Groundwater Arsenic Contamination Inventories and Risk Assessment using Geographic Information System: Case Studies Kishoreganj and Netrokona Districts of Bangladesh.

99- Abstract #840

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ABSTRACT

Groundwater in Bangladesh is contaminated with Arsenic, which occurs naturally in alluvial and deltaic sediments. The first official detection in 1993 and subsequent confirmation after 1995 of high levels of Arsenic in numerous shallow and deep wells in various parts of the country has raised serious health concerns. Recent investigations, though incomplete, confirm that the occurrence of Arsenic in groundwater is more widespread than assumed at first and that it already affects a large number of people. The latest statistics available on the arsenic contamination in groundwater indicates that 52 districts around 80% of the total area of Bangladesh and about 40 million people are at risk. It is estimated that at least 1.2 million people are exposed to Arsenic poisoning with tens of millions potentially exposed. The reported number of patients seriously affected by arsenic in drinking water has now risen to 6000 demands extensive research in this field.

Emission inventories are essential tools for assessing releases to the environment. Analysis on emissions inventory data can be useful for environmental program planning and management purposes as well as identifying emissions that are potentially above the standard level. In identifying only the level of concentration is not enough; the concentrations resulting from the emissions are important to estimating exposure and risk. Geographic Information Systems (GIS) used in this study for visualizing water quality characteristics in Union census block, distribution of arsenic groundwater concentration, and exposure risk zones for two northeastern districts, Kishoreganj and Netrokona of Bangladesh.

INTRODUCTION

In recent years Geographic Information Systems (GIS), have become more available to various environmental agencies as these sophisticated computer information systems, once available only on large mainframe computers, have gradually migrated to workstations and personal computers. A GIS can store, manage, analyze, and display a wide range of geographic, demographic, and environmental quality data in a variety of formats. Various environmental agencies have begun to use GIS for numerous disaster planning tasks as well as the basis for a more general "environmental database" which can provide both local and international exposure with information about the depth of the disaster and also a further planning tool to make future studies.

Arsenic groundwater contamination of Bangladesh has already got a wide range of international
media coverage. So far multinational organizations have already promised in some capacity, help Government of Bangladesh promoting the deadly situation of the arsenic disaster. They are World Bank, UNDP, UNICEF, British - DFID, and Switzerland Government. Field surveys on arsenic concentration and water quality measurements have already started using various methods by different organizations. These databases are scattered and no exchange of study findings is observed. It is really very necessary to have the results coordinated and shared with other organization. In this connection, Bangladesh Government in one of its recent movements set a National Arsenic Mitigation Information Center (NAMIC). This is a part of the World Bank financed Arsenic Mitigation Project, which will deal to collect, manage, interpret, and disseminate all relevant hydrogeological, water quality, health, socioeconomic, and technical information. Total project costs are estimated to be US $44.4 million. This includes an IDA credit of US$ 32.4 million and a US $ 3 million grant from the Swiss Agency for Development and Cooperation. It should be noted here that special care should be taken on laboratory methods and data accuracy, as some of the previous study results troubles to determine the nature and the extent of the arsenic contamination and its possible remedies due to the lack of reliable data.

Groundwater contamination of arsenic has already affected 52 out of 64 districts of Bangladesh. It is estimated that around 0.7 million out of 2.5 million tubewells of the whole country are contaminated by arsenic. Based on this statistics it can be understood that working with such large set of environmental databases poses certain problems. As there are many sample sites, sampling time frames, and multiple parameters like tubewell depth, water qualities; not all of which are measured at each site and each time frame. A proper management of these databases is required so that it be handled on a geographic basis. The reason is to enable hydrologists, policy makers, and community leaders to discover the way, in which the arsenic flows through the aquifer and recommend sufferers to avoid drinking water, which contain high level of arsenic. It also helps taking measures not to sink new tubewells in the same geographical location and water aquifer where contaminated tubewell has been identified.

Water quality refers to the characteristics of water that will influence its suitability for a specific use. Emphasis normally placed in the chemical and physical properties of water. Water quality measurement is important especially when certain chemical and physical quantity exceeds the normal levels.

A formal risk assessment of arsenic exposure may be conducted under the standard framework used for chemical risk assessment. This consists of three steps- dose-response assessment, exposure assessment, and risk characterization. A retrospective case-control study showed a significant association between duration of consuming high-arsenic well water and cancers of the liver, lung and bladder. In this study, cancer deaths in the Blackfoot disease (BFD) endemic area of Taiwan between January 1980 and December 1982 were chosen for the case group. About 90% of the 86 lung cancers and 95 bladder cancers in the registry were histologically or cytologically confirmed and over 70% of the liver cancers were confirmed by biopsy. A control group of 400 persons living in the same area was frequency-matched with cases by age and sex. Standardized questionnaires of the cases (by proxy) and controls determined the history of artesian well water use, socioeconomic variables, disease history, dietary habits, and lifestyle. Similarly, in a 15-year study of a cohort of 789 patients of Blackfoot disease, an increased mortality from cancers of the liver, lung, bladder and kidney was seen among BFD patients when compared with the general population in the endemic area or when compared with the general population of Taiwan.
A significant dose-response relationship was found between arsenic levels in artesian well water in 42 villages in the southwestern Taiwan and age-adjusted mortality rates from cancers at all sites, cancers of the bladder, kidney, skin, lung, liver and prostate. An ecological study of cancer mortality rates and arsenic levels in drinking water in 314 townships in Taiwan also corroborated the association between arsenic levels and mortality from the internal cancers.

Chen and others conducted an analysis of cancer mortality data from the arsenic-exposed population to compare risk of various internal cancers and compare risk between males and females. The study area and population have been described by Wu and others. It is limited to 42 southwestern coastal villages where residents have used water high in arsenic from deep artesian wells for more than 70 years. Arsenic levels in drinking water ranged from 0.010 to 1.752 ppm. The study population had 898,806 person-years of observation and 202 liver cancer, 304 lung cancer, 202 bladder cancer and 64 kidney cancer deaths. The study population was stratified into four groups according to median arsenic level in well water (< 0.10 ppm, 0.10-0.29 ppm, 0.30-0.59 ppm and 0.60+ ppm), and also stratified into four age groups (< 30 years, 30-49 years, 50-69 years and 70+ years). Mortality rates were found to increase significantly with age for all cancers and significant dose-response relationships were observed between arsenic level and mortality from cancer of the liver, lung, bladder and kidney in most age groups of both males and females. The data generated by Chen and others provide evidence for an association of the levels of arsenic in drinking water and duration of exposure with the rate of mortality from cancers of the liver, lung, bladder, and kidney.

This study has been conducted on the database of North East Minor Irrigation Project, Ministry of Agriculture, Bangladesh Government. Under this project water samples from tubewells were collected from six northeastern districts of Bangladesh. Water samples were analyzed to measure arsenic concentration and various water quality characteristics. This paper will deal with databases of two northeastern districts: Kishoreganj and Netrokona. These basic databases are utilized for visualizing geographically located arsenic contamination level, water quality characteristics, and a general outline for arsenic risk assessment.

DATA AND METHOD

Districts Kishoreganj and Netrokona are two affected northeastern districts where arsenic groundwater contamination exceeds Bangladesh permissible limit of 0.05 ppm. These two districts having population of 1.73 and 2.3 millions and total areas of 2689 and 2810 km², respectively. 375 water samples from Kishoreganj and 333 samples from Netrokona district are analyzed for arsenic concentration using Silverdiethyl Dithocarbonate (SDDC) method (Standard Method #307B). On the other hand, tubewell water quality measurements for 30 samples of Kishoreganj district and 30 from Netrokona district using standard methods. The following parameters of water were analyzed: pH, electrical conductivity (ECw), Sodium ion (Na⁺), Potassium ion (K⁺), Calcium ion (Ca²⁺), Magnesium ion (Mg²⁺), Ferrous ion (Fe²⁺), Nitrate ion (NO₃⁻), Chlorine ion (Cl⁻), Boron (B), and Carbonate/Bicarbonate (CO₃²⁻/HCO₃⁻), and on the basis of experimental data Sodium Adsorption Ratio (SAR) was estimated. The population data for the smaller geographic area Unions are collected from the 1991 census data adjusted for 1995 of Bangladesh Bureau of Statistics. These databases are composed of Union level data of male and female groups, age wise population distribution in each geographic location.
pH was measured with a HANNA pH meter. Electrical conductivity was measured with a HANNA conductometer and the results are expressed in Deci Siemens per meter (dS/m). A Jenway PFP7 flame analyzer was used for the determination of Na\(^+\) and K\(^+\) against the usual practice of calibration with standard solutions of Na\(^+\) and K\(^+\). Calcium and Magnesium were determined by complexometric titration. For greater accuracy preconcentration of water samples were done to an exact volume when necessary. Both Ca\(^{++}\) and Mg\(^{++}\) were obtained by using Erichrome Black T (EBT) indicator and back titration with standard Mg\(^{++}\) solution at pH 8-10. For Ca\(^{++}\) only, calcon indicator was used after removing Mg\(^{++}\) at about pH 12. Alternatively Ca\(^{++}\) was titrated using Murexide indicator. Iron was reduced to the Fe (II) State by NH\(_2\)OH and pH was adjusted to 3.2-3.3. 1, 10 Phenanthroline reagent was added in presence of acetate buffer and the resulting orange-red color was measured in a spectrophotometer at 510 nm against a reagent blank as usual. Nitrate was determined by using the reagent phenol disulphonic acid and measured the absorbence in a spectrophotometer at 420 nm against the standard calibration as usual. Chloride content was determined by using Mohr's method of titration using AgNO\(_3\) as the standard titrating reagent in presence of K\(_2\)CrO\(_4\) indicator or for back titration with standard NH\(_4\)CNS solution using ferric-alum indicator. Boron was determined by the carmine method in concentrated H\(_2\)SO\(_4\) and the absorbence was measured at 585 nm in the spectrophotometer Photic-100. Carbonate and Bicarbonate was determined by titrimetric method using mixed indicator (universal indicator) with the help of standard acid/alkali solutions.

The sodium adsorption ratio (SAR) is the standard measure of the sodicity of soil/water. The sodium adsorption ratio (SAR) is calculated from the concentrations in milliequivalents per liter (me/l) of sodium, calcium, and magnesium in the saturation extract:

\[
\text{SAR} = \text{Na}^+ + \text{Ca}^{++} + \text{Mg}^{++}
\]

A dose response relationship has been developed to estimate the health impacts of arsenic contamination in two districts. The health impact for relative risk measurement can be estimated using the following relationship:

\[
dH_i = b_i \times P_i \times dC
\]

where,

- \(dH_i\) = the change in population risk of health effect \(i\),
- \(b_i\) = slope of the dose-response curve for health impact \(i\),
- \(P_i\) = Population at risk of health effect \(i\), and
- \(dC\) = change in arsenic concentration under consideration.

A major question for cancer risk characterization of ingested arsenic using data mainly gathered at relatively high arsenic concentrations is whether the overall dose-response relationship remains linear down to zero dose or not. This is of particular concern when dealing with internal cancers with their associated higher mortality rates compared to skin cancer. Smith and others, using linear regression analysis for age adjusted mortality rates for bladders, kidney, liver, and lung cancer from the cumulative Taiwan data set, reported that US subjects consuming one liter water daily with an
arsenic content of 0.05 µg/l would have a combined lifetime risk of dying from cancer in any of the four organs of 13/1000. Chen and others have also reported using mortality rates in an area of Taiwan with chronic arsenicalism, estimated drinking water arsenic cancer potency in Taiwanese males at an intake of 10 µg/kg/d for various organs: liver, 0.0043; lung, 0.012; bladder 0.012; kidney, 0.0042. Brown and others modeled the Taiwanese skin cancer data. Four exposure duration and three dose intervals were employed. Risk increases as a power of three in age and is linear (0.003) or quadratic (0.0013) in arsenic dose, with a linear coefficient. The authors note that the Taiwanese database risk estimates are consistent with data reported for water arsenic effects in Northern Mexico.

In estimating the coefficient b, the fatal dose of ingested arsenic (III) oxide for human body has been reported to range from 70-180 mg are taken in this study. Due to the lack of epidemiological study and enough information related to recent mortality of Kishoreganj and Netrokona districts of Bangladesh. The coefficient b has been taken from an arsenic contamination dose-response study of Taiwan. In this study a relationship has been developed between excess morbidity and dose of arsenic in various ages of arsenic affected people. Tseng developed three dose response curves for age groups of 20-39 years, 40-59 years, and 60+ years, assuming daily average intake of 2 liters water. The slopes of these curves are 0.0001176, 0.000833, and 0.00144, respectively. In Bangladesh it has been observed that people in the village area usually consumes daily 2.5 liters of water for drinking. The average slope of the dose response curve using 2.5 liters water intake and 0.0086 crude mortality rate of rural Bangladesh is estimated to a value equal to 0.000996.

The GIS system has been utilized to carry out investigation on arsenic concentration data in the smallest geographic location of villages and depth of tubewells. The village level arsenic concentration has been adjusted for the Union level contamination taking weighted average data for water quality and risk factor analysis. This is due to the lack of village level population and water quality data. Geographic maps of village level arsenic distribution, Union level water quality data normalized by depth of wells, risk factor by population weighted exposures by Union level census block are created to visualize the impacts of emission sources, exposures, and risk assessment.

RESULTS

Water Quality Data

Spatial representations of water quality data normalized by the tubewell depths are provided in Figures 1 and 2. The water qualities are analyzed for the suitability to use for the irrigation purposes in Kishoreganj and Netrokona districts. The pH values ranged from 6.3 to 7.7 in Kishoreganj and 6.1 to 7.8 in Netrokona districts. pH values in both districts fall under the standard limit of drinking water quality 6.5 to 8.5. If there are many ionic substances dissolved in the water the electrical conductivity value will be higher. The EC \(_w\) ranges from 0.206 to 0.747 dS/m in Kishoreganj district and 0.117 to 0.917 dS/m in Netrokona district. This is an important parameter to consider because the higher the conductivity value, the higher should be the amount of adsorbent requires for the removal of arsenic. Water having EC \(_w\) between 0.1 to 0.25 dS/m is categorized as of low salinity, between 0.25 to 0.75 dS/m as of medium salinity and between 0.75 to 2.25 dS/m as of high salinity. It appears that the water samples of Kishoreganj district fall under low to medium salinity groups and of Netrokona district they fall medium to high salinity groups. Among the cations, the concentration of Na\(^+\), Ca\(^{++}\) and Mg\(^{++}\) are ranges 24-250 mg/l, 8.41-63.92 mg/l, 1-30.84 mg/l in Kishoreganj district and 19-237.5 mg/l, 10.94-65.6 mg/l, 1.15-30.25 mg/l in Netrokona district,
respectively. The other two cations K\(^+\) and Fe\(^{2+}\) concentration ranges from 0.01-18.5 mg/l, 0.1-1.1 mg/l in Kishoreganj district and 0-100 mg/l, 0.15-1.25 mg/l in Netrokona district, respectively. K\(^+\) concentration appears to be very high and Fe\(^{2+}\) concentration exceeds the international standard of 0.3 mg/l, in 30% samples of Kishoreganj district and 43% samples of Netrokona district. The concentrations of Cl\(^-\), B, NO\(_3\)\(^-\), and CO\(_3\)\(^-\)/HCO\(_3\)\(^-\) in water samples are ranges 8.16-74.97 mg/l, 0.145-0.93 mg/l, 0.08-1.85 mg/l, 85.4-409.9 mg/l in Kishoreganj district and 6.12-148.92 mg/l, 0.005-1.037 mg/l, 0.11-4.29 mg/l, 92.72-341.6 mg/l in Netrokona district, respectively. The presence of excessive levels of sodium in soils and irrigation waters causes deleterious effects on their use for crop production. The sodium adsorption ratios (SAR) vary from 0.78-15.4 me/l in Kishoreganj district and from 0.48-9.94 me/l in Netrokona district, respectively. The SAR value exceed the high levels (>3 me/l) in 43% samples of Kishoreganj and in 20% samples of Netrokona district. Figures 3 and 4 indicate the relationship between SAR and electrical conductivity of the samples in Kishoreganj and Netrokona districts, respectively.

**Arsenic Concentration**

Groundwater concentration below 0.01 mg/l is considered safe according to World Health Organization (WHO) Drinking Water Guidelines.\(^{16}\) However, in Bangladesh, the maximum permissible limit of arsenic in drinking water is 0.05 mg/l, irrigation water 1 mg/l, livestock and coastal water is 1 mg/l.\(^{17}\) The arsenic concentration of the tubewell water samples in Kishoreganj and Netrokona districts are presented in Figures 5 and 6. It is observed that among the 375 samples of Kishoreganj district 38% are under the WHO standard of 0.01 mg/l, 29% samples contain arsenic concentration in >0.01<0.05 mg/l, 18% are under the range of >0.05<0.1 mg/l, and 15% samples show >0.1 mg/l. On the other hand, among the total 333 samples of Netrokona district 50% samples are under the WHO standard limit, 22% samples contain arsenic concentration in >0.01<0.05 mg/l, 13% are under the range of >0.05<0.1 mg/l, and 15% samples show >0.1 mg/l. It is difficult to understand the movement of arsenic contaminated water and predict how long a water production tubewell yielding safe drinking water will remain safe.

Previous studies\(^{18, 19}\) found an inverse relationship between well water arsenic concentration versus depth. However, this is not the generalized condition. Some surveyed data also opposed this trend. Figures 7 and 8 provide a relationship between arsenic concentration of tubewells and depth of the wells to show whether condition exists for the databases of Kishoreganj and Netrokona.

**Risk Assessment**

The fact that inorganic arsenic has been a recognized poison since ancient times does not help the people of Bangladesh in awareness buildup. Judging from the lack of awareness a lot of people are unwarned about the health consequences of this carcinogen. Some people practices drinking arsenic contaminated water even after knowing the health hazards of arsenic. This is because sometimes they do not have access to safe alternative drinking water and also due to the socio-economic factors. The slow ingestion of arsenic over a long period of time can cause several forms of cancer like skin, liver, lung, kidney and bladder, as well as other diseases. Already the manifestation of arsenic-related illnesses is becoming alarmingly high in some parts of Bangladesh. Apart from the human cost, it is very likely to become an unwarranted large burden on the already hard-pressed health services. WHO estimates the time factor for the appearance of cancer is between ten to twenty years of exposure and, although this may mean it is too early to detect any increase in mortality from cancer. However, it is though uncertain the exact time when the arsenic
groundwater contamination in the water aquifer has started. The problem though known to the
WHO, UNICEF, and Government of Bangladesh sometimes in the 1990's. That is a reported
exposure period of almost 10 years. There have been number of cancer cases identified by the
health observers all along Bangladesh arsenic affected areas. There also are cases of gangrene,
hyper pigmentation, dorsum, and some other skin diseases.

Both the pentavalent and trivalent forms of inorganic arsenic are found in groundwater of
Bangladesh. However, trivalent form is prevalent in the most contaminated areas, which is more
toxic than other forms of arsenic. Trivalent arsenic may be oxidized to pentavalent form and/or
methylated in the human body. The methylation of inorganic arsenic in the human body is a
detoxification process, which occurs in the kidney and reduces the affinity of the compound for the
tissue.20 24 hours after injection into the blood arsenic is concentrated in liver, kidney, lung, spleen,
bone, muscle, and skin tissues. Smaller amounts are stored in brain, hearts, and uterine tissues. The
frequency and severity of chronic arsenic intoxication correlate with the incidence of skin cancer.15

Figures 9 and 10 explain the arsenic risks in two districts: Kishoreganj and Netrokona. Using
weighted average arsenic concentration, in each Union census block two USEPA measurements: no
observed-adverse-effect level (NOAEL) and lowest observed-adverse-effect level (LOAEL) are
undertaken.21 NOAEL is based on arsenic concentration range of WHO standard 0.01 mg/l and
LOAEL is based on arsenic concentration of Bangladesh maximum permissible limit of 0.05 mg/l.
Other assumption is daily water intake of 2.5 liters. Based on these background information it is
estimated that in Kishoreganj district the number of people at risk under NOAEL is 117 and that of
LOAEL is 72, that is 67 per million and 41 per million. The group in NOAEL is supposed to be
affected by hyper pigmentation, keratosis, and possible vascular complications. On the other hand,
chronic illness and various cancers can affect LOAEL group. The same estimation has been
followed for Netrokona district. The census-block wise risk distribution of Kishoreganj district is
displayed in Figures 10 (a) and (b). It is observed that in Netrokona district, population in the
affected area in risk under NOAEL is equivalent to 145 and in LOAEL is 90. This estimates values
of 63 and 39 per million, respectively. Figures 9 and 10 show population weighted exposures for
arsenic. The Unions where larger number of people and the size of the Unions affect the pattern of
risks. Though these estimates are not maintaining a good accuracy, a wide range of over/under
estimation may exist. This needs further site investigation and collection of epidemiological data to
calculate more accurate risk levels of exposures.

CONCLUSION

Tubewell water samples under northeast minor irrigation project were collected primarily for analysis
for irrigation purpose. The results discussed the general water quality databases of groundwater for
drinking purposes, as the tubewells are withdrawing water from the same water aquifer. The water
quality data are required for recommending specific arsenic removal method. The higher values of
EC_w and consecutively SAR values recommend that groundwater contains a lot of ionic substances
which implies high dose of adsorbent to treat arsenic from the groundwater. This paper
demonstrates how an emissions inventory can be used with GIS to conduct visualizing the level of
contamination and risk assessment. GIS presented highly contaminated Unions, water quality
characteristics, and risk of two different exposure levels NOAEL and LOAEL. It is revealed that if
the current level of contamination and trend in water use habit of the villagers continue in these
districts there will be further risks of cancer and other skin manifestations among the people. Hence
it is the time to better aware of the disaster and change groundwater use habit so that a number of lives can be saved from the arsenic contamination.

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REFERENCE


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Figure 1: Spatial distribution of groundwater quality in Kishoreganj district.
Figure 2: Spatial distribution of groundwater quality in Netrokona district.
Figure 3: $EC_w$ versus SAR value in tubewell water of Kishoreganj district.

Figure 4: $EC_w$ versus SAR value in tubewell water of Netrokona district.
Figure 7: Depth versus arsenic concentration in tubewell water of Kishoreganj district.

Figure 8: Depth versus arsenic concentration in tubewell water of Netrokona district.
Figure 5: Spatial distribution of arsenic concentration in union levels of Kishoreganj district.

Figure 9: Risk assessment due to arsenic contamination in Kishoreganj. (a) LOAEL, (b) NOAEL.
Figure 6: Spatial distribution of arsenic concentration in union levels of Netrokona district.

Figure 10: Risk assessment due to arsenic contamination in Netrokona. (a) LOAEL, (b) NOAEL.