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Groundwater Arsenic in Bangladesh: GIS based spatial mitigation planning with public participation

Abstract:

The paper has highlighted the importance of participation geographic information system (PPGIS) to mitigate the arsenic problem in Bangladesh. PPGIS has recently been developed in combination with PRA (Participatory Rural Appraisal) and GIS (Geographical Information Systems) methodologies to utilise GIS in the context of the needs of communities that are involved with, and affected by development programmes. Furthermore, it has been developed to integrate local people's perceptions and analyze their knowledge as part of the 'participatory development' and for future spatial decision-making as the representation of 'multiple realities for single uses'. It attempts to design and adapt GIS that specifically address the needs of participant communities.

The arsenic problem was found in Bangladesh 'tragic and painful' on patients' health and their social life. This paper mainly explores the application and suitability of GIS with local community participation in deep tubewell planning for arsenic mitigation. It was found f this study that that tubewells installed at a depth between 100 and 150 feet are concentrated with high levels of arsenic; while concentrations are very low in deep tubewells. To set deep tubewell it also found from the fieldwork that more than 350 users for a deep tubewell could generate chaos and overcrowding at the deep tubewell platform in collecting water. Therefore, to avoid this problem, one deep tubewell for each 350 people, generally who live within a buffer distance of 300m were considered for the planning.

1. Introduction:

The existence of arsenic in water has become a more significant issue in water and wastewater treatment. Arsenic can enters into human body through water and causes different types of acute and chronic diseases like cancer of the bladder, lungs, skin, kidney, liver and prostate. Sources of arsenic contamination include both natural and anthropogenic (industrial waste, mining, agricultural, etc.). Due to minimize the health risks, the World Health Organization (WHO) has set a guideline limit of 10µg/L in drinking water [Holm, 2002] and these new limit has become effective from January 2006 for drinking systems.

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 [NAISU; Arsenic 2002] and more than 30% of the tubewells out of the analysed 4.37 million are found to be contaminated with arsenic, and so far 36,477 patients have been registered [BAMWSP, 2004], but the true numbers are thought to be much higher.

The concept of a public participation geographic information system (PPGIS) was developed in the context of the information society, especially from the critical GIS trend, in order to boost public participation and foster the empowerment of local communities [Sheppard et al., 1999].There has been a remarkable interest towards integrating GIS into participatory planning in dealing with spatial information and decision-making. A PPGIS (Public Participatory Geographical Information System) has been developed in combination with a PRA (Participatory Rural Appraisal) and GIS (Geographical Information Systems) modeling. Traditionally, GIS has been 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. Moreover, a GIS is frequently used for digital map production and in some cases stand accused of transforming bad data into impressive looking maps [Weiner et al., 2003].

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)].

2. Objectives:

The capability of a PPGIS to support and stimulate public involvement is limited by several major contextual factors (social, political, cultural), and a lot of research has been conducted on those topics over the last decade. Most of the efforts made by practitioners and researchers aimed at improving PPGIS applications and focused on the participative process. At the same time, PPGISs still rely on classical GIS technologies (including web and wireless flavours of GIS) and do not benefit from the major improvements brought by the business intelligence (BI) technologies. This lack of technological innovation appears as another limiting factor for PPGIS applications since BI technologies are specifically aimed at supporting decision making [Rosemarie et al., 2008].

A PPGIS is assumed to be cost-effective and more accurate over a full-blown GIS and it provides a critical complement to grassroots efforts that are undertaken to empower communities [Hassan et al., 2005]. This paper is concerned with participatory application of GIS in support of community perceptions regarding arsenic mitigation and the main objectives are: (a) integration of socially differentiated local knowledge in the form of cognitive maps; (b) embedding the 'community perceptions' within a GIS for spatial arsenic mitigation policy with deep tubewell planning and management. The study seeks to maximize the participation of diversity of communities in GIS production by drawing on relevant experiences, perspectives and skills on arsenic mitigation. Besides, origin of arsenic in ground water, effect of arsenic in ground water; Bangladesh scenario of arsenic in ground water is discussed in brief.

3. Literature Review:

3.1. Features of GIS:

A GIS is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display many forms of geographically referenced information [ESRI, 1995]. That is, GIS are '.computer-based information systems that attempt to capture, store, manipulate, analyze and display geographically referenced and associated tabular attribute data, for solving complex research, planning and management problems' [Fischer and Nijkamp, 1993]. GIS are 'used extensively in various applications such as land-use mapping, transportation mapping and analysis, and natural resource assessment. GIS allow efficient and flexible storage, display, and exchange of spatial data. Like all technologies, GIS are a part of the larger society and co-evolve with it' [Sadagopan, 2000].

Even though 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……..?

3.2. Importance of PPGIS:

M. Manzurul Hassan described in his study that GIS is viewed as an ‘intelligent information technology’ that allows spatial relationships for economic, social and natural resource issues. AGIS can be used for mapping the socio-economic indicators, commonly called ‘indicators of development’. In recent times, GIS with its ‘unique analytical capabilities’ in representing spatial information, has faced criticisms that it has concentrated on the ‘easy equation’ of environmental investigations rather than socio-cultural analysis. A PPGIS has been developed to integrate local people’s perceptions and analyse their knowledge as part of the ‘participatory development’ and for future spatial decision-making as the representation of ‘multiple realities for single uses’. A PPGIS attempts to design and adapt GIS that specifically address the needs of participant communities. The diversity of approaches to PPGIS are characterised by: (a) a system that seeks to empower communities and individuals and encourage public participation in spatial decisionmaking; (b) the integration of local knowledge with GIS is to minimise the distortion of traditional GIS applications [Weiner D, Harris T]. A GIS for community empowerment requires the ‘demand-driven’ rather than ‘technologydriven’ conventional top–down applications.

In an another study, Abbot et al. commented on the conceptual framework of a PPGIS that is Participatory GIS draws on the diversity of experiences associated with ‘participatory development’ and involves communities in the production of GIS data and spatial decision-making. Local people could interpret output from a GIS or contribute to it, such as by integrating Participatory mapping information to modify or update a GIS” [Abbot et al., 1998].

Indeed PPGIS has become increasingly popular due to the publication of Craig et al.'s (2002) seminal text and the rise of the annual PPGIS Conferences which began in 2002. There are different applications for PPGIS practice that include: mapping ''environmental racism'', i.e. the spatial correlation between environmental degradation and the distribution of ethnic or socioeconomic groups in urban areas; social equity mapping, i.e. the identification of socio-economic groups that are relatively disadvantaged by economic class, employment status, ethnicity, language, caste, gender, age, or, by location; analyzing differential mobility and people's access to services according to social categories; a significant component of this item is the gendered differences in mobility and access [Michael et al., 2003]; empowering marginalised groups through supplying them with appropriate geo-information and utilising GIS to promote transparency in decisionmaking [Michael et al., 2003].

3.3. Arsenic Contamination in Groundwater:

Arsenic is a contaminant of well-known toxicity and it is not an uncommon contaminant in groundwaters. It is the twentieth most abundant element in the earth's crust, fourteenth in seawater and it is the twelfth most abundant element in the human body [Sevil, 2003]. Although arsenic is necessary as a nutrient to humans in small quantities, it also leads to death in chronic intakes.

Arsenic contamination of the surface and subsurface water has been reported in many parts of the world, including South-Western Taiwan, Southern Thailand, Inner Mongolia, China, West Bengal of India, Bangladesh, and Northern Mexico. Although arsenic concentrations in the U.S. source waters are typically low, elevated arsenic concentrations are also encountered primarily in the northern and southern parts of the western United States, particularly in groundwaters and in surface waters with hydrothermal inputs [AWWA Committee Report, 1985; Wilkie and Hering, 1996].

Organic forms of arsenic that may be present in food are less toxic to humans; however, inorganic forms of arsenic dissolved in drinking water constitute the most significant toxicity. Recent studies conducted to understand the long term health risks associated with ingestion of low levels of arsenic have indicated that arsenic in drinking water is more dangerous than previously suspected. Therefore, the World Health Organization (WHO) and the U.S. Environmental Protection Agency (USEPA) promulgated more stringent arsenic regulations to minimize these risks [Sevil, 2003].

3.4. Mobility of Arsenic:

Arsenic and its compounds are mobile in the environment. Weathering of rocks converts arsenic sulfides to arsenic trioxide, which enters the arsenic cycle by dissolution in rain, rivers, or groundwater or as dust. Arsenic cycle (Figure 1) occurs among land, air, and water after the liberation of arsenic from rocks and soil. Volatile forms of arsenic enter the atmosphere from land and water, and then they are returned by rain or atmospheric fallout. The oxidized forms of arsenic are reduced back to sulfides under anaerobic conditions on land and water sediments [Sevil, 2003].

Water is one of the major ways of arsenic transport in the environment. Naturally elevated arsenic concentrations are particularly common in places with high geothermal activities and groundwaters in mining areas. Although low arsenic levels are usually detected in rivers and lakes, higher concentrations (up to several hundred micrograms per liter) occur in surface waters under the influence of hydrothermal inputs.

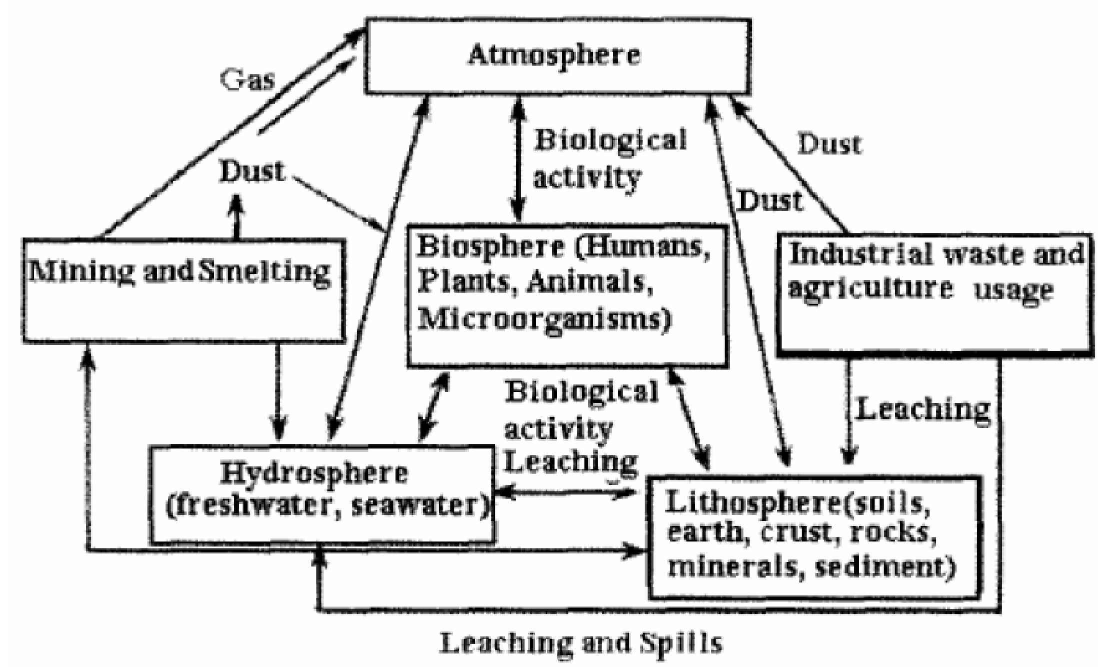

Figure 1: The global arsenic cycle [Sevil, 2003]

3.5. Health Impacts of Arsenic:

Due to the carcinogenicity of some arsenic compounds, regulatory agencies have established the maximum contaminant level for arsenic in drinking water. The objective is to reduce arsenic exposure to a level as close to zero as possible, considering its health effects and toxicology, occurrence, human exposure, feasibility of the treatment technology, availability of analytical techniques to quantify the lower levels of arsenic, and estimated risk for cancer as a consequence of long term exposure.

The study was done by Md. Safiuddin and he collected data by the governmental bodies, NGOs and private organizations reveal that a large number of populations in Bangladesh are suffering from melanosis, leuco-melanosis, keratosis, hyperkeratosis, dorsum, non-petting oedema, gangrene and skin cancer. Melanosis (93.5%) and keratosis (68.3%) are the most common presentations among the affected people. Patients of Leucomelanosis (39.1%) and hyper-keratosis (37.6%) have been found in many cases [Safiuddin]. Few cases of skin cancer (0.8%) have also been identified among the patients seriously affected by the arsenicals (arsenite and arsenate). Fig. 2 and Fig. 3 show skin lesions on palm and soles, respectively. It has been reported that 40% to 60% arsenic can be retained by the human body19. It indicates that the level of hazards will be higher with the greater consumption of arsenic contaminated water. The analysis was done by Safiuddin that around 90% of people have arsenic in their hair, nail and urine above the normal level. The normal concentration of arsenic in hair is 0.08-0.25 mg/kg and 1 mg/kg indicates the toxic level20. The normal arsenic content in nails is 0.43-1.08 mg/kg21 and the normal amount of arsenic in urine ranges from 0.005 to 0.040 mg/day20. Table 3 shows that the arsenic contents in hairs, nails, urine and skin scales of the affected people are very high in Bangladesh.

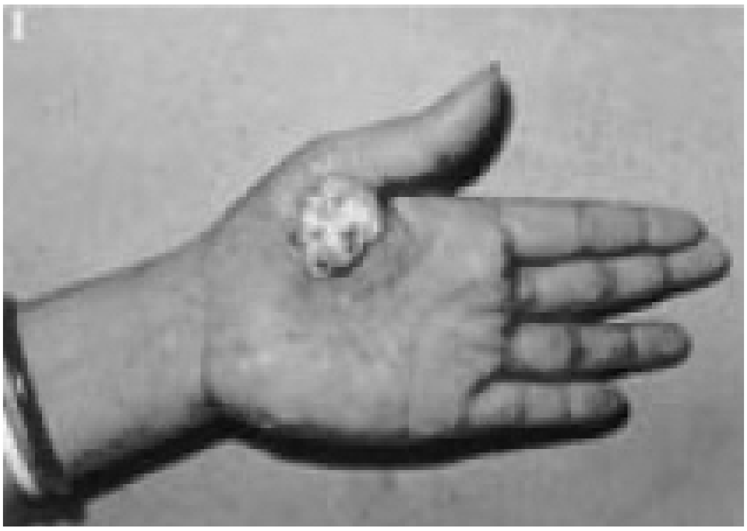

Figure 2: Skin Lesions on Palm due to Arsenic Intake in Drinking Water [Safiuddin, 2001]

Figure 4: Skin Lesions in Soles due to Arsenic Intake in Drinking Water [Safiuddin, 2001]

3.6. Toxicity of Arsenic:

Arsenic is considered to be an essential element, but many arsenic compounds are known to be toxic. The lethal dose for adults is 1-4 mg As/kg body weight. Humans are exposed to arsenic from air, food, and water. The concentration of arsenic in air is usually only a few ng As/m3, and estimated average in the United States is 0.006 µg/L As/m3. Food is an important source of arsenic. According to the studies in Canada, the arsenic content of many foods is mainly inorganic (typically 65-75 percent), except for fish, fruits and vegetables. The differences in eating habits significantly affect inorganic arsenic intake since some types of foods contain much higher arsenic levels. For instance, marine crabs, lobster, and shrimp contain about 10-40 mg As/kg, while pork, beef, and freshwater fish have arsenic levels less than 1 mg As/kg [Sevil, 2003].

Arsenic forms both organic and inorganic compounds, and the inorganic compounds are more toxic than the organic compounds. The toxicity of arsenite, the trivalent inorganic species, is higher than the toxicity of arsenate, the pentavalent species. The toxicity scale of arsenic can be presented in that decreasing order: arsine > inorganic As(III) > organic As(III) > inorganic As(V) > organic As(V) > arsonium compounds and elemental arsenic [Pontius et al., 1994]. In addition to oxidation state and chemical form of arsenic, its solubility in the biological media also affects the toxicity of arsenic [Sevil, 2003] .

To evaluate the health protection provided by the current arsenic MCL, the health effects of arsenic are quantified considering acute toxicity (relatively high exposures for a short time period resulting in effects other than cancer), chronic toxicity (relatively low exposures for a long period of time causing diseases other than cancer), and cancer effects (the risk of cancer at different exposure levels) [Pontius et al., 1994]. Arsenical poisoning involves four major areas: (1) digestive system, (2) skin, (3) nervous system, (4) motor paralysis, which causes death upon paralysis of the heart [Gulledge and O'Connor, 1973].

Arsenic in water supplies causes chronic poisoning rather than acute poisoning; therefore, chronic toxicity of arsenic is of main concern in the evaluation of health significance of arsenic in drinking water [Sevil, 2003]. Chronic arsenic poisoning leads to non-specific symptoms including chronic weakness, loss of reflexes, gastritis, anorexia, weight loss, hair loss, and long term exposure results in hyperpigmentation, cardiovascular diseases, disturbance in nervous systems and circulatory disorders. The common signs of acute arsenic poisoning are vomiting, dryness of the mouth and throat, muscle cramps, circulatory disorders, nervous weakness, hallucinations, and fatal shock can develop due to renal failure [Bissen and Frimmel, 2003].

The most significant consequence is the cancer effect in various organs, especially in the skin, lung, kidney, and bladder. Therefore, arsenic has been classified as human carcinogen and is of public concern due to its natural origin and widespread usage in industry.

4. Study Area:

The study introduced ground water arsenic in different places in Bangladesh and initiated with the applicability and relevance of a PPGIS in the context of arsenic issues in Bangladesh.

4.1. Location of Bangladesh:

Bangladesh extends between longitudes 888010 and 928400 east and latitudes 208250 and 268380 north. Geographically, Bangladesh consists of the great flood plain of the Bengal Delta bordered by the Himalaya–Arakan–Yoma mountain range complex in the north and east. It is low lying country and 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].

Bangladesh is a densely populated country with 128 million people (Bangladesh Bureau of Statistics, BBS, 1998) living in a comparatively small area of 147,570 km^2 (867 persons km2). Furthermore, it has a high population growth rate of 1.8% per annum (BBS, 1998). The country is now well known as a land of natural calamities where flood and drought are recurrent phenomena. 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].

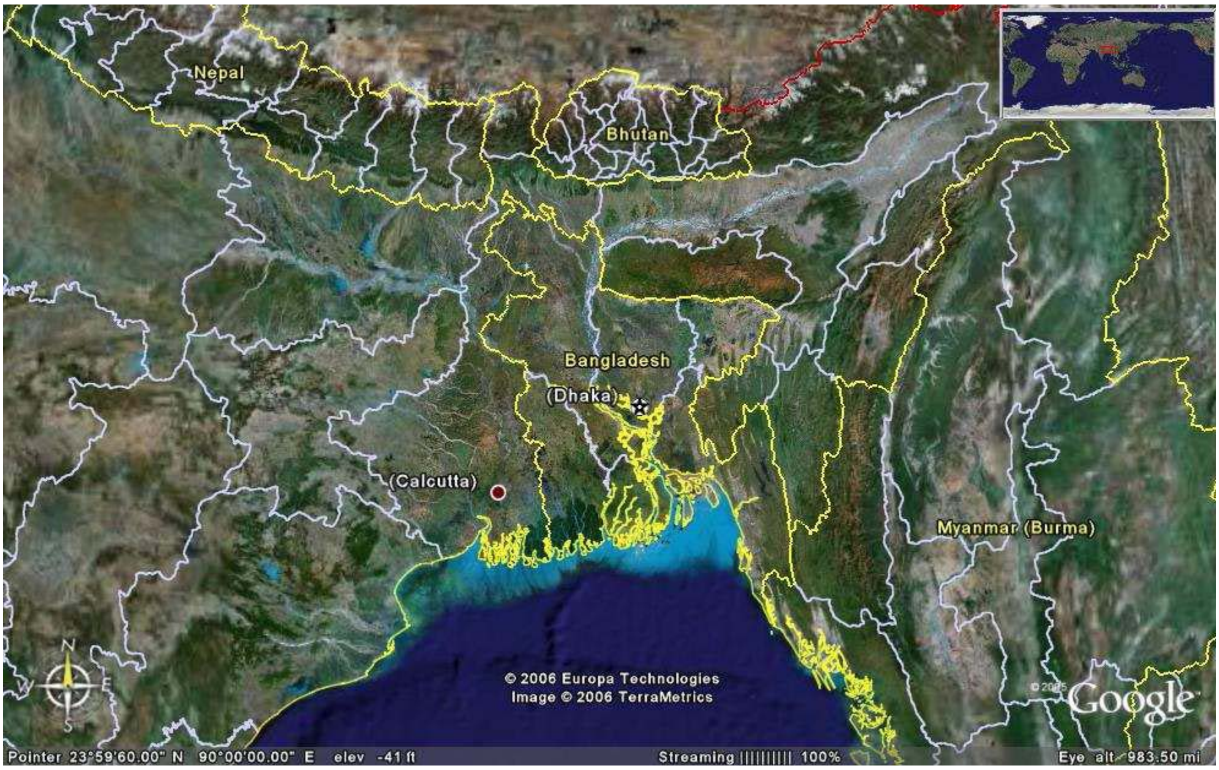

Figure 2: Geographical Location of Bangladesh [Google Earth, 2006].

4.2. Distribution of Arsenic in Bangladesh:

There is a strong correlation between the occurrence of As and the surface geology and geomorphology. The worst affected aquifers are alluvial deposits beneath the recent floodplains [Hossain, 2006]. Older sediments beneath the Barind and Madhupur Tracts and the eastern hills and their adjoining piedmont plains are not significantly affected by As. There are also important differences with the floodplains. The floodplains of the Brahmaputra and the Tista rivers in the north of the country show the lowest levels of contamination. The most affected aquifers lie beneath the Meghna floodplains of southeast Bangladesh. The Ganges floodplains, which have been the most extensively sampled, show the greatest spatial variability. The distribution of As in groundwater of Bangladesh is shown in Fig. 3 [BGS, 1999].

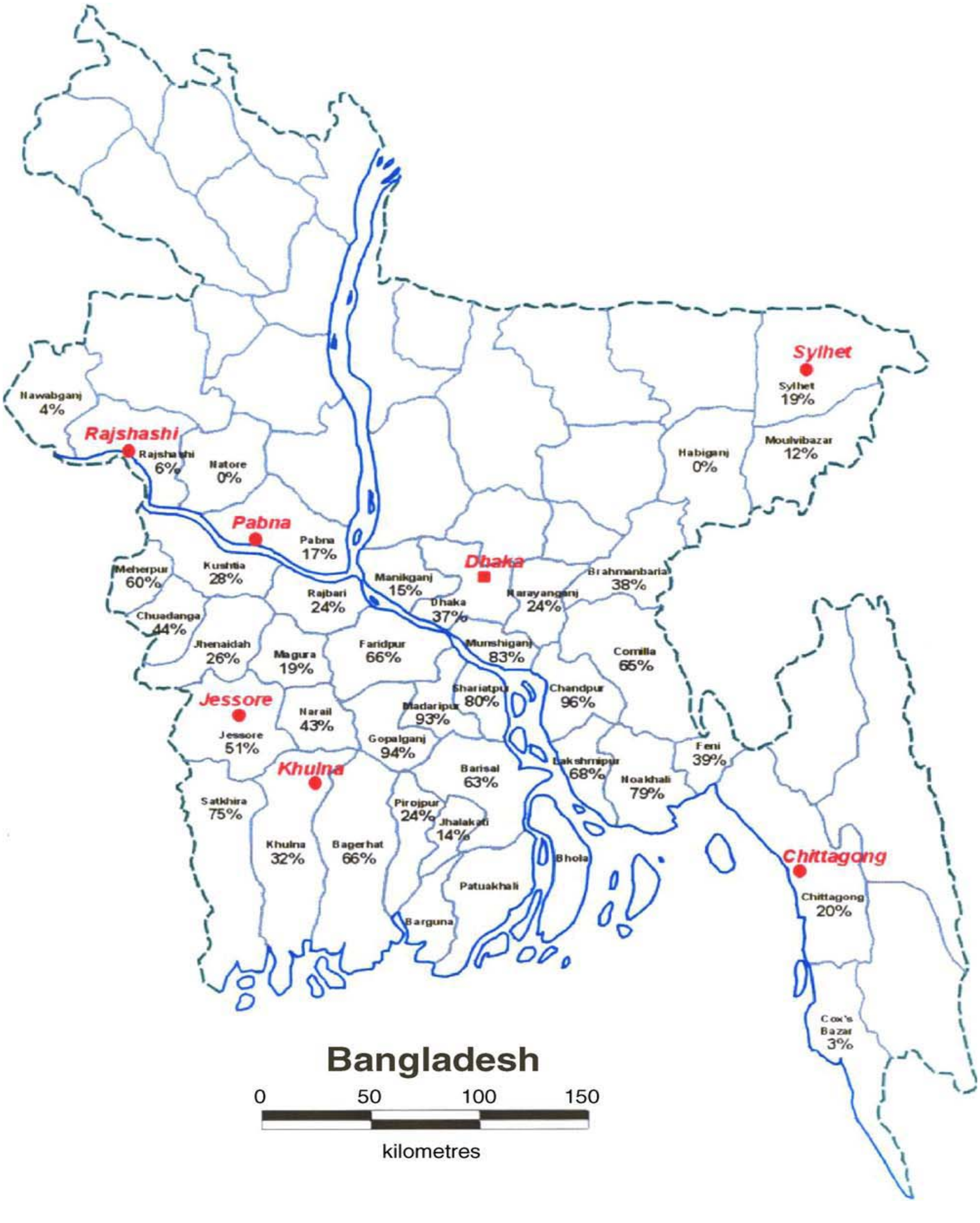

Figure 3. Percentage of groundwaters from the shallow aquifer (less than 150 m deep) **[**BGS, 1999]

Figure 4 shows another form of geographical map that presents the geographic distribution of arsenic concentration in the wells. The spatial distribution of arsenic concentration has both small-scale variability and large-scale trends. Concentrations can differ greatly in nearby wells, e.g., concentrations as high as 1,000 mg/L occur within hundreds of meters of concentrations as low as 1 mg/L. Despite this small-scale variability, regional patterns in arsenic concentrations are evident. For example, the south-central area near the confluence of the Ganges, Brahmaputra, and Meghna rivers has the highest concentrations while the southeastern hills and northwest piedmont plains generally have the lowest concentrations.

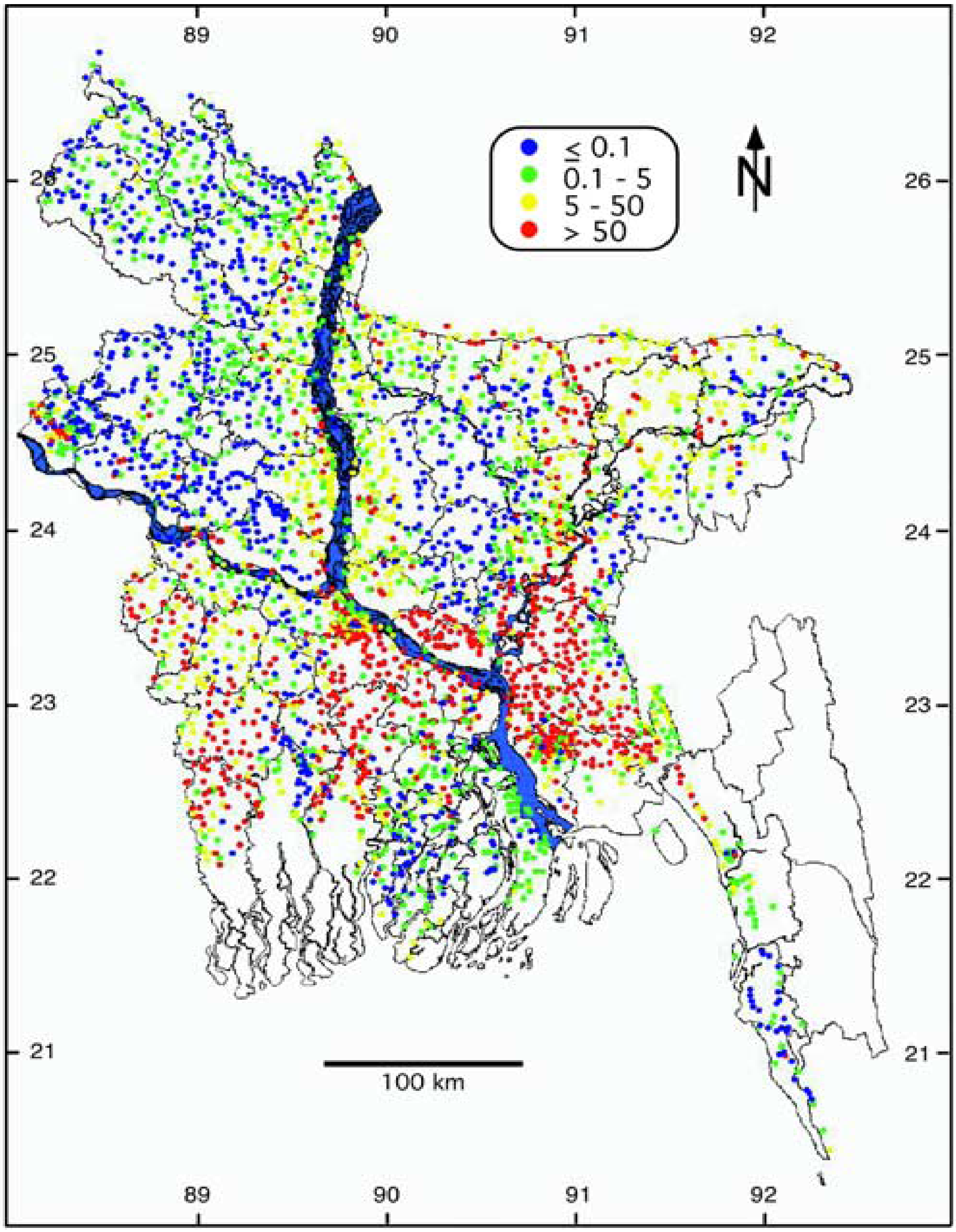

Figure 4. Geographic distribution of arsenic concentrations (Concentrations are in mg/L.) [Hossain, 2006]

4.3. Soil Arsenic in Bangladesh:

Soil As in some Bangladesh areas where irrigation is carried out with As contaminated groundwater, soil As level can reach up to 83 mg kg 1 (Ullah, 1998). This As content falls in the reported range of 10– 2470 mg As kg 1 for soils contaminated by pesticides wastes or industrial activity [Hassan, 2005]. Alam and Sattar (2000) reported that elevated As concentrations up to 57 mg kg 1 in Bangladesh soils collected from different locations could lead to elevated concentrations of As in rice grain and rice straw, which is used to feed cattle's and cows. A detailed As survey in soils of Bangladesh has been done by BGS (1999), and is presented in Fig. 5.

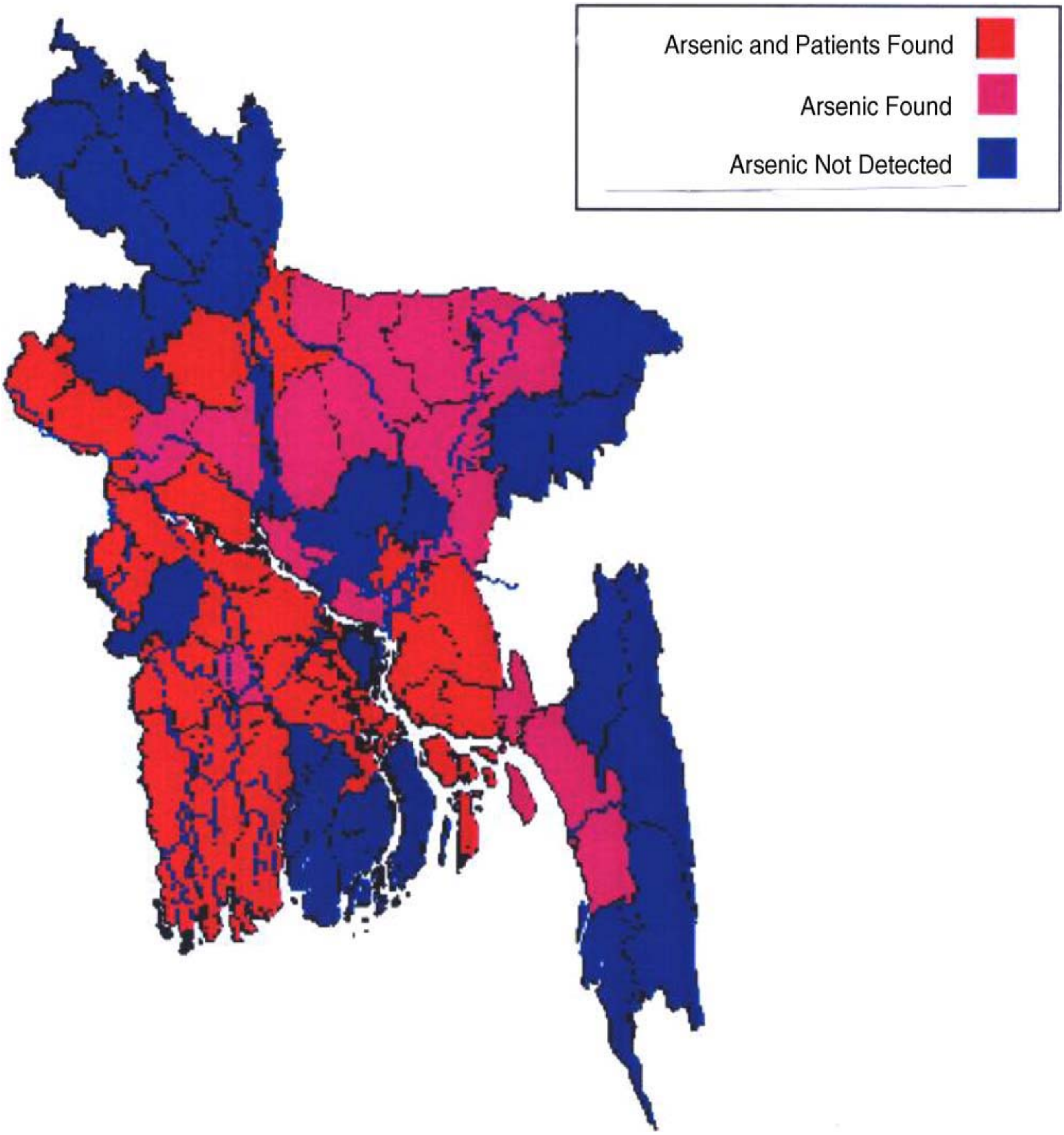

Figure 5. Arsenic contaminated areas in Bangladesh [Jakaria, 2000].

5. Methodology:

The paper try to explore the critiques levelled at GIS and with questions as to how a PPGIS technique might be designed and implemented in a decision-making process, where access to a GIS is severely limited in Bangladesh. The main focus was shifted towards examining a systematic approach for participatory arsenic mitigation with arsenic-free deep tubewell management. The research methodology combines the construction of a traditional GIS with participatory techniques. Socially differentiated local knowledges were compiled through participatory mapping exercises over GIS maps.

6. Case study:

The investigation was done for Ghona Union (the fourth order local government administrative unit in Bangladesh) of southwest Bangladesh by Hassan in his study. His studied area was characterized by low levels of education and low income levels with primary economic activities relating mainly to the traditional agrarian economy. He was collected arsenic data by analyzing 375 water samples. His study area was given on figure 6. Furthermore, he was discussed a techniques for spatial deep tubewell planning with PPGIS and the chart is given in figure 7.

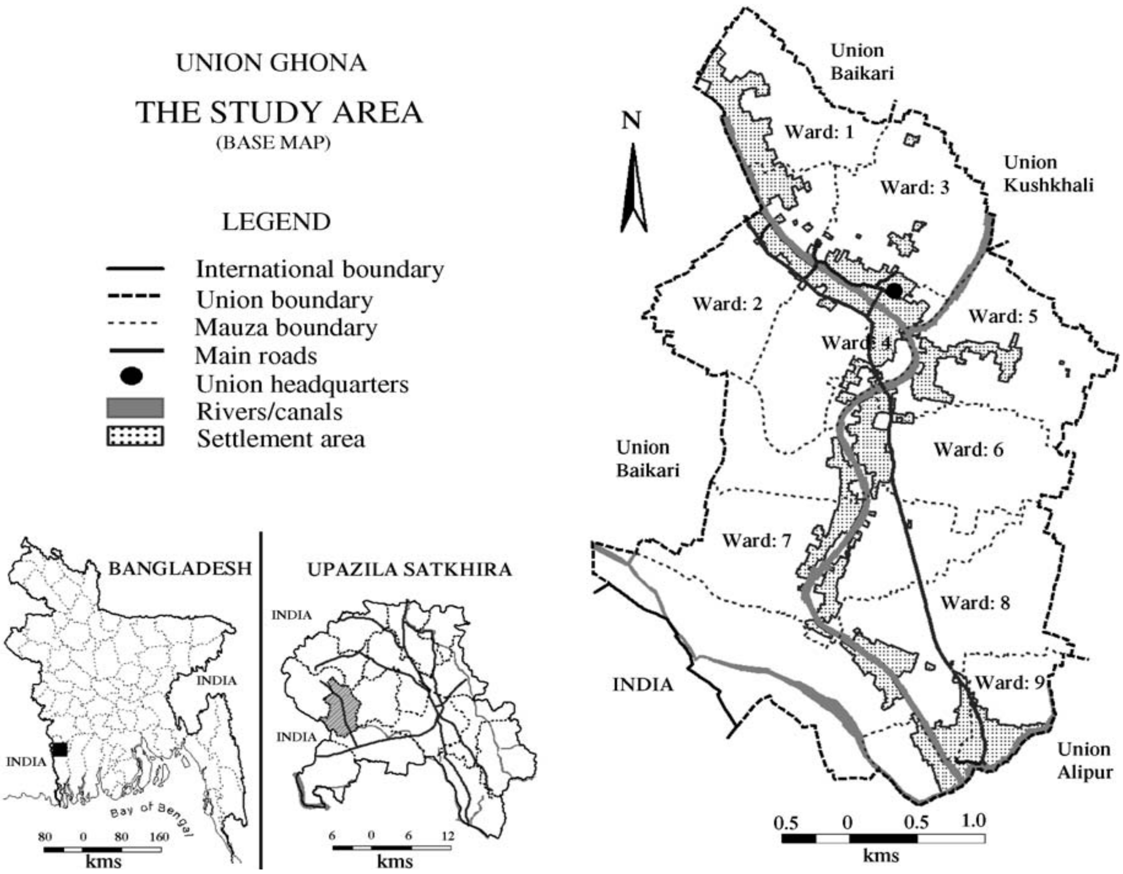

Figure 6. The study area [Hassan, 2005]

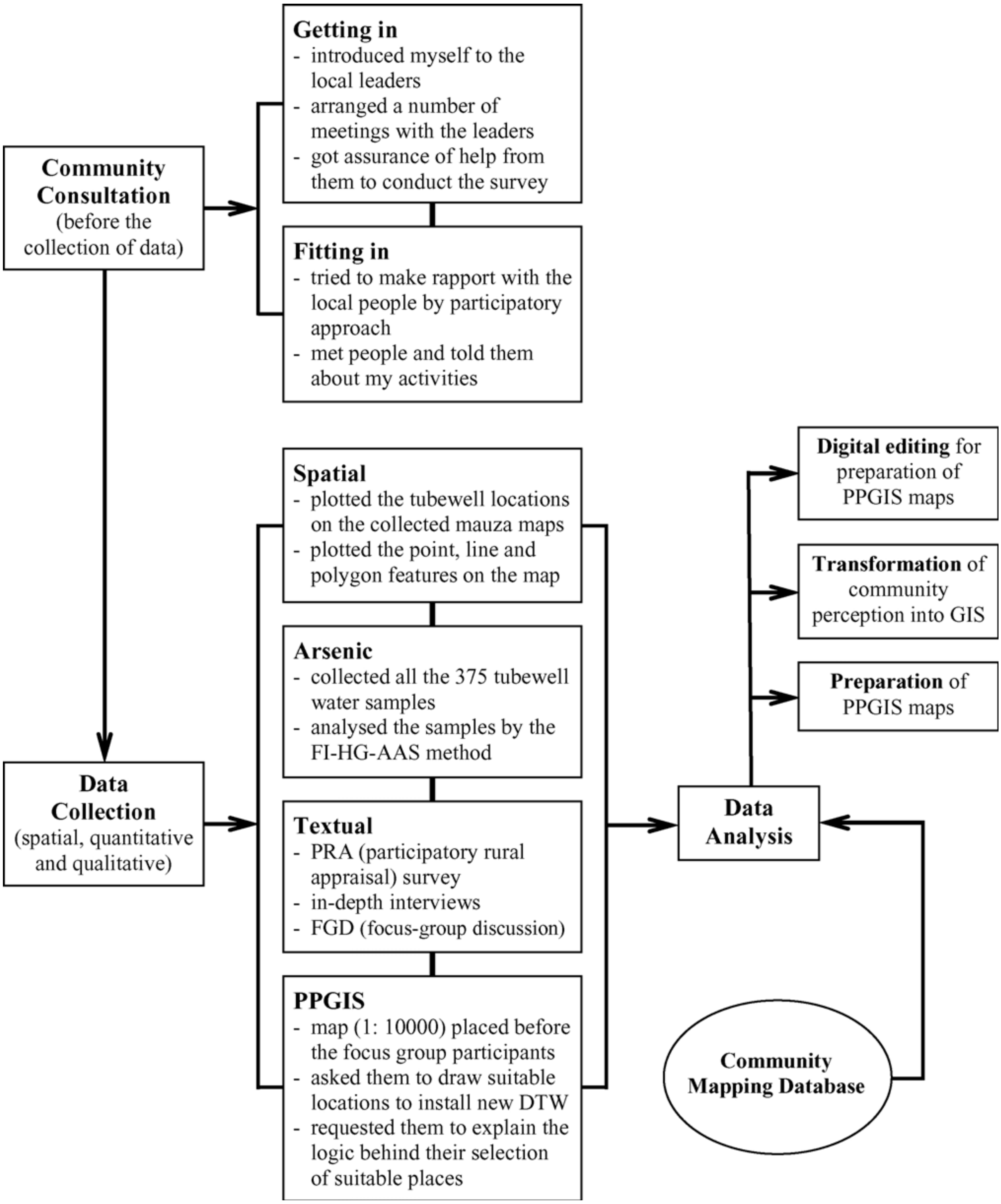

Figure 7. Flow chart for spatial deep tubewell planning with PPGIS techniques.

[Hassan, 2005]

Hassan was seek in his study to maximize the participation of a diversity of communities in a GIS production by drawing on relevant experiences, perspectives and skills on arsenic mitigation. Deep tubewell planning for arsenic mitigation was also examined in his study through the combination of a PRA and group interviews using GIS maps. Participatory mental mapping involved mapping the layers of different voices overlaid on GIS maps.

7. Results and discussion:

Hassan found in his study that arsenic-free safe drinking water was available from deep tubewells. He has come to know from some training that tubewells installed at a depth between 100 and 150 feet are concentrated with high levels of arsenic; while concentrations are very low in deep tubewells. It was found that the deep aquifer is much less contaminated than the shallow one. He assumed that it is the responsibility of the government to help poor people. If the government installed deep tubewells for arsenic-free water, there would be no arsenic problems as well as might not water-borne diseases like cholera and diarrhoea. Since most people in the study area cannot afford a deep tubewell, it would be necessary to install deep tubewells in suitable locations with the help of government funds.

The study was investigated for the transformation of people's opinions into a GIS could be regarded as the valuable measure for a PPGIS. In checking the voices of the community people, this transformation was used as a 'triangulation' for method verification. The authenticity of the local decision-making process and multiple viewpoints for a single issue could be verifiable through this 'method triangulation'. It has been seen from all the focus-group discussions and participatory mental mapping that the focus-group participants considered different parameters for deep tubewell planning. They drew maps (participatory sketching) for the locations of deep tubewells with their 'buffer zones' following the 'threshold distance'. Transforming the mental maps into a GIS shows a number of overlapping and unserved settlement areas in the study sites (Fig. 8) for a proper spatial deep tubewell planning. This inconsistency raises issues concerning to the participatory mapping suitability in spatial decision-making process.

In formulating a spatial deep tubewell planning with an 'expert view' of GIS for his study area, population size, 300m buffer distance, and maximum users of a deep tubewell was considered. The buffer distance of each deep tubewell was measured in his study from the field survey following the maximum users of each deep tubewell. It was found from the fieldwork that more than 350 users for a deep tubewell could generate chaos and overcrowding at the deep tubewell platform in collecting water. Therefore, to avoid this problem, one deep tubewell for each 350 people, generally who live within a buffer distance of 300m were considered for the planning.

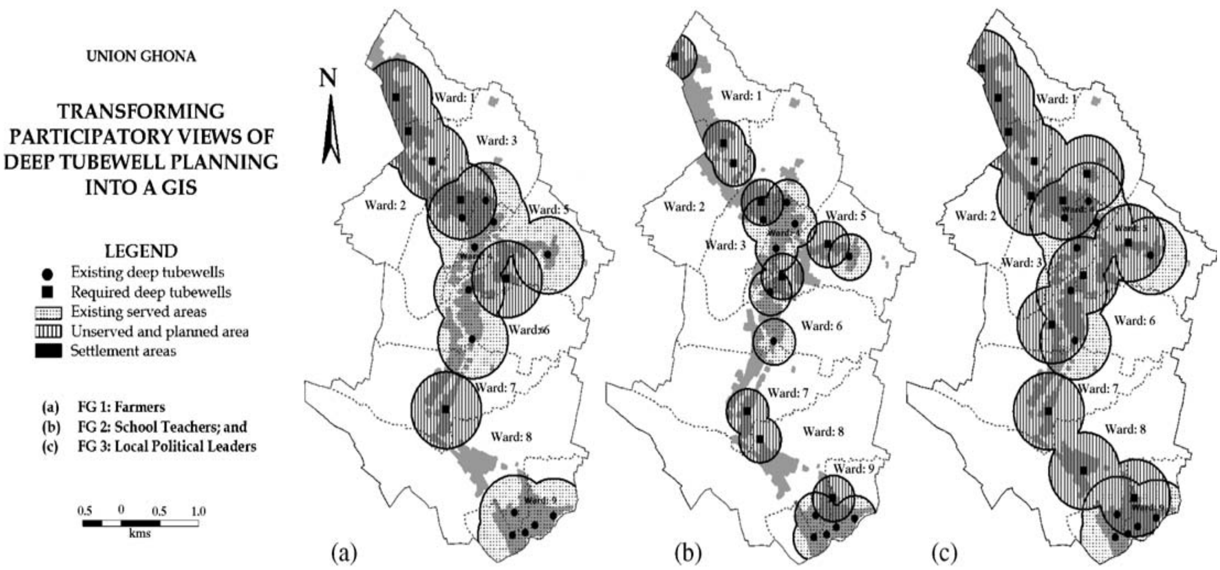

Figure 8. Transforming participatory views of spatial deep tubewell planning into a GIS.

[Hassan, 2005]

8. Conclusion:

The paper has try to investigate the importance of integrating GIS and participatory approaches to explain arsenic mitigation through deep tubewell planning in southwest Bangladesh. Furthermore, it is needed to investigate the capabilities of GIS enhanced to depict the real scenario of Arsenic Problem in Bangladesh.

The important findings in this study are listed below:

- A PPGIS has been developed to integrate local people's perceptions and analyze their knowledge as part of the 'participatory development' and for future spatial decision-making as the representation of 'multiple realities for single uses' [Abbot et al., 1998].
- A PPGIS attempts to design and adapt GIS that specifically address the needs of participant communities.
- The diversity of approaches to PPGIS are characterised by: (a) a system that seeks to empower communities and individuals and encourage public participation in spatial decision making; (b) the integration of local knowledge with GIS is to minimise the distortion of traditional GIS applications.
- A PPGIS emphasises the participatory approaches used in introduction of GIS, which are a combination of digital mapping activities and local sketch mapping by members of the public, individual or grassroots groups, for participation in public processes that affect their lives [Hassan, 2005].
- A PPGIS can be used as a new window to view the whole of GIS practices in social setting within the domain of 'information-democracy' [Dervin, 1994].

- From the discussion it was found that tubewells installed at a depth between 100 and 150 feet are concentrated with high levels of arsenic; while concentrations are very low in deep tubewells.
- It was found from the study, to avoid overcrowding problem at the deep tubewell platform in collecting area, one deep tubewell for each 350 people, generally who live within a buffer distance of 300m were considered as a mitigation planning for arsenic problem.

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