A Remote Sensing and GIS approach for mapping of arsenic contaminated area in the district of North 24 Parganas, West Bengal, India for management of water use pattern.

SYNOPSIS

Introduction

Formidable concentration of Arsenic (As) in ground water of Bengal Basin has been ascribed as the greatest mass poisoning in human history. A huge population is badly affected. The average arsenic concentration in ground water is found to be 22.5 times of the maximum permissible limit (0.05mg/L), set by WHO and at places crosses even 50 times of the said limit. Unfortunately, such a dangerously contaminated ground water is the principal source of drinking water as well as irrigation water of this vast flood plain. Perhaps the entire gamut of the biosphere thriving here is therefore compelled to this intake of poison day after day. Considering the magnitude of this problem, it is very imperative to explore all possible means to combat such menace.

Arsenic is a commonly occurring toxic metal in natural ecosystem. Inorganic arsenic is a established human carcinogen. Inhalation of arsenic dust particles and from drinking water is the main sources of human exposure. Providing arsenic free drinking water to vast rural masses of West Bengal is a major challenge to the planners, policy makers and executors.

The present study is aimed at mapping the arsenic presence, the contour of its concentration and depth of its presence in the district of North 24 Parganas in West Bengal, India. For the purpose, Geographical Information System and Satellite Image Processing are used to identify, locate, map and analyze the existing data on the district for modeling the hazard zones in the district. GIS acts as an excellent tool to unify data from various source and integrate them to a single environment to analyse the relationship amongst them. The satellite images helps in identifying the various land use pattern and provided clue to identification of patterns and source with respect to its geological setup. Though arsenic mapping requires a broad zonal understanding of the whole dynamics to achieve a strategic mapping and remediation, yet the present study at block level for a single district can act as a precursor to the whole process to initiate and set a strategic model subsequently. Thus Geomatics acts as a decision support tool to analyse the various data source for mapping the risk zone map of the area. This thesis is a unique example of applying GIS and Remote Sensing for environmental mapping.

Brief Background of Arsenic Poisoning in Bengal Delta and Associated Aquifers, India.

Many of the world's aquifers with recognized arsenic problems are located in Asia where large alluvial and deltaic plain occurs, particularly around the perimeter of the Himalayan mountain range. This section gives an account of the occurrence and scale of ground water arsenic problems in countries specially West Bengal, where such problems have been identified. There may be other Quaternary aquifers with high groundwater arsenic concentrations that have not yet been identified, but since awareness of the arsenic problem has grown substantially over the last few years, these are likely to be on a smaller scale than those already identified.

The information in this section has been compiled from published literature, as well as various unpublished reports and websites. The information available has been brought together to provide a critical assessment of the current state of knowledge of the scale of groundwater contamination of the aquifers in the Asia and to detail where apparent data gaps exist. A summary of the recognized occurrences, aquifers involved, and populations potentially at risk (that is, using drinking water with arsenic concentrations >50µg/L) is given in below table. Some of these population statistics are poorly constrained given the present state of knowledge.

Summary of the Distribution, Nature, and Scale of Documented Arsenic Problems (>50µg/L) in Aquifers in South and East Asia.

Location	Areal extent (sq. km.)	Population at risk	Arsenic range (µg/L)
Bangladesh	150,000	35,000,000	<1-2,300
China (Inner Mongolia,Xinjiang,shanxi)	68,000	5,600,000	40-4,400
India (West Bengal)	23,000	5,000,000	< 10-3,200
Nepal	30,000	550,000	<10-200
Taiwan	6000	10,000	10-1800
Vietnam	1000	10,000,000	1-3100
Myanmar	3000	3,400,000	
Cambodia	<1000	320,000	
Pakistan			

Source: World Bank Regional Operational Responses to Arsenic Workshop in Nepal,26-27 April 2004.

Social Problems Due to Arsenic Contamination

The common social problems due to arsenic toxicity as noticed from West Bengal, India are as follows:

1. Marriage break-down: Affected wives are sent back from In-laws' house to their parents, sometimes even with their children.
2. Marriage/ match-making of eligible candidates of either sex from the affected villages are difficult to accomplish.

3. Often jobs / service are denied / ignored to the arsenic affected persons.
4. When a spouse is diagnosed as an arsenic patient, several social problems crop up and might destroy the social fabric.
5. Due to ignorance, the villagers sometimes view it as a case of leprosy and force the arsenic patients to an isolated life and who often take to begging for survival.

Objectives and outline of the thesis

The major objective of this study has been to make use of the astounding potentials of the tool called Geographic Information System to get to the goals underlined below by appropriate analysis of data, garnered from authentic sources (published or unpublished).

The following goals have been attempted for realization –

1. **To review the origin and mechanism of arsenic release into aquifers (mobilization of As in ground water) so as to explain the elevated As contents in ground waters of the investigated area.**

2. **To test several hypothesis viz.**

A. "Physical setting has profound impact in worsening of As contamination" –

i). Geomorphology of the terrain
ii) Litho- strata of the terrain
iii) General climate of the area

B. "Socio-economic setting has profound impact in worsening of As contamination" in potable ground water as well as the differential impact on human beings consuming same contaminated water-

i). unsustainable land utilization
ii). population density
iii). level of nutrition
iv). literacy status

3. **To identify and locate the well locations on the maps.**

4. **To attach field data on arsenic contamination with well locations.**

5. **To create arsenic concentration map, depth map of arsenic contaminated aquifers.**

6. **To find the land use of the area using satellite images and correlation of different land use/ land cover pattern with arsenic concentration.**

7. To find the reason about the transfer of arsenic from water to crop.

8. To find how much of that arsenic is passing into food.

Study Area

The district of North 24 Parganas of West Bengal is in the southern part of the Bengal Basin. The geographical extent of the district lies between 88d19m E, 23d20m N to 89d10m E, 22d01m N and total area is 4094Sq.Km (4.61% of the State, W.B.). the districts consists of 22 blocks. Officially there are 1582 inhabited villages in North 24 Parganas district. There are 679 Municipal areas (known as wards) in North 24 Parganas district. The district has 89, 34,286 inhabitants (46, 38,756 are males and 42, 95,530 females). **(*Source – Census 2001*)**

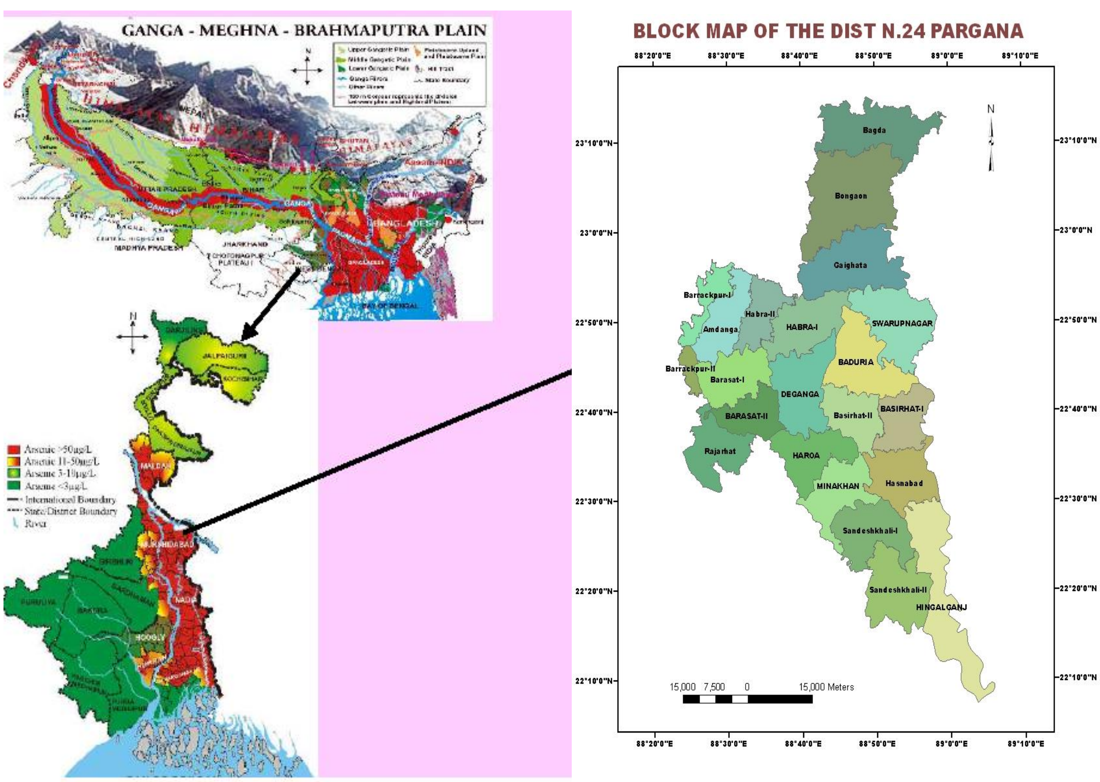


Figure 1 Location of Study Area with Respect of West Bengal and Bengal Basin

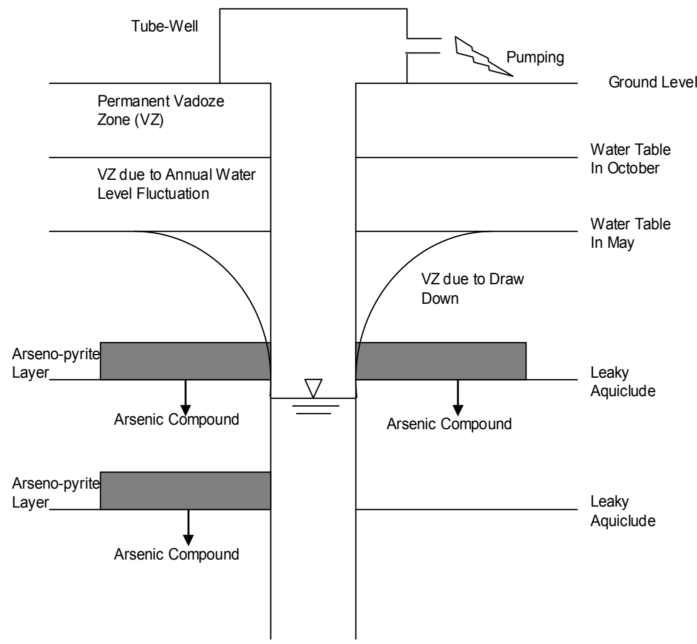
GEOCHEMISTRY OF MOBILIZATION OF ARSENIC (As) IN GROUND WATER:

The mechanism of arsenic release in groundwater can be explain by two ways.

1. **Oxidation process**
2. **Oxy-hydroxide reduction process**

- ### Oxidation of Sulfide Minerals

  Through this process, arsenic is released from the sulphide minerals (arseno-pyrite) in the shallow aquifer due to oxidation. The lowering of water table owing to over exploitation of groundwater for irrigation has initiated the release of arsenic. The large scale withdrawal of groundwater for agriculture due to the green revolution has caused rapid intake of O2 (oxygen)within the pore spaces of sediments as well as increase in dissolved oxygen in the upper part of the groundwater. The newly introduced oxygen oxidizes the arseno-pyrite and forms hydrated iron arsenate compound known as pitticite in presence of water.This is very soft and water-soluble compound. The light pressures of tube-well water break the pitticite layer into fine particles and make it readily soluble in water. Then it seeps like drops and percolates from the subsoil into the water table. Then, when the tube-well is in operation, it comes out with the extracted water.



Aerobic Condition in Groundwater around a Heavy-Duty Tube Well

Factors not in agreement with this model:

- There is not enough hydrological and geochemical data to validate the process.
- The mechanism does not take into account the physico-chemical characteristics of the groundwater samples.
- The oxidation products i.e., Fe-oxihydroxides of above mentioned mechanism are notorious absorbents of As and would not permit the release of As into solution. Thus these carriers therefore represent as sink rather than source for arsenic.

Arsenic Release from Iron Oxides

Release under Reducing Conditions

Hypothesis

Arsenic is fixed on Fe-oxyhydroxides from which it is released under reducing conditions in As-enriched groundwater of Bengal Delta Plain.

- Based on this hypothesis, arsenic is scavenged and immobilized by Fe-oxyhydroxides in an aerated aquatic system, but in the presence of organic material and as a consequence of changing redox conditions it can be released again due to the microbial mediated reductive dissolution of Fe-oxyhydroxides. This is a widely accepted model in several arsenic enriched regions across the world.

- Recently, Ravenscraft et al., (2001) suggested that biodegradation of buried peat deposits are the main driving factor in causing reducing conditions and the consequent dissolution of FeOOH. Paludal basins are widespread in the Bengal Plain and they correlate well with the distribution of arsenic enriched areas. Peat can even accumulate As, thus representing a potential source for As.

Application of RS & GIS (Geoinformatics) for mapping ground water arsenic contamination status of the study area

Geoinformatics can provide a powerful and highly flexible tool to quantify environmental processes that can increase the sophistication of any risk assessment methodology. Valuable quantitative information can be incorporated into risk assessment procedures with the help of GIS and, through spatial representation, the estimated risk becomes more apparent, thus facilitating the decision making process (Korre et al.2002). GIA has been widely used to visualize, integrate, and analyze spatial data pertinent to evaluating changes in environmental ecological systems. The use of GIS software as a model integration framework is often preferred because of the important role of spatial and temporal dynamics in evaluating complex ecosystem processes.

The present study is based on the District North 24 Parganas, one of the worst arsenic affected district of West Bengal. With the use of data from various source arsenic contaminations status mapping of the district had been done

Data Used:

The arsenic related data products used in this research are:

- Arsenic concentration value (μg/L) of the water samples collected from different tube well block wise of districts North 24 Parganas from year 2006 to 2008 in two seasons (pre-monsoon and post-monsoon) and

- The depth values (in mts.) below ground level (bgl) of arsenic occurrence of each tubewell block wise of the said district.

- The water pH value of every sample collected from each tube well of the district.

Secondary data of arsenic level were collected from various published research papers of School of Environmental Studies, Jadavpur University, Kolkata.

Some water samples were also collected from different tube wells and tested in the chemical laboratory of SWID (State Water Investigation Directorate, Govt. of West Bengal, India).and Department of environmental science, Kalyani University and analysed by applying hydride generation techniques.

Other supplementary data products used in this research are as follows:

- NATMO (National Atlas and Thematic Mapping Organization, India) district planning map of the said district.
- The Survey of India (SOI) topographical sheets.
- The Districts Statistical Handbook, published by Bureau of Applied Economics and Statistics, Govt. of West Bengal, India.
- Socio-economic information from Census- 2001.
- District Resource Map, Geological Survey of India.
- Report on Arsenic contamination of the district, published by P.H.E. Department, Barasat Division.
- Soil type data collected from National Bureau of Soil Survey, Salt Lake.
- Satellite Image of the area of IRS-1D LISS-III from NRSA, Hyderabad.

The application software on GIS used was- ArcGIS 9.3. The image processing application software used were- ERDAS IMAGINE 9.0, PCI Geomatica 9.1. The graphical software used were- Origine7.0, SPSS.

Methodology Adopted:

Available software resources like ERDAS IMAGINE's image processing techniques and Arc GIS's Geographical Information System had been used to derive a method of compiling all available data to assess the nature and condition of ground water in the study area.

The processing steps involved and followed in this research study are as follows-

1. Data Georeferencing:

The NATMO district planning map series of North 24 Parganas was scanned at a resolution of 400 dpi in the Tagged Information File Format and then was georegistered with the Survey of India toposheets. The georeferencing information was collected from the 8 topographical sheets. The process of geocoding was done using Universal Transverse Mercator projection and referenced ellipsoid with Everest datum.

The satellite image (IRS 1D LISS III) was also georeferenced through abovementioned co-ordinate system. The process of geocoding required ground control points which was collected uniformly over the whole district.

2. Data Digitization:

I) Preparation of district boundary and block boundary map of North 24 Parganas:

From the geocoded scanned NATMO map the district boundary was digitized. The block boundaries were also digitized. The digitization was done in the Arc GIS environment. The different blocks and their names were taken into the database of Arc GIS in .mxd format.

II) Preparation of Geomorphological and Geohydrological Map of North 24 Parganas:

The geomorphologic and geohydrological map of the district collected from Geological Survey of India was also georeferenced through the above mentioned process and then digitization had been done in Arc GIS. The area of different geomorphic and geohydrological unit has been digitize separately and their names have been taken into the database of Arc Map with .mxd format. The block boundary map was overlaid on both the maps. The different geomorphic unit was

a). Upper matured deltaic plain b) Lower matured deltaic plain
c) Flood plain of river basin d) Lower active tide dominated deltaic plain.

The different geohydrologic unit was-

a) Fresh water overlain by saline ground water b) Aquifer with primary intergranular porosity
c) Area under water table condition d) Area where shallow tubewell irrigation is practiced
e) Area where tubewells tap deeper aquifer and are generally under flowing condition.

3. Data Input:

i) Preparation of point map (location of tube well) block wise of the district (Spatial data input):

This is the process to identify and locate the well location on the map block wise. To de this we selected three or more tube wells in each block. We pronounced this tube well as 'hydraulic station'. The x,y lat/long value was evaluated by GPS survey. From that value we encode the location of tube well in the block map of the said district by spatial entity of point. All the process has been done through the Arc GIS's data editing technology. In this research study 80 tube well has been surveyed and located throughout the district.

ii) Attribute data entry:

The water samples collected from each tube well from year 2006 to 2008 for two seasons (Pre monsoon/ Post monsoon) has been tested in the chemical laboratory of SWID. From that laboratory we get the arsenic concentration value, water pH value and iron concentration value temporally from 2006. The depth of each tube well has also been collected from field survey. These data served as attribute data for my research study. Various fields in attribute database of arsenic point map are – Block name, Location of hydraulic station as point information, year of sample collection, season of collection, water pH value and depth of tube wells recorded in the database. Attribute data resides as tables in a relational database. An attribute table was organized by row and column. Each row represents a spatial feature, and each column or field describe characteristics. Whole the process has been done through the Arc GIS's data editing technology

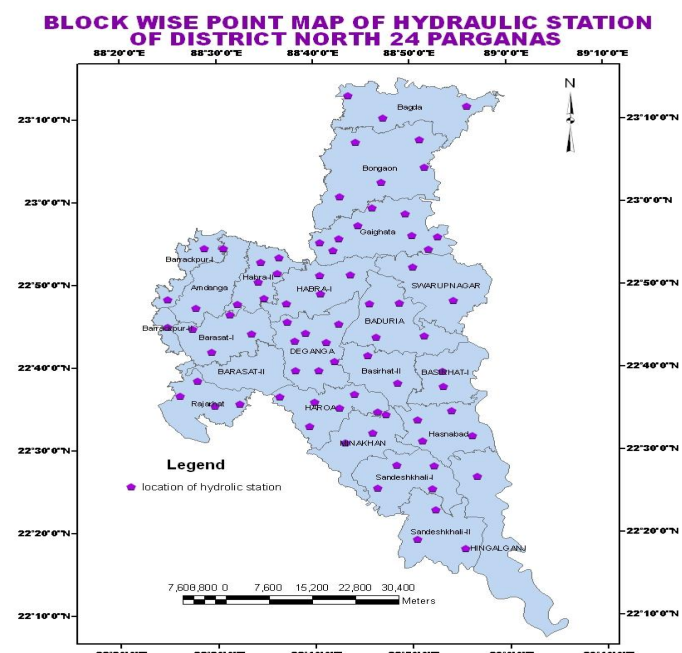


Figure 2 Point map showing location of Hydraulic Station (Tube Well) of Study Area.

iii) Joining between spatial and attribute data:

The georalational data model stores attribute data separately from spatial data in a split system. The two data components are linked through the feature IDs. The object-based data model stores spatial data as an attribute along with other attributes in a single system. Thus the object based data model eliminates the complexity of coordinating and synchronizing two sets of data files as required in a split system. It also brings GIS closer to other nonspatial information systems because spatial data files are no longer needed.

The feature ID serves as the key in the georelational data model to link spatial data and attribute data.

This unique combination enhances the role of GIS in decision making process

4. Preparation of Arsenic Concentration Map Using Spatial Interpolation Technique (Thiessen Polygon):

- Spatial Interpolation is the process of using points with known values to estimate values at other points.

- Thiessen polygon is a Deterministic (exact) Spatial Interpolation.

- Thiessen Polygon assumes that any point within a polygon is closer to the polygons known point than any other known point.

- These are used in a variety of application, especially for service area analysis of public facilities such as drinking water facility, hospital.

- In this research study total 80 sample points (Hydraulic Station) with their corresponding attribute values are available throughout the study area. This is very limited in respect to the whole district. With this limited data set arsenic concentration mapping in spatial domain is impossible. In this position only GIS can help us. If we spatially interpolate our limited sample data set through Thiessen Polygon technique, then we can achieve our goal.

- The Delaunay Triangulation method is often used in preparing Thiessen polygon. This process ensures that each known point is connected to its nearest neighbors, and that triangles are as equilateral as possible. After triangulation, Thiessen polygons can be easily constructed by connecting lines drawn perpendicular to the sides of each triangle at their midpoints.

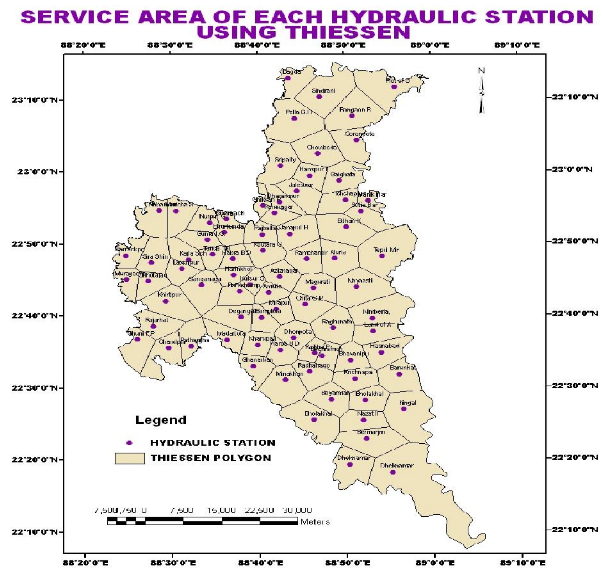


Figure 3 Service area of each hydraulic station using thiessen (output Thiessen Layer).

◆ After distribution of arsenic concentration value spatially from a point information throughout the district, classification of arsenic concentration value in seven category has been done, using Arc GIS's Classifier tool.

The thematic map indicates the range of arsenic concentration in (μg/L):

- Below 0.01
- (0.01 – 0.03)
- (0.03 – 0.05)
- (0.05 – 0.075)
- (0.075 – 0.100)
- (0.100 – 0.125)
- Above 0.125

By this way arsenic Concentration map of the district has been prepared.

In this research study total six arsenic concentration maps has been prepared for two seasons (Pre-monsoon and Post-monsoon) from 2006 to 2008 to study temporal change of arsenic concentration value.

This temporal change has been shown statistically also.

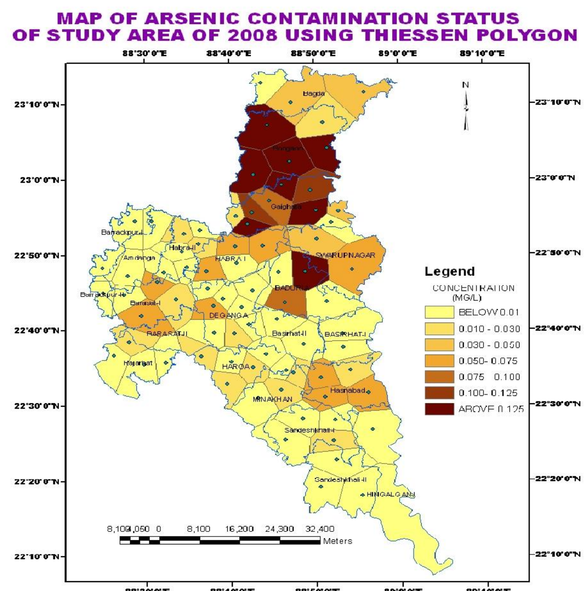


Figure 4 GIS based Arsenic concentration map of study area prepared using 2008 data applying theory of Thiessen Polygon technique.

5. Finding correlation of different land use/ land cover and other physical parameter of the study area through Buffering Technique:

- Buffering creates buffer zones by measuring straight-line distances from selected features. Buffering creates two areas: one area that is within a specified distance of selected features and the other area that is beyond. Buffering around points creates circular buffer zones.

- In this research study buffering has been done several times for doing GIS based analysis using tools of ESRI's Arc GIS software package.

- For buffering we selected 40 Hydraulic Station randomly out of total 80 throughout the study area. Then we classified those H.S. in four categories according to their arsenic concentration value: Worstly Affected (0.20-0.70)µg/L, Highly Affected (0.05-0.2) µg/L, Low Affected (0.02-0.05) µg/L and Very Low or Arsenic Free (below 0.02) µg/L. Next we selected 10 tube wells from each category and a ring buffer had been done around each tube well with straight line distance of 1km from the centre of the ring. After that, we overlaid this buffered layer on previously prepared land use/ land cover layer, geomorphologic layer and geohydrological layer to analyze how each and every parameter is correlated with arsenic concentration value.

- Statistical Analysis also had been done to prove their correlation ship.

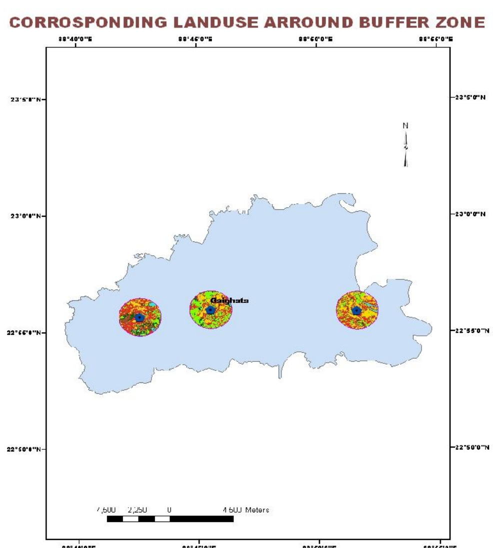


Figure 5 Ring Buffer around selected Tube Wells in Block Gaighata.

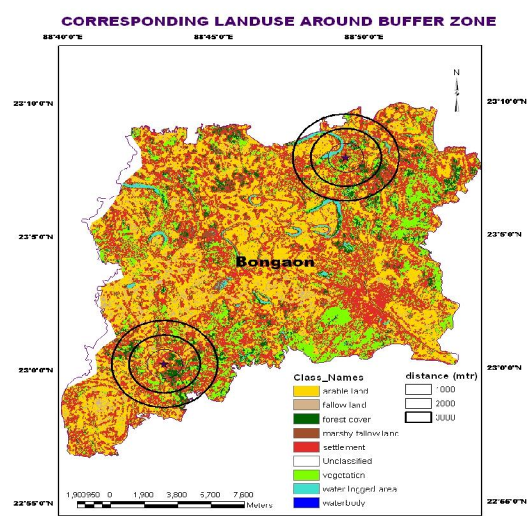


Figure 6 Corresponding land use within buffer zone in Block Bongaon (one of the highest arsenic affected block in North 24 Parganas).

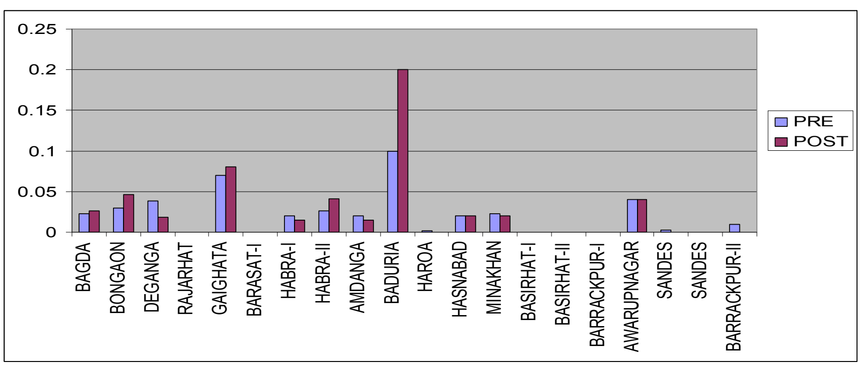
Result and Discussion

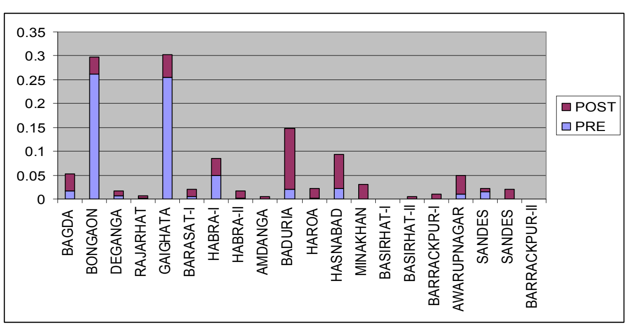
The work that has been done for the particular district in this chapter, the following results and discussions can be concluded:

1. The geocoded satellite image of the area is perfectly overlaid on the base map. This indicates that when the block boundaries are overlaid, we get the exact amount of actual earth surface within the block. Any observation on the land use and land cover within a block is very clearly observed, hence the changes that might occur in the coming few years in terms of surface water or urbanization or natural features can clearly be measured for changes in actual earth co-ordinates over a period of time.

2. In this research study it has been seen that the arsenic concentration value of any Hydraulic Station is not constant. It fluctuates seasonally as well as annually irrespective of depth of tube well. The arsenic concentration value in pre-monsoon season differs from that value in post-monsoon season. As arsenic occurrence in ground water is governed through a complex geogenic process so there is no significant trend of direction in fluctuation. In some areas arsenic concentration value is greater in pre-monsoon season than post-monsoon season and in some places it is vice-versa.

Multiple bar diagram showing arsenic concentration in different blocks in pre and post monsoon period in the year 2006





3. From depth value of tube well it has been seen that the average depth of tube well (Hydraulic station) is between (20-80) mts. below ground level in area under dangerly affected zone. Also it is noted that average depth of tube well is normally above 110mts below ground level in the arsenic free zone. So it can be said that shallow tube well are mostly affected by arsenic contamination. Interpreting arsenic concentration map prepared by data collected from year 2006 to 2008 it has also been seen that the blocks which was not affected in pre-monsoon of 2006 became affected at the end of 2008 and also the blocks which were at low arsenic concentration range in pre-monsoon of 2006 transferred to high concentration range at end of 2008. ***It implies that average arsenic concentration value keeps increasing even irrespective of depth of tube well. Unfortunately the study reveals that the arsenic menace is slowly but surely spreading its tentacles spatially with the passage of time.***

4. From Overlay and Buffering it has been seen that average arsenic concentration also depends on some land use/ land cover parameter. After doing buffer of 1sq.km around at least 10 selected Hydraulic Station of each category (worstly affected to arsenic free) we overlaid that buffered zone on land use/ land cover map of that study area. Then we calculated the area of each land use/land cover class from that classified land use/ land cover map, using ERDAS Imagine's Image Processing technology.

After doing that we have taken average area of each land use/land cover class of category of Hydraulic Station (worstly affected to arsenic free). Below table illustrated that figure:

Arsenic Concentration Class	***Land Use / Land Cover Class (aerial extent in acres)***					
	Surface Water	***Arable Land***	***Settlement***	***Fallow Land***	***Forest Cover***	***Marshy Fallow***
i) Worstly Affected Hydraulic Station (0.20-0.70)µg/L	***0***	***220.365***	***320.836***	***14.130***	***49.659***	***18.261***
ii) Highly Affected Hydraulic Station (0.05-0.2)µg/L	***0.566***	***209.644***	***263.07***	***21.481***	***13.73***	***157.95***
iii) Low Affected Hydraulic Station (0.02-0.05)µg/L	***9.978***	***315.410***	***310.370***	***25.635***	***0.609***	***69.556***
iii) Very Low or arsenic free Hydraulic Station (below 0.02 µg/L)	***35.346***	***241.764***	***219.673***	***58.182***	***3.829***	***174.836***

◆ Investigation for land use/land cover study for this research area it has been seen that ground water arsenic contamination of any area depends directly or indirectly on dominating Land Use / Land Cover feature of that area. In this research the study area has been classified in six LU/LC class: Surface Water (i.e., Water Body), Arable Land, Settlement, Fallow Land, Forest Cover and Marshy Fallow Land. But for a definite aerial extent (for this study one square km), the average aerial extent of each LU/LC class is not uniform for all arsenic concentration class (Above Table).

- From above table and also above mentioned graph it has been seen that presence of average aerial extent of 'Surface Water' is very very low (i.e. Zero/sq.km) compared to 'Arable Land' (220.365 acres/sq.km) and 'Settlement' (320.836 acres/sq.km) around buffered zone of 'Severely (Worstly) Affected Hydraulic Stations'. The blocks falls under this category are: Bongaon, Gaighata, and Baduria. Because of lack of surface water people have to depend mostly on ground water both for their irrigation and other utility purposes. So lots of pressure on ground water occurs here. Besides, presence of ground water in shallow depth (average depth of tube well is 50-60 mts), shallow pumps are extensively used for extracting ground water. Water from shallow tube well is mostly affected by arsenic. Furthermore, high population Density (1235/ sq.km) of this area causes unsustainable land utilization and also this high population is responsible for over extraction of ground water which is another cause for increasing trend of arsenic concentration.

- On the other hand in case of 'Arsenic Free Hydraulic Station', presence of average aerial extent of surface water is 35.346 acres/sq.km compared to 'Arable Land' (241.764 acres/sq.km.) and 'Settlement' (219.673 acres/sq.km) within the buffered zone. The sources of "Surface Water" in this area are: so much smaller river channels like Raimangal, Kalindi, Haribhanga, vidyadhari etc. People use this river water through canal system for their irrigation and other utilization purposes. This water is mostly arsenic free. Blocks falls under this arsenic class are: Sandeshkhali-I, SandeshKhali-II, Hingalganj etc. From geohydrological map it has been seen that, in this area fresh water is overlain by saline ground water. So shallow tube wells yield brackish water. People do not construct shallow tube well. Average depth of tube well is 110 mts. (bgl) here. Ground water from this depth is normally arsenic free. Population density in these zone is also lower (655 per sq km), compared to highly affected zone, which maintain sustainability of land utilization.

- Noticeably aerial extent of 'fallow land' and 'marshy fallow' also increases with the transition of 'very highly affected' arsenic class to 'arsenic free' class.

- Above information also indicate that, geomorphology in the severely as well as highly arsenic affected zone falls under mostly 'Upper matured deltaic plain', which formed under varying hydrodynamic condition in a typical fluvial regime(*Strahler and Strahler, 1989*). The ground water in the upper delta plain, primarily in the area of abandons meander belts, is mostly affected by arsenic enrichment (*SOES, JU, 1996*). But in order to establish a relationship between ground water arsenic concentration and corresponding geomorphology or geohydrology further extensive research is needed.

Arsenic total daily intake (Dietary exposure to arsenic):

The Provisional Maximum Tolerable Daily Intake (PMTDI) for inorganic As is (0.126mg/day for a 60 kg person). And it has been concluded that rice is the predominant source of inorganic As from foods. Assuming a person of age 60, rice consumptions is 400g/day, vegetables consumption 130 g/day, and a water intake of 4 l/day the total daily intake of inorganic As will be 0.43 mg/kg, which exceeds the PMTDI (0.126mg/day for a 60 kg person) by a factor ~3.5. Rice contribute 58% of total daily intake of As.

Williams et al. (2006) estimated the daily intake based on a daily consumption of 500 g rice, 130 g vegetables, 12 g pulses and 5 g spices (all weight based on unprepared products) and data on inorganic arsenic and total As in a range of food items from Bangladesh. Assuming a realistic level of inorganic As of 0.2 mg/kg in rice, a drinking water concentration of 0.050 mg/l (Bangladesh drinking water std.) and a water consumption of 3 l/day, the total daily intake of inorganic As would be 0.25 mg/day, exceeding the PMTDI by a factor of two. Rice would contribute 40 percent of total daily intake of As.

After assessing the exposure levels, the results need to be compared to a reference value such as a tolerable daily intake (TDI) value. For As, only a provisional maximum tolerable daily intake (PMTDI) is available. This provisional value of 0.0021 mg/kg body weight/day for inorganic As was established in 1988 and is commonly used to evaluate dietary intake (WHO, 1996). After almost two decades, the PMTDI still has not been ratified.

When evaluating risks to human health associated with As in foods, other sources of exposure such as drinking-water have to be taken into account as well. The WHO guideline value is 0.010 mg/l and the Indian drinking-water standard is 0.050 mg/l (Duxbury and Zavala, 2005; Williams et al., 2005). Assuming a body weight of 60 kg, the PMTDI is 0.126 mg/day. A water consumption of 3 l/day with 0.05 mg/l would already exceed the PMTDI, regardless the levels of As in foods. This suggests that the PMTDI and the Indian drinking-water standard need to be evaluated so that a proper assessment of As in foods can be made.

Findings of the research study:

The major findings of this research study are as follows:

- **Arsenic mobilization in ground water is governed by a complex interaction of different factors. Microbial mediated reductive dissolution of As rich Fe–oxyhydroxide is the main exposure path of arsenic in groundwater. Among other different factors are pyrite oxidation, absorption/desorption, and ligand exchange. The weights of these individual factors differ from case to case due to**

varied local conditions that prevail. Also anthropogenic inputs locally contribute to the arsenic enrichment of the region.

- **The higher the content of organic matter in the grey soft clay, greater is the released arsenic in the underlying aquifer. The nature of overlying grey soft clay, therefore, determines the concentration of groundwater arsenic and the spatial distribution of these type aquifers delineates the arsenic distribution pattern of a particular area.**

- **Ground water arsenic concentration value fluctuates temporally irrespective of depth of tube well. This fluctuation occurs in an increasing fashion with respect of time.**

- **Analyzing arsenic concentration map from 2006 to 2008 it has been observed that the tube well which was arsenic free in pre-monsoon of 2006 had been affected by arsenic at the end of 2008. It implies that if we declare a tube well as arsenic safe today, the same may become arsenic prone in near future. So it is paramount to monitor periodically the tube wells which are extensively used by the rural populace.**

- **As arsenic concentration value decreases with increasing depth of tube well so people should go for deep tube wells for supply of drinking water rather than be complacent with the shallow tube wells. From depth profile study it has seen that the depth zone between (20-90) mts bgl is normally danger prone in this study area and above 110mts bgl is safe.**

- **Over extraction of ground water appears to be the main cause of increasing arsenic concentration in ground water. Use of surface water is important factor to combat against arsenic menace. So we should protect our surface water resources. There is a court verdict in the state of West Bengal that the ponds and tanks cannot be filled for development purposes. The research finding corroborates the importance of surface water in precluding arsenicosis.**

- **Unsustainable use of LU/LC which is aggravated owing to high population density might be another cause of increasing arsenic concentration in ground water.**

- **Different geomorphologic and geohydrologic units also possibly contribute to some extent in ground water arsenic.**

- **Prolonged use of arsenic contaminated irrigation water possibly plays a major role in transferring arsenic from water to crop.**
- **The largest contributor to As intake in affected regions is contaminated drinking water. The second largest contributor is food, notably rice. Followed by vegetables. Rice contribute 40% of total daily intake of As.**