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GIS Mapping of Correlation between Arsenic and Iron Concentration of Ground Water of Bangladesh

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Abstract: High iron concentration in the groundwater of Bangladesh was observed long ago. Existence of high arsenic concentration was observed in early 1990s. Determining iron concentration is cheaper and some indigenous methods are applied locally for such a purpose. Determining concentration of arsenic is more expensive and a relatively new issue even though the measurement is very important from monitoring point. The correlation between these two will ensure the possibility of simple and cheaper option for monitoring arsenic concentration from that of the iron concentration. This made the correlation analysis between arsenic and iron concentration of ground water more rational. In this study, data of 4367 wells were categorized for analysis as per geographic location in 61 administrative districts of Bangladesh. Results were compared with the results of analysis performed without categorizing data as per geographic locations. It is evident from the study that correlation between arsenic and iron concentration of ground water is not constant nationwide, rather it is a zonal phenomenon. Geographic Information Sustem (GIS) maps were produced with the correlation analysis data which represents the correlation status of each individual district of Bangladesh. Outcome of this study reveals that a zone or belt of a region can be observed within a band of similar correlation coefficient. From the analysis and produced GIS (Geographic Information System) maps it was observed that 50.4% districts of Bangladesh showed correlation coefficient in excess of 0.4 and 37% districts show correlation coefficient in excess of 0.5. In the eastern part of Bangladesh a belt of very low correlation was observed. The produced GIS maps and the study results enable to predict tentatively or statistically the arsenic concentration of a well by only knowing the iron concentration of the same well. This will help in reducing the need and thus cost for frequent measurement of arsenic in many areas where high correlation of the two is observed and reported.

Key words: GIS mapping, correlation, arsenic, iron, contamination.

Introduction

In Bangladesh, water extracted from shallow aquifers is the primary source of drinking and cooking water for most of its over 150 million population. The rural water supply is almost entirely based on groundwater through use of hand pump tube wells; an estimated ten million domestic wells constitute the backbone of rural water supply in the country. The urban water supply is also heavily dependent on groundwater. The discovery of widespread arsenic contamination of groundwater in Bangladesh has led to a need for frequent monitoring of water quality. The national hydrogeochemical survey of groundwater conducted by the British Geological Survey

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(BGS) and the Department of Public Health Engineering (DPHE) have shown that large numbers of wells in Bangladesh also exceed permissible limits for iron (Fe) and arsenic (As) (BGS, DPHE, 2001). Arsenic contamination in groundwater has originated in the Indian state of West Bengal and neighbouring Bangladesh, particularly on the east side of the Ganges-Bhagirati contaminating ground water of Bangladesh (Karim Md. Masud, 2000). The eastern part (most of the deltaic region) of Bangladesh is affected by arsenic contamination. The aquifer of the contaminated zone in West Bengal and that of Bangladesh are hydro geologically connected. Arsenic occurrence in groundwater in some part of Bangladesh is so severe that it has caused a national problem. The World Health Organization (WHO) has set guideline value for arsenic in drinking water as 0.01 mg/L (WHO, 1993). Department of Environment (DoE) of Bangladesh has set the standard value of arsenic for Bangladesh as 0.05 mg/L (DoE, 1991). For drinking water allowable limit for iron is 0.3 to 1 mg/L. But in Bangladesh iron content is very high in ground water.

Measurement of arsenic concentration in water is very expensive wbich requires modern laboratory facility and expensive chemicals. Determination of iron concentration is relatively simpler and cheaper than that of determination of concentration of arsenic and also easily available in Bangladesh. GIS – one tool for decision making was used in the study to describe the geographical distribution of the correlation between arsenic and iron concentration in ground water. By using the regression analysis and GIS maps of correlation between the two parameters the presence of arsenic in a well can be tentatively predicted by testing the presence of iron of the same well only. This can save a lot of money if it is used in a large scale. This map will also show the population vulnerable due to high arsenic and iron content of ground water of Bangladesh.

The correlation is one of the most common and most useful statistics. A correlation is a single number that describes the degree of relationship between two variables. The measurement scales used should be at least interval scales but other correlation coefficients are available to handle other types of data. Correlation coefficients can range from –1.00 to +1.00. The value of –1.00 represents a perfect negative correlation while a value of +1.00 represents a perfect positive correlation. A value of 0.00 represents no correlation.

Data Collection

The national hydrochemical survey of groundwater conducted by the British Geological Survey (BGS) and the Department of Public Health Engineering (DPHE), Bangladesh in 2001 (BGS–DPHE, 2001) presented water quality data of 3364 wells. This data was a major source of the study. Data of another survey conducted by DPHE in 2007 for the second phase of DPHE–JICA project in the south-eastern part of Bangladesh was also used in this research. Those two data sets were compiled together to form a water quality data base of 4367 wells. Data of 61 administrative districts of Bangladesh was thus available for analysis. Data of Rangamati, Bandorban and Khagrachori are not available for analysis.

Methodology

Data base of 4367 wells was categorized as per geographical location of Bangladesh. Bangladesh has 64 administrative districts but data of 61 districts is available for analysis. This leads to separation of 61 sets of water quality data which includes arsenic and iron concentration of ground water. Initially correlation analysis was performed taking all the data together. Later, correlation analysis was performed for each district separately.

A comprehensive correlation map of different areas of Bangladesh was developed using GIS. Results of data analysis for different districts were used to prepare this correlation map. Regression models were also developed for each district so that the arsenic concentration in a well can be tentatively verified by testing the presence of iron of the same well in the same district.

Result and Discussion

Total 4367 number of data were used for analysis in this study. Data of 61 administrative districts of Bangladesh were available (Table 1) for analysis. Arsenic concentration in 38.2% of data exceeds the WHO guideline value of 10 µg/L. For Bangladesh, Department of Environment (DoE, 1997) sets the arsenic standard for drinking water to be 50 µg/L. 20.3% of data exceeds the standard value of 50 µg/L for drinking water.

Minimum number of samples (15 data) are available for Meherpur and maximum (250 data) for Jessore. Munshiganj, Chandpur, Noakhali, Meherpur, Gopalganj, Lakshmipur, Faridpur, Bagerhat, Satkhira, Comilla, Narail and Chuadanga are the 12 most arsenic contaminated districts. On the other hand Sirajganj, Sylhet,

Table 1: Distribution of data for 61 districts of Bangladesh

District	*Number of wells*	*% of wells exceeding As>50 μg/L*	*% of wells exceeding Fe>5 mg/L*	*District*	*Number of wells*	*% of wells exceeding As>50 μg/L*	*% of wells exceeding Fe>5 mg/L*
Bagerhat	78	47.4	43.6	Magura	62	9.7	8.1
Barguna	48	0.0	0.0	Manikganj	47	14.9	38.3
Barisal	92	30.4	15.2	Maulvibazar	60	10.0	48.3
Bhola	48	4.2	2.1	Meherpur	15	60.0	6.7
Bogra	94	8.5	16.0	Munshiganj	46	82.6	30.4
Brahamanbaria	93	22.6	9.7	Mymensingh	109	12.8	6.4
Chandpur	68	77.9	30.9	Naogaon	92	2.2	6.5
Chittagong	109	6.4	22.0	Narail	24	41.7	29.2
Chuadanga	34	41.2	11.8	Narayanganj	37	18.9	10.8
Comilla	173	42.2	11.0	Narsingdi	63	23.8	11.1
Cox's Bazar	62	1.6	27.4	Natore	51	0.0	2.0
Dhaka	57	24.6	29.8	Nawabganj	45	4.4	2.2
Dinajpur	94	2.1	8.5	Netrokona	76	27.6	25.0
Faridpur	74	55.4	28.4	Nilphamari	53	0.0	17.0
Feni	60	28.3	16.7	Noakhali	49	69.4	6.1
Gaibandha	71	7.0	40.8	Pabna	78	16.7	16.7
Gazipur	44	2.3	0.0	Panchagarh	39	0.0	7.7
Gopalganj	58	56.9	34.5	Patuakhali	61	0.0	1.6
Habiganj	82	7.3	41.5	Pirojpur	54	14.8	7.4
Jaipurhat	40	0.0	7.5	Rajbari	47	17.0	17.0
Jamalpur	63	6.3	33.3	Rajshahi	78	6.4	3.8
Jessore	250	13.2	8.0	Rangpur	86	1.2	34.9
Jhalakati	33	6.1	3.0	Satkhira	88	46.6	23.9
Jhenaidah	103	13.6	7.8	Shariatpur	81	39.5	17.3
Khulna	93	18.3	10.8	Sherpur	51	11.8	27.5
Kishoreganj	169	17.2	11.2	Sirajganj	89	23.6	51.7
Kurigram	77	9.1	44.2	Sunamganj	87	32.2	19.5
Kushtia	59	22.0	16.9	Sylhet	88	15.9	50.0
Lakshmipur	34	55.9	11.8	Tangail	91	8.8	45.1
Lalmonirhat	39	0.0	15.4	Thakurgaon	46	0.0	4.3
Madaripur	75	37.3	14.7				

Moulovibazar, Tangail, Kurigram, Bagerhat, Habiganj, Gaibandah, Manikganj, Rangpur, Gopalganj, Jamalpur, Chandpur and Munshiganj are the 14 most iron contaminated districts.

All available data were used to analyse (Table 2) the correlation between arsenic and iron concentration. The correlation coefficient is 0.195. Figure 1 represents the graphical variation.

Soil profile varies as the major part of Bangladesh is on the delta formed by the three major rivers Brahmaputra, Ganges and Meghna. This leads to an idea that correlation of arsenic and iron concentration of ground water may be a zonal phenomenon rather than a national phenomenon. When district-wise categorized data were analysed, correlation coefficient varied at different locations of Bangladesh. Results of correlation analysis as per geographical locations are provided in the Table 3.

Correlation analysis (Table 2) was performed using all available (4367 number) data without district wise categorization as per geographical locations, correlation coefficient which was found to be 0.192 is very insignificant. When all the data were reorganized as per their location, correlation coefficient improved in most of the districts drastically (Table 3). In Panchagar the value of the coefficient is 0.932 (Figure 4) which shows strong correlation. Significance level of this value is 0.0001 which shows that less than 0.01% chance that this correlation occurred by chance. Correlation coefficient of 23 districts exceeds 0.5 which is 38% of all the districts (Figure 2). On the other hand 50.4% districts show correlation coefficient in excess of 0.4 (Figure 3).

Munshiganj, Chandpur, Noakhali, Meherpur, Gopalganj, Lakshmipur, Faridpur, Bagerhat, Satkhira, Comilla, Narail and Chuadanga are the 12 most arsenic contaminated districts (Table 1). Arsenic contamination ranges from 40% to 80% of wells of these districts. Figure 5 shows the correlation coefficient of these 12 most arsenic contaminated districts.

Barguna, Jaipurhat, Lalmonirhat, Natore, Nilphamari, Panchagarh, Patuakhali, Thakurgaon, Rangpur, Cox's

Table 2: Correlation between arsenic and iron using all available data

Correlation coefficient	0.195
Number of Data	4367
Significance	0.0001

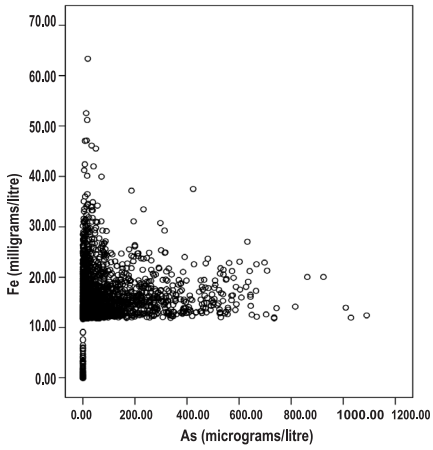

Figure 1: Variation of arsenic vs iron concentration of ground water of Bangladesh.

Table 3: Correlation coefficients of 61 districts of Bangladesh and the significance level of the result

District	*Correlation coefficient*	*Significance level*	*District*	*Correlation coefficient*	*Significance level*
Bagerhat	0.55	0.0001	Magura	0.61	0.0001
Barguna	0.36	0.011	Manikganj	0.44	0.002
Barisal	0.60	0.0001	Maulvibazar	0.02	0.871
Bhola	0.86	0.0001	Meherpur	0.69	0.004
Bogra	0.43	0.0001	Munshiganj	0.15	0.318
Brahamanbaria	0.19	0.069	Mymensingh	0.76	0.0001
Chandpur	0.11	0.381	Naogaon	0.20	0.051
Chittagong	–0.08	0.439	Narail	0.66	0.0001
Chuadanga	0.51	0.002	Narayanganj	0.43	0.008
Comilla	0.14	0.076	Narsingdi	0.53	0.0001
Cox's Bazar	–0.05	0.701	Natore	0.47	0.0001
Dhaka	0.44	0.001	Nawabganj	0.21	0.175
Dinajpur	0.72	0.0001	Netrokona	0.31	0.007
Faridpur	0.58	0.0001	Nilphamari	0.82	0.0001
Feni	–0.07	0.587	Noakhali	0.05	0.729
Gaibandha	0.10	0.394	Pabna	0.33	0.004
Gazipur	0.27	0.073	Panchagarh	0.93	0.0001
Gopalganj	0.58	0.0001	Patuakhali	0.30	0.021
Habiganj	0.09	0.428	Pirojpur	0.60	0.0001
Jaipurhat	0.21	0.193	Rajbari	0.56	0.0001
Jamalpur	0.45	0.0001	Rajshahi	0.53	0.0001
Jessore	0.39	0.0001	Rangpur	0.46	0.0001
Jhalakati	0.88	0.0001	Satkhira	0.48	0.0001
Jhenaidah	0.36	0.0001	Shariatpur	0.68	0.0001
Khulna	0.36	0.0001	Sherpur	0.17	0.233
Kishoreganj	0.62	0.0001	Sirajganj	0.19	0.071
Kurigram	0.19	0.105	Sunamganj	–0.16	0.139
Kushtia	0.07	0.579	Sylhet	0.11	0.289
Lakshmipur	0.06	0.752	Tangail	0.33	0.002
Lalmonirhat	0.67	0.0001	Thakurgaon	0.56	0.0001
Madaripur	0.74	0.0001			

Bazar, Dinajpur and Naogaon are the least arsenic contaminated districts. Figure 6 shows the correlation coefficient of these districts.

50% of these 12 most arsenic contaminated districts show correlation coefficient greater than 0.5. Similarly 50% of the 12 least arsenic contaminated districts show correlation coefficient greater than 0.5.

This district-wise correlation analysis of arsenic and iron reveals that correlation of arsenic and iron in ground water is a zonal phenomenon. Soil character is different in different parts of Bangladesh which leads to the difference in correlation. It is due to the difference in sediment characteristics throughout the country. Sediments are typical of alluvial and deltaic sediments with normal amounts of arsenic, mainly in the 1–10mg kg^{-1} range for total arsenic (BGS–DPHE, 2001). This normal amount of arsenic is sufficient to give excessive arsenic in the groundwater if dissolved or desorbed in sufficient quantity. Arsenic-rich ground water is tended to be found in areas with sediments containing relatively high concentrations of oxalate-extractable iron and arsenic (BGS–DPHE, 2001). Results of this correlation analysis also reveal the fact that zonal difference in sediment characteristic instigates the difference of correlation between arsenic and iron concentration of ground water.

GIS map (Figure 7) represents the zonal correlation status of Bangladesh. Data of 61 districts were separated as per their geographical locations. Figure 8 shows the districts which have correlation coefficient between 0.4 and 0.6. Bagerhat, Gopalganj Faridpur, Rajbari, Manikganj, Dhaka, Narayanganj and Narshingdi form a belt which shows similar correlation between As and Fe. Another similar type of belt is found around Rajshahi, Natore, Bogra and Jamalpur districts.

The total range of coefficient was divided into five groups for mapping. They are 0–0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1. Districts falling in each of these groups are mapped with same colours. Figure 7 represents the zonal correlation status of Bangladesh. Data of 61

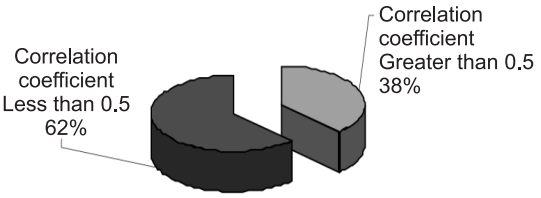

Figure 2: Percentage of districts showing correlation coefficient greater than 0.5.

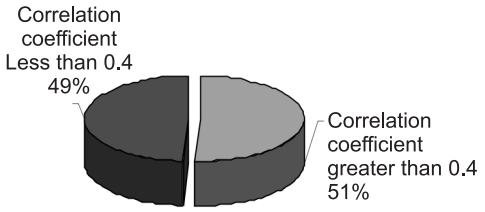

Figure 3: Percentage of districts showing correlation coefficient greater than 0.4.

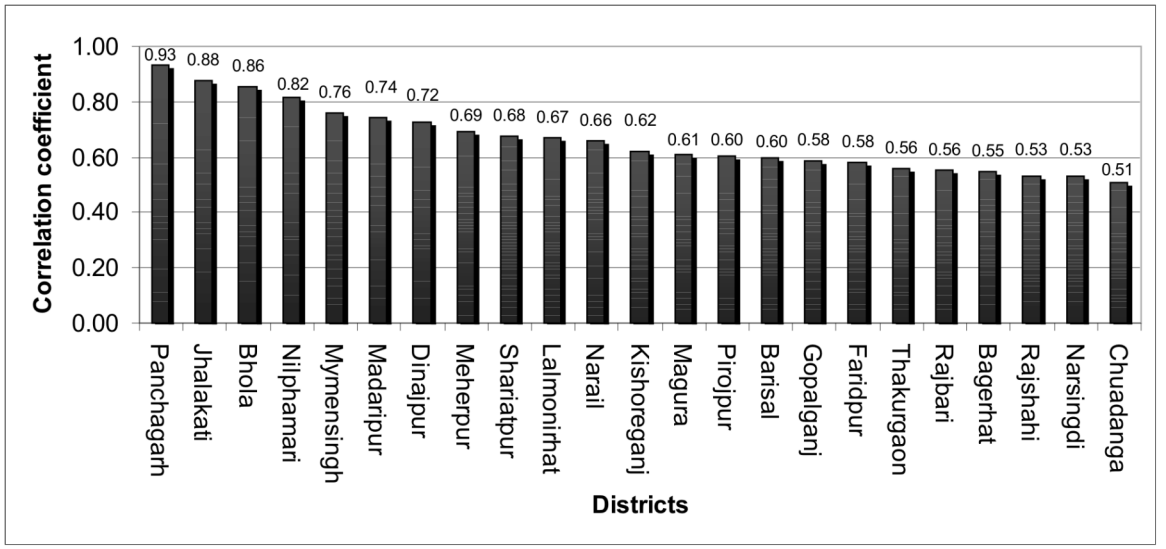

Figure 4: Districts showing correlation coefficient greater than 0.5.

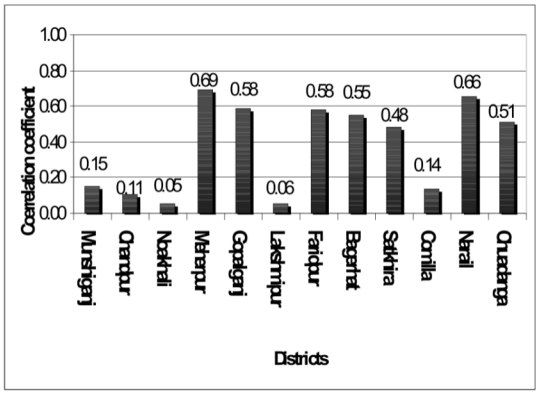

Figure 5: Correlation coefficient of 12 most arsenic contaminated districts.

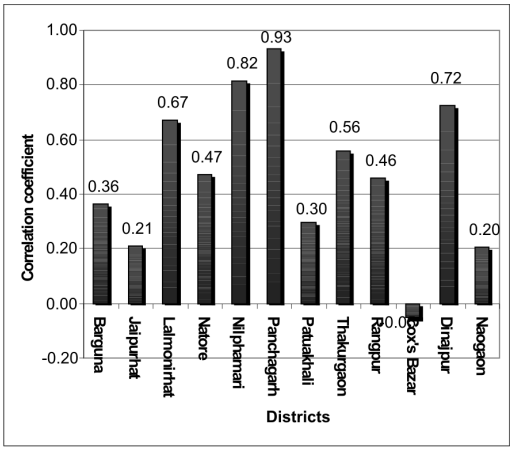

Figure 6: Correlation coefficient of 12 least arsenic contaminated districts.

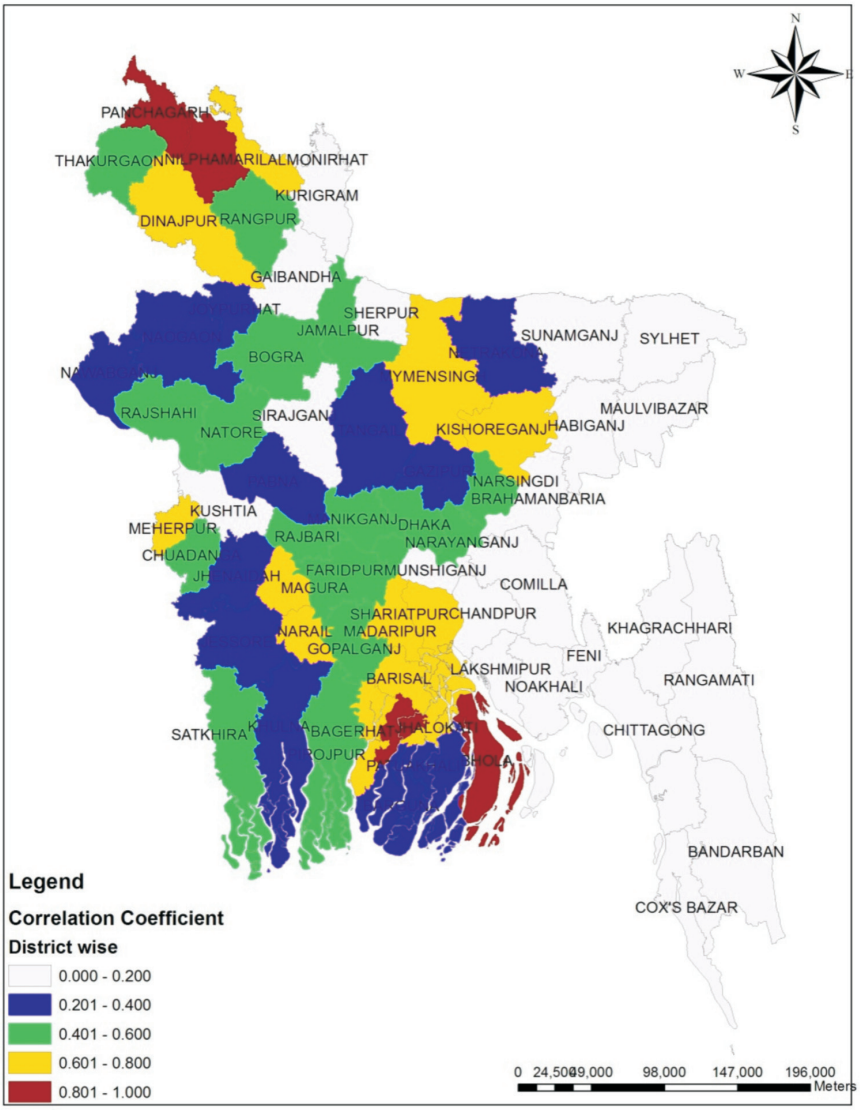

Figure 7: GIS map of correlation between arsenic and iron concentration of ground water of Bangladesh.

districts were separated as per their geographical locations. It can be summarized (Figure 7) that districts of similar range of correlation coefficient reside in a close belt. A belt of districts showing less correlation can be found in Khulna, Jessore, Jhinaidah, Kustia, Pabna, Sirajganj, Tangail Gazipur. Figure 8 shows the districts which have correlation coefficient between 0.4 and 0.6. Bagerhat, Gopalganj Faridpur, Rajbari, Manikganj, Dhaka, Narayanganj and Narshingdi form a belt which shows similar correlation between As and Fe. If this 0.4–0.6 range is considered as moderate correlation then this belt represents moderate correlation.

For experimental analysis correlation coefficient between the ranges of 0.4 to 0.8 is statistically considered moderate to high. If this ranges of data are separated from the GIS map, Figure 9, can be produced to show the districts of moderate to higher correlation coefficients between arsenic and iron concentration. It is evident from Figure 9 that a belt of similar correlation (moderate to high) exists in the middle and southern part of Bangladesh.

Mymensingh, Kishoreganj, Magura, Narail, Shariatpur, Barishal and Pirojpur districts show correlation coefficient between 0.6 and 0.8. If these seven districts are added with the map shown in Figure 8 another map can be produced (Figure 9) for similar correlation zone. There is a high possibility that similar sort of sediment characteristics trigger this zone of similar correlation between arsenic and iron concentration.

Correlation coefficient between the ranges of 0.4 to 1 is statistically considered moderate to higher. Figure 10 shows the districts which have correlation coefficient between 0.4 and 1. Pirojpur and Bhola are showing higher correlation coefficient between 0.8 and 1. Adding these districts with the map shown in Figure 9 makes a complete zone of moderate to higher arsenic and iron correlation map. This reveals that a geographical belt is evident where correlation between arsenic and iron concentration of ground water is moderate to higher. Another similar type of zone of moderate to higher correlation coefficient is found in the northern part of Bangladesh. Panchagarh, Thakurgaon, Nilphamari,

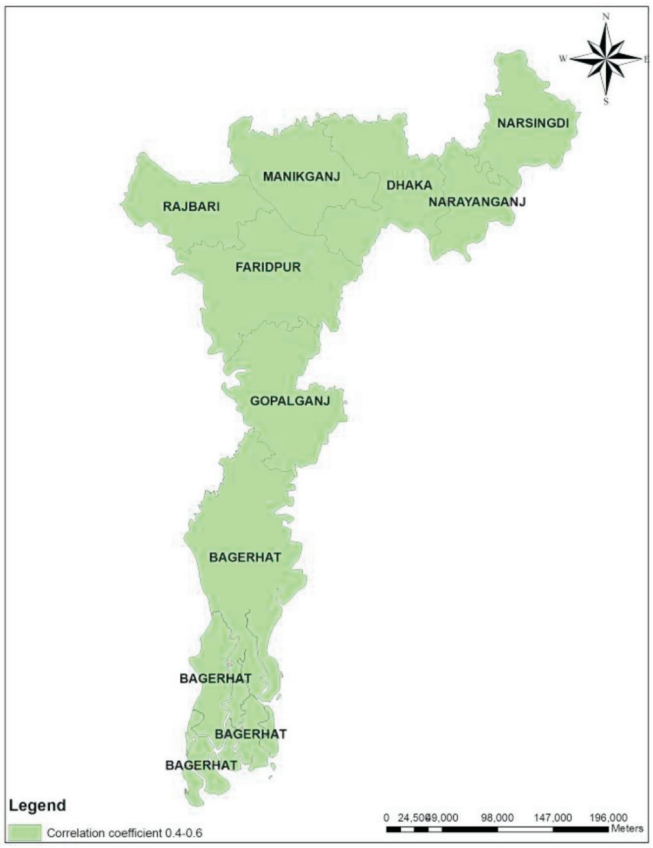

Figure 8: Districts showing correlation coefficient in the range between 0.4 and 0.6.

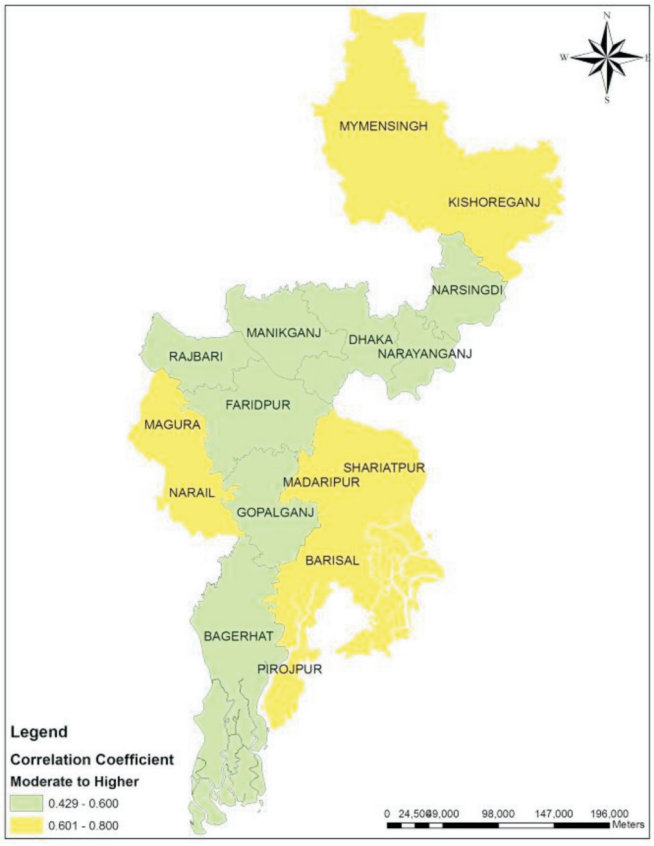

Figure 9: Districts showing correlation coefficient in the range between 0.4 and 0.8.

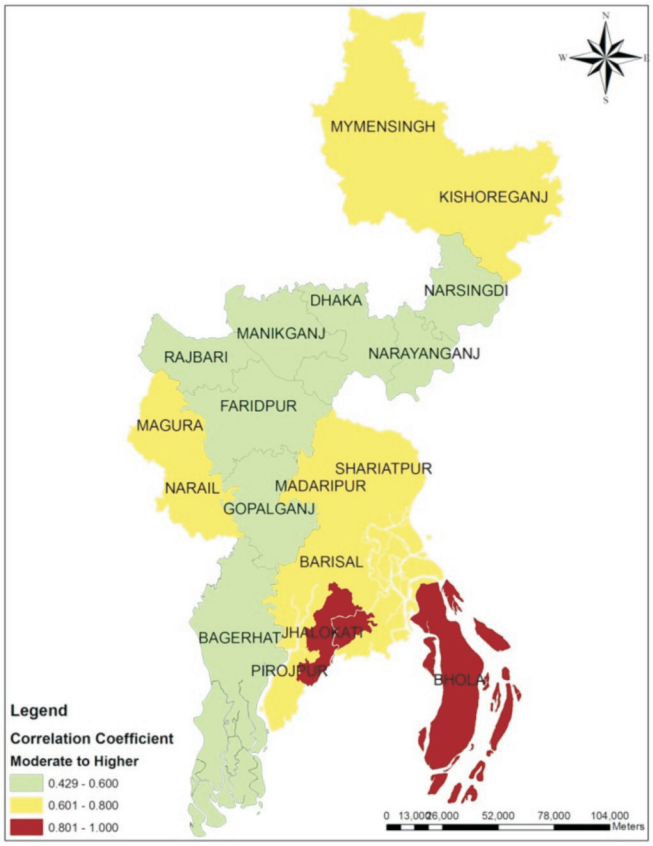

Figure 10: Districts showing correlation coefficient in the range between 0.4 and 1.

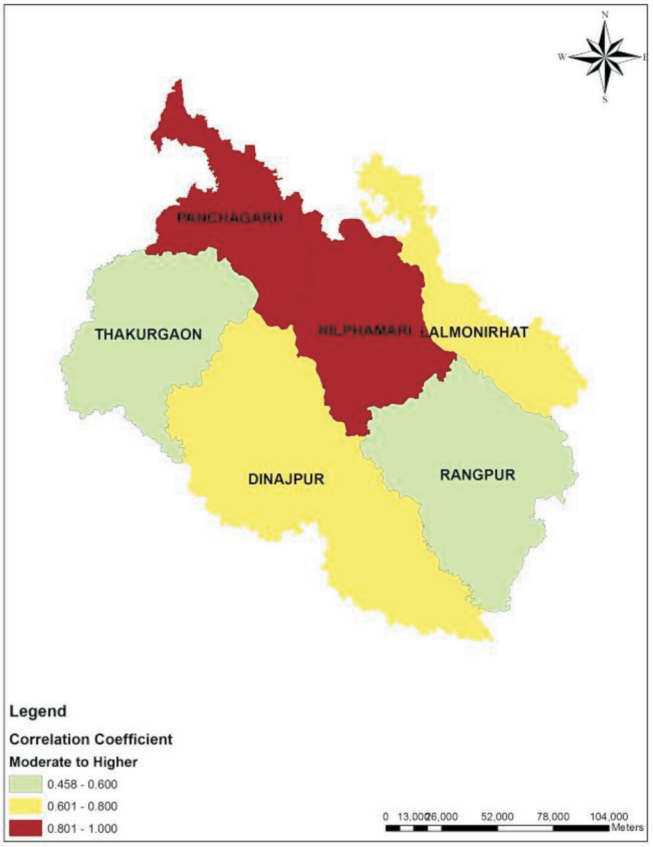

Figure 11: Districts in the northern part of Bangladesh showing correlation coefficient in the range between 0.4 and 1.

Lalmonirhat, Dinajpur and Rangpur districts show correlation in a range between 0.4 and 1 (Figure 11).

Seven out of twelve most arsenic contaminated districts show moderate to high correlation. But Chandpur, the most As contaminated district shows very little correlation (0.108). On the other hand six out of twelve least arsenic contaminated districts show very little correlation.

Table 4 shows the state of arsenic contamination in the districts which show moderate to higher correlation coefficient. Eight out of seventeen of these districts have more than 20% of their wells contaminated by arsenic. It means that 47% of these 17 districts, which show moderate to higher correlation coefficient, are arsenic contaminated.

An important observation from the maps (Figures 7, 8, 9, 10, 11, 12) is – correlation pattern is not scattered over the country. In most of the cases a belt of similar correlation pattern in observed. A belt of low correlation zone is found in the eastern part on the country. Sylhel, Moulovibazar, Habiganj, Sumanganj, Brahmanbaria, Comilla, Cox's Bazar are the districts forming a belt which shows almost no correlation (Figure 12).

Table 4: State of arsenic contamination in the districts which are showing moderate to higher correlation coefficient

District	*% of wells exceeding As>50 µg/L*
Faridpur	55.4
Bagerhat	47.4
Narail	41.7
Shariatpur	39.5
Madaripur	37.3
Barisal	30.4
Dhaka	24.6
Narsingdi	23.8
Narayanganj	18.9
Kishoreganj	17.2
Rajbari	17.0
Manikganj	14.9
Pirojpur	14.8
Mymensingh	12.8
Magura	9.7
Jhalakati	6.1
Bhola	4.2

Figure 12: Districts in the eastern part of Bangladesh showing less or no correlation.

Regression Analysis of Data

It is evident from the analysis that correlation between arsenic and iron concentration is not a national phenomenon rather it is a zonal phenomenon. Therefore an attempt has been made to correlate arsenic and iron for the zones where correlation coefficient between arsenic and iron concentration is higher. When regression analysis was performed using the data separating them as per their geographical locations results were found as shown in Table 5. In this analysis arsenic is taken as the dependent variable.

Linear model (Equation 1) was assumed for regression analysis between arsenic and iron. A and B are the constants of the regression model. In this model iron concentration is taken as milligram/Litre and arsenic concentration as microgram/Litre. In Table 5 "r-square" value for each model is provided. "r-square" is the square of correlation coefficient "r" and it represents the proportion of variance in one variable accounted for (or explained) by the other variable.

$$\text{Arsenic } (\mu g/L) = A + (B)\ (\text{Iron in mg/L}) \quad (1)$$

where A, B = constants from regression model

Using this regression model for 61 districts of Bangladesh (Table 5) arsenic concentration of any well of those districts can be tentatively measured, if iron concentration of that well is known.

For example, the iron concentration of a well of Bagerhat district, Thana kochua, union Raripar and mouza Bandarkhola (Lat 22.606, Long 89.85) is found to be 9.4 mg/L. From Table 5 the value of regression coefficients found of the regression model for Bagerhat district are found to be 39.37 and 17.019. The equation for this district becomes like the following one.

$$\text{Arsenic } (\mu g/L) = A + (B)\ (\text{Iron in mg/L})$$

$$\text{Arsenic } (\mu g/L) = 39.37 + 17.019(9.4)$$

$$= 199.35$$

r-square for this value is 0.3.

Actual arsenic concentration of that well was measured as 177 µg/L.

Conclusion

Total 4367 number of data is used for analysis in this research. Data of 61 administrative districts of Bangladesh were available for analysis. When all the data were used collectively and analysed without any grouping, the correlation coefficient was found to be very insignificant of 0.195. When the data were separated as per geographical location which is 61 districts of Bangladesh the correlation coefficient varied significantly in different districts. 37.7% districts showed correlation coefficient more than 0.5 which is considered to be moderate to high correlation. 50.4% districts shows correlation coefficient more than 0.4

GIS maps were produced with the results of the analysis. GIS map in Figure 7 shows the nation wide correlation status. GIS map in Figure 8 shows the districts which has correlation coefficient between 0.4 and 0.6. Bagerhat, Gopalganj Faridpur, Rajbari, Manikganj, Dhaka, Narayanganj and Narshingdi forms a belt which shows similar correlation between As and Fe. If we consider this 0.4–0.6 range moderate correlation, then this belt shows moderate correlation. Another similar type of belt is found in Rajshahi, Natore, Bogra and Jamalpur districts. If 0.6 to 1 is considered to be as high correlation coefficient then through Figure 10 shows the districts which has moderate to high correlation between As and Fe. This reveals that a geographical belt exists where correlation between arsenic and iron concentration of ground water is moderate to high.

Seven out of twelve most arsenic contaminated districts show moderate to high correlation. But Chandpur, the most As contaminated district shows very little correlation (0.108). Six out of twelve least arsenic

Table 5: Regression model for 61 districts of Bangladesh

District	*A*	*B*	*r-square*	*District*	*A*	*B*	*r-square*
Bagerhat	37.92	17.02	0.299	Magura	4.22	19.93	0.372
Barguna	0.73	1.94	0.132	Manikganj	13.02	2.42	0.191
Barisal	23.85	36.04	0.36	Maulvibazar	18.52	0.12	0.000
Bhola	–4.21	31.63	0.734	Meherpur	–10.96	48.44	0.482
Bogra	4.04	4.53	0.187	Munshiganj	164.95	5.20	0.023
Brahamanbaria	43.07	6.53	0.036	Mymensingh	4.65	8.44	0.579
Chandpur	287.12	7.60	0.012	Naogaon	2.82	2.38	0.042
Chittagong	21.61	–0.60	0.006	Narail	38.44	14.29	0.432
Chuadanga	5.12	30.00	0.261	Narayanganj	22.75	7.52	0.184
Comilla	79.33	7.59	0.018	Narsingdi	20.20	11.05	0.281
Cox's Bazar	4.84	–0.09	0.003	Natore	0.98	1.43	0.223
Dhaka	16.21	5.05	0.194	Nawabganj	5.35	1.84	0.042
Dinajpur	–0.22	2.23	0.524	Netrokona	28.00	4.08	0.095
Faridpur	25.79	25.92	0.338	Nilphamari	–0.05	0.79	0.664
Feni	50.87	–1.11	0.005	Noakhali	154.98	5.61	0.003
Gaibandha	14.98	1.18	0.011	Pabna	17.14	6.78	0.106
Gazipur	0.64	7.25	0.075	Panchagarh	0.49	0.83	0.869
Gopalganj	46.78	20.67	0.341	Patuakhali	3.36	1.39	0.087
Habiganj	15.29	0.56	0.008	Pirojpur	–1.93	14.61	0.361
Jaipurhat	1.17	0.16	0.044	Rajbari	9.76	10.48	0.308
Jamalpur	1.73	3.00	0.203	Rajshahi	3.20	6.20	0.283
Jessore	9.40	9.79	0.153	Rangpur	–2.29	2.45	0.210
Jhalakati	–19.91	48.50	0.767	Satkhira	27.96	20.78	0.231
Jhenaidah	7.39	11.43	0.131	Shariatpur	11.50	32.35	0.457
Khulna	12.44	9.54	0.128	Sherpur	18.47	0.76	0.029
Kishoreganj	2.54	16.93	0.387	Sirajganj	21.91	1.17	0.037
Kurigram	13.22	1.22	0.035	Sunamganj	47.24	–1.81	0.026
Kushtia	68.21	7.45	0.005	Sylhet	19.12	0.34	0.013
Lakshmipur	168.14	4.18	0.003	Tangail	9.66	2.04	0.106
Lalmonirhat	0.36	0.44	0.449	Thakurgaon	0.55	0.46	0.310
Madaripur	1.09	46.03	0.552				

contaminated districts show very little correlation. A belt of districts showing less correlation can be found in Khulna, Jessore, Jhinaidah, Kustia, Pabna, Sirajganj, Tangail Gazipur. Arsenic-iron correlation pattern is not scattered over the country (Figure 7). In most of the cases a belt of similar correlation pattern in observed. Such a less correlative zone is found in the eastern part on the country (Figure 12). Sylhel, Moulovibazar, Habiganj, Sumanganj, Brahmanbaria, Comilla, Cox's Bazar etc districts are forming a belt which shows almost no correlation.

Recommendations

The present study analyses the correlation between arsenic and iron on an administrative zone basis in the groundwater samples of Bangladesh. Further study is needed where the analysis is performed considering (i) the variation of groundwater depth and (ii) the concentration of arsenic and iron, in the ground water.

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