06'06"

The western part of the river has thick semi confined aquifer and the northern most part exhibit unconfined type of aquifer. The overall direction of groundwater flow is from north-west to south-east. (Das et *al.,* 1994). The present study is mainly confined in the thick unconfined aquifer mainly lying in the eastern part of Bhagirathi River (Fig. 2).

Objective:

Main objective of this paper is to investigate the spatial and temporal variation of arsenic concentration in the thick unconfined aquifer of Murshidabad district.

2.3 Methodology:

2.3.1 Data Collection and Sample Analysis:

Eight sample spots were selected through random sampling in the eastern part of River Bhagirathi and were collected for three successive years between 2009 to 2011 in premonsoon , monsoon and winter seasons. In Murshidabad district the duration of rainfall is long. Rain starts from the month of May and extends upto October. The samples in the present study have been chosen considering the rainfall pattern. One of the samples has been collected in the months of July (monsoon), the other in December (winter) and the third in February (premonsoon) (Table-1). Thus six times samples have been taken in to consideration. Garmin E-trex Vista HCx® handheld GPS was used for marking the location of tube wells and data were tripped through Mapsource Software® in Computer. Groundwater of the selected spot tube wells were collected in 250ml Capped Polyethylene bottles acidified with HNO_3 for prevention from any bacterial growth.

2.3.2 Instrumentation and Glassware:

Elico Double Beam UV-VIS Spectrophotometer Model S1-210 was used in detection the arsenic concentration in water samples. Pyrex evolution vessel was used for arsenic extraction from the water samples. All of the glass utensils (Borosil) are thoroughly cleaned in different stage of experiment to prevent from any impurities.

2.3.3 Regents:

All the reagents in the experiment are analytical grade and double distilled water (Aquapure) is used. Standard Molybdenum Blue method for arsenic detection was employed for detection of trace arsenic in water samples (Bassett et al. 1978). Stock solutions of As (1000mg/l) are prepared from arsenic trioxide (As_2O_3), Loba Chemical pvt. Mumbai, India, with proper dilution. Highly pure Hydrochloric Acid (35-38%) (SD Fine Chemical Limited, Mumbai, India) is used at different levels of the experiment. Further, Potassium Iodide (KI), Tin(II) Chloride ($SnCl_2.2H_2O$), Zinc granules (Zn), Iodine, Sodium Bisulphite (SO_2), Sodium Hydrogen Carbonate ($NaHCO_3$), Hydrazinium Sulphate ($NH_2.NH_2.H_2SO_4$) and Ammonium Molybdate ($(NH_4)_6Mo_7O_{24}.4H_2O$) are obtained from Mark India Limited, Mumbai.

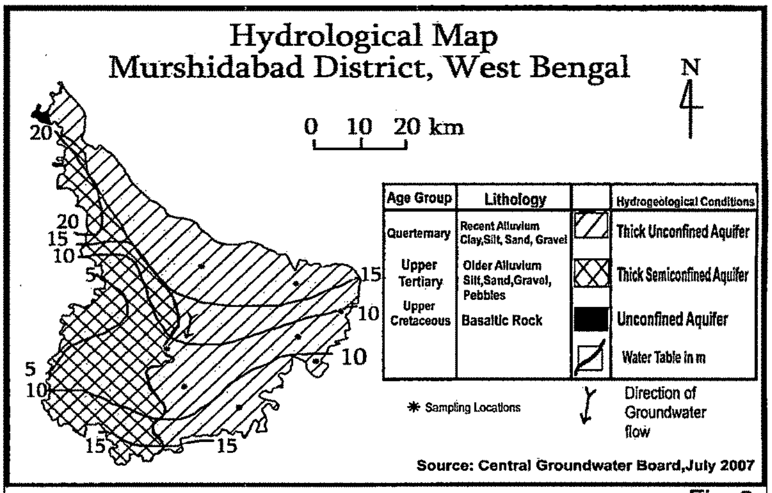

Fig. 2

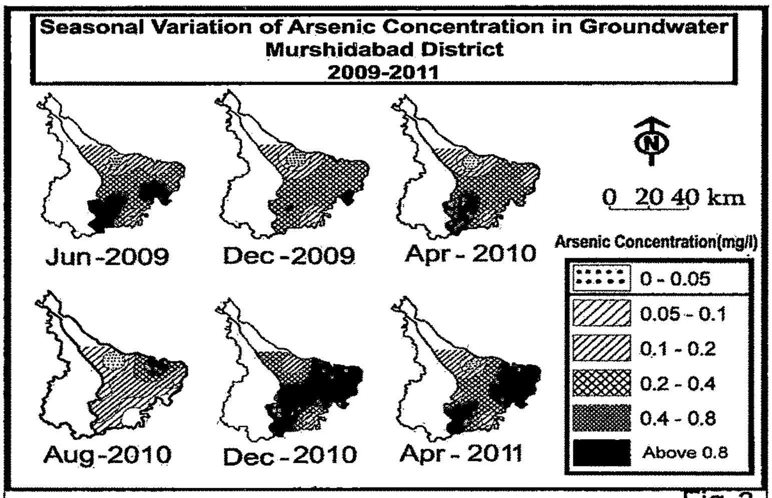

Fig. 3

Table 2: Concentration of Arsenic (mg/l) in Wells in different Seasons

Well ID	Monsoon 2009	Post-monsoon 2009	Pre-monsoon 2010	Monsoon 2010	Post-monsoon 2010	Pre-monsoon 2011	Mean
Well No.1	0.012	0	0	0.004	0.051	0.020	0.014
Well No.2	0.087	0.210	0.210	0.696	0.834	0.456	0.415
Well No.3	0.181	0.290	0.140	0.073	0.630	0.677	0.331
Well No.4	0.458	0.520	0.361	0.012	0.421	0.400	0.362
Well No.5	0.632	0.337	0.352	0.094	0.602	0.614	0.438
Well No.6	0.036	0.050	0.050	0	0.040	0.021	0.032
Well No.7	1.000	0.420	0.907	0.130	0.913	0.820	0.698
Well No.8	0.236	0.230	0.378	0.087	0.425	0.093	0.241

Table 3: Mean Monthly Rainfall (mm) of Murshidabad District

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec
2009	0.2	0	24.4	0	176.6	73.8	185.8	358.5	381.6	150.7	0	0
2010	0.2	0.1	0	0	88	263.5	100.9	171.3	174.4	89.9	2.0	50.4

Source: Indian Meteorological Department

3.0 Results and Discussion:

3.1 Spatial Pattern:

The level of arsenic is much higher than the permissible limit throughout the thick unconfined aquifer zone in all the seasons (monsoon 2009 to premonsoon 2011). Fluctuations are keenly observed in Well No.7, 8, 4, 5 and 3 where concentration varies between 1mg/l to 0.01mg/l. Contrary to this condition, consistency in the level is noticed in Well No.1 and Well No.6 blocks. In these two points the concentration of arsenic is below the permissible limit (0.05mg/l) in all the seasons. Fluctuations can be observed in the entire aquifer except in the two peripheral points laying in the extreme north and south (Table-2) (Fig. 3). Lithology of the area is helpful in explaining the pattern of arsenic concentration. In several parts clay layer is noticed in the upper part of the aquifer. Clay layer plays an important role in restricting the infiltration of water to the subsurface and act as an Aquitard.

Table 4: Mean Rainfall (mm) in different seasons

Year	Premonsoon (February to April)	Monsoon (May to October)	Winter (November to January)
2009	8.10	221.16	0.06
2010	0.03	148.00	52.7

In the eastern and the western part of this aquifer the layer of clay is either discrete, thin or absent. Contrary to this in the northern and southern part presence of clay layer is much more prominent (Mukherjee *et al.,* 2007). In the former condition water can easily infiltrate through the layers. In this condition dilution effect during monsoon season and drying effect during winter and premonsoon season are much more prominent leading to fluctuation. Such a phenomena is seen in Well No.7, 4, 5 and 8. Opposing to this presence of clay layer restrict easy infiltration of rainwater which delays the process of dilution and thus a consistent state is observed in Well No.1 and Well No.6 (Fig. 4).

3.2 Temporal Pattern:

Variations are noticed in the amount of rainfall in the years 2009 and 2010. The mean rainfall is 112 cm where as in 2010 it is just 78 cm (Table-3). Similar pattern is seen in the average rainfall of different seasons (2009-2011) (Table-3) (Fig. 5). Mean rainfall in 2009 (221.16 cm) and 2010 (148 cm) shows a decreasing trend during the monsoon season of 2010 (Table-4). In the premonsoon and winter seasons mean rainfall decreases considerably. 2009 monsoon data is taken in the month of July, which is just the onset of the heavy persistent rain period. The elevated amount of arsenic in the groundwater during 2009 monsoon is associated with it. (Fig. 6) Arsenic concentration fluctuation during these seasons is correlated in terms of its concentration. Definite relationship between the behavior of arsenic and rainfall intensity exists. With increasing rainfall intensity rate of dilution increases which minimizes the arsenic concentration in the groundwater (Farooq *et al.,* 2010). During monsoon period there is considerable decrease in the arsenic concentration. In monsoon 2009 the concentration varies between 1 to 0.01mg/l where as in 2010 the concentration rages between 0.69 to 0.004mg/l. In the case of Well No.7 (1mg/l) arsenic concentration does not vary significantly throughout the time (Fig. 7). This can be considered as the only exception. Thus it can be said that there is a strong correlation exists between rainfall condition, dilution effect and arsenic concentration. Contrary to this, during winter season and premonsoon seasons there is an increase in the concentration which is associated with the decrease in dilution effect. Lesser presence of rainwater in the aquifer triggers the mechanism of releasing arsenic in the shallow aquifer during Premonsoon and winter season. Well No.2 shows completely different pattern where during the monsoon 2010 shows concentration as high as 0.69mg/l and in winter 2010 it is 0.83 mg/l (Fig. 8). This type of pattern might be attributed due to local circumstances of the aquifer.

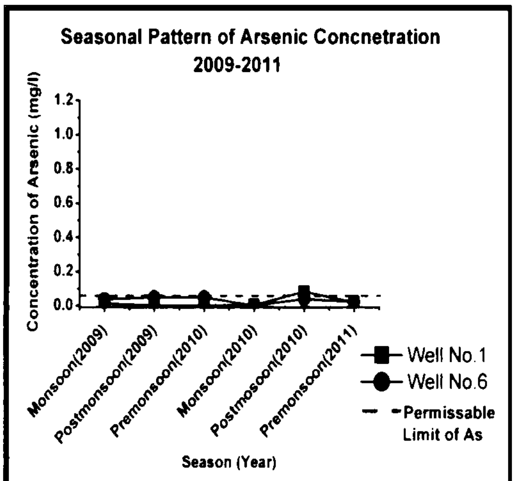

Fig. 4

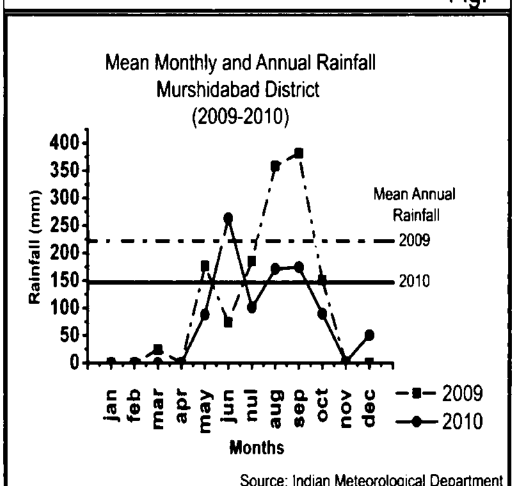

Fig. 5

4.0 Conclusions:

1. There is a prominent seasonal variability in the arsenic concentration in different wells in three different seasons.
2. There is an inverse relationship is found between the rainfall intensity and arsenic concentration.
3. The type of behavior of Arsenic is correlated with the subsurface lithology and layer of clay which is found to be an important parameter.

5.0 Acknowledgement:

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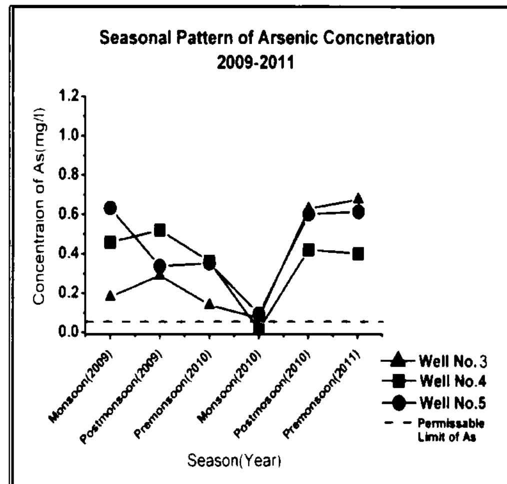

Fig. 6

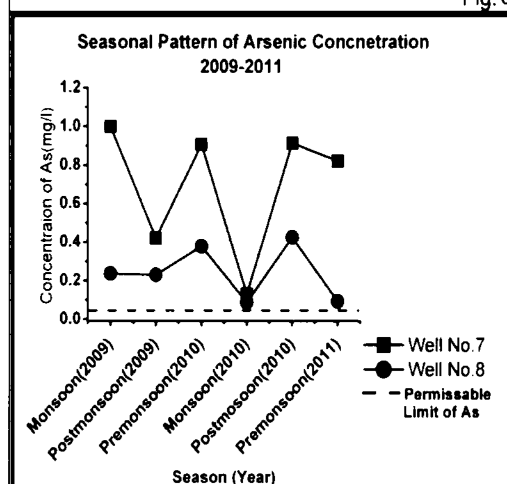

Fig. 7

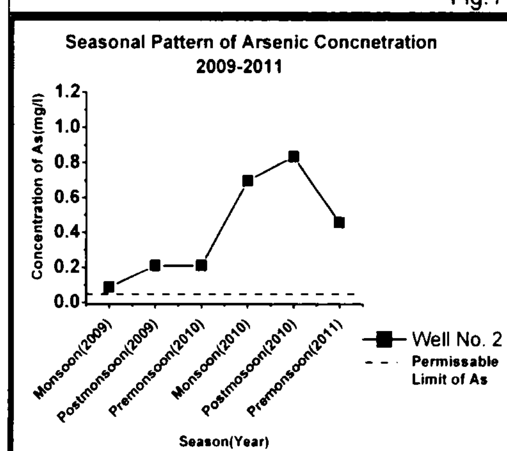

Fig. 8

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