USE OF GEOGRAPHIC INFORMATION SYSTEM (GIS) IN STUDYING GROUNDWATER CONTAMINATION: AN APPLICATION TO ARSENIC PROBLEM IN BANGLADESH

By

IBRAHIM TAIWO ABDULKADIR

(ID#: 230341)

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Course Instructor:
Dr. Baqer Al-Ramadan

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ABSTRACT

Assigning responsibility for the cleanup of groundwater contamination requires the analysis of large amounts of complicated data. The data and findings produced here are produced by the British Geological Survey and the Department of Public Health Engineering (Bangladesh) undertaking a project funded by the UK Department for International Development (DFID). One of the main aims of the project was to assess the scale of the groundwater arsenic problem in order to aid the rapidly developing arsenic mitigation programme. A second aim was to increase our understanding of the origins and behavior of arsenic in Bangladesh aquifers. These aims were subsequently expanded to include a broader range of hydrochemical parameters.

GIS has become a powerful tool to allow volumes of data to be quickly and accurately displayed. ArcView GIS is used to create base maps consisting of divisions, districts, cities, building locations, villages, well locations, and other features. A Microsoft Excel database is developed for the storage of environmental data consisting of groundwater location, rare elements analysis, groundwater depth, type and owners, and sampling locations. From this database, queries are preformed and linked to ArcView for spatial analysis. Custom visualization tools were developed to allow for complicated analysis of the data.

LIST OF FIGURES

1. INTRODUCTION

Analyzing large amounts of groundwater and soil contaminant data generated from numerous site investigations can be an overwhelming task. Especially when that data is in a variety of formats, produced by numerous consultants, and have questionable levels of accuracy. The use of GIS software like ArcView and a Microsoft Excel spreadsheet can make the visualization of data much simpler. Before visualization and analysis can be done an analytical database and GIS basemap must be developed. Microsoft Excel spreadsheet is the preferred format for storing analytical data because of its simplicity and widespread use. ArcView is used to compile, edit, and display GIS feature and raster data. ArcView's ability to retrieve data from a Microsoft Excel spreadsheet is a benefit, in that; the GIS data can be displayed quickly and efficiently. Because data may exist in various digital or hardcopy formats a database must be developed. This database must be robust enough to handle various types of data but simple enough for novice Excel users to query data. It is also important that the data is accurate and has source of information. Therefore quality assurance or quality control methods are established and followed. In this project, data from the analytical Excel spreadsheet is queried and displayed on basemap using a variety of techniques that allow for hydrogeological analysis.

2. PROBLEM STATEMENT

There have been various surveys of water quality in Bangladesh. These surveys provided useful data that gave a broad indication of major elements in groundwater contamination in Bangladesh. Most of these data are then queried, analyzed and displayed on maps using different techniques to give a reliable national picture of groundwater contamination by Arsenic.

3. OBJECTIVES

The main aims of this project are:

(i) to produce maps showing the regional distribution of arsenic and other elements in the groundwater and

(ii) to provide estimates of the percentage of wells exceeding various limits for arsenic and other elements on maps.

4. STUDY LIMITATIONS /CONSTRAINTS

Most data used are from wells drilled by private contractors with no requirement or system to record details of the borehole logs during and/on completion. In addition, details of the government-drilled wells are not readily available. Hence, no sufficient sample density to give a reliable national picture of ground water contamination by arsenic.

5. REVIEW OF LITERATURE

The first reported case of arsenic-contaminated groundwater (greater than 50 µgAsL) from the Bengal Basin was recorded in 1978 in West Bengal (Acharyya et al., 2000) and the first cases of arsenic poisoning there were diagnosed in 1983. These early cases of arsenic-induced skin lesions were identified by K.C. Saha then at Department of Dermatology, School of Tropical Medicine in Calcutta, India (Saha, 1995; Smith et al., 2000). The patients seen were from West Bengal but by 1987 several patients had already been identified who came from neighboring Bangladesh (Smith et al., 2000). The contamination of groundwater by arsenic in Bangladesh was first confirmed by the Department of Public Health Engineering (DPHE) in Chapai Nawabganj in late 1993 following reports of extensive contamination in the adjoining area of West Bengal. The issue of arsenic contamination in West Bengal achieved international recognition in 1995 when the School of Environmental

Studies (SOES) at Jadavpur University, Calcutta hosted an international conference on the subject. Arsenic-affected patients from both West Bengal and Bangladesh were presented to participants. Since the mid-1990s, SOES in conjunction with Dhaka Community Hospital (DCH) have conducted field investigations over much of Bangladesh including a large number of water analyses and tissue analyses. British Geological Survey (BGS) first became involved in the groundwater arsenic issue in Bangladesh when it was awarded a grant by the UK Department for International Development (DFID) to study arsenic contamination of groundwater in Bangladesh and Argentina. Initial investigations were carried out in Chapai Nawabganj in February 1997. These confirmed the high arsenic contamination of groundwater in that area and established the reducing nature of the groundwater. The data obtained pointed away from the pyrite oxidation hypothesis then being promoted by West Bengal scientists. Thereafter, the DPHE with UNICEF assistance carried out a massive screening programme of wells for arsenic across the whole of Bangladesh using simple field-test kits.

The results of this survey showed for the first time the scale of the problem and identified the centre of the worst-affected area as an area south-east of Dhaka. Northern Bangladesh was also found to be substantially uncontaminated in terms of the prevailing Bangladesh drinking water standard for arsenic (50 mg/kg). However, some hot spots had been found in northern Bangladesh, including Chapai Nawabganj, largely because arsenic patients had been identified there. Subsequent testing has confirmed the overall pattern that emerged from the survey. In the world as a whole, the most noteworthy occurrences are in parts of West Bengal and Bangladesh, Taiwan, northern China, Hungary, Mexico, Chile, Argentina and many parts of the USA but particularly the south-west (figure 1).

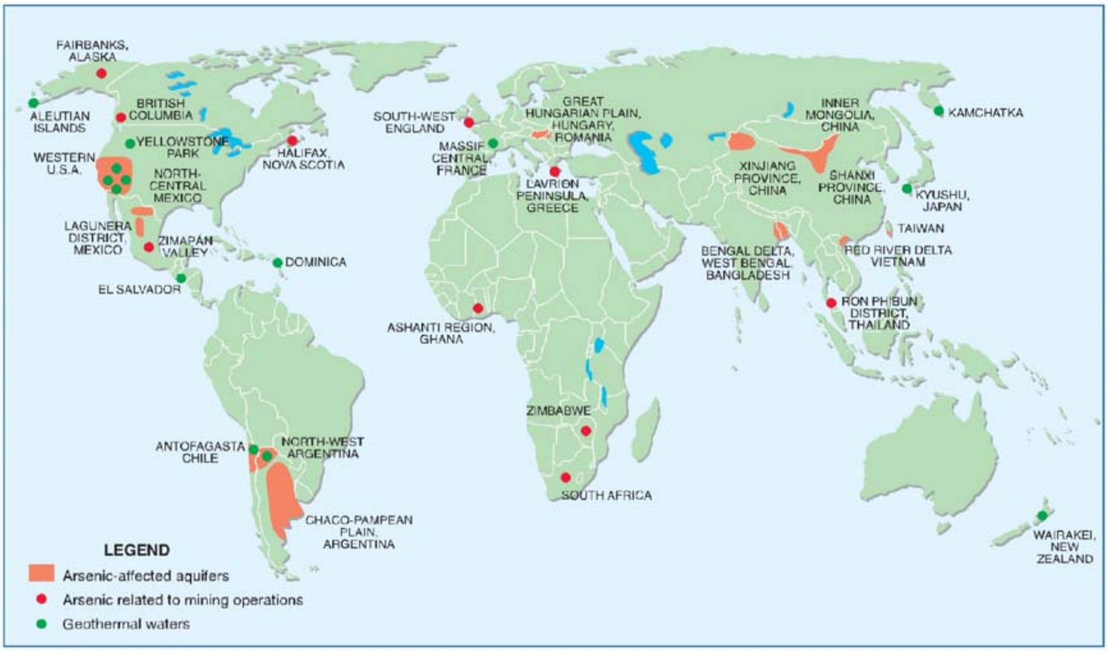

Figure 1: Documented cases of arsenic problems in groundwater related to natural contamination

6. STUDY AREA

Groundwater contamination by arsenic was first discovered in the west of Bangladesh in late 1993 following reports of extensive contamination of water supplies in the adjoining areas of India. A World Bank Fact Finding Mission visited Bangladesh in April 1997 to assess the situation and to initiate a mitigation programme. Part of their recommendations included a broad-ranging Rapid Investigation Programme to collate the available data, fill in critical gaps in knowledge and undertake surveys of the affected area (http://www.bgs.ac.uk/arsenic/bphase1/b_intro.htm).

7. DATA AND THEIR SOURCE

The data used in this project are downloaded from http://www.bgs.ac.uk/arsenic/bangladesh/datadownload.htm from which various maps in this project were produced. See the appendix for the raw data in a Microsoft Excel spreadsheet format. These data are by-product of survey carried out in Bangladesh from which geochemical investigations were conducted on the collected water samples. A survey work funded by UK Department for International Development (DFID) was carried out by both British Geological Survey (BGS) and Department of Public Health Engineering (DPHE) between January, 1998 and Mach, 2000.

The principal aims of the work were to: (i) compile, review and database existing groundwater and sediment arsenic data from Bangladesh; (ii) review Bangladesh geology and hydrogeology; (iii) carry out a systematic groundwater quality survey using laboratory analyses of what were believed to be the 41 worst-affected districts of Bangladesh (out of 64 districts); (iv) carry out detailed geochemical investigations in three Special Study Areas, and (v) model the movement of groundwater and arsenic in a typical Bangladesh situation.

8. TOOLS OF STUDY

Having downloaded the data from the said website and converted them from Excel formats to shape files, a standard ArcGIS system (ArcView) was used to query and analyze data and finally making different maps. See the list of figures for different maps generated from the data. One of the important features of the results is the well-to-well variation in water quality.

9. METHODOLOGY OF STUDY

The sampling of wells from which groundwater data were collected was organized on a district and upazila basis. Well selection was made using the following strategy:

(i) a 3 x 3 grid was penciled on the upazila map to divide the upazila into approximately nine equal-area cells;

(ii) a route was planned between the cells; and

(iii) at least one well was selected from each cell ensuring that there was at least 2 km between samples from adjacent wells.

In most of Bangladesh, the wells are predominantly in the shallow aquifer __usually in the range 15-70 m depth. The number of deep wells in existence was small outside of the southern coastal area, affected by salinity and the north-east region, where the shallow aquifer is sometimes poor (Smith et al., 2000). A total of 326 samples were collected from the deep aquifers for hydrogological analysis purpose.

The data in Microsoft Excel sheets are converted to shape files formats for compatibility with ArcGIS. Thereafter, ArcGIS is used to query and display the data on different maps.

10. ANALYSIS/DISCUSSION

10.1 PRESENTATION OF DATA

10.1.1 DISTRIBUTION OF SAMPLED WELLS

A total of 3534 sites were sampled in the survey between 1998 and 1999. This amounts to a sample density of approximately one per 37 km^2 or an average site-to-site separation of about 6 km. The distribution of sample sites can be seen in figures 2 and 3.

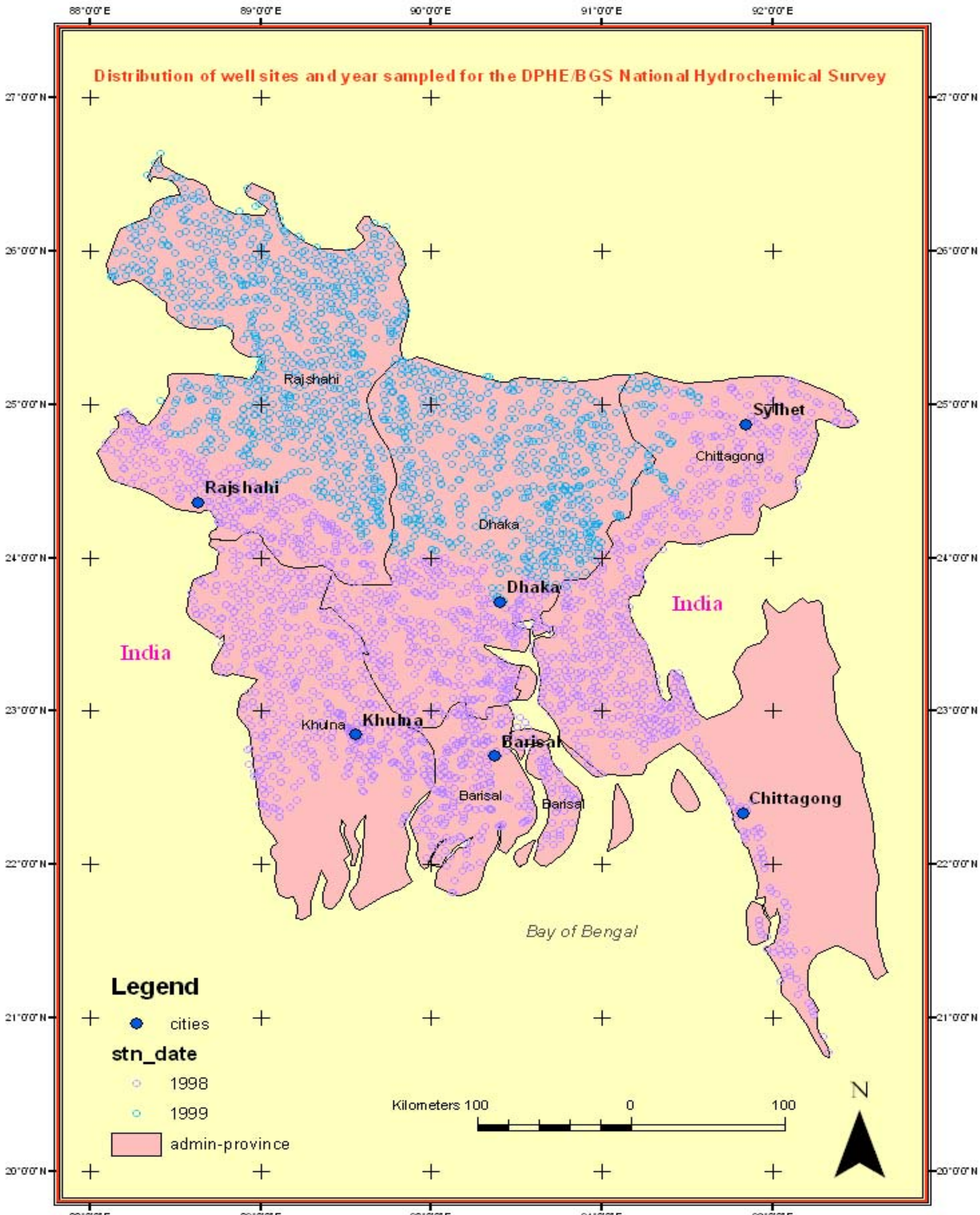

Figure 2: Distribution of well sites and year

The areas of low sample density are those where access is particularly difficult, for example the south-western, the north-eastern and the western parts of the map.

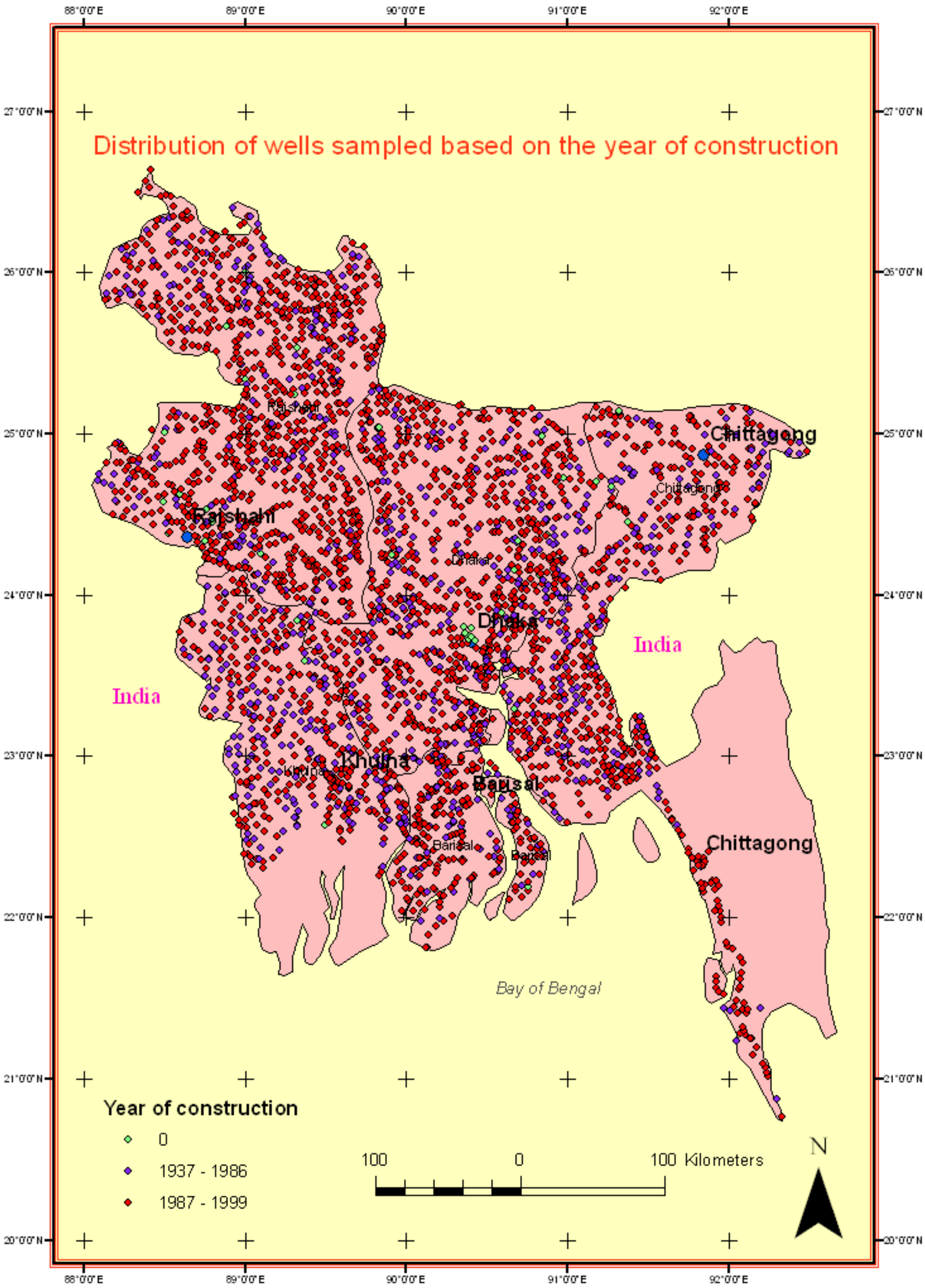

Figure 3: Distribution of wells sampled based on the year of construction

10.1.2 DEPTH OF SAMPLED WELLS

The depth distribution of wells is shown in figure 4. Of the sampled wells, about 70% were in the depth interval 0-60 m. Although, there is a distinct geographical distribution which is largely based on the minimum depth needed to obtain water of acceptable yield and quality (notably salinity). In the southern coastal region, mangrove swamps of the Sundarbans in the west mean that there are few people or wells present there.

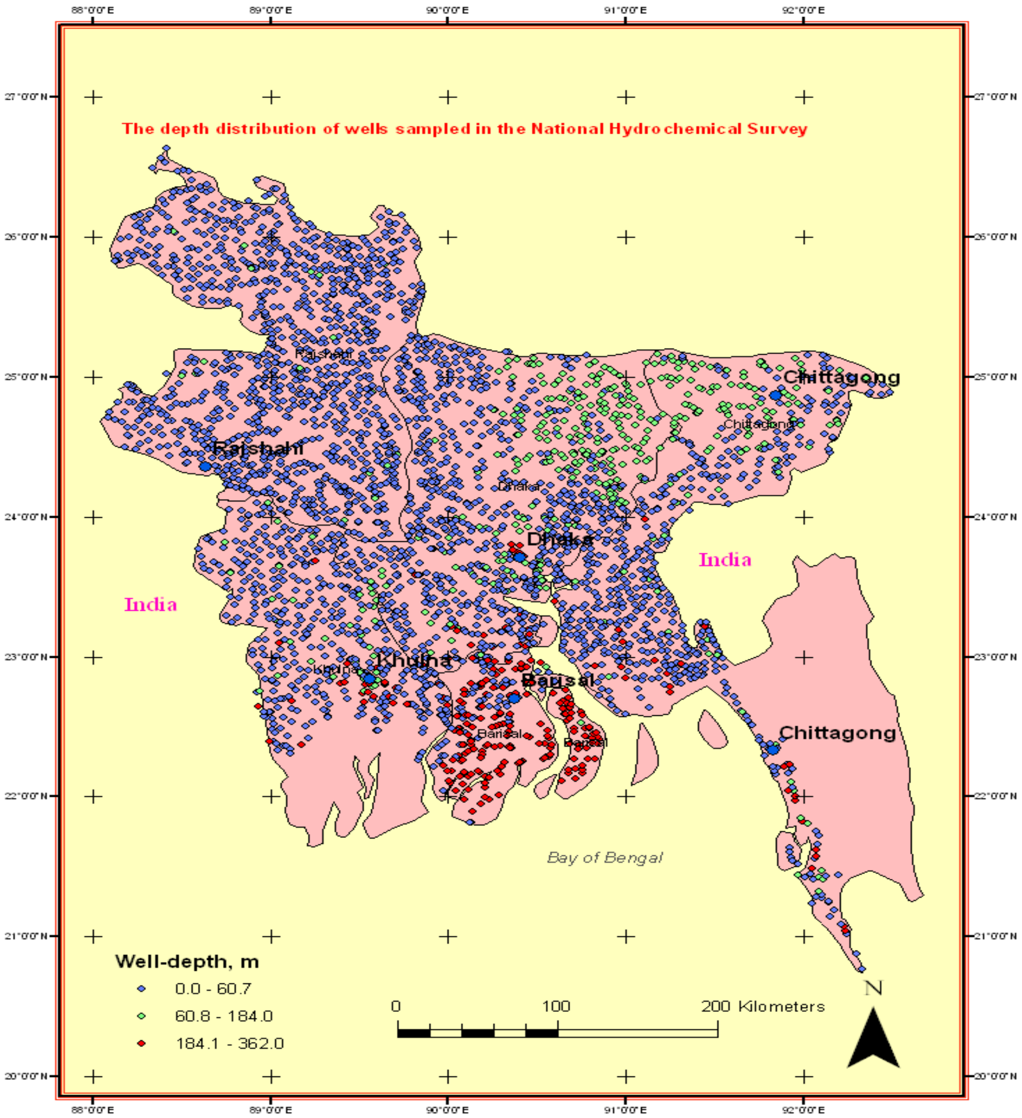

Figure 4: The depth distribution of wells sampled

Further east, the wells either need to be very deep (greater than 150 m) as in the Barisal-Patuakhali region or very shallow, as in the Lakshmipur-Noakhali region further to the east, in order to avoid salinity. Relatively deep wells are also found in the Sunamganj-Sylhet region where shallow aquifers are poor or non-existent. Very shallow wells are also found in north-western Bangladesh where there is little or no overlying silt or clay layer. The cluster of deep wells in central Bangladesh corresponds with the deep wells of the city of Dhaka where extensive drawdown (and pollution) of the shallow aquifer necessitates the use of deep wells.

10.1.3 GEOGRAPHICAL DISTRIBUTION OF ARSENIC

There is a distinct geographical distribution of arsenic with the greatest concentrations in the south and south-east and the smallest concentrations in the north and north-west of Bangladesh. This can be clearly seen in the map of the regional trends (figure 5). In the arsenic map, the lowest concentration class symbols have been plotted first, then the symbols for the next lowest class, and so on. Therefore where there is some overlap of symbols, the higher concentration symbol will fall on top of the lower symbol and will tend to dominate the map.

There is a large variation in the average arsenic concentration found in each administrative division (figure 6). All divisions contain at least one well which exceeds the Bangladesh standard. A broad north-south band of low As wells is found in SE Bangladesh. This follows the Gorai-Bhairab valleys and may reflect a palaeo-channel.

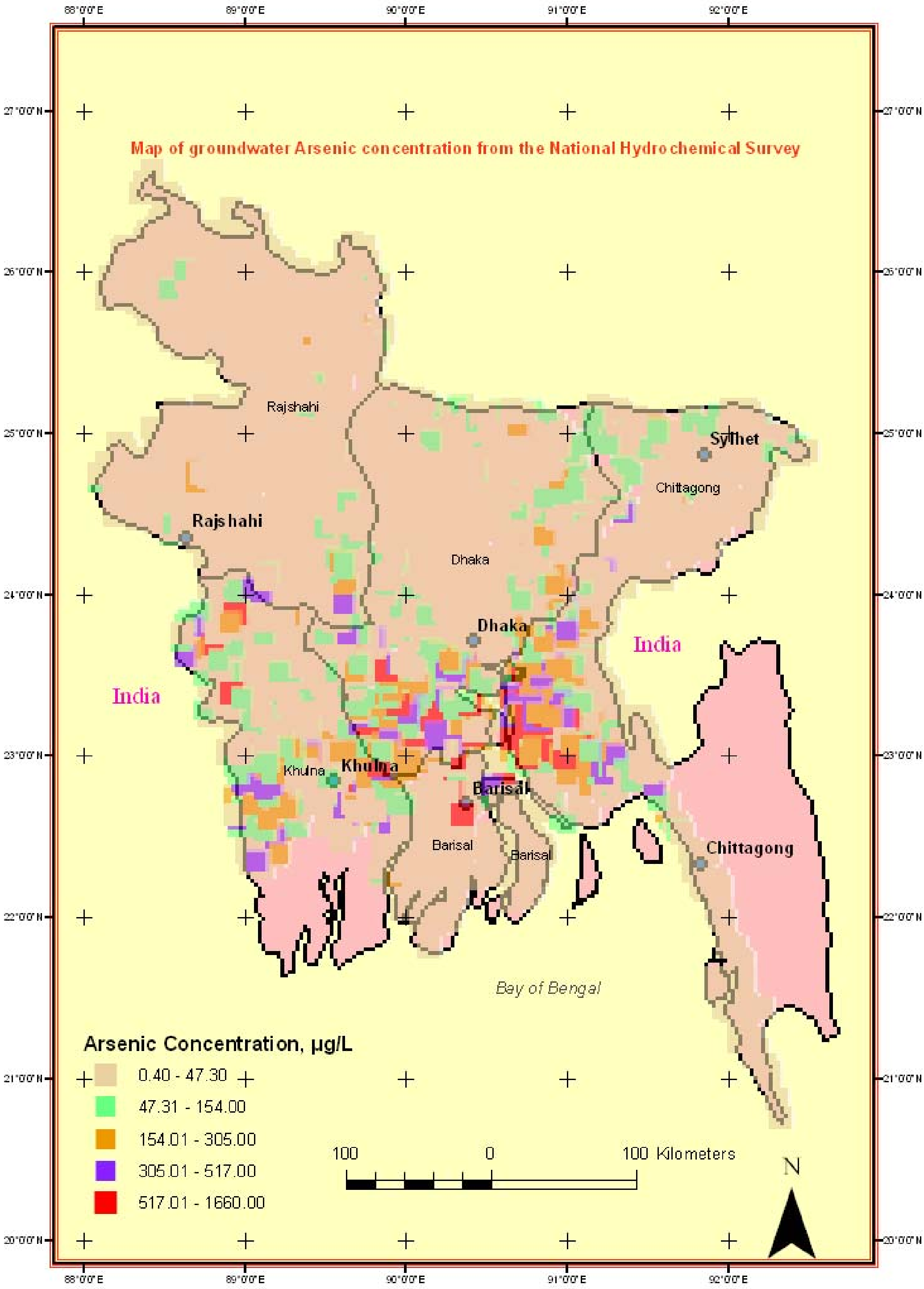

Figure 5: Concentrations of groundwater arsenic

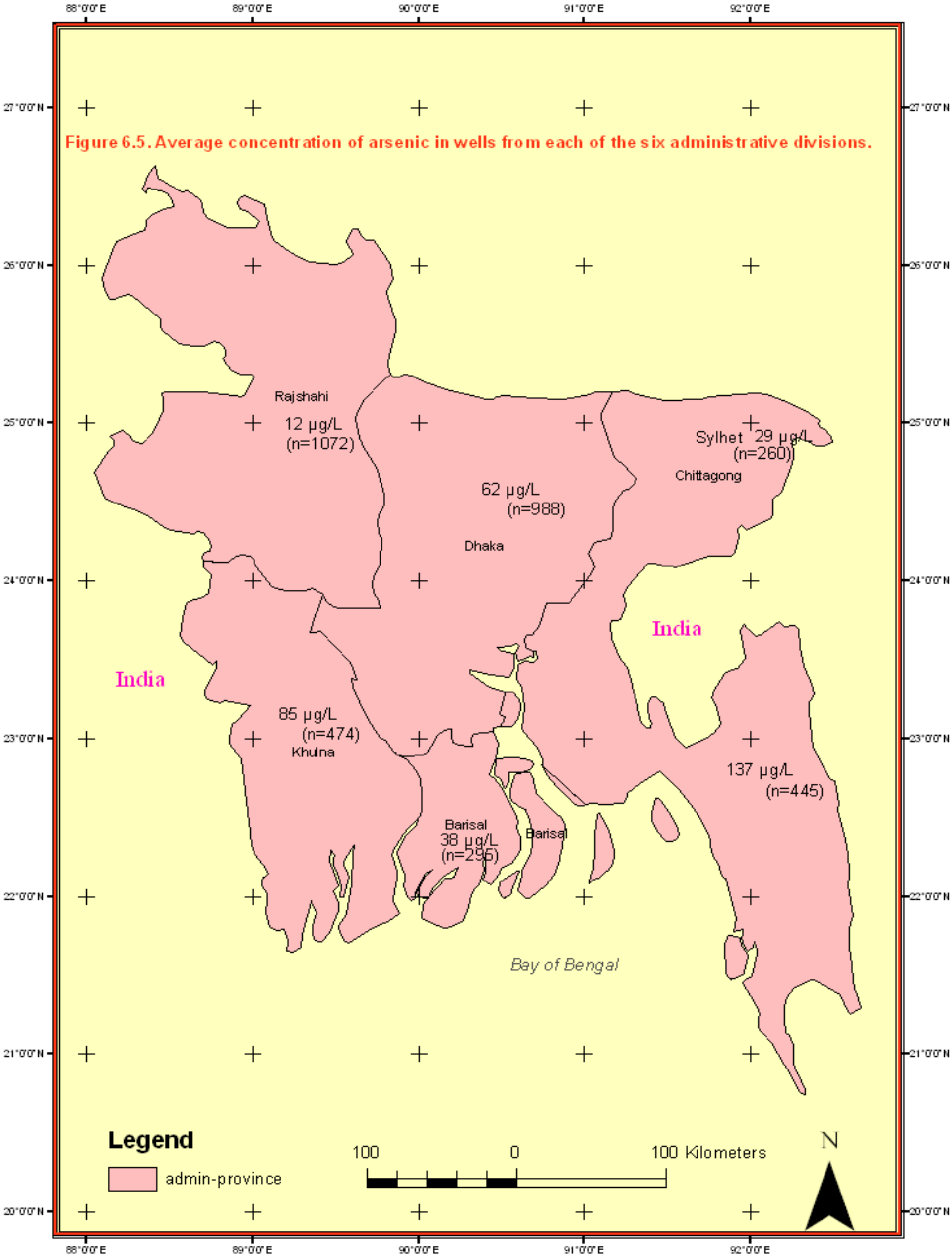

Figure 6: Average concentration of arsenic in wells from each of the six administrative divisions

10.1.4 ARSENIC CONCENTRATION VERSUS WELL DEPTH

Perhaps the most important distinction in arsenic concentrations is between shallow and deep wells (figure 7). Wells deeper than 150 m to 200 m show a sharp reduction in their average arsenic concentration and in the percentage of wells that exceed both the World Health Organization (WHO) guideline value and the Bangladesh standard.

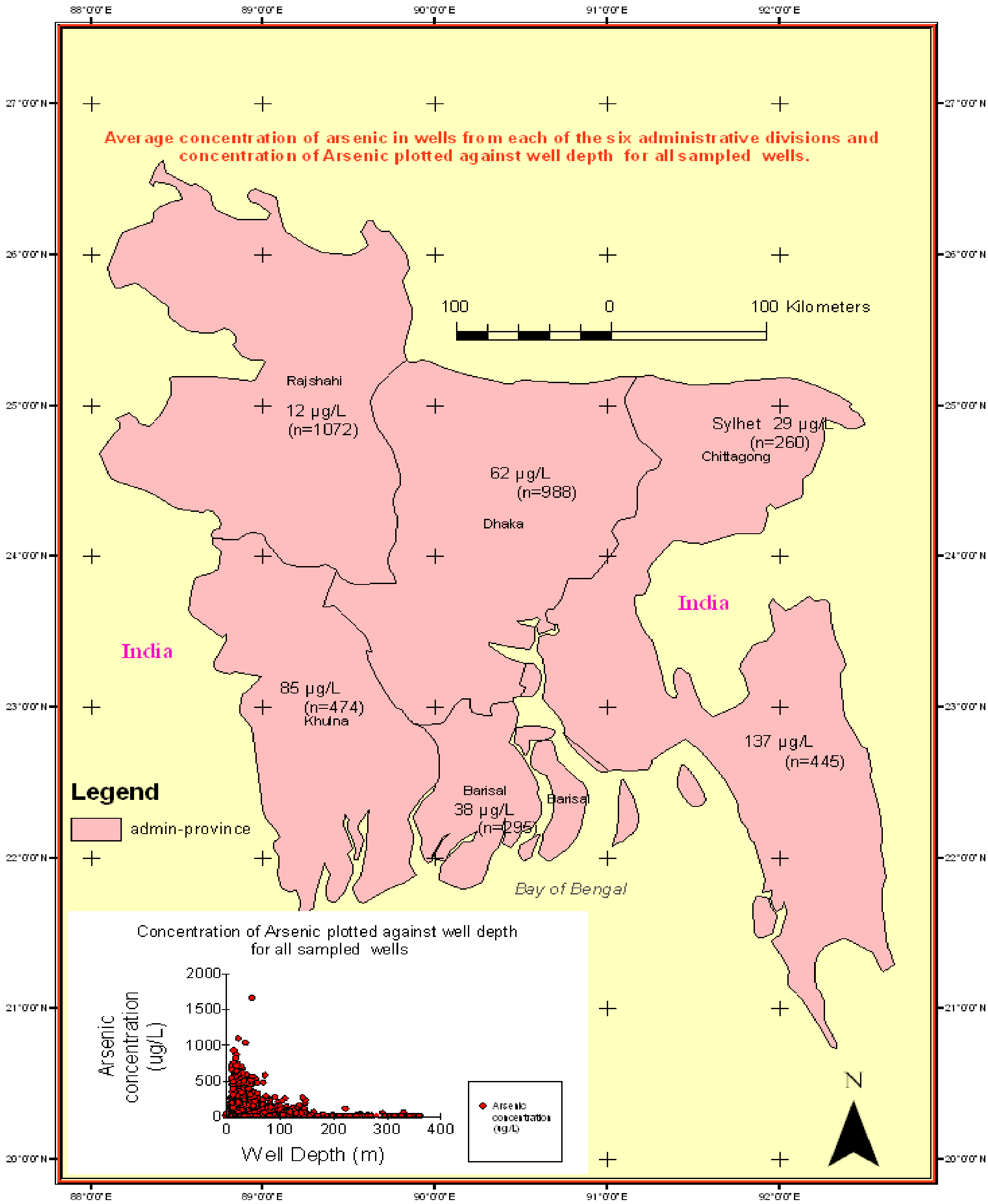

Figure 7: Concentration of arsenic plotted against well depth for all sampled wells

The “cut-off” depth depends on geographic location. Even though only 4% of sampled wells in the 100 - 150 m depth range, 37% of them exceeded 50 µg/L. Therefore, in many areas it appears that it would not be sufficient to drill just a little deeper for low-As water but wells would need to exceed at least 150 m to provide low-As water.

10.1.5 ARSENIC VERSUS GEOLOGY

Each of the sampled wells was assigned to a geological unit based on the Geological Survey

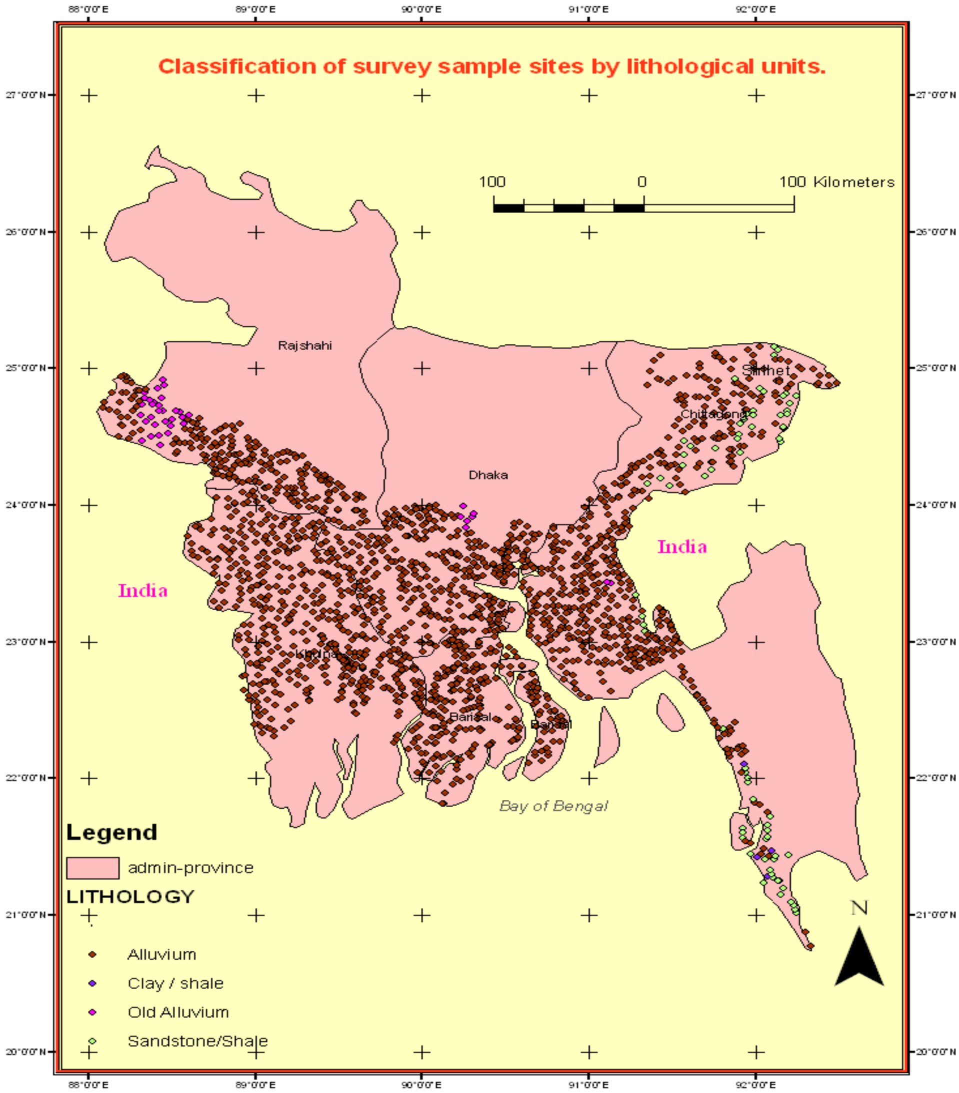

Figure 8: Classification of sampled sites by lithological units

of Bangladesh classification as given by the most recent geological map of Bangladesh (Alam et al. 1990). This allocation was based on the GPS measured well position and a digital form of the geological map. The most significant observation is that high arsenic concentrations are confined to recent (Holocene) sediments - conversely, the older sediments are essentially arsenic-free.

10.1.6 DISTRIBUTION OF SODIUM, POTASSIUM AND BORON

These elements are indicators of groundwater salinity and reflect relict seawater influences either by marine inundation of low-lying areas or saline intrusion of near-coastal aquifers. Concentrations of Na, K and B are in general greater in the deep groundwater sampled in the survey, although this is because a large proportion of these were collected from the Barisal region of southern (coastal) Bangladesh, as well as from the Sylhet region. Figure 9 shows that, the highest concentrations of Na (like K and B) are mainly found in the south and south-eastern parts of Bangladesh and in the low-lying haor region of the north-east.

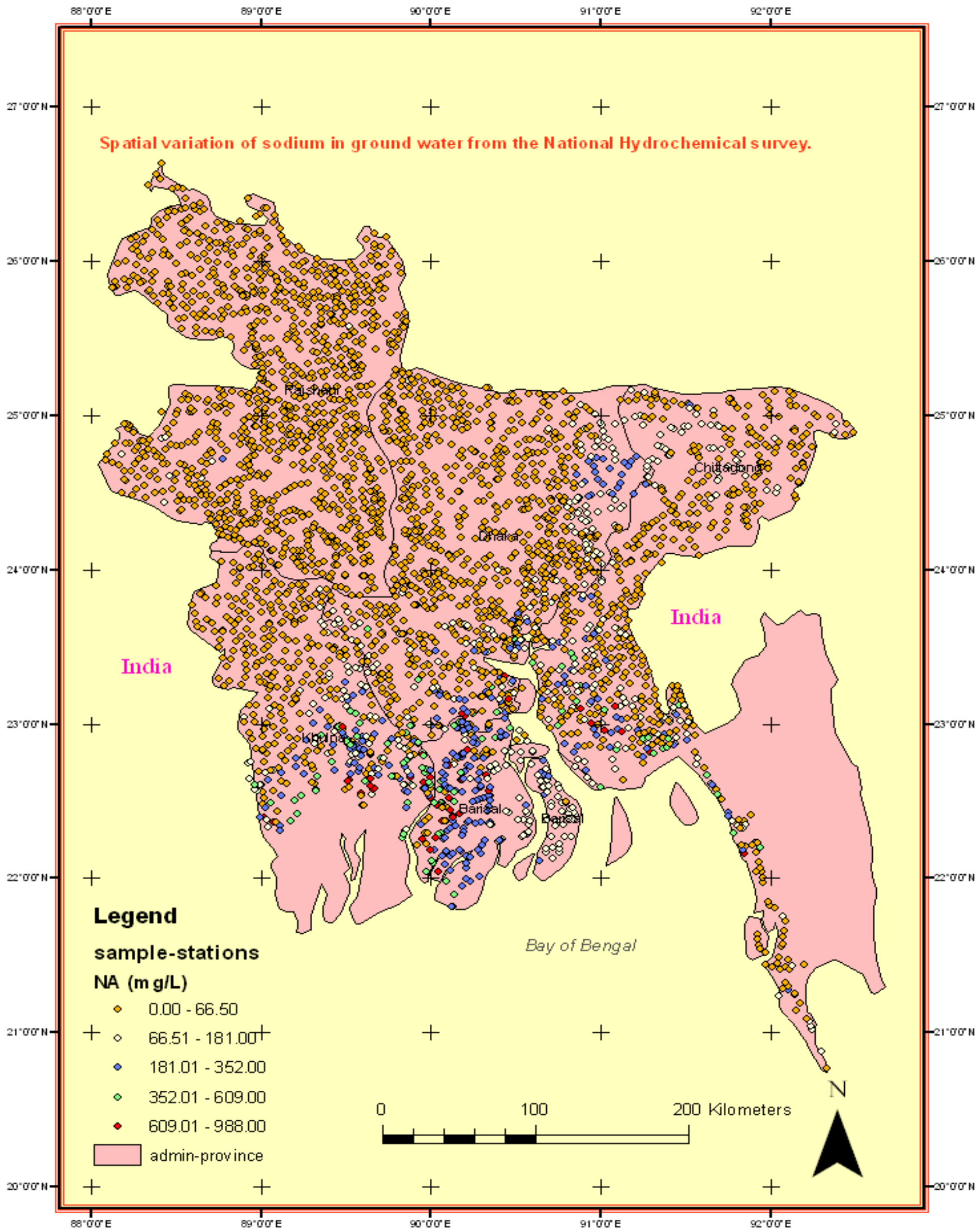

Figure 9: Spatial variation of sodium in the groundwater

10.1.7 HYDROGEOCHEMISTRY OF THREE SPECIAL STUDY AREAS

Chemical data collected for groundwater from the Bangladesh National Hydrochemical Survey give useful information about the inorganic groundwater quality and the regional variations. These parameters are of great potential value in assessing hydrogeochemical processes in the aquifers and for this reason, three Special Study Areas were chosen from which more detailed groundwater chemical analysis were carried out. The areas chosen were headquarter (sadar) upazilas of the Districts of Lakshmipur, Faridpur and Nawabganj (figure 10). The areas were selected as they have recognized arsenic problems and have differing geological and hydrogeological characteristics.

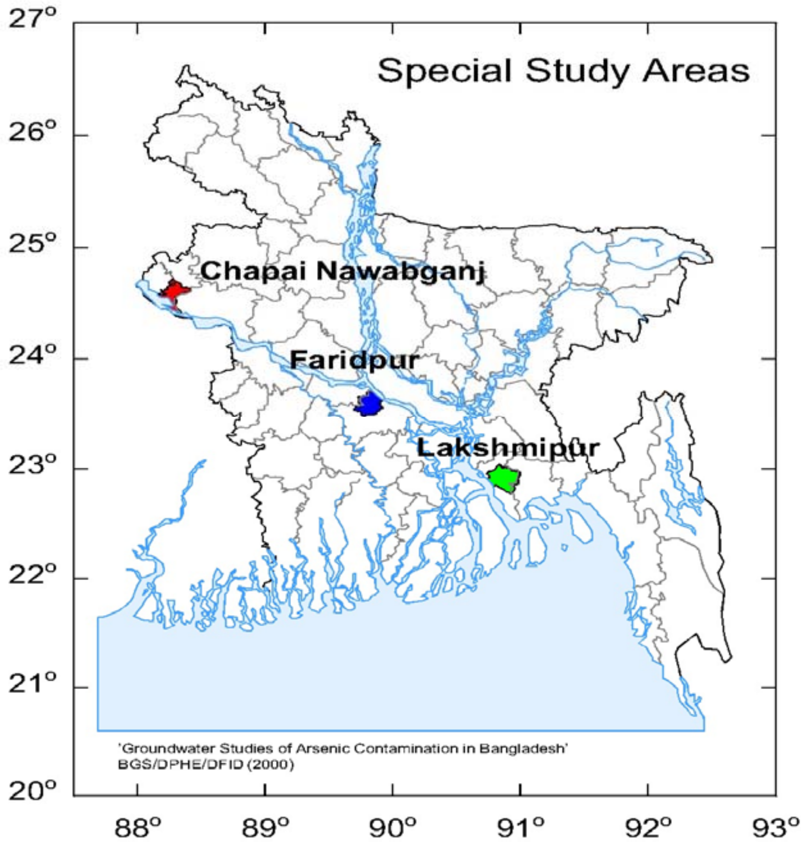

Figure 10: Sketch map of Bangladesh showing the major river systems and the locations of the three Special Study Areas.

Arsenic concentrations in the three Special Study Areas clearly vary considerably. From the statistical data (percentage exceedances), the worst-affected of the areas appears to be Lakshmipur and the least-affected is Chapai Nawabganj. However, the highest absolute concentrations (up to 2400 µg/L) were observed in the localized hot spot of Chapai Nawabganj. This might go some way to explaining why reported arsenicosis cases have been more prevalent in Chapai Nawabganj as As doses will have been considerably higher from chronic use of such high-As drinking water.

11. CONCLUSIONS AND RECOMMENDATIONS

Arsenic contamination threatens water resources and has become an emerging issue in the nation (Bangladesh). This project utilizes the ESRI's ArcGIS Geostatistical Analyst to analyze the spatial distribution patterns of arsenic in groundwater. The maps generated in this project show an effective way to help investigate and remedy arsenic contamination in Bangladesh. They provide visual representations of arsenic and other elements distributions in groundwater and help environmental professionals prioritize their limited budgets for groundwater cleanup, develop field investigation strategies and design remedial systems.

The ability to use GIS created data along with data queried from a Microsoft Excel spreadsheet is beneficial for contamination analysis. The ability of ArcView to display data queried directly from Excel in a spatial context is extremely valuable.

There are uncertainties and limitations found in this project in using the sample data for the determination of elemental distributions in groundwater for the study area. First, Most data used are from wells drilled by private contractors with no requirement or system to record details of the borehole logs during and/on completion. In addition, details of the government-drilled wells are not readily available. Hence, no sufficient sample density to give a reliable national picture of ground water contamination by arsenic. There is need to license drilling of boreholes by the government and for details of the borehole logs to be logged in a systematic way. This could form a beginning to an aquifer protection policy for the deep aquifers. Some incentive would probably need to be given to private contractors to make such a notification scheme work. It would be very useful to always record the lithological variations with depth (sand, silt, clay, peat etc.) and the color of the sediments (grey, brown etc.). The texture is obviously important in terms of potential groundwater yield but can also yield valuable information about the depositional environment. The color is useful since it reflects the oxidation state (and may be age) of the sediments. For example, a change from grey to orange-brown may help to identify the Holocene-Pleistocene boundary.

The arsenic concentrations were significantly widely distributed. A larger size of random samples should be needed if physical and economic constraints are not significant.

Second, arsenic concentrations in the groundwater can be influenced by rock types, soil (Boyle et al., 1973), and hydrologic condition of the area. Arsenic, once released into the ground, might undergo some physical, chemical and biological reactions that could possibly alter concentration distribution (Manning et al., 1997b; Livesey et al., 1981; Matisoff et al., 1982; 1991; Korte et al., 1991). Human errors and laboratory uncertainties during sampling and data acquisition are also possible factors for prediction errors. These uncertainties and limitations should be considered in the assessment of arsenic contamination.

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