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Arsenic in the groundwater of the Brahmaputra floodplains, Assam, India

– Source, distribution and release mechanisms

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Abstract

Arsenic (As) enrichment in groundwater in India is widespread and poses a threat to a large number of people. The concentration in groundwater is often higher than both the World Health Organisation (WHO) and Indian guidelines for drinking water, and alternative sources of potable drinking water are scarce.

Assam is a state situated in the northeastern part of India. The Brahmaputra river flows through the whole length of the state, and its floodplain is the dominating feature of the geomorphology of the area. The results from quite recent studies performed by the Public Health Engineering Department (PHED) and the Central Ground Water Board (CGWB) have shown that arsenic enriched groundwater exists. There has however not been many cases of arsenicosis (arsenic poisoning) reported in the area. The continued monitoring of arsenic concentrations has been secured by the joint plan of action that has been set up in collaboration with Unicef.

The aim of this study has been to gain an understanding about the distribution, origin and release mechanisms of arsenic in Assam by investigating the water and sediment chemistry. An identification of the chemistry of arsenic-free groundwater, and the characteristics of those aquifers could be used by drillers to find sources of arsenic-free groundwater.

The study was conducted in the Bongaigaon and Darrang districts of Assam, where previous studies have indicated arsenic enrichment. Water was collected from a number of domestic wells and public water supply schemes and sediments were sampled from five drilling sites. Measurements of pH, Eh and Electric conductivity (EC) were taken in the field. A Hach field kit was used to obtain a first indication of the As concentration. Sediment samples were collected at four well drilling sites and classified regarding texture and colour according to the Munsell chart. A thorough chemical analysis of the groundwater was performed in Stockholm at the laboratories of the Department of Land and Water Resources Engineering, Royal Institute of Technology (KTH) and Stockholm University.

Arsenic enrichment in groundwater in the area was found to be severe. Of a total of 50 sampled wells, 15 revealed an arsenic concentration above the Indian national drinking standard of 50 µg/l, and 33 of them had As concentrations above the WHO guideline of 10 µg/l. No distinct zones or depths with specific sedimentological features producing arsenic free water were identified. It is thus hard to identify arsenic-free areas. However, sediments with a colour on the green-olive scale are probably more likely bearing As contaminated water than white sediments. The reductive dissolution of ferric hydroxides is thought to be the release mechanism controlling the mobility of As, rather than the oxidation of arsenopyrite or pH induced desorption.

The sand filters, commonly used in Assam to reduce the high iron content in groundwater seem to reduce the As content of the water rather effectively. Since filters are widely used in the region, this might be the reason why no signs of arsenicosis have been observed in Assam. Arsenic rich water is also partly avoided since the drillers seek water low in iron, which often also has low arsenic content.

Preface

This study was preformed by Gustav Enmark and Daniel Nordborg, students at the Master of Science programme in Aquatic and Environmental Engineering, Uppsala University. The study consisted of two months of field work in Assam conducted in the autumn of 2005, the report was completed in Sweden during the spring of 2006.

The study was made possible by a grant received from the Committee of Tropical Ecology at Uppsala University. The grant, known as Minor Field Study (MFS), is funded by the Swedish International Development Cooperation Agency (Sida). The purpose of the MFS is to give Swedish students a chance to gain knowledge about developing countries and experience in working with development issues.

The project was preformed in collaboration between Uppsala University, The Royal Institute of Technology (KTH) and The Indian Institute of Technology Guwahati (IITG).

We would like to thank our supervisors Dr Chandan Mahanta, Associate Professor, IITG, Dr Prosun Bhattacharya, Associate Professor, KTH and our examiner Dr Roger Herbert, researcher, Uppsala University.

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1. Introduction

1.1 Overview

The seriousness of the arsenic enrichment present in groundwater worldwide has quite recently got the global community's attention. Many times, the arsenic concentration is much higher than the WHO guideline of 10 µg/l used for drinking water (Internet, WHO, 2006a). The areas with arsenic enriched groundwater are often remote, where antropogenic sources of arsenic is lacking. The problem can instead be explained by natural sources and processes. Because of this fact, research about the source, distribution and release mechanisms in affected areas is important, in order to gain a better understanding of the problem.

In addition to being acutely toxic, the continuous consumption of arsenic contaminated water leads to arsenic poisoning, also known as arsenicosis (Internet, WHO, 2006b). The first symptom is the appearance of skin lesions and the development of crusty and scaly bumps on palms of the hands and soles of feet. A prolonged ingestion of As contaminated water can lead to skin, lung or liver cancer as well as cardiovascular problems and damage to internal organs (Internet, Lenntech, 2006).

The most widespread As enrichment found so far has been discovered in regions covering West Bengal, India and Bangladesh (Bhattacharya et al., 2002;Das et al., 2003; Mukherjee and Bhattacharya, 2001; Smedley and Kinniburgh, 2002). In West Bengal, more than 0.2 million people have shown clinical manifestation of As-related toxicity. In Bangladesh, 40 millions of the country's inhabitants are living in areas affected by As enrichment. In developing countries like these, water scarcity and high frequency of waterborne diseases limit the access to alternative safe sources of potable drinking water.

Assam is a state in the northeastern part of India where the presence of arsenic in the groundwater has recently been discovered. Assam has a lot of similarities to the Bangladesh plains regarding sedimentology. The problem of As enrichment might therefore be of the same magnitude in Assam, and possibly be explained by the same source. However, clinical manifestations of arsenicosis have until now been quite uncommon among the Assamese population (personal communication, Mr Paul, Unesco, 2005).

1.2 Purpose of the study

The purpose of this study is to target some of the arsenic-contaminated areas in the Bongaigaon and Darrang districts of Assam. By looking at the spatial distribution of arsenic enrichment in the study area together with the colour and texture of the sediments of the aquifers, an understanding about the source of arsenic can be gained. By thorough water analysis, the relationship between water chemistry and As can be used to gain an understanding of mechanisms that control the mobility of As.

Information regarding the source and mobilization of arsenic can be used to identify arsenic-prone areas. Moreover, if specific sediment types and water chemistry conditions in the Brahmaputra plains can be related to arsenic-contaminated water, this information may be used by well drillers and villagers in their search for safe drinking water.

2. Background

2.1. Geochemistry of arsenic

2.1.1. Characteristics of arsenic

Arsenic is a chemical element of group 15 in the periodic table. It is a metalloid, which in its elemental form appears either as a yellow or gray/metallic solid. There are both organic and inorganic forms of arsenic found in nature.

Arsenic is present in a number of different forms and oxidation states (-III, 0, +III, +V). However, in aqueous environments, dissolved arsenic is normally found as part of oxyanions in either arsenate (+V) or arsenite (+III) form. Arsenite has for long been thought to be the most toxic of the two, but quite recent studies have shown that arsenate is reduced within the human body and can therefore be thought to have the same toxicity.

Redox potential and pH are considered the most important factors controlling the speciation of arsenic. The stability diagram for arsenic (Figure 1), suggests that arsenate is more stable in oxidizing environments, while arsenite is the predominant species under more reducing conditions. It can also be concluded that arsenic is found in dissolved form under a wide range of pH and Eh conditions.

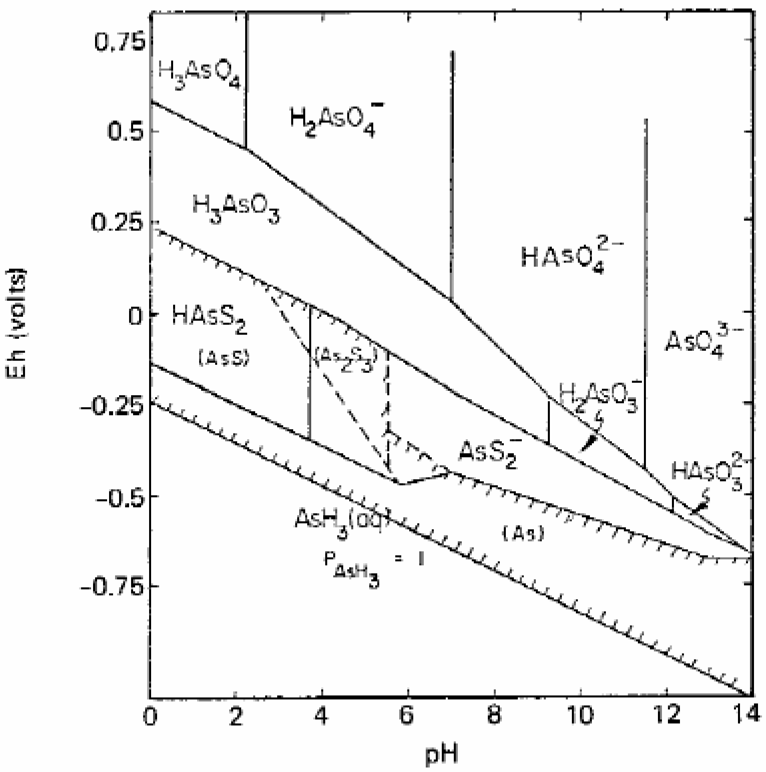


Figure 1. Stability diagram for arsenic in As-S-O-H system at 25°C. Total dissolved As-species is set to 50 ug/l (Smedley and Kinniburgh, 2002).

2.2 The origin of arsenic in groundwater

2.2.1. Natural sources

Arsenic is a natural constituent of the earth's crust, ranking as the 20^{th} in abundance. It is a part of over 200 different minerals, all of which are relatively rare.

Arsenopyrite (FeAsS), or to an even larger extent; arsenic-rich pyrite ($Fe(S,As)_2$), is thought to be the most common arsenic containing mineral (Smedley and Kinniburgh, 2002). Arsenic in dissolved form is (due to its electrical charge as an anion) attracted to surfaces carrying charges, such as for example various oxides and hydroxides. Ferric hydroxides are especially good at adsorbing arsenic; Al and Mn hydroxides are other possible adsorbents. Dissolved arsenic may also be adsorbed to the surfaces of clay particles (Smedley and Kinniburgh, 2002).

2.2.2. Anthropogenic sources

In addition to natural sources, arsenic found in the groundwater may stem from human activities such as the combustion of fossil fuel, chemical manufacturing industries, the use of fertilizers and wood preservatives as well as from mine waste (Bhattacharya, 2005).

2.3. Mobilization of arsenic

2.3.1. Oxidation of Arsenopyrite

Arsenic is, as stated earlier, commonly found in nature in the form of arsenic-bearing sulphides like arsenopyrite. Although the mineral is stable under anoxic conditions, it can be oxidized by O_2, Fe^{3+}, NO_3^- or other electron acceptors. The oxidation of the mineral will release dissolved arsenic to the groundwater.

The oxidation of arsenopyrite when exposed to air is expressed as:

$$FeAsS + 3.5\,O_2 + 4\,H_2O \rightarrow Fe(OH)_3 + H_3AsO_4 + 2\,H^+ + SO_4^{2-} \quad \text{(Equation 1)}$$

The oxidation of arsenopyrite, and its subsequent release of arsenic as a result of an excessive withdrawal of groundwater, has earlier been suggested as an explanation of the arsenic contamination phenomenon (Hossain, 2004).

2.3.2. Reductive dissolution of Iron Hydroxides

In many earlier studies (Bhattacharya et al., 2005; Bhattacharya et al., 2006; McArthur et al., 2004; Smedley and Kinniburgh, 2002) the importance of reductive dissolution of metal (iron) oxides/hydroxides and subsequent release of the adsorbed arsenic has been concluded to be a key mobilization process.

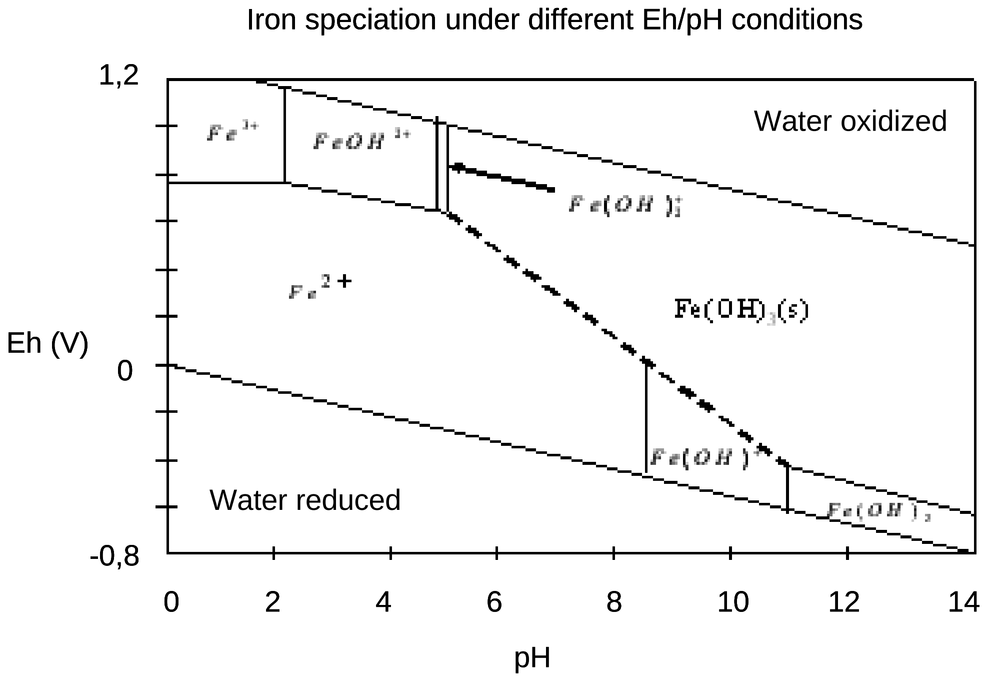


Figure 2. Stability of iron in the Fe-O-H system at 25°C at different Eh/pH conditions.

As for arsenic, the speciation of iron is controlled by the Eh and pH conditions of the surrounding environment (Figure 2). A low Eh brought on by, for example, the degradation of organic matter will cause the reductive dissolution of the iron hydroxide and cause the desorption of any adsorbed arsenic (Nickson et al., 1999).

Assuming that it is in fact iron hydroxides that control the mobility of arsenic, a consultation of the combined stability diagram of iron and arsenic can be used to conclude that arsenic will be mobile under a wide range of conditions (Figure 3).

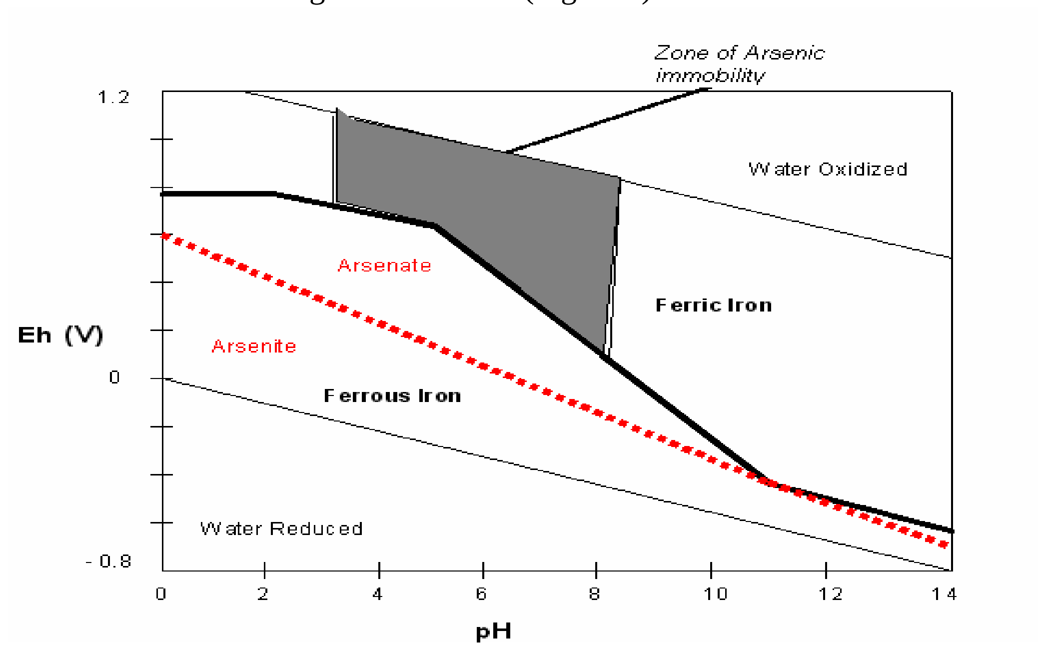


Figure 3. Combined stability diagrams for As and Fe in Fe-O-H and As-O-H system. Note that sulphur is not included in the combined figure (cf. Figure 1).

2.3.3 pH controlled desorption

As mentioned, iron hydroxides carry a surface charge, and can therefore adsorb the electrically charged arsenic ions. To which extent arsenic is either adsorbed or desorbed to surfaces is pH dependant and related to the net charge of the adsorbing surface (Figure 4). At low pH, iron hydroxides effectively adsorb the negatively charged oxyanions of arsenic. If the pH increases, for example due to the degradation of organic matter, the net charge will change to negative, resulting in the desorption of arsenic (Parkhurst, 1995).

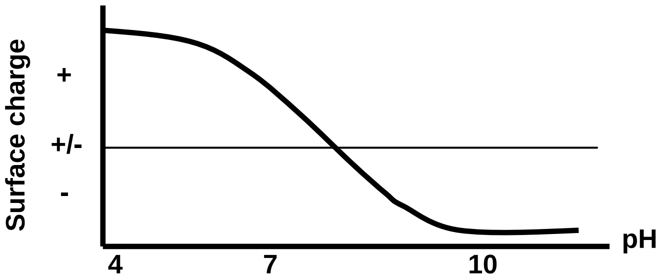


Figure 4. Surface charge of iron oxy-hydroxides as a function of pH (Jonsson and Lundell, 2004).

2.4. The state of Assam

2.4.1. Geography

The northeastern state of Assam, also known as one of the seven sister states, is connected to the rest of India by a narrow piece of land known as the “chicken’s neck” (Figure 5). Assam borders the other six sister states as well as Bhutan and Bangladesh. In India, the states are divided into the following administrative units: Divisions, Districts, Sub-Divisions, Blocks, and Panchayats. Assam consists of 23 districts and every district is divided into 5 to 16 blocks (Internet, Maps of India, 2006).

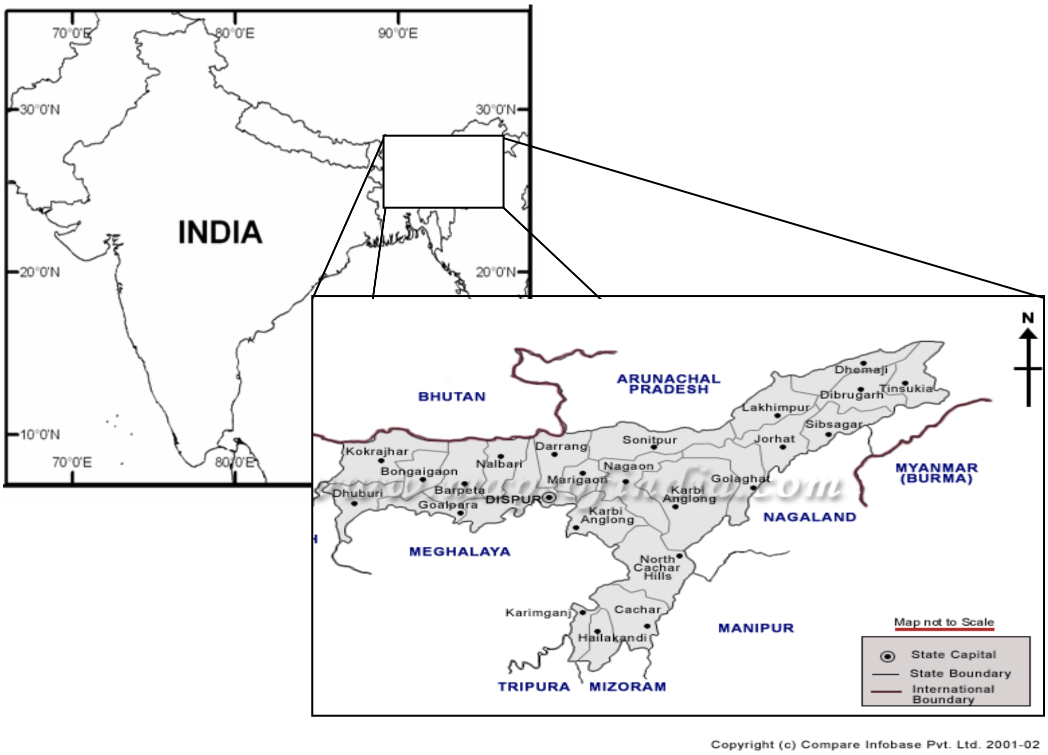


Figure 5. The location of Assam within India (Internet, Maps of India, 2006)

The greater pa rt of Assam is within the Brahmaputra valley, while the southernmost part lies in the Barak valley, separated from the Brahmaputra valley by the Central Assam range. The inselbergs (isolated hill, knob, ridge, or small mountain that rises abruptly from a plain or gently sloping surrounding), situated in the central districts south of the Brahmaputra are distinct features of the area. The Brahmaputra valley is about 800 km long and 130 km wide. The river covers 720 km of its total 2,890 km, decending 28 m in Assam (Singh et al., 2004). The area of the state is 78,438 km^2 and it inhabits 26 million people (2001), resulting in a population density of 286/km^2 (Internet, absolute astronomy, 2006).

The state capital is Dispur but the largest city in the state is Guwahati (800 000 inhabitants). The two cities are situated next to each other on the south bank of the Brahmaputra River. The people of the state represent many ethnic groups but can roughly be divided into tribal, living in the hills, and plains people. The official language of the state is Assamese. In addition, English, Hindi and a number of regional languages are widely spoken (Internet, assamgovnt, 2006).

2.4.2. Climate

The climate of the Brahmaputra basin is humid sub-tropical and characterized by high rainfall and high humidity. It is influenced by the southwest monsoon, the surrounding hills of the lower Himalayas and the Assam Plateau. Four distinct seasons can be identified: pre-monsoon, monsoon, post-monsoon and winter. The monsoon rains account for 90 % of the annual precipitation, and average between 2500-3200 mm. During this time of year, flooding is common and some of the roads are impassable for weeks. Average temperatures vary between about in summer 29 ^{o}C (August) and 16 ^{o}C in winter (January) (Internet, Maps of India, 2006).

2.4.3. Hydrogeology

The Brahmaputra plain is, with a few exceptions, covered by young alluvial sediments, which are deposited from the great sediment load carried by the river and its tributaries. The minerals on the south and north side differ a lot. The north side is fed with sediments derived from the young Himalayas while the sediments on the south side originate from the older Assam plateau. The gradient of the northern tributaries is steeper and the flows generally larger than in the southern tributaries. The steeper gradients, together with more easily eroded bedrock and larger flows, result in a higher sediment load from this part of the drainage area.

Due to the widespread problem of arsenic enrichment of the groundwater found in Bangladesh and West Bengal there have been extensive studies performed to investigate the source and mobilization of arsenic in these areas (Ahmed et al., 2004; Bhattacharya et al., 1997, 2001; Nickson et al., 1999; Breit et al., 2003). The sedimentological history of the Brahmaputra valley in Assam is similar to the one in Bangladesh. Therefore conclusions about the source of arsenic found there are therefore thought to be applicable in Assam.

The general conclusion has been that it is in the Holocene sedimentary aquifers, located in the plains, which arsenic enrichment is occurring. On the other hand the aquifers found in Pleistocene sediments upland show low As content. The explanation for this fact lies in the environmental conditions during the time of sediment formation (McArthur et al., 2004). The Holocene sediments were derived under a period of low temperatures, which resulted in little chemical weathering and therefore a low degree of FeOOH coatings. The material was deposited under a period of high sea levels, flushing finer particles with high adsorption capacity. The older Pleistocene sediments, on the other hand, were subjected to a long period of oxidative weathering due to the lowering of the sea level. Under this period, the sediment acquired the FeOOH coatings needed to adsorb any dissolved arsenic.

Studies in Bangladesh have shown that the Holocene sediments are characterized by a grey colour and contain significant amount of organic matter, while the Pleistocene sediments are characteristically reddish-brown and contain less organic matter (Bhattacharya et al., 2002a).

According to the Central Groundwater Board, CGWB (Bakshi, 2005), the groundwater table generally lies within 10 m under ground level in Assam. The CGWB monitors groundwater movement (four times a year) and groundwater quality (once a year) in 381 National Hydrograph stations throughout the state. In the Brahmaputra valley the water table is found within five metres below the surface in pre-monsoon and the annual fluctuation is moderate, about two metres. In the Central Assam range the groundwater is seldom monitored but is thought to lie between 6-10 m below ground level. In the Barak valley, with its enclosed topography, the groundwater level can be found within 2 metres below the surface. The groundwater resources in Assam are poorly exploited, it is estimated that 93 % of the groundwater in the state is unutilized (Bakshi, 2005).

2.5. Arsenic in Assam

The problem of arsenic in groundwater in Assam is just starting to get into the limelight. In a study conducted by the North Eastern Regional Institute of Water and Land Management

(NERIWALM) (Singh, 2004) 1500 water samples from tube and dug wells were taken during post monsoon in the year 2003. The NERIWALM study shows that 20 out of Assam's 24 districts have groundwater with an As content exceeding 50 µg/l. Another even more recent study by the School of Environmental Studies, Javadaur University (SOES, 2004) shows that in the two supposedly worst effected districts, Karimganj and Dhemaij, 19.1 % of the samples contain higher concentrations than the Indian guideline of 50 µg/l, and 2.1 % contain more than 300 µg/l. With the above mentioned studies showing a potentially severe arsenic problem in the state, the Public Health Engineering Department (PHED) in Assam decided to conduct their own study. 5729 samples from 22 out of Assam's 23 districts were taken and analyzed for As. The results were that in 18 of the districts, water samples were found to contain As concentrations higher the national limit and 72 blocks were affected (JOPA, 2005).

PHED in Assam is currently in the process of starting up their Joint Plan of Action (JPOA, 2005) in cooperation with the United Nations Children Fund (UNICEF). In the first stage, PHED will test all government tube wells. The pumps will be painted red or blue depending on whether the As content exceeds 50 µg/l or not. In the second stage, laboratories for As testing are intended to be set up in the affected blocks. In these laboratories, well owners/users are offered to test their water for a low cost. The JPOA also includes setting up district laboratories, health clinics, information and education.

3. Materials and Method

3.1. The study area

The two areas selected for the study are situated in the Darrang district and the Bongaigaon district. Both areas are located on the northern bank of Brahmaputra. Darrang is located in central Assam, whilst Bongaigaon is situated in the western part of the state. Groundwater samples were collected from near the riverbank of the Brahmaputra as well as upstream the tributaries from the north.

Several tributaries are flowing through both districts. One of the main rivers in Bongaigaon is the Manas River. It is adjoined by several other rivers, such as the Aie River, on its course down to the Brahmaputra. The Bongaigaon tributaries originate in the trans-Himalayan range whilst the rivers flowing through Darrang are sub-Himalayan. Darrang is drained by the Dhansiri sub basin, bordering the Manas sub basin (CGWB, 1985). Due to the flat topography of the area and the large deposits of sediment the tributaries change their courses regularly. The palaeochannels left behind have a sediment composition that differs from the surrounding overbank deposits, the high load of organic material once deposited by the river is degraded and produces reducing conditions.

The geology in both districts is generally characterized by recent alluvial formations. In the northernmost parts of the districts older alluvium is found. In Bongaigaon a few inselbergs consisting of metamorphic complexes of gneiss and schists from middle Proterozoic to Archaean are surfacing. The recent alluvial sediments lithology is described by sorted gravel, sand, silt and clay (CGWB, 1985)

Most people in the study area rely on groundwater as a source of drinking water. The use of tube wells is the most common way to access the water. Within the districts there is also a number of Public Water Supply Schemes run by the PHED. These schemes tap deeper aquifers and the water is treated by aeration and slow sand filter filtration (personal communication, Mr Abhimanyu Paul, PHED, 2005). Dug wells are also used to some extent.

The groundwater of Assam has a high iron content (Aowal, 1981). Most households in the area of study use domestic filters for iron removal. The filters usually consist of a concrete ring; about 0.5 m in diameter and 0.8 m high, filled with sand and gravel and in some cases a bottom layer of charcoal. The filter medium is cleaned or changed whenever it is found to have lost its capacity, which can be after a period of two weeks if the iron content is high. .

3.1.1. Selection of wells

In selecting wells for sampling, the before mentioned studies by PHED, SOES and NERIWALM were consulted. Wells previously tested by PHED as well as previously untested wells were sampled. When possible, wells where information about the sediments was available were chosen. When deciding where samples would be taken, the geographical distribution was also taken into account in a way that relatively consistent study areas were achieved.

The drilling sites for sediment sampling were selected next to sampled wells with different depths and arsenic contents.

3.2. Field Studies

The fieldwork was performed during 26th of October until 19th November 2005, which is just after the monsoon season of the area. It consisted of the collection of water samples from 50 different tube wells; 16 from Darrang and 34 from Bongaigaon. In addition to the 50 water samples, field measurements of arsenic as well as water chemistry parameters were taken from another 9 wells in Bongaigaon and 2 in Darrang.

Four exploratory wells were drilled by personnel hired by PHED. Sediment samples were collected from the drilling for analysis.

3.2.1. Measurement of field parameters and groundwater sampling

The depth of the wells, as well as information on the installation date, sediment colour, and other relevant information was gathered from the owners of the wells through the help of an interpreter. The location of the well was recorded with a handheld GPS.

The wells were purged thoroughly before sampling because of the necessity to sample fresh and not stagnant water from the pipes. Some of the wells had been sealed off by the PHED because of high concentration of arsenic or some other reason. These wells were purged for a greater duration to ensure the representative water quality.

At each site visited, water parameters such as temperature, pH, Eh and electric conductivity (EC) were measured using portable field equipment and a flow through cell. The flow through cell consists of a container with a lid where the electrodes are placed. The container is fitted with a hose, connected to the outlet of the pump. The container is also fitted with a hose at the top, allowing the water to flow freely through the cell (Figure 6).

Figure 6. Flow through cell in which pH, EC and Eh-readings were taken.

The Eh, pH and EC meters need some time to stabilize. The readings of pH and EC were taken after 5 minutes, the Eh reading after 10 minutes.

Four water samples were taken from each tube well. The samples were all filtered using a 45 µm filter. One sample was stored in a 50 ml bottle. Two of the samples were after filtering acidified for preservation, using 5 drops of 0.5 % HNO_3 in 25 ml bottles. The fourth sample was filtered, acidified and prepared for As speciation. The As speciation is done possible by using disposable cartridges in which the As(V) is adsorbed while As(III) passes through the cartridge into a 25 ml bottle (Internet, Sandia, 2006).

3.2.2. Hach test

At each well a field test kit for arsenic known as the Hach test was used in order to get a first estimate of the arsenic concentration (Internet, Hach, 2006). The Hach test is performed by pouring a water sample into a container. Two arsenic reagents, sulfamic acid and powdered zinc, are added to the water and a test strip is inserted into a slit in the lid. The container is swirled continuously for twenty minutes. The reagents react with the water, producing the toxic arsine gas which reacts with the test strip. The colour of the test strip is compared to a colour chart. The test can be performed at two different ranges, 0-500 ppb (µg/l) or 0-1500 ppb.

3.2.3. Sediment sampling

Four exploratory drillings were conducted, three in Bongaigaon and one in Darrang. Sediment samples were taken at different depths of the wells so that a litholog could be constructed. The Munsell chart was used to classify the colour of sediments. Both the colour of moist and dry samples was determined.

The drilling of tube wells is performed by using a simple but very effective technique. A team of 3-4 drillers dig a hole in the ground and fill it with water. Then a rig of bamboo sticks is set up. The bamboo rig is used as a lever and steel pipes of the diameter of 2 inches are pushed through the sediments. The water in the pit works as lubricant and by putting a hand on the pipe a negative pressure is created which makes water and soil ascend through the pipe. Once one pipe is pushed down another is attached. The sediment samples could be collected as disturbed samples coming up the pipe and the depth was measured by knowing the number of pipes used and the length of them (Figure 7).

Figure 7. A group of drillers installing a tube well in a small village. Sediment samples were taken from the wells drilled during the time of the study.

3.2.4. Filters

Samples of filtered water as well as samples of filter medium (sand) were taken from two domestic filters and one slow sand filter at a Public Water Supply Scheme (Figure 8). The filters are mainly meant to reduce the iron content since it brings an undesired taste and colour to the water.

Figure 8. Typical domestic filter (to the left) and slow sand filter at Public Health Department Scheme (right).

3.3. Laboratory studies

The water and sediment samples collected in Assam were shipped to Stockholm, Sweden for analysis at KTH and Stockholm University.

3.3.1. Major cations and trace elements

The cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and trace elements (Fe, Mn, As) were analyzed by inductively coupled plasma (ICP) emission spectrometry (Varian Vista-PRO Simultaneous ICP-OES equipped with SPS-5 autosampler) at Stockholm University. Following a run of every 10 samples, certified standards, SLRS-4 (National Research Council, Canada) and GRUMO 3A (VKI, Denmark) and synthetic multi-element chemical standards were run and background correction was done based on Y and Sc. Relative percent difference among the duplicate runs was within ± 10 %. As(V) was calculated as a difference between total As and As(III) in the samples.

3.3.2. Anions

The water samples were analyzed for anions such as chloride, sulphate, nitrate and fluoride using a Dionex DX-120 ion chromatograph with an AS 9-SE column. Filtered samples were used for this analysis and the analysis was preformed at KTH.

3.3.3. Alkalinity

Alkalinity was measured on a Radiometer Copenhagen PHM 82 Standard pH meter equipped with an ABU 80 autoburette. The alkalinity was determined according to the standard method SS-EN ISO 9963-2. The filtered, unacidified samples were titrated with 0.02 M HCl to pH 4.5. The precision and accuracy of analyses were tested by running duplicate analyses on selected samples.

3.3.4. Ammonium and Phosphate

The Flow Injection Analysis (FIA) method was used to analyze the ammonium (NH_4-N) in filtered samples at a wavelength of 540 nm. The same method was used to analyze phosphate (PO_4-P) on filtered and acidified samples at a wavelength of 690 nm.

The method used for the ammonium and phosphate analysis gives the results as NH_4-N and PO_4-P. The results have been recalculated as mg/L of NH_4 and PO_4.

3.3.5. Dissolved Organic Carbon (DOC)

The dissolved organic carbon content was determined with the use of a Shimadzo TOC-5000 with a ASI 5000 autosampler. The Non-Purgeable Organic Carbon (NPOC) method with IC-check was used.

4. Results and discussion

4.1. General water chemistry

The results from the field work and laboratory analyses are presented below. The full results are listed in Appendices 1, 2, and 3 and the results are summarized in Table 1.

Table 1. General water chemistry in the Darrang and Bongaigaon Districts, Assam, India

ID	**Depth** m	**pH**	**EC** µS/cm	**Eh** mV	**HCO_3^-** mg/l	**Cl^-** mg/l	**PO_4^{3-}** mg/l	**$SO4^-$** mg/l	**NH_4^+** mg/l	**Na^+** mg/l	**K^+** mg/l	**Mg^{2+}** mg/l	**Ca^{2+}** mg/l
D1	24.4	6.6	200	30	116.06	6.06	3.51	0.37	0.29	19.89	<0.48	5.03	11.00
D2	57.9	6.7	130	-39	81.28	0.25	3.09	0.06	0.54	17.09	<0.48	3.67	8.28
D3	36.6	7	140	60	54.67	0.68	0.00	0.13	0.50	25.41	<0.48	3.11	7.58
D4	91.4	7.4	180	-65	92.51	0.4	1.12	6.95	0.00	14.62	<0.48	5.08	12.26
D5	27.4	7.1	100	-75	93.36	3.62	2.36	3.36	0.08	16.29	<0.48	4.75	8.38
D7	27.4	7.6	560	-110	381.74	0.09	2.20	1.1	0.52	67.29	<0.48	16.44	30.44
D8	26.6	6.9	170	-72	71.03	1.39	0.71	0.05	1.18	7.37	<0.48	4.56	8.61
D9	20.1	6.5	240	-72	56.63	22.87	2.89	10.63	0.55	8.86	<0.48	7.58	12.59
D10	39	6.8	240	-72	91.9	1.24	0.25	0	0.80	9.13	<0.48	5.30	11.21
D11	27.7	6.6	220	-85	104.83	2.54	5.25	0.13	1.31	8.40	<0.48	7.37	16.54
D12	27.4	6.6	160	-70	97.02	4.38	2.34	0	1.85	8.43	<0.48	5.96	16.32
D13	54.9	6.8	150	26	135.1	0.93	1.02	0.51	0.00	9.93	<0.48	8.67	19.98
D14	67.1	6.4	130	-36	56.14	2.37	2.00	0.85	0.19	6.19	<0.48	3.70	7.96
D15	20.1	6.4	200	-34	75.3	7.63	2.81	0.22	0.37	7.71	<0.48	4.69	10.17
D16	30.5	6.7	170	-57	98.49	0.34	3.22	0.12	1.52	16.78	<0.48	3.76	9.53
D17	24.4	6.7	130	-66	93.24	0.26	3.34	0.07	1.49	15.36	<0.48	3.83	9.29
B1	30.5	6.9	680	-89	493.29	6.06	2.99	0.38	1.00	6.20	<0.48	35.84	132.64
B2	24.4	7	620	-111	147.3	10.63	1.92	0.25	0.93	9.04	<0.48	38.72	140.30
B3	18.3	7	540	-116	135.83	8.94	2.11	0.33	1.12	8.81	<0.48	32.13	121.85
B4	15.2	7.1	340	-93	105.08	3.92	2.13	0.07	0.71	3.99	<0.48	22.52	62.16
B5	21.3	7.3	410	-104	114.96	1.73	0.86	0.69	0.07	2.49	<0.48	21.63	73.88
B6	21.3	7	580	-116	184.04	3.68	2.73	0.07	0.72	5.96	<0.48	33.91	125.43
B7	21.3	7	540	-114	145.23	3.22	2.34	0.07	0.95	5.76	<0.48	35.28	128.11
B8	24.4	6.8	590	-78	127.78	0.62	1.05	0.51	0.16	4.43	<0.48	36.86	132.99
B9	21.3	6.9	620	-112	139.49	20.33	0.24	0.25	6.83	12.93	<0.48	32.40	120.90
B10	21.3	6.9	540	-105	114.84	16.85	1.76	0.09	4.76	9.60	<0.48	27.18	101.63
B11	22.9	7	320	-37	64.56	1.34	0.25	4.25	0.00	5.72	<0.48	22.37	44.96
B12	38.1	6.8	300	31	57.48	0.56	0.02	6.35	0.00	4.75	<0.48	21.49	36.78
B13	32	6.8	380	-67	74.57	5	0.94	1.33	0.43	4.41	<0.48	27.87	49.50
B14	32	6.8	490	-27	120.7	3.2	0.26	0.85	0.14	6.94	<0.48	39.92	88.46
B15	30.5	7	230	-37	62.61	0.35	0.27	29.8	0.00	9.27	<0.48	20.31	54.48
B16	48.8	7	200	-71	89.21	0.43	0.00	0.46	0.08	9.17	<0.48	7.34	9.93
B17	48.8	6.9	580	-94	128.39	14.63	1.08	0.29	2.86	11.79	<0.48	29.63	118.15
B18	24.4	7.2	550	25	130.7	15.19	0.08	0.24	1.64	12.59	<0.48	29.77	121.16
B19	48.8	6.8	690	-107	164.39	69.13	2.00	0.12	9.32	28.03	<0.48	39.06	132.38
B20	10.7	7	500	-76	122.53	3.96	1.13	0.51	0.77	10.57	<0.48	27.37	109.70
B21	25.9	6.8	590	-112	126.31	50.84	3.80	0.52	6.59	25.38	<0.48	35.82	99.60
B22	15	7	520	-120	138.39	8.45	2.42	0.19	1.26	5.42	<0.48	25.73	139.61
B23	18.3	6.9	460	-27	121.06	1.96	0.18	24.08	0.00	4.84	<0.48	28.09	118.14
B24	24.4	6.8	550	-97	193.19	2.15	1.76	2.44	0.81	4.22	<0.48	30.07	204.88
B25	25.9	6.9	230	54	113.86	2.86	0.07	3.95	0.00	4.05	<0.48	15.46	29.20
B26	27	7.2	450	-107	84.45	18.45	3.59	0.24	3.46	12.84	<0.48	29.21	85.99
B27	38.4	6.6	350	-93	83.6	5.34	1.41	4.74	0.00	6.12	<0.48	22.87	69.77
B28	24.4	6.9	170	58	108.49	0.71	0.18	0.72	0.65	13.68	<0.48	6.58	13.62
B29	24.4	6.9	450	-82	135.95	0.86	0.55	1.3	1.76	5.22	<0.48	24.95	126.29
B30	24.4	6.2	430	104	143.89	3.2	1.03	15.87	2.14	4.13	<0.48	28.60	139.24
B31	39.6	6.9	220	30	75.05	2.6	0.09	1.99	0.00	9.14	<0.48	15.23	24.19
B32	18.3	7.1	430	11	136.93	7.07	0.07	18.02	0.09	4.10	<0.48	34.22	126.73
B33	12	6.9	340	-90	96.41	3.52	0.04	?	0.00	3.37	<0.48	24.71	84.86
B34	30	7.1	470	135	178.18	3.51	1.04	4.52	0.13	5.87	<0.48	35.83	177.52

4.1.1. Field parameters

The temperature of the groundwater did not vary much in between wells within the study areas. The recorded values were in the range of 21.5 to 23 degrees Celsius.

The electric conductivity was in the range of 100 to 690 µS/cm, with a median value of 335 µS/cm for the two study areas combined. There is a slight trend towards higher conductivity at more reducing conditions.

The majority of the sampled wells in both study areas had a pH value very close to neutral. The recorded values ranged between 6.2 and 7.6 with a median of 6.8.

The field measurements of Eh of the groundwater in the study area showed values in the range of 100 to -100 mV, with a median of -30 mV. These values are, however, not likely to represent the actual redox values of the aquifers. The redox potentials obtained with redox electrodes are not very exact. Information can instead be gathered by looking at concentrations of redox sensitive species and the redox speciation of the groundwater.

The Hach kit gave results on arsenic content ranging from 0 to 500 µg/l. When comparing the results with the lab analyses on arsenic one can see a good correlation (R^2=0,89). The results based on the colour of the test strip have been overestimated in some cases but the general trend is an underestimation of arsenic content. The results are good enough to recommend the Hach kit as a relatively cheap way of testing whether the water is suitable for drinking.

4.1.2. Alkalinity, ammonium and phosphate

The alkalinity of the groundwater was in the range of 54.7 mg/l to 493.0 mg/l HCO_3^-, with a median of 174 mg/l HCO_3^-. These values can be considered high; the waters are thus in general quite good at buffering pH variations. Ammonium varied between 0 and 9.32 mg/l, median 0.60 mg/l. The lab results showed phosphate contents ranging between 0 and 5.25 mg/l with a median of 1.16 mg/l.

4.1.3. Dissolved organic carbon (DOC)

The analysis of the water samples showed DOC amounts between 0.3 mg/l to 4.2 mg/l with a median of 1.5 mg/l. These values are considered to be moderately high.

4.1.4. Major Ions

Piper plots can be used to classify the chemistry in groundwater according to the relative concentration of some major ions.

The water in Bongaigaon can predominately be classified as being of Ca-Mg-HCO_3 type (Figure 8). The water of the wells with an arsenic concentration below 10 ppb, can be identified as having slightly higher Mg concentrations. The wells with an arsenic concentration of 10-50 and >50 ppb have similar relative ion concentrations. The sulphate concentrations are in general low.

In Darrang District, the wells can be classified as either Na-Ca-Mg-HCO_3 type or Ca-Mg-HCO_3 type (Figure 9). Most of the wells with high As content (>50 ppb) are of Na-Ca-Mg-HCO_3 type, whereas the majority of wells with low to intermediate arsenic content are of Ca-Mg-HCO_3 type. The sulphate concentrations are low, as in the Bongaigaon District.

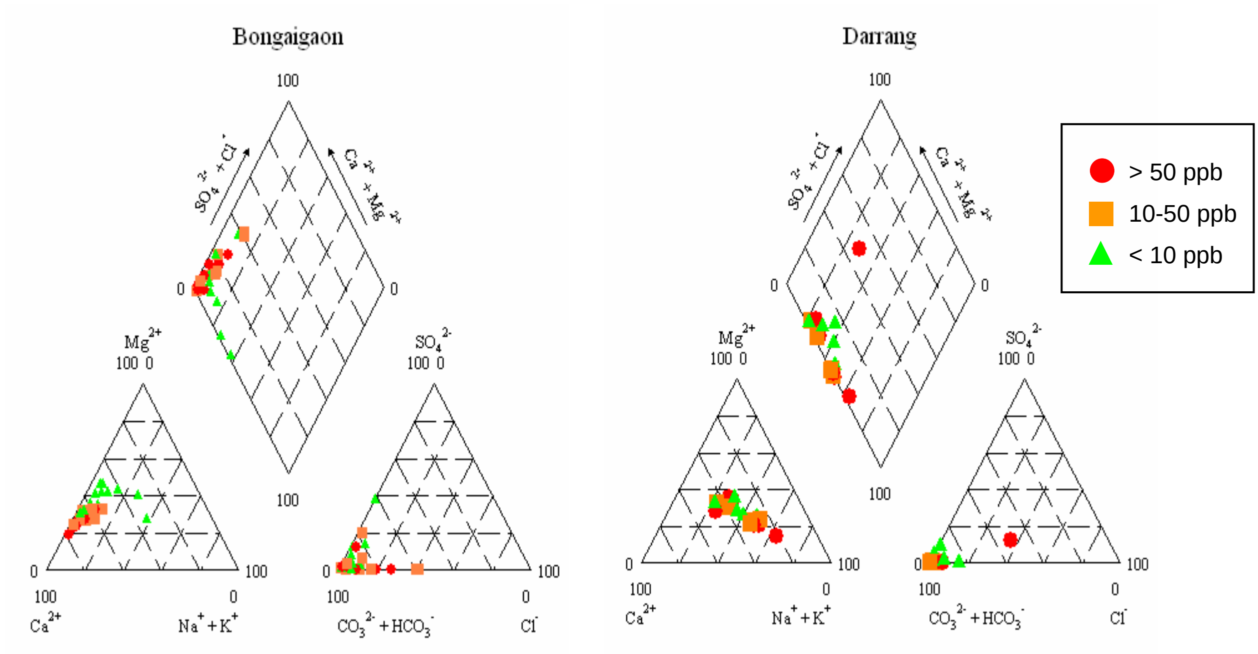


Figure 9. Piper plots showing the overall major ion chemistry of the groundwater in the Bongaigaon and Darrang districts.

4.1.5. Arsenic

Arsenic was found in 36 out of 50 wells, the recorded concentration ranging between 5 and 606 µg/l. Between 85 and 100 percent of the arsenic was found to be present in the As(III) form. The high amount of As (III) indicates reducing conditions in the groundwater. As(III) was also found to be the dominating species where oxidative conditions had been indicated by the field measurement of Eh (positive). This is partly due to the fact that the reduction of As(V) sometimes can be slow, as well as the fact that field measurements of Eh do not necessarily give an accurate representation of an Eh value supported by specific redox couples (as earlier mentioned).

The degree of arsenic enrichment in the study area should be seen in context of the WHO guideline of 10 ppb (10 µg/l) and the national Indian guideline of 50 ppb (50 µg/l). In total 15 (30 %) of the sampled wells showed As content above the national guideline and 33 (66 %) above the WHO guideline.

4.1.6 Trace Metals

A high concentration of iron is common to almost all of the wells within the study areas, the recorded levels were in the range of 27 to 43 000 µg/l (Appendix 2) Almost all wells had a concentration higher than the WHO guideline of 300 µg/l. Reddish colouring at the well could be taken as an indication of the presence of iron, since ironhydroxides are red (rust-coloured). One should mention that the guideline set by WHO concerning iron is not of health concern but rather of taste and appearance of the water (Internet, WHO, 2006). The levels of manganese found were in the range of 32 and 6000 µg/l. These values are considered high, when comparing them to the WHO guideline of 400 µg/l.

The fluoride concentration was in general higher in the Darrang District. Even if the concentration in some wells came close to the WHO guideline of 1.5 mg/l, most wells of the two districts showed fluoride concentrations below the target level of 0.8-1.2 mg/l set by the WHO as a guideline to the minimisation of harmful effects and maximisation of benefits (Internet, WHO, 2006c).

None of the other trace metals analyzed was present in elevated amounts (above WHO drinking standards (Internet, WHO, 2006a). The full results of the analysis can be found in appendix 2.

4.2. Inter-element relationships

In order to investigate the mechanism responsible for the release of arsenic to groundwater, it is important to look at the relationships between different water chemistry parameters, and to interpret the relationships found.

4.2.1. Relations between As and pH

As stated earlier, the adsorption capacity for arsenic to different surfaces decreases as the pH increases due to a higher negative surface charge on Fe hydroxides. However, when looking at the total arsenic concentration versus pH, no such relation could be identified (Figure 10). The pH range in these waters is probably too narrow for such a relation to be detectable.

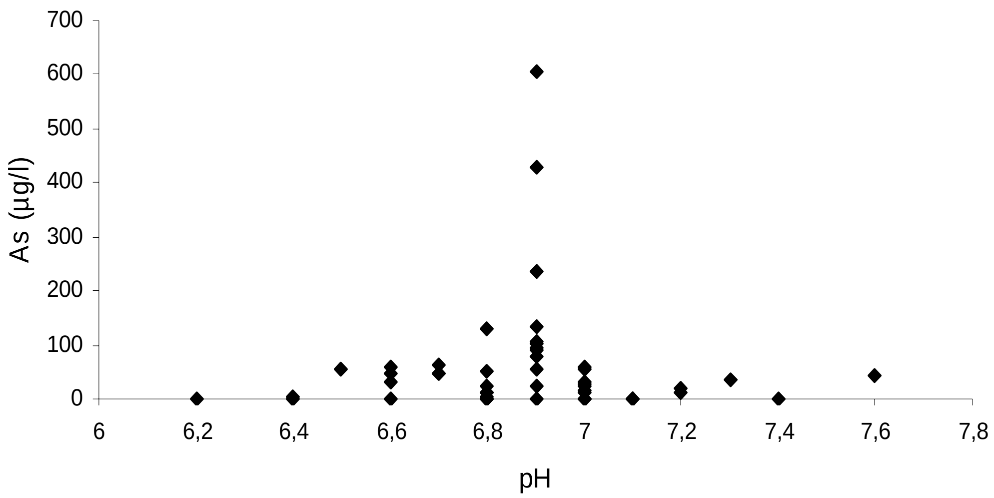


Figure 10. The relation between arsenic and pH in sampled groundwater (Bongaigaon and Darrang district).

4.2.2. Relations between As, Fe, Mn and sulphate

When looking at the relation between dissolved iron and arsenic (Figure 11), water from both areas show a weak correlation. As previously noted, in many earlier studies (Bhattacharya et al., 1997, Nickson et al., 1999, 2003) it has been concluded that it is the reductive dissolution of iron hydroxide that is the main release mechanism for arsenic. If this was true, arsenic and iron would be expected to exist in solution simultaneously, and there should exist a strong correlation between them. But why is it not so? It can be explained by the fact that the dissolved iron does not act conservatively, which means that the dissolved iron takes part in other chemical reactions, and is therefore not accumulated in dissolved form to the same extent as the arsenic.

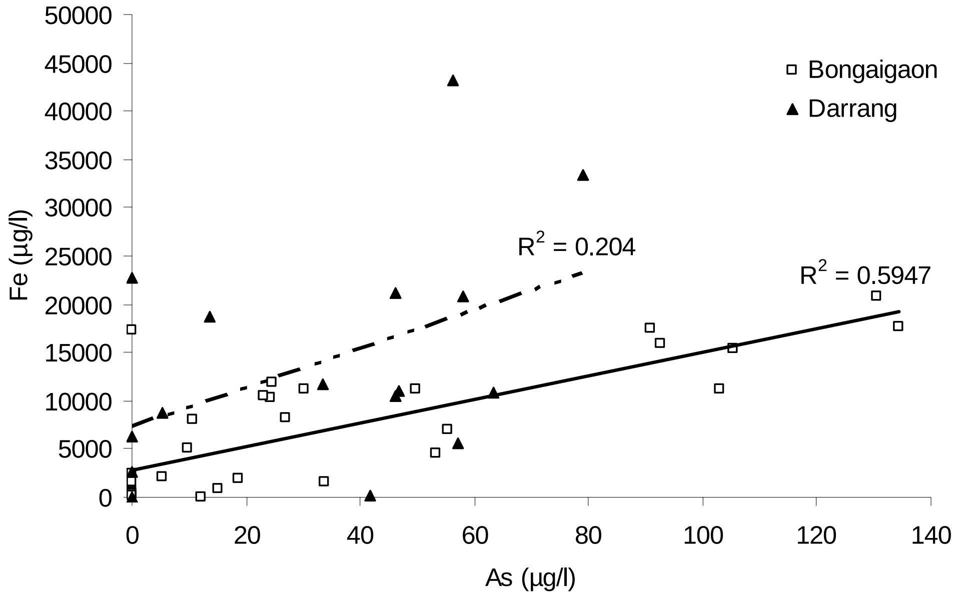


Figure 11. Bivariate plots of the arsenic and iron concentrations in Bongaigaon and Darrang districts. The weak correlation factor indicates that iron is acting non-conservatively.

As mentioned earlier, the reducing environment causing the dissolution of iron hydroxides could be the result of the bacterial breakdown of organic matter (McArthur et al., 2004).

$$4\ FeOOH + CH_2O + 7\ H_2CO_3 \rightarrow 4\ Fe^{2+} + 8\ HCO_3^- + 6\ H_2O \quad \text{(Equation 2)}$$

By looking at equation 2, one can see that the ratio between the HCO_3^- and iron found in the groundwater should be about two. However, as can be seen in Figure 12, this is not the case. The released iron is acting “non-conservatively” as mentioned before, e.g. taking part in other reactions, precipitating like for example as $FeCO_3$ (siderite) and forming other substances. Because of this, the relationship between HCO_3^- and iron as well as arsenic and iron is not equal to that expected by looking at equation 2.

HCO_3^- is produced from either dissolution of carbonates or degradation of organic matter. The dissolution of carbonates also produces calcium or magnesium ions and by examining the molar ratios between these ions (see appendix 4) one can predict from where the HCO_3^- was formed (Wagner et al., 2005), that is if the HCO_3^-/(Mg + Ca)-ratio is less then 1 it is probable that the HCO_3^- was formed by degradation of organic matter . The groundwater in Darrang contains low amounts of Ca and Mg and it's obvious that HCO_3^- was formed through degradation of organic matter (HCO_3^-/Ca+Mg ratios between 3.0 and 8.6). In Bongaigaon, the concentration of Ca and Mg are substantially higher but the molar ratios (HCO_3^-/Ca+Mg ratios between 0.8 and 5.6) still suggest that, to some extent, HCO_3^- is formed from degradation of organic matter.

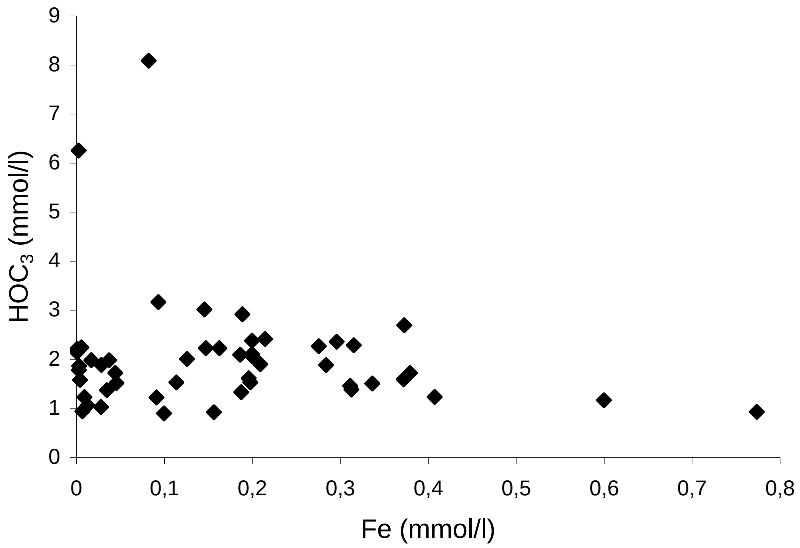


Figure 12. Bivariate plot of the iron and HCO_3 concentrations in the Bongaigaon and Darrang districts. Iron is acting non-conservatively.

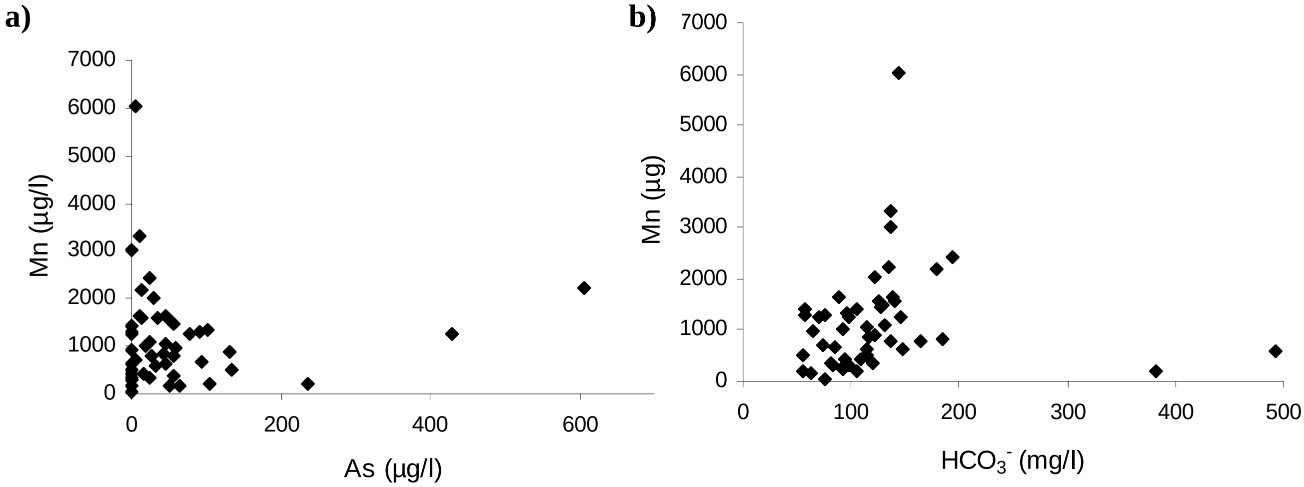


Figure 13. Bivariate plots of Mn concentration and **a)** As concentration **b)** HCO_3^- (alkalinity) in the Bongaigaon and Darrang districts.

In addition to ferric hydroxides, manganese oxides and hydroxides have earlier been stated as alternative places for the adsorption of arsenic. When solid phases containing manganese are reduced, the arsenic would be released in the same manner as for iron hydroxides. In the case of manganese there is no correlation at all between As and Mn (Figure 13 a). Manganese could simply be acting non-conservatively (Figure 13 b), for instance precipitating as rhodochrosite ($MnCO_3$) (Sracek et al., 2000; McArthur et al., 2001; Ahmed et al.., 2004). Another more feasible explanation is that the adsorption/desorption from manganese hydroxides/oxides plays a minor role in controlling the mobility of arsenic. The reduction of Mn is more energetically favourable than the reduction of iron, therefore any arsenic released from the reductive dissolution of Mn oxides/hydroxides can be re-adsorbed by iron hydroxides (McArthur et al., 2004).

As mentioned earlier, the oxidation of arsenopyrite and arsenic-bearing pyrite was long considered to be the mechanism controlling the mobilisation of arsenic. However, if this would be the case, there should exist a relationship between dissolved arsenic and sulphate. The data from Bongaigaon and Darrang district do not support this theory (Figure 14).

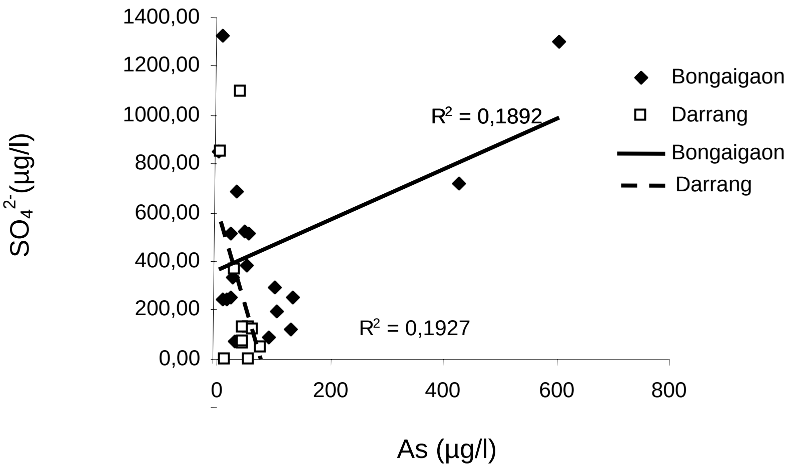


Figure 14. Bivarate plot of As and SO_4^{2-} concentrations in the groundwater of the Bongaigaon and Darrang districts.

4.2.3 Relations between As, DOC, alkalinity, ammonium and phosphate

As mentioned, degradation of organic matter in the sediments plays an important roll in the hypothesis of As mobilisation. DOC can be seen as an indicator of the presence of organic matter, and a weak correlation between DOC and As can be identified (Figure 15 a). Other factors that could indicate presence of organic matter are increased alkalinity and ammonium concentration.

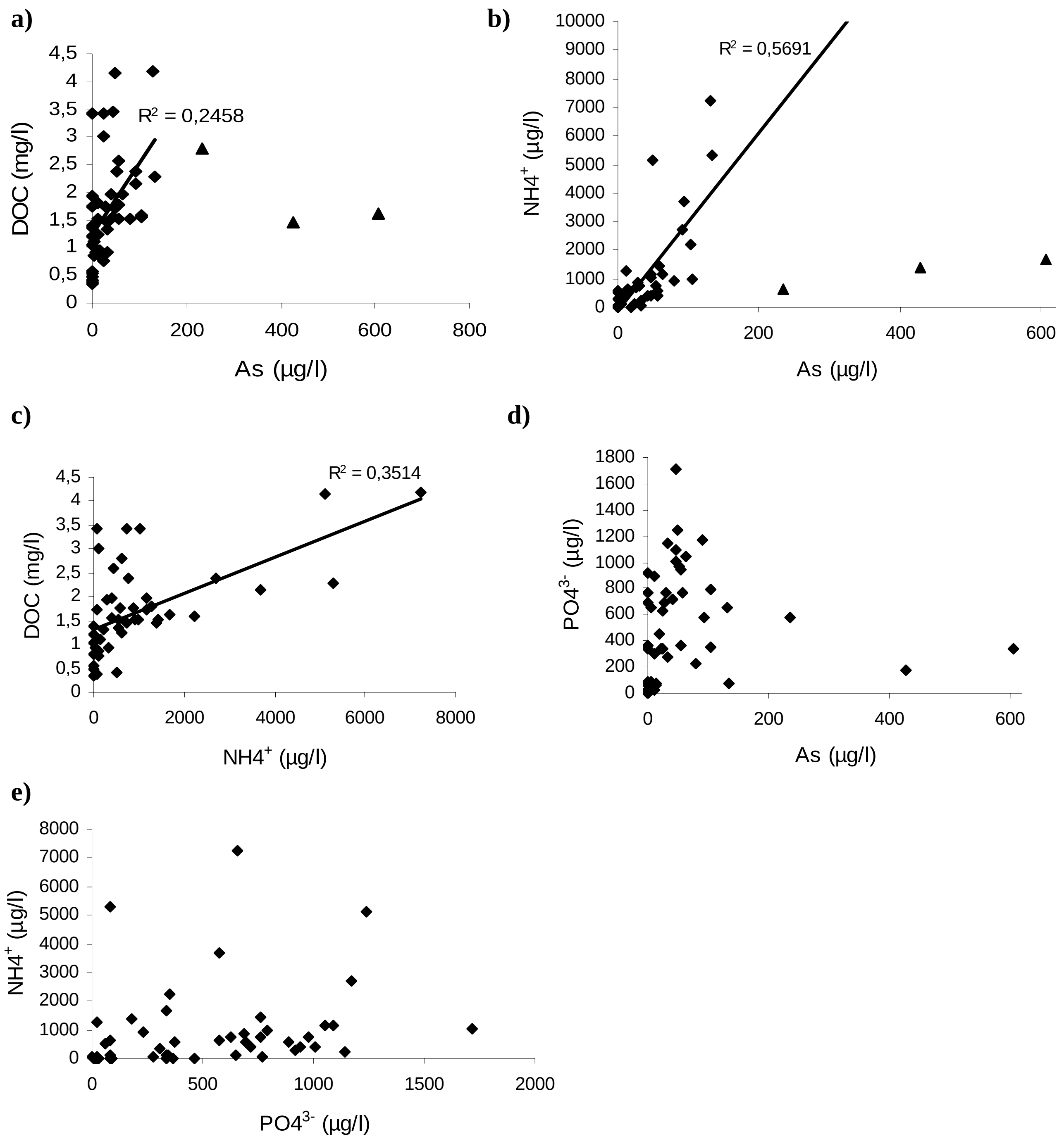


Figure 15. Results from water analysis shown as bivariate plots. **a)** As and DOC, **b)** As and NH_4^+ (note that outliers in form of the highest As values are excluded from the regressions), **c)** NH_4^+ and DOC, **d)** As and PO_4^{3-} and **e)** PO_4 and NH_4^+.

Elevated concentrations of phosphate and ammonium are indicators of the degradation of organic matter (Bhattacharaya et al., 2002b). The evidence of degrading matter is strengthened if more than one indicator is present. A correlation between As and NH_4^+ can be seen in Figure 15 b. DOC and NH_4^+ are also weakly correlated (Figure 15 c). On the other hand, no trends between PO_4^{3-} and As or NH_4^+ can be distinguished (Figure 15 d, e). One reason why PO_4^{3-} and NH_4^+ do not correlate is that the phosphorus might have its origin in the application of fertilizers.

4.3. Spatial variations in water chemistry

4.3.1 Hydrogeochemical variations in waterchemmistry between the areas

Temperature, pH and Eh showed no significant difference between the two study areas. The electric conductivity on the other hand showed significantly different values. In Darrang District, the median value is 170 µS/cm while in Bongaigaon it is as high as 450 µS/cm. There is no apparent trend with depth of the wells.

The median iron content in Darrang was 11.0 ± 11.9 mg/l and in Bongaigaon 6.1 ± 7.2 mg/l. The corresponding values for manganese were 0.7± 0.6 mg/l and 1.0 ± 1.1 mg/l in Darrang and Bongaigaon respectively.

4.3.2. Arsenic distribution in the area

It is hard to identify any definite regional trends of As occurrence within the areas. The contamination varies much between neighbouring wells.

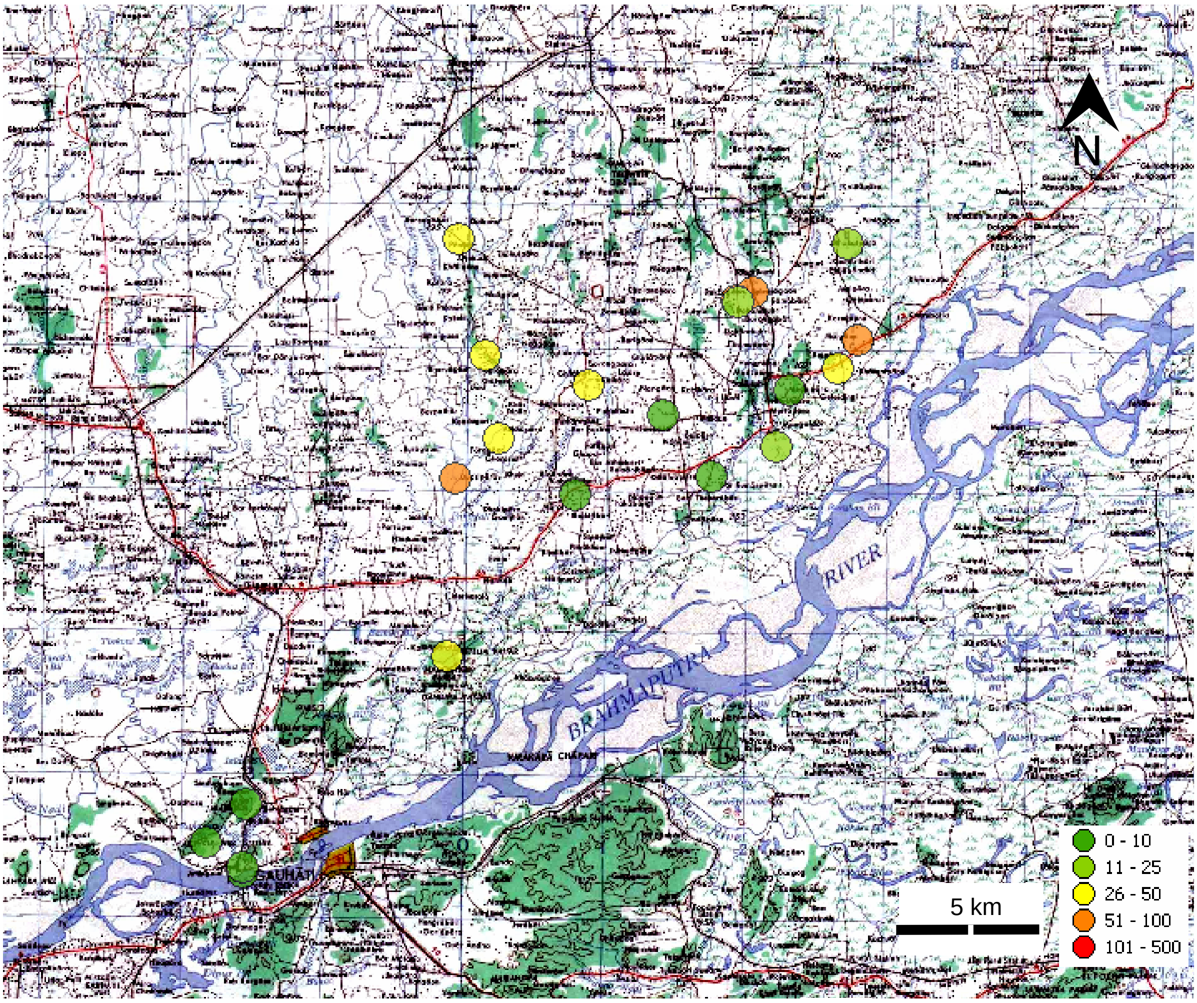


Figure 16. Arsenic distribution in Darrang district. Results in µg/l total arsenic from Hach test (Army Map Service, 1955).

However, in the Darrang district, two sub-areas with arsenic enrichment can be identified (Figure 16). The As concentrations in these areas are moderate, the highest concentration being 60 µg/l. The samples taken north of Guwahati city showed no As content above the detection limits.

In the Bongaigaon area the samples taken furthest away from the Brahmaputra were arsenic free. An arsenic contaminated belt was found to some extent following the Manas River. The concentrations in this belt vary between 0 and 600 µg/l (Figure 17).

NERIWALM found that groundwater adjacent to foothills is highly As-contaminated (Singh, 2004). Since the samples in this study were collected from lower lying areas, this cannot be confirmed.

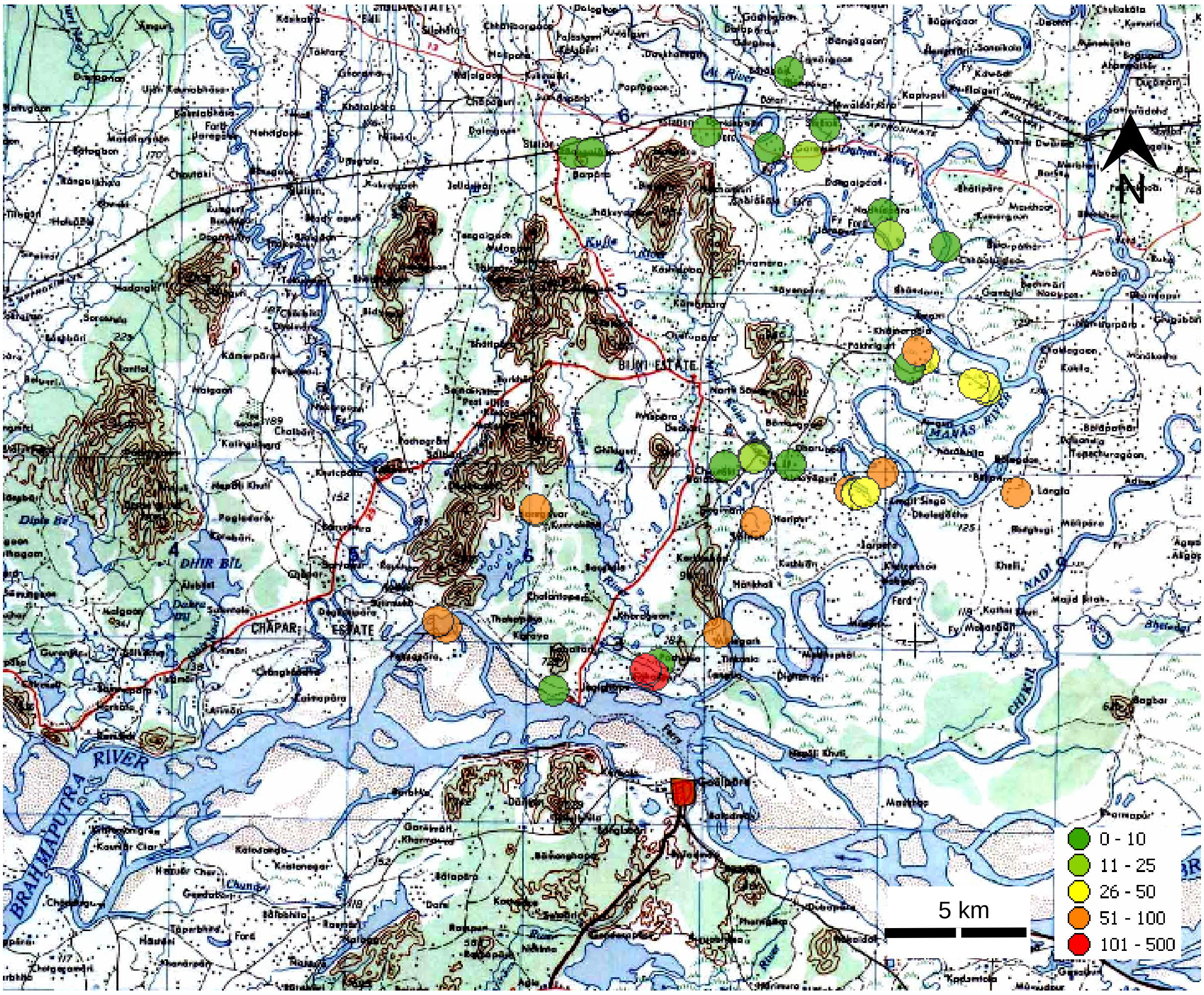


Figure 17. Arsenic distribution in Bongaigaon district. Results in µg/l total arsenic from Hach test (Army Map Service, 1955).

4.3.3 Relations between depth of wells and arsenic content

In the NERIWALM study it was concluded that water from very shallow aquifers (within 20 m from ground level) and deep aquifers (>150 m) are less As contaminated. The reason for arsenic free water from deeper wells is that these aquifers are Pleistocene. Not much can be said about this in this study, since no samples from wells deeper than 100 m were collected. The groundwater is in general found very close to the surface and the drillers usually don't need to drill very deep to find, what they think, is potable drinking water. It is also costly to drill deep wells, and it is in general only Public water schemes and private motorized wells that tap deeper aquifers. By looking at the few deeper wells sampled, there is however a slight trend towards less arsenic with depth (Figure 18). If deeper wells would be sampled, the depth trend found in the NERIWALM study might be confirmed.

Although the wells with the water with highest As enrichment is between 20 and 30 m deep, it is not established that shallow aquifers contain water that is less As contaminated (Figure 18). Local conditions like the occurrence of paleochannels with a lot of organic matter and the earthquakes of the area have worked together to produce a heterogeneity which makes it difficult to predict the location of high-As regions.

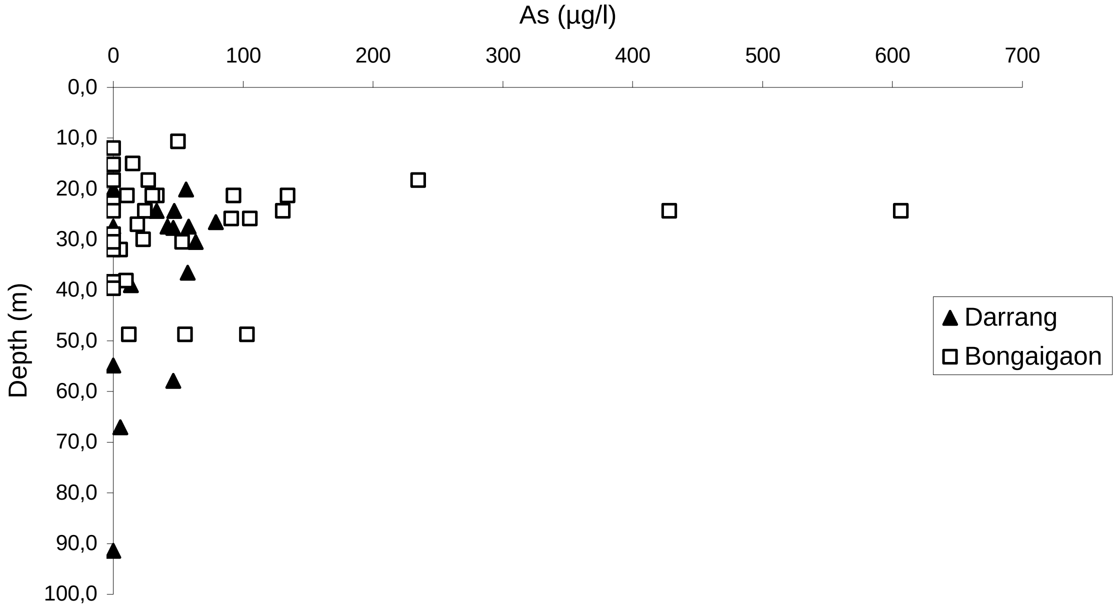
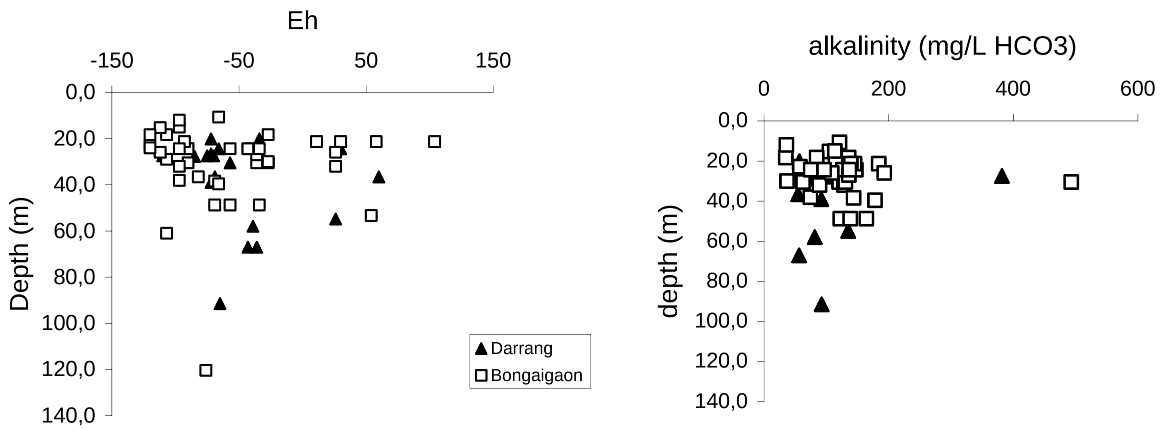


Figure18. Arsenic content in wells of different depth in both districts. Results from water samples taken in November 2005.

There is no visible trend between alkalinity or Eh and study area or depth (Figure 19), indicating that there are no distinct lithological sequences with more or less reducing conditions; instead the high alkalinity in individual wells is thought to be the result of localized zones with high degradation of organic matter and resulting reducing conditions.



Figur 19. Alkalinity and Eh plotted against well depth.

4.4. Sediment characteristics

According to other studies (van Geen et al., 2003; Mc Arthur et al. 2004; Jonsson and Lundell, 2004) the sediments found to be the source of arsenic free water have had a reddish colour. This colour can be attributed to the presence of ferric hydroxide (FeOOH). If the environment is more reducing, there will be a partial reduction of iron hydroxide, producing a brownish sediment colour. The readsorption of arsenic to residual FeOOH in these sediments keeps the As concentration reasonably low. If all FeOOH is reduced and vanishes, the sediments will get a greyish colour (McArthur et al., 2004).

4.4.1. Exploratory wells

Both samples dried in oven and semi-moist samples were colour classified. Since the moist samples would resemble the natural conditions of the sediments better, the emphasis is put on interpreting those results. The full results of the sediment classification are presented in appendix 5 and an overview seen in Figure 20.

The sediment samples from the four exploratory wells all had upper layers of clay in varying thickness from 6 to 12 m. These layers might confine the underlying sand aquifers.

The sand in the sediment samples taken in connection to well B1 showed a slight greenish colour. The uppermost 12 m consisted of clay and silt layers. Water samples from the 30.5 m deep B1 well was taken and contained 53 µg/l As. Another well (B4, 15.2 m deep) located just 25 m away showed no As content.

The sediment samples from well B10 were similar to B1 in colour. The clay layer was about 6 m thick. The well B10 was 21.3 m deep and the water had an As content of 93 µg/l. Water samples from three other wells in the same village were taken and showed an arsenic content between 50 and 130 µg/l.

The third set of sediment samples in Bongaigaon district was taken in connection to well B30. This well was the one containing the highest amount of arsenic of all the sampled wells, 606 µg/l. The colour of the sand was greyish olive and was topped by a 6 m thick layer of grey clay.

In Darrang district one exploratory well was drilled. Here the aquifer consists of coarse grey sand. The water in the well D15 (20.1 m deep) next to the exploratory well does not contain any As but shows a high Fe content. The drillers at the site were also asked to classify the colour of the sand and they classified the sand in the deepest layer as “grey”.

The general idea among well drillers and local population seems to be to find “white” sand, which is known to supply “good” water which probably means low iron content and no organic material. What is stated “white” or “whitish” sand by local population would probably be classified as something between light grey and greyish in the Munsell classification. One should mention that sand can be quite hard to colour classify since the grains are all distinguishable and can vary between anything between black and white in the same sample. The moisture content of the sand when being classified is also important; when the sand dries it tends to “lose” its colour and becomes more greyish (see Appendix 5).

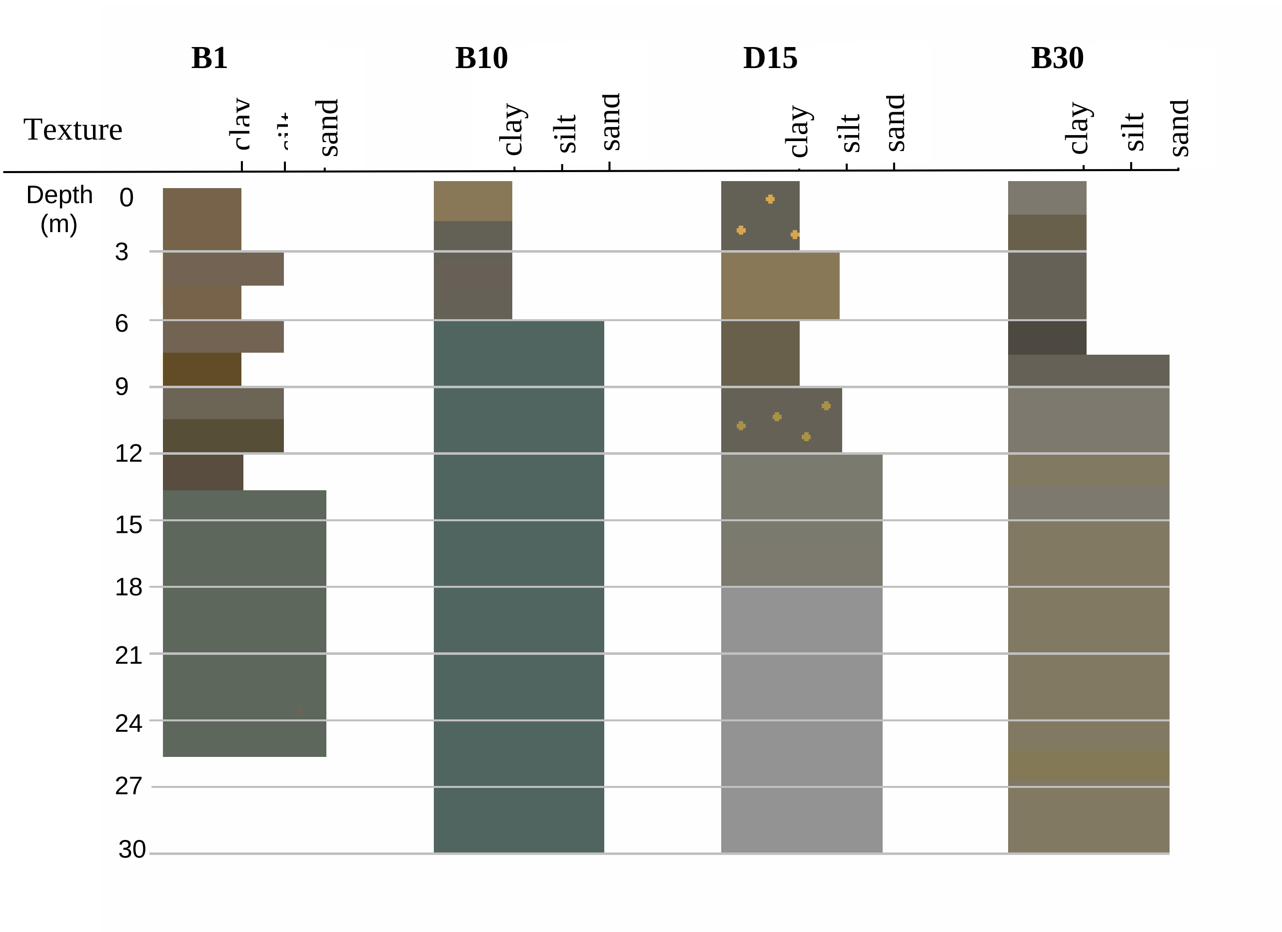


Figure 20. Lithologs of the four exploratory wells. Colours generated with *Munsell Conversion version 6.5.7* (Internet, wallkillcolor, 2006).

All the three exploratory wells in Bongaigaon lie close to tube wells with water containing As concentrations over the national drinking water standard. The aquifers consist of sand on the green-grey colour scale. The only set of sediment samples from Darrang was taken next to a tube well free of As and the sand there was a colourless grey. This could indicate that when the drillers choose colour of sand in an iron perspective, they end up choosing a sand void of arsenic as well. One can also note a weak correlation between Fe and As (Figure 11); this correlation would probably be stronger if Fe behaved conservatively.

None of exploratory wells have red or brown sediments, which have been found to be free of arsenic in studies conducted in Bangladesh (Jonson and Lundell 2004). However, in this study the red sediments bearing less As rich water were discovered at depths beyond the depth of all the exploratory wells drilled in this study. Had the wells been deeper, it is likely that aquifers having similar conditions would have been found. Since no wells in the studied areas are drilled to deep depths, finding such an aquifer would not help the local population much.

The reason that the grey sediment sample in Darrang does not bear As-enriched water is hard to see. The fact that the As situation seems to be less severe in Darrang compared to Bongaigaon might be the reason; the sediments derived from the Darrang tributaries might not have carried As-containing minerals in as high an amount as the ones in Bongaigaon.

The results from the relatively few sets of sediment samples should however be interpreted carefully since they are too few to give statistically significant results. They also do not cover the dept of the whole aquifer.

4.4.2. Sediment characteristics at water sampling sites

In addition to the sediment information from the exploratory wells, the users were asked if they had any knowledge about the characteristics of the sediments from all sampled wells. Since most of the wells had been rather recently drilled, one can assume that the information can be quite accurate. For some older wells however, sediment information was lacking. When no information could be received from the well users' general information on the sediment layers in the area, this was instead received from PHED staff members. The stated sediment characteristics can be found in appendix 1.

The stated colour of the tapped sediment layer was noted down and when categorized into two colour groups one can compare the arsenic content dependent on colour of the sediments (Table 2).

Table 2. Mean and standard deviation (stdv) of arsenic (Hach results) and iron content in wells classified by sediment colour stated by users.

Stated colour (sample size)		No info (18)	White, whitish, off-white, gray (23)	Red, reddish, reddish brown, brown, brownish (5)
As	**mean**	42	69	93
(µg/l)	**stdv**	40	113	120
Fe	**mean**	9,97	8,39	13,8
(mg/l)	**stdv**	8,58	9,65	7,72

One can see that, contrary to other studies and the theoretical expectation, the allegedly reddish and brownish sediments have the highest arsenic content. The iron content is as highest in the water tapped from red/brown sediments. This may seem as a contradiction to the iron hydroxide release theory but the red/brown sediments are probably partly reduced and are releasing Fe to a certain amount.

One should consider that extreme values will influence the statistics very much in such small data sets. One better way of looking at the differences in As content between the different sediment samples is checking how many wells that have waters with As above the guidelines. In Figure 21, one can see that the proportion of wells showing As enrichment is quite evenly distributed between the sediment colours.

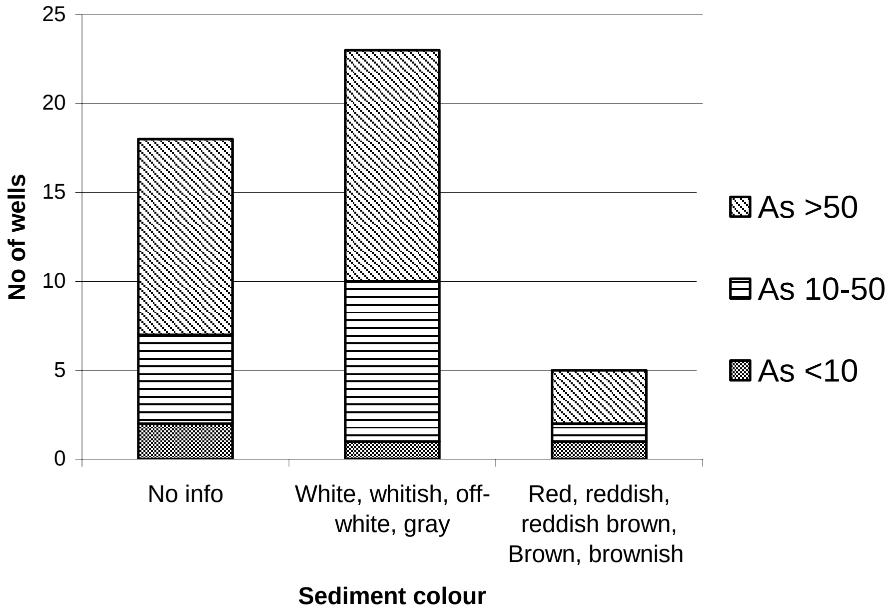


Figure 21. As content linked to sediment colour as stated by users of the sampled wells.

These results of As content and sediment colour, based on oral information, should however be interpreted even more carefully than the results from the sediment samples. What is stated as brown by one user might be given as the colour grey by another. The depth of the well and sediment layers may also be uncertain. Language barriers may also influence the result; different interpreters were for instance used at different sites.

4.5. Filters

4.5.1 Domestic filters

The Hach test for total As was preformed on water from well B26 and B29 after being filtered through a domestic filter. The unfiltered water contained 91 µg/l and 428 µg/l As, respectively. After filtration, the Hach kit showed concentrations of 25 and 60 µg/l As.
The filters are used by the households to remove the iron. The iron is oxidised and precipitated on the sand particles. It seems that arsenic is co-precipitated together with or adsorbed on the formed iron hydroxides (Internet, SOS, 2006). Sharma et al. (2005) have done experiments on iron removal units and their ability to reduce arsenic. They conclude that a Fe/As molar ratio above 80 is needed for an effective As removal. They also express that As(III) needs to be oxidized to As(V) for effective co-precipitation with iron hydroxides. In the unfiltered water from B26 and B29, the As(V) amounts are low, yet it seems possible to receive a rather efficient decrease in As concentration. In B26 the Fe/As-ratio was high (258) but in B29 as low as 28. A higher Fe/As-ratio or oxidation of As(III) to As(V) could contribute to a more effective removal, but this needs to be further investigated (Appendix 4).

4.5.2. Public Water Supply Scheme filter

Raw water taken from one Public Water Supply Scheme (PWSS) (sample B17) showed an arsenic content of 103 µg/l. Filtered water was also sampled (B18) in which the As content was reduced to 12 µg/l. In the PWSS the water is aerated before filtering through the filter medium. The Hach test was preformed on aerated but unfiltered water at the tested PWSS but no reduction of As was detected. In the untreated water the Fe/As ratio was high (145) and almost all arsenic in the As(III) state. The As removal in the PWSS filter seems to be a bit more effective than in the domestic filters. The aeration might help oxidize the arsenic and contribute to a better efficiency in As removal. The different design of the filter compared to domestic filters might be another reason for a higher efficiency in As removal.

5. Conclusions

- The As enrichment in groundwater in the studied area is severe. Of a total of 50 sampled wells in the Darrang and Bongaigaon districts, 15 showed arsenic concentration values above the national drinking standard of 50 µg/l and 33 above the WHO guideline of 10 µg/l.

- There are no distinct regions or sediment layers in the study areas where specific sedimentological features or water chemistry can be identified to produce arsenic enriched groundwater. It is thus hard to identify arsenic free areas.

- The large local variations in As concentrations are probably due to the heterogeneity of the sediments and the resulting variations in redox conditions.

- The domestic sand filters and slow sand filters in public water schemes seem to reduce the As content of the water rather effectively. Since filters are widely used in the region this might be the reason why no signs of arsenicosis have been documented in Assam. The mechanism and efficiency of the sand filters needs to be more thoroughly investigated.

- Sediments with a colour on the green-olive scale are probably more likely bearing As contaminated water than white sediments. The data in this study does not support theory that red and brown sediments indicate less As. The sediment colour classification should, however, be carefully interpreted.

- Local drillers' knowledge about which types of aquifers that provide potable water is important and probably valid in terms of As contamination. Yet, due to economical and practical reasons, wells are often established in locations where these preferred conditions are not found.

- The reductive dissolution of ferric hydroxides is thought to be the release mechanism controlling the mobility of arsenic.

- When looking at the Fe/As molar ratio, there is a weaker trend than would be expected. This is probably due to the fact that the iron is acting non-conservatively to some extent.

- The manganese oxides/hydroxides are probably playing a minor role in the control of arsenic mobility since any arsenic released from these surfaces is likely to be readsorbed to ferric hydroxides.

- Desorption from metal oxides due to a pH induced change in surface charge is not likely, since the pH range between samples is too narrow.

- Oxidation of arsenopyrite is not likely to be the causing mechanism of the arsenic enrichment of the groundwater.

6. References

Ahmed K.M., Bhattacharya P., Hasan M.A., Akhter S.H., Alam S.M.M., Bhuyian M.A., Imam M.B., Khan A.A. and Sracek O., 2004, *Arsenic enrichment in groundwater of the alluvial aquifers in Bangladesh: An overview,* Appl. Geochem. 19: 181–200.

Aowal A.F.S.A, 1981, *Design of an iron eliminator for hand tube wells,* Journal of I.W.W.A. 13: 65.

Appelo C.A.J., Van Der Weiden M.J.J, Tournassat C. and Charlet L., 2002, *Surface Complexation of Ferrous Iron and Carbonate on Ferrihydrite and the Mobilization of Arsenic,* Environ. Sci. Technol. 36: 3096-3103.

Army Map Service, 1955, *NG-46-6 series U502*, US Army, Washington DC, USA.

Bakshi A.R., 2005, *Overview of Groundwater situation in Assam,* Central Groundwater Board, Guwahati.

Bhattacharya P., Chatterjee D. and Jacks G., 1997, *Occurrence of arsenic contaminated groundwater in alluvial aquifers from delta plains, eastern India: options for safe drinking water supplies,* International Journal of Water Resources Development 13: 79-92.

Bhattacharya P., Jacks G., Jana J., Scracek A.., Gustafsson J.P. and Chatterje D., 2001, *Geochemistry of the Holocene alluvial sediments of Bengal Delta plains from West Bengal, India: implications on arsenic contamination in groundwater,* in: *Groundwater Arsenic Contamination in the Bengal Delta Plain of Bangladesh*, KTH special publication TRITA-AMI Report 3084: 21-40.

Bhattacharya P., Frisbie S.H., Smith E., Naidu R., Jacks G. and Sarkar B., 2002a, *Arsenic in the Environment: A Global Perspective,* in: *Handbook of Heavy Metals in the Environment* Sarkar B.(ed.), Marcell Dekker Inc., New York, pp. 147-215.

Bhattacharya P., Jacks G., Ahmed K.M., Khan A.A., Routh J., 2002b. *Arsenic in groundwater of the Bengal Delta Plain aquifers in Bangladesh*, Bull. Environ. Contam. Toxicol. 69: 538–545.

Bhattacharya P., Ahmed K.M., Hasan M.A., Broms S., Fogelström J., Jacks G., Sracek O., von Brömssen M. and Routh J., 2006, *Mobility of arsenic in groundwater in a part of Brahmanbaria district, NE Bangladesh*, in: *Managing Arsenic in the Environment: From soil to human health,* Naidu R., Smith E., Owens G., Bhattacharya P. and Nadebaum P. (eds.), CSIRO Publishing, Melbourne, Australia, pp. 95-115.

Breit G.N., Lowers H.A., Foster A.L., Bernmy M., Yount J.C., Whitney J., Clark D.W., Uddin M.D. N., and Muneem A.A., 2003, *Changes in the binding of arsenic to sediment in southern Bangladesh – A record of microbially facilitated transformations,* Presentation at 2004 Denver Annual Meeting, Current Perspectives in Environmental Biogeochemistry.

CGWB, 1985, Central Groundwater Board, Ministry of water resources, Government of India, *Hydrogeological atlas of Assam.*

Das H.K., A.K. Mitra, Sengupta P.K., Hossain A., Islam F. and Rabbani G.H., 2003, *Arsenic concentrations in rice, vegetables, and fish in Bangladesh: a preliminary study,* Environment international 30:383-7.

Hossain M.F., 2004, *Arsenic contamination in Bangladesh—An overview,* Agriculture, ecosystems & environment 113:1-16.

Jonsson L., Lundell L., 2004, *Targeting safe aquifers in regions with arsenic-rich groundwater in Bangladesh,* Swedish University of Agricultural Sciences SLU External Relations Uppsala, Minor Field Studies 277.

JOPA, 2005, *Joint plan of Action for Arsenic and Fluoride Mitigation in Assam,* Public Health Engineering Department, Assam.
McArthur J.M., Ravencroft P., Safiullah S. and Thirlwall M.F., 2001, *Arsenic in groundwater: testing pollution mechanism for sedimentary aquifers in Bangladesh,* Water Resour. Res. 37: 109–117.

McArthur M., Banerjee D.M, Hudson-Edwards K.A, Mishra R., Purohit R., Ravenscroft P., Cronin A., Howarth R. J, Chatterjee A., Talukder T., Lowry D., Houghton S. and Chadha D.K, 2004, *Natural organic matter in sedimentary basins and its relation to arsenic in anoxic ground water: the example of West Bengal and its worldwide implications,* Appl. Geochem.19: 1255–1293.

Mukherjee, A.B. and Bhattacharya, P., 2001, *Arsenic in groundwater in the Bengal Delta Plain: Slow Poisoning in Bangladesh,* Environmental Reviews 9: 189-220.

Nickson R.T., McArthur J.M., Ravenscroft P.,Burgessa W.G. and
Ahmed K.M., 1999, *Mechanism of arsenic release to groundwater, Bangladesh and West Bengal,* Appl. Geochem. 15: 403-413.

Nickson R.T., McArthur J.M., Shrestha B., Kyaw-Myint T.O. and Lowry D., 2003, *Arsenic and other drinking water quality issues, Muzaffargarh District, Pakistan,* Appl. Geochem. 20: 55-68.

Parkhurst D.L., 1995, *User's Guide to PHREEQC-A computer program for speciation, reaction-path, advectivetransport, and inverse geochemical calculations,* U.S. Geol. Survey Water Res. Invest. Rpt. 95-4227.

Sharma A.K., Tjell J.C. and Mosbaek H., 2005, *Optimisation of iron removal units to include arsenic removal,* In: Natural Arsenic, in: *Groundwater: Occurrence, Remediation and Management*, Bundschuh J., Battarcharya P. and Chandrasekharam D. (eds.), Taylor and Francis Group plc, London, UK.

Singh A.K., 2004, *Arsenic Contamination in Groundwater of North Eastern India,* Eastern Regional Institute of Water and Land Management – Neriwalm.

Singh V. P., Sharma N., Ojha C. and Shekhar P. (eds.), 2004, *The Brahmaputra basin water resources*, Kluwer Academic Publishers, Dordrecht, Germany.

Smedley P.L and Kinniburgh D.G., 2001, *A review of the source, behaviour and distribution of arsenic in natural waters*, Appl. Geochem. 17: 517–568.

SOES, 2004, *Groundwater arsenic contamination in Assam: The latest findings in the Ganga-Meghna-Brahmaputra Plai*, the School of Environmental Studies, Javadaur University.

Sracek A., Bhattacharya P., Jacks G., Chatterjee D., Larsson M. and Liess A., 2000, *Groundwater arsenic in the Bengal Delta Plains: a sedimentary geochemical overview*, in: *Proceedings of the International Seminar on Applied Hydrogeochemistry*, Ramanathan A.L., Subramanian V. and Ramesh R. (eds.), Annamalan University, Tamil Nadu, India, pp. 47–56.

van Geen A., Ahmed K.M., Seddique A. and Shamsudduha M. 2003. *Community wells to mitigate the arsenic crisis in Bangladesh*, Bull World Health Organ 81: 132-138.

Wagner F., Berner Z.A. and Stuben D., 2005, *Arsenic in the groundwater of the Bengal Delta Plain: geochemical evidences for small redox zonation in the aquifer*, in: *Natural Arsenic in Groundwater: Occureence, Remediation and Management*, Bundschuh J., Battarcharya P. and Chandrasekharam D. (eds.), Taylor and Francis Group plc, London, UK.

Internet references:

absolute astronomy, 2006, http://www.absoluteastronomy.com/encyclopedia/a/as/assam.htm (accessed 2006-05-11)

Assamgovt, 2006, http://assamgovt.nic.in (2006-05-11)

Hach, 2006, http://www.hach.com/hc/search.product.details.invoker/VendorProductCode=2822800/ (2006-06-28)

Lenntech, 2006, http://www.lenntech.com/Periodic-chart-elements/As-en.htm (2006-05-11)

Maps of India, 2006, http://www.mapsofindia.com/stateprofiles/assam/index.html (2006-05-11)

SOS, 2006, http://www.sos-arsenic.net/english/removal_progs/ (2006-05-11)

Sandia, 2006, http://www.sandia.gov/water/docs/SAND2006-1324.pdf (2006-11-09)

wallkillcolor, 2006, http://www.wallkillcolor.com/ (2006-08-20)

WHO, 2006a, http://www.who.int/water_sanitation_health/dwq/en/gdwq3_ann4tab.pdf (2006-05-11)

WHO, 2006b, http://www.who.int/water_sanitation_health/diseases/arsenicosis/en/ (2006-06-16)

WHO, 2006c, http://www.who.int/water_sanitation_health/naturalhazards/en/index2.html (2006-06-16)

Personal communications:

Mr Paul, UNESCO, 2005

Mr Abhimanyu Paul, PHED, 2005

Appendix 1. Field parameters, general information on the tested wells

SampleID	Sample_Date	Water color	Sed color ID (r=red/brown, w=white/gray)	Sample type	Installation date
D1	2005-10-05	clear	w	Tubewell	1986
D2	2005-10-05	clear	w	Tubewell	1996
D3	2005-10-05	clear	r	Tubewell	1992
D4	2005-10-05	clear	-	Deep tubewell	?
D5	2005-10-05	clear	-	tubewell	?
D7	2005-10-05	clear	w	Tubewell	1988
D8	2005-10-05	clear	-	Tubewell	2002
D9	2005-10-05	clear	w	Tubewell	2002
D10	2005-10-05	clear	-	Tubewell M-II Hama Deka	1991
D11	2005-10-05	clear	w	Tubewell	2002
D12	2005-10-05	clear	r	Tubewell	2002
B1	2005-11-03	clear	w	Tubewell	2004
B2	2005-11-03	clear	w	Tubewell	2004
B3	2005-11-03	clear	w	Tubewell	1987
B4	2005-11-03	clear	w	Tubewell	?
B5	2005-11-03	clear	-	Tubewell	2004
B6	2005-11-03	clear	-	Tubewell	2004
B7	2005-11-03	clear	-	Tubewell	?
B8	2005-11-03	clear	-	Tubewell	?
B9	2005-11-03	clear	-	Tubewell	?
B10	2005-11-03	clear	w	Tubewell	2004
HB1	2005-11-04	clear	-	Tubewell	1998
HB2	2005-11-04	clear	-	Tubewell, diesel motor	1998
B11	2005-11-04	clear	-	Tubewell	?
B12	2005-11-04	clear	w	Tubewell	2005
B13	2005-11-04	clear	-	Tubewell	1995
HB 3	2005-11-04	clear	-	Tubewell	?
HB 4	2005-11-04	clear	-	Tubewell	?
HB 5	2005-11-04	clear	-	Tubewell	?
B14	2005-11-04	clear	w	Tubewell	2005
B15	2005-11-04	clear	w	Tubewell	2003
B16	2005-11-05	clear	r	Tubewell	1991
B17	2005-11-05	clear	w	Tubewell	?
B18	2005-11-05	clear	w	Tubewell	?
B19	2005-11-05	clear	-	Tubewell	?
B20	2005-11-05	clear	-	Tubewell	2005
B21	2005-11-05	clear	-	Tubewell	1992
HB 6	2005-11-05	clear	-	Tubewell	?
HB 7	2005-11-05	clear	-	Tubewell	?
B22	2005-11-05	clear	w	Tubewell	2003
HB 8	2005-11-05	clear	w	Tubewell	2003
B23	2005-11-05	clear	-	Tubewell	2005
B24	2005-11-05	clear	-	Tubewell	2001
D13	2005-11-17	clear	w	Tubewell	1999
D14	2005-11-17	clear	w	PWSS	1986
HD1	2005-11-17	clear	r	Tubewell	2005
D15	2005-11-17	clear	w	Tubewell	2005
HD2	2005-11-17	clear	-	Tubewell	1990
D16	2005-11-17	clear	w	Tubewell	2005
D17	2005-11-17	clear	-	Tubewell	1990
B25	2005-11-19	clear	w	Tubewell	1998
B26	2005-11-19	clear	w	Tubewell	2004
FB26	2005-11-19	clear	-	Filter	-
B27	2005-11-19	clear	w	Tubewell	2005
B28	2005-11-19	clear	r	Tubewell	2005
B29	2005-11-19	clear	w	Tubewell	2003
FB29	2005-11-19	clear	-	Filter	-
HB9	2005-11-19	turbid	w	Tubewell	1998
B30	2005-11-19	clear	w	Tubewell	?
B31	2005-11-19	clear	w	Tubewell	2005
B32	2005-11-19	clear	w	Tubewell	2005
B33	2005-11-19	clear	w	Tubewell	1995
B34	2005-11-19	clear	w	Tubewell	1998

Appendix 1. Field parameters, general information on the tested wells

SampleID	District	Block	Panchayat	Village
D1	Darrang	Sipajhaar		Kaikara
D2	Darrang	Sipajhaar	Dipila Gaon	Nagaon
D3	Darrang	Sipajhaar		Taragaon
D4	Darrang	Sipajhaar		
D5	Darrang	Sipajhaar		
D7	Darrang	Sipajhaar	Ganesh Kuwari	Kuwarisan
D8	Darrang	Pachim Manngoldoi	Ramhari	Kochomari
D9	Darrang	Pachim Manngoldoi	Ramhari	Kochomari
D10	Darrang	Pachim Manngoldoi	Ramhari	Dekargaom
D11	Darrang	Pub Margaldai	Khataniapara	?
D12	Darrang		Dhula Dalgaeon	?
B1	Bongaigaon	Srijawgram	Koikila	Maulavipara ?
B2	Bongaigaon	Srijawgram	Koikila	Maulavipara ?
B3	Bongaigaon	Srijawgram	Koikila	Maulavipara ?
B4	Bongaigaon	Srijawgram	Koikila	Maulavipara ?
B5	Bongaigaon	Srijawgram	Balachar	Balarchar part 3
B6	Bongaigaon	Srijawgram	Balachar	Balarchar
B7	Bongaigaon	Srijawgram	Balachar	Balarchar
B8	Bongaigaon	Tapartary	Santoshpur	Dumerguri part 2
B9	Bongaigaon	Tapartary	Lentisinga	Lentisinga
B10	Bongaigaon	Tapartary	Lentisinga	Lentisinga
HB1	Bongaigaon	Dangtol	Bongaigaon	Bongaigaon town
HB2	Bongaigaon	Dangtol	Bongaigaon	Bongaigaon town
B11	Bongaigaon	Dangtol	Chaprakata	Baghmara
B12	Bongaigaon	Manikpur	Chouraguri	Goraimari, Bijni
B13	Bongaigaon	Manikpur	Chouraguri	Goraimari
HB 3	Bongaigaon	Borobazar	Bijni	Bijni
HB 4	Bongaigaon	Borobazar	Batanbari	Batabari
HB 5	Bongaigaon	Manikpur	Bhandara	Kachdaha
B14	Bongaigaon	Manikpur	Bhandara	Bhandara
B15	Bongaigaon	Manikpur	Bhandara	Salabila part 3`
B16	Bongaigaon	Tapartary	Borigaon	Borigaon
B17	Bongaigaon	Tapartary	Lentisinga	Lengtasinga
B18	Bongaigaon	Tapartary	Lentisinga	Lengtasinga
B19	Bongaigaon	Tapartary	Lentisinga	Janermukh
B20	Bongaigaon	Tapartary	Lentisinga	Janermukh
B21	Bongaigaon	Tapartary	Lentisinga	Janermukh
HB 6	Bongaigaon	Tapartary	Abhayapuri town	Televerket, Abharapuri (50 m away)
HB 7	Bongaigaon	Tapartary	Abhayapuri town	Big scheme, Abharapuri
B22	Bongaigaon	Tapartary	Mererchar	Kushbari Primary School(near Abhayapuri)
HB 8	Bongaigaon	Tapartary	Nasatra	West nasatra (Khaspar)
B23	Bongaigaon	Boitamari	Majer Alga	Iswarjhari Part I
B24	Bongaigaon	Boitamari	Majer Alga	Iswarjhari Part I
D13	Darrang	Kalagaon	Chapai	Medhipara
D14	Darrang	Pub Mangaldoi	Bhakat Para	Bhahatpara
HD1	Darrang	Pub Mangeldoi	Mowamari	Garvi Mri
D15	Darrang	Pachim Mangaldoi	Auolachouka Janavam	Barkumarpara
HD2	Darrang	Pachim Mangaldoi	Chouka	Kobikara
D16	Darrang	Khairabari	Namkholla	Bakmolla
D17	Darrang	Khairabari	Namkholla	Namkhola (Khaloi para)
B25	Bongaigaon	Srijawgram	Kakoijana	Charakhola
B26	Bongaigaon	Taparetary	Kolbari	Amguri part III
FB26	Bongaigaon	Taparetary	Kolbari	Amguri part III
B27	Bongaigaon	Tapartari	Malegar	Malegarh part II
B28	Bongaigaon	Tapartari	Pachania Khoragaon	Pachania part II
B29	Bongaigaon	Tapartari	Pachania Khoragaon	Mohanpur prt II
FB29	Bongaigaon	Tapartari	Pachania Khoragaon	Mohanpur prt II
HB9	Bongaigaon	Tapartari	Pachania Khoragaon	Mohanpur prt II
B30	Bongaigaon	Tapartari	Pachania Khoragaon	Mohanpur prt II
B31	Bongaigaon	Boitamari	Jogighopa	Bhatipara
B32	Bongaigaon	Boitamari	Jogighopa	Jogighopa Battikchar
B33	Bongaigaon	Boitamari	Jogighopa	Jogighopa Battikchar
B34	Bongaigaon	Boitamari	Jogighopa	Jogighopa Battikchar

Appendix 1. Field parameters, general information on the tested wells

SampleID	Sediment
D1	grey/blueish (Stated)
D2	reddish/whitish bottom uncertain.mostly whitish (S)
D3	Brownish sandy soil, (S)
D4	-
D5	-
D7	interlayers brown, reddish, black soil. Whitish at depth of well. (S)
D8	no info
D9	dark grayish mixed with white sand (S by owner)
D10	-
D11	sand/clay at beginning, coarse off-white sand at 90 feet (S)
D12	red coloured sandy layers (S)
B1	See sediment samples B1
B2	Same village as B1
B3	Same village as B1
B4	See sediment samples B1
B5	-
B6	-
B7	-
B8	-
B9	-
B10	See sediment samples B10
HB1	-
HB2	-
B11	-
B12	Gravel/sand before 5 ft till end. No reddish sand, whitish-grey sand. Paleochannel.
B13	-
HB 3	-
HB 4	-
HB 5	-
B14	To 60 ft coarse sand, to 75 ft small size pebbles, then bigger pebbles Towards the end sand of white color.
B15	"Pebbles/cobbles after 2/3 of depth finally white sand"
B16	"White clay at top, reddish sand/pebbles below 49 ft" mr paul
B17	Sediment samples taken from B10
B18	Sediment samples taken from B10
B19	0-60 ft Sand, 60-90 ft pebbles, 90-95 ft bigger pebbles, 95-200 ft pebbles (S by owner)
B20	Sediment samples taken from B10
B21	Sediment samples taken from B10
HB 6	-
HB 7	-
B22	"Same sediment layers as Jai Jawan club"
HB 8	Below 45 ft white pebbles, clay <5m, Different sandlayers above 45 ft
B23	Sandy layer, fine sand (silty) 130-175 ft to Peliochannel
B24	Same
D13	>16 ft Fe free water, 16-25 ft white sand, 60-80 ft Reddish-black sand, water contaions Fe, 85-100 stones, boulders, 120-180 ft White sand, Fe free water
D14	Sandy layer starts from 12 ft, 12-20 ft sand, 20-25 Clay, 25-30 ft whitish sand, 120-130 Reddish sand , contains iron, >130 ft clear and white sand
HD1	After 20 ft sandlayer, the water from this layer is mostly conaining iron. The color of the sediment is brownish or reddish
D15	Drilling taking place 8 m from well. Samples taken 10 ft apart 10-100.
HD2	-
D16	Same color&texture as at 100ft(D15). D15 sample shown to owner.
D17	No info available, but close to D16
B25	< 65 ft blackish mud, >65 ft whitish sand
B26	< 30 ft clay, 30-85 Whitish sand
FB26	Filter: Multiple sand/pebbles layers, sample taken
B27	"this area waterbearing layer normaly whitish sand (river sand)"
B28	< 105 ft clay soil, >105 ft sand, >120 ft reddish coarse sand, small pebbles
B29	" Mostely white sand with intercolations of clay layers (1-4 ft thick)"
FB29	Sand/pebbles filter
HB9	see B30
B30	> 30 ft whitish sand
B31	< 60 ft fine clay, 60-130 ft medium whitsh (colourless) sand
B32	"white sand layer"
B33	see B32
B34	see B33

Appendix 1. Field parameters, general information on the tested wells

SampleID	Owner/Location	Well depth (m)	Filter length (m)
D1	Community well. 8 households, about 50p, currently not used.	24,4	2
D2	Public well at a house, currently used	57,9	2
D3	Community well, 15-20 families, 150p	36,6	2
D4	Community well (PHED) 64 households (50 Rp/month) , 56 commuinty taps	91,4	2
D5	PHED treatment plant	27,4	2
D7	Public well	27,4	2
D8	private Narayan Hazarika	26,6	2
D9	private Narayan Hazarika	20,1	2
D10	public well	39,0	2
D11	School well	27,7	2
D12	LP school	27,4	2
B1	LP School	30,5	2
B2	Private	24,4	2
B3	Private, Cobiruddin Ahmed	18,3	2
B4	LP school	15,2	2
B5	public	21,3	2
B6	private	21,3	2
B7	Balarchelar Primary school	21,3	2
B8	Primary health center	24,4	2
B9	No 8090 Lentisinga LP school	21,3	2
B10	Jai Jawan Club Int. development service center	21,3	2
HB1	Private	36,6	2
HB2	Birjhora Tea Estate	53,3	2
B11	Chilarai ME school	29,0	2
B12	Gas statuion, Sada Sukh Service station	22,9	2
B13	Goraimari pipe water supply scheme	38,1	2
HB 3	Birji Bodo Primary School	?	2
HB 4	Batabasi Primary school	30,5	2
HB 5	Kachdaha primary school	?	2
B14	Bhandara south primary school	32,0	2
B15	Mr Jail Hussein	32,0	2
B16	Torani Banikya	30,5	2
B17	Public water treatment scheme	48,8	2
B18	Public water treatment scheme	48,8	2
B19	Private	24,4	2
B20	Private	48,8	2
B21	Private, Madan Das	10,7	2
HB 6	Televerket	61,0	2
HB 7	Big Water Scheme	120,4	2
B22	Primary school ?	25,9	2
HB 8	Near Mosque, public	24,0	2
B23	Near LP School	15,0	2
B24	Public well	18,3	2
D13	Medhiapara ME school	54,9	2
D14	Bhahatpara PWSS	67,1	2
HD1	Neo town LP school	36,6	2
D15	Well for establishment of PWSS well (need water for drilling)	20,1	2
HD2	Water Scheme PWSS	67,1	2
D16	Private, house of Muhammed Badur Ali	30,5	2
D17	Public, next to KW bicycle shop	24,4	2
B25	Saralkola LP school	24,4	2
B26	Private Masjid	25,9	2
FB26	Private Masjid		2
B27	Mosque	27,0	2
B28	Private , Hareswar Das	38,4	2
B29	Private, Jaychand Bepari	24,4	2
FB29	Private, Jaychand Bepari		2
HB9	Chaitanya LP school	24,4	2
B30	Chaitanya LP school	24,4	2
B31	Monoar Ali Hagi Shop	39,6	2
B32	Batikchar LP school	18,3	2
B33	Batikchar LP school	12,0	2
B34	Batikchar LP school	30,0	2

Appendix 1. Field parameters, general information on the tested wells

SampleID	East	North	Elevation m(asl)	Status
D1	91 54.689	26 27.692	54	Sealed by PHED 2 months ago
D2	91 50.885	26 28.784	62	Currently used well
D3	91 51.338	26 25.892	57	Currently not used well, due to As
D4	91 54.251	26 24.056	55	in use
D5	92 54.251	27 24.056	55	not used?
D7	91 49.428	26 18.465	60	sealed 1 month ago
D8	92 00.378	26 30.623	69	sealed
D9	93 00.378	27 30.623	69	in use
D10	92 00.870	26 30.877	62	sealed 14/09/05
D11	92 04.210	26 28.334	-	sealed
D12	92 04.939	26 29.245	54	sealed
B1	91 54.687	26 27.692	58	in use (previously tested?)
B2	91 49.433	26 18.463	60	in use, not previously tested
B3	91 52.427	26 27.692	58	in use, not previously tested
B4	91 54.687	26 27.692	58	in use, not previously tested
B5	90 47.074	26 22.066	38	in use, not previously tested?
B6	90 47.077	26 22.165	56	in use, not previously tested
B7	90 46.656	26 22.220	56	in use, not previously tested
B8	90 43.928	26 19.752	32	in use, not previously tested
B9	90 42.877	26 19.166	52	in use, not previously tested
B10	90 48.118	26 19.154	35	in use, not previously tested
HB1	90 34.091	26 28.518	49	in use, not previously tested
HB2	90 3474	26 28.55	64	in use, not previously tested
B11	90 38.33	26 29.24	54	in use, not previously tested
B12	90 40.24	26 28.83	50	In use
B13	90 41.41	26 28.59	48	In use
HB 3	90 42.03	26 29.34	55	In use
HB 4	90 40.82	26 30.90	57	In use
HB 5	90 43.78	26 27.01	36	in use
B14	90 44.02	26 26.37	30	in use
B15	90 45.83	26 26.00	71	IN use
B16	90 41.10	26 19.97	35	in use
B17	30 m NW from W Lentisinga LPS	30 m NW from W L LPS	-	In use
B18	30 m NW from W Lentisinga LPS	30 m NW from W L LPS	-	In use
B19	90 43.094	26 19.123	31	Has been replaced by B20
B20	see B19	see B19	31	In use
B21	90 43.372	26 19.146	49	In use
HB 6	91 39.92	26 20.14	42	In use
HB 7	90 39.92	26 20.14	42	In use
B22	90 39.915	26 20.138	42	In use
HB 8	90 39.92	26 20.14	42	In use
B23	90 30.44	26 15.25	26	In use
B24	90 30.157	26 15.396	32	Well painted red, but not sealed
D13	92 02.41	26 27.58	50	In use
D14	92 04.556	26 32.632	54	In use
HD1	92 01.821	26 25.626	50	In use
D15	91 59.374	26 24.615	49	Not used, needed for PWSS
HD2	91 57.579	26 26.765	54	In use
D16	91 49.735	26 31.948	59	In use
D17	91 49.689	26 32.687	62	In use
B25	90 39.05	26 27.342	42	in use
B26	90 40.02	26 18.19	23	in use
FB26	90 40.02	26 18.19	23	newly poured
B27	90 38.86	26 15.25	35	in use
B28	90 36.92	26 14.22	43	in use
B29	90 36.90	26 14.01	46	in use
FB29	90 36.90	26 14.01	46	newly poured
HB9	90 36.639	26 14.117	28	not in use
B30	90 36.639	26 14.117	28	in use
B31	90 33.711	26 13.496	33	in use
B32	90 33.11	26 18.57	23	in use
B33	90 33.11	26 18.57	23	not in use (?)
B34	90 33.11	26 18.57	23	in use (?)

Appendix 1. Field parameters, general information on the tested wells

SampleID	**pH**	**Eh** (mV)	**Cond** (µS/cm)	**Temp** (°C)	**As Hach** (µg/l)
D1	6,6	30 (10 min)	200	22,5	around 50
D2	6,7	-39	130	22,5	25-50
D3	7,0	60	140	22	around 50
D4	7,4	-65	180	23	0
D5	7,1	-75	100	22,5	0
D7	7,6	-110	560	22,5	50+
D8	6,9	-72	170	22,5	70+
D9	6,5	-72	240	22,5	20
D10	6,8	-72	240	22,5	65+
D11	6,6	-85	220	22,5	50
D12	6,6	-70	160	22,5	90
B1	6,9	-89	680	-	90
B2	7,0	-111	620	-	70
B3	7,0	-116	540	-	50
B4	7,1	-93	340	-	10
B5	7,3	-104	410	-	50
B6	7,0	-116	580	-	<50
B7	7,0	-114	540	-	>50
B8	6,8	-78	590	-	80
B9	6,9	-112	620	-	100
B10	6,9	-105	540	-	90
HB1	6,1	135	160	-	0
HB2	6,7	133	170	-	0
B11	7,0	-37	320	-	10
B12	6,8	31	300	-	?
B13	6,8	-67	380	-	25
HB 3	7,1	100	230	-	0
HB 4	6,9	-3	320	-	0
HB 5	6,8	-49	380	-	0
B14	6,8	-27	490	-	(10-25)
B15	7	-37	230	-	0
B16	7	-71	200	-	0
B17	6,9	-94	580	-	100
B18	7,2	25	550	-	10
B19	6,8	-107	690	-	more than 100
B20	7	-76	500	-	50, 40 in filtered water
B21	6,8	-112	590	-	<50
HB 6	not taken	not taken	not taken	-	0
HB 7	not taken	not taken	not taken	-	0 (used strip)
B22	6,9	-120	520	-	more than 100
HB 8	7	-97	400	-	25
B23	7	-27	460	-	85
B24	6,9	-97	550		mer an 100
D13	6,8	26	150	22,5	0
D14	6,4	-36	130	22	25-okt
HD1	6,9	-69	150	22	25
D15	6,4	-34	200	22	10 wet,0 dry
HD2	6,7	-43	180	22,5	0
D16	6,7	-57	170	21	50-100(uneven)
D17	6,7	-66	130	21,5	50
B25	6,8	54	230	23	0
B26	6,9	-107	450	23	100
FB26	-	-	-	-	25
B27	7,2	-93	350	23,5	80
B28	6,6	58	170	22	0
B29	6,9	-82	450	23	250-500
FB29	-	-	-	-	60
HB9	6,8	-107	450	23	250-500 (450)
B30	6,9	-112	430	23	500
B31	6,2	104	220	23	0
B32	6,9	30	430	23	10 to 25
B33	7,1	11	340	23	0
B34	6,9	-90	470	23	60

Appendix 1. Field parameters, general information on the tested wells

SampleID	Comment_station
	-
D1	-
D2	-
D3	-
D4	-
D5	-
D7	-
D8	-
D9	-
D10	-
D11	-
D12	-
B1	-
B2	-
B3	-
B4	-
B5	-
B6	-
B7	-
B8	-
B9	-
B10	-
HB1	Samples not taken
HB2	Samples not taken
B11	-
B12	No filter for Iron used (low)
B13	-
HB 3	Samples not taken
HB 4	Samples not taken
HB 5	Samples not taken
B14	-
B15	Was joined with Aie last year." Aie changes course a lot" "No iron"
B16	-
B17	-
B18	Water that has been filtered.
B19	-
B20	Hach taken 03/11/05
B21	Hach taken 03/11/05
HB 6	Televerket, Samples not taken
HB 7	Big water scheme, Samples not taken
B22	-
HB 8	Near Mosque, toilets quite nearby, Samples not taken
B23	On a riverine island of the Bhramaputra, formed 50 years ago.
B24	On a riverine island of the Bhramaputra, formed 50 years ago.
D13	-
D14	Nest to SOS childerns village, Scheme filter not tested
HD1	there are toilets close to well, Samples not taken
D15	-
HD2	Samples not taken
D16	-
D17	-
B25	No iron in water
B26	High iron content, Hach test fron filterde water and filter medium sample taken
FB26	Fe filter
B27	Next to old tributary
B28	-
B29	-
FB29	Fitlered water from B29, Samples not taken
HB9	not in use cause of turbid water, Samples not taken
B30	20 m eastward of HB9
B31	close to riverbank of Brahmaputra
B32	B32, B33, B34 within 15 m
B33	5 m from B32
B34	15 m from B32

Appendix 2. Cation analysis, groundwater samples analysed by ICP-OES.

Detection limit	0,679	5,2	5,2	5,2	1,25	0,472	0,093	0,161	0,89
Unit	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)
Sample/Element	Al	As (tot)	As (III)	As (V)	B	Ba	Be	Ca	Cd
B1	18,19	53,17	50,69	2,48	21,06	159,68	<0.093	132641,00	<0.890
B2	11,48	24,68	25,05	-	25,82	178,28	<0.093	140299,00	<0.890
B3	7,69	27,01	23,70	3,31	22,00	115,43	<0.093	121847,00	<0.890
B4	7,38	<5.20	<5.20	<5.20	19,19	72,10	<0.093	62162,30	<0.890
B5	12,17	33,63	32,60	1,03	12,66	77,35	<0.093	73883,30	<0.890
B6	11,92	10,57	10,90	-	21,05	150,91	<0.093	125433,00	<0.890
B7	12,94	30,25	25,84	4,41	24,04	169,53	<0.093	128114,00	<0.890
B8	11,68	24,41	26,19	-	21,66	138,13	<0.093	132988,00	<0.890
B9	17,92	134,25	130,09	4,16	32,27	161,89	<0.093	120897,00	<0.890
B10	11,66	92,78	89,88	2,89	28,57	207,87	<0.093	101626,00	<0.890
B11	9,26	<5.20	<5.20	<5.20	10,42	42,38	<0.093	44958,50	<0.890
B12	5,31	<5.20	<5.20	<5.20	9,03	39,47	<0.093	36781,00	<0.890
B13	8,64	9,86	9,41	0,45	15,11	44,67	<0.093	49502,80	<0.890
B14	8,99	5,30	<5.20	<5.20	12,27	54,23	<0.093	88455,80	<0.890
B15	19,94	<5.20	<5.20	<5.20	10,79	43,96	<0.093	54477,60	<0.890
B16	18,09	<5.20	<5.20	<5.20	23,93	20,62	<0.093	9931,33	<0.890
B17	5,90	103,11	99,26	3,85	23,19	166,64	<0.093	118149,00	<0.890
B18	10,00	12,09	<5.20	<5.20	13,40	126,17	<0.093	121162,00	<0.890
B19	9,32	130,53	129,17	1,36	35,25	353,83	<0.093	132384,00	<0.890
B20	8,19	55,22	52,62	2,61	19,08	122,24	<0.093	109702,00	<0.890
B21	8,31	49,85	51,79	-1,94	27,75	184,23	<0.093	99596,60	<0.890
B22	9,89	105,37	103,41	1,96	26,68	186,40	<0.093	139605,00	<0.890
B23	8,08	15,09	14,19	0,89	16,06	106,32	<0.093	118139,00	<0.890
B24	30,80	234,95	227,55	7,40	24,33	124,77	<0.093	204883,00	<0.890
B25	9,82	<5.20	<5.20	<5.20	7,95	53,15	<0.093	29201,90	<0.890
B26	10,04	90,89	-	-	25,60	185,04	<0.093	85992,40	<0.890
B27	11,28	18,75	16,96	1,79	13,27	84,62	<0.093	69766,90	<0.890
B28	4,26	<5.20	<5.20	<5.20	10,38	43,86	<0.093	13616,60	<0.890
B29	7,26	428,11	416,31	11,80	23,46	121,63	<0.093	126286,00	<0.890
B30	13,38	606,43	591,44	14,99	31,08	181,99	<0.093	139241,00	<0.890
B31	7,08	<5.20	<5.20	<5.20	9,86	31,10	<0.093	24190,00	<0.890
B32	14,33	<5.20	<5.20	<5.20	13,62	116,64	<0.093	126734,00	<0.890
B33	11,20	<5.20	<5.20	<5.20	12,30	82,16	<0.093	84859,90	<0.890
B34	30,43	23,04	24,09	-	34,51	184,92	<0.093	177522,00	<0.890
D1	2,76	33,41	31,59	1,82	19,17	70,69	<0.093	10998,30	<0.890
D2	3,08	46,14	46,44	-0,30	19,04	54,47	<0.093	8280,71	<0.890
D3	2,04	57,25	53,75	3,50	15,19	64,36	<0.093	7581,49	<0.890
D4	2,69	<5.20	<5.20	<5.20	11,58	46,48	<0.093	12260,90	<0.890
D5	1,55	<5.20	<5.20	<5.20	15,27	65,88	<0.093	8377,21	<0.890
D7	5,05	41,80	39,80	2,00	10,88	69,44	<0.093	30436,30	<0.890
D8	2,67	79,07	77,81	1,26	35,99	120,53	<0.093	8605,28	<0.890
D9	2,90	56,14	51,99	4,15	46,05	231,67	<0.093	12592,50	<0.890
D10	2,20	13,55	11,18	2,37	23,84	102,75	<0.093	11210,40	<0.890
D11	4,77	46,22	50,34	-4,12	26,31	71,65	<0.093	16540,30	<0.890
D12	3,27	58,00	57,31	0,69	25,56	60,71	<0.093	16324,50	<0.890
D13	4,27	<5.20	<5.20	<5.20	8,98	36,35	<0.093	19975,10	<0.890
D14	1,05	5,31	5,97	-	15,17	58,20	<0.093	7959,45	<0.890
D15	11,84	<5.20	<5.20	<5.20	30,49	112,66	<0.093	10169,60	<0.890
D16	10,11	63,46	59,59	3,86	18,16	60,25	<0.093	9534,19	<0.890
D17	6,45	46,90	45,51	1,39	17,93	63,79	<0.093	9285,08	<0.890

Appendix 2. Cation analysis, groundwater samples analysed by ICP-OES.

Detection limit	0,95	0,481	0,341	0,803	0,84	0,97	1,776	0,06
Unit	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)
Sample/Element	Co	Cr	Cu	Fe	K	La	Li	Mg
B1	<0.950	<0.481	<0.341	4575,29	3754,12	13,11	2,76	35835
B2	<0.950	<0.481	<0.341	11970	4689,74	14,02	4,15	38722,4
B3	<0.950	<0.481	<0.341	8202,56	3480,70	11,65	3,49	32131,7
B4	<0.950	<0.481	<0.341	2467,5	2772,31	8,87	<1.776	22515,6
B5	<0.950	<0.481	<0.341	1585,635	5624,31	10,74	<1.776	21631,7
B6	<0.950	<0.481	<0.341	8113,105	5679,32	13,08	<1.776	33905,3
B7	<0.950	<0.481	<0.341	11132,4	6534,75	12,63	4,03	35282,6
B8	<0.950	<0.481	<0.341	10381,85	5353,97	12,79	3,71	36858
B9	<0.950	<0.481	<0.341	17597	8287,42	10,83	4,07	32403,5
B10	<0.950	<0.481	<0.341	15839,85	7151,83	10,99	5,76	27179
B11	<0.950	<0.481	<0.341	697,964	3745,47	9,07	<1.776	22374
B12	<0.950	<0.481	<0.341	379,1565	1737,56	8,12	<1.776	21485,8
B13	<0.950	<0.481	<0.341	5078,89	3011,54	8,23	<1.776	27873
B14	<0.950	<0.481	<0.341	2072,215	2798,48	12,12	<1.776	39924,3
B15	<0.950	<0.481	<0.341	1564,815	2790,16	11,16	<1.776	20305,5
B16	<0.950	<0.481	<0.341	17363,05	799,57	3,59	<1.776	7343,67
B17	<0.950	<0.481	<0.341	11137,75	7843,34	12,12	2,59	29634,3
B18	<0.950	<0.481	<0.341	27,0611	8099,70	12,49	2,77	29774,3
B19	<0.950	<0.481	<0.341	20787,2	13192,35	15,03	8,22	39064,9
B20	<0.950	<0.481	<0.341	7020,125	6531,45	12,64	1,89	27367,3
B21	<0.950	<0.481	<0.341	11127,1	19626,00	13,53	5,29	35822,5
B22	<0.950	<0.481	<0.341	15371,2	7511,35	12,45	4,68	25730,7
B23	<0.950	<0.481	<0.341	943,6005	6162,96	15,36	2,54	28092,1
B24	<0.950	<0.481	<0.341	5193,94	7949,97	15,47	1,88	30069,5
B25	<0.950	<0.481	<0.341	175,2635	3250,60	8,09	<1.776	15462,3
B26	<0.950	<0.481	<0.341	17440,9	3958,63	13,11	5,40	29205,6
B27	<0.950	<0.481	<0.341	1932,97	4291,03	14,46	<1.776	22868,8
B28	<0.950	<0.481	<0.341	157,339	1193,29	4,70	<1.776	6575,7
B29	<0.950	<0.481	<0.341	9064,615	6803,15	12,92	5,71	24948,1
B30	<0.950	<0.481	<0.341	16506,75	7968,99	17,81	4,13	28596,9
B31	<0.950	<0.481	<0.341	504,469	865,22	7,59	<1.776	15225,5
B32	<0.950	<0.481	<0.341	319,186	6667,08	15,28	3,53	34218
B33	<0.950	<0.481	<0.341	223,2525	5534,84	14,15	2,21	24706,8
B34	<0.950	<0.481	<0.341	10528,6	6983,04	15,36	3,93	35834,7
D1	<0.950	<0.481	<0.341	11666,2	1297,72	3,35	<1.776	5030,47
D2	<0.950	<0.481	<0.341	10461,8	1027,29	3,52	<1.776	3671,76
D3	<0.950	<0.481	<0.341	5552,15	1146,05	2,58	<1.776	3114,79
D4	<0.950	<0.481	<0.341	2542,25	1411,80	5,15	<1.776	5077,54
D5	<0.950	<0.481	<0.341	6333,19	1889,10	3,64	<1.776	4745,41
D7	<0.950	<0.481	<0.341	146,521	1157,68	8,88	<1.776	16435,7
D8	<0.950	<0.481	<0.341	33466,75	2551,30	3,42	<1.776	4563,29
D9	<0.950	<0.481	<0.341	43161,85	5169,78	5,30	<1.776	7577,31
D10	<0.950	<0.481	<0.341	18765,85	2180,41	4,86	<1.776	5301,04
D11	<0.950	<0.481	<0.341	21155,1	2795,74	6,72	3,62	7368,12
D12	<0.950	<0.481	<0.341	20759,3	2993,88	5,70	<1.776	5963,93
D13	<0.950	<0.481	<0.341	55,5433	2351,49	8,38	<1.776	8670,74
D14	<0.950	<0.481	<0.341	8724,235	3797,08	3,39	<1.776	3697,55
D15	<0.950	<0.481	<0.341	22716,6	6739,29	4,28	3,80	4694,47
D16	<0.950	<0.481	<0.341	10922,25	1126,17	4,09	<1.776	3764,27
D17	<0.950	<0.481	<0.341	11021,6	1071,41	3,64	<1.776	3833,4

Appendix 2. Cation analysis, groundwater samples analysed by ICP-OES.

Detection limit	0,116	1,89	0,214	2,485	15,872	2,05	11,25	35,745
Unit	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)
Sample/Element	Mn	Mo	Na	Ni	P	Pb	Rb	S
B1	567,63	<1.89	6198,46	<2.49	1103,39	<2.05	<11.25	106,59
B2	616,10	<1.89	9040,47	<2.49	816,62	<2.05	<11.25	68,29
B3	792,38	<1.89	8807,23	<2.49	768,72	<2.05	<11.25	138,40
B4	176,56	<1.89	3988,38	<2.49	781,74	<2.05	<11.25	45,90
B5	636,74	<1.89	2485,57	<2.49	284,80	<2.05	<11.25	44,13
B6	822,02	<1.89	5957,4	<2.49	1038,91	<2.05	<11.25	56,41
B7	1250,43	<1.89	5756,22	<2.49	881,37	<2.05	11,55	53,32
B8	1461,88	<1.89	4434,43	<2.49	357,09	<2.05	<11.25	178,27
B9	1578,40	<1.89	12928,2	<2.49	<15.87	<2.05	<11.25	153,76
B10	1058,57	<1.89	9602,59	<2.49	629,67	<2.05	<11.25	61,24
B11	975,36	<1.89	5723,65	<2.49	18,73	<2.05	<11.25	1459,70
B12	1407,70	<1.89	4748,54	<2.49	<15.87	<2.05	<11.25	2278,42
B13	705,98	<1.89	4412,09	<2.49	324,53	<2.05	<11.25	520,15
B14	341,17	<1.89	6935,38	<2.49	26,84	<2.05	<11.25	298,32
B15	170,17	<1.89	9273,45	<2.49	38,71	<2.05	<11.25	10345,09
B16	1640,67	<1.89	9165,48	<2.49	<15.87	<2.05	<11.25	192,73
B17	1490,34	<1.89	11792,3	<2.49	372,60	<2.05	<11.25	56,09
B18	1106,23	<1.89	12586,9	<2.49	<15.87	<2.05	<11.25	58,77
B19	799,97	<1.89	28034,8	<2.49	692,55	2,57	12,07	117,27
B20	911,46	<1.89	10573,95	<2.49	401,02	<2.05	<11.25	<35.75
B21	1572,53	<1.89	25382,5	<2.49	1339,62	2,19	<11.25	258,20
B22	1652,11	<1.89	5416,32	<2.49	853,88	<2.05	<11.25	43,16
B23	2030,08	<1.89	4836,04	<2.49	<15.87	<2.05	<11.25	7971,03
B24	2428,58	<1.89	4221,33	<2.49	599,00	<2.05	<11.25	946,36
B25	510,41	<1.89	4046,57	<2.49	<15.87	<2.05	<11.25	1414,91
B26	674,05	<1.89	12835,1	<2.49	1291,52	<2.05	<11.25	62,86
B27	300,05	<1.89	6117,58	<2.49	480,51	<2.05	<11.25	1579,94
B28	430,71	<1.89	13679,3	<2.49	<15.87	<2.05	<11.25	189,45
B29	3313,84	<1.89	5221,51	<2.49	125,33	2,28	<11.25	488,04
B30	6028,08	<1.89	4134,79	<2.49	321,22	<2.05	<11.25	5354,43
B31	31,86	<1.89	9143,56	<2.49	<15.87	<2.05	<11.25	691,67
B32	3025,52	<1.89	4101,05	<2.49	<15.87	<2.05	<11.25	6168,29
B33	1338,16	<1.89	3365,09	<2.49	<15.87	<2.05	<11.25	2564,17
B34	2171,46	<1.89	5874,11	<2.49	365,10	<2.05	<11.25	207,20
D1	859,39	<1.89	19885,9	<2.49	1272,51	<2.05	<11.25	38,70
D2	362,18	<1.89	17093	<2.49	1167,25	2,23	<11.25	<35.75
D3	178,31	<1.89	25406	<2.49	1358,33	<2.05	<11.25	47,25
D4	224,70	<1.89	14623,2	<2.49	358,30	<2.05	<11.25	2588,87
D5	422,42	<1.89	16286,2	<2.49	866,28	<2.05	<11.25	1037,14
D7	210,35	<1.89	67292,3	<2.49	741,95	<2.05	<11.25	58,91
D8	1256,81	<1.89	7373,27	<2.49	252,16	<2.05	<11.25	58,50
D9	1289,54	<1.89	8860,96	<2.49	1105,03	5,72	<11.25	3943,40
D10	1016,46	<1.89	9130,31	<2.49	49,28	<2.05	<11.25	<35.75
D11	1405,22	<1.89	8396,82	<2.49	1999,89	<2.05	<11.25	82,93
D12	1248,95	<1.89	8433,08	<2.49	878,73	<2.05	<11.25	47,26
D13	2211,60	<1.89	9927,39	<2.49	306,11	<2.05	<11.25	204,73
D14	509,60	<1.89	6193,35	<2.49	728,40	2,21	12,33	326,90
D15	1279,38	<1.89	7705,81	<2.49	1061,75	<2.05	14,98	127,00
D16	299,86	<1.89	16783,9	<2.49	1165,88	<2.05	<11.25	63,62
D17	325,22	<1.89	15355,4	<2.49	1217,40	<2.05	<11.25	37,26

Appendix 2. Cation analysis, groundwater samples analysed by ICP-OES.

Detection limit	14,033	5,123	0,011	0,117	1,12	0,127	0,087	1,116	0,336
Unit	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)
Sample/Element	Se	Si	Sr	Ti	V	Y	Yb	Zn	Zr
B1	<14.03	12823,5	188,23	1,043	<1.120	<0.127	0,219	54,01	<0.336
B2	<14.03	10986,75	229,58	0,274	<1.120	<0.127	0,263	32,21	0,517
B3	<14.03	11780,8	203,08	<0.117	<1.120	<0.127	0,225	51,49	0,544
B4	<14.03	13027,2	98,17	<0.117	<1.120	<0.127	0,089	407,02	<0.336
B5	<14.03	5664,06	98,06	<0.117	<1.120	0,129	0,116	24,52	<0.336
B6	<14.03	9768,00	232,261	0,120	<1.120	<0.127	0,220	59,08	0,572
B7	<14.03	9740,58	230,131	0,270	<1.120	<0.127	0,230	83,11	1,02
B8	<14.03	8929,8	114,43	<0.117	<1.120	<0.127	0,212	60,08	0,478
B9	<14.03	9778,48	252,116	0,369	<1.120	<0.127	0,235	25,97	1,07
B10	<14.03	8945,61	199,81	0,124	<1.120	<0.127	0,215	68,60	0,981
B11	<14.03	7626,66	61,99	<0.117	<1.120	0,153	0,110	38,49	<0.336
B12	<14.03	8760,36	48,57	<0.117	<1.120	0,220	<0.087	2502,38	<0.336
B13	<14.03	7006,28	42,03	0,136	<1.120	<0.127	0,104	41,17	0,372
B14	<14.03	11141,05	178,70	<0.117	<1.120	0,136	0,105	76,35	<0.336
B15	<14.03	8694,33	81,91	0,453	<1.120	<0.127	<0.087	71,30	<0.336
B16	<14.03	9970,89	25,35	0,133	<1.120	<0.127	<0.087	382,18	0,698
B17	<14.03	10112,04	241,40	<0.117	<1.120	<0.127	0,195	51,73	0,726
B18	<14.03	9487,435	242,52	<0.117	<1.120	0,130	0,185	28,22	<0.336
B19	<14.03	9767,936	281,44	<0.117	<1.120	<0.127	0,210	18,19	1,76
B20	<14.03	10261,9	225,28	<0.117	<1.120	<0.127	0,200	21,43	<0.336
B21	<14.03	9364,23	146,47	<0.117	<1.120	<0.127	0,154	25,21	0,841
B22	<14.03	10507,25	296,57	<0.117	<1.120	<0.127	0,237	44,45	0,826
B23	<14.03	9906,46	310,07	<0.117	<1.120	0,161	0,193	43,16	<0.336
B24	<14.03	17587,5	474,03	0,731	<1.120	0,201	0,313	19,80	<0.336
B25	<14.03	6069,31	31,40	0,350	<1.120	<0.127	<0.087	40,30	<0.336
B26	<14.03	15195,8	203,42	<0.117	<1.120	<0.127	0,193	99,74	1,62
B27	<14.03	7147,84	67,47	0,141	<1.120	<0.127	0,138	99,96	<0.336
B28	<14.03	16233	74,46	0,146	<1.120	<0.127	<0.087	158,66	<0.336
B29	<14.03	13266,05	352,79	<0.117	<1.120	<0.127	0,237	31,04	0,385
B30	<14.03	14908,25	622,77	<0.117	<1.120	<0.127	0,316	78,72	0,912
B31	<14.03	13990,5	72,91	0,239	<1.120	<0.127	<0.087	156,46	<0.336
B32	<14.03	9473,59	313,14	0,308	<1.120	0,143	0,239	237,10	<0.336
B33	<14.03	7434,98	200,04	<0.117	<1.120	0,139	0,141	53,57	<0.336
B34	<14.03	10176,85	470,94	1,065	<1.120	0,181	0,316	409,81	0,791
D1	<14.03	18839,6	91,98	<0.117	<1.120	<0.127	<0.087	459,96	0,902
D2	<14.03	19332,1	67,10	<0.117	<1.120	<0.127	<0.087	495,72	0,894
D3	<14.03	16104,7	54,47	<0.117	<1.120	<0.127	<0.087	825,73	<0.336
D4	<14.03	22023,8	78,98	<0.117	<1.120	<0.127	<0.087	21,38	<0.336
D5	<14.03	19559,5	57,33	<0.117	<1.120	<0.127	<0.087	1437,87	0,439
D7	<14.03	7092,23	179,33	<0.117	<1.120	<0.127	<0.087	8,26	<0.336
D8	<14.03	13188,85	79,33	<0.117	<1.120	<0.127	<0.087	904,22	2,93
D9	<14.03	11308	80,24	0,126	<1.120	<0.127	0,100	155,91	4,04
D10	<14.03	16396,1	86,17	<0.117	<1.120	<0.127	<0.087	10774,95	1,62
D11	<14.03	23049,2	58,44	<0.117	<1.120	<0.127	<0.087	95,46	1,73
D12	<14.03	18308,8	74,21	0,142	<1.120	<0.127	<0.087	116,50	2,10
D13	<14.03	21913,4	111,75	<0.117	<1.120	<0.127	<0.087	29,36	<0.336
D14	<14.03	18424,5	41,39	<0.117	<1.120	<0.127	<0.087	22,06	1,08
D15	<14.03	15959,5	72,67	<0.117	<1.120	<0.127	<0.087	1470,14	2,31
D16	<14.03	20331	74,52	0,193	<1.120	<0.127	<0.087	94,69	0,724
D17	<14.03	20269,7	73,10	<0.117	<1.120	<0.127	<0.087	33,34	0,915

Appendix 3. Results from groundwater samples analysed with Ion Cromatograph and flow injection analysis.

Sample ID	NH4-N (µg/l)	PO4-P (µg/l)	NPOC (mg/l)	NH4 (mg/l)	PO4 (mg/l)	HCO3 (mg/l)	Cl mg/l	NO3 mg/l	SO4 mg/l	F mg/l
B1	776	975	2,38	0,997	2,988	493,29	6,06	0,08	0,38	0,2209
B2	722	628	3,43	0,928	1,924	147,30	10,63	0,02	0,25	0,2438
B3	870	687	1,75	1,119	2,105	135,83	8,94	0,10	0,33	0,2542
B4	554	695	1,35	0,712	2,130	105,08	3,92	0,10	0,07	0,3107
B5	53	280	0,92	0,068	0,858	114,96	1,73	0,00	0,69	0,179
B6	557	892	1,51	0,716	2,732	184,04	3,68	0,05	0,07	0,1967
B7	738	763	1,47	0,949	2,339	145,23	3,22	0,05	0,07	0,1102
B8	126	342	0,76	0,161	1,048	127,78	0,62	0,10	0,51	0,1297
B9	5313	78	2,28	6,831	0,240	139,49	20,33	0,01	0,25	0,226
B10	3703	574	2,16	4,761	1,760	114,84	16,85	0,01	0,09	0,1388
B11	0	80	0,34	0,000	0,245	64,56	1,34	0,02	4,25	0,1892
B12	0	6	0,56	0,000	0,017	57,48	0,56	0,02	6,35	0,2217
B13	337	307	0,93	0,433	0,940	74,57	5,00	0,09	1,33	0,2392
B14	111	85	0,85	0,143	0,262	120,70	3,20	0,00	0,85	0,1412
B15	2	87	0,48	0,002	0,267	62,61	0,35	0,04	29,80	0,1667
B16	62	0	0,39	0,079	0,000	89,21	0,43	0,04	0,46	0,4262
B17	2225	353	1,59	2,860	1,081	128,39	14,63	0,07	0,29	0,1666
B18	1278	25	1,8	1,643	0,076	130,70	15,19	3,79	0,24	0,1734
B19	7245	654	4,18	9,315	2,004	164,39	69,13	0,39	0,12	0,1386
B20	596	370	1,77	0,766	1,134	122,53	3,96	0,04	0,51	0,2011
B21	5125	1241	4,15	6,589	3,802	126,31	50,84	0,14	0,52	0,278
B22	979	789	1,54	1,259	2,418	138,39	8,45	0,07	0,19	0,2165
B23		60	0,94	0,000	0,184	121,06	1,96	0,03	24,08	0,0915
B24	629	574	2,8	0,809	1,760	193,19	2,15	0,25	2,44	0,2465
B25	0	21	1,05	0,000	0,065	113,86	2,86	0,05	3,95	0,353
B26	2692	1170	2,39	3,461	3,586	84,45	18,45	0,03	0,24	0,2375
B27	0	459	0,81	0,000	1,407	83,60	5,34	0,00	4,74	0,285
B28	504	58	0,42	0,648	0,176	108,49	0,71	0,49	0,72	0,5385
B29	1372	180	1,47	1,764	0,550	135,95	0,86	0,00	1,30	0,3473
B30	1664	337	1,61	2,140	1,033	143,89	3,20	0,10	15,87	0,3239
B31	0	29	0,54	0,000	0,088	75,05	2,60	0,00	1,99	0,2515
B32	71	24	3,41	0,091	0,074	136,93	7,07	0,51	18,02	0,0845
B33	0	11	1,39	0,000	0,035	96,41	3,52	?	?	0,0994
B34	99	338	3,01	0,128	1,036	178,18	3,51	1,80	4,52	0,0127
D1	224	1145	1,32	0,288	3,508	116,06	0,97	0,24	0,37	0,5141
D2	417	1009	1,55	0,536	3,092	81,28	0,25	0,01	0,06	0,7372
D3	386			0,497	0,000	54,67	0,68	0,14	0,13	0,924
D4	0	365	0,56	0,000	1,117	92,51	0,40	0,00	6,95	0,3935
D5	64	771	1,74	0,082	2,364	93,36	3,62	0,24	3,36	0,5723
D7	405	717	1,97	0,521	2,197	381,74	0,09	0,09	1,10	1,3509
D8	919	232	1,53	1,181	0,710	71,03	1,39	0,06	0,05	0,5074
D9	426	943	2,58	0,547	2,891	56,63	22,87	1,19	10,63	0,2873
D10	619	82	1,25	0,796	0,250	91,90	1,24	0,10	0,00	0,4876
D11	1015	1714	3,44	1,305	5,251	104,83	2,54	0,51	0,13	1,0612
D12	1439	763	1,53	1,851	2,339	97,02	4,38	0,09	0,00	0,8605
D13	0	334	1,2	0,000	1,023	135,10	0,93	0,00	0,51	0,525
D14	144	653	1,1	0,185	2,000	56,14	2,37	0,26	0,85	0,3095
D15	284	916	1,94	0,365	2,807	75,30	7,63	0,11	0,22	0,211
D16	1178	1049	1,96	1,515	3,215	98,49	0,34	0,03	0,12	0,8876
D17	1156	1091	1,72	1,486	3,344	93,24	0,26	0,08	0,07	0,7551
median	503,86	370,06	1,53	0,60	1,13	114,35	3,20	0,07	0,51	0,25

Appendix 4. Molar ratios

Sample ID	As (mmol/l)	Fe (mmol/l)	Ratio Fe/As	Mg+Ca (mmol/l)	HCO3 (mmol/l)	Ratio HCO3/(Ca+Mg)
D1	0,00	0,21	468,8	0,25	1,90	7,6
D2	0,00	0,19	304,4	0,19	1,33	7,2
D3	0,00	0,10	130,2	0,17	0,90	5,4
D4	0,00	0,05	-	0,27	1,52	5,6
D5	0,00	0,11	-	0,20	1,53	7,5
D7	0,00	0,00	4,7	0,73	6,26	8,6
D8	0,00	0,60	568,3	0,20	1,16	5,7
D9	0,00	0,77	1032,3	0,31	0,93	3,0
D10	0,00	0,34	1860,1	0,26	1,51	5,9
D11	0,00	0,38	614,5	0,37	1,72	4,6
D12	0,00	0,37	480,5	0,35	1,59	4,6
D13	0,00	0,00	-	0,44	2,21	5,0
D14	0,00	0,16	2204,7	0,18	0,92	5,1
D15	0,00	0,41	-	0,23	1,23	5,3
D16	0,00	0,20	231,1	0,21	1,61	7,8
D17	0,00	0,20	315,5	0,20	1,53	7,5
B1	0,00	0,08	115,5	2,62	8,09	3,1
B2	0,00	0,21	651,2	2,78	2,41	0,9
B3	0,00	0,15	407,8	2,39	2,23	0,9
B4	0,00	0,04	-	1,31	1,72	1,3
B5	0,00	0,03	63,3	1,48	1,88	1,3
B6	0,00	0,15	1031,0	2,47	3,02	1,2
B7	0,00	0,20	494,2	2,54	2,38	0,9
B8	0,00	0,19	571,2	2,64	2,09	0,8
B9	0,00	0,32	176,0	2,38	2,29	1,0
B10	0,00	0,28	229,2	2,00	1,88	0,9
B11	0,00	0,01	-	1,05	1,06	1,0
B12	0,00	0,01	-	0,90	0,94	1,0
B13	0,00	0,09	691,8	1,20	1,22	1,0
B14	0,00	0,04	525,2	1,99	1,98	1,0
B15	0,00	0,03	-	1,16	1,03	0,9
B16	0,00	0,31	-	0,27	1,46	5,5
B17	0,00	0,20	145,0	2,29	2,10	0,9
B18	0,00	0,00	3,0	2,34	2,14	0,9
B19	0,00	0,37	213,8	2,66	2,69	1,0
B20	0,00	0,13	170,7	2,13	2,01	0,9
B21	0,00	0,20	299,7	2,10	2,07	1,0
B22	0,00	0,28	195,9	2,57	2,27	0,9
B23	0,00	0,02	84,0	2,27	1,98	0,9
B24	0,00	0,09	29,7	3,65	3,17	0,9
B25	0,00	0,00	-	0,69	1,87	2,7
B26	0,00	0,31	257,6	1,79	1,38	0,8
B27	0,00	0,03	138,4	1,44	1,37	1,0
B28	0,00	0,00	-	0,31	1,78	5,7
B29	0,01	0,16	28,4	2,35	2,23	0,9
B30	0,01	0,30	36,5	2,61	2,36	0,9
B31	0,00	0,01	-	0,61	1,23	2,0
B32	0,00	0,01	-	2,50	2,24	0,9
B33	0,00	0,00	-	1,70	1,58	0,9
B34	0,00	0,19	613,6	3,31	2,92	0,9

Appendix 5. Sediment classifications, color and texture of sediment samples.

Well ID	Depth (feet)	Munsell Color Code	Munsell Classification	Texture
B1				
(moist samples)	0-10	Hue Y5 4/2	Grayish Olive	clay
	10_15	Hue Y5 4/1	Gray	silt
	15-20	Hue Y5 4/2	Grayish Olive	clay
	20-25	Hue Y5 4/1	Gray	silt
	25-30	Hue Y5 3/4	Dark Olive	clay
	30-35	Hue 5GY 4/1	Dark Olive Gray	silt
	35-40	Hue 10Y 3/2	Olive Black	silt
	40-45	Hue 7.5Y 3/1	Olive Black	clay
	45-50	Hue 10G 4/2	Dark Greenish Gray	sand
	50-55	Hue 10G 4/2	Dark Greenish Gray	medium sand
	55-60	Hue 10G 4/2	Dark Greenish Gray	fine sand
	60-65	Hue 10G 4/2	Dark Greenish Gray	medium sand
	65-85	Hue 10G 4/2	Dark Greenish Gray	Finer than 50/55, coarser than 55/60

Well ID	Depth (feet)	Munsell Color Code	Munsell Classification	Texture
B1				
(dried samples)	0-10	Hue 5Y 7/1	Ligth gray	clay
	10_15			silt
	15-20	Hue 5Y 7/1 and Hue 2.5 5/4	Ligth Gray and Yellowish Gray	clay
	20-25			silt
	25-30	Hue 2.5Y 7/3	Ligth yellow	clay
	30-35	Hue 7.5Y 6/1	Gray	silt
	35-40	Hue 7.5Y 6/1	Gray	silt
	40-45	Hue 10Y 6/1	Gray	clay
	45-50	Hue 7.5Y 7/1	Ligth gray	sand
	50-80	Hue 7.5Y 6/1	Gray	fine to medium sand
	80-85	Hue 7.5Y 6/1	Gray	fine to medium sand

Appendix 5. Sediment classifications, color and texture of sediment samples.

Well ID	Depth (feet)	Munsell Color Code	Munsell Classification	Texture
B10				
(moist samples)	0-5	Hue 2.5Y 5/3	Yellowish Gray	clay
	5_10	Hue 7.5Y 4/1	Gray	clay
	10_15	Hue 2.5Y 4/1	Yellowish Gray	clay
	15-20	Hue 5Y 4/1	Gray	clay
	20-50	Hue 10G 4/2	Dark Greenish Gray	sand
	50-60	Hue 10G 4/2	Dark Greenish Gray	Coarser Sand than 20-50
	60-70	Hue 10G 4/2	Dark Greenish Gray	As 20-50
	70-75	Hue 10G 4/2	Dark Greenish Gray	As 50-60
	75-85	Hue 10G 4/2	Dark Greenish Gray	As 20-50
	85-90	Hue 10G 4/2	Dark Greenish Gray	Finer than 20-50
	90-95	Hue 10G 4/2	Dark Greenish Gray	As 20-50
	95-100	Hue 10G 4/2	Dark Greenish Gray	As 85-90
B10				
(dry samples)	0-5	Hue 5Y 7/2	Light Gray	clay
	5_10	Hue 5Y 6/1	Gray	clay
	10_15	Hue 5Y 5/2	Grayish Olive	clay
	15-20	Hue 5Y 7/1	Light Gray	clay
	20-25	Hue 2.5 GY 7/1	Light Olive Gray	sand
	25-50	Hue N 7/0	Grayish White	sand
	50-60	Hue N 7/0	Grayish White	Coarser Sand than 20-50
	60-70	Hue N 7/0	Grayish White	As 20-50
	70-75	Hue N 7/0	Grayish White	As 50-60
	75-85	Hue N 7/0	Grayish White	As 20-50
	85-90	Hue N 7/0	Grayish White	Finer than 20-50
	90-95	Hue N 7/0	Grayish White	As 20-50
	95-100	Hue N 7/0	Grayish White	As 85-90

Appendix 5. Sediment classifications, color and texture of sediment samples.

Well ID	Depth (feet)	Munsell Color Code	Munsell Classification	Texture
D 15 (moist samples)	0-10	Hue 7.5Y 4/1, spots of Hue 10 YR 7/8	Gray, spots: Yellow	clay
	10-20	Hue 2.5Y 5/3	Yellowish Gray	silt
	20-30	Hue 5Y 4/2	Grayish olive	clay
	30-40	Hue 5Y 4/1 segments of 5Y 6/6	gray segments of olive	clay/silt
	40-50	Hue 10Y 5/1	gray	fine/medium sand
	50-60	Hue 7.5 5/1	gray (tinch of yellow)	medium sand
	60-70	Hue N 6/0	gray	coarse sand
	70-80	Hue N 6/0	gray	coarse sand
	80-90	Hue N 6/0	gray	coarse sand
	90-100	Hue N 6/0	gray	coarse sand
D 15 (dry samples)	0-10	Hue 2.5Y 7/1 spots of Hue 10YR 7/8	Light Gray, spots of Yellow Orange	clay
	10-20	Hue 2.5Y 7/2 spots of Hue 10YR 7/8	Grayish Yellow spots of Yellow Orange	silt
	20-30	Hue 2.5Y 7/1	Light Gray	clay
	30-40	Hue 2.5Y 6/1	Yellowish Gray	clay/silt
	40-50	Hue 2.5Y 6/2	Grayish Yellow	fine/medium sand
	50-60	Hue 2.5Y 7/2	Grayish Yellow	medium sand
	60-70	Hue 7.5Y 7/1	Light Gray	coarse sand
	70-80	Hue 7.5Y 7/1	Light Gray	coarse sand
	80-90	Hue 7.5Y 7/1	Light Gray	coarse sand
	90-100	Hue 7.5Y 7/1	Light Gray	coarse sand

Appendix 5. Sediment classifications, color and texture of sediment samples.

Well ID	Depth (feet)	Munsell Color Code	Munsell Classification	Texture
B 30 (moist samples)	0-5	Hue 5Y 5/2	Grayish Olive	clay
	5-10	Hue 5Y 4/2	Gray	clay
	10-15	Hue 5Y 4/1	Gray	clay
	15-20	Hue 5Y 4/1	Gray	clay
	20-25	Hue 5Y 3/1	Olive Black	clay
	25-30	Hue 5Y 4/1	Gray	fine sand
	30-35	Hue 5Y 5/1	Gray	medium sand
	35-40	Hue 5Y 5/1	Gray	medium sand
	40-45	Hue 5Y 5/2	Grayish Olive	medium sand
	45-50	Hue 5Y 5/1	Gray	medium sand
	50-55	Hue 5Y 5/2	Grayish Olive	medium sand
	55-60	Hue 5Y 5/2	Grayish Olive	medium sand
	60-65	Hue 5Y 5/2	Grayish Olive	medium sand
	65-70	Hue 5Y 5/2	Grayish Olive	medium sand
	70-75	Hue 5Y 5/2	Grayish Olive	medium sand
	75-80	Hue 5Y 5/2	Grayish Olive	medium sand
	80-85	Hue 5Y 5/3	Grayish Olive	coarse sand
	85-90	Hue 5Y 5/2	Grayish Olive	medium sand
	90-95	Hue 5Y 5/2	Grayish Olive	medium sand