Data Collection

The national hydrochemical survey of groundwater conducted by the British Geological Survey (BGS) and the Department of Public Health Engineering (DPHE) in 2001 (BGS, DPHE, 2001) presented water quality data of 3364 wells. Those data were a major source of this study. Data of another survey conducted by DPHE in 2007 for the 2nd 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 of 61 among 64 administrative districts of Bangladesh are available for analysis. This leads to separation of 61 sets of water quality data which includes arsenic and iron concentration of ground water. Correlation analysis was performed in four different patterns (Table 1). In pattern-01 analysis was performed without categorizing any data. In pattern-02 correlation analysis was performed by separating data as per depth of wells. In pattern-03 correlation analysis was performed by separating data as per geographical location which is 61 administrative districts of Bangladesh. In pattern-04 data were separated both by geographic locations and depth of wells. Aquifer classification as per Ground Water Task Force shown in Fig 1 shows two models of wells, Old and New. In this study old model of classification was followed as all the wells of the data set of this study lies within the three layers shown in this model, 0 to 50m, 51 to 150m and greater than 150m (Fig 1). These three depth layers are termed in this research as D1, D2 and D3 respectively.

Table: 1 Analysis patterns used in this study.

	Depth Variation	Geographical Location
Pattern-01	X	X
Pattern-02	√	X
Pattern-03	X	√
Pattern-04	√	√

X = not considered, √ = Considered

Four different comprehensive correlation maps of different area of Bangladesh was developed using Geographic Information System (GIS) software. Results of data analysis of four different patterns showed in Table 1 were used to prepare these correlation maps. Regression models were also developed for each depth layers of each district so that the presence of arsenic in a well of each district can be tentatively verified by testing the presence of iron of the same well only.

Result and Discussion

Total 4367 number of data is used for analysis in this study. Data of 61 administrative districts of Bangladesh were available for analysis. In this analysis wells are classified in three depth layers. One group is less than 50m depth (D1). Another one is between 50m to 150m depth (D2). The last one is greater than 150m depth (D3). The first depth range D1 is chosen as depth below 50m which is the most common source of palatable water through hand tube well in the village areas of Bangladesh.

More over depth of 56.23% sample of this analysis is less than 50m where arsenic problem is acute (Fig 3). The second range D2 in which well depth of 20% sample lies. In this layer arsenic concentration is less acute than the first layer. The least contaminated layer is depth greater than 150m (D3) in which 23.67% sample lies.

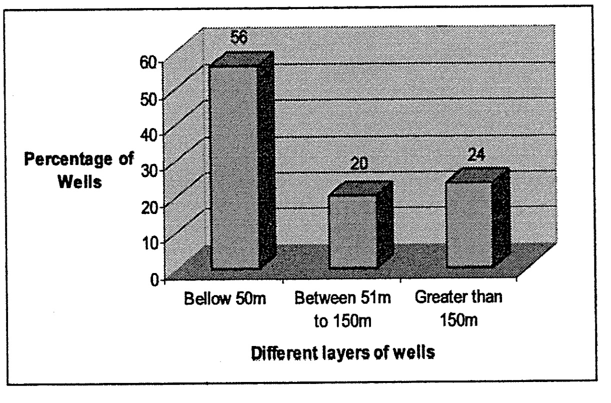

Figure 3: Percentage of wells in each depth group.

If the depth range of wells below 50m, wells between 50m to 150m and wells above 150m depth are termed as 1, 2 and 3 respectively. The graphical representation of arsenic and iron concentration in these layers can be shown in Figure 4. In D1 (Termed as 1 in Fig 4) both arsenic and iron concentration is higher than the other two depth ranges. In D3 group (Termed as 3 in Fig 4) less concentration of both arsenic and iron are observed.

When the data of 4367 wells were analyzed it was found that total 38.2% of data exceed the WHO guideline value of *As* of 10μg/L. Among these 34.5% data which are of shallow wells (Depth<150m) exceeds WHO guideline value of 10μg/L. For Bangladesh DoE (DoE, 1997) sets the arsenic guideline value as 50μg/L. For this 20.3% data exceeds the Bangladesh standard of 50μg/L. Problem is more acute in shallow wells as it shows 20.1% data exceeding the Bangladesh standard. Only 0.1%

of deep wells exceed Bangladesh standard. The results are shown in the tabular form in the tables 2 and 3.

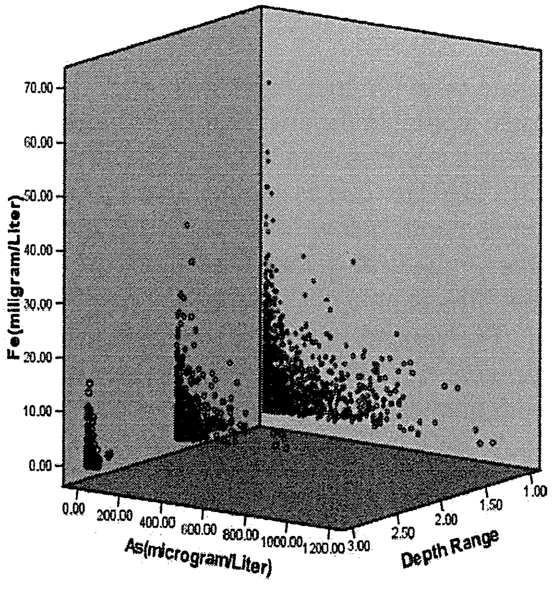

Figure 4: Depth variation for arsenic and iron.

Table 2: Frequency and Percentage of wells exceeding Bangladesh standards of arsenic.

	Frequency	Percent	Cumulative Percent
As>50μg/L Depth<50m	689.0	15.8	15.8
As>50μg/L Depth 50m-150m	190.0	4.4	20.1
As>50μg/L Depth>150m	6.0	0.1	20.3
As<50μg/L Depth<50m	1767.0	40.5	60.7
As<50μg/L Depth 50m-150m	687.0	15.7	76.5
As<50μg/L Depth>150m	1028.0	23.5	100.0
Total	4367.0	100.0	

Table 3: Frequency and Percentage of wells exceeding WHO standards of arsenic.

	Frequency	Percent	Cumulative Percent
As>10µg/L Depth<50m	1097.0	25.1	25.1
As>10µg/L Depth 50m-150m	408.0	9.3	34.5
As>10µg/L Depth>150m	165.0	3.8	38.2
As<10µg/L Depth<50m	1359.0	31.1	69.4
As<10µg/L Depth 50m-150m	469.0	10.7	80.1
As<10µg/L Depth>150m	869.0	19.9	100.0
Total	4367.0	100.0	

All available data irrespective of combination and depth range were analyzed (Table 4) to find the correlation between arsenic and iron concentration. The correlation coefficient is 0.195.

Table 4: Correlation between arsenic and iron using all available data (Pattern-01).

Correlation coefficient	0.195
Number of Data	4367
Significance	0.0001

In pattern-02 all the data (4367) were categorized as per three depth layers, D1, D2 and D3 as described earlier. Correlation analysis was performed with those three separated data sets. All the three layers show very insignificant correlation coefficient (Table 5). Among these three layers depth layer between 50m and 150m shows maximum correlation of 0.189.

Table 5: Correlation between arsenic and iron for three depth layers (Pattern-02).

	Correlation Coefficient	Significance level
Depth<50m	0.15	0.00001
Depth between 50m & 150m	0.189	0.00001
Depth>150m	0.18	0.00001

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 a national phenomenon. In pattern-03 data were categorized considering the geographic location only. In this pattern-03 depth variation of wells are considered. When district wise categorized data were analyzed, correlation coefficient varies for different location of Bangladesh. Results of correlation analysis as per geographical locations are provided in the Table 6.

Table 6: 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	0.6	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	0.2	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	0.1	0.394	Pabna	0.33	0.004
Gazipur	0.27	0.073	Panchagarh	0.93	0.0001
Gopalganj	0.58	0.0001	Patuakhali	0.3	0.021
Habiganj	0.09	0.428	Pirojpur	0.6	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			

In pattern-04 data were categorized not only as per geographic locations but also as per depth layer of wells. Data of each of 61 districts were separated as per their depth layer which means 3 set of data for each of 61 districts. Correlation analysis was performed for each data set and results are provided in the Table 7.

Table 7: Correlation coefficient of arsenic and iron concentration of three depth layers of 61 districts (Pattern-04) and comparison with correlation coefficient.

	Depth<50m		Depth between 50m & 150m		Depth>150m		Without Depth variation
District	Correlation coefficient	Significance level	Correlation coefficient	Significance level	Correlation coefficient	Significance level	Correlation coefficient
Bagerhat	0.40	0.0024	0.00	-	0.32	0.1458	0.55
Barguna	0.22	0.8594	0.00	-	0.02	0.8849	0.36
Barisal	0.38	0.0148	1.00	-	0.04	0.7757	0.60
Bhola	1.00	-	0.00	-	-0.05	0.7282	0.86
Bogra	0.43	0.0000	0.00	-	0.00	-	0.43
Brahamanbaria	0.15	0.2915	0.30	0.3516	0.38	0.0329	0.19
Chandpur	0.02	0.9076	-0.36	0.6410	0.00	0.9946	0.11
Chittagong	-0.11	0.5774	-0.52	0.0080	-0.01	0.9367	-0.08
Chuadanga	0.52	0.0031	-0.56	0.4399	0.00	-	0.51
Comilla	0.16	0.1156	0.28	0.0904	0.36	0.0222	0.14
Cox's Bazar	-0.06	0.7911	0.77	0.0254	-0.07	0.7268	-0.05
Dhaka	0.44	0.1551	0.33	0.1017	0.52	0.0238	0.44
Dinajpur	0.72	0.0000	0.00	-	0.00	-	0.72
Faridpur	0.47	0.0011	0.60	0.0138	0.00	0.9959	0.58
Feni	-0.16	0.3099	-0.05	0.9206	-0.18	0.5774	-0.07
Gaibandha	0.11	0.3667	-0.95	0.1984	0.00	-	0.10
Gazipur	0.76	0.0000	0.15	0.5191	0.00	-	0.27
Gopalganj	0.17	0.3746	0.41	0.3073	0.77	0.0000	0.58
Habiganj	0.11	0.5733	-0.04	0.8070	-0.18	0.4063	0.09
Jaipurhat	0.21	0.2039	0.00	-	0.00	-	0.21
Jamalpur	0.45	0.0002	0.00	-	0.00	-	0.45
Jessore	0.49	0.0003	0.12	0.6059	0.22	0.0033	0.39
Jhalakati	0.89	0.0000	0.00	-	0.61	0.0057	0.88
Jhenaidah	0.22	0.1631	0.68	0.0000	0.42	0.2302	0.36
Khulna	-0.03	0.9060	0.75	0.0000	0.25	0.1335	0.36
Kishoreganj	0.51	0.0148	0.51	0.0000	-0.02	0.8791	0.62
Kurigram	0.19	0.1079	-0.35	0.6505	0.00	-	0.19
Kushtia	0.03	0.8748	0.50	0.0291	0.00	-	0.07
Lakshmipur	0.10	0.6026	0.00	-	0.48	0.3295	0.06

Lalmonirhat	0.67	0.0000	0.00	-	0.00	-	0.67
Madaripur	0.55	0.0069	0.58	0.4193	0.34	0.0174	0.74
Magura	0.61	0.0370	0.64	0.0026	0.28	0.1294	0.61
Manikganj	0.50	0.0020	0.20	0.5569	0.00	-	0.44
Meherpur	0.79	0.0012	1.00	-	0.00	-	0.69
Maulvibazar	0.02	0.8990	0.09	0.6723	-0.66	0.0759	0.02
Munshiganj	0.08	0.7640	0.16	0.3772	0.00	-	0.15
Mymensingh	0.80	0.0000	0.70	0.0000	0.00	-	0.76
Naogaon	0.20	0.0584	0.00	-	0.00	-	0.20
Narail	0.49	0.2626	0.76	0.0006	0.00	-	0.66
Narayanganj	0.35	0.1368	-0.16	0.6407	-0.01	0.9797	0.43
Narsingdi	0.51	0.0001	1.00	0.0000	0.36	0.3744	0.53
Natore	0.47	0.0006	0.00	-	0.00	-	0.47
Nawabganj	0.24	0.1351	0.00	-	0.00	-	0.21
Netrokona	-0.23	0.5558	0.45	0.0002	0.00	-	0.31
Nilphamari	0.82	0.0000	0.91	0.2664	0.00	-	0.82
Noakhali	0.15	0.3337	0.00	-	0.08	0.8864	0.05
Pabna	0.32	0.0046	-1.00	-	0.00	-	0.33
Panchagarh	0.93	0.0000	0.00	-	0.00	-	0.93
Patuakhali	-0.76	0.4473		-	0.52	0.0000	0.30
Pirojpur	0.54	0.0011	0.00	-	0.67	0.0009	0.60
Rajshahi	0.54	0.0000	0.00	-	0.00	-	0.53
Rajbari	0.49	0.0081	0.70	0.0232	0.62	0.0777	0.56
Rangpur	0.48	0.0000	0.56	0.4401	0.00	-	0.46
Shariatpur	0.48	0.0024	1.00	-	0.43	0.0048	0.68
Satkhira	0.18	0.2281	0.93	0.0002	0.46	0.0080	0.48
Sirajganj	0.19	0.0860	0.35	0.5027	0.00	0.6541	0.19
Sherpur	0.17	0.2493	0.00	-	0.00	-	0.17
Sunamganj	0.28	0.6541	-0.27	0.0250	-0.17	0.5713	-0.16
Sylhet	0.18	0.3134	0.04	0.8004	-0.45	0.1678	0.11
Tangail	0.27	0.0190	0.60	0.0116	0.00	-	0.33
Thakurgaon	0.62	0.0000	0.00	-	0.00	-	0.56

While correlation analysis was performed using all available 4367 data without categorizing as per geographical locations (Pattern-01), correlation coefficient was found to be 0.192 (Table 4) which is very insignificant. Similarly in pattern-02 in which correlation analysis was performed for depth wise categorized data, correlation coefficient was found very insignificant (0.15, 0.189 and 0.18 for D1, D2 and D3 respectively). But when all the data were reorganized as per their location (Pattern-03), correlation coefficient improved in most of the district drastically. In Panchagar the value of the coefficient is 0.932 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.

Result of data analysis as per pattern-04 (depth wise analysis of each district) is shown in Table 7. Comparison with the correlation coefficient of each district found without depth wise categorization of data was also shown in Table 7. Analyzing the correlation coefficients of three depth layers of 61 districts it was revealed that for wells less than 50m depth (D1) 46% districts show correlation coefficient greater than 0.4 (Fig 5). The percentage decreases to 28% if the threshold value considered as 0.5 (Fig 5).

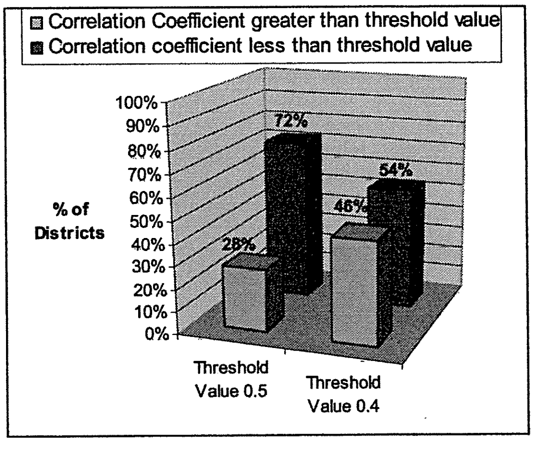

Figure 5: Percentage of districts showing correlation coefficient greater than 0.5 and 0.4 for wells less than 50m deep (D1).

For wells having depth between 50m and 150m (D2) correlation coefficient exceeds 0.4 for 34% districts (Fig6). The percentage decreases to 31% if the threshold value is taken as 0.5 (Fig6).

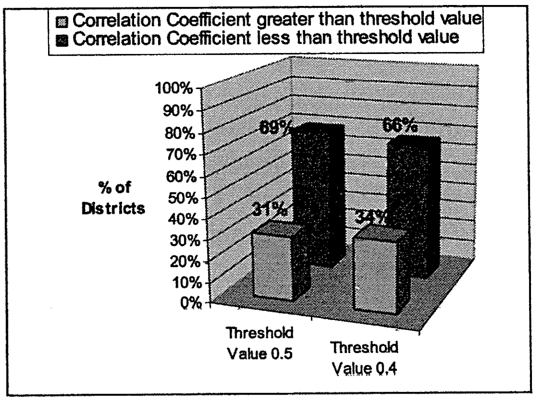

Figure 6: Percentage of districts showing correlation coefficient greater than 0.5 and 0.4 for wells between 50m & 150m deep (D2).

For wells having depth greater than 150m (D3) 16% of districts show correlation coefficient greater than 0.4 (Fig 7). The percentage again decreases to 10% if the threshold value is considered as 0.5 (Fig 7).

Arsenic contamination is very acute in upper layer of wells (Table 2 and Table 3). If the Table 7 and Fig 5 to Fig 7 are analyzed then it is clear that Correlation between arsenic and iron concentration is also found acute in upper layers of wells.

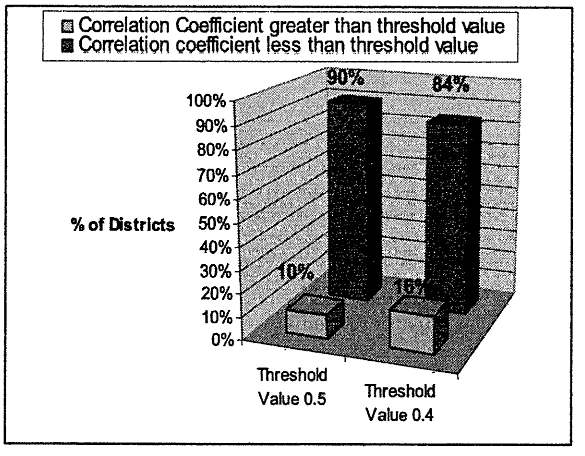

Figure 7: Percentage of districts showing correlation coefficient greater than 0.5 and 0.4 for wells between 50m & 150m deep (D3).

From Table 7 it was observed that for 50.82% districts (31 districts) correlation coefficient reduces for D2 than D1. Among those 31 districts which have lower correlation coefficient for D2, 25 districts are such that correlation coefficient of them reduces for D3 as well. On the other hand 75.41% districts (46 districts) have lower range of correlation coefficient for wells of D3 in comparison with the wells of D1. Which means for 41% districts correlation coefficient pattern is like D1>D2>D3. So it indicates that there is a tendency of reduction of correlation between arsenic and iron concentration of ground water with the increased well depth.

Munshiganj, Chandpur, Noakhali, Meherpur, Gopalganj, Lakshmipur, Faridpur, Bagerhat, Satkhira, Comilla, Narail and Chuadanga are the 12 most arsenic contaminated districts. 5 of these 12 districts show correlation coefficient greater than 0.4 for D1 and D2. Only 3 of these districts show correlation coefficient greater than 0.4 for D3. Among these 12 most *As* contaminated districts, without any depth wise separation of data maximum correlation coefficient was found in Meherpur as 0.69. When wells of depth less than 50m were separated correlation coefficient was found to be 0.79 for the same district. For the other 2 depth range of the district correlation coefficient was found as 1 and 0. These two results were found because of lack of data of those two depth layers of that specific district. Correlation coefficient of Noakhali was very insignificant of 0.05. It remained insignificant when data were separated as per depth layers, 0.15, 0 and 0.08 for D1, D2 and D3 respectively. Correlation coefficient of D1 reduces than correlation coefficient found without grouping as per depth for 7 out of these 12 most arsenic contaminated districts.

This depth wise correlation analysis of arsenic and iron reveals that correlation of arsenic and iron in ground water is not constant throughout the depth of wells. Sediment character is different in different portion of Bangladesh which leads the variation in correlation coefficient not only in geographical locations but also variation as per depth of wells. 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 waters 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 for different depth layers.

GIS map (Fig 8) represents the zonal correlation status of Bangladesh for well depth less than 50m. Data of 61 districts were separated as per their geographical locations and depth variation. The total range of coefficient was divided into ten groups for mapping. Five of them are negative range while rest five is positive range. Each of these groups is plotted with different colors. One thing is prominent in the map for D1 (Fig 8) that districts of similar range of correlation coefficient reside in a close belt. A belt of districts showing less correlation can be found in Sunamganj, Sylhet, Maulvibazar, Habiganj, Brahmanbaria, Comilla, Munshiganj, Chandpur,Lakshmipur, Noakhali, Feni, Chittagong and Cox's bazaar.

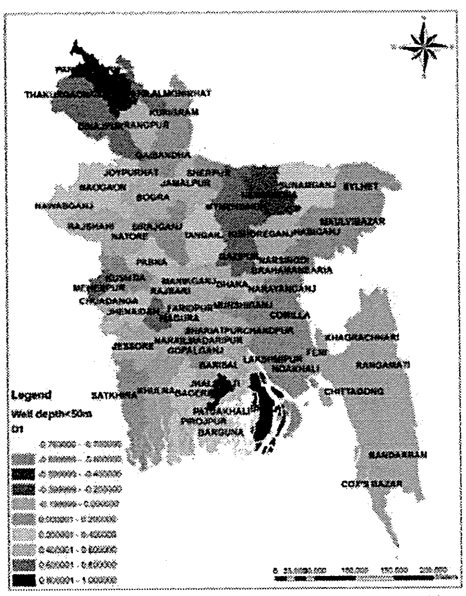

Figure 8: Distribution of correlation coefficient for wells of depth less than 50m (D1).

On the other hand Fig 9 shows the districts which have correlation coefficient between 0.4 and 0.1. Jessore, Narail, Magura, Faridpur, Madaripur, Sariatpur, Rajbari, Manikganj, Dhaka, Narshingdi, Gazipur, Mymensingh, Kishoreganj form a belt which shows similar correlation between *As* and *Fe*. For experimental analysis correlation coefficient between the ranges of 0.4 to 1 is statistically considered moderate to high. If this ranges of data are separated from the GIS map Fig 9 can be produced to show the districts of moderate to higher correlation coefficients between arsenic and iron concentration of ground water.

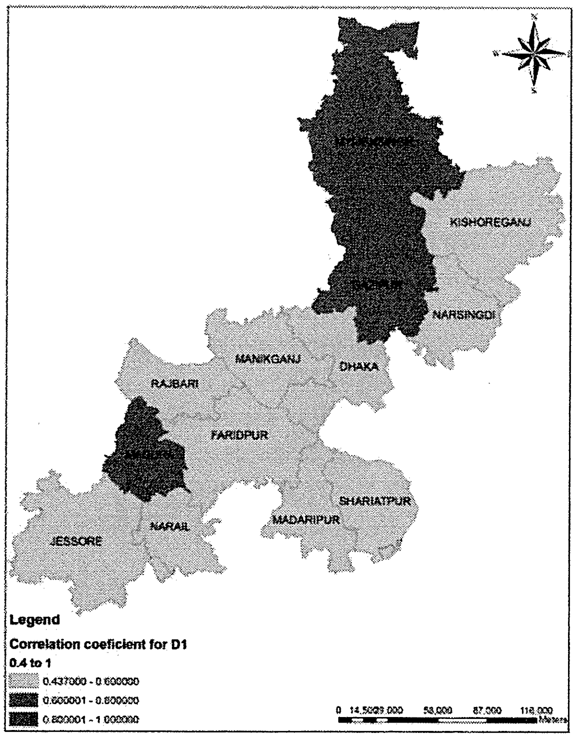

Figure 9: Districts of correlation coefficient between 0.4 and 1 for wells of depth less than 50m (D1).

It is evident from the Fig 9 that a belt of similar correlation (moderate to high) exists in the middle and southern part of Bangladesh. Another similar type of belt is found around Thakurgaon, Dinajpur, Rangpur, Nilphamari and Lalmonirhat districts (Fig 10).

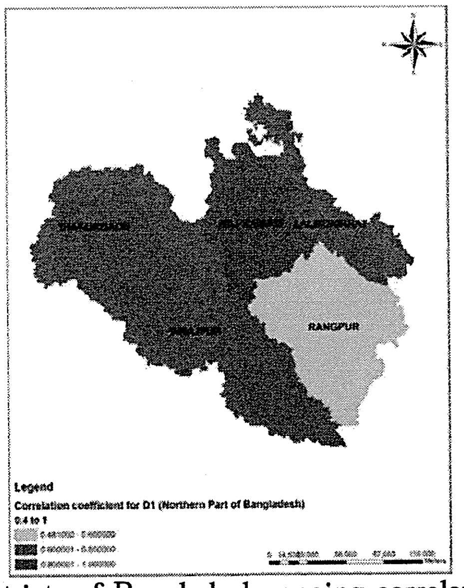

Figure 10: Northern districts of Bangladesh ranging correlation coefficient between 0.4 and 1 for D1.

In Fig 11 GIS map represents the zonal correlation status of Bangladesh for well depth between 50m and 150m (D2). It is visible from the map that for this depth zone most of the districts show lower range of correlation coefficient (light green and sky blue color). Earlier discussion about the tendency of reduction of correlation coefficient in lower depth of wells becomes more evident from the analysis of GIS maps. But one thing is prominent that similar range of correlation coefficient resides in a close belt.

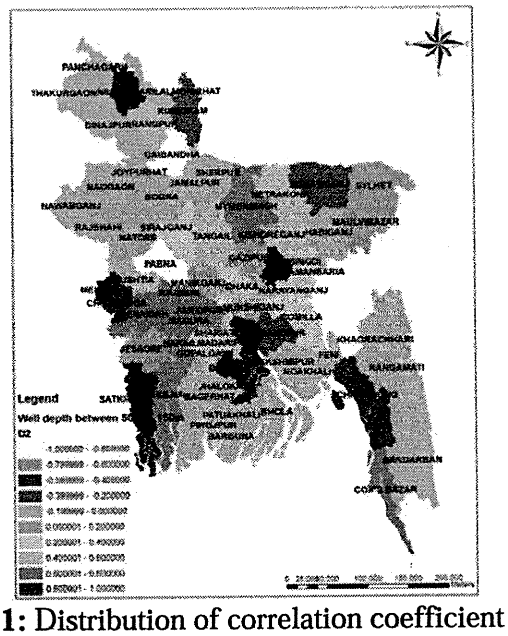

Figure 11: Distribution of correlation coefficient for D2.

Fig 12 shows the districts which show correlation coefficient range form 0.4 to 1 for wells of depth range 50m to 150m. Meherpur, Jhenaidah, Kustia, Rajbari, Faridpur, Magura, Narail, Khulna, Stakhira, Gopalganj, Madaripur, Barisal, Sariatpur reside in this close belt of similar correlation (Fig 12).

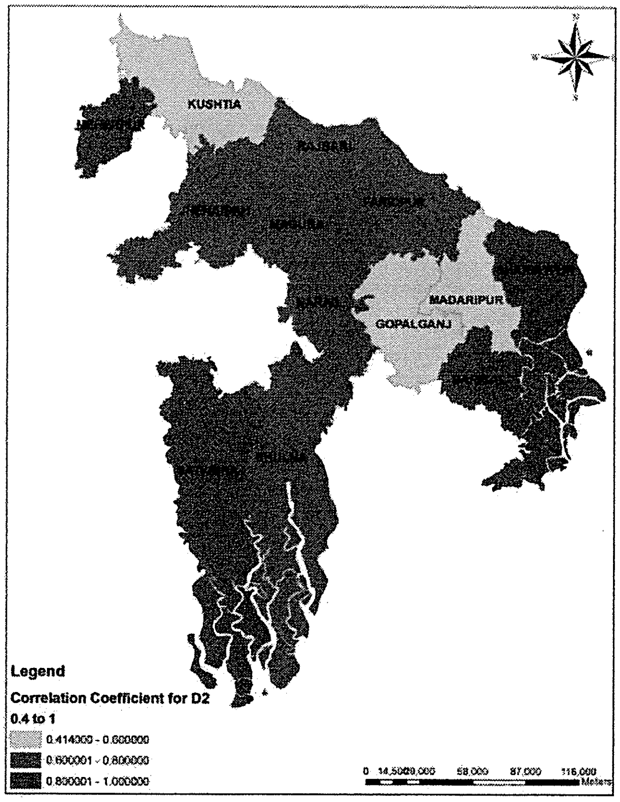

Figure 12: Districts of correlation coefficient between 0.4 and 1 for wells of depth between 50m and 150m (D2).

In Fig 13 GIS map represents the zonal correlation status of Bangladesh for well depth greater than 150m (D3). It is visible from the map that for this depth zone most of the districts show lower range of correlation coefficient (light green and sky blue color). Whole North Bengal (Rajshahi Division) and parts of Dhaka and Sylhet division show correlation coefficient near to zero for this depth layer than the upper two layers. But one thing is also prominent in this map that similar range of correlation coefficient resides in a close belt. Fig 14 shows the districts which show correlation coefficient range form 0.2 to 0.8. Few of the districts are showing correlation coefficient as 0. This is due to the absence of data of well depth greater than 150m category of that specific district.

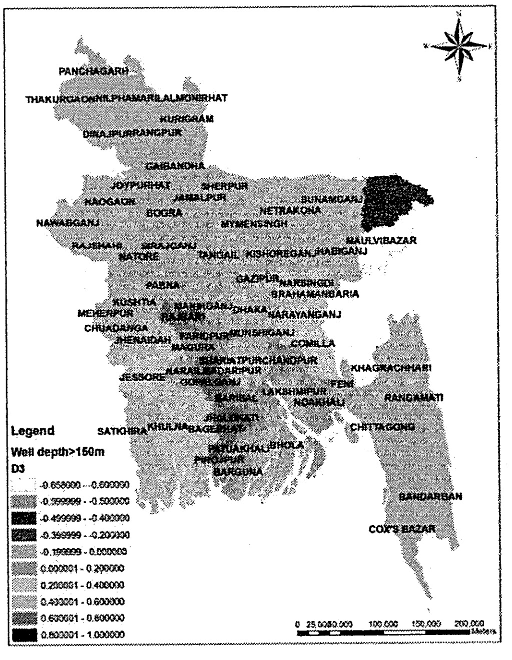

Figure 13: Ddistribution of correlation coefficient for wells of depth greater than 150m (D3).

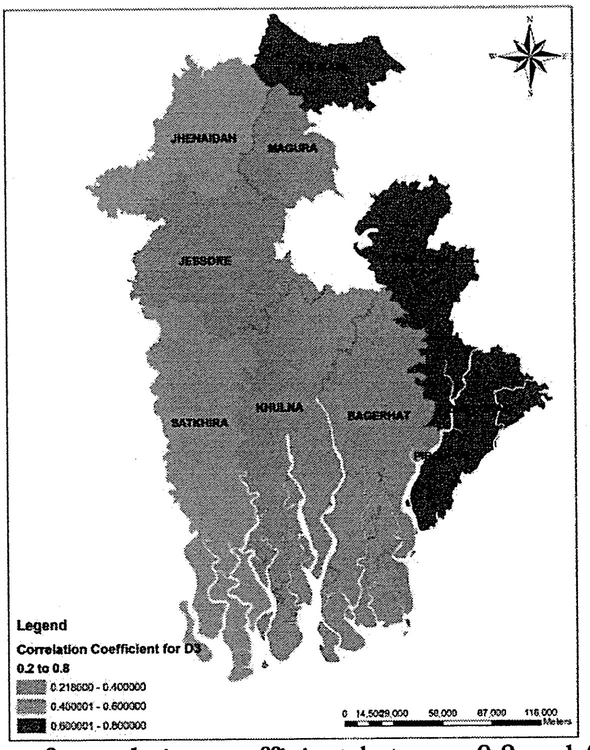

Figure 14: Districts of correlation coefficient between 0.2 and 0.8 for well depths greater than 150m (D3).

Table 8 describes that for wells less than 50m (D1), 45.9% districts show correlation coefficient more than 0.4. The percentage reduces to 34% districts for wells between 50m and 150m depth (D2) and 16.39% for wells greater than 150m depth (D3). It reveals that higher percentage of districts show correlation coefficient greater than 0.4 for D1 than the other two depth layers D2, D3. Analysis of GIS maps (Fig 8, 11, 13) also act as a useful tool for showing the tendency of reduction of correlation coefficient in the lower depth layers. Few of the districts represent correlation coefficient as 1 or 0. This represents the lack of data in that depth group of that particular district.

Table 8: Comparison of correlation coefficient in three depth layers.

	% of districts in each depth layer		
	D1	D2	D3
Correlation Coefficient>0.4	45.90%	34.43%	16.39%
Correlation Coefficient>0.5	27.90%	31.15%	9.84%

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. Not only that this correlation also varies with the depth of wells. Therefore an attempt has been made to correlate arsenic and iron for the zones and well depths 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 and well depth variation, results were found as shown in Table 9. In this analysis arsenic is taken as the dependent variable.

Equation (1) is formed through regression analysis. A and B are the constants derived from the regression model. In this model iron concentration is taken as milligram/Liter and arsenic concentration as microgram/Liter. In the Table 9 R-square values for each model is provided. "R-square" is the square of correlation coefficient "r" and it represents the proportion of variance in one variable is accounted for (or explained) by the other variable. In Table 9 results of regression analysis for 3 depth layers of 61 districts are provided.

Arsenic (μg/L) = A + (B) (Iron in mg/L) (1)
A, B = Constants from regression model

Table 9: Regression model for three depth layers of 61 districts of Bangladesh.

District	D1 (<50m)			D2 (between 50&150m)			D3 (D>150m)		
	A	B	R-square	A	B	R-square	A	B	R-square
Bagerhat	84.96	12.87	0.16	-	-	-	1.11	0.95	0.1
Barguna	3.26	1.22	0.05	-	-	-	1.14	0.15	0
Barisal	104.52	24.64	0.14	-12.43	233.33	1	3.75	0.88	0.002
Bhola	148.65	11.77	1	-	-	-	2.02	-0.31	0.003
Bogra	4.14	4.53	0.19	-	-	-	-	-	-
Brahamanbaria	82.39	4.95	0.02	10.8	18.82	0.09	-0.11	3.89	0.14
Chandpur	405.1	0.9	0	332.3	-43.16	0.13	10.39	0.004	0
Chittagong	51.76	-1.01	0.01	16.63	-0.92	0.27	7.56	-0.02	0
Chuadanga	0.51	31.71	0.27	62.51	-8.59	0.31	-	-	-
Comilla	143.75	9.92	0.03	11.5	2.2	0.08	1.64	2.71	0.13
Cox's Bazar	5.79	-0.11	0.003	-0.36	0.2	0.59	5.44	-0.3	0.01
Dhaka	17.03	3.03	0.19	31.36	4.62	0.11	1.36	9.74	0.27
Dinajpur	-0.22	2.23	0.52	-	-	-	-	-	-
Faridpur	55.7	22.45	0.22	22.46	29.22	0.36	4.08	0.004	-
Feni	74.7	-2.4	0.03	7.06	-0.11	0.003	3.85	-0.45	0.03
Gaibandha	14.43	1.36	0.01	24.07	-0.23	0.91	-	-	-
Gazipur	-8.89	51.08	0.58	0.89	0.24	0.02	-	-	-
Gopalganj	187	6.63	0.03	78.85	24.89	0.17	-0.27	3.11	0.6
Habiganj	16.54	0.47	0.01	28.59	-0.46	0.002	14.44	-3.48	0.03
Jamalpur	1.49	3.02	0.2	-	-	-	-	-	-
Jessore	17.47	18.02	0.24	59.42	3.86	0.02	9.14	1.22	0.05
Jhalokati	-54.13	55.96	0.8	-	-	-	-1.18	17.56	0.37
Jhenaidah	28.53	8.06	0.05	-2.14	14.23	0.47	0.89	7.25	0.17
Joypurhat	1.18	0.16	0.04	-	-	-	-	-	-
Khulna	72.51	-0.81	0.001	0.72	22.07	0.57	1.43	0.6	0.07
Kishoreganj	42.19	14.78	0.26	6.69	14.01	0.26	7.92	-0.31	0
Kurigram	13.26	1.24	0.04	31.79	-2.1	0.12	-	-	-
Kushtia	111.37	2.84	0	5.42	4.59	0.25	-	-	-
Lakshmipur	196.55	7.89	0.01	-	-	-	5.25	0.21	0.24
Lalmonirhat	0.37	0.44	0.45	-	-	-	-	-	-
Madaripur	150.99	29.62	0.3	37.63	23.72	0.34	0.33	8.23	0.12
Magura	2.89	15.06	0.37	7.84	14.77	0.4	10.43	3.6	0.08
Manikganj	10.22	2.89	0.25	22.58	0.89	0.04	-	-	-
Maulvibazar	13.84	0.15	0.001	24.96	0.64	0.01	10.86	-1.18	0.43
Meherpur	-60.49	59.42	0.63	11.38	259.42	1	-	-	-
Munshiganj	212.44	2.3	0.01	144.77	6.19	0.03	-	-	-
Mymensingh	8.6	8.75	0.63	4.13	7.77	0.48	-	-	-
Naogaon	3.11	2.4	0.04	-	-	-	-	-	-
Narail	103.74	8.59	0.24	12.7	17.35	0.58	-	-	-
Narayanganj	52.77	5.96	0.13	4.25	-0.46	0.03	4.46	-0.22	0

Narsingdi	22.82	10.65	0.26	-1.91	25.97	1	11.98	19.33	0.13
Natore	1	1.43	0.22	-	-	-	-	-	-
Nawabganj	5.84	2.18	0.06	-	-	-	-	-	-
Netrakona	68.9	-2.01	0.05	21.72	7.88	0.2	-	-	-
Nilphamari	-0.04	0.8	0.67	0.21	1.41	0.84	-	-	-
Noakhali	163.68	17.43	0.02	-	-	-	5.94	0.16	0.01
Pabna	17.72	6.73	0.1	0.85	-2.78	1	-	-	-
Panchagarh	0.49	0.83	0.87	-	-	-	-	-	-
Patuakhali	17.15	-1.69	0.58	-	-	-	1.05	10.4	0.27
Pirojpur	-3.13	14.84	0.3	-	-	-	0.74	9.57	0.45
Rajbari	22.05	9.42	0.24	1.25	6.48	0.5	-1.53	7.35	0.38
Rajshahi	3.02	6.24	0.29	-	-	-	-	-	-
Rangpur	-2.76	2.72	0.23	1.5	0.44	0.31	-	-	-
Satkhira	101.5	7.83	0.03	-39.42	62.38	0.87	-4.14	10.9	0.21
Shariatpur	87.56	22.67	0.23	-47.74	54	1	2.2	2.95	0.19
Sherpur	18.84	0.74	0.03	-	-	-	-	-	-
Sirajganj	21.99	1.17	0.04	19.8	1.45	0.12	-	-	-
Sunamganj	6.22	0.28	0.08	64.64	-5.02	0.07	19.01	-1.93	0.03
Sylhet	11.88	0.43	0.03	26.11	0.15	0.002	24.38	-4.53	0.2
Tangail	12.03	1.81	0.07	3.21	4.67	0.36	-	-	-
Thakurgaon	0.46	0.47	0.38	-	-	-	-	-	-

Using this regression model for 61 districts of Bangladesh provided in Table 9 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 21m deep of Nilphamari district, Thana domar, union Gomnati and mouza Dakshi (Lat 26.22 Long 88.82) is found to be 0.67 mg/L. From Table 9 the value of regression coefficient found from regression model for Bagerhat district for wells less than 50m depth is found to be -0.04 and 0.8. The equation for this district becomes like the following one.

Arsenic (μg/L) = A + (B) (Iron in mg/L)

Arsenic (μg/L) = -0.04+ 0.8(0.67)

= 0.496

Correlation coefficient "r" found for the wells of depth less than 50m of this district is 0.82. R-square is the square of this value which represents the proportion of variance in one variable accounted for (or explained) by the other variable. R-square for this value is 0.67.

Similarly if depth of any well of Nilphamari district is 95m then arsenic of that well can be tentatively assessed by using the regression model of that specific depth zone (D2) of Nilphamari district. This depth wise regression model gives more flexibility as arsenic concentration of any well can be assessed by using the regression model of that specific depth zone of a specific district.

Scope and features of the produced GIS map

These GIS maps and analysis results can be used for determining arsenic concentration of different wells of different locations. As an example if arsenic concentration of a well of 270m depth of Madaripur district needs to be assessed, GIS maps can be helpful for that. For a district, regression model (Table 9) can be utilized for approximation of arsenic concentration from the know iron concentration of a well. Through this equation the arsenic concentration can be tentatively verified. Reliability of this result should be assessed by R-square value. This method can prove to be very economical if it is used in large scale.

Conclusion

Total 4367 number of data is used for analysis in this research. Data of 61 administrative districts of Bangladesh were available for analysis. Considering the difference in sedimentation characteristics data of 4367 wells were categorized in three depth layers, Well depth less than 50m, Well depth between 50m and 150m, well depth greater than 150m. Analysis was performed in four different patterns. While correlation analysis was performed using all available 4367 data without categorizing as per geographical locations and depth variation (Pattern-01), correlation coefficient was found to be 0.192 (Table 4) which is very insignificant. Pattern-02 represents the correlation analysis with depth wise categorized data. In this pattern correlation coefficient was also found very insignificant (0.15, 0.189 and 0.18 for depth<50m, Depth between 50m &150m and Depth>150m respectively). But when all the data were reorganized as per their geographic location (Pattern-03), correlation coefficient improved in most of the district drastically.

In pattern-04 data were categorized as per both geographical location (61 districts) and depth variation of wells. Three depth layers were considered in this study, well depth less than 50m, between 50m and 150m, greater than 50 were termed as D1, D2 and D3 respectively. Analyzing the correlation coefficients of three depth layers of 61 districts it was observed that for D1 46% districts show correlation coefficient greater than 0.4 (Fig 5). The percentage decreases to 28% if the threshold value considered as 0.5 (Fig 5). For wells of D2 correlation coefficient exceeds 0.4 for 34% districts. The percentage decreases to 31% if the threshold value is taken as 0.5. For wells of D3 16% of districts show correlation coefficient greater than 0.4 (Fig 7). The percentage again decreases to 10% if the threshold value is considered as 0.5 (Fig 7).

For 41% districts correlation coefficient pattern is like D1>D2>D3. 5 out of 12 most arsenic contaminated districts show correlation coefficient greater than 0.4 for D1 and D2. Only 3 of these districts show correlation coefficient greater than 0.4 for D3. So it indicates that there is a tendency of reduction of correlation between arsenic and iron concentration of ground water with the increased well depth. Difference in sedimentation characteristics triggers this variation in depth layers.

Arsenic contamination is acute in the wells of depth less than 50m. As the depth of wells increases arsenic contamination tends to decrease in most of the districts (Table 2 and 3). Similar trend is observed for correlation coefficient between arsenic and iron concentration of groundwater in most of the districts of Bangladesh.

GIS maps were produced with the results of the analysis. Fig 8, 11 and 13 show the representation of correlation coefficient of three depth layers of 61 districts of Bangladesh. These three figures show that similar range of correlation resides in a close belt of zone for each depth layer. Fig 9 and 10 portray the districts of similar higher range of correlation coefficient for well depth less than 50m. On the other hand Fig 12 and 14 portray the districts of similar higher range of correlation coefficients for D2 and D3 respectively. This reveals that a geographical belt exists for each depth layer where correlation between arsenic and iron concentration of ground water is moderate to High.

Regression models were developed for 3 depth layers of 61 districts. This depth wise regression model gives more flexibility as arsenic concentration of any well can be assessed by using the regression model of that specific depth zone of a specific district.

References

[1] Aggarwal, P K, A R Basu, R J Poreda, K M Kulkarni, K Froehlich, S A Tarafder, M Ali, N Ahmed, A Hossain, M. Rahman, S R Ahmed, (2000). A Report on Isotope Hydrology of Groundwater in Bangladesh: Implications for Characterization and mitigation of arsenic in Groundwater. IAEA TC Project BGD/8/016

[2] BGS-DPHE (2001), Arsenic contamination of groundwater in Bangladesh, BGS Technical Report, WC/00/19

[3] DPHE-APSU-JICA, (2006), Final report on development of deep aquifer data base and preliminary deep aquifer map, First phase, DPHE-APSU-JICA (Its link should be referred somewhere else, since the reference was deleted from the text)

[4] DoE (1991), Environmental Quality Standard for Bangladesh, Department of Environrncnt

[5] DoE (1997), Environmental Quality Standard for Bangladesh, Department of Environment

[6] GWTF, (2002) Report of the Ground Water Task Force. Local Government Division, Ministry of Local Government and Engineering Department

[7] Karim Md. Masud (2000), Arsenic in Groundwater and health problems In Bangladesh. Water Research, Vol. 34, No. 1, pp. 304-310

[8] WHO (1993) “Guidelines for drinking water quality”, Volume-01: Recommendations, 2nded, Geneva, Switzerland: WHO; 39-57, 174

バングラデシュ農村部における経済的に妥当な代替水の選択に関する研究

Study on Selection Methodology for Economically Feasible Alternative Water Supply in Rural Area in Bangladesh

眞子岳*　北脇秀敏**　モハメド・マフィズル・ラーマン***

Gaku MANAGO* Hidetoshi KITAWAKI** Md. Mafizur Rahman

(*東洋大学大学院　国際地域学専攻　博士後期課程　**東洋大学　国際地域学部　***バングラデシュ工科大学)

(* Regional development studies, TOYO university **Regional development studies, TOYO university

***Bangladesh university of engineering and technology)

I　はじめに

バングラデシュ人民共和国(以下，「バ」国)農村部では，下痢疾患の死亡率の削減を目的として，1980年代からUNICEF等のドナーによる安全な水供給事業が行われ，地下水を汲み上げる管井戸が建設された。その結果，生物汚染による健康障害は軽減されたが，地下水に含まれる自然由来の高濃度のヒ素によって，新たな健康障害をもたらした。ヒ素による慢性ヒ素中毒疾患者は，地下水を管井戸から直接多飲する農村部において約38,000人確認されている[1]。これは，安全な水供給に国際機関や研究機関等が20年以上携わっているにも関わらず，「バ」国農村部における貧困層に，持続可能で普遍的な水供給が行われていない現状であると言える。この背景には貧困層におけるヒ素除去装置等の普及において，経済面や文化面等の制約要因が強く存在していると考えられる。こうした制約要因を配慮せずに建設された水供給装置は，住民の装置利用に必要な行動変容や持続的な支払いの欠如等により，運転維持管理が持続されない場合が多く見られる。建設された装置の持続性を確保するためには，現地で資機材や部品が入手可能で，水供給装置が製造販売されるサプライチェーンがあること，住民とって安価であることが重要となる。また，安全な水供給を行うための技術は多様であり，表流水や雨水利用が可能であることから，農村部の貧困層(BOP: Bottom of the pyramid)住民にとって文化的及び経済的に妥当である安全な水供給手法を提案する必要がある。

類似の先行研究として，杉村[2]はヒ素除去装置における構造や砂を用いたろ過による，ヒ素除去のシステムについて検討している。また，萩原ら[3]は水運びに対する住民ストレスの算出や代替技術の性能と特徴について検討している。これらの先行研究では，除去装置の技術面や住民の水使用形態を取り上げられているが，地下水ヒ素汚染地域住民に対して経済的に妥当で内発的発展を促す除去装置等の普及手法については考察されていない。一方，眞子ら[4]は，地場産業によるヒ素除去装置の施工手法，農村部住民の水使用形態及びアフォーダビリティー等を明らかにしている。

II　研究目的・手法

1　研究目的

地下水中のヒ素による健康被害を回避するためには，ヒ素除去装置の使用，または手汲みによる表流水利用が必要である。前者は初期投資や運転維持管理等に対して支払可能な価格でなければ持続できない。後者は，設備投資を必要としないが，生物汚染が懸念されるため，煮沸や塩素剤等が必要となる。よって本研究は，「バ」国農村部における住民の収入額，水に対する支出額，現地で入手可能な除去装置等の初期投資・維持管理費や水処理薬品の市場価格等の経済面，水使用形態，用途別水源や習慣等の文化面を明らかにし，現地住民に経済的に妥当な装置や代替水を定量的に選定できる手法を考案することを目的としている。

2　研究手法

本研究では，2005 年以降，年 2 回「バ」国で調査を行っている。その内の 2006 年，'07 年，'09 年，'10 年の地下水ヒ素汚染の代替水の普及に関する調査結果を用いて，現地住民に経済的に妥当であり，入手可能な代替水を選