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A COMPARATIVE STUDY ON DISPERSIVITY OF ARSENIC AMONG SURMA, SARI AND VOLAGANJ SAND

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ABSTRACT

Transport mechanism of Arsenic (As) through the Surma, Sari and Volaganj sand is the prime concern of this study. Three column leaching tests were performed to find the dispersivity property of As. Numerous physical properties of these sand samples were determined and it shows Volaganj sand is most permeable. From the collected data experimental and theoretical breakthrough curve (BTC) were prepared and compared with each other. The value of dispersion coefficient and Index of dispersion were calculated. Dispersion coefficient (773.763cm^2/min) and index of dispersion (844.3cm^2/min) was higher for Surma sand. The leaching rate was found higher for higher pore water velocity of the Volaganj sand. The study also reveals that there is a significant difference between theoretical and experimental breakthrough curve. So not only convection/dispersion but also other processes such as adsorption, reaction with other compound are associated with the movement of arsenic through the sand medium.

Key words: Soil pollution, arsenic movement, dispersion, breakthrough curve.

I. INTRODUCTION

Nowadays Arsenic (As) is a great concern in many countries. The natural presence of arsenic in groundwater is related to the arsenic complexes present in soil. Due to high mobility of As once it is liberated, it causes possible groundwater contamination (Safiuddin and Karim, 2001). Many nations have reported high concentrations of As in their groundwater such as Bangladesh, Cambodia, China, India, Lao PDR, Nepal, Pakistan, Thailand, Viet Nam (Berg et.al. 2001, Chakraborti et.al., 2002, Mandal and Suzuki, 2002, Ng et.al., 2003 and Polya et.al., 2005). Increasing demand of food in densely populated countries like Bangladesh boosted the use of As contaminated groundwater for irrigation leaving soil progressively As rich. In addition, anxieties over As contamination in water sources, it also alarms that dietary consumption of As from contaminated soil (Abedin et. al., 2002) through the food chain may adversely upset human health (Arnt et. al., 1997) and already groundwater arsenic contamination in Bangladesh is testified to be the major arsenic calamity in the world in terms of the affected population (Talukder *et al.*, 1998) and hence As transport through soil is a issue of significance.

Unwholesome soil management methods have extremely despoiled soil feature, triggered soil as a ground water contamination. Materials accumulate when added in larger amounts than their decomposition rate cause a major problem (Microsoft Encarta, 2006). Iron (Fe) oxides, clay minerals, and organic materials in soil will adsorb or desorb as when the ionic composition in soil water changes (Gambrell and Khalid, 1980). Transport of organic material or other reducing agents into soil can initiate reduction condition and subsequently lead to dissolution of ferric hydroxides (Stumm and Sulzberger, 1992). One important way through which the groundwater is contaminated with As is the reductive dissolution of iron oxyhydroxide (FeOOH) stimulated by microbial activity and organic materials (Smedley and Kinniburgh, 2002, Ahmed et.al., 2004, McArthur et.al., 2004, Mukherjee and Bhattacharya, 2001, Ravenscroft et.al., 2001 and Zheng et.al., 2004).

The groundwater in Bangladesh has deteriorated gradually due to the extreme withdrawal of water for irrigation and domestic water supply, lack of water management and inadequate recharge of the aquifer. Excessive withdrawal of groundwater may be the vital reason for building up a zone of aeration in clayey and peaty sediments containing arseno-pyrite. Under aerobic state, arseno-pyrite decomposes and releases arsenic that mobilizes to the subsurface water. The enrollment of arsenic is further enriched by the compaction of aquifers caused by groundwater extraction (Subramanian *et al.,* 2002).

Transport mechanism of As through soil is very crucial to know the degree of pollution in subsurface, to predict the concentration at different layer of soil or at groundwater, etc. A study by Rahman (2005) on nitrogen transport phenomena in saturated disturbed soil sample which investigated the possibilities of groundwater contamination by NO_3-N of the same study area. A study conducted by Bejat et. al. (2000) on solute transport and showed the effect of soil type and land use management on solute movement.

In Sylhet, Bangladesh as naturally ensues in several geological formations. It is chiefly found in shale rock, which points to arsenic's favored adsorption on clays and sand, and in pyrites that are prevalent in the earth's crust. When water approaches into contact with these rocks and minerals on the earth's surface and in the subsurface, a fraction of As dissolves. The objective of this study is to find out the transport mechanism of arsenic through sands and to compare it's mobility among different sands of Sylhet.

II. MATERIALS AND METHODS

THEORY

In this study, theoretical breakthrough curve will be developed assuming the flow of arsenic through sand is a non-reactive convective dispersive solute transport.

Hypotheses for model development:

i. Sand samples are homogeneous

ii. Flow of arsenic through sand only one dimensional, only in z direction

iii. During leaching temperature is constant

iv. Only one incompressible liquid medium (water) and it is completely mobile

v. Arsenic is completely dissolved in water

vi. The flow is convective and dispersive/ diffusive

vii. No consumption or production of arsenic when move

viii. The water flow is steady state

Invoking these assumptions, the continuity equation comes as:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial Z^2} - v \text{...(1)}$$

This equation is called classical convection dispersion equation. The solution of equation (1) subjects to the following boundary conditions-

$$C_{z,t} = 0,\ \textit{for}\ z > 0\ \ \textit{and}\ \ t = 0 \text{.........................}(a)$$

$$C_{z,t} = 0,\ \textit{for}\ z = 0\ \ \textit{and}\ \ t = 0 \text{.........................}(b)$$

$$\lim_{z\to\infty} C_{z,t} = 0,\ \textit{for}\ t > 0 \text{..............................}(a)$$

Solving equation (1),

$$C_{z,t} = \frac{1}{2}C_0\left[erfc\,\frac{z - v_p t}{2\sqrt{Dt}} + e^{\frac{vz}{D}} erfc\,\frac{z + v_p t}{2\sqrt{Dt}} \right] \text{..........(2)}$$

By knowing v, D and C_0, the arsenic concentration at a particular depth and time can be determined.

In terms of pore volume P, equation (2) can be written as,

$$\frac{C}{C_0} = \frac{1}{2} C_0 \left[erfc \frac{1-p}{2\sqrt{\frac{Dp}{\nu_p}}} + e^{\frac{vz}{D}} erfc \frac{1+p}{2\sqrt{\frac{Dp}{\nu_p}}} \right] \text{...........(3)}$$

$$P = \frac{Qt}{V_0} = \frac{AV_d t}{Al_a} = \frac{V_d t}{l_a} = \frac{V_p t}{l}$$

Where, Q = Flux of water through the sand
t = time
V_0 = Pore water velocity
V = bulk volume of sand
a = porosity factor
V_d = Darcy's velocity
V_p = pore water velocity
l = length of sand column
A = Area of cross section of the column

The plot of C/C_0 for various values of P, termed as breakthrough curve, is used to find the dispersion coefficient, D.

BREAKTHROUGH CURVE

It refers the relationship of leachate concentrations (or relative concentration) against time or pore volume or effluent volume. It expresses: (a) how fast a solute is moving towards the bottom of the soil column, (b) how long it will take for a solute to appear at the bottom, and (c) what kinds of transport mechanism are significant in solute transport. There are various factors that affect the shape of the solute breakthrough curve. These are concentrations of solute, mode of solute application, effect of flow velocity, water content of the media, cation exchange capacity of the media, etc. The Fig. 1 to 4 shows standard breakthrough curves for different types of solute transport (Wagenet, 1983).

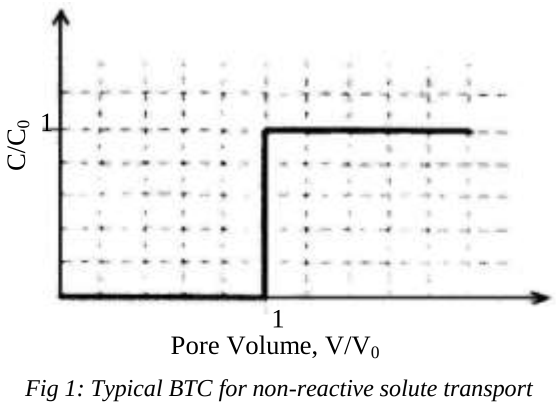

Fig 1: Typical BTC for non-reactive solute transport

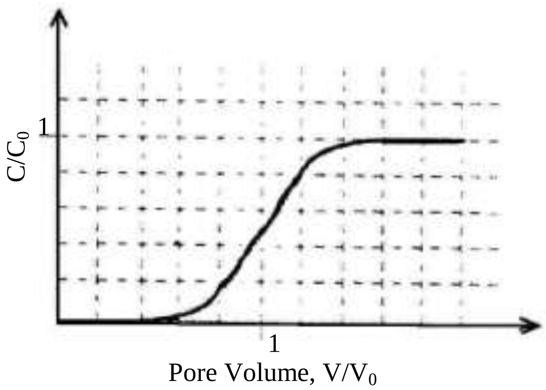

Fig 2: Typical BTC for non-reactive convective/ dispersive solute transport

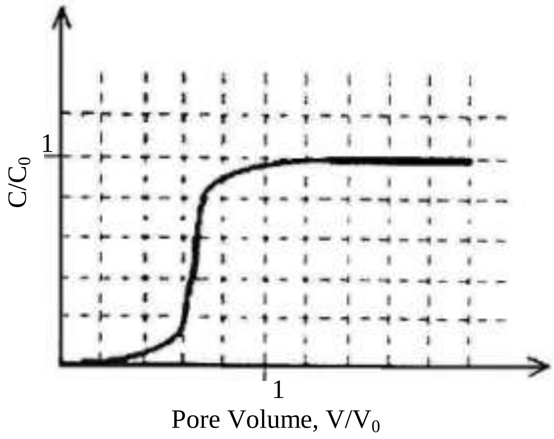

Fig 3: Typical BTC for reactive solute transport (linear sorption isotherm)

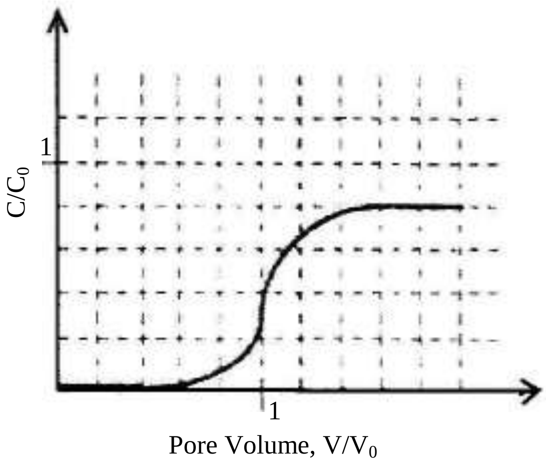

Fig 4: Typical BTC for reactive solute transport (first order degradation)

SAND SAMPLE COLLECTION

Three sand samples were collected from three sources. *Sari sand* from river Sari, which is also known as Sylhet sand; *Volaganj sand* from Volaganj and *Surma sand* from Surma River. Plants, roots, organic debris etc. were removed carefully from the collected sample. The soil samples were then oven dried.

ANALYSIS OF PHYSICAL PROPERTIES

Specific gravity and dry density of soil were determined by Pycnometer method and particle size analysis was done by sieve analysis method as described by T. W. Lambe.

PROCEDURE OF COLUMN TEST

i. The filter net was placed at the bottom of the column.
ii. Soil sample was poured into the column by consecutive 3 steps (each step 4 inch) adding soil and distilled water to compact it up to 12 inch height.
iii. In column, soil sample was washed two times by distilled water.
iv. Initial concentration and seepage velocity was determined passing distilled water in third times.
v. Known concentration of Arsenic solution (0.5 mg/L) was prepared from standard solution.
vi. Soil column and upper bucket was filled with known concentration of Arsenic solution.
vii. For constant flooding depth the discharge rate of bucket was adjusted with the seepage velocity of the soil column.
viii. Conical flask was placed at the bottom of the soil column and sample solution was collected.
ix. Time was recorded each collection.
x. Each sample was filtered by filter paper.
xi. Arsenic solution was determined of each sample by standard procedure of SDDC (Silver Di-thio Di-ethyl Carbamate) method.

III. DATA ANALYSIS AND DISCUSSION

All the experiments were done at the laboratory of Civil and Environmental Engineering Laboratory, Shahjalal University of Science and Technology. Table 1 shows the physical properties of sand samples collected from three locations of Sylhet

Table 1: Physical property of the sand samples

Sl. #	Property	Sari	Surma	Volaganj
01	Length of soil column, cm	30.48	30.48	30.48
02	Column diameter, cm	6.0225	6.0225	6.0225
03	Cross sectional area, cm^2	28.5	28.5	28.5
04	Volume of soil in the column, cm^3	868.68	868.68	868.68
05	Flooding depth over soil column, cm	6	6	6
06	Dry density, gm/cm^3	1.57	1.56	1.54
07	Wet density, gm/cm^3	1.67	1.68	1.71
08	Water content, %	24.9	27.87	28.23
09	Specific gravity	2.73	2.76	2.54
10	Degree of saturation	1.00	1.00	1.00
11	Air filled porosity	0.3848	0.43479	0.4352
12	Void ratio	0.6256	0.7692	0.7707
13	1 pore volume, cm^3	334.26	377.69	378.05
14	Coefficient of permeability, cm/s	0.001365	0.000841	0.0142

PERMEABILITY

The permeability of soil samples, shown in Fig-5, shows that Volaganj sand is more permeable than the others. It has taken less time than the others to pass the solute.

UNIFORMITY COEFFICIENT

The uniformity coefficient of the samples was 2.05, 1.54 and 2.13 for Sari, Surma and Volaganj sand respectively, as shown in Fig-6, which reveals that Volaganj sand is more vulnerable for arsenic transport.

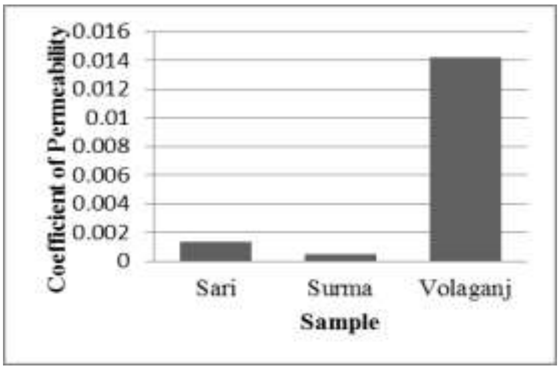

Fig-5. Coefficient of permeability

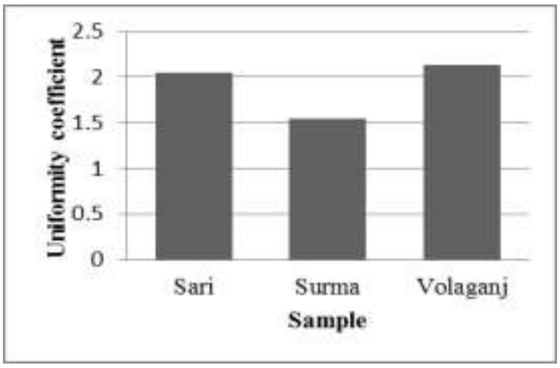

Fig-6. Uniformity coefficient

DISPERSION COEFFICIENT AND INDEX OF DISPERSION

In case of non-reactive convective/ dispersive transport, Dispersion coefficient and index of dispersion are $D = \frac{V_D L}{4\pi S^2}$ and $I = \frac{2D}{V_p}$ respectively.

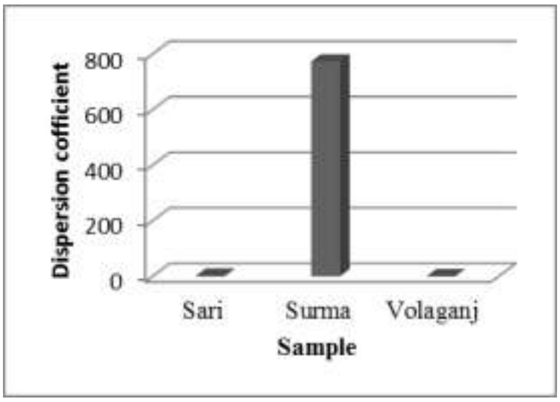

Fig- 7. Dispersion coefficient

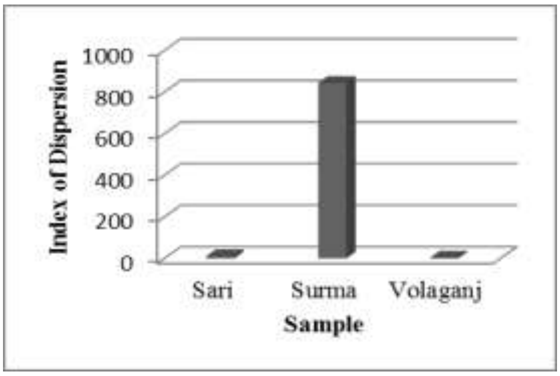

Fig.8. Index of Dispersion

The highest value of dispersion coefficient, Fig- 7, and index of dispersion, Fig- 8, is for the Surma sand. So dispersion of arsenic within an area at a specific time is highest for this time

SOLUTE BREAKTHROUGH CURVE

The breakthrough curves for Sari sand, Surma sand, Volaganj sand are shown in Fig- 9 to 11.

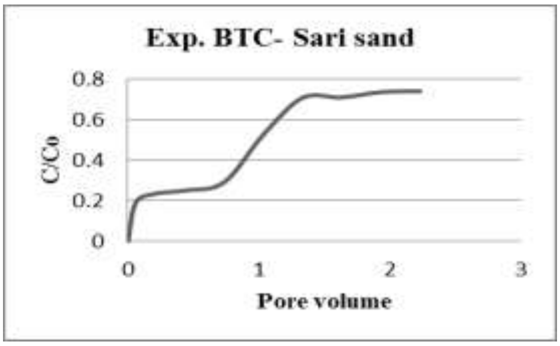

Fig-9. Experimental BTC of Sari sand

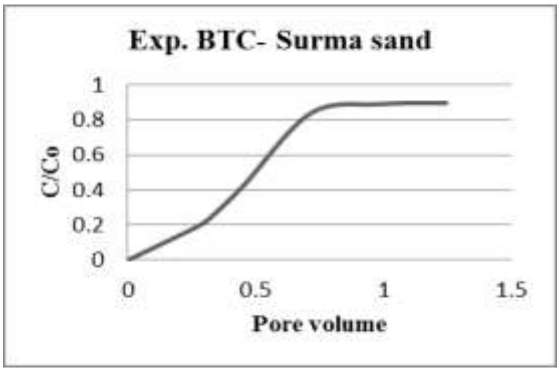

Fig-10. Experimental BTC of Surma sand

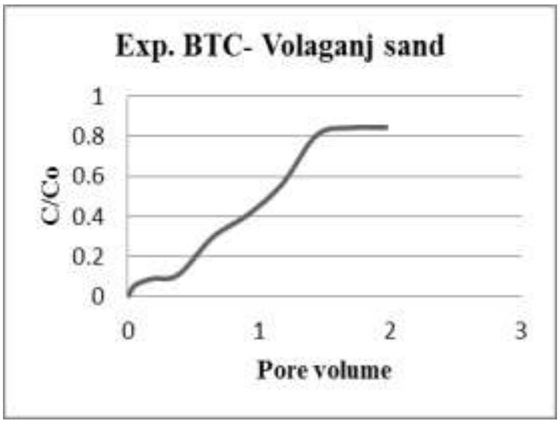

Fig-11. Experimental BTC of Volaganj sand

Sari sand: Comparing the experimental BTC of Sari sand with the standard BTC, it is found that the longitudinal dispersion was dominant in this sand column. Some points look inconsistent with the standard BTC. This might be due to poor packing as well as for ignoring the flow through boundary wall.

Surma sand: Surma sand was the finer among sample. The BTC of it was more smooth than similar with the standard one. It had ended up before relative concentration was below 1. It surely indicates some chemical reaction had taken place in the sand column, because it was more similar with the typical BTC of reactive solute transport.

Volaganj sand: Longitudinal dispersion was dominant for this sample like Sari sand. The BTC was very much steep. This might be due to continuous solute application. Because Volaganj sand was the coarser, to maintain constant head, it was necessary to apply solute continuously

THEORETICAL BREAK THROUGH CURVE

The theoretical BTC has been drawn, shown in Fig. 12 to Fig. 14 by solving non-reactive CDE (convection dispersion equation [equation- (3)] for all the sand samples:

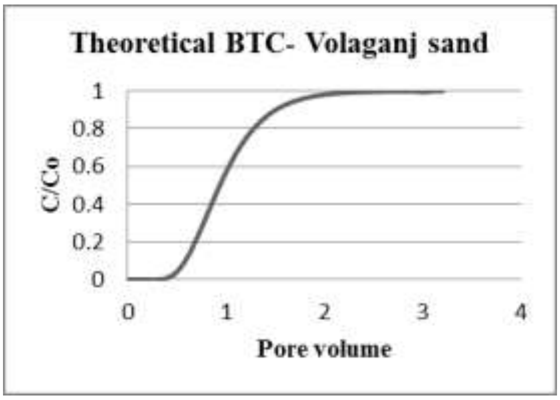

Fig-12. Theoretical BTC of sari sand

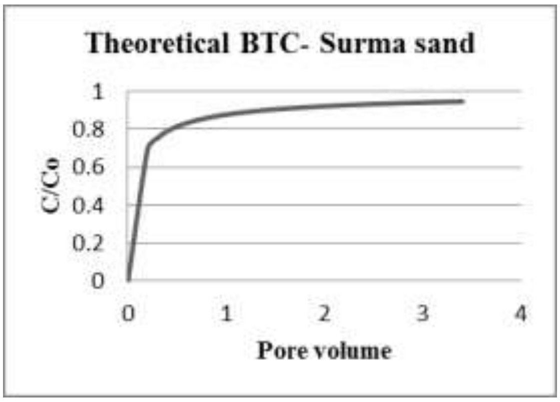

Fig-13. Theoretical BTC of Surma sand

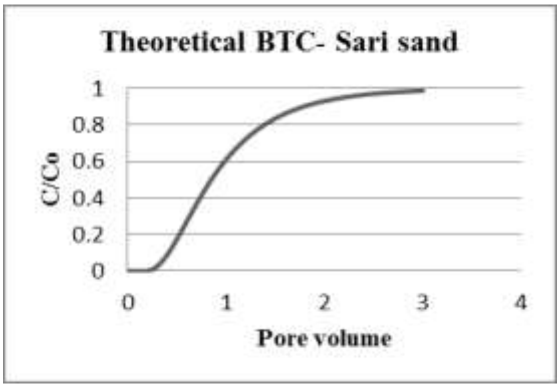

Fig-14. Theoretical BTC of Volaganj sand

COMPARISON BETWEEN THEORETICAL AND EXPERIMENTAL BTC

Few discrepancies have found between theoretical and experimental BTC for each sample. This reveals that not only convection/ dispersion is dominant but also other mechanism such as adsorption, reaction, ion exchange etc. may be associated with the transport/movement of arsenic through sand medium.

IV. CONCLUSION

Volaganj sand is most vulnerable because the coefficient of permeability is highest and so arsenic complex can easily percolate through it. The dispersion coefficient and index of dispersion is highest for Surma sand and lower for Volaganj sand. The higher the volumetric water content and higher dispersion coefficient will reduce the arsenic leach through the sand and so arsenic flow through Volaganj and Surma sand is highest and lowest respectively. Considering all things Volaganj sand is most vulnerable and Suma sand is less vulnerable while Sari sand medium vulnerable for arsenic transport. Uniformity coefficient shows that, uniform particle soil is less vulnerable to arsenic mobility. There are little dissimilarities between the theoretical and experimental BTC and this happened due to along with convection or dispersion, other mechanism of solute transport may be associated. Future study is deemed to find other methods of arsenic transport is involved in this medium.

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REFERENCES

1. Abedin, M.J., Cotter-Howells, J. and Mehrag, A.A. (2002), *Plant Soil*, **240**, pp. 311.

   doi:10.1023/A:1015792723288

2. Ahmed, K.M., Bhattacharya, P., Hasan, M.A., Akhter, S.H., Alam, S.M.M., Bhuyian, M.A.H., Imam, M.B., Khan, A.A. and Sracek, O. (2004), *Appl. Geochem.*, **19**, pp. 181.

   doi:10.1016/j.apgeochem.2003.09.006

3. Bejat, L., Perfect, E., Quesenberry, B.L., Coyne, M.S. and Haszler, G.R. (2000), “Soil transport as related to soil structure in unsaturated intact soil block”, *Soil Sci. Soc. Am. Proc.*, **64**, pp. 818-826.

4. Berg, M., Tran, H.C., Nguyen, T.C., Schertenleib, R. and Giger, W. (2001), *Environ Sci. Technol.*, **35**, pp. 2621. doi:10.1021/es010027y

5. Chakraborti, D., Rahman, M.M., Paul, K., Chowdhury, U.K., Sengupta, M.K., Lodh, D, Chanda, C.R., Saha, K.C. and Mukherjee, S.C. (2002), *Talanta*, **58**, pp. 3. doi:10.1016/S0039-9140(02)00270-9

6. Gambrell, R.P. and Khalid, R.A. (1980), *Environ. Sci. Technol.*, **14**, pp. 431. doi:10.1021/es60164a012

7. Gulens, J, Champ, D.R. and Jackson, R.E. (1979), *American Chemical Society Symposium Series*, **93**, pp. 81.

8. Independent Report, (1998), Remedies for Arsenic Poisoning, *The Independent*, A national daily newspaper of Bangladesh.

9. Kuhlmeier, P.D. (1997), *Journal of soil Contamination*, **6**(1), pp. 21.

10. Mandal, B.K. and Suzuki, K.T. (2002), *Talanta*, **58**, pp. 201. doi:10.1016/S0039-9140(02)00268-0

11. McArthur, J.M., Banerjee, D.M., Hudson-Edwards, K.M., Mishra, R., Purohit, R., Ravenscroft, P., Cronin, A., Howarth, R.J., Chatterjee, A., Talukder, T., Lowry, D., Houghton, S. and Chadha, D.K. (2004), *Applied Geochemistry*, **19** (8), pp. 1255. doi:10.1016/j.apgeochem.2004.02.001

12. Microsoft Encarta, (2006). 1993-2005 Microsoft Corporation.

13. Mukherjee, A. and Bhattacharya, P. (2001), *Environ Rev.*, **9**, pp.189. doi:10.1139/er-9-3-189

14. Ng, J.C., Wang, J. and Shraim, A. (2003), *Chemosphere*, **52**, pp. 1353. doi:10.1016/ S0045-6535(03)00470-3

15. Polya, D.A., Gault, A.G., Diebe, N., Feldman, P., Rosenboom, J.W., Gilligan, E, Fredericks, D., Milton, A.H., Sampson, M., Rowland, H.A.L., Lythgoe, P.R., Jones, J.C., Middleton, C. and Cooke, D.A. (2005), *Mineral Mag.*, **69**, pp. 807.

    doi:10.1180/0026461056950290

16. Rahman, M.S. “(2005), “A Study on Nitraet Nitrogen Transport Phenomena in Disturbed Soil Sample of Sylhet Sadar Upazila”, B.Sc. Engineering Thesis, SUST, Sylhet.

17. Ravenscroft, P., McArthur, J.M. and Hoque, B.A. (2001), “In: Arsenic exposure and health

effects IV", Eds W.R. Chappel *et al*. (Elsevier Science Ltd. Oxford, 2001) pp. 53-78.

18. Safiuddin, M. and Karim, M.M. (2001). "Groundwater arsenic contamination in Bangladesh: causes, effects and remediation", *Proceedings of the 1st IEB international conference*, Chittagong, Bangladesh.
19. Smedley, P.L. and Kinniburgh, D.G. (2002), *App. Geochem.*, **17**, pp. 517. doi:10.1016/S0883-2927(02)00018-5
20. Subramanian, V., Madhvan, N. and Naqvi, S.A.S. (2002), "Arsenic in our environment- A critical review, Environment Hazards in South Asia", *Capital Publishing Company*, New Delhi, pp. 189-214.
21. Talukder, S.A., Chatterjee, A., Zheng, J., Kosmus, W. (1998), "Studies of Drinking Water Quality and Arsenic Calamity in Groundwater of Bangladesh", *Proceedings of the International Conference on Arsenic Pollution of Groundwater in Bangladesh: Causes, Effects and Remedies*, Dhaka, Bangladesh.
22. Wagenet, R.J. (1983), Principles of salt movement in soils. Pp. 123–140. In Nelson, D.W. et al. (ed.), Chemical mobility and reactivity in soil systems, SSSA, Madison, WI.
23. W. Stumm and B. Sulzberger, Geochim. Cosmochim. Acta **56**, 3233 (1992). doi:10.1016/0016-7037(92)90301-X
24. Zheng, Y., Stute, M., Van-Geen, A., Gavrieli, I., Dhar, R., Simpson, H.J, Schlosser, P. and Ahmed, K.M. (2004), *Appl. Geochem.*, **19**, pp. 201. doi:10.1016/j.apgeochem.2003.09.007