An intelligent Decision Support System for Arsenic Mitigation in Bangladesh

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***Abstract*—Arsenic contamination of groundwater in many nations including Bangladesh shows that this is a global problem. Because of the delayed health effects, poor reporting, and low levels of awareness in some communities, the extent of the adverse health problems caused by arsenic in drinking water is at alarming level in Bangladesh. Also, allocating resources such as tube wells efficiently and effectively to mitigate arsenic hazard is a challenging task in Bangladesh. To allocate resources based on different arsenic hazard parameters, we have developed a Decision Support System that enables the user to observe the effect of allocation policy both in tabular and spatial format using statistical models. We have also developed an algorithm for optimal allocation of resources. A Smart User Interface is designed for the users so that they will find an interactive, user-friendly, intelligible, logical, clear, and sound environment to work with. Finally, we have analyzed and demonstrated the efficacy of our algorithm graphically.**

Index Terms—*Arsenic hazard, Decision Support System, Geographic Information System, and Vulnerability Index.*

I. Introduction

Water is a basic requirement of human life. The right to a source of safe drinking water is enshrined in the Universal Declaration of Human Rights and, although there is much debate about the implications of this 'rights-based' approach to water, the Government of Bangladesh is committed to provide safe drinking water for all by 2011. In this context 'safe' water means water which is free from contamination that could cause illness or death.

Drinking-water situation towards the Millennium Development Goal (MDG) is in progress but yet insufficient [1]. As a result, arsenic mitigation both in short term and long term basis has become a burning issue for Bangladesh. Deep tube well is a safe option in terms of public health risks from both arsenic and microbial contamination if there is a suitable deep aquifer and conditions are appropriate.

The specific objective of this paper is to help users (mainly for people in the management of water resources) to retrieve and analyze arsenic related information, identify vulnerable communities, prepare mitigation plans and further monitor the impact of arsenic mitigation work. So, we propose a resource distribution method for a decision support system that is capable of analyzing the arsenic situation of an area using a statistical model and it can also suggest optimal decisions for replacing unusable tube wells by new ones. A smart user interface is designed for the users to find an interactive, user-friendly, intelligible environment to work with. The users can see the effects of resource distribution by changing different arsenic parameters and finally decide on an optimal allocation of the available resources. The output can be shown in both tabular and spatial format. Different scenarios can be compared by changing the important parameters and optimal decisions can be taken according to the given criterion by selecting the best option from the output of the decision support system software.

The paper is organized as follows. Section II provides present arsenic situation in Bangladesh. Section III gives an overview of geographic information system (GIS). Section IV describes a decision support system on top of which we have applied our algorithm. Section V describes the proposed algorithm in details. Section VI illustrates the smart interface and shows how both tabular and spatial output can be shown by changing parameters. Section VII demonstrates the results and shows the efficacy of our approach. Finally, section VIII ends the paper with concluding remarks.

II. Present Arsenic Situation in Bangladesh

The use of groundwater in Bangladesh for potable water supply and irrigation has rapidly increased since 1970. Arsenic contamination was first detected in 1993 by the Department of Public Health Engineering (DPHE), and its presence was subsequently confirmed after 1995 in numerous shallow and deep wells in different parts of the country.

According to the British Geological Survey (BGS), "the groundwater Arsenic (As) problem in Bangladesh arises because of an unfortunate combination of three factors: a source of As (As is present in the aquifer sediments), mobilization (As is released from the sediments to the groundwater) and transport (As is flushed in the natural groundwater circulation)" [9].

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Bangladesh is one of the most heavily populated countries in the world and its drinking water is collected from different sources, such as surface water, rain water and ground water. Surface water of Bangladesh is extremely contaminated with fecal bacteria, residues from fertilizers and pesticides. About 97% of the population of Bangladesh relies on ground water for drinking purpose according to "National policy for Arsenic mitigation 2004" report [2].

In Bangladesh, rice and curry are usually cooked with a substantial amount of water which is sometimes contaminated with arsenic. Since an adult Bangladeshi man consume an average 1500 gram of cooked rice per day, which contain at least one liter of drinking water, water intake through cooked rice would add substantially to the amount of arsenic ingested. Cooked rice and curry could be an important source of arsenic if it is boiled in arsenic contaminated water. Intensive programs to provide safe drinking water through protected groundwater sources (mainly tube wells) might help to control diseases caused by arsenic.

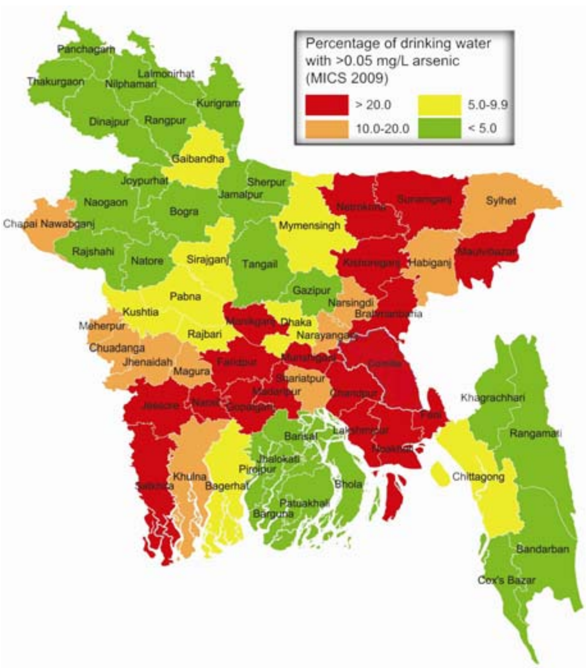

Figure 1. Percentage of drinking water with > 0.05 mg/L arsenic in 2009 in 64 districts of Bangladesh; Photo Courtesy: UNESCO [4]

In Bangladesh, according to the Government's water quality standard, the permissible level of arsenic in drinking water is 50µg/L [3]. Ground water used for drinking in many areas of Bangladesh has been reported as contaminated by arsenic above this level [1]. According to a survey conducted by MICS in 2009, the population exposed to arsenic is estimated to 17.9 million [4]. Thousands of people have already been diagnosed with poisoning symptoms, even though much of the at-risk population has not yet been assessed for arsenic-related health problems, some of them even are not aware of arsenic contamination.

The World Health Organization (WHO) calls Bangladesh's arsenic crisis "The largest mass poisoning of a population in history". Measuring arsenic is a complex process that requires specialized equipment under controlled conditions. In other words, arsenic cannot be detected by looking at water, or even by placing water under a microscope. All groundwater sources used for drinking water should be tested for arsenic. Testing arsenic level of tube wells and identifying arsenic patients is expensive, so, it is important to utilize our limited resources shared with a vast community.

The scale of the arsenic problem in Bangladesh, together with infrastructural, economic and social factors, makes the task of mitigation extremely difficult. Options for the provision of safe drinking water include screening of affected ground water to locate safe sources, development of the deep aquifer, and use of disinfected dug-well water, treatment of arsenic-affected ground water, rainwater harvesting and development of piped surface-water schemes. Many of these are currently being assessed and tried. One clear outcome is that no single solution will be universally applicable to solve the problem and in practice, combinations of these approaches will eventually be set up to find solutions [5].

III. Geographic Information System (GIS)

The Geographic Information System (GIS) integrates hardware, software, and data for capturing, managing, analysing, and displaying all forms of geographically referenced information. It is an important decision making tool because it can assist the transition from data to wisdom. GIS can provide an effective way to filter data and information to enhance decision making. In the past, decisions were made upon variables such as "who", "why," "when", and "how much". GIS adds "where", which is incredibly valuable piece of information. Most of the real world decisions are complex, involving multiple factors.

This is where GIS comes in to improve and simplify decision making by making the consequences of decisions easier to visualize. It allows us to analyze the various courses of action, and picking the one that works the best. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts.

The following activities were carried out to contribute in arsenic mitigation planning for the ADSS (a) GIS data layers were constructed for presenting and assessing the extent of the arsenic problem at the national and regional levels, (b) GIS tools were developed for data organization, analysis, and presentation for managers, analysts/scientists, and decision-makers addressing the arsenic problem.

A. Components of a Geographic Information System

A Geographic Information System (GIS) combines computer cartography with a database management system. These components consist of Input, Computer hardware and software, and Output subsystems [7].

- Input system: It allows for the collection of data (tube well locations in administrative boundary, usable ponds, rivers, health centers) to be used and analyzed for some purpose. For our case, Arsenic related data that are collected from field are treated as Input of ADSS.
- Computer hardware and software system: It stores the data, allow for data management and analysis, and can be used to display data manipulations on an output subsystem such as computer monitor. We have used Microsoft Access, Microsoft Visual Basic, Microsoft Map Object and Crystal Report as Software in our ADSS application.
- Output system: It generates output after processing information by software applications. Example of output system includes Printer which may be used for hard copy of maps or images and Computer Monitor for viewing it.

B. Steps for building a GIS

- Data capture: If the data to be used are not already in digital form, that is, in a form the computer can recognize, various techniques can capture the information. Maps can be digitized by hand-tracing with a computer mouse on the screen or on a digitizing tablet to collect the coordinates of features. Electronic scanners can also convert maps to digits. Coordinates from Global Positioning System (GPS) receivers can also be uploaded into a GIS.
- Data integration: A GIS makes it possible to link, or integrate, information that is difficult to associate through any other means. Thus, a GIS can use combinations of mapped variables to build and analyze new variables.
- Projection and registration: Projection is a fundamental component of mapmaking. A projection is a mathematical means of transferring information from the Earth's three-dimensional, curved surface to a two-dimensional medium—paper or a computer screen. Map information in a GIS must be manipulated so that it registers, or fits, with information gathered from other maps. Before the digital data can be analyzed, they may have to undergo other manipulations—projection conversions, for example—that integrate them into a GIS.
- Data structures: Can a land use map be related to a satellite image, a timely indicator of land use? Yes, but because digital data are collected and stored in different ways, the two data sources may not be entirely compatible. Therefore, a GIS must be able to convert data from one structure to another. Satellite image data that have been interpreted by a computer to produce a land use map can be "read into" the GIS in raster format. Raster data files consist of rows of uniform cells coded according to data values. An example is land cover classification (Figure 3).

1	1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	3	3	3	3
1	1	1	2	2	2	2	3	3	3
1	1	1	2	2	2	2	3	3	3
1	1	1	2	2	2	2	3	3	3
1	1	1	1	2	2	2	3	3	3
1	1	1	1	1	1	3	3	3	3
1	1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	1	1	3	3

Figure 2. Structure of a raster file.

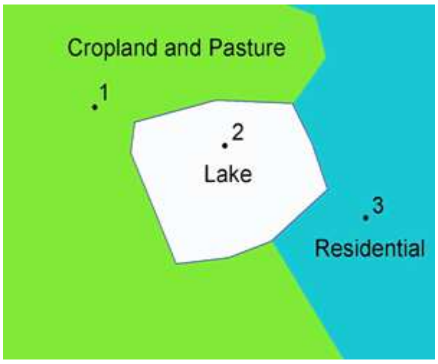

Figure 3. Structure of a vector data file.

Raster files can be manipulated quickly by the computer, but they are often less detailed and may be less visually appealing than vector data files, which can approximate the appearance of more traditional hand-drafted maps. Vector digital data have been captured as points, lines (a series of point coordinates), or areas (shapes bounded by lines) (Figure 4). An example of data typically held in a vector file would be the property boundaries for a particular housing subdivision.

- Data modeling: It is impossible to collect data over every square meter of the Earth's surface. Therefore, samples must be taken at discrete locations. A GIS can be used to depict two and three dimensional characteristics of the Earth's surface, subsurface, and atmosphere from points where samples have been collected. For example, a GIS can quickly generate a map with isolines that indicate the pH of soil from test points. Such a map can be thought of as a soil pH contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. Two and three dimensional contour maps created from the surface modeling of sample points from pH measurements can be analyzed together with any other map in a GIS covering the area.

- Networks: When nutrients from farmland are running off into streams, it is important to know in which direction the streams flow and which streams empty into other streams. This is done by using a linear network. It allows the computer to determine how the nutrients are transported downstream. Additional information on water volume and speed throughout the spatial network can help the GIS determine how long it will take the nutrients to travel downstream.
- Overlay: Using maps of wetlands slopes, streams, land use, and soils, the GIS might produce a new map layer or overlay that ranks the wetlands according to their relative sensitivity to damage from nutrient runoff.
- Data output: A critical component of a GIS is its ability to produce graphics on the screen or on paper to convey the results of analyses to the people who make decisions about resources. Wall maps, Internet-ready maps, interactive maps, and other graphics can be generated, allowing the decision makers to visualize and thereby understand the results of analyses or simulations of potential events.

IV. ARSENIC DECISION SUPPORT SYSTEM

A. Decision Support System

A decision support system (DSS) is a computer-based Information System that supports business or organizational decision-making activities. It serves the management, operations, and planning levels of an organization and help to make good decisions, which may be rapidly changing and not easily specified in advance. It includes knowledge-based systems. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from a combination of raw data, documents, personal knowledge, or business models to identify and solve problems and make decisions. DSSs are built in a variety of ways to classify data.

B. Components of a Decision Support System

Three fundamental components of DSS architecture are: Database, Model and User Interface.

- Database: A database is the information related to a particular organization that is processed and stored by a Database Management System (DBMS). DBMS is a software package with computer programs that control the creation, maintenance such as browsing, querying, updating, deleting and inserting of a database.
- Model: The quality and reliability of modelling tools and the internal architectures of DSS is very important for a DSS. The most important result of a session with a DSS is insight into the decision problem. The decision context and user criteria are specified using Model.
- User Interface: User Interface abbreviated as UI, the junction between a user and a computer program. An interface is a set of commands or menus through which a user communicates with a program. The user interface is one of the most important parts of any program because it determines how easily you can make the program do what you want. While the quality and reliability of modeling tools and the internal architectures of DSS is important, the most crucial aspect of DSS is, by far, the user interfaces [8]. A good user interface to DSS should support model construction and model analysis, reasoning about the problem structure in addition to numerical calculations and both choice and optimization of decision variables.

C. Overview of the Arsenic Decision Support System

The Arsenic Decision Support System (ADSS) has been developed for visualizing arsenic situation, finding the suitable location to replace unusable tube wells (those with level of arsenic more than permissible limit, hence, marked as red tube well) in order to achieve the best result for reducing arsenic hazard of an area. To start with ADSS let us first discuss about ADSS input data, which includes (1) Arsenic data (Arsenic Concentration, Number of people using tube wells), (2) Safe water option data (Pond sand filter, dug well, rainwater harvesting), (3) Arsenic related socio-economic data (drinking water sources, population awareness, and arsenic patients). ADSS inputs and calculates all data based on some administrative boundaries in Bangladesh. The lowest boundary is a 'Mouza', which is mainly a village containing multiple clusters of houses. A 'Union' consists of a number of Mouzas, while a 'Thana' contains a number of Unions. All parameters are calculated Mouza-wise.

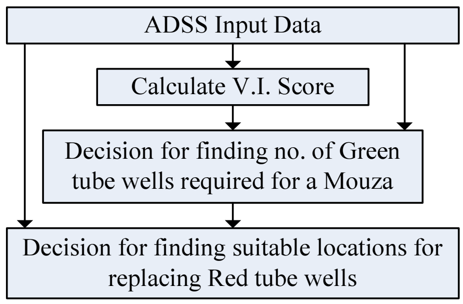

Figure 4. Process flow of ADSS system

Figure 5 depicts the process flow of the ADSS. Tube wells are categorized mainly in two types. Red tube wells indicate containing non-acceptable arsenic level to be used as the safe drinking water source. Green tube wells are marked to indicate that those are safe to be used as the source of drinking water. The decision making system will find the required number of green tube wells in a particular area along with suitable locations to place the new tube wells.

When all the input parameters are available, the framework can produce one of the major ADSS primary outputs, Vulnerability Index (VI), which is calculated from some pre-defined formulas based on domain knowledge, mathematical knowledge and statistical knowledge. This index represents the arsenic situation of a Mouza and can be compared with other Mouzas. Using VI information, ADSS helps to find number of new tube wells required for a Mouza and finally, tells the user where to place those tube wells.

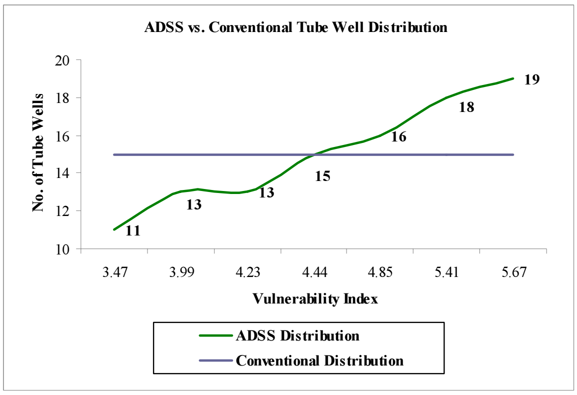

Figure 5. ADSS vs. Conventional Tube Well Distribution

Since ADSS resource distribution is based on their vulnerability which means more vulnerable Mouzas are provided more tube wells then the less vulnerable Mouzas. Figure 6 depicts the distribution of 105 tube wells among 7 Mouzas. X-axis shows the Mouza VI, and Y-axis shows no. of tube wells to be distributed. It is assumed that the conventional distribution allocates tube wells equally among all the Mouzas without counting or prioritizing vulnerability level, whereas, ADSS resource distribution method allocates tube wells according to their VI level.

Vulnerability Index (VI): The Vulnerability Index (VI) of a Mouza is a numerical value, which represents the arsenic situation of that Mouza under a thana or a union. ADSS can calculate VI score in two different ways: absolute VI score represents vulnerability in a Mouza irrespective of other Mouzas in a thana or union. On the other hand, relative VI score enables us to compare among the Mouzas in a thana or union. However, the greater the VI value, the greater the arsenic risk.

VI is calculated mainly from four main components: arsenic hazard, resources, coping capacity, and health hazard. The main components consist of other sub parameters. All these parameters (4 main and 10 sub-parameters) are listed in following table (Table 1). As shown in the table, main parameters can be given a particular weight, i.e., arsenic hazard component has a weight of W_P. Sum of all weights (W_P, W_Q, W_R, and W_S) must equal to 1. Similarly, each sub-parameter also has a weight i.e., percentage of red tube wells (A) has a weight W_A and sum of weights of all sub-parameters under any particular main parameter must equal to 1. A framework was designed to input the weights according to preference of the user as shown in figure 6.

TABLE 1. VI COMPONENTS (ADSS INPUT)

Main Parameter Name	Main Parameter Weight	Sub Parameter Name	Sub Parameter Weight
Arsenic Hazard Component	W_P	Percentage of red tube well (A)	W_A
		Average arsenic concentration (B)	W_B
		Percentage of population using red tube well (C)	W_C
Resource Component	W_Q	Percentage of green tube well (D)	W_D
		Average distance from usable pond (E)	W_E
		Average distance from house to nearest safe water option (F)	W_F
Coping Capacity Component	W_R	Percentage of population aware of arsenic (G)	W_G
		Average distance from health center (H)	W_H
		Socio economic status (I)	W_I
Health Hazard Component	W_S	Percentage of arsenic patients (J)	W_J

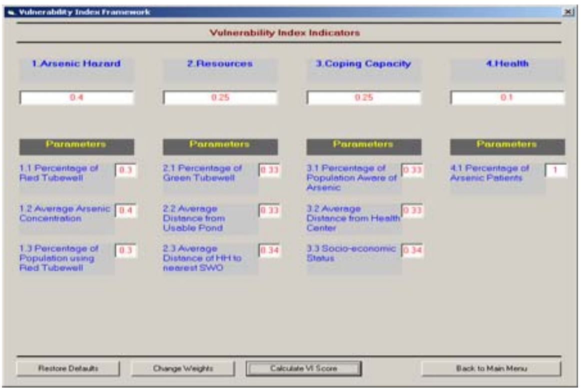

Figure 6. VI parameters framework to adjust weights

D. Formulae for Sub parameters absolute score calculation

The absolute scores of the sub-parameters are calculated as follows.

- Percentage of Red Tube well $A_A = (R_T / T_T) \times 100$

Where, R_T = No. of Red tube wells in a Mouza, and, T_T = Total no. of tube wells in a Mouza.

- Average Arsenic Concentration, $B_A = (\Sigma A_{LV}) / T_N$

Where, ΣA_{LV} = Summation of arsenic level value of all tested tube wells, and, T_N = No. of Total Tube wells tested.

- Percentage Total People drink water from Red Tube well, $C_A = P_M \times (P_{RS} + P_{RO}) / P_T \times 100$

Where, P_M = Total population under a Mouza, P_{RS} = No. of people drinking water from own Red tube well,

P_{RO} = Number of people drinking water from other Red tube well,

P_T = Total population under survey.

- Percentage of green tube well, $D_A = (G_T/T_T) \times 100$

Where, G_T = No. of Green tube wells in a Mouza, and, T_T = Total no. of tube wells in a Mouza.

The absolute scores of average distance from usable pond (E), average distance from house to nearest safe water option (F), percentage of population aware of arsenic (G), and average distance from health center (H) are calculated manually by domain experts as shown in the tables from 2 to 5.

TABLE 2. THE ABSOLUTE SCORE OF "AVERAGE DISTANCE FROM HOUSEHOLD TO USABLE POND", E_A:

Distance (m)	E_A Score
0 - 100	1
100 - 300	3
300 - 500	6
> 500	10

TABLE 3. THE ABSOLUTE SCORE OF "AVERAGE DISTANCE FROM HOUSE TO NEAREST SAFE WATER OPTION", F_A:

Distance (m)	F_A Score
0 - 100	1
100 - 300	3
300 - 500	6
> 500	10

TABLE 4. THE ABSOLUTE SCORE OF "PERCENTAGE OF POPULATION AWARE OF ARSENIC", G_A:

Reason for drinking water from Red tube well	G_A Score
Aware but don't care	10
Option available but too far	20
No available option	60
Unaware	80
Other	100

TABLE 5. THE ABSOLUTE SCORE OF "AVERAGE DISTANCE FROM HOUSEHOLD TO HEALTH CENTER", H_A:

Distance (m)	H_A Score
0 - 2000	1
2000 - 5000	3
5000 - 10000	6
> 10000	10

- Socio-economic Status, $I_A = (I_1 + I_2 + I_3 + I_4 + I_5) / 5$

Where, scores for I_1 to I_5 are calculated manually by the domain experts as shown in the tables 6 to 10.

TABLE 6. EDUCATION LEVEL (I_1)

Education Level	I_1 Score
Graduate	10
SSC - HSC	50
Five – Ten	70
Under Primary	100

TABLE 7. ROOF MATERRIAL TYPE (I_2)

Roof Material Type	I_2 Score
RCC	10
Tiles	20
Tin	60
Others	100

TABLE 8. FLOOR MATERIAL TYPE (I_3)

Floor Material Type	I_3 Score
Earth	100
Brick	50
Concrete	20
Others	80

TABLE 9. WALL MATERIAL TYPE(I_4)

Wall Material Type	I_4 Score
Earth	80
Brick	10
Tin	40
Others	100

TABLE 10. RADIO/ TV (I_5)

Has Radio/TV	I_5 Score
Yes	10
No	100

- Percentage of arsenic patients, $J_A = (T_{PAT}/T_{POP})$ x100

Where, T_{PAT} = Number of total patients in Mouza, and, T_{POP} = Total population in a Mouza.

E. Formulae for Sub parameters relative score calculation

Once we get absolute scores of all the 10 parameters (A_A, B_A, C_A, D_A, E_A, F_A, G_A, H_A, I_A, J_A), we move to find their relative scores (A_R, B_R, C_R, D_R, E_R, F_R, G_R, H_R, I_R, J_R). Relative measurements are important because that enables us to compare between areas. The scale of relative measurement is assumed from 1 to 10 and hence any ratio is multiplied by 10 (scaling factor is 10).

The generalized formula to find the relative scores of these 10 parameters is given below:

- The relative score of "Parameter i", (P_{Ri}):

$$P_{Ri} = (X_B - P_{Ai}) / (X_B - X_W) \times 10$$

Where,

P_{Ri} = Relative score of Parameter i of a Mouza, $[P_{R1} = A_R; P_{R2} = B_R; P_{R3} = C_R; P_{R4} = D_R; P_{R5} = E_R; P_{R6} = F_R; P_{R7} = G_R; P_{R8} = H_R; P_{R9} = I_R; P_{R10} = J_R;]$

P_{Ai} = Absolute score of Parameter i of a Mouza, $[P_{A1} = A_A; P_{A2} = B_A; P_{A3} = C_A; P_{A4} = D_A; P_{A5} = E_A; P_{A6} = F_A; P_{A7} = G_A; P_{A8} = H_A; P_{A9} = I_A; P_{A10} = J_A;]$

X_B = Highest absolute score of Parameter Mouza i under the whole thana,

X_W = Lowest absolute score of Parameter Mouza i under the whole thana.

F. Formulae for finding respective Weights of Sub and Main parameters,

When we have relative scores of parameters we pass these parameters into a VI (Vulnerability Index) Framework that generates weights of 10 Sub parameters (W_A, W_B, W_C, W_D, W_E, W_F, W_G, W_H, W_I, and W_J) and weights of 4 main parameters (W_P for arsenic hazard, W_Q for resource, W_R for coping capacity, and W_S for health hazard). These weights are learned from the existing data set to deprecate or overrate a particular group of parameters. This biasing is important because the resource distribution should be different according to their level of severity. However, we have manual option to assign these weights from the human knowledge domain.

G. Formulae for VI Calculation

Scores of main parameters are termed as "main score" and calculated as follows:

- The "Arsenic Score",

$$\text{Main\_Score}_1 = \frac{A_R \times W_A + B_R \times W_B + C_R \times W_C}{3}$$

- The "Resource Score",

$$\text{Main\_Score2} = \frac{D_R \times W_D + E_R \times W_E + F_R \times W_F}{3}$$

- The "Coping Capacity Score",

$$\text{Main\_Score3} = \frac{G_R \times W_G + H_R \times W_H + I_R \times W_I}{3}$$

- The "Health Hazard Score",

$$\text{Main\_Score4} = \frac{J_R \times W_J}{1}$$

- Finally, The "Vulnerability Index (VI)":

$$\text{V. I.} = \sum_{i=1}^{4} (\text{Main\_Score}_i \times \text{Main\_Weight}_i)$$

Where,

Main_Score_1 = Arsenic Hazard Component Score,
Main_Score_2 = Resource Component Score,
Main_Score_3 = Coping Capacity Component Score,
Main_Score_4 = Health Hazard Component Score.
Main_Weight_1 = Weight of Arsenic (W_P),
Main_Weight_2 = Weight of Resource (W_Q),
Main_Weight_3 = Weight of Coping Capacity (W_R),
Main_Weight_4 = Weight of Health Hazard (W_S).

When we have all the VI scores for all Mouzas we are now ready to view the arsenic situation of a Thana.

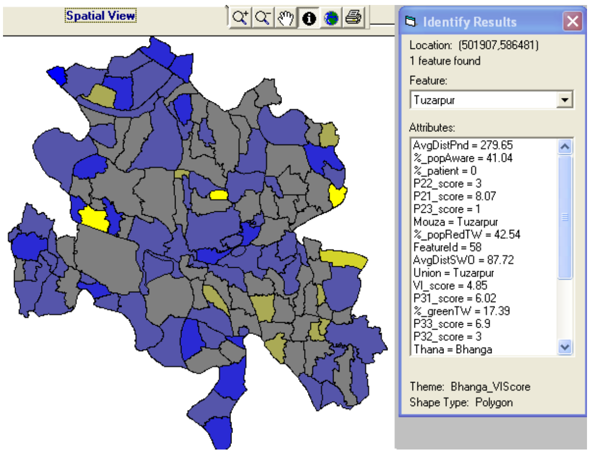

Figure 7. Spatial View of Bhanga Thana using ADSS

Figure 7 shows the arsenic situation of Bhanga Thana. There are 137 Mouzas under Bhanga Thana, Among them "Goaldangi" is the most severely arsenic affected Mouza, and lowest vulnerable Mouza is "Dakshin Char Chandra", It can also be seen that clicking on "Tuzarpur" Mouza, the detailed information of that Mouza is displayed on the right side box. However, the ADSS also has the option for a tabular view.

V. Proposed Resource Distribution Method Using ADSS

A. Decision for finding number of green tube wells required for a Mouza.

ADSS follows tube well distribution proportionate to the Mouza VI or in other words according to the Arsenic crisis level whereas conventional distribution is assumed to be distributing same number of tube wells for all Mouzas regardless their different level of severity.

Once we have VI information, the system is now able to take decisions to find the number of red tube wells to be replaced in the selected Mouzas under a union in a thana. To calculate the new VI, overall hazard takes into account all the 10 parameters, whereas, arsenic hazard and health hazard consider only the arsenic and health related parameters.

The formula for finding number of green tube wells required for a Mouza is:

$$RT[p] = \frac{VI[p]}{\sum_{i=1}^{m} (VI[i])} \times A$$

Where, m = Number of selected Mouzas for which the distribution is being considered under a particular union and thana,

p = The Mouza named "p" from m no. of Mouzas,
RT[p] = Required number of tube wells for the Mouza "p",
VI[p] = Vulnerability Index of the Mouza named "p",
VI[i] = Vulnerability Index of the Mouza named "i", i being a value from 1 to m,
A = No. of tube wells to be distributed set by the user.

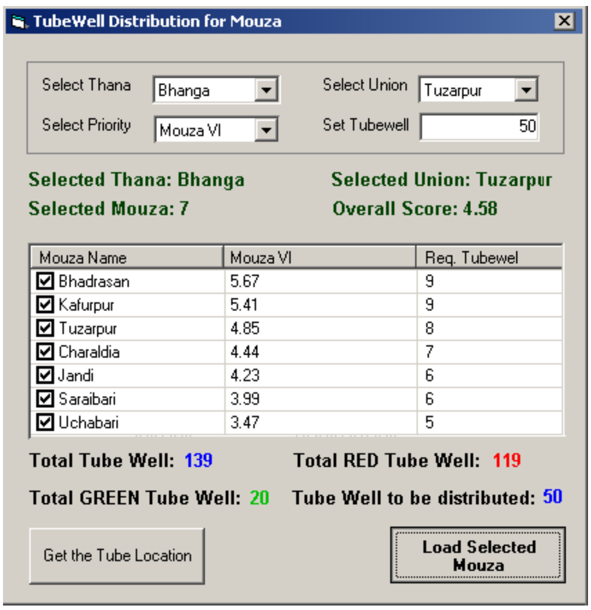

Figure 8. User Interface for distributing Green tube wells based on Mouza VI

The user can select any one of three hazards such as overall hazard, arsenic hazard, and health hazard as the parameter to see the effect of changed VI. Selecting any of these priorities, the system returns the list of Mouzas along with their required tube wells.

Figure 8 shows the list of Mouzas of “Tuzarpur” Union of “Bhanga” Thana, sorted by “Mouza VI” for distributing 50 green tube wells. Mouzas are listed according to descending VI values, where a greater Mouza VI means more severely affected Mouzas requiring more green tube wells. Arsenic Hazard includes only Arsenic related parameters (Percentage of red tube well, Average arsenic concentration, Percentage of population using red tube well).

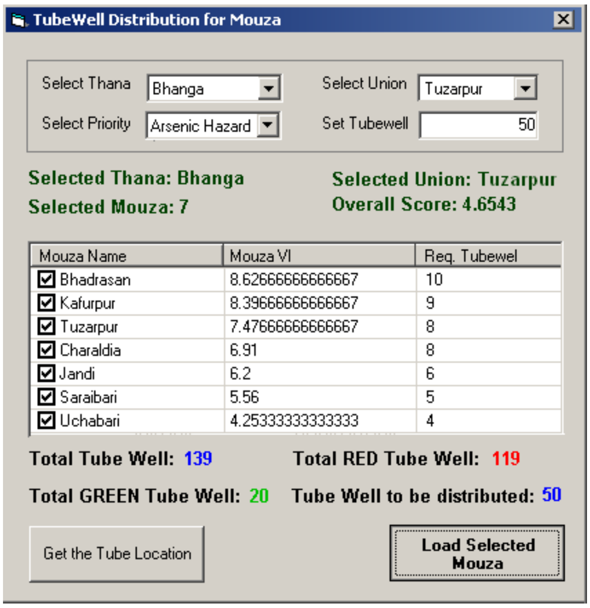

Figure 9. User Interface for distributing Green tube wells based on Arsenic Hazard

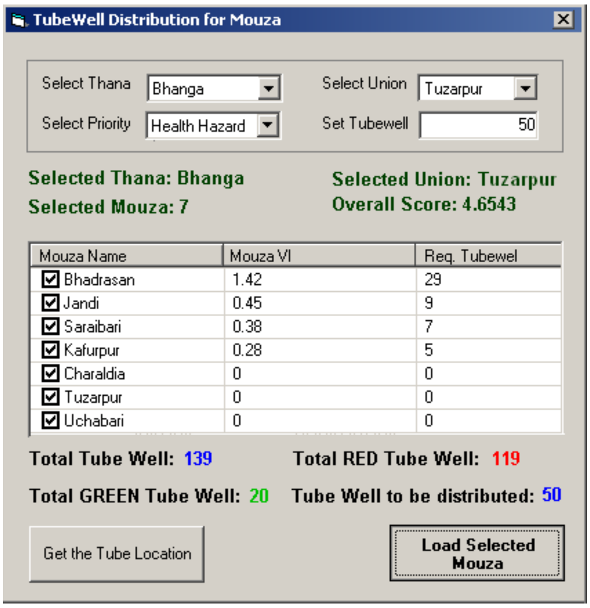

Figure 10. User Interface for distributing Green tube wells based on Health Hazard

Figure 9 illustrates tube well distribution based on Arsenic Hazard. It shows the 7 Mouzas of “Tuzarpur” Union under “Bhanga” Thana along with the required tube wells to be replaced. Since, we are taking only 3 parameters out of 10 parameters, the distribution is different from the tube well distribution based on Mouza VI. For example, “Bhadrasan” Mouza is assigned 9 tube wells for the previous distribution but 10 tube wells are assigned for Arsenic Hazard distribution.

Figure 10 illustrates tube well distribution based on Health Hazard. Since, we are taking only 1 parameter (Percentage of arsenic patients) out of 10 parameters, the distribution is different from the tube well distribution based on Mouza VI and Arsenic Hazard described previously. According to this distribution “Bhadarsan” Mouza is assigned 29 tube wells and since Charadia, Tuzarpur and Uchabari Mouza have no arsenic patients, they need no Tube wells.

B. Algorithm to find number of green tube wells required for a Mouza

function *calculate_greenTW(VI[n], A)*

```
01    Sort VI[n] in descending order
02    SumOfVI = 0
03    for p ← 1 to n do
04        SumOfVI = VI[p] + SumOfVI
05    TWDistributed = 0
06    for p ← 1 to n do
07        RT[p] = Integer ((VI[p] / SumOfVI) x A)
08        TWDistributed = TWDistributed + RT[p]
09    for p ← 1 to n do
10        If TWDistributed == A then
11            Exit
12        Else
13            RT[p] = RT[p] + 1
14            TWDistributed = TWDistributed + 1
```

The algorithm to find the required number of green tube wells in a particular Mouza. The function calculate_greenTW(VI[n], A) takes VIs (VI[n]) of all the selected Mouzas, number of tube wells to be distributed (A) set by the user as input, and returns the required number of tube wells, RT[p] for selected Mouzas. The algorithm is briefly described as follows:

At line 1 Mouzas with higher VIs are listed at top as vulnerable Mouzas have priorities for more tubewells than the Mouzas with lower VIs. At line 2 to 4 we compute the total of all VIs for n selected Mouzas.

To track the total no. of tube well distributed in all Mouzas RT[n], we have used “TWDistributed” counter that acts as the flag. At line 5 we initialized “TWDistributed” counter to 0 and it is updated when required tube wells RT[p] are distributed.

At line 7 we take the component of VI of a Mouza and multiply the value by “A”. Finally this computed value is assigned to required tube well, RT[p], but this is not the final figure of required tube well in Mouza p. “TWDistributed” counter is updated by the value of component of VI, RT[p] at line 8. However, since we have discarded fractional values we may need to distribute more tube wells. Tube well distribution is completed if the condition at line 10 satisfies. This happens only when there is no fraction in any of the VI components which is computed at line 7. However, the remaining tube wells, if any, are assigned at line 13.

C. Decision for finding suitable locations for replacing red tube wells

Once we have decisions for finding number of green tube wells required for a Mouza, we proceed to the second decision for finding suitable locations for replacing red tube wells. To start with, we first need to calculate a parameter called "tube well VI" for all red tube wells under a Mouza in order to be able to compare vulnerabilities among all tube wells. ADSS searches and takes all red tube well information, calculates tube well VI, based on different hazards and further selects the most vulnerable tube wells.

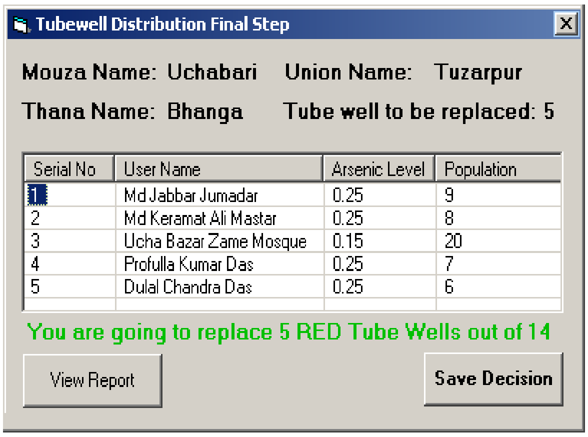

Figure 11. User Interface for finding locations for replacing Red tube wells

Figure 11 shows worst 5 red tube wells out of 14 red tube wells in "Uchabari" Mouza under "Bhanga" Thana. It is to be noted that, both arsenic level value of red tube and number of people using that red tube well is considered in order to find vulnerable tube wells. For example, record no. 4 has greater arsenic value (0.25) than the 3[rd] record (0.15) but it is listed afterwards considering no. of people using red tube wells.

D. Algorithm for finding locations for replacing red tube wells

Pseudo-code for finding locations for replacing red tube wells is given below. The function get_TWLocation takes arsenic level values of n of red tube wells (AL[n]), population using those red tube wells P[n], and number of red tube wells to be replaced (R), and returns tube well IDs of R number of red tube wells to be replaced (T[R]).

function *get_TWLocation(**AL[n], P[n], R)***

```
1   for j ← 1 to n do
2       TVI[j] = AL[j] x P[j]
3   Sort TV[n] in descending order
4   for j ← 1 to R do
5       T[j] = TubeID(TVI[j])
```

The algorithm is briefly described as follows. At line 1, *get_TWLocation* function uses a loop to find the tube well VI according to the given formula in line 2. At line 2, tube well VI of red tube well j (TVI[j]) is calculated. At line 3, more vulnerable tube wells are listed at top than tube wells with less vulnerability index. At line 5, the tube wells are ordered according to descending VI.

VI. An Integrated Smart User Interface

An integrated smart user interface is designed for the user where they will find an interactive, user-friendly, intelligible environment to work with. The designed system is capable of comparing and differentiating between old VI (before distribution of tube wells) and new VI (after distribution of tube wells) by a single click and can display data output in both tabular and spatial format.

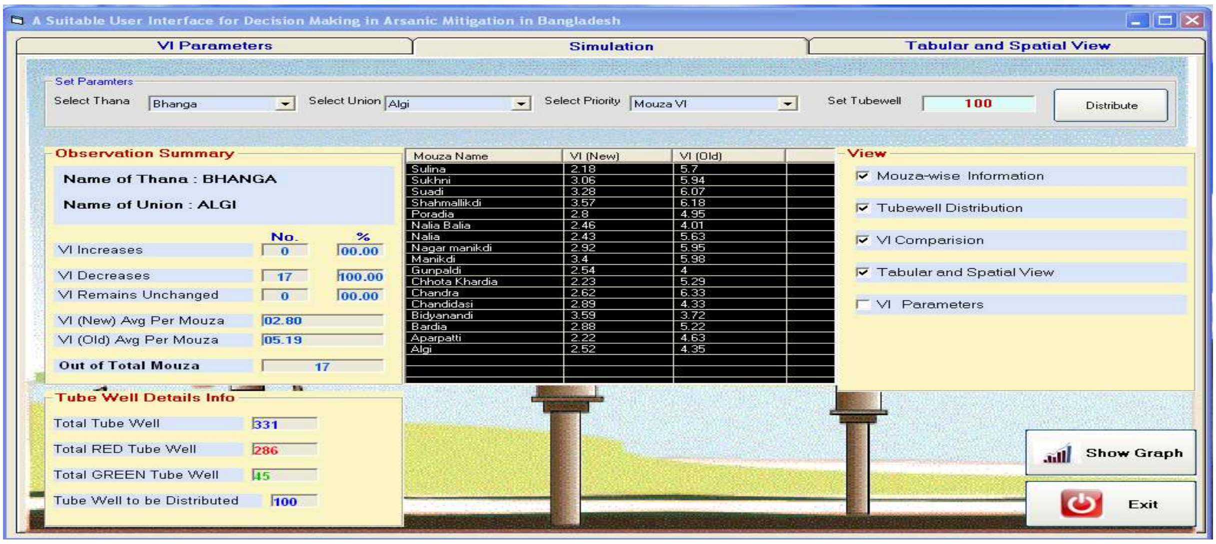

Figure 12. A Smart User Interface in Decision Making in Arsenic Mitigation in Bangladesh

As shown in figure 12, users can set their priorities to view the effect of resource allocation. After setting the view options, change in arsenic situation in different areas is displayed with other useful information. Figure 13 and 14 shows the tabular and spatial output.

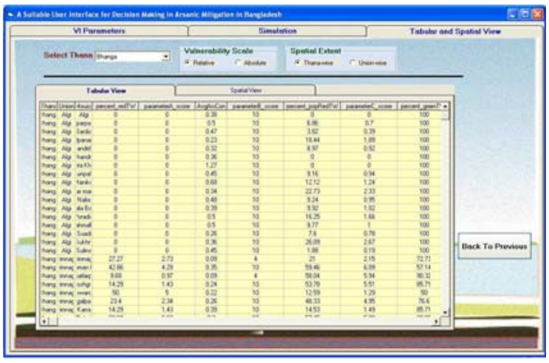

Figure 13. Tabular view

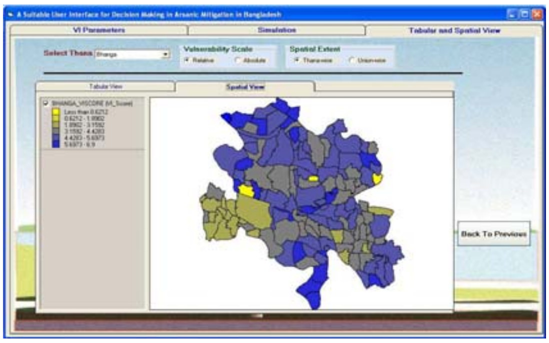

Figure 14. Spatial view

The following Table depicts the comparison between VI (Old) and VI (New) as an example.

TABLE 11. VI COMPARISON

Mouza Name	VI (New)	VI (Old)
Sulina	2.18	5.7
Sukhni	3.06	5.94
Suadi	3.28	6.07
Shahmallikdi	3.57	6.18
Poradia	2.8	4.95
Nalia Balia	2.46	4.01
Nalia	2.43	5.63
Nagar manikdi	2.92	5.95
Manikdi	3.4	5.98
Gunpaldi	2.54	4
Chhota Khardia	2.23	5.29
Chandra	2.62	6.33
Chandidasi	2.89	4.33
Bidyanandi	3.59	3.72
Bardia	2.88	5.22
Aparpatti	2.22	4.63
Algi	2.52	4.35

Figure 15 shows the corresponding graph that shows the difference between old VI and new VI.

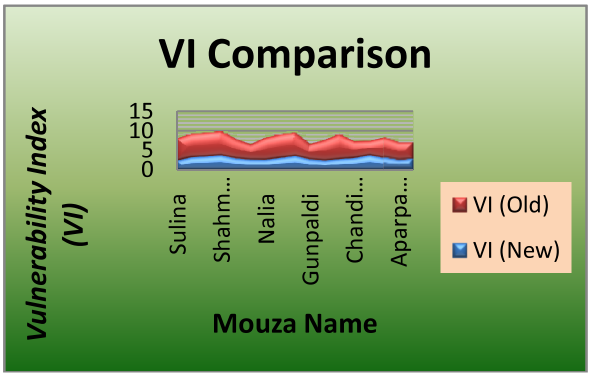

Figure 15. VI comparison

VII. RESULTS ANALYSIS

A. VI comparison between ADSS and conventional tube well distribution method

ADSS system analyzes different hazards (i.e., overall hazard, arsenic hazard, health hazard etc.) and measures the Vulnerability Index (VI) of respective areas (Mouza). We take this relative measurement to find out more vulnerable Mouzas that requires more tube wells than the less vulnerable Mouzas. Conventional tube well distribution method does not take this relative measurement into account. So, the proposed ADSS resource distribution method is capable of reducing vulnerability more than the conventional tube well distribution method.

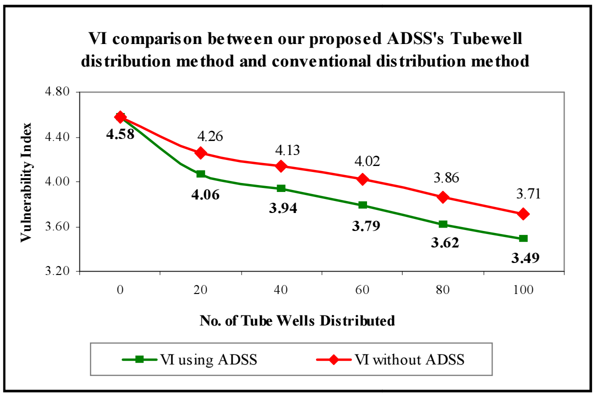

Figure 16. VI comparison between ADSS and conventional tube well distribution method

Figure 16 illustrates overall VI comparison between conventional and ADSS tube well distribution methods in 7 Mouzas of "Tuzarpur" union under "Bhanga" thana. The upper line (red line) depicts the projected overall VI after distributing 20, 40, 60, 80, and 100 tube wells using conventional tube well distribution method, which takes equal or random tube well distribution and the lower line (green line) shows VI using our proposed ADSS distribution method. The lower line (green) clearly shows that the proposed ADSS is capable of reducing overall VI more than the conventional method. The improved reduction of VI increases between the ADSS and conventional resource distribution method as the resources i.e., tube wells increase. For example, overall VI is reduced more after 100 tube wells were distributed than the case where 20 tube wells were distributed.

B. Mouza-wise VI comparison after distributing 100 Tube wells.

The conventional tube well distribution method is not capable of distinguishing among Mouzas according to their vulnerabilities, because it provides the same priority to all Mouzas even though some of the Mouzas might be severely affected. Considering this, ADSS has been given the capability to measure the vulnerabilities and preferentially distribute tube wells to more vulnerable Mouzas than less vulnerable Mouzas.

Figure 17 depicts Mouza-wise VI comparison among all the 7 Mouzas under "Hamidri" union of "Bhanga" thana after distributing 100 tube wells using proposed ADSS and conventional tube well distribution method. It clearly shows that, in most of the cases, Mouza VI is better with ADSS method than the conventional distribution method. Mouzas at left side are more vulnerable than Mouzas on the right side. As the figure shows, "Uchabari" Mouza is found as the least vulnerable Mouza.

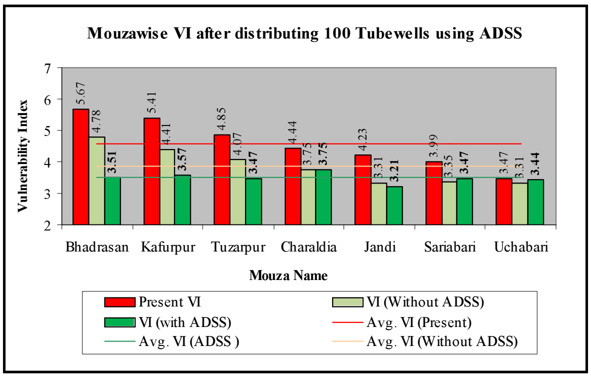

Figure 17. Mouza-wise VI Comparison after distributing 100 Tube wells

ADSS is intelligent enough to suggest distributing less tube wells to "Uchabari" Mouza than all 6 other Mouzas in the union, which is logical. However, since conventional tube well distribution suggests distributing same number of tube wells to this Mouza as it does for others, it can result in better Mouza VI changes than the ADSS, but overall VI changes for that union is still better using our ADSS method than the conventional resource distribution method.

VIII. CONCLUSION

Arsenic contamination is an overwhelming problem in the context of Bangladesh. A number of studies were done previously to assess the situation and some database-oriented software was developed to measure the vulnerability in different areas. But not enough work is done on simulating the effect of resource allocation based on different parameters that affect arsenic vulnerability. In this paper, we have presented a decision support system for optimal allocation of resources such as tube wells in different areas. The proposed resource distribution framework along with the developed smart user interface is useful for supporting optimal decision making to assist in mitigating arsenic contamination in highly vulnerable areas. It can be primarily used by the Government agencies for Arsenic Mitigation, as well as Research organizations working on Arsenic Mitigation in Bangladesh.

ACKNOWLEDGEMENT

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REFERENCES

[1] Planning Commission, "Millennium Development Goals: Needs Assessment and Costing 2009-2015 Bangladesh", General Economics Division, Planning Commission, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh, 2009.

[2] BBS, "Bangladesh Compendium of Environment Statistics", BBS, Dhaka, Bangladesh, 2004.

[3] UNICEF, "Arsenic Mitigation in Bangladesh", UNICEF-Bangladesh, Dhaka, Bangladesh, 2000.

[4] BBS & UNICEF, "Multiple Indicator Cluster Survey 2009", *BBS &* Ministry of Planning, Government of the People's Republic of Bangladesh & UNICEF, Dhaka, Bangladesh, 2010.

[5] Smedley, PL, Nicolli, HB, & Luo, ZD, "Arsenic in ground waters from major aquifers: sources, effects and potential mitigation", BGS Technical Report WC/99/38, BGS, NERC, Nottingham, UK, 2000.

[6] Matin, MA, Hassan, A, Sarke, MH, Elahi, MM, Shafey, MAL (February 2006). "CEGIS ADSS: Arsenic Decision Support System [online]. Avialable: http://www.cegisbd.com/soft13.htm

[7] Pidwirny, M., Geographic Information Systems (2011). Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment) [online]. Available: http://www.eoearth.org/article/Geographic_Information_Systems_%28GIS%29?topic=49501

[8] Druzdzel, MJ, and Flynn, RR., Decision Support Systems, Encyclopedia of Library and Information Science, 2nd Edition, Marcel Dekker Inc., New York, USA, 2002.

[9] Flanagan SV, and Zheng Y., Making Economics Sense for Arsenic Mitigation: A Case Study of Comilla District, Bangladesh, UNICEF Bangladesh, Dhaka, Bangladesh, 2011.