GIS BASED SPATIAL ANALYSIS OF ARSENIC -CONTAMINATED GROUND WATER: A CASE STUDY OF BANGLADESH

(Final Paper)

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Abstract

The paper has highlighted the importance of GIS to explain real scenario of arsenic-contaminated groundwater in Bangladesh. Generally, GIS is considered to represent a top–down and technology driven approach in spatial decision-making processes. It is a computer-based technology for integrating spatial and non-spatial information into a common environment for spatial analysis, mapping and graphic display as well as spatial decision-making.

Arsenic is a known carcinogen and groundwater arsenic concentrations in Bangladesh are thought to be one of the biggest environmental health and social disasters. It is reported that 61 districts out of the 64 are said to be contaminated with arsenic and more than 30% of the tube wells out of the analyzed 4.37 million are found to be contaminated with arsenic, and so far 36,477 patients have been registered, but the true numbers are thought to be much higher. WHO guideline value of arsenic in groundwater is 0.01 mg/L and Bangladesh standard for arsenic of 0.05 mg/L. The shallow groundwater only 47% exceeds the WHO guideline value and 27% exceed the Bangladesh standard. Only 1% of the deep wells exceed 0.05 mg/L. Arsenic contamination of ground water in Bangladesh is from natural source and not from any man made sources. The distribution of arsenic both geographically and vertically is related to the geological age of the sediments. Geographically, the tube wells in the delta proper and the flood plain areas are mostly affected by arsenic contamination. The hilly areas and the areas of Pleistocene Uplands are not affected and ground water from those areas is arsenic safe.

British geological survey, Department of public health and engineering, and Bangladesh arsenic mitigation water supply project are combating with this problem. GIS provide platforms for managing these data, computing spatial relationships such as distance, connectivity and directional relationships between spatial units, and visualizing both the raw data and spatial analytic results within a cartographic context.

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Introduction

In Bangladesh surface water is abundantly available during monsoon but it is scarce during the dry season. Ninety seven percent of the population relies on ground water for drinking purpose. Ground water used for drinking in many areas of Bangladesh has been reported to have contamination by arsenic above the Bangladesh National Standard of 50 parts per billion (ppb). The percentage of contaminated tubewells in villages varies from more than ninety percent to less than five percent. Geographically, the tube wells in the delta and the flood plains regions, which comprise 72% of the land area, are more or less affected by arsenic contamination (WHO, 2005).

The impact of arsenic poisoning in Bangladesh is tragic and painful on patients' health and their social life what was described as the worse mass poisoning in human history in a WHO report. Deep tube well is said to be a source of arsenic-free safe drinking water and people are mainly interested in deep tube well water rather than rainwater harvesting, dug-wells, and pond-sand-filters (PSF) approved by the BAMWSP (Bangladesh Arsenic Mitigation Water Supply Project).

Nation-wide studies reveal that the problem of arsenic is of an enormous magnitude engulfing almost the entire country. Arsenic contamination of groundwater is as much a health and environmental issue as it is a water supply issue. There is yet no strong evidence to suggest that arsenic in groundwater adversely impacts agriculture, crops and livestock. Studies are underway to determine whether or not there is any impact of arsenic on agriculture and food chain.

The capabilities of GIS, which is a powerful tool, can be used to process both spatial and attribute data (Al-Ramadan, 2004). To display the real scenario of metal contamination in ground water geographic information system offers a great opportunity. Not only the manipulating and analyzing the spatial data, GIS crosses the limit of paper map helping planners to make the effective decision for future (Al-Ramadan, 2004). In short, the advantage of GIS is quick updating of information, automated map making, linking spatial and attribute data, spatial analysis, relaxed option in map scale and visualization (Al-Ramadan, 2004).

This paper discusses in detailed the GIS based spatial distribution of arsenic in ground water of Bangladesh and some recommendations is placed fore the future guideline of the study. Besides, origin of arsenic in ground water, effect of arsenic in ground water; world and Bangladesh scenario of arsenic in ground water is discussed in brief.

Features of GIS

DoE (1987) defined GIS as “a system for capturing, storing, checking, manipulating, analyzing and displaying data which are spatially referenced to the Earth”. In fact, there is no rigid consensus on the definition of GIS but many of the prevailing definitions have common features, namely that GIS deals with geographical information and considers geographical element as more important than the attribute element. In GIS, the representation of reality comprises of a series of geographical features defined according to locational and non-locational (attribute) data element (Maguire, 1991). Maguire (1991) finds out three distinct but overlapping views based on the various ideas about GIS, namely the map, database and spatial analysis views. The map view originated in the work of Markham (2002) focuses on cartographic aspects of GIS such as map processing or display systems. The supporter of database view emphasizes on the importance of a well-designed and implemented database (Frank, 1988). The spatial analysis view focuses on analysis and modelling which can be regarded as a spatial information science rather than a technology (Abowd, 2000). In an institutional perspective, GIS possesses four basic elements, which are computer hardware and software, data and live-ware (Maguire, 1991).

Although GIS can be applied to many types of problem, Rhind (1990) develops a general classification of the types of generic queries (Table).

Table 1: Basic queries, which can be explored using GIS (Rhind, 1990).

Location	What is at……..?
Condition	Where is it……..?
Trend	What has changed…….?
Routing	Which is the best way……?
Pattern	What is the pattern……..?
Modeling	What if……..?

Spatial Analysis

Spatial analysis refers to the formal techniques used in various fields of research which study entities using their topological, geometric, or geographic properties (Wikipedia, 2006). Spatial analysis provides the quantitative tools that have formed the bases for modern quantitative analysis in fields such as geography, location analysis, regional economics, and many physical sciences requiring the analysis of spatially-separated phenomena (Wikipedia, 2006).

Understanding the spatial distribution of data from phenomena that occur in space constitute today a great challenge to the elucidation of central questions in many areas of knowledge, be it in health, in environment, in geology, in agronomy, among many others. Such studies are becoming more and more common, due to the availability of low cost Geographic Information System (GIS) with user-friendly interfaces. These systems allow the spatial visualization of variables such as individual populations, quality of life indexes or company sales in a region using maps. To achieve that it is enough to have a database and a geographic base, and the GIS is capable of presenting a colored map that allows the visualization of the spatial pattern of the phenomenon (Camara, 2001).

The most used taxonomy to characterize the problems of spatial analysis consider three types of data such as Events or point patterns, Continuous surfaces and Areas with Counts and Aggregated Rates (Camara, 2001).

ArcGIS Spatial Analyst provides a broad range of powerful spatial modeling and analysis features previously not available to desktop users. It allows us to create, query, map, and analyze cell-based raster data and to perform integrated vector–raster analysis (ESRI, 2006).

With Spatial Analysis of ArcGIS we can perform the followings:

- Convert feature themes (point, line, or polygon) to grid themes.
- Create raster buffers based on distance or proximity from feature or grid themes.
- Create density maps from themes containing point features.
- Create continuous surfaces from scattered point features.
- Create contour, slope, and aspect maps and hill shades of these surfaces.
- Perform cell-based map analysis.
- Perform Boolean queries and algebraic calculations on multiple grid themes simultaneously.
- Perform neighborhood and zone analysis.
- Perform grid classification, display, and more.

Study Area

Bangladesh belong to South Asia and lies between 20034´ and 26038´ N, and 88001´ and 92041´ E. The area of the country is 147,570 square km with more than 700 km long coastlines (Wikipedia, 2006).

Bangladesh is located in the low-lying Ganges-Brahmaputra River Delta or Ganges Delta. This delta is formed by the confluence of the Ganges (local name Padma or Pôdda), Brahmaputra (Jamuna or Jomuna), and Meghna rivers and their respective tributaries. The alluvial soil deposited by these rivers has created some of the most highly fertile plains of the world (Wikipedia, 2006).

Most parts of Bangladesh are within 10 meters (33 ft) above the sea level, and it is believed that about 10% of the land would be flooded if the sea level were to rise by 1 metre (3 ft). The highest point in Bangladesh is in Mowdok range at 1,052 meters (3,451 ft) in the Chittagong Hill Tracts to the southeast of the country. A major part of the coastline comprises a marshy jungle, the Sundarbans, the largest mangrove forest in the world and home to diverse flora and fauna (Wikipedia, 2006).

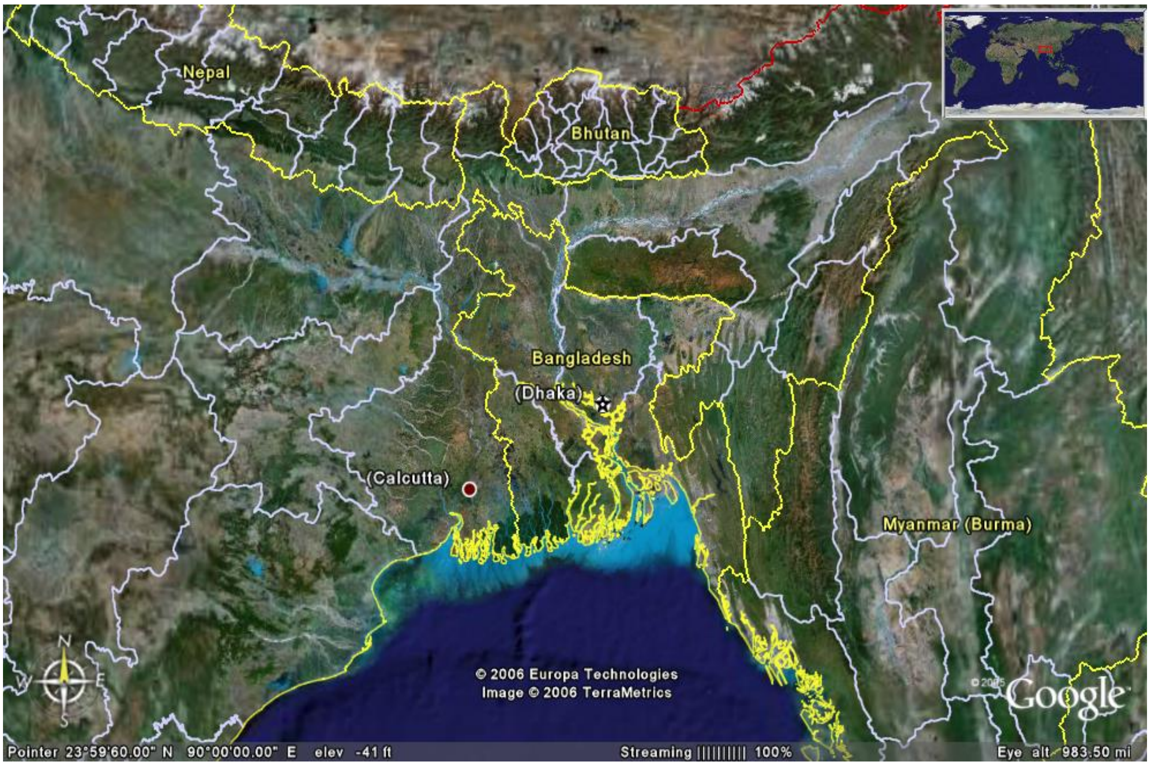

Figure 1: Location map of Bangladesh (Google Earth, 2006).

Arsenic in Groundwater

Arsenic is a chemical element that has the symbol As and atomic number 33. It is considered as toxic in ground water. This is a notoriously poisonous metalloid that has many allotropic forms; yellow, black and gray are a few that are regularly seen. Arsenic is not found free in nature, but its compounds are widely distributed in minerals. Arsenic and its compounds are used as pesticides, herbicides, insecticides and various alloys. Arsenic is very similar chemically to its predecessor phosphorus, so much so that it will partly substitute for phosphorus in biochemical reactions and is thus poisonous (Wikipedia, 2006).

Arsenopyrite also called mispickel (FeSAs) is the most common mineral from which, on heating, the arsenic sublimes leaving ferrous sulfide. Other arsenic minerals include realgar, mimetite, cobaltite and erythrite. The most important compounds of arsenic are white arsenic, orpiment, realgar, Paris Green, calcium arsenate, and lead hydrogen arsenate. Paris Green, calcium arsenate, and lead arsenate have been used as agricultural insecticides and poisons. Orpiment and realgar were formerly used as painting pigments, though they have somewhat fallen out of use due to their toxicity and reactivity. It is sometimes found native, but usually combined with silver, cobalt, nickel, iron, antimony, or sulfur (Nikson, 2000).

In addition to the inorganic forms mentioned above, arsenic also occurs in various organic forms in the environment. Inorganic arsenic and its compounds, upon entering the food chain, are progressively metabolised to a less toxic form of arsenic through a process of methylation (Nikson, 2000).

Arsenic is of natural origin and is believed to be released to ground water as a result of a number of mechanisms which are poorly understood. This release appears to be associated with the burial of fresh sediment and the generation of anaerobic (oxygen-deficient) groundwater condition (Saifuddin, 2001).

The source of arsenic in sediments is mainly the parent rock materials from which it is derived. Arsenic associated with sediment particles can be a major source of arsenic contamination when particles are detached and carried as sediments during erosion. Sediments can contain substantial amounts of total arsenic. During the formation of sedimentary rocks, arsenic is carried down by precipitation of iron hydroxides and sulphides. In a moist climate, arsenic sulphides are easily oxidized, become water-soluble, are washed out of the sediment particles by meteoric precipitation, and are transported with run off (Nikson, 2000).

Arsenic undergoes reactions of oxidation -reduction, precipitation-dissolution, absorption- desorption, and organic and biochemical methylation. All of these reactions control mobilization and accumulation of arsenic in the environment. A biotic reaction between arsenic species and the substrates on the species and the substrates on the sediment surface, as well as physical disturbance of sediments, all play very important roles in controlling the mobilization of arsenic (Saifuddin, 2001).

In nature, arsenic bearing minerals undergo oxidation and release arsenic to water. The problems of arsenic in Bangladesh in its Ganges delta region, however, because of the complexity and the size of the problems, the geological studies are yet to come to a conclusive finding. The following conceptual hypotheses have been put forward by many research workers based on various direct findings as well as indirect supporting evidence on arsenic contamination in the Ganges delta (Karim, 2000).

a) oxidation of pyrite and arsenopyrite due to excessive withdrawal and lowering of ground water is responsible for arsenic contamination in ground water,

b) reduction of oxyhydroxides is the source for arsenic contamination in ground water,

c) unconfined aquifers subjected to oxidation and reduction, and underlain by peaty clay and/ or clay layer is responsible for arsenic contamination.

Mine wastes, especially carbonaceous shale, dumped to the surface from coal mining in the Rajmahal basins are transported and deposited along with the river and flood-born sediments may be responsible for the formation of the peaty clay layer in the deltaic domain. The continued abstraction of water from unconfined aquifer releases pentavatent arsenic and is transformed into trivatent arsenic on reduction to become soluble and mobile in water.

However, all three hypotheses may be operative in the Ganges delta region and responsible for arsenic contamination (Kamal, 2000).

Effect of Arsenic in Groundwater

Arsenic and many of its compounds are especially potent poisons. Arsenic disrupts ATP production through several mechanisms including allosteric inhibition of the metabolic enzyme lipothiamide pyrophosphatase during glycolysis. At the level of the citric acid cycle, arsenic inhibits succinate dehydrogenase and by competing with phosphate it uncouples oxidative phosphorylation, thus inhibiting energy-linked reduction of NAD+, mitochondrial respiration, and ATP synthesis. Hydrogen peroxide production is also increased, which might form reactive oxygen species and oxidative stress. Arsenic kills by enzyme inhibition because enzymes are the best documented targets of metals; in this case, it causes toxicity but can also play a protective role. These metabolic interferences lead to death from multi-system organ failure (see arsenic poisoning) probably from necrotic cell death, not apoptosis. A post mortem reveals brick red colored mucosa, due to severe hemorrhage (Karim, 2000).

The IARC recognizes arsenic and arsenic compounds as group 1 carcinogens, and the EU lists arsenic trioxide, arsenic pentoxide and arsenate salts as category 1 carcinogens (UNESCO, 2005).

Arsenic is a slow killer. The most obvious signs are the blisters found on the palms of the hands and soles of the feet, which can eventually turn gangrenous and cancerous. Meanwhile, the poison also attacks internal organs, notably the lungs and kidneys, which can result in a battery of illnesses including cancers. It can take a decade or more of drinking poisoned water before the physical symptoms emerges.

Arsenicosis, a disease born by drinking arsenic contaminated water which can lead to a very painful death. Arsenite and arsenate are known as carcinogens and have an affinity to deposit in hair, nail, bone etc. Arsenic is found in high concentration in liver, spleen, kidney and lungs as well (WHO, 2005).

The arsenic poisoning from the contamination of ground water is very chronic in nature. The above symptoms are also very difficult to identify from other clinical conditions. The present experience to identify the arsenic cases are by external manifestations specially with the presentation on the skin called melanosis (blackening of skin) and keratosis (hardening of palms and soles) with the history of consuming arsenic contaminated source water (WHO, 2005).

Cancer of the skin along with cancer of some internal organs - liver, kidney, bladder is not uncommon. The stage of keratosis is known as potentially malignant. It is also observed that even if a person having no manifestations after consuming contaminated water the chance of having cancer cannot be ruled out (WHO, 2005).

Arsenic in ground water used for irrigation may also have affect on agriculture and food chain. So far as we know there is no medicine available for chronic arsenic toxicity.

World Scenario of Arsenic in Groundwater

Many underground water sources around the world contain arsenic. Parts of Taiwan, Argentina, Chile and China have all suffered epidemics of skin diseases, gangrene and cancer as a result. Smith's analysis of the Taiwan epidemic in particular helped set the WHO arsenic standards for water and is the basis for his current predictions. The delayed health effects of exposure to arsenic, the lack of common definitions and of local awareness as well as poor reporting in affected areas are major problems in determining the extent of the arsenic-in-drinking-water problem.

Reliable data on exposure and health effects are rarely available, but it is clear that there are many countries in the world where arsenic in drinking-water has been detected at concentration greater than the Guideline Value, 0.01 mg/L or the prevailing national standard. These include Argentina, Australia, Bangladesh, Chile, China, Hungary, India, Mexico, Peru, Thailand, and the United States of America. Countries where adverse health effects have been documented include Bangladesh, China, India (West Bengal), and the United States of America.

Seven of 16 districts of West Bengal have been reported to have ground water arsenic concentrations above 0.05 mg/L; the total population in these seven districts is over 34 million and it has been estimated that the population actually using arsenic-rich water is more than 1 million (above 0.05 mg/L) and is 1.3 million (above 0.01 mg/L) (BGS, 2001).

According to a British Geological Survey study in 1998 on shallow tube-wells in 61 of the 64 districts in Bangladesh, 46% of the samples were above 0.010 mg/L and 27% were above 0.050 mg/L. When combined with the estimated 1999 population, it was estimated that the number of people exposed to arsenic concentrations above 0.05 mg/l is 28-35 million and the number of those exposed to more than 0.01 mg/l is 46-57 million (BGS, 2000).

Environment Protection Agency of The United States of America has estimated that some 13 million of the population of USA, mostly in the western states, are exposed to arsenic in drinking- water at 0.01 mg/L, although concentrations appear to be typically much lower than those encountered in areas such as Bangladesh and West Bengal (Wikipedia, 2006).

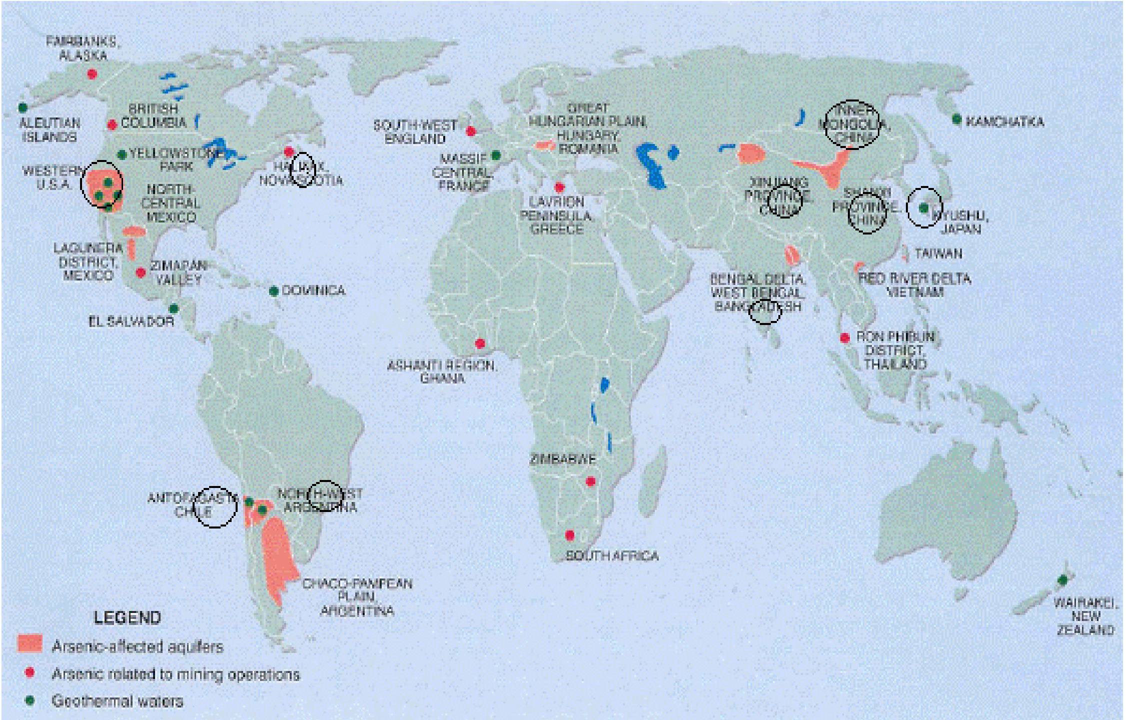

Figure 2: Global situation of arsenic contamination (Harvard, 2001).

Arsenic in Groundwater in Bangladesh

In Bangladesh, West Bengal (India) and some other areas, most drinking-water used to be collected from open dug wells and ponds with little or no arsenic, but with contaminated water transmitting diseases such as diarrhoea, dysentery, typhoid, cholera and hepatitis. Programmes to provide "safe" drinking-water over the past 30 years have helped to control these diseases, but in some areas they have had the unexpected side-effect of exposing the population to another health problem - arsenic.

Arsenic in drinking-water in Bangladesh is attracting much attention for a number of reasons. It is a new, unfamiliar problem to the population, including concerned professionals. There are millions of people who may be affected by drinking arsenic-rich water. Last, but not least, fear for future adverse health effects as a result of water already consumed.

Background

- In recent years, extensive well drilling programme has contributed to a significant decrease in the incidence of diarrhoeal diseases.
- It has been suggested that there are between 8-12 million shallow tube-wells in Bangladesh. Up to 90% of the Bangladesh population of 130 million prefer to drink well water. Piped water supplies are available only to a little more than 10% of the total population living in the large agglomerations and some district towns (WHO, 2005).
- Until the discovery of arsenic in groundwater in 1993, well water was regarded as safe for drinking.
- It is now generally agreed that the arsenic contamination of groundwater in Bangladesh is of geological origin. The arsenic derives from the geological strata underlying Bangladesh.

Situation

- The most commonly manifested disease so far is skin lesions. Over the next decade, skin and internal cancers are likely to become the principal human health concern arising from arsenic.
- According to one estimate, at least 100,000 cases of skin lesions caused by arsenic have occurred and there may be many more.
- The number of people drinking arsenic-rich water in Bangladesh has increased dramatically since the 1970s due to well-drilling and population growth.
- The impact of arsenic extends from immediate health effect to extensive social and economic hardship those effects especially the poor. Costs of health care, inability of affected persons to engage in productive activities and potential social exclusion are important factors.
- The national standard for drinking-water in Bangladesh is 0.05 mg/L, same as in India (WHO, 2005).
- District and sub-district health officials and workers lack sufficient knowledge as to the identification and prevention of arsenic poisoning.

Adopted GIS based Approach

The point source map for arsenic shows the distributions based on rounded quartiles including the WHO guideline value of 0.01 mg/L and Bangladesh standard for arsenic of 0.05 mg/L. The maps include groundwater from both the shallow and deep aquifers. The rounded quartile map is also displayed in terms of grey scale (BGS & DPHE,2001).

The map indicates the large spatial variability in arsenic concentration. Concentration shows with an overall median value in the shallow groundwater of .006 mg/L and in the deep groundwater of about 1 mg/L. Considering the shallow groundwater only 47% exceed the WHO guideline value and 27% exceed the Bangladesh standard. Only 1% of the deep wells exceed 0.05 mg/L (BGS & DPHE, 2001).

Despite the variability, some distinct regional patterns exist. These patterns are best revealed by smoothing the point source data. The maps show distinct regional trends with a clear geological control. Low arsenic concentrations tend to be found in the older sediments (BGS & DPHE, 2001).

There are wells low arsenic (blue) areas and within high arsenic (red) areas. The map shows average concentration but it does not give any indication of the variability of individual wells. The greatest proportion of high-arsenic wells are in the south-east of Bangladesh. High concentrations are also found in the groundwater of the Jamuna Valley and with patchy high values in the south-west and the north-east. Sporadic high are also found in other areas (BGS & DPHE, 2001).

Despite the considerable variability, the patterns of arsenic distribution often show a good relationship with surface geology. Low arsenic concentrations are picked out wells in the Pleistocene aged rock (Kamal, 2000). Low concentrations are also found in the deep groundwater from the southern coastal areas (Karim, 2000)

Highest arsenic concentrations and the greatest proportion of high-arsenic wells are in the Holocene and deltaic sediments. The overall worst-affected area is to the south-eastern low-lying part of Bengal delta (BGS & DPHE, 2001). Low overall concentrations of arsenic are found in the northern Bangladesh in the Tista Fan sediments. Aquifer of this region is consisting of main coarse grained sediments (Kamal, 2000).

The estimated population exposed to arsenic in the drinking water from the smoothed distribution is about 35 million at greater than 0.05 mg/L and 57 million at greater than 0.01 mg/L. This estimation is done from the polygonal distribution of population (BGS & DPHE, 2001).

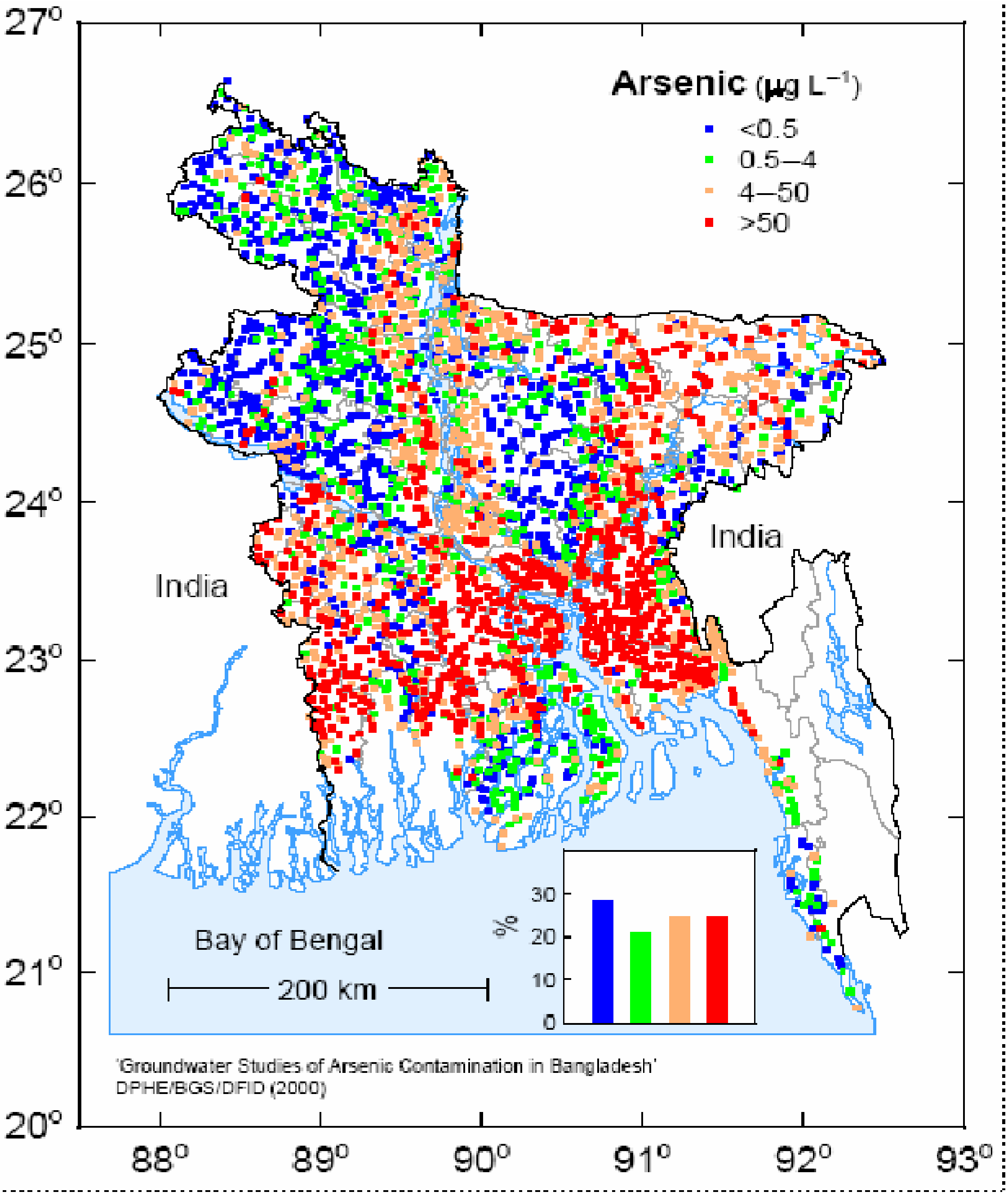

Figure 3: Groundwater studies of Arsenic concentration in Bangladesh.

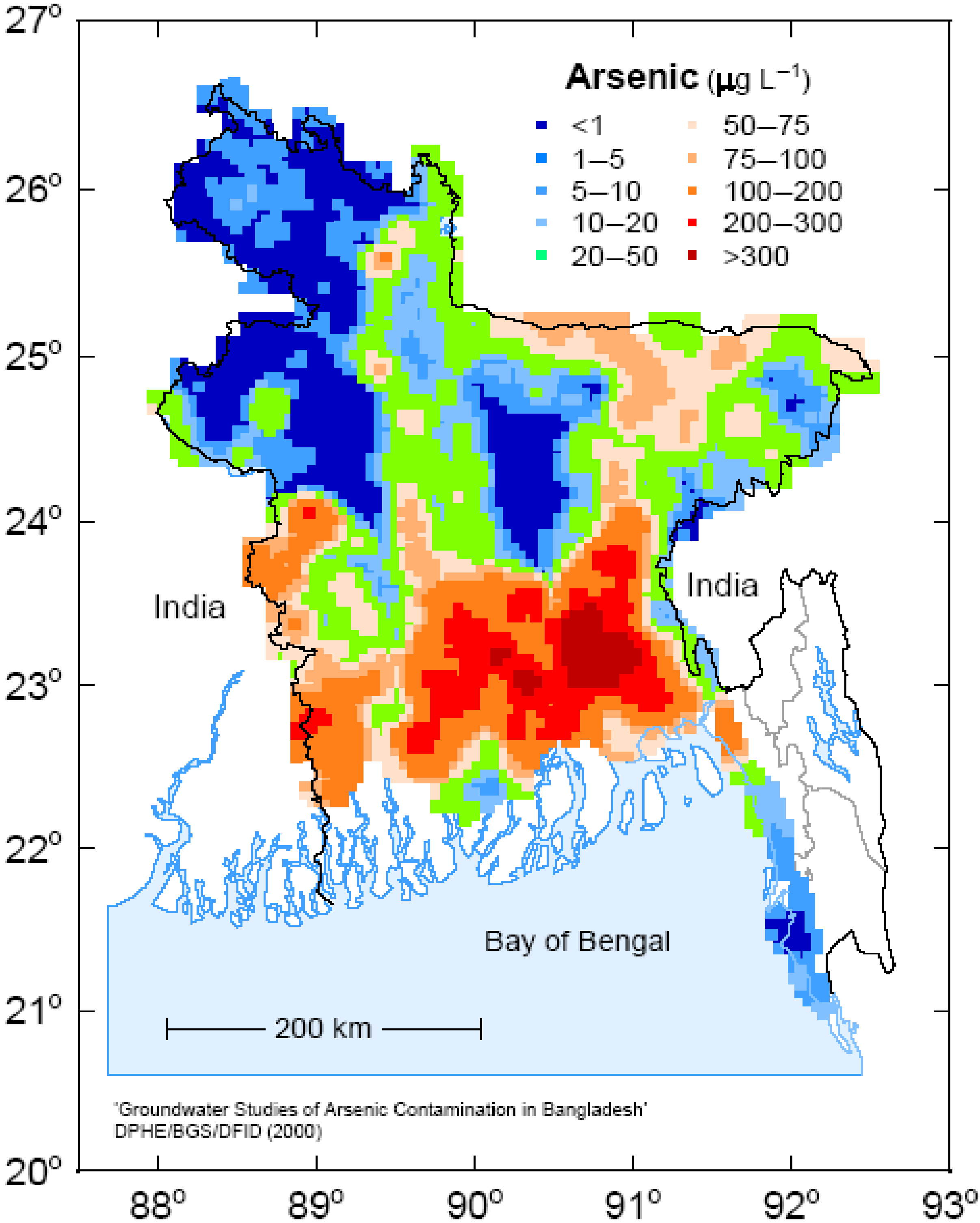

Figure 4: Groundwater studies of Arsenic concentration in Bangladesh.

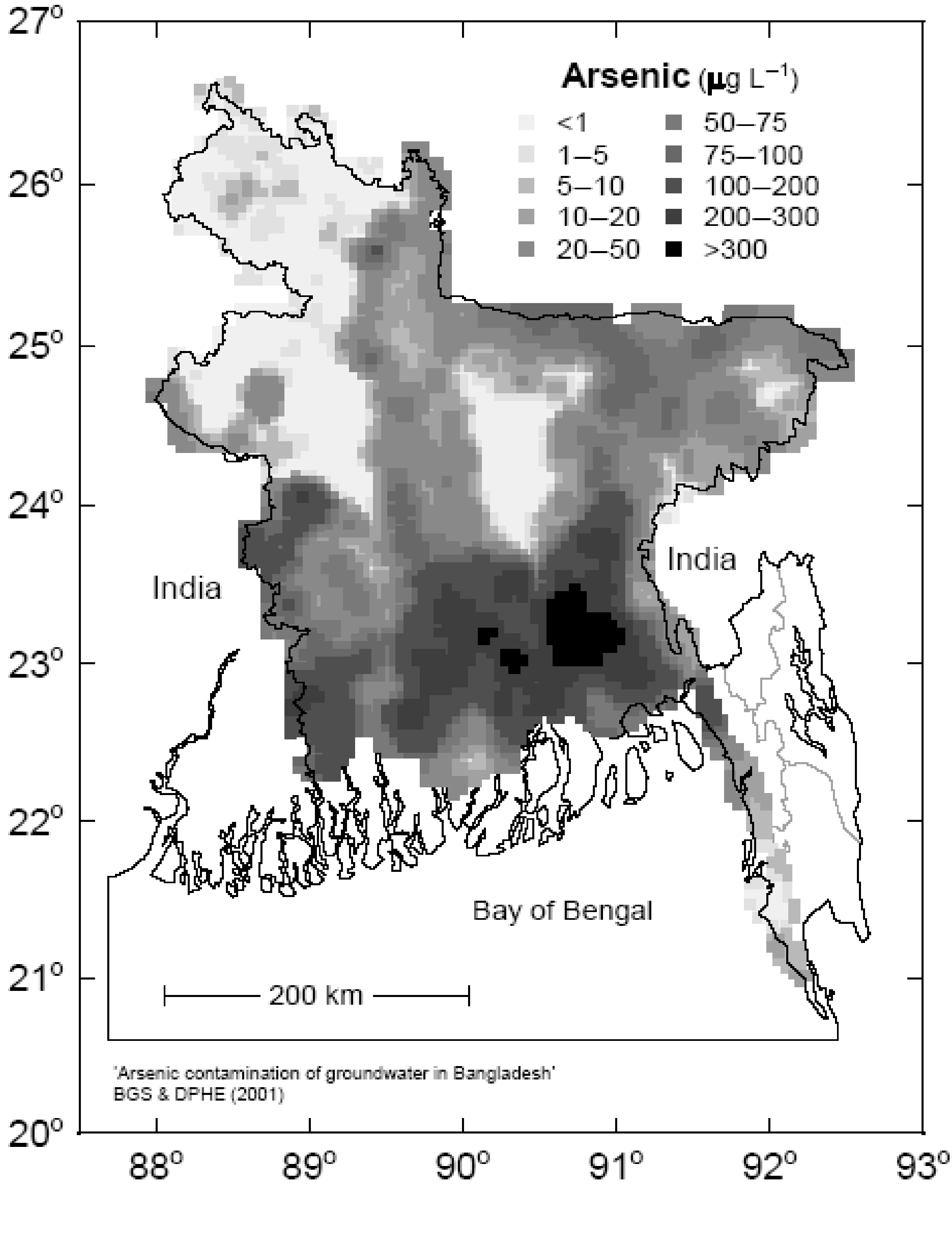

Figure 5: Groundwater studies of Arsenic concentration in Bangladesh.

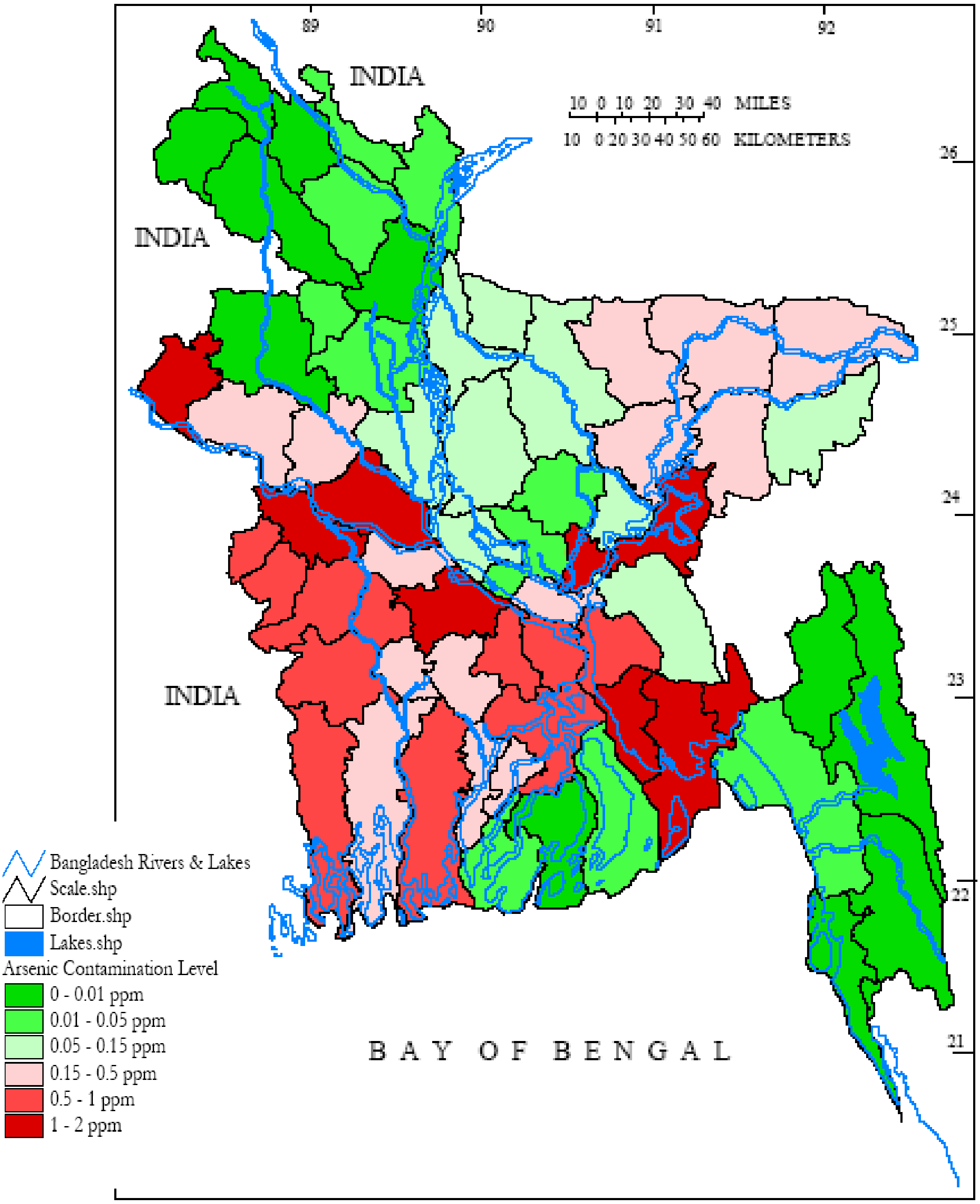

Figure 6: Polygon based Groundwater studies of Arsenic concentration in Bangladesh.

Figure 7: District based exact value of Arsenic concentration in groundwater in Bangladesh.

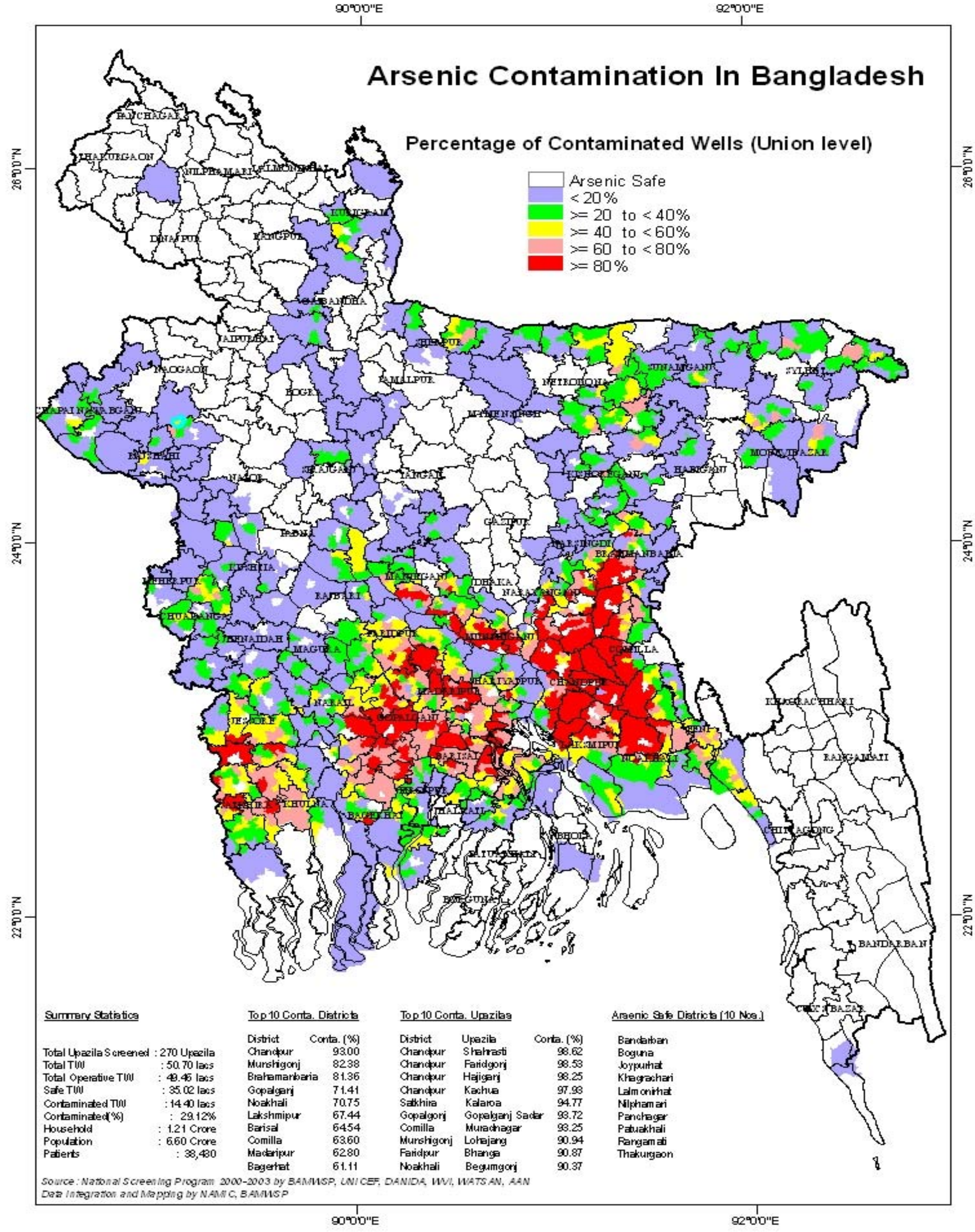

Figure 8: Sub-district based Arsenic concentration in groundwater in Bangladesh.

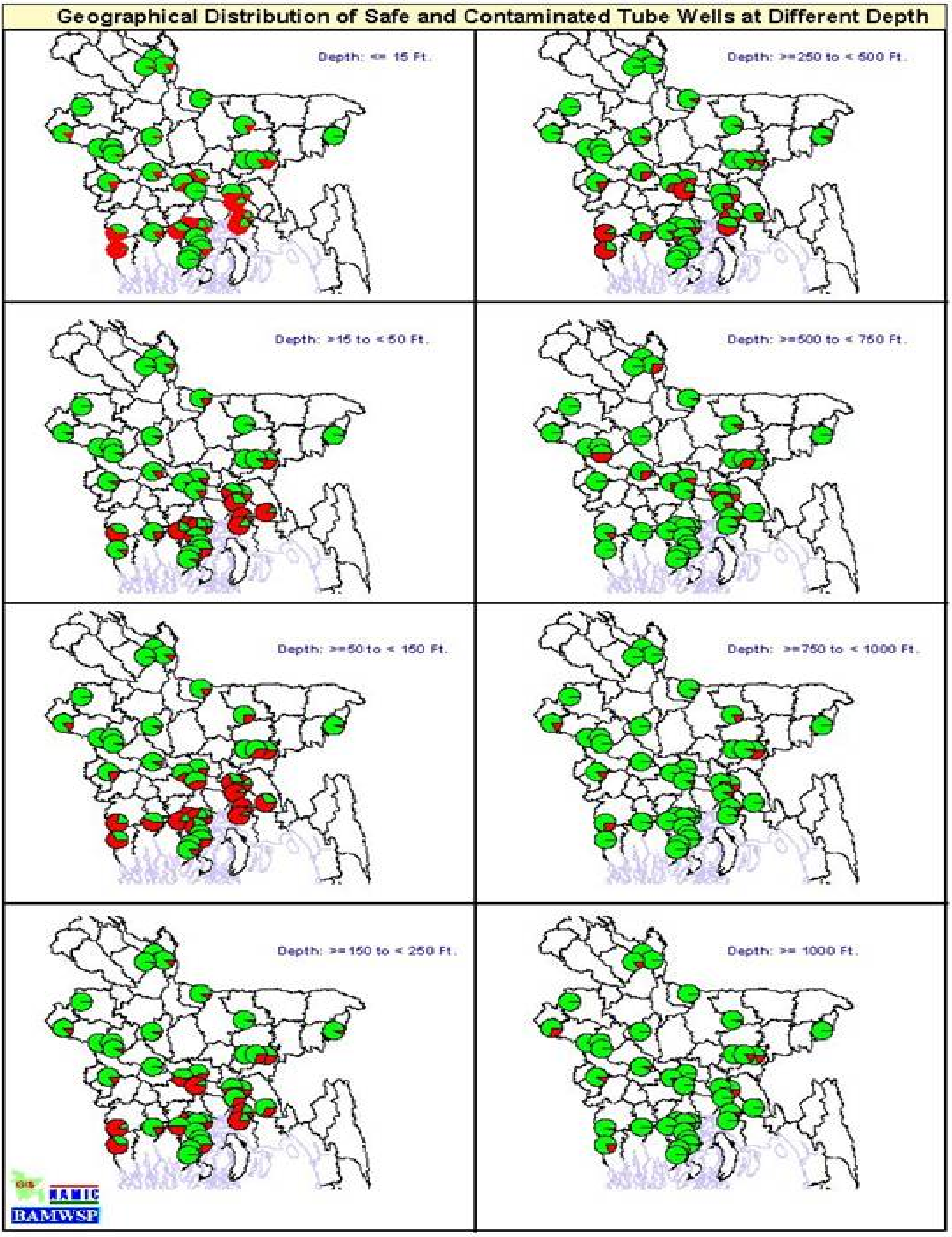

Figure 9: Depth based Arsenic concentration in groundwater in Bangladesh with pie diagram.

Conclusion

The capabilities of GIS enhanced to depict the real scenario of Arsenic Problem in Bangladesh. GIS was used to organise, analyse, and display the Arsenic contamination and potential hazards.

The analysis indicates large spatial variability in arsenic concentration. Greatest proportion of high arsenic wells are found in south-east of Bangladesh. Low overall concentrations are found in northern part of Bangladesh. With the increase of depth arsenic concentrations become less. The maps show average concentration but it does not give any indication of the variability of individual wells. The contaminated wells almost all take water from a depth of 20 to 100 meters. Shallower wells are clean because they contain mostly recent rainwater or water flowing swiftly through the sediments. Deeper wells tap water in older sediments which have by now been flushed clean of arsenic.

Recommendations

- A comprehensive information management approach must be adopted to centralize and organize the vast volumes of data with the knowledge of GIS.
- GIS can play a significant role by providing a long term management of water resources, farmland etc.
- GIS can be used to estimate the spatial distribution of arsenicosis patients and those are at risk.
- Subsurface based spatial analysis of As concentration can contribute in building cause-and-effect relationship.

- Soil arsenic analyses in the arsenic contaminated areas should be undertaken and research continued more seriously on the uptake of arsenic by different agricultural products and arsenic in the food chain.

- Investigate the seasonal changes in arsenic concentration and other information required for developing a reliable and cost effective monitoring program.

- Investigate the release mechanism and mobilization as well as mobility of arsenic in the ground water on a priority basis.

- Aquifer characteristics of these standard sections are to be established along with study of the aquifer sediments using GIS.

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