# Studies on Chemical Effect and Feasibility of Biosensor for Arsenic Detection in Water.

by

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A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Philosophy
in Department of Chemistry

Khulna University of Engineering & Technology
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**June 2011**

**Dedicated**
To
My Beloved parents

**Md. Fakhruddin**
**&**
**Shakila Banu**

# Declaration

This is to certify that the thesis work entitled "Studies on Chemical Effect and Feasibility of Biosensor for Arsenic Detection in Water" has been carried out by Shahnaz Parveen in the Department of Chemistry, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

23.6.11

Signature of Supervisor

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# Acknowledgement

# Approval

This is to certify that the thesis work submitted by Shahnaz Parveen "Studies on Chemical Effect and Feasibility of Biosensor for Arsenic Detection in Water" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Masters of Philosophy in the Department of Chemistry, Khulna University of Engineering & Technology, Khulna, Bangladesh in May 2011.

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## Abstract

220 water samples of different Arsenic (*As*) -affected areas in Bangladesh have been collected for analysis. Of them 58 samples were from Sagordari village of Jessore, 53 from Koyra village of Kolaroa, 56 from Hajigong village of Chandpur and 53 from Arihazar village of Narayangonj district. Various water quality parameters such as, pH, conductivity, chloride, iron content, hardness and dissolved oxygen were analyzed using standard analytical techniques. The suitability of investigated water for drinking and other purposes was also analyzed comparing with standard values. *As* content for the 220 different water samples have been perceived in there different methods, i.e., Merck field test kit, ARSOlux biosensor and ICP-MS methods. To find out an easy, low cost and environmentally friendly method for *As* content in ground water three different methods have been adopted. A comparison has been made among the three different test methods. Effect of different water quality parameters on *As* test methods has been analyzed. The pH range has been found to 6.2 - 8.1. It is seen that most of the samples i.e., 88.6% are alkaline while those of 10.5% are acidic and only 0.9% are neutral in nature. It is seen that only 4.5% samples have conductivity values with in the limit of drinking water range. Rest of the samples has high conductivity values. Of which 78.6% samples have the conductivity ($\sigma$) values of $0.5 \leq \sigma \leq 1.0$ mS/cm and 15.0% samples have that of abnormally high values. The chloride values of the investigated 220 Tube-well (TW) water samples varied from 35.5 – 496.2 ppm. No health-based guideline value is proposed for chloride in drinking-water. Chloride concentrations in excess of about 250 ppm can give rise to detectable taste in water and not suitable for drinking. But the threshold depends upon the associated cations. Consumers can, however, become accustomed to concentrations in excess of 250 ppm. Only 10% samples have the chloride value beyond the mentioned value. In drinking water, iron is seldom found at concentrations greater than 10 ppm. 220 TW water samples have been investigated for the iron content and the results varied from 1.2 – 18.4 ppm. No sample was found less than 0.3 ppm can cause water to turn a reddish brown color is the maximum permissible limit of iron for drinking purpose. Hardness is most commonly expressed as milligrams of calcium carbonate equivalent per liter or ppm, water containing less than 60 ppm generally being considered as soft. 220 TW water samples have been investigated for the determination of hardness. The average value of hardness is 0.74 ppm. It is seen that the minimum value of hardness was found in Chandpur and Narayangonj districts and the value is 0.2 ppm while that of the maximum is 2.6 ppm in Jessore. It is

found that all the samples have hardness value with in drinking water range. 220 TW water samples have been investigated for the determination of dissolved oxygen. The average value of dissolved oxygen is 1.8 ppm. It is seen that the minimum value of dissolved oxygen was found in Narayangonj district and the value is 1.3 ppm while that of the maximum is 3.2 ppm in Chandpur district. The mentioned values of dissolved oxygen of the investigated samples are quite permissible for the drinking purpose.

For *As* test, it is found that ARSOlux biosensor method is inexpensive, accurate, easy and simple. On the other hand Merck field test kit method is expensive, unreliable and environmentally problematic. Arsine gas is produced in Merck field test kit method is environmentally hazardous and carcinogenic. But there is no environmental threat in ARSOlux biosensor method. *As* test results by ARSOlux biosensor and ICP – MS methods are very close to each other. ICP – MS method is accurate and reliable but expensive and laboratory based while both ARSOlux biosensor method and Merck field test kit method are mobile techniques. No Effects of different water quality parameters on *As* test methods were unearthed.

# Contents

# CHAPTER I

## Introduction

### 1.1 Arsenic

Arsenic is the chemical element that has the symbol *As*, atomic number 33. *As* was first documented by Albertus Magnus in 1250 [1]. Elemental *As* is a silver-gray crystalline metallic solid that exhibits low thermal conductivity. The principal of *As* are +3, +5 and -3. Only one stable isotope of *As* having mass 75 (100 percent natural abundance) has been observed. Melting point (at 39.1 MPa), boiling point, density (at 26°C), specific heat are 816 °C, 615 °C, 5,778 kg/m$^3$ and 24.6 J/(mol.K) respectively [2]. Crystal system is hexagonal (rhombohedral) [2]. *As* in water is found in two oxidation states, *As* (III) and *As* (V) [3]. *As* is a naturally occurring element that is widely distributed in the Earth's crust. *As* is classified chemically as a metalloid, having both properties of a metal and a nonmetal; however, it is frequently referred to as a metal. *As* has a long and nefarious history; its very name has become synonymous with poison. It is a heavy metal that exists in three metallic forms, alpha or yellow, beta or black and gamma or grey. It also exists in compounds that may be organic (arsines) or inorganic. *As* is usually found in the environment combined with other elements such as oxygen, chlorine, and sulfur. *As* combined with these elements is called inorganic *As*. It combined with carbon and hydrogen is referred to as organic *As*. Most inorganic and organic *As* compounds are white or colorless powders that do not evaporate. They have no smell, and most have no special taste. Thus, it is difficult to identify if *As* is poison. Inorganic compounds are much more toxic than organic compounds. *As* (III) is considered more toxic than *As* (V), and is generally less mobile. It is ubiquitous in the environment. It ranks 20th in abundance in the earth's crust, 14th in seawater and 12th in the human body [4].

### 1.2 Sources of Arsenic

Arsenic is found in many different places. Sources of *As* can include the soil we walk on, food we eat, the air we breathe, and the water we drink. This is because these sources of *As* are contaminated by other sources. It is also found in certain water supplies and seafood and often contaminates fruits and vegetables particularly rice. *As* occurs naturally in the earth's crust, is also released into the air by volcanoes as well as by commercial and

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industrial processes. The most significant source of commercial *As* is a byproduct for the treatment of copper, lead, cobalt and gold ores. Commercial end uses of *As* include the following: wood preservatives (e.g., chromium copper arsenate); electronics (e.g., semiconductors); medicinals and botanicals [5]; agriculture products (e.g., fungicides, herbicides, pesticides, and silvicides) [6]; desiccants; nonferrous alloys; animal feed additives; glass; ceramics; dyeing and printing. Common *As* compounds are *As*. *As* is a colorless, very poisonous gas that is used as a doping in the semiconductor industry [7], and is used to produce gallium arsenide, (Ga *As)*, which is used in the field of optoelectronic and microwave devices [8].

Arsenic disulfide exists in ruby-red crystals. Today, red glasses typically contain around 61 to 64 percent *As*. *As* trioxide is the most commercially important *As* compound. It is used in pigments, ceramic enamels, aniline colors, decolorizing agent in glass, insecticide, rodenticide, herbicide, sheep and cattle dip, hide preservative, preparation of other *As* compounds. *As* acids are used in various industrial applications. They have been used as corrosion inhibitors for iron and steel, and as additives for motor fuel, agricultural bactericides, herbicides, and fungicides. It is used in manufacture of arsenates, glass making, Wood treating process, defoliant (regulated), desiccant for cotton, soil sterilant.

Arsenic is also used in the tanning industry as a preservative. It is widely used as a weed killer. Other potential exposures to *As* are generally at lower levels and for shorter periods of time than those from past occupational exposures or from highly contaminated drinking water. Hazardous waste sites can be another source of *As* exposure. Copper acetoarsenite was used as a green pigment known under many different names, including 'Paris Green' and 'Emerald Green' [9].

Though human activities were once believed to be the major source of *As* in food and water, natural geological sources of *As* now appear to be a far more significant source.

### 1.3 Effect of Arsenic

Arsenic is one of the most toxic elements that can be found. *As* causes serious bad effect to human health. Symptoms of *As* poisoning begin with headaches, confusion and drowsiness. As the poisoning develops, convulsions and changes in fingernail pigmentation may occur. When the poisoning becomes acute, symptoms may include

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diarrhea, vomiting, blood in the urine, cramping muscles, hair loss, stomach pain, and more convulsions. The organs of the body that are usually affected by *As* poisoning are the lungs, skin, kidneys, and liver. The final result of *As* poisoning is coma or death.

Long-term exposure to *As* in children may result in lower IQ scores. There is also some evidence that exposure to *As* in the womb and early childhood may increase mortality in young adults, thickening and discoloration of the skin; nausea and diarrhea; decreased production of blood cells; abnormal heart rhythm and blood vessel damage; or numbness in the hands and feet.

Reproductive effects of *As* in humans have not been extensively investigated. Evidence from both animal and human studies suggests reproductive toxicity from *As*, but data in humans is still sparse, and the results from laboratory experiments in animals are not conclusive. The evidence from a few human studies suggests that *As* exposure may increase the incidence of pre-clampsia in pregnant women, decrease birth weight of newborn infants and increase in the risk of malformations and stillbirths, as well as that of spontaneous abortions [10 - 11]. Recent laboratory studies suggest an increase in malformations and stillbirths in animals [12 - 13]. The relationship between *As* exposure and other health effects is not clear-cut i.e., heart disease (hypertension related cardiovascular), cancer, stroke (cerebrovascular diseases) chronic lower respiratory diseases, [14 - 21] and diabetes.

## 1.4 Arsenic in water

Arsenic is an odorless and tasteless semi-metal element. It enters into water supplies from natural deposits in the earth or from agricultural and industrial practices. It is naturally a fairly a mobile component. *As* occurs naturally in soil and minerals and it therefore may enter the air, water, and land from wind-blown dust and may get into water from runoff and leaching. *As* may enter lakes, rivers or underground water naturally, when mineral deposits or rocks containing *As* dissolve. *As* may also get into water through the discharge of industrial wastes. In the case of the massive epidemic in Bangladesh the *As* is released to the groundwater through goethite (FeOOH) reduction [19]. This is driven by microbial degradation of buried deposits of peat. The peat acts as an electron donor so that iron oxide reduction can take place. Underground water flowing over *As*-rich rock may become

contaminated with high concentrations of a toxic form of *As*, which can make its way into private wells and public water supplies. It is now generally agreed that the *As* contamination of drinking water in Bangladesh is of geological origin. The *As* derives from the geological strata underlying Bangladesh.

Once in water, the transport and partitioning of *As* will depend upon its chemical form as well as interactions with other materials present. Any soluble forms will move with the water, and can be carried long distances through rivers. However, *As* can also be adsorbed from water onto sediments and soils, particularly clays, iron oxides, aluminum hydroxides, manganese compounds and organic material. Once in sediments, *As* can be released back [22] into the water through chemical and biological interconversions of *As* species.

## 1.5 Background of groundwater drinking

Until the early 1970s, the 100 million-plus inhabitants of Bangladesh and neighboring West Bengal drank from shallow hand-dug wells, canals, rivers and ponds. Surface water sources in Bangladesh have been contaminated with microorganisms, causing a significant burden of disease and mortality, notably cholera, diarrhea, dysentery, typhoid etc. Infants and children suffered from acute gastrointestinal disease resulting from bacterial contamination of stagnant pond water. Diarrheal diseases have long plagued the developing world as a major cause of death, especially in children. Prior to the 1970s, Bangladesh had one of the highest infant mortality rates in the world. Ineffective water purification and sewage systems as well as periodic monsoons and flooding exacerbated these problems. Consequently, during the 1970s the United Nations Children's Fund (UNICEF) worked with the Department of Public Health Engineering to install TWs to provide what was apparently a "safe" source of drinking-water for the population. At the time the wells were installed, *As* was not recognized as a problem in water supplies, and therefore standard water testing procedures did not include tests for *As* [23]. For this, infant mortality and diarrheal illness were reduced by fifty percent. Till now groundwater provides safe drinking water to over 97% of the rural population in Bangladesh. Shallow (10-50 meters) groundwater is an alternate drinking water supply. The people of this region got relief significantly from this epidemic because of germ free groundwater. Today there are an estimated 8-10 million TWs in Bangladesh, providing 95 per cent of the drinking water whereas they were only about 50,000 during the British colonial rule. The vast

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majority of these are private TWs that penetrate the shallow alluvial wells to depths typically of 10-60 m. In the south and in the Sylhet Basin from northeast Bangladesh, deep TWs abstract groundwater from depth of 150m or more. *As* contaminated TW water was first detected in Bangladesh in early 1990s. Until the discovery of *As* in the groundwater in 1993, well water was regarded as safe for drinking. The number of people drinking *As*-rich water in Bangladesh has increased dramatically since the 1970s due to well-drilling and population growth. The impact of *As* extends from immediate health effects to extensive social and economic hardship that affects especially the poor.

## 1.6 Arsenic in Groundwater

Under natural conditions, the greatest range and the highest concentrations of *As* are found in groundwater as a result of the strong influence of the water–rock interactions and the favorable physical and geochemical conditions in aquifers for the mobilization and accumulation of *As*. *As* is particularly mobile at pH values typically found in groundwater (pH, 6.5–8.5) under both oxidizing and reducing conditions. Accepted concentrations of *As* in groundwater in most countries are less than 10 µg/L and sometimes substantially lower. However, values quoted in the literature show a very wide range, from < 0.5 to 5000 µg/L. Most high levels of *As* in groundwater are the result of natural occurrences of *As*. Cases of *As* pollution caused by mining are numerous but tend to be localized. *As* can occur in the environment in several oxidation states (−3, 0, +3 and +5) but, in natural waters, is mostly found in inorganic forms as oxyanions of trivalent arsenite (AsIII) or pentavalent arsenate (AsV). Redox potential and pH are the most important factors controlling *As* speciation. Under oxidizing conditions, arsenate is dominant, as the $H_2AsO_4^-$ form at low pH (less than approximately 6.9), or as the $HAsO_4^{2-}$ form at higher pH. Under reducing conditions at pH less than approximately 9.2, the uncharged arsenite species $H_3AsO_3$ predominates. Review [3], focused extensively on the factors that control *As* concentration in groundwater. There are three major types of natural geological condition giving rise to high levels of *As* in ground waters: (i) aquifers composed of rocks or sediments enriched with *As*-containing minerals of geogenic origin, such as sulfide mineralization; (ii) aquifers containing sediments coated with iron oxyhydroxide (FeOOH) phases enriched in *As* through hydrological action, where *As* is mobilized into pore water by reducing conditions; (iii) aquifers enriched in *As* through high rates of evaporation in arid areas, leading to

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increased mineral concentration in groundwater; the *As* is mobile in such aquifers because of the high pH (> 8.5) caused by concentration of alkali and alkali earth metals in solution. Geochemical conditions similar to the alluvial sediments in Bangladesh exist in the Red River alluvial tract in the city of Hanoi, Viet Nam, where FeOOH reduction is thought to have led to the high *As* levels recorded in groundwater [24]. Smedley *et al.* outline that the reducing conditions observed in Bangladesh / West Bengal and Viet Nam aquifers are similar to those in the regions of Taiwan, China, northern China and Hungary that suffer from high levels of *As* in groundwater [3].

## 1.7 Arsenic poisoning due to groundwater drinking

Arsenic contamination of groundwater is a natural occurring high concentration of *As* in deeper levels of groundwater, which became a high-profile problem in recent years due to the use of deep TWs for water supply, causing serious *As* poisoning to large numbers of people. *As* in drinking water remains a global problem. It is estimated that of the 160 million inhabitants of Bangladesh between 35 million and 82 million are at risk of drinking contaminated water [25 - 26]. TWs have been used in Bangladesh since the 1940s [23]. However, the problem of *As* contaminated water has only recently come to light due to the increasing number of TWs used over the past 20 years and the subsequent increase in the number of individuals drinking from them. But it is a matter of regret that though people got rid from one epidemic, groundwater arsenicosis problem has been broken out for last few years. The World Health Organization (WHO) has called it the "largest mass poisoning of a population in history" and a public health emergency [27]. In 1983, the first cases of *As*-induced skin lesions were identified by K.C. Saha then at the Department of Dermatology, School of Tropical Medicine in Calcutta, India [28]. The first patients seen were from West Bengal, but by 1987 several had already been identified who came from neighboring Bangladesh. *As*-poisoned patients were first discovered in Bangladesh in the early 1994. But now it is thought likely that more than six million people in West Bengal and 35 million in Bangladesh are drinking water contaminated with *As*. It gradually emerged that 70 million people drank water which exceeds the WHO guidelines of 10 microgram of *As* per liter, and 30 million drank water containing more than the Bangladesh National Standard of 50 microgram per liter, leading to chronic *As* poisoning [29]. *As* poisoning can lead to skin cancer and excessive growth of keratin on the feet. The

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characteristic skin lesions included pigmentation changes, mainly on the upper chest, arms and legs, and keratoses of the palms of the hands and soles of the feet (Figure- 1.7.1). Various internal cancers, skin cancer, cardiovascular and neurological diseases have also been linked to *As* exposure and ingestion. The harmful effects of *As* poisoning are magnified by other health problems such as Hepatitis B or malnutrition. Now *As* is a social and national problem. This problem creates illness as well as handicaps society. Many of them become victim of mental disorders. They think that they are affected by a serious disease or any terrible infection. Even the marriage of an *As* affected girl has been hampered. Today, more than 30 million people in Bangladesh are affected by contaminated water. After ruling out other causes, water sources used by the patients were analyzed, and the diagnosis of *As*-caused disease was confirmed. The primary drinking-water sources for the patients were TWs, which drew water from underground aquifers [28].



Figure- 1.7.1: Growth of skin cancer, keratin on the feet and palms of the hands.

## 1.8 Quantitative data

Bangladesh is a very small country with a total area of 147,570 sq.km and the total population accounts for about 160 millions people. Bangladesh has a large area of surface waters taking the form of the major Padma (Ganges), Jamuna (Brahmaputtra), Meghna Rivers and their tributaries [30]. A summary of their last 8 years survey by School of Environmental Studies (SOES) report on Bangladesh is presented in Table 1.8.1 and Figure- 1.8.1 showed the groundwater *As* contamination status in different districts of Bangladesh.

Table 1.8.1:     Distribution of *As* concentrations in water samples from hand tube-wells

| Total no. of water samples analyzed | Arsenic concentration range (ppm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | < 10 | 10–50 | 51–99 | 100–299 | 300–499 | 500–699 | 700–1000 | > 1000 |
| 34,000 | 14 991 | 6429 | 2949 | 5812 | 2174 | 894 | 479 | 272 |
| | 4.1% | 18.9% | 8.7% | 17.1% | 6.4% | 2.6% | 1.4% | 0.8% |

They have so far analyzed 50,515 hand tube-well water samples from Bangladesh by FI-HG-AAS, of which 43% contained *As* above 10 ppm. and 27.5% *As* above 50ppm. SOES estimation on the basis of 50,515 water samples analyses from Bangladesh shows that at least 32 million people are drinking *As* contaminated water in Bangladesh above 50 ppm.



**GROUNDWATER ARSENIC CONTAMINATION IN BANGLADESH
(10 years study done by SOES-DCH)**
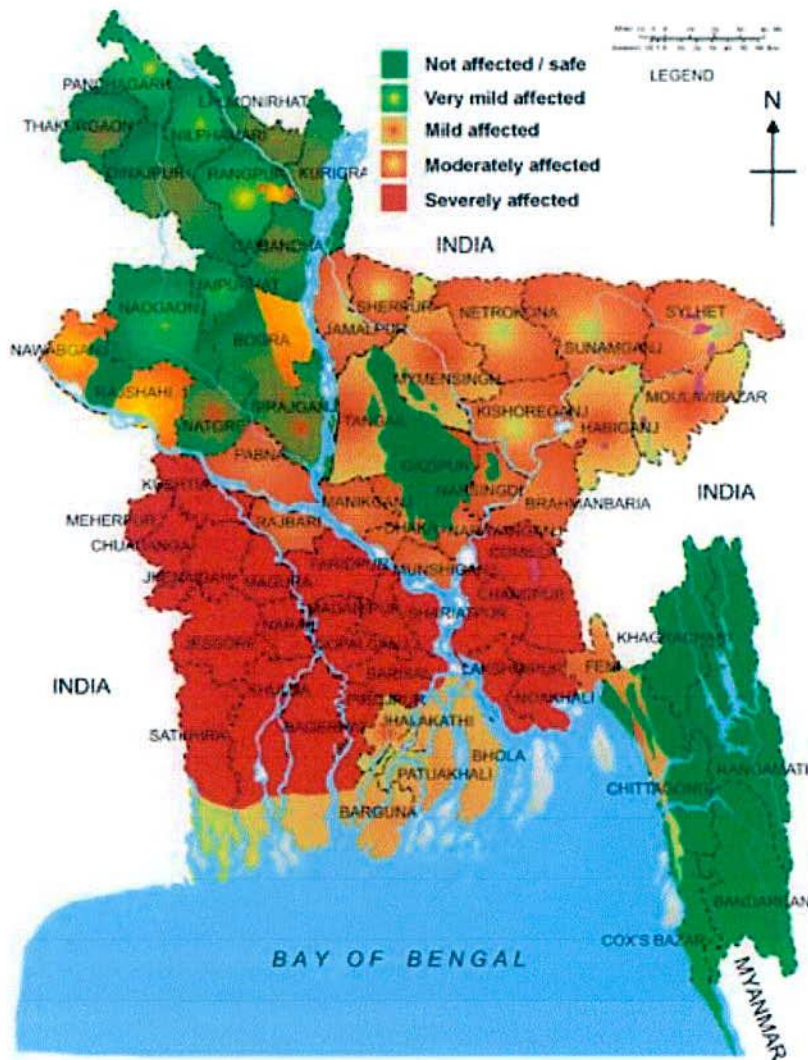
**Figure-1.8.1: Status of contamination of groundwater by arsenic in Bangladesh**

British Geological Survey (BGS) estimated that 35 million people in Bangladesh are at present drinking water contaminated with *As* above 50 ppm. So far they have screened 18,991 people in Bangladesh for arsenical skin lesions from 244 villages and 3,762 (19.8%) have been registered with arsenical skin lesions. Sub-clinically affected individuals were identified from their analyses of 11,000 biological (hair, nail and urine) samples of people living in *As* affected areas and on an average 89% of biological samples from *As* affected districts of Bangladesh have *As* above the normal level. A total of 4.7 million TWs in Bangladesh have been tested and 1.4 million of those were found to contain *As* above the Government drinking water limit of 50 ppm. The highest concentration of *As* measured in drinking-water in Bangladesh was 4700 ppm. In the Chiladi village of Senbagh Thana in the Noakhali district, 100% of TW water samples contained *As* concentrations $\geq$ 50 ppm, 94% contained $\geq$ 300 ppm and 28% contained $\geq$ 1000 ppm. [30]. Combined with another 200,000 unscreened TWs, which are estimated to also exceed this limit, it means that almost one in five TWs is not providing safe drinking water. Approximately 20 per cent of shallow TWs are contaminated. There are more than 8,000 villages where 80 per cent of all TWs are contaminated.

Nearly two million wells were tested for *As* using Merck field test kits, approximately 1.5 million with UNICEF support. The bulk of the testing took place from 2000 through 2003, but in some cases testing continued up to 2006. More than 100,000 safe water sources have been installed in *As* -affected areas between 2000 and 2005. Of these, 14,000 were through UNICEF-supported projects.

Although significant numbers of tube wells were tested for *As* but still a large number of TWs remain untested. Even continuous monitoring of *As* level in ground drinking water is necessary as the ground water is moving and concentration of *As* is changing. Though Merck Field test kits are simple and easy to use but it is available with varying levels of complexity. It is unreliable and environmentally problematic. It required a 30-minutes incubation time while the *As* in the sample is reduced to arsine gas, which is very harmful to the environment and to human health. Its cost is too high. The average price per test between $1.50 to $2.40. Therefore for large number and accurate *As* detection Merck Field test kits method is not so suitable. In this thesis a fast, accurate, less expensive and less

labor intensive method have been searched for *As* detection in water sample. Bacterial biosensors have been taken an interesting alternative, as they are easily produced, simple, and highly accurate devices. The Merck Field test kits method and biosensor method have been validated by ICP-MS method. Different chemical parameters of water samples have been checked. Effect of chemical parameters on the *As* detection method have also been investigated.

# CHAPTER II

## Literature Review

### 2.1 Literature Review

Arsenic contamination in Tube-well water, which serves as the primary source of drinking water in Bangladesh has now been recognized as a serious public health problem [25, 31 – 38]. Groundwater has been the main element for two recent achievements of Bangladesh in the field of access to safe water and food security. Due to extensive use of groundwater from the shallow aquifers of the Bengal Delta Plain in Bangladesh and the ease of TW installation at affordable costs, the number of domestic water supply wells increased many folds over the last three decades and 90 % of these are privately owned [39]. The number of TWs present today is estimated between 8–10 million whereas it was only about 50,000 during the British colonial rule [40]. Most of the hand pumped TWs are installed at depths varying between 20-30 m [41]. The presence of *As*, above the limits of Bangladesh Drinking Water Standard (BDWS, 50 ppm), was detected in groundwater in 1993 [3, 29, 42 - 47]. Since groundwater is the main source of potable water for nearly 98 % of the population, this resulted in a severe environmental disaster, affecting millions of people in the region [43, 47]. The presence of *As* in groundwater in Bangladesh has thus destroyed this decade-long success of provision of safe water, and the access to safe drinking water has now declined to almost 80 % [29].

Elevated *As* concentration exceeding the WHO guideline value for drinking water (10 ppm) [29], is also observed in TW waters in several other regions of the world including Argentina, Australia, Bangladesh, Cambodia, Chile, China, Hungary, Indo-Gangetic Plains of Uttar Pradesh, Bihar and Jharkhand states as well as the Brahmaputra plains of Assam of India, Huhott Alluvial Basin, Inner Mongolia in China, Mexico, Nepal, New Zealand, Pakistan, the Philippines, Taiwan, Thailand, Vietnam, Sweden, Finland, Denmark, Germany, Australia and the United States [3, 43, 44, 48 - 61]. Elevated *As* levels in groundwater have also recently been found in several countries of Latin America, such as in Bolivia, Uruguay, Ecuador, Nicaragua, Honduras, and El Salvador [62 - 65]. Estimates indicate that at least 42 million people worldwide are exposed to drinking water with *As* concentrations in excess of 50 ppm and with more than 100 million people believed to be

exposed to *As* concentrations above the WHO drinking water guideline [3, 29, 60] However, the problem is most acute in the BDP of Bangladesh and in the adjoining state of West Bengal-India, where it has emerged as one of the greatest environmental health disaster of this century. Nearly 70 million people are exposed to elevated *As* concentration from drinking groundwater from shallow TWs in the BDP and many of them have already been diagnosed with symptoms of *As* toxicity.

Arsenic is a naturally occurring poisonous, colorless, tasteless and odorless element and is widely distributed in the crystal rocks [43]. It occurs in the naturally occurring alluvial sediments as a component of different minerals. Generally, TWs installed at shallower depths (15–50 m) is found to be highly contaminated [42, 66 - 67]. Several hypotheses have been suggested for the mechanisms to cause the substantial input of *As* in the groundwater of Bangladesh [47, 56, 60]. The current consensus is that the cause of widespread *As* contamination in the groundwater of the BDP is geogenic. *As* is released in groundwater from the sediments deposited during the Holocene period [43 – 44, 47, 50].

The cause of the widespread *As* occurrences in groundwater of the BDP is a matter of debate. The most widely accepted theory suggests that mobilization of *As* from the alluvial aquifers of the BDP groundwater is primarily due to the mechanism of reductive dissolution of the Fe-oxyhydroxides in the sediments [47, 50, 68]. Pyrite oxidaion was advocated as a mechanism of the release of *As* in the groundwater of the BDP [69]. . However, evidences based on the groundwater chemistry, indicate that *As* is mobilized in the alluvial aquifers under reducing environment, where secondary pyrite is found to be stable. Thus, mobilization of *As* is primarily caused due to the reductive dissolution of the Fe-oxyhydroxides within the sediments, rather than the oxidation of pyrite, as hypothesized by other workers.

The toxic properties of *As* have been known for centuries [60]. In the recent reviews by [70 - 71] it is evident that *As* is a unique carcinogen. It is the only known human carcinogen for which there is adequate evidence of carcinogenic risk by both inhalation and ingestion. Studies carried out by [72] Rahman *et al.* over a seven-year period indicated that *As*-affected patients in West Bengal, India had severe skin lesions. Further, during follow-up visits it was observed that people exposed to high levels of *As* from drinking water and/or foods for many years were frequently developing cancer. The presence of *As* in drinking

water is thus considered as one of the most significant environmental causes of cancer in the world. The consequences of chronic *As* exposure are dependent on the susceptibility, the dose and the duration of exposure. The disease symptoms are termed arsenicosis. Long-term exposure to high levels of *As* leads to public health problems including melanosis, leukomelanosis, hyperkeratosis, black foot disease, cardiovascular disease, hepatomegaly, neuropathy and can lead to cancer or gangrene [73 - 74].

The effect on human health through exposure of naturally occurring (geogenic) *As* in groundwater is due to exposure through three pathways: i) ingestion of *As* through drinking groundwater; ii) ingestion of *As* through cooking processes; and iii) intake of crops irrigated with high *As* groundwater. It has been observed that drinking high *As* groundwater is the primary pathway for exposure of humans [26, 74].

There is no known treatment available for *As* related diseases; drinking *As* -safe water is the only way to avoid *As* poisoning [26, 75 - 76]. As a consequence, out of a total population of 144 millions in the country, about 35 millions are believed to be exposed to *As* concentration in drinking water above 50 ppm, and about 57 million to concentration greater than 10 ppm [77 - 81]. Given the present scenario of safe water status, it would not be possible for Bangladesh as well as other *As* affected regions of the globe to ensure the target of the Millennium Development Goals of ensuring safe drinking water supply to the population by the year 2015, unless necessary measures are taken on an urgent basis to alleviate the crisis.

Though the elevated level of *As* in groundwater in Bangladesh was detected in the early 1990's, it has only been received adequate attention since 1998. The Government of Bangladesh, nongovernmental organizations (NGOs) and donors are working together to address this critical issue. The *As* contamination in the groundwater of Bangladesh poses six major challenges for action:

> ▹ Test all TWs for *As*; there are over eight million such wells in the Bangladesh;
> ▹ Investigate the mechanisms of *As* contamination in groundwater;
> ▹ Raise community awareness about the *As* problem;
> ▹ Identify and treat arsenicosis (the disease caused by *As* poisoning) patients;

> Provide alternative *As*-safe water options which are culturally acceptable, technically feasible, environmentally benign, and affordable by common people; Investigate the impact of *As* contaminated groundwater.

The most daunting challenge among the above is screening all the TWs water through out the country for *As* contamination. Frequent and time to time checking of *As* in TW water is also necessary. So in this thesis advantages and disadvantages of Merck field test kit have been checked. Viability and sustainability of bacteria based biosensor, namely ARSOlux biosensor invented by Helmholtz Center of Environment, Germany have been investigated. Effect of different chemical parameter of water on *As* test have also been studied.

# CHAPTER III

## Experimental

### 3.1 Determination of pH

The pH of water is determined by a pH Meter (Model- HI 96107). For very precise work the pH meter should be calibrated before each measurement. Calibration was performed with two standard buffers at pH 4 and pH 10. After each single measurement, the probe is rinsed with distilled water to remove any traces of the solution being measured, blotted with a clean tissue and thus alter the reading, and then quickly immersed in another solution. And record the reading.

### 3.2 Determination of conductance

Conductivity of a substance is defined as 'the ability or power to conduct or transmit heat, electricity, or sound'. Its units are milliSiemens/cm (mS/cm). Conductivity increases as the concentration of ions increases. The conductivity of a liquid is determined by a conductivity meter (Model- HI 98304). At first the conductivity meter was calibrated with standard KCl solution. Then the reading of the sample was taken.

### 3.3 Determination of chloride

**Principle**: In this method, the chloride of the sample is determined by titration with a standard silver nitrate ($AgNO_3$) solution in the presence of potassium chromate ($K_2CrO_4$) indicator. The chloride is precipitate as a silver chloride (a white precipitate).

$$Cl^- + AgNO_3 = AgCl + NO_3^-$$
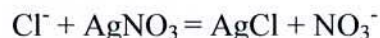
The end point of the titration is reached when a red precipitate of silver chromate first appears owing to the reaction of a slight excess of silver nitrate with potassium chromate.

$$K_2CrO_4 + 2AgNO_3 = Ag_2CrO_4 + 2KNO_3$$
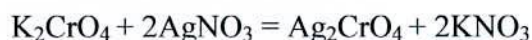
**Reagents:** Potassium chromate indicator, Silver nitrate solution.

50.0 mL of the sample water was taken into a conical flask. 3-5 drops of potassium chromate indicator was added into the flask. Then the solution will turn yellow in color.

Standard silver nitrate was added from a burette until the appearance of first permanent reddish color.

### 3.4 Determination of Iron

**Reagents:** Sulfuric acid ($H_2SO_4$), Potassium permanganate ($KMnO_4$).

25.0 mL of the sample water was taken into a conical flask. A little bit sulfuric acid was added and heated it. Then potassium permanganate was added from a burette. When the color of the solution became pink addition of potassium permanganate solution from the burette was stopped.

### 3.5 Determination of Total Hardness

The hardness of water is generally due to dissolved calcium and magnesium salts and may be determined by complexometric titration.

**Reagents:** Standard Calcium solution, EDTA solution (0.01 M), Buffer solution, Eriochrome Black-T indicator.

25.0 mL of the sample water was taken into a 250 mL conical flask. 2.0 ml buffer solution was added with a pipette and was transferred this into the conical flask. Then 100-200mg (one fifth of a spoon or a pinch) of Eriochrome Black – T was added into it. The solution was turned into wine red in color. After that, EDTA solution was taken in a burette. This solution was added slowly into the conical flask. While doing gently rotate the flask, taking care not to fall the solution. When the color turned to violate EDTA solution was add drop by drop. Addition of the EDTA solution from the burette was stopped when the color of the solution just becomes blue.

### 3.6 Determination of Dissolved Oxygen

Dissolved oxygen analysis measures the amount of gaseous oxygen ($O_2$) dissolved in water. Oxygen gets into water by diffusion from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. During performing the dissolved oxygen test, only grab samples was used, and the analysis has been performed immediately on the experimental sites by portable HI 98186 dissolved oxygen meter.

### 3.7 Arsenic test:

Studies of human exposure to Arsenic and its consequences for human health require two different kinds of *As* analyses depending on whether quantitative or qualitative results are required. Several methods have been developed and improved for the measurement of total *As*, and have been widely used for the evaluation of drinking-water contamination and the resulting concentrations of *As* in humans. The methods used for the analysis of *As* in water samples are described below.

### 3.7.1 Merck Field Test Kit Method

This is done in a controlled reaction between an acidified water sample and zinc powder. A volume-specific reaction vessel, usually a plastic bottle supplied in the test kit, is used for this reaction. At first, the reaction bottle was filled up to the mark. Two drops *As*-1 reagent was added and was swirled. Then one level red dosing spoon *As* -2 reagent was added and was swirled until the reagent is dissolved completely. After that one level green dosing spoon reagent *As* -3 was added and immediately recluse the reaction bottle with the screw cap. The black test strip holder integrated in the screw cap was filled, with the white dot facing outside. Immediately the test strip was inserted into the opening reaction zone first, as far as the mark and flips the test strip holder down completely. Then it kept stand for thirty minutes, swirling two or three times during this period. Any contact between the test strip and the sample solution was avoided. As the *As* converts to arsine gas and comes in contact with the test strip, the mercuric bromide indicator on the test strip changes in color from white to shades of yellow, brown or orange. This chemical reaction varies in time between test kits from 20 to 30 minutes. After 30 minutes the strip was removed, was briefly dipped into the water, excess liquid was shake off and was determined with color comparator chart to obtain a quantitative measure for *As* in the tested sample. The corresponding result was read off in ppm *As*. But kit test is available with varying levels of complexity. Testing for *As* was not as easy as testing for many other ions.

### 3.7.2 Biosensor Test Method

A biosensor namely ARSOlux biosensor has been used to detect Arsenic in water has been successfully applied in the field. Here, Prototype of *As* biosensor has been used, the

development of a set of ARSOlux biosensors based on a nonpathogenic laboratory strain of Escherichia coli DH5α bacteria [invented by Helmholtz center of environment, Germany]. These prototype bacteria absorb *As* and react with the reporter enzyme of bacteria results the emission light as shown in Figure-3.7.2.1. The emission of light is proportional to the absorption of *As* directly. For the experiment, at first, a series of known concentrations of
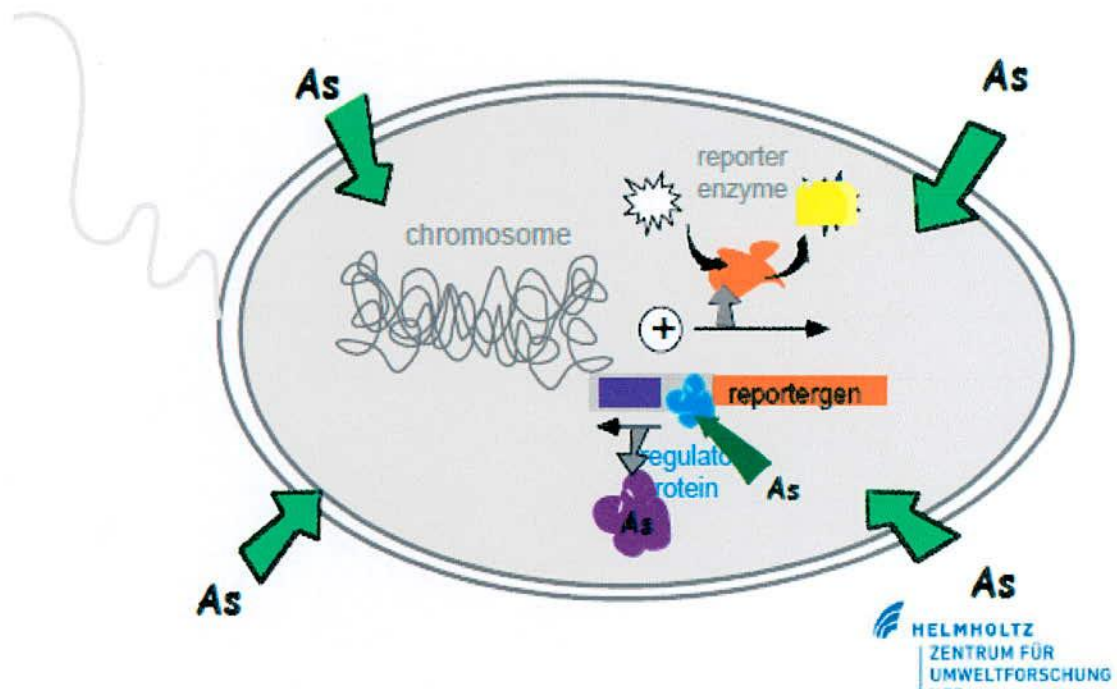


Figure-3.7.2.1: Prototype Escherichia coli DH5α bacteria absorb As and emit luminescence as shown by yellow color.

*As* containing water was prepared for preparation of standard curve. 1.0 mL of each concentration was injected into the biosensor containing vials. Each concentration was duplicated twice. Luminescence of all inoculated biosensor vials was measured after one and two hours incubation with a luminometer. The readings were put into a graph against the known concentrations of *As* and a calibration curve was constructed. Then the water samples were tested in the same procedure; by inoculating 1.0 mL of each in the biosensor vials and measuring luminescence after 1 hour incubation. These were also duplicated. The readings were put in the graph and by comparing with the calibration curve, the concentration of *As* in sample waters were determined.

**3.7.3 Inductively Coupled Plasma–Mass Spectrometry (ICP–MS)**

ICP-MS method has become an invaluable analytical tool for the determinations of trace levels of arsenic. The first step in analysis is the introduction of the sample. This has been achieved in ICP-MS through use of a nebulizer. This is a device which converts liquids into an aerosol, and that aerosol can then be swept into the plasma to create the ions. The carrier gas was argon was sent through the central channel and into the very hot plasma. The sample is then exposed to radio frequency which converts the gas into a plasma. The high temperature of the plasma is sufficient to cause a very large portion of the sample to form ions. A fraction of the formed ions has been passed through a ~1 mm hole (sampler cone) and then a ~0.4 mm hole (skimmer cone). The purpose of which was to allow a vacuum that was required by the mass spectrometer. The vacuum was created and maintained by a series of pumps. The main component to the sample is an internal standard, acted as diluent. This internal standard consists primarily of deionized water, with nitric and Indium. 5 mL of the internal standard was added to a test tube along with 10–500 μL of sample. This mixture was then vortexed for several seconds or until mixed well and then was loaded onto the autosampler tray. Before mass separation, a beam of positive ions has been extracted from the plasma and was focused into the mass-analyzer. It is important to separate the ions from UV photons, energetic neutrals and from any solid particles that may have been carried into the instrument from the ICP. The plasma was used in an ICP-MS is made by partially ionizing argon gas ($Ar \rightarrow Ar+ + e-$). The energy required for this reaction is obtained by pulsing an electrical current in wires that surround the argon gas. An Inductively Coupled Plasma (ICP) for spectrometry is sustained in a torch that consists of three concentric tubes, usually made of quartz. The end of this torch is placed inside an induction coil supplied with a radio-frequency electric current. A flow of argon gas was introduced between the two outermost tubes of the torch and an electrical spark is applied for a short time to introduce free electrons into the gas stream. These electrons interact with the radio-frequency magnetic field of the induction coil and are accelerated first in one direction, then the other, as the field changes at high frequency. The accelerated electrons collide with argon atoms, and sometimes a collision causes an argon atom to part with one of its electrons. The released electron is in turn accelerated by the rapidly changing magnetic field. The ICP-MS allows determination of elements with atomic mass ranges 7 to 250. *As* in this method has been measured in the laboratory of Helmholtz Center of Environment in Germany.

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# CHAPTER IV

## Results and Discussions

### 4.1    General

According to environmental conditions of our country ground water is considered safe for drinking and other purposes. But ground water is contaminated by different sources. Now-a-days *As* in ground water is of far greater concern. Significant numbers of TWs were tested for *As* but still a large number of TWs remain untested. Even continuous monitoring of *As* level in ground drinking water is necessary as the ground water is moving and concentration of *As* is changing. To find out an easy, low cost and environmentally friendly method for *As* content in ground water three different methods have been adopted. A comparison has been made among the three different test methods. The water quality parameters such as, pH, conductivity, chloride, iron content, hardness and dissolved oxygen were analyzed using standard analytical techniques. Effect of different water quality parameters on *As* test methods has been observed. The suitability of investigated water for drinking and other purposes was also analyzed comparing with standard values. 220 water samples of different *As* -affected areas in Bangladesh have been collected for analysis. Of them 58 samples were from Sagordari of Jessore, 53 from Koyra of Satkhira, 56 from Hajigong of Chandpur and 53 from Arihazar of Narayangonj district.

### 4.2  pH

A critical examination of the results revels that the pH values of 220 water samples varied from 6.2-8.1 indicating the water samples are slightly acidic and alkaline range and also within safe limit for drinking and other purposes. The higher pH value may be resulted from high level of alkalinity minerals such as, Ca, Mg, etc. High alkalinity does not pose a health risk, but can cause aesthetic problems, such as an alkali taste to the water that makes coffee taste bitter. The lower pH value occurs as the bicarbonate buffering capacity ($CO_3^{2-}$ and $HCO_3^-$). Common sources of acidity include mine drainage, runoff from mine tailings. Figure- 4.2.1 shows the values of pH of 58 TW water samples of Sagordari village of Jessore district. The minimum pH value is 6.3 while that of maximum is 7.9. Most
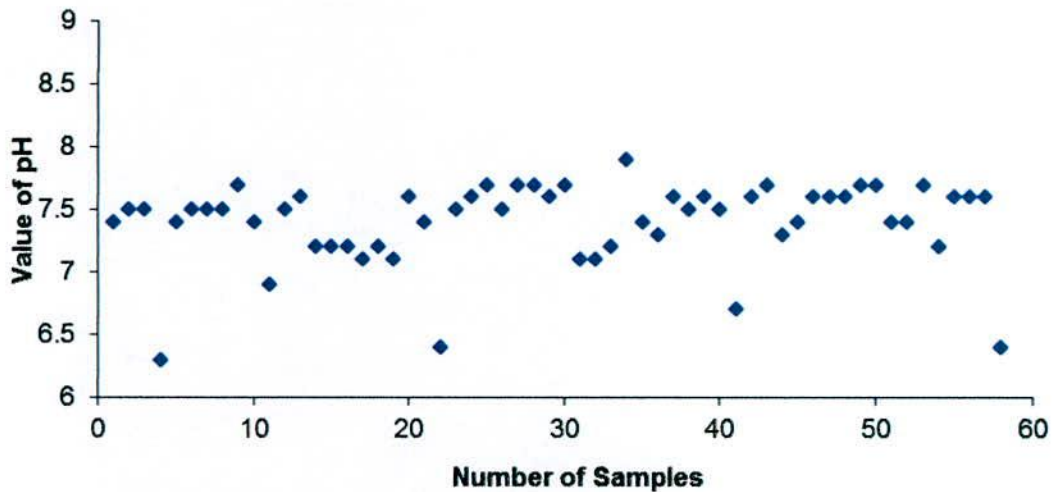
Figure- 4.2.1:    Plot of pH values of Tube-well water sample of Sagordari village
                  of Jessore District

of the samples have the pH values ≤7.0 i.e., have neutral or alkaline pH. Only 8.6%
samples have acidic pH. Figure- 4.2.2 shows the values of pH of 53 TW water
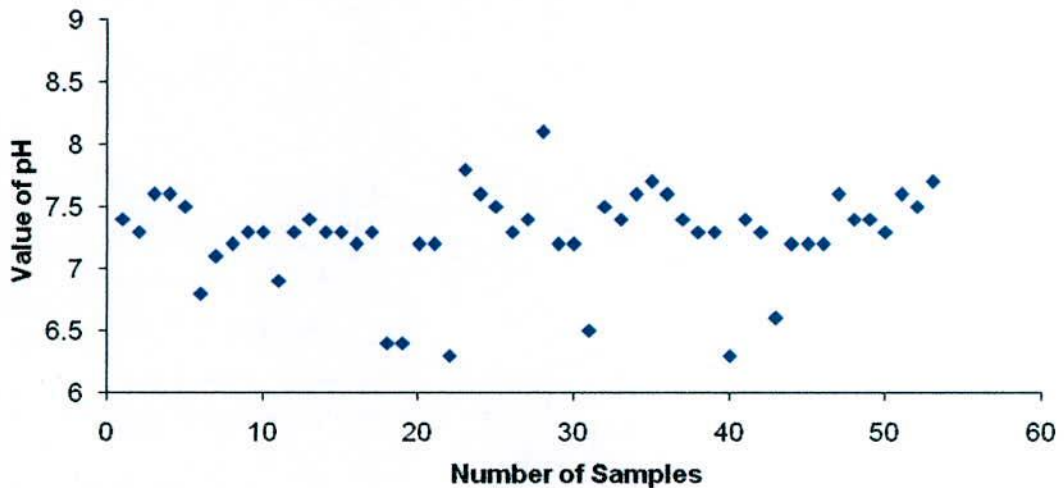


Figure- 4.2.2:    Plot of pH values of Tube-well water sample of Koyra village of
                  Satkhira District

samples of Koyra village of Satkhira district. The minimum pH value is 6.3 while that of
maximum is 8.1. Most of the samples have the pH values ≤7.0 while only 15.1% samples
have acidic pH. Figure- 4.2.3 shows the values of pH of 56 TW water samples of Hajigong
village of Chandpur district. The minimum pH value is 6.2 while that of maximum is 7.8.
From the result it is seen that 7.1% samples are acidic, 1.8% neutral and rest have alkaline
pH    values.    Figure-    4.2.4    shows    the    values    of    pH    of    53    TW    water

21
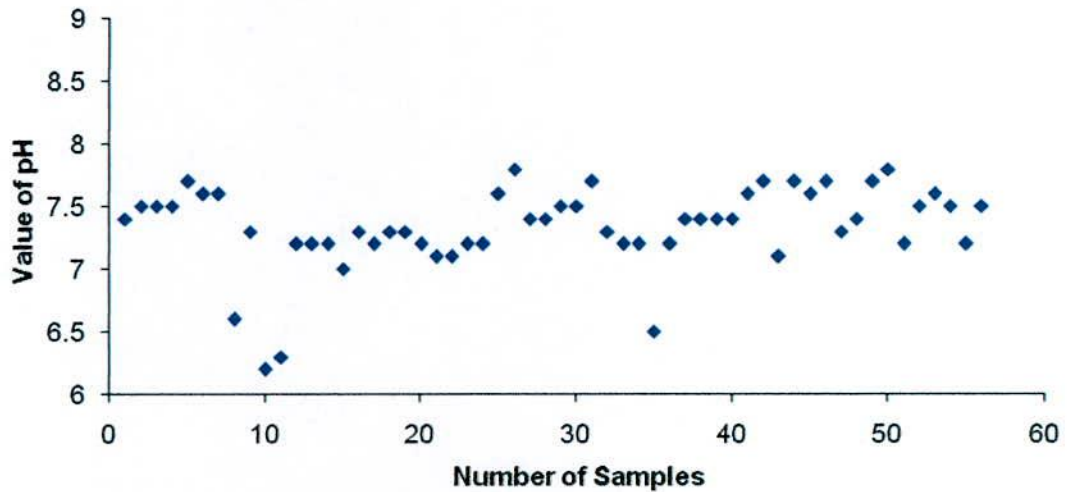
Figure- 4.2.3:    Plot of pH values of Tube-well water sample of Hajigong village
                  of Chandpur District

samples of Arihazar village of Narayangonj district. The minimum pH value is 6.3 while
that of maximum is 8.0. From the result it is seen that 11.3% samples are acidic,
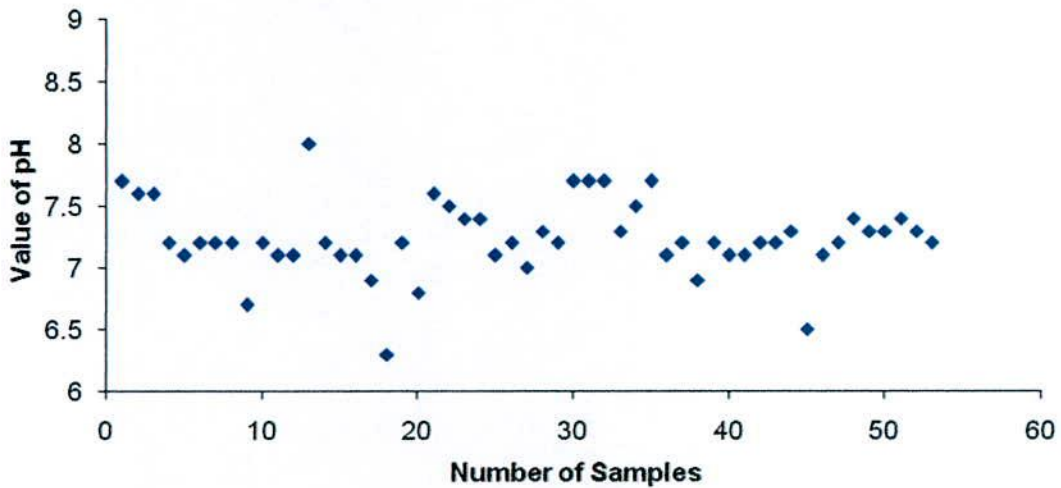


Figure- 4.2.4:    Plot of pH values of Tube-well water sample of Arihazar village
                  of Narayangonj District

1.8% neutral and rest have alkaline pH values. Figure- 4.2.5 shows the values of pH of
220 water samples of different *As*-affected areas in Bangladesh. It is seen that most of the
samples i.e., 88.6% are alkaline while those of 10.5% are acidic and only 0.9% are neutral
in nature. Table 4.2.1 represents the maximum and minimum pH values of Jessore,
Satkhira, Chandpur and Narayangonj. Results reveal that water sample of Chandpur has
the lowest pH value 6.2 and that of Satkhira is the highest and the value is 8.1.

22
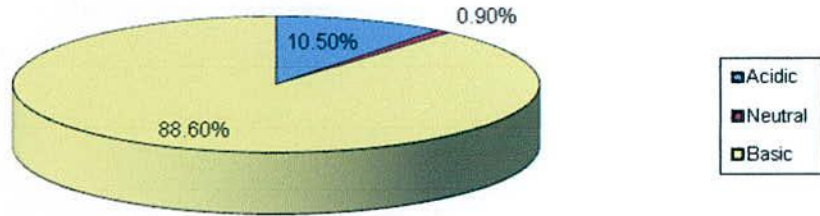
Figure- 4.2.5:  Plot of pH of 220 water samples of different arsenic-affected areas in Bangladesh.

Table 4.2.1:  Table for the maximum and minimum pH values of Jessore, Satkhira, Chandpur and Narayangonj.

| | pH | | | |
|---|---|---|---|---|
| | Jessore | Satkhira | Chandpur | Narayangonj |
| Minimum | 6.3 | 6.3 | 6.2 | 6.3 |
| Maximum | 7.9 | 8.1 | 7.8 | 8.0 |

According to United States Environmental Protection Agency (USEPA) the maximum permissible limit of pH for drinking and other purposes is 8.5 and lower limit is 6.2. So the present investigation, therefore, indicates that the pH values of the samples within safe limit for drinking and other purposes. In the section 4.8 it has also been shown wide range pH value, 6.2 – 8.1, have no significant effect on *As* detection by different methods.

## 4.3 Conductivity

Conductivity, σ is a measure of the ability of water to carry an electric current. This ability depends on the presence of ions, which are expressed as dissolved solids in the water. Water with high dissolved solids will have a high conductivity. Although it is related to the dissolved minerals in water but does not give an indication of minerals are present. Generally water with high conductivity does not taste good. This water also tends to leave white spots on dishes when used for dish washing. The conductivity values of the investigated samples varied from 0.4 – 2.7 mS/cm indicating high mineralization of the sample water. Pure water would theoretically have a specific conductance value of zero but

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practically the conductance of ultra pure water is $5.5 \times 10^{-5}$ mS/cm at 25 $^\circ$C. This is of course due to the presence of ionic species in water. According to USEPA the conductivity of drinking water is 0.05 – 0.5 mS/cm.

Figure- 4.3.1 shows the values of conductivity of 58 tube-well water samples of Sagordari village of Jessore district. The minimum conductivity value is 0.4 mS/cm while that of



Figure- 4.3.1:    Plot of Conductivity values of Tube-well water sample of Sagordari village of Jessore District.

maximum is 1.8 mS/cm. Within the drinking water range there are only 6.9% samples. Rest of the samples has higher conductivity values than the drinking water range. It is significant to mention that 15.5% of total samples have conductivity values have more than 1.0 mS/cm which is really abnormally high.  Figure- 4.3.2 shows the values of conductivity of 53 TW water samples of Koyra village of Satkhira district. The minimum conductivity value is 0.4 mS/cm while that of maximum is 2.4 mS/cm. Within the drinking water range there are only 3.8% samples. Rest of the samples has higher conductivity values than the drinking water range. It is significant to mention that 13.2% of total samples have conductivity values have more than 1.0 mS/cm which is really abnormally high.

Figure- 4.3.3 shows the values of conductivity of 56 TW water samples of Hajigong village of Chandpur district. The minimum conductivity value is 0.4 mS/cm while that of maximum is 2.7 mS/cm. Within the drinking water range there are only 1.8% samples. Rest of the samples has higher conductivity values than the drinking water range. It is significant to mention that 17.9% of total samples have conductivity values have more than 1.0 mS/cm which is really abnormally high. Figure- 4.3.4 shows the values of

24
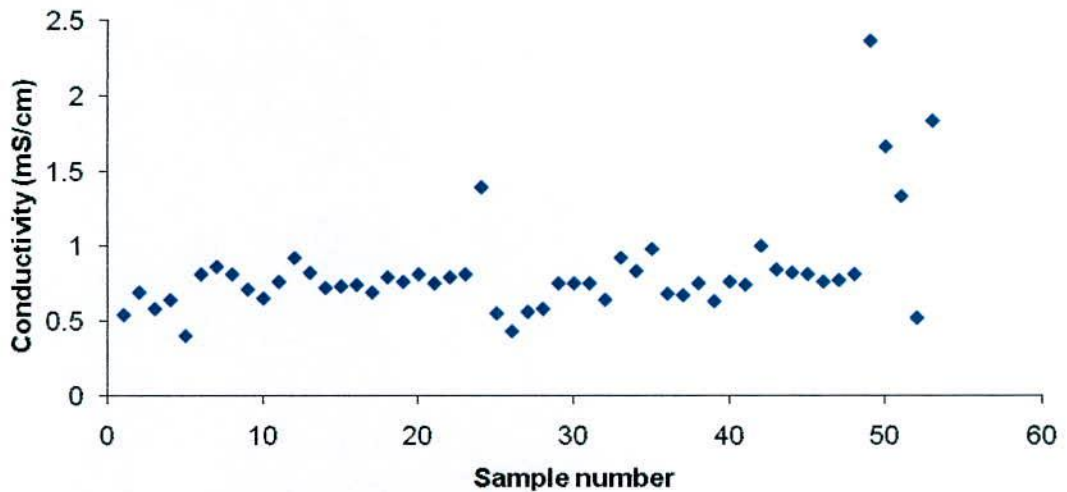
Figure- 4.3.2:   Plot of Conductivity values of Tube-well water sample of Koyra village of Satkhira District.
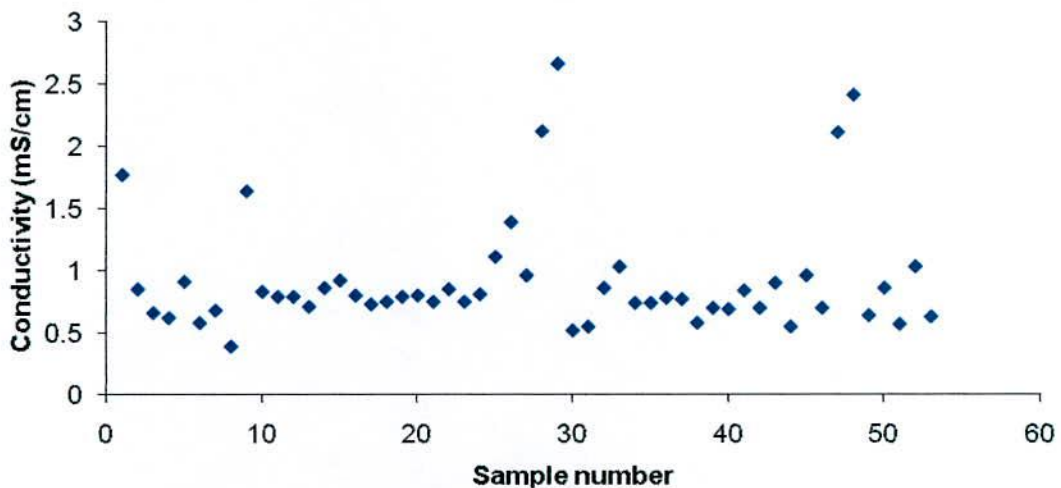


Figure- 4.3.3:   Plot of Conductivity values of Tube-well water sample of Hajigong village of Chandpur district.

conductivity of 53 TW water samples of Arihazar village of Narayangonj district. The minimum conductivity value is 0.4 mS/cm while that of maximum 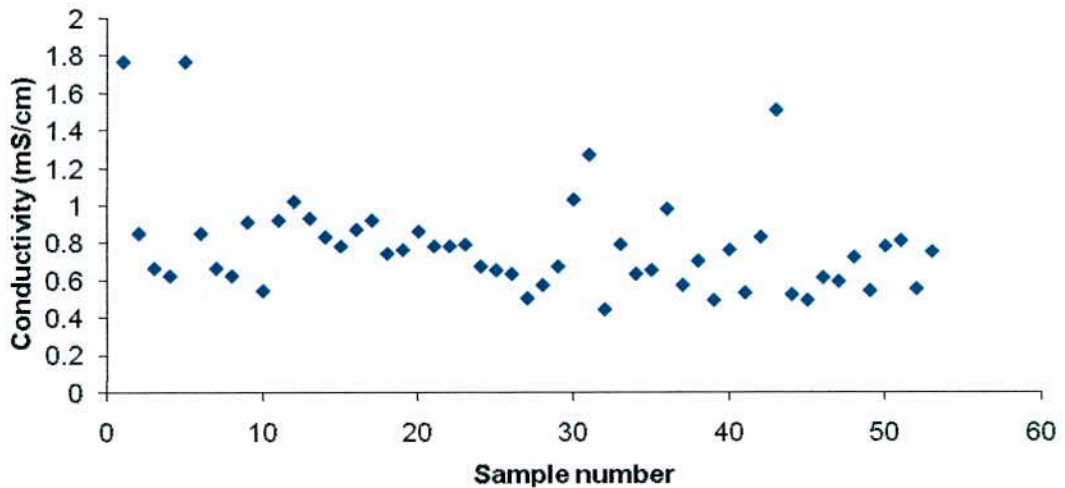is 2.5 mS/cm. Within the drinking water range there are only 5.7% samples. Rest of the samples has higher conductivity values than the drinking water range. It is significant to mention that 13.2% of total samples have conductivity values have more than 1.0 mS/cm which is really abnormally high. Figure- 4.3.5 shows the values of conductivity of 220 water samples of different investigated areas. It is seen that only 4.5% samples have conductivity values

25
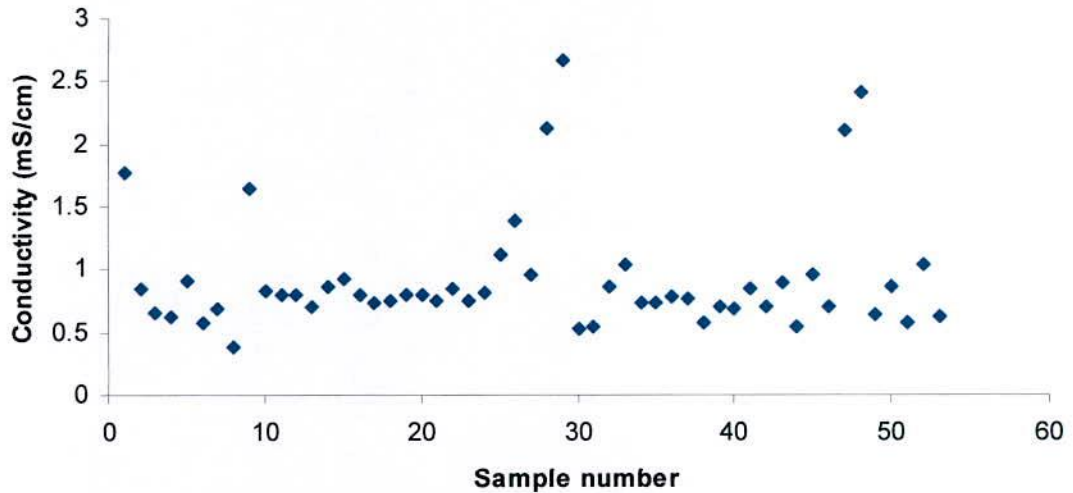
Figure- 4.3.4:    Plot of Conductivity values of Tube-well water sample of Arihazar village of Narayangonj district.
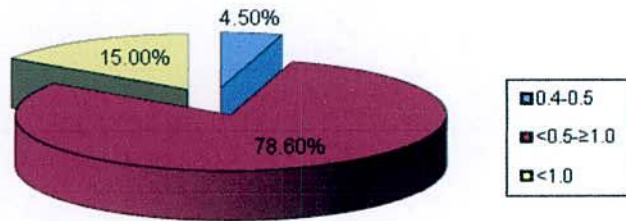


Figure- 4.3.5:    Plot of Conductivity of 220 water samples of different arsenic-affected areas in Bangladesh.

within the limit of drinking water range. Rest of the samples has high conductivity values. Of which 78.6% samples have the conductivity values of $0.5 \leq \sigma \leq 1.0$ mS/cm and 15.0% samples have that of abnormally high values.

## 4.4 Chloride

If a daily water consumption of 2 liters and an average chloride level in drinking-water of 10 mg/L are assumed, the average daily intake of chloride from drinking-water would be approximately 20 mg per person [82], but a figure of approximately 100 mg/day has also been suggested [83]. Based on these estimates and the average dietary (not salt free) intake

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of 6 g/day, drinking water intake accounts for about 0.33–1.6% of the total intake. The toxicity of chloride salts depends on the cation present; that of chloride itself is unknown. Although excessive intake of drinking-water containing sodium chloride at concentrations above 2.5 g/L has been reported to produce hypertension [84] this effect is believed to be related to the sodium ion concentration. Chloride concentrations in excess of about 250 ppm can give rise to detectable taste in water and not suitable for drinking [84], but the threshold depends upon the associated cations. Consumers can, however, become accustomed to concentrations in excess of 250 mg/L. No health-based guideline value is proposed for chloride in drinking-water.

The chloride values of the investigated 220 TW water samples varied from 35.5 – 496.2 ppm. Figure- 4.4.1 shows the values of chloride content of 58 TW water samples of Sagordari village of Jessore district. The minimum chloride content is 56.8 ppm while that of maximum is 433.7 ppm. 75.9% samples have the chloride content 56.8 – 250
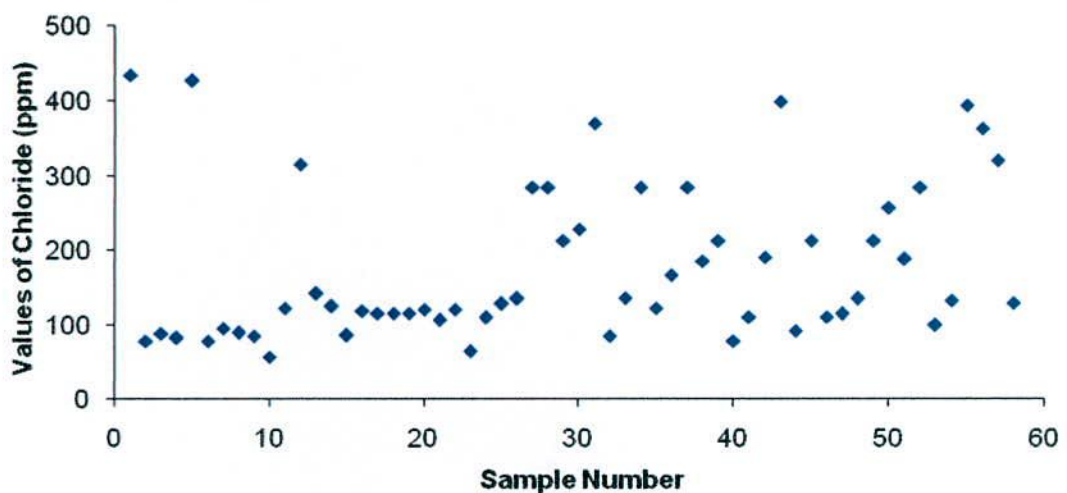


Figure- 4.4.1:    Plot of the values of chloride content of Tube-well water sample of Sagordari village of Jessore District.

ppm at the upper limit of drinking water. 24.1% samples have chloride content more than 250 ppm and not suitable for drinking.  The average value of the chloride content of the investigated 58 TW water samples of Sagordari village of Jessore district is 176.5 ppm although a high value. Figure- 4.4.2 shows the values of chloride content of 53 TW water samples of Koyra village of Satkhira district. The minimum chloride content is 56.8 ppm while that of maximum is 411.7 ppm. 92.4% samples have the chloride content 56.8 – 250 ppm at the upper limit of drinking water. 5.6% samples have chloride content more than 250 ppm and not suitable for drinking. The average value of the chloride content

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Figure- 4.4.2:    Plot of the values of chloride content of Tube-well water sample of Koyra village of Satkhira District.

of the investigated 53 TW water samples of Koyra village of Satkhira district is 141.2 ppm although a high value. Figure- 4.4.3 shows the values of chloride content of 56 TW water samples of Hajigong village of Chandpur district. The minimum chloride content is 58.6 ppm while that of maximum is 496.2 ppm. 85.7% samples have the
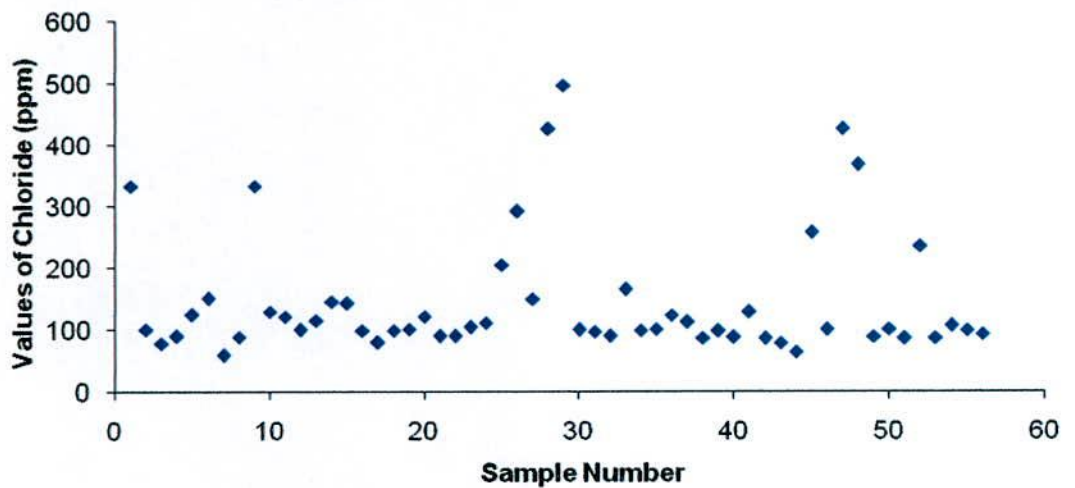


Figure- 4.4.3: Plot of the values of chloride content of Tube-well water sample of Hajigong village of Chandpur district.

chloride content 58.6 – 250 ppm at the upper limit of drinking water. 14.3% samples have chloride content more than 250 ppm and not suitable for drinking. The average value of the

chloride content of the investigated 56 TW water samples of Hajigong village of Chandpur district is 144.7 ppm although a high value. Figure- 4.4.4 shows the values of chloride content of 53 TW water samples of Arihazar village of Narayangonj district. The minimum chloride content is 35.5 ppm while that of maximum is 296.7 ppm. 96.2%
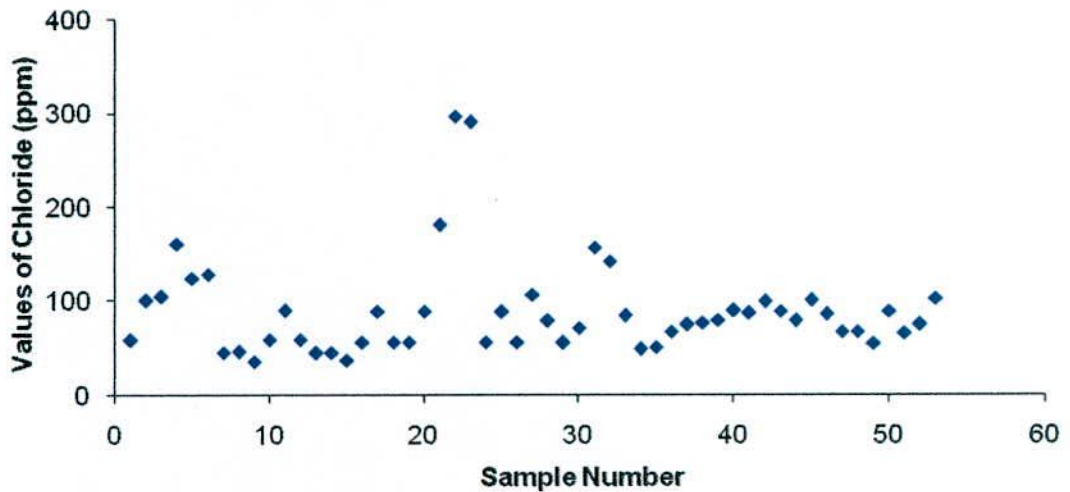


Figure- 4.4.4:    Plot of the values of chloride content of Tube-well water samples
of Arihazar village of Narayangonj district.

samples have the chloride content 35.5 – 250 ppm at the upper limit of drinking water. 3.8% samples have chloride content more than 250 ppm and not suitable for drinking. The averag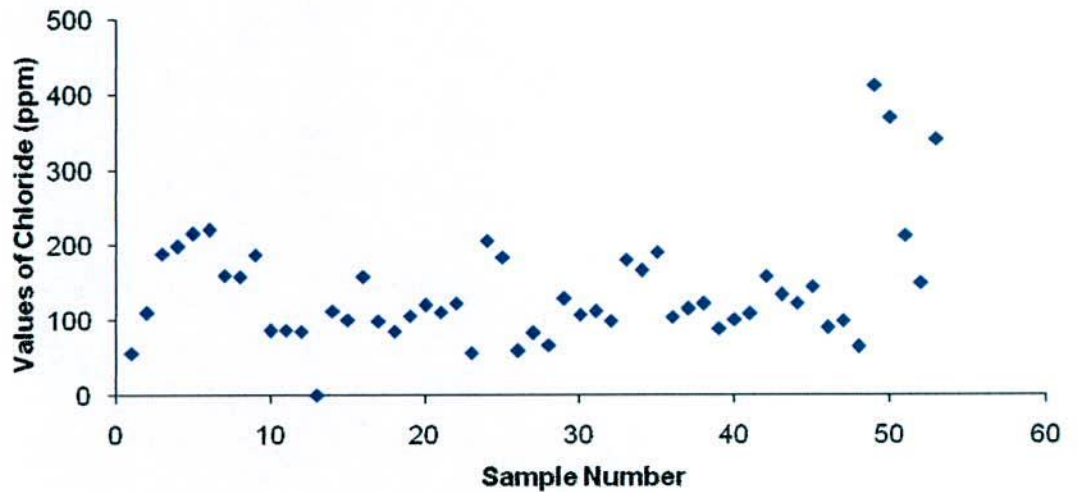e value of the chloride content of the investigated 53 TW water samples of Koyra village of Satkhira district is 88.4 ppm.

## 4.5 Iron

Iron is the second most abundant metal in the earth's crust, of which it accounts for about 5%. Elemental iron is rarely found in nature, as the iron ions $Fe^{2+}$ and $Fe^{3+}$ readily combine with oxygen- and sulfur-containing compounds to form oxides, hydroxides, carbonates, and sulfides. Iron is most commonly found in nature in the form of its oxides [85, 86]. Iron is mainly present in water in two forms: either the soluble ferrous iron or the insoluble ferric iron. Water containing ferrous iron is clear and colorless because the iron is completely dissolved. When exposed to air in the pressure tank or atmosphere, the water turns cloudy and a reddish brown substance begins to form. This sediment is the oxidized or ferric form of iron that will not dissolve in water. Iron can be a troublesome chemical in

drinking water. Although present in drinking water, iron is seldom found at concentrations greater than 10 milligrams per liter (mg/L) or 10 ppm. However, as little as 0.3 mg/L can cause water to turn a reddish brown color is the maximum permissible limit of iron for drinking purpose [87].

220 TW water samples have been investigated for the iron content and the results varied from 1.2 – 18.4 ppm. Figure- 4.5.1 shows the values of iron content of 58 TW water samples of Sagordari village of Jessore district. The minimum iron content is 1.9 ppm while that of maximum is 18.1 ppm. No TW was found having the iron content within the maximum permissible limit of 0.3 ppm. There are 81.0% TWs have the iron content within the limit of 1.2 – 10 ppm may be used for house hold works but should not drink for long time. Rest 19.0% TWs can be treated as very high iron content. The average value of the



Figure- 4.5.1:  Plot of iron values of Tube-well water sample of Sagordari village of Jessore District.

iron content of the investigated 58 TW water samples of Sagordari village of Jessore district found to 5.9 ppm. Figure- 4.5.2 shows the values of iron content of 53 TW water samples of Koyra village of Satkhira district. The minimum iron content is 2.1 ppm while that of maximum is 18.4 ppm. No TW was found having the iron content within the maximum permissible limit of 0.3 ppm. There are 86.8% TWs have the iron content within the limit of 1.2 – 10 ppm may be used for house hold works but should not drink for long time. Rest 13.2% TWs can be treated as very high iron content which is more than 10 ppm. The average value of the iron content of the investigated 53 TW water samples of Koyra village of Satkhira district found to 6.6 ppm. Figure- 4.5.3 shows the values of iron content of 56 TW water samples of Hajigong village of Chandpur district. The minimum iron

30
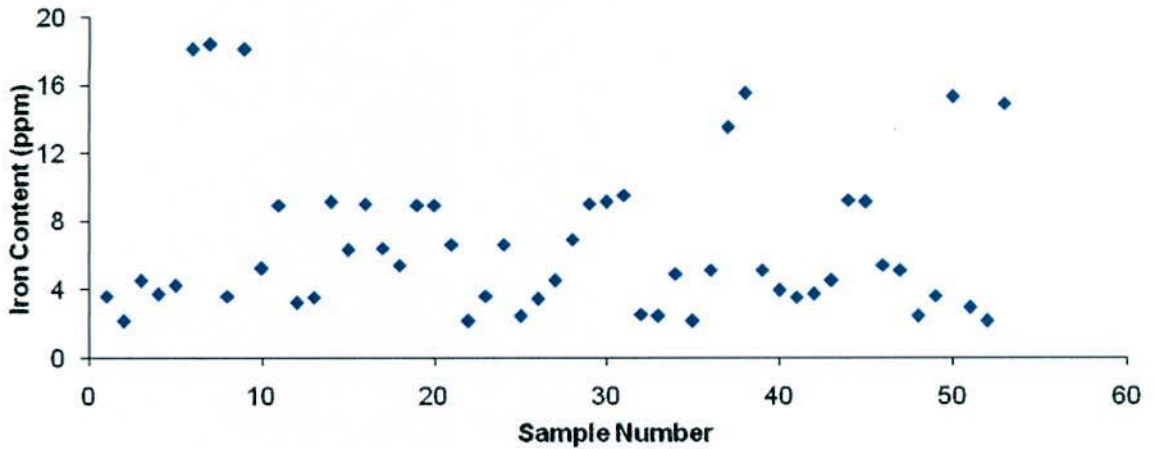
Figure- 4.5.2:    Plot of iron values of Tube-well water sample of Koyra village of
                  Satkhira District.

content is 1.2 ppm while that of maximum is 17.9 ppm. No TW was found having the iron
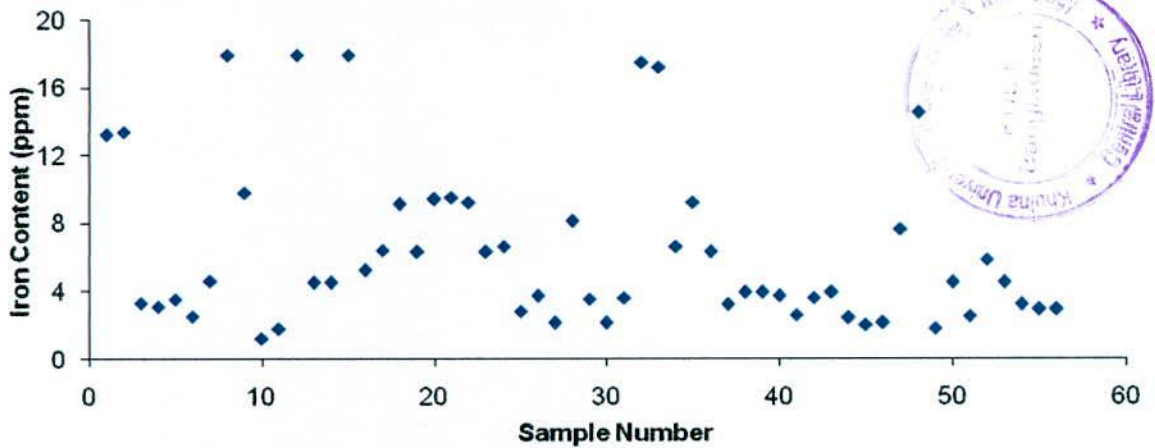


Figure- 4.5.3:    Plot of iron values of Tube-well water sample of Hajigong village
                  of Chandpur district.

content within the maximum permissible limit of 0.3 ppm. There are 85.7% TWs have the
iron content within the limit of 1.2 – 10 ppm may be used for house hold works but should
not drink for long time. Rest 14.3 TWs can be treated as very high iron content which is
more than 10 ppm. The average value of the iron content of the investigated 56 TW water
samples of Hajigong village of Chandpur district found to 6.3 ppm. Figure- 4.5.4 shows the
values of iron content of 53 TW water samples of Arihazar village of Narayangonj district.
The minimum iron content is 1.9 ppm while that of maximum is 18.1 ppm. No TW was
found having the iron content within the maximum permissible limit of 0.3 ppm. There are
83.0% TWs have the iron content within the limit of 1.2 – 10 ppm may be used
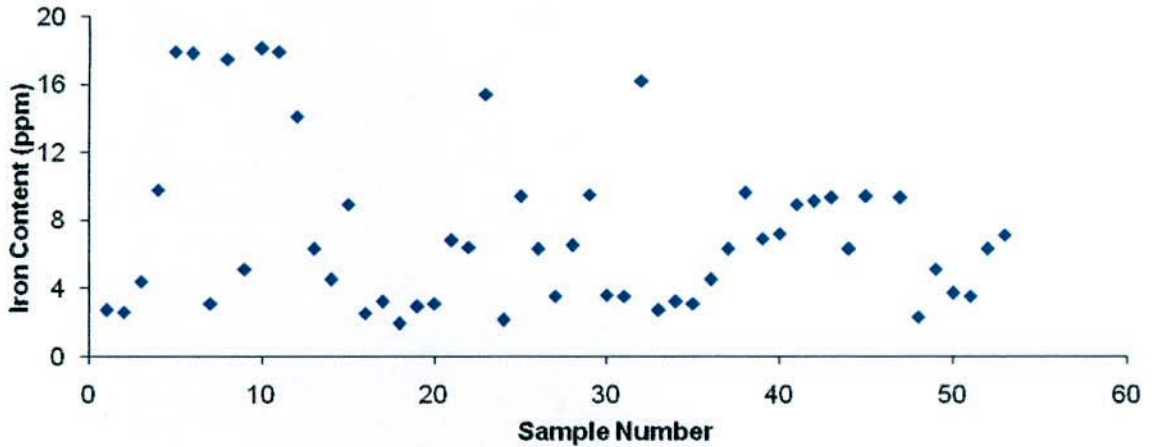
Figure- 4.5.4:   Plot of iron values of Tube-well water sample of Arihazar village of Narayangonj district.

for house hold works but should not drink for long time. Rest 17.0 TWs can be treated as very high iron content which is more than 10 ppm. The average value of the iron content of
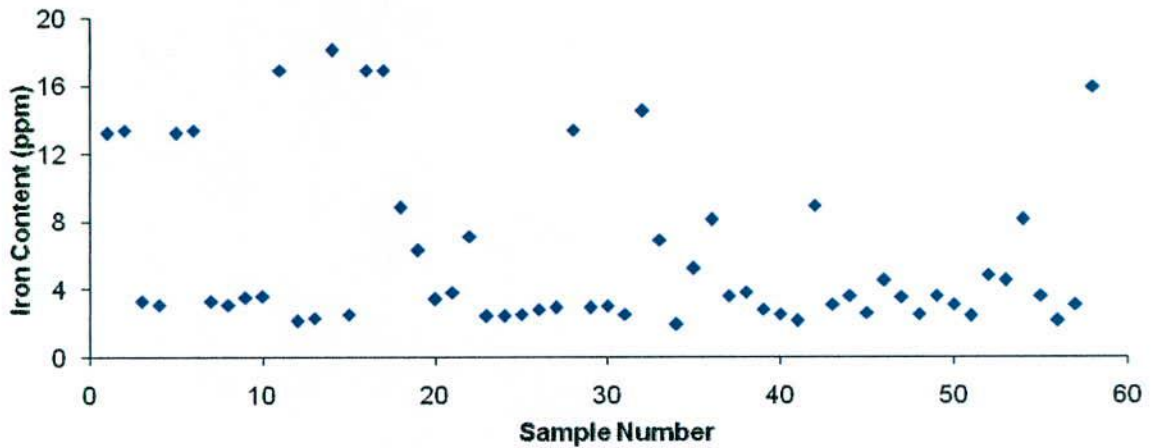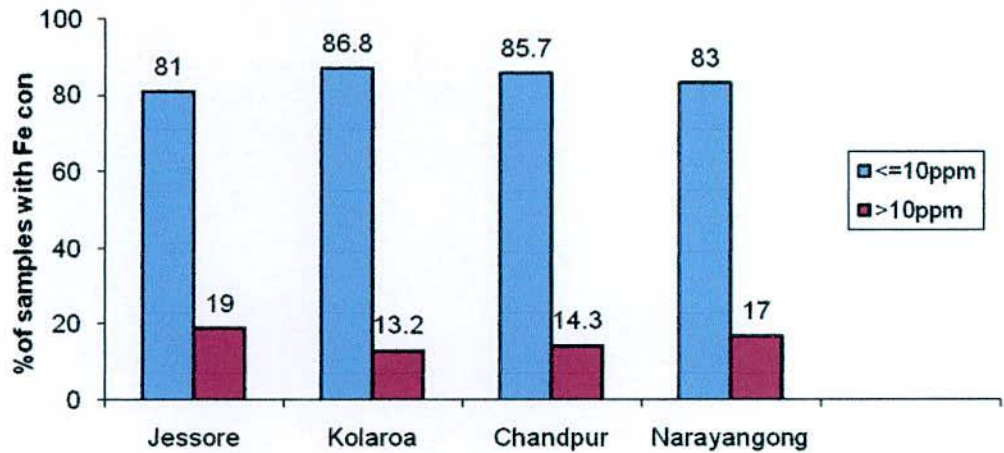


Figure- 4.5.5:   Plot of iron of 220 water samples of different arsenic-affected areas in Bangladesh.

the investigated 53 TW water samples of Arihazar village of Narayangonj district found to 7.5 ppm.

## 4.6 Hardness

Hardness is caused by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium cations, although other cations, e.g. barium, iron, manganese, strontium and zinc, also contribute. Hardness is most commonly expressed as milligrams

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of calcium carbonate equivalent per liter or ppm, water containing less than 60 ppm generally being considered as soft. The taste threshold for the calcium ion is in the range 100–300 ppm, depending on the associated anion, but higher concentrations are acceptable to consumers. Hardness levels above 500 ppm are generally considered to be aesthetically unacceptable, although this level is tolerated in some communities [88]. In drinking-water, hardness is in the range 10–500 mg of calcium carbonate per liter [89]. Estimated daily intakes of 2.3 and 52.1 mg of magnesium in soft- and hard-water areas, respectively, have been reported, based on adults drinking 2 litres of water per day [90].

There does not appear to be any convincing evidence that water hardness causes adverse health effects in humans. In contrast, the results of a number of epidemiological studies have suggested that water hardness may protect against disease. However, the available data are inadequate to prove any causal association. No health-based guideline value for water hardness is proposed.
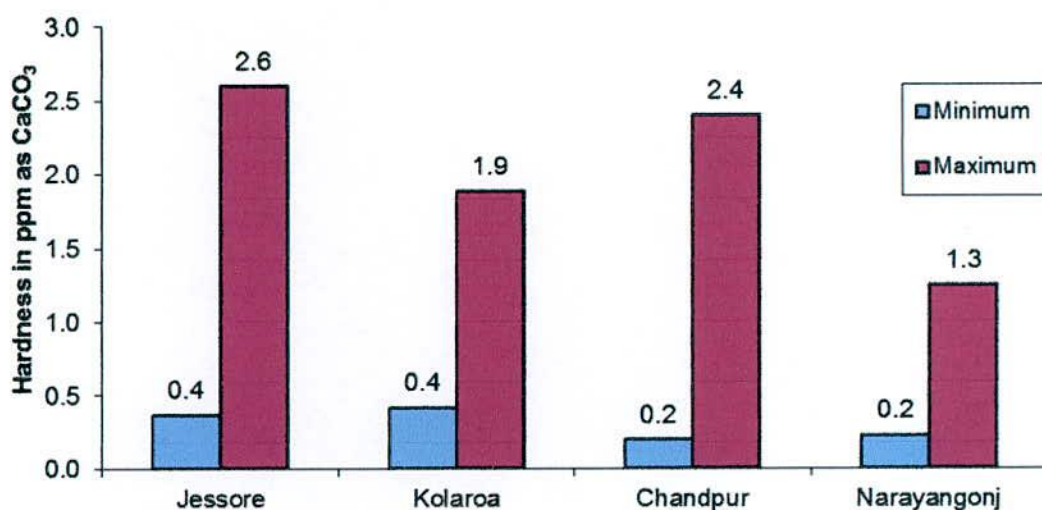


Figure- 4.6.1:    Figure for the maximum and minimum values of Hardness of Jessore, Satkhira, Chandpur and Narayangonj.

220 TW water samples have been investigated for the determination of hardness. The average value of hardness is 0.74 ppm. From Figure-4.6.1 it is seen that the minimum value of hardness was found in Chandpur and Narayangonj districts and the value is 0.2ppm while that of the maximum is 2.6 ppm in Jessore. The average value of hardness of the investigated water samples of Jessore and Satkhira were same, 0.77 ppm while those of the Chandpur and Narayangonj were 0.75 and 0.67 ppm respectively.

## 4.7 Dissolve Oxygen (DO)

Dissolved oxygen (DO) refers to the volume of oxygen that is contained in water. A high DO level in water is good because it makes drinking water taste better. Oxygen comprises approximately 21% of the total gas in the atmosphere; however, it is much less available in water. The amount of oxygen that can be held by the water depends on the water temperature, salinity, and pressure. The amount of oxygen water can hold depends upon temperature (more oxygen can be dissolved in colder water), pressure (more oxygen can be dissolved in water at greater pressure) and salinity (more oxygen can be dissolved in water of lower salinity). Flowing water is more likely to have high dissolved oxygen levels compared to stagnant water because the water movement at the air-water interface increases the surface area available to absorb the oxygen. In flowing water, oxygen-rich
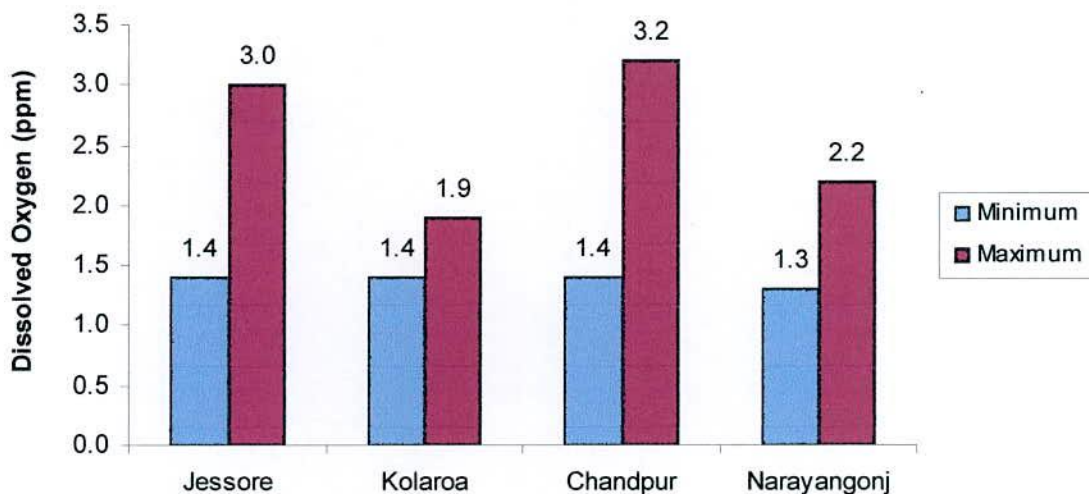


Figure- 4.7.1:    Figure for the maximum and minimum values of Dissolve Oxygen of Jessore, Satkhira, Chandpur and Narayangonj.

water at the surface is constantly being replaced by water containing less oxygen as a result of turbulence, creating a greater potential for exchange of oxygen across the air-water interface. Ground water normally contains low DO than surface water or pipe line supply water from surface water treatment.

220 tube-well water samples have been investigated for the determination of dissolved oxygen. The average value of dissolved oxygen is 1.8 ppm. From Figure-4.7.1 it is seen that the minimum value of dissolved oxygen was found in Narayangonj district and the value is 1.3 ppm while that of the maximum is 3.2 ppm in Chandpur district. The average

value of dissolved oxygen of Jessore, Chandpur and Narayangonj were same, 1.8 ppm while that of the Satkhira was 1.9 ppm. The mentioned values of dissolved oxygen of the investigated samples are quite permissible for the drinking purpose. Relatively lower values of DO of TW water than that of surface water also are in good agreement with literature.

## 4.8 Arsenic in Drinking Water

Arsenic occurs naturally in sulphide minerals such as pyrite. It is found in many countries but especially those located south of the Himalayas, such as Bangladesh, India (West Bengal), and China. The main challenge in tackling *As* in ground water is that it does not follow a specific pattern. For example, it can occur in one TW and not in another one located less than 100 meters away. Furthermore, a TW that was previously tested to show an acceptable amount of *As* might test non-acceptable at a later date. It is therefore vital to test and monitor on a continual basis, with blanket coverage of all TWs in those countries affected. It is equally important to ensure that people are made aware of the *As* content in TW water and promote *As* mitigation activities.

All the 220 tube-well water samples in the study area were tested using Merck field test kit, ARSOlux biosensor and ICP-MS methods. A wide distribution of *As* contents was found. A comparison of the overall results of *As* determinations by the field test kit, ARSOlux biosensor and the ICP-MS methods in terms of distribution of TW water in the different *As* categories. It is seen from the results that test results of ARSOlux biosensor method are very close to those of ICP-MS method. But the test results obtained by Merck field test kit varied a lot from those of the other two methods. Figure-4.8.1 shows a comparison of the overall test results of Jessore district of *As* determinations by the Merck field test kit, ARSOlux biosensor and the ICP-MS methods in terms of distribution of TW in the different *As* categories. 58 TW water samples were tested by three different methods for *As* content. 10.3% samples showed positive *As* content having the concentration $\leq 50$ ppm. But there was no sample having the *As* concentration $\leq 50$ ppm as shown by ARSOlux biosensor method and also was confirmed by well accepted ICP-MS method. It is observed that *As* concentration categories of $0 - 50$ ppm (10.3%), $51 - 100$ ppm

(12.1%), 201 – 300 ppm (50.0%) and 401 – 500 ppm (27.6%) were found by Merck field



Figure- 4.8.1: Comparison of the results of the determination of As concentrations in tube-well water samples of Jessore with Merck filed test kit, ARSOlux biosensor and ICP-MS methods.

test kit method completely different from other two methods. The minimum values for *As* content by Merck field test kit, ARSOlux biosensor and the ICP-MS methods were 50, 92 and 95 ppm respectively while those for maximum were 500, 756 and 760 ppm respectively. From the test results of ARSOlux biosensor and ICP-MS there was no sample found in Sagordari village of Jessore district of which the *As* concentration was <50 ppm, the Bangladesh standard according to WHO. So it may be concluded that, agreement between Merck field test kit and the respective ICP-MS results was found to be comparatively poor. But there is strong concurrence between the results of ARSOlux biosensor method and ICP-MS method. Figure-4.8.2 shows a comparison of the overall test results of Satkhira district of *As* determinations by the Merck field test kit, ARSOlux biosensor and the ICP-MS methods in terms of distribution of TW water in the different *As* categories. 53 TW water samples were tested by three different methods for *As* content. 17.0% samples showed positive *As* content having the concentration ≤50 ppm but those for ARSOlux biosensor method and well accepted ICP-MS method were only 3.8% and 1.9% respectively. It is observed that *As* concentration categories of 0 – 50 ppm (17.0%), 51 – 100 ppm (32.1%), 201 – 300 ppm (43.4%) and 401 – 500 ppm (7.5%) were found by Merck field test kit method completely different from other two methods. The minimum

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values for *As* content by Merck field test kit, ARSOlux biosensor and the ICP-MS methods were 10, 10 and 15 ppm respectively while those for maximum were 500, 644 and 650 ppm respectively. The agreement between Merck field test kit and the respective ICP-MS
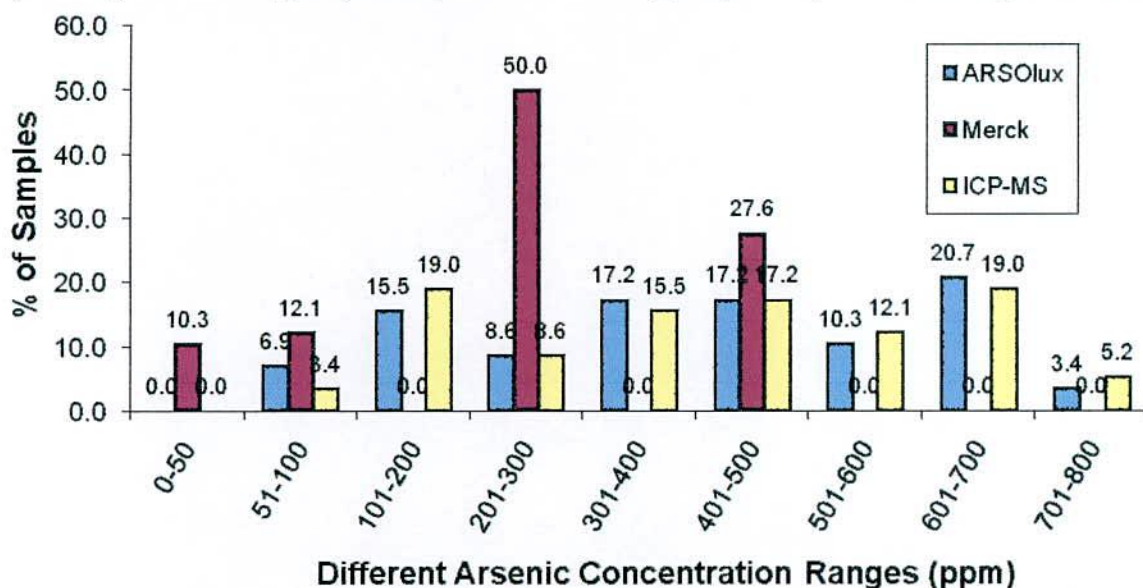


Figure- 4.8.2:   Comparison of the results of the determination of *As* concentrations in tube-well water samples of Kolaroa with Merck filed test kit, ARSOlux biosensor and ICP-MS methods.

results was found to be comparatively poor. But there is strong concurrence between the results of ARSOlux biosensor method and ICP-MS method. Figure-4.8.3 shows a comparison of the overall test results of Chandpur district of *As* determinations by the Merck field test kit, ARSOlux biosensor and the ICP-MS methods in terms of distribution of TW water in the different *As* categories. 56 TW water samples were tested by three different methods for *As* content. 8.9% samples showed positive *As* content having the concentration ≤50 ppm. But there was no sample having the *As* concentration ≤50 ppm as shown by ARSOlux biosensor method and also was confirmed by well accepted ICP-MS method. It is observed that *As* concentration categories of 0 – 50 ppm (8.9%), 51 – 100 ppm (23.2%), 201 – 300 ppm (58.9%) and 401 – 500 ppm (8.9%) were found by Merck field test kit method completely different from other two methods. The minimum values for *As* content by Merck field test kit, ARSOlux biosensor and the ICP-MS methods were 0, 85 and 87 ppm respectively while those for maximum were 500, 630 and 640 ppm respectively. The agreement between Merck 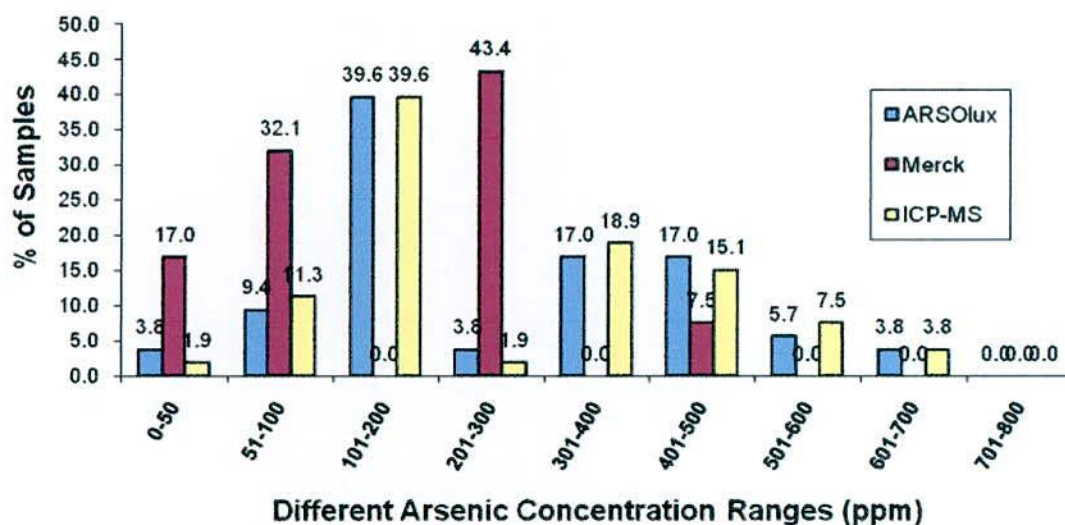field test kit and the respective ICP-MS results was found to be comparatively poor. But there is strong concurrence between the
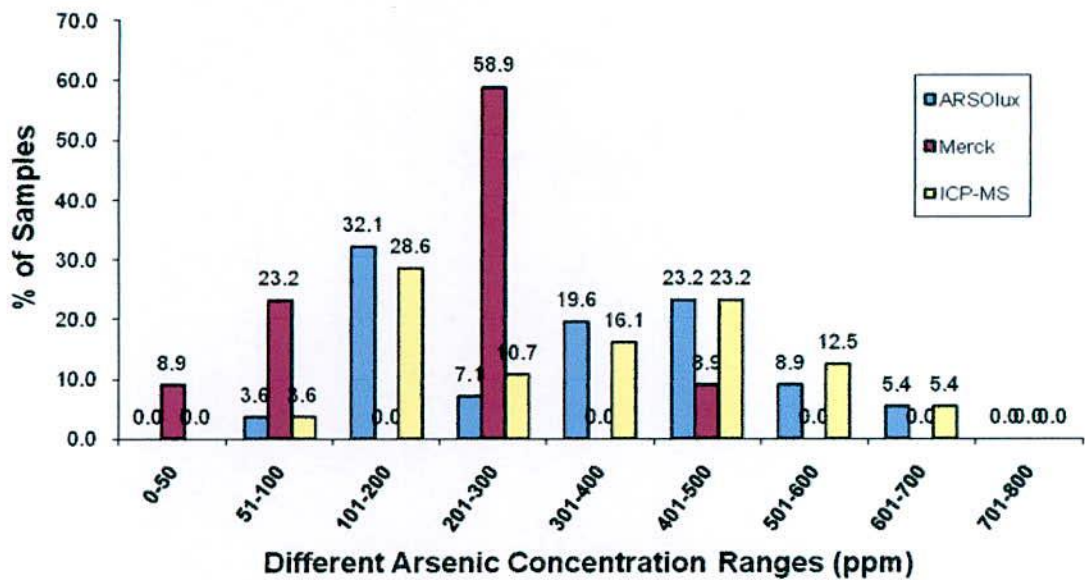
Figure- 4.8.3:  Comparison of the results of the determination of As concentrations in tube-well water samples of Chandpur with Merck filed test kit, ARSOlux biosensor and ICP-MS methods.

results of ARSOlux biosensor method and ICP-MS method. Figure-4.8.4 shows a comparison of the overall test results of Narayangonj district of *As*
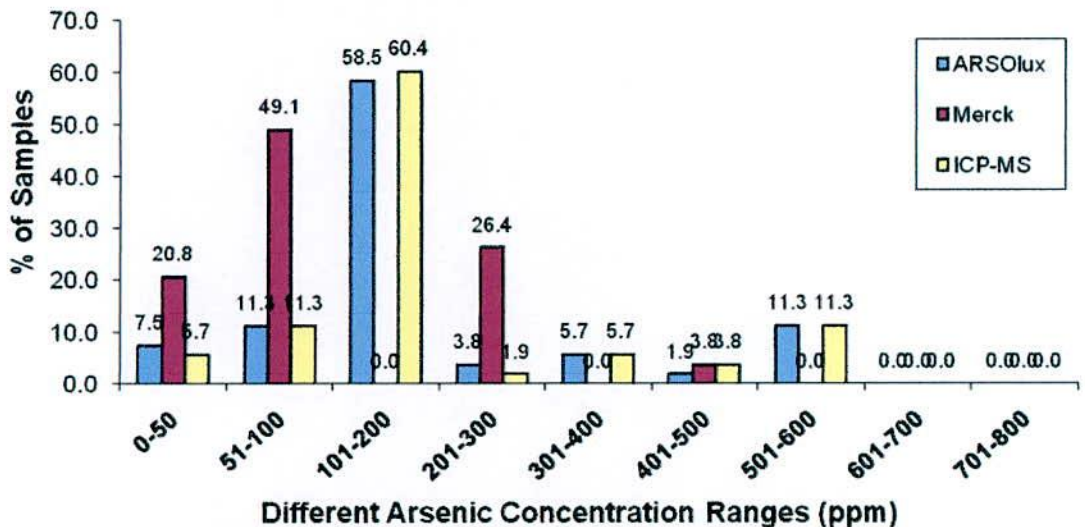


Figure- 4.8.4:  Comparison of the results of the determination of As concentrations in tube-well water samples of Narayangonj with Merck filed test kit, ARSOlux biosensor and ICP-MS methods.

determinations by the Merck field test kit, ARSOlux biosensor and the ICP-MS methods in terms of distribution of TW water in the different *As* categories. 53 TW water samples

were tested by three different methods for *As* content. 20.8% samples showed positive *As* content having the concentration ≤50 ppm but those for ARSOlux biosensor method and well accepted ICP-MS method were only 3.8% and 1.9% respectively. It is observed that *As* concentration categories of 0 – 50 ppm (20.8%), 51 – 100 ppm (49.1%), 201 – 300 ppm (26.4%) and 401 – 500 ppm (3.8%) were found by Merck field test kit method completely different from other two methods. The minimum values for *As* content by Merck field test kit, ARSOlux biosensor and the ICP-MS methods were 50, 40 and 43 ppm respectively while those for maximum were 500, 590 and 600 ppm respectively. The agreement between Merck field test kit and the respective ICP-MS results was found to be comparatively poor. But there is strong concurrence between the results of ARSOlux biosensor method and ICP-MS method.

Figure-4.8.5 shows the Arsenic test results of different concentration range for Merck field test kit method of 220 investigated samples of Jessore, Satkhira, Chandpur and Narayangonj districts. It is seen from the figure that there are 14.1%, 28.6%, 45.0% and 12.1% samples are in the *As* concentration range of 0 – 50, 51 – 100, 301 – 400 and 401 – 500 ppm respectively. 14.1% water samples are in the drinking range, 0 – 50 ppm, the Bangladesh



Figure- 4.8.5: Arsenic test results of different concentration range for Merck field test kit method of 220 investigated samples of Jessore, Sathkhira, Chandpur and Narayangonj districts.

standard according to WHO. No sample was found in the *As* concentration range of 101 – 200, 201 – 300, 501 – 600, 601 – 700 and 701 – 800 ppm. But ARSOlux biosensor

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method as well as ICP-MS method showed that all the 220 water samples have *As*, distributed in all the ranges mentioned above.

Figure-4.8.6 shows the Arsenic test results of different concentration range for ARSOlux biosensor method of 220 investigated samples of Jessore, Satkhira, Chandpur and Narayangonj districts. It is seen from the figure that there are 2.7%, 7.7%, 35.9%, 5.9%, 15.0%, 15.0%, 9.1%, 7.7% and 0.9% samples are in the *As* concentration range of 0 – 50, 51 – 100, 101 – 200, 201 – 300, 301 – 400, 401 – 500, 501 – 600, 601 – 700 and 701 – 800 ppm respectively. This result shows that *As* concentrations in water are widely distributed.



Figure- 4.8.6:   Arsenic test results of different concentration range for ARSOlux biosensor method of 220 investigated samples of Jessore, Satkhira, Chandpur and Narayangonj districts.

Only 2.7% water samples are in the drinking range, 0 – 50 ppm, the Bangladesh standard according to WHO.

Figure-4.8.7 shows the Arsenic test results under different concentration range for ICP-MS method of 220 investigated samples of Jessore, Satkhira, Chandpur and Narayangonj districts. It is seen from the figure that there are 1.8%, 7.3%, 36.4%, 5.9%, 14.1%, 15.0%, 10.9%, 7.3% and 1.4% samples are in the *As* concentration range of 0 – 50, 51 – 100, 101 – 200, 201 – 300, 301 – 400, 401 – 500, 501 – 600, 601 – 700 and 701 – 800 ppm respectively. This result shows that *As* concentrations in water are widely distributed. Only 1.8% water samples are in the drinking range, 0 – 50 ppm, the Bangladesh standard according to WHO.
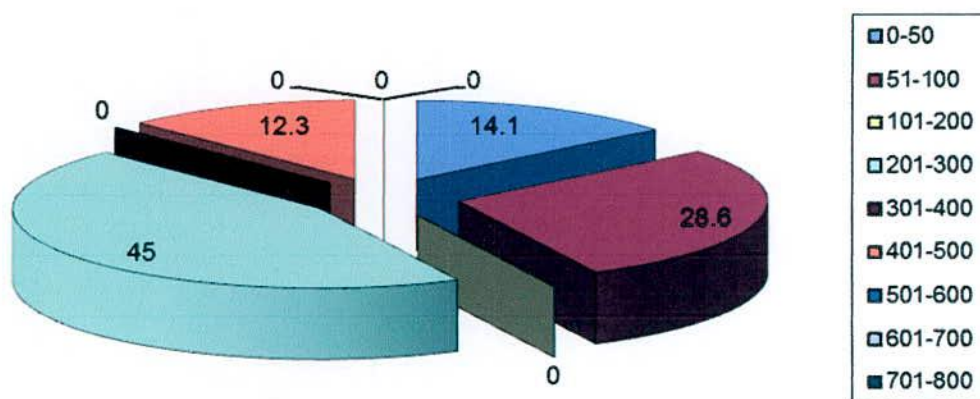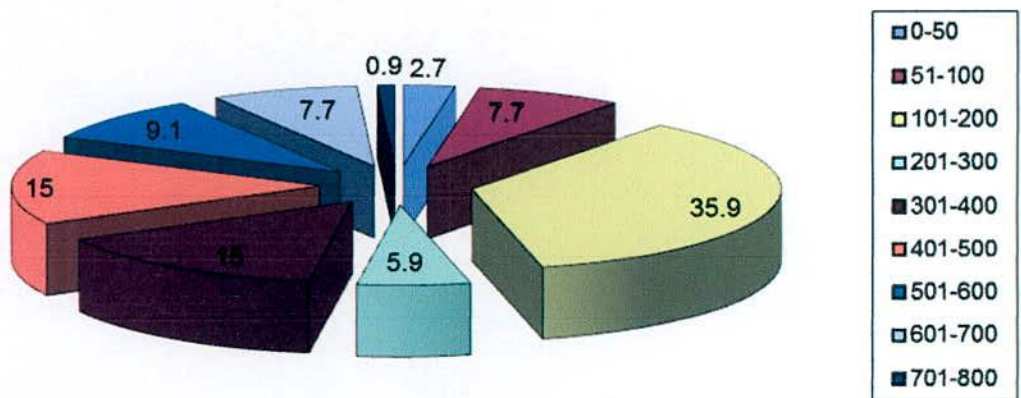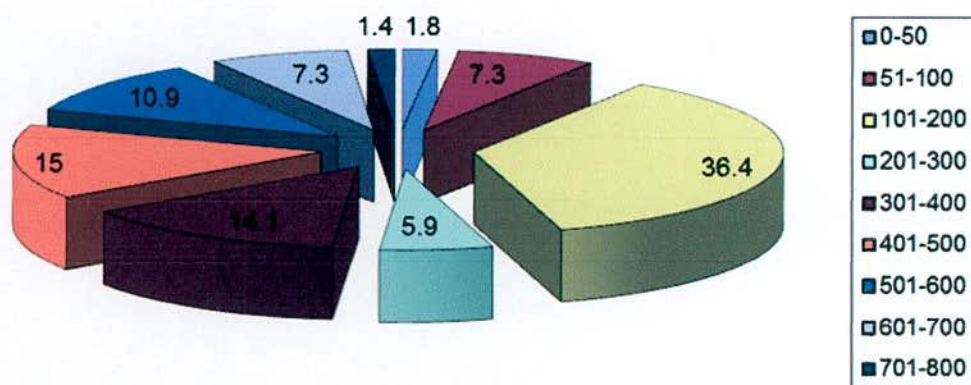
Figure- 4.8.7:    Arsenic test results of different concentration range for ICP-MS method of 220 investigated samples of Jessore, Satkhira, Chandpur and Narayangonj districts.

Table-4.8.1 also shows comparative results of *As* concentration of 220 investigated samples by the Merck field test kit, ARSOlux biosensor and the ICP-MS methods. These also have been discussed in Figure-4.8.5, Figure-4.8.6 and Figure-4.8.7. It is seen from the table that test results of ARSOlux biosensor are very close to those of ICP-MS method but unlike to Merck field test kit method.

Table 4.8.1:    Comparative results of arsenic concentration of 220 investigated samples by the Merck field test kit, ARSOlux biosensor and the ICP-MS methods.

| Range (ppm) | Merck Field Test Kit Method | | ARSOLux Biosensor Method | | ICP-MS Method | |
|---|---|---|---|---|---|---|
| | Number of Sample | % of Sample | Number of Sample | % of Sample | Number of Sample | % of Sample |
| 0 - 50 | 31 | 14.1 | 6 | 2.7 | 4 | 1.8 |
| 51 - 100 | 63 | 28.6 | 17 | 7.7 | 16 | 7.3 |
| 101 -200 | 0 | 0 | 79 | 35.9 | 80 | 36.4 |
| 201 - 300 | 99 | 45 | 13 | 5.9 | 13 | 5.9 |
| 301 - 400 | 0 | 0 | 33 | 15 | 31 | 14.1 |
| 401 - 500 | 27 | 12.3 | 33 | 15 | 33 | 15 |
| 501 - 600 | 0 | 0 | 20 | 9.1 | 24 | 10.9 |
| 601 - 700 | 0 | 0 | 17 | 7.7 | 16 | 7.3 |
| 701 - 800 | 0 | 0 | 2 | 0.9 | 3 | 1.4 |

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Various chemical parameters such as, pH, conductivity, chloride, iron content, hardness and dissolved oxygen have also been determined. There are a lot of variations in their values in the investigated TW water samples. But no effect was found in *As* detection by ARSOlux biosensor method and has been confirmed by ICP-MS method.

Biosensors are fast, less expensive and less labor intensive than other traditional methods such as Merck field test kit method, atomic absorption spectrometry, inductively coupled atomic electron spectrometry, and sequential extraction procedure. The results obtained from biosensors are compatible with and comparable to chemical analysis, while being free of chemical extractions and analytical procedures. Biosensors has been found to more sensitive than chemical methods. In this investigation ARSOlux biosensors are an interesting alternative as they are easily produced, simple, and highly accurate devices.

From the results some advantages of ARSOlux biosensor method were found over Merck field test kit method. Firstly, it is accurate. It is cheaper. The cost for per sample is ~10.00 taka in ARSOlux biosensor method while that for Merck field test kit method is ~70.00 taka. ARSOlux biosensor method requires relatively less time. After incubation period about 3 – 4 hours, for testing it requires only 4 – 5 minutes. So a large number of samples can be tested in a day. On the other hand about 40 – 50 minutes are required for one sample to detect *As* by Merck field test kit method. Arsine gas is produced which is environmentally hazardous and carcinogenic. But there is no environmental threat in ARSOlux biosensor method.

## Conclusion

A significant number of Tube-well water samples of four villages of four different Arsenic-affected districts in Bangladesh were investigated. Various chemical parameters such as, pH, conductivity, chloride, iron content, hardness and DO have been tested. pH, hardness and DO of the investigated samples were found well accepted in the range of drinking water. Only 4.5% samples have conductivity values within the limit of drinking water range. Rest of the samples has high conductivity values. Of which 78.6% samples have the conductivity values of $0.5 \leq \sigma \leq 1.0$ mS/cm and 15.0% samples have that of abnormally high values. The chloride values of the investigated 220 tube-well water samples varied from $35.5 - 496.2$ ppm. Although no health-based guideline value is proposed for chloride in drinking-water but chloride concentrations in excess of about 250 ppm can give rise to detectable taste in water and not suitable for drinking. Only 10% samples have the chloride value beyond the mentioned value. For the iron content the results varied from $1.2 - 18.4$ ppm. So, no sample was found less than 0.3 ppm can cause water to turn a reddish brown color is the maximum permissible limit of iron for drinking purpose. For *As* test, it is found that ARSOlux biosensor method is inexpensive, accurate, easy and simple. But Merck field test kit method is relatively expensive, unreliable and environmentally problematic. Arsine gas is produced in Merck field test kit method is environmentally hazardous and carcinogenic. *As* test results by ARSOlux biosensor method are accurate and reliable to those of ICP – MS method. No Effects of different water quality parameters on *As* test methods were divulged.

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Test results of 50 water samples of Sagardari village of Jessore district

| Sl No | Test Method of As | | | pH | Chemical Parameters | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | AMSOilus Biosensor | Merck Kit Test | ICP-MS | | Cond. (mS/cm) | Cl (ppm) | HCO₃ as CaCO₃ (ppm) | Iron (ppm) | DO (ppm) |

# Appendix

| 33 | 130 | 100 | 140 | 7.2 | 0.79 | 136.5 | 0.77 | 6.9 | 1.9 |
|----|-----|-----|-----|-----|------|-------|------|------|-----|
| 34 | 700 | 500 | 701 | 7.9 | 0.63 | 284 | 0.37 | 1.9 | 2.1 |
| 35 | 110 | 100 | 117 | 7.4 | 0.65 | 122.3 | 0.75 | 5.2 | 1.7 |
| 36 | 100 | 50 | 108 | 7.3 | 0.98 | 166.6 | 0.75 | 8.1 | 1.4 |
| 37 | 570 | 500 | 580 | 7.6 | 0.57 | 284 | 0.87 | 3.6 | 2.1 |
| 38 | 520 | 500 | 530 | 7.5 | 0.7 | 185.5 | 0.83 | 3.8 | 2 |
| 39 | 685 | 250 | 690 | 7.6 | 0.49 | 213 | 0.5 | 2.8 | 2.1 |
| 40 | 365 | 250 | 370 | 7.5 | 0.76 | 78.1 | 0.56 | 2.5 | 1.9 |
| 41 | 140 | 100 | 145 | 6.7 | 0.53 | 111.2 | 0.52 | 2.1 | 1.7 |
| 42 | 318 | 250 | 330 | 7.6 | 0.83 | 190.6 | 0.45 | 8.9 | 2.1 |
| 43 | 292 | 250 | 300 | 7.7 | 1.51 | 398.2 | 0.42 | 3.1 | 1.9 |
| 44 | 315 | 250 | 320 | 7.3 | 0.52 | 92.5 | 0.87 | 3.6 | 1.9 |
| 45 | 425 | 250 | 430 | 7.4 | 0.49 | 213 | 0.72 | 2.6 | 1.8 |
| 46 | 545 | 500 | 550 | 7.6 | 0.61 | 110.3 | 0.65 | 4.5 | 2 |
| 47 | 610 | 500 | 620 | 7.6 | 0.59 | 115.2 | 0.81 | 3.5 | 2 |
| 48 | 285 | 250 | 290 | 7.6 | 0.72 | 135.2 | 0.51 | 2.5 | 1.5 |
| 49 | 681 | 500 | 690 | 7.7 | 0.54 | 213 | 0.8 | 3.6 | 2.1 |
| 50 | 655 | 500 | 660 | 7.7 | 0.78 | 256.8 | 0.58 | 3.1 | 1.7 |
| 51 | 399 | 250 | 400 | 7.4 | 0.81 | 188.5 | 0.7 | 2.4 | 1.8 |
| 52 | 442 | 250 | 450 | 7.4 | 0.55 | 284 | 1.31 | 4.8 | 2 |
| 53 | 270 | 250 | 280 | 7.7 | 0.75 | 99.4 | 2.6 | 4.5 | 1.4 |
| 54 | 260 | 250 | 263 | 7.2 | 0.69 | 133.2 | 0.78 | 8.1 | 1.8 |
| 55 | 356 | 250 | 360 | 7.6 | 1.41 | 393.2 | 0.52 | 3.6 | 1.8 |
| 56 | 530 | 250 | 540 | 7.6 | 1.26 | 362.3 | 0.71 | 2.1 | 1.9 |
| 57 | 120 | 50 | 124 | 7.6 | 1.06 | 320.2 | 0.58 | 3.1 | 1.7 |
| 58 | 95 | 50 | 98 | 6.4 | 0.82 | 129.3 | 0.78 | 15.9 | 1.5 |

# Appendix-II

**Test results of 53 water samples of Koyra village of Satkhira district:**

| Sl No | Test Method of *As* | | | Chemical Parameters | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ARSOlux Biosensor | Merck Kit Test | ICP-MS | pH | Cond. (mS/cm) | Cl⁻ (ppm) | HCO₃⁻ as CaCO₃(ppm) | Iron (ppm) | DO (ppm) |
| 1 | 332 | 250 | 340 | 7.4 | 0.54 | 56.8 | 0.78 | 3.6 | 1.9 |
| 2 | 445 | 250 | 450 | 7.3 | 0.69 | 110.2 | 0.63 | 2.1 | 2 |
| 3 | 470 | 250 | 490 | 7.6 | 0.58 | 188.7 | 0.72 | 4.5 | 2.1 |
| 4 | 438 | 250 | 440 | 7.6 | 0.64 | 198.2 | 0.66 | 3.7 | 1.4 |
| 5 | 364 | 250 | 370 | 7.5 | 1.03 | 215.5 | 0.75 | 4.2 | 1.5 |
| 6 | 180 | 100 | 183 | 6.8 | 1.06 | 220.3 | 0.58 | 18.1 | 1.9 |
| 7 | 140 | 50 | 150 | 7.1 | 0.86 | 160.2 | 0.63 | 18.4 | 1.9 |
| 8 | 155 | 250 | 159 | 7.2 | 0.81 | 158 | 0.87 | 3.6 | 1.7 |
| 9 | 70 | 25 | 73 | 7.3 | 0.71 | 187.5 | 0.87 | 18.1 | 1.6 |
| 10 | 120 | 100 | 121 | 7.3 | 0.65 | 86.2 | 0.56 | 5.2 | 1.8 |
| 11 | 50 | 50 | 58 | 6.9 | 0.76 | 86.5 | 0.47 | 8.9 | 1.7 |
| 12 | 245 | 250 | 249 | 7.3 | 1.02 | 85.6 | 0.56 | 3.2 | 1.8 |
| 13 | 55 | 50 | 58 | 7.4 | 0.82 | 10.3.5 | 0.58 | 3.5 | 1.8 |
| 14 | 150 | 100 | 160 | 7.3 | 0.72 | 112.5 | 0.6 | 9.1 | 1.8 |
| 15 | 150 | 100 | 154 | 7.3 | 0.73 | 100.8 | 1.11 | 6.3 | 1.8 |
| 16 | 145 | 100 | 148 | 7.2 | 0.74 | 158.3 | 0.45 | 9 | 2.1 |
| 17 | 140 | 100 | 146 | 7.3 | 0.69 | 98.6 | 0.42 | 6.4 | 2 |
| 18 | 150 | 100 | 153 | 6.4 | 0.79 | 85.6 | 1.11 | 5.4 | 1.8 |
| 19 | 170 | 100 | 172 | 6.4 | 0.76 | 105.2 | 0.5 | 8.9 | 1.8 |
| 20 | 156 | 100 | 160 | 7.2 | 0.81 | 120.3 | 0.97 | 8.9 | 1.9 |
| 21 | 160 | 100 | 168 | 7.2 | 0.75 | 110.5 | 0.87 | 6.6 | 1.8 |
| 22 | 145 | 100 | 150 | 6.3 | 0.79 | 122.6 | 0.5 | 2.1 | 1.7 |
| 23 | 468 | 500 | 470 | 7.8 | 0.81 | 56.8 | 0.45 | 3.6 | 1.8 |
| 24 | 370 | 250 | 380 | 7.6 | 1.39 | 205.9 | 0.96 | 6.6 | 1.9 |
| 25 | 491 | 250 | 500 | 7.5 | 0.55 | 184 | 0.52 | 2.4 | 1.7 |
| 26 | 420 | 250 | 430 | 7.3 | 0.43 | 58.6 | 0.42 | 3.4 | 1.8 |
| 27 | 345 | 250 | 350 | 7.4 | 0.56 | 82.7 | 1.23 | 4.5 | 2.1 |
| 28 | 178 | 250 | 183 | 8.1 | 0.58 | 66.9 | 0.68 | 6.9 | 2.8 |
| 29 | 175 | 100 | 178 | 7.2 | 0.75 | 128.6 | 1.25 | 9 | 1.9 |
| 30 | 170 | 100 | 176 | 7.2 | 0.75 | 106.9 | 0.8 | 9.1 | 1.9 |
| 31 | 165 | 100 | 170 | 6.5 | 0.75 | 111.5 | 0.62 | 9.5 | 1.8 |

| 32 | 500 | 100 | 510 | 7.5 | 0.64 | 99.3 | 0.46 | 2.5 | 1.9 |
|----|-----|-----|-----|-----|------|------|------|-----|-----|
| 33 | 644 | 100 | 650 | 7.4 | 0.92 | 180.2 | 0.78 | 2.4 | 1.9 |
| 34 | 559 | 500 | 560 | 7.6 | 0.83 | 166.4 | 0.8 | 4.9 | 1.9 |
| 35 | 410 | 250 | 420 | 7.7 | 1.04 | 190.8 | 0.57 | 2.1 | 2.1 |
| 36 | 622 | 500 | 630 | 7.6 | 0.68 | 104.2 | 1.84 | 5.1 | 1.8 |
| 37 | 367 | 250 | 370 | 7.4 | 0.67 | 115.2 | 0.68 | 13.5 | 1.8 |
| 38 | 70 | 50 | 74 | 7.3 | 0.75 | 121.5 | 0.75 | 15.5 | 1.5 |
| 39 | 95 | 50 | 96 | 7.3 | 0.63 | 88.5 | 0.48 | 5.1 | 1.6 |
| 40 | 60 | 50 | 67 | 6.3 | 0.76 | 100.8 | 0.87 | 3.9 | 2 |
| 41 | 373 | 25 | 380 | 7.4 | 0.74 | 108.3 | 0.78 | 3.5 | 2.1 |
| 42 | 10 | 10 | 15 | 7.3 | 1 | 158.3 | 0.85 | 3.7 | 2.1 |
| 43 | 140 | 100 | 148 | 6.6 | 0.84 | 133.7 | 0.75 | 4.5 | 2 |
| 44 | 170 | 250 | 174 | 7.2 | 0.82 | 122.3 | 0.66 | 9.2 | 1.9 |
| 45 | 170 | 250 | 180 | 7.2 | 0.81 | 145.3 | 0.96 | 9.1 | 1.9 |
| 46 | 165 | 250 | 171 | 7.2 | 0.76 | 89.3 | 1.18 | 5.4 | 1.8 |
| 47 | 560 | 250 | 570 | 7.6 | 0.77 | 98.4 | 1.89 | 5.1 | 1.7 |
| 48 | 398 | 250 | 400 | 7.4 | 0.81 | 63.9 | 0.7 | 2.4 | 1.8 |
| 49 | 300 | 250 | 310 | 7.4 | 2.36 | 411.7 | 0.83 | 3.6 | 1.6 |
| 50 | 325 | 250 | 330 | 7.3 | 1.66 | 369.3 | 0.42 | 15.3 | 1.8 |
| 51 | 480 | 250 | 490 | 7.6 | 1.33 | 213 | 0.99 | 2.9 | 1.7 |
| 52 | 515 | 500 | 520 | 7.5 | 0.52 | 150 | 0.79 | 2.1 | 1.9 |
| 53 | 316 | 250 | 320 | 7.7 | 1.83 | 340.8 | 0.72 | 14.9 | 1.9 |

# Appendix-III

**Test results of 56 water samples of Hajigong village of Chandpur district:**

| Sl No | Test Method of *As* | | | Chemical Parameters | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ARSOlux Biosensor | Merck Kit Test | ICP-MS | pH | Cond. (mS/cm) | Cl⁻ (ppm) | HCO₃⁻ as CaCO₃(ppm) | Iron (ppm) | DO (ppm) |
| 1 | 355 | 250 | 360 | 7.4 | 1.77 | 333.7 | 0.68 | 13.2 | 1.8 |
| 2 | 630 | 250 | 640 | 7.5 | 0.85 | 99.8 | 0.57 | 13.4 | 1.9 |
| 3 | 481 | 500 | 490 | 7.5 | 0.66 | 78.1 | 0.78 | 3.3 | 1.7 |
| 4 | 615 | 500 | 620 | 7.5 | 0.62 | 88.6 | 0.69 | 3.1 | 1.8 |
| 5 | 400 | 250 | 410 | 7.7 | 0.91 | 123.5 | 0.48 | 3.5 | 1.9 |
| 6 | 405 | 250 | 410 | 7.6 | 0.58 | 150.2 | 0.66 | 2.5 | 1.7 |
| 7 | 450 | 250 | 470 | 7.6 | 0.68 | 58.6 | 0.57 | 4.6 | 1.6 |
| 8 | 155 | 100 | 150 | 6.6 | 0.39 | 87.9 | 0.6 | 17.9 | 1.8 |
| 9 | 260 | 250 | 266 | 7.3 | 1.64 | 333.7 | 1.11 | 9.8 | 2 |
| 10 | 242 | 250 | 250 | 6.2 | 0.83 | 128.5 | 0.36 | 1.2 | 1.6 |
| 11 | 160 | 250 | 170 | 6.3 | 0.79 | 120.3 | 0.44 | 1.8 | 1.9 |
| 12 | 156 | 100 | 160 | 7.2 | 0.79 | 99.1 | 0.78 | 17.9 | 1.5 |
| 13 | 120 | 50 | 126 | 7.2 | 0.71 | 114.4 | 0.69 | 4.5 | 1.4 |
| 14 | 210 | 0 | 215 | 7.2 | 0.86 | 145.3 | 0.85 | 4.5 | 1.6 |
| 15 | 120 | 50 | 122 | 7 | 0.92 | 142.3 | 0.74 | 17.9 | 1.6 |
| 16 | 500 | 250 | 510 | 7.3 | 0.8 | 98.5 | 0.63 | 5.2 | 1.9 |
| 17 | 165 | 100 | 166 | 7.2 | 0.73 | 78.8 | 1.08 | 6.4 | 2 |
| 18 | 170 | 250 | 179 | 7.3 | 0.75 | 98.5 | 1.23 | 9.1 | 1.8 |
| 19 | 180 | 250 | 185 | 7.3 | 0.79 | 100.2 | 0.83 | 6.3 | 1.8 |
| 20 | 145 | 100 | 150 | 7.2 | 0.8 | 120.2 | 0.42 | 9.4 | 1.8 |
| 21 | 170 | 100 | 179 | 7.1 | 0.75 | 88.6 | 0.41 | 9.5 | 1.9 |
| 22 | 166 | 100 | 171 | 7.1 | 0.85 | 88.9 | 0.42 | 9.2 | 2.1 |
| 23 | 160 | 100 | 163 | 7.2 | 0.75 | 103.3 | 0.62 | 6.3 | 2.1 |
| 24 | 151 | 100 | 159 | 7.2 | 0.81 | 110.5 | 0.69 | 6.6 | 2.1 |
| 25 | 595 | 250 | 600 | 7.6 | 1.11 | 205 | 0.54 | 2.8 | 1.9 |
| 26 | 570 | 250 | 580 | 7.8 | 1.39 | 291.1 | 0.6 | 3.7 | 1.9 |
| 27 | 615 | 100 | 630 | 7.4 | 0.96 | 149.1 | 1.18 | 2.1 | 1.8 |
| 28 | 350 | 250 | 360 | 7.4 | 2.12 | 426 | 0.96 | 8.1 | 1.5 |
| 29 | 365 | 250 | 370 | 7.5 | 2.66 | 496.2 | 1.18 | 3.5 | 1.5 |
| 30 | 500 | 500 | 520 | 7.5 | 0.52 | 99.2 | 0.79 | 2.1 | 1.9 |
| 31 | 468 | 250 | 470 | 7.7 | 0.55 | 96.3 | 2.4 | 3.6 | 1.9 |

| 32 | 382 | 500 | 390 | 7.3 | 0.86 | 88.7 | 0.56 | 17.5 | 1.6 |
| 33 | 200 | 0 | 220 | 7.2 | 1.03 | 164.5 | 0.63 | 17.2 | 1.8 |
| 34 | 170 | 100 | 171 | 7.2 | 0.74 | 98.3 | 0.99 | 6.6 | 2 |
| 35 | 161 | 100 | 170 | 6.5 | 0.74 | 100 | 0.58 | 9.2 | 2 |
| 36 | 95 | 100 | 99 | 7.2 | 0.78 | 122.5 | 0.52 | 6.3 | 1.8 |
| 37 | 200 | 250 | 211 | 7.4 | 0.77 | 111.2 | 0.74 | 3.2 | 1.9 |
| 38 | 325 | 250 | 330 | 7.4 | 0.58 | 85.5 | 0.63 | 3.9 | 1.8 |
| 39 | 369 | 250 | 370 | 7.4 | 0.7 | 97.6 | 0.54 | 3.9 | 1.7 |
| 40 | 85 | 50 | 87 | 7.4 | 0.69 | 87.1 | 0.85 | 3.7 | 1.8 |
| 41 | 450 | 250 | 460 | 7.6 | 0.84 | 127.8 | 0.74 | 2.6 | 1.4 |
| 42 | 360 | 250 | 370 | 7.7 | 0.7 | 85.3 | 0.66 | 3.6 | 1.8 |
| 43 | 362 | 250 | 370 | 7.1 | 0.9 | 78.1 | 0.48 | 3.9 | 1.8 |
| 44 | 445 | 250 | 450 | 7.7 | 0.55 | 63.9 | 0.59 | 2.4 | 1.5 |
| 45 | 530 | 250 | 540 | 7.6 | 0.96 | 256.2 | 0.9 | 2 | 1.9 |
| 46 | 485 | 250 | 490 | 7.7 | 0.7 | 99.4 | 0.42 | 2.1 | 3.2 |
| 47 | 318 | 250 | 320 | 7.3 | 2.11 | 426 | 1.08 | 7.6 | 1.9 |
| 48 | 281 | 250 | 290 | 7.4 | 2.41 | 366.5 | 1.23 | 14.5 | 1.7 |
| 49 | 550 | 250 | 560 | 7.7 | 0.64 | 88.2 | 0.64 | 1.8 | 2.1 |
| 50 | 400 | 250 | 410 | 7.8 | 0.86 | 100.5 | 0.2 | 4.5 | 2 |
| 51 | 444 | 250 | 450 | 7.2 | 0.57 | 85.2 | 0.92 | 2.5 | 1.9 |
| 52 | 438 | 500 | 440 | 7.5 | 1.03 | 234.9 | 1.44 | 5.8 | 1.9 |
| 53 | 555 | 250 | 560 | 7.6 | 0.63 | 86 | 0.79 | 4.5 | 1.5 |
| 54 | 146 | 100 | 150 | 7.5 | 0.62 | 105.3 | 0.54 | 3.2 | 1.7 |
| 55 | 435 | 250 | 450 | 7.2 | 0.69 | 98.6 | 0.62 | 2.9 | 1.6 |
| 56 | 422 | 250 | 430 | 7.5 | 0.84 | 92.3 | 0.69 | 2.9 | 1.6 |

# Appendix-IV

**Test results of 53 water samples of Arihazar village of Narayangonj district:**

| Sl No | Test Method of *As* | | | Chemical Parameters | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ARSOlux Biosensor | Merck Kit Test | ICP-MS | pH | Cond. (mS/cm) | Cl⁻ (ppm) | HCO₃⁻ as CaCO₃(ppm) | Iron (ppm) | DO (ppm) |
| 1 | 495 | 250 | 500 | 7.7 | 0.68 | 58 | 1.11 | 2.7 | 1.6 |
| 2 | 532 | 250 | 540 | 7.6 | 0.6 | 100.2 | 0.5 | 2.6 | 1.9 |
| 3 | 590 | 500 | 600 | 7.6 | 0.68 | 104.4 | 0.95 | 4.4 | 1.9 |
| 4 | 130 | 100 | 139 | 7.2 | 0.8 | 160.5 | 0.75 | 9.8 | 1.8 |
| 5 | 170 | 250 | 173 | 7.1 | 0.99 | 124.1 | 0.78 | 17.9 | 1.3 |
| 6 | 150 | 100 | 152 | 7.2 | 0.83 | 128.3 | 0.75 | 17.8 | 1.7 |
| 7 | 185 | 100 | 189 | 7.2 | 0.87 | 45.3 | 0.9 | 3.1 | 1.7 |
| 8 | 150 | 100 | 156 | 7.2 | 0.78 | 45.6 | 0.71 | 17.5 | 1.6 |
| 9 | 190 | 100 | 198 | 6.7 | 0.95 | 35.5 | 0.89 | 5.1 | 1.4 |
| 10 | 180 | 100 | 186 | 7.2 | 0.88 | 58.3 | 0.65 | 18.1 | 1.7 |
| 11 | 130 | 100 | 134 | 7.1 | 0.89 | 89.2 | 0.54 | 17.9 | 1.8 |
| 12 | 80 | 50 | 90 | 7.1 | 0.89 | 58.3 | 0.52 | 14.1 | 1.4 |
| 13 | 155 | 100 | 160 | 8 | 0.74 | 44.2 | 0.87 | 6.3 | 1.9 |
| 14 | 190 | 100 | 192 | 7.2 | 0.74 | 45.3 | 0.92 | 4.5 | 1.9 |
| 15 | 175 | 100 | 178 | 7.1 | 0.73 | 36.6 | 0.67 | 8.9 | 2 |
| 16 | 160 | 100 | 164 | 7.1 | 0.81 | 56.2 | 0.7 | 2.5 | 2.1 |
| 17 | 162 | 100 | 169 | 6.9 | 0.8 | 88.7 | 0.6 | 3.2 | 2 |
| 18 | 185 | 50 | 187 | 6.3 | 0.62 | 56.2 | 0.36 | 1.9 | 1.8 |
| 19 | 100 | 50 | 110 | 7.2 | 0.75 | 56.1 | 0.44 | 2.9 | 1.7 |
| 20 | 111 | 50 | 115 | 6.8 | 0.93 | 88.3 | 0.35 | 3.1 | 1.8 |
| 21 | 355 | 250 | 360 | 7.6 | 1.53 | 180.3 | 0.48 | 6.8 | 1.7 |
| 22 | 360 | 250 | 370 | 7.5 | 2.07 | 296.7 | 0.68 | 6.4 | 1.7 |
| 23 | 282 | 250 | 290 | 7.4 | 2.52 | 291 | 1.25 | 15.4 | 1.7 |
| 24 | 520 | 250 | 530 | 7.4 | 0.48 | 56.3 | 0.41 | 2.1 | 1.9 |
| 25 | 160 | 100 | 162 | 7.1 | 0.82 | 88.1 | 0.56 | 9.4 | 1.9 |
| 26 | 170 | 100 | 177 | 7.2 | 0.76 | 56.1 | 0.52 | 6.3 | 2.1 |
| 27 | 572 | 250 | 580 | 7 | 0.99 | 106.5 | 0.78 | 3.5 | 1.8 |
| 28 | 150 | 250 | 151 | 7.3 | 0.71 | 78.5 | 0.66 | 6.5 | 2 |
| 29 | 170 | 250 | 177 | 7.2 | 0.77 | 55.3 | 0.48 | 9.5 | 1.9 |
| 30 | 400 | 250 | 410 | 7.7 | 0.91 | 71 | 0.58 | 3.6 | 2.1 |
| 31 | 545 | 500 | 550 | 7.7 | 1.46 | 156.8 | 0.8 | 3.5 | 2.1 |
| 32 | 300 | 250 | 310 | 7.7 | 1.13 | 142 | 0.71 | 16.2 | 1.9 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 33 | 561 | 250 | 570 | 7.3 | 0.58 | 84 | 0.97 | 2.7 | 1.9 |
| 34 | 40 | 50 | 43 | 7.5 | 0.44 | 48.2 | 0.7 | 3.2 | 1.9 |
| 35 | 87 | 50 | 92 | 7.7 | 0.41 | 50.3 | 0.78 | 3.1 | 2.1 |
| 36 | 140 | 100 | 148 | 7.1 | 0.84 | 66.8 | 0.75 | 4.5 | 2 |
| 37 | 150 | 250 | 153 | 7.2 | 0.74 | 74.5 | 0.57 | 6.3 | 1.9 |
| 38 | 175 | 100 | 179 | 6.9 | 0.82 | 76.5 | 0.3 | 9.6 | 1.8 |
| 39 | 170 | 100 | 178 | 7.2 | 0.79 | 78.8 | 0.77 | 6.9 | 1.9 |
| 40 | 173 | 100 | 178 | 7.1 | 0.77 | 89.5 | 0.45 | 7.2 | 2 |
| 41 | 180 | 100 | 183 | 7.1 | 0.75 | 86.5 | 0.96 | 8.9 | 2.1 |
| 42 | 145 | 100 | 146 | 7.2 | 0.76 | 98.6 | 0.71 | 9.1 | 1.8 |
| 43 | 120 | 100 | 124 | 7.2 | 0.77 | 88.5 | 0.57 | 9.3 | 1.9 |
| 44 | 180 | 100 | 185 | 7.3 | 0.73 | 78.3 | 0.23 | 6.3 | 2 |
| 45 | 160 | 100 | 169 | 6.5 | 0.81 | 100.3 | 0.37 | 9.4 | 1.6 |
| 46 | 40 | 50 | 48 | 7.1 | 0.81 | 85.3 | 0.45 | 9.3 | 1.9 |
| 47 | 65 | 50 | 70 | 7.2 | 0.7 | 66.9 | 0.78 | 2.3 | 2.1 |
| 48 | 60 | 50 | 66 | 7.4 | 0.7 | 66.7 | 0.58 | 3.6 | 1.9 |
| 49 | 40 | 50 | 44 | 7.3 | 0.63 | 54.2 | 0.87 | 5.1 | 1.6 |
| 50 | 50 | 50 | 56 | 7.3 | 0.78 | 88.9 | 0.89 | 3.7 | 1.7 |
| 51 | 90 | 100 | 91 | 7.4 | 0.69 | 65.2 | 0.74 | 3.5 | 1.8 |
| 52 | 171 | 100 | 179 | 7.3 | 0.77 | 74.5 | 0.72 | 6.3 | 1.8 |
| 53 | 175 | 100 | 179 | 7.2 | 0.85 | 102.5 | 0.61 | 7.1 | 2.2 |

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# List of the symbols and abbreviations

| Symbols / Abbreviations | Explanation |
| --- | --- |
| *As* | Arsenic |
| UNICEF | United Nations Children's Fund |
| WHO | World Health Organization |
| SOES | School of Environmental Studies |
| NGOs | Non-governmental Organizations |
| BDP | Bengal Delta Plain |
| TW | Tube-well |
| BDWS | Bangladesh Drinking Water Standard |
| MDG | Millennium Development Goals |
| mS/cm | Milli Siemens/cm |
| μS/cm | Micro Siemens/cm |
| mg/L or ppm | Milligrams per liter |
| GFP | Green Fluorescent Protein |
| ICP–MS | Inductively coupled plasma–mass spectrometry |
| HPLC | High-performance liquid chromatography |
| HG | Hydride generation |
| TMAO | Trimethylarsine oxide |
| TMA | Tetramethylarsonium ion |
| USPH | United States Public Health Drinking Water Standard |
| DO | Dissolved oxygen |
| mL | Milliliter |
| EDTA | Ethylene di-amine tetra acetic acid |
| USEPA | United States Environmental Protection Agency |
| BGS | British Geological Survey |
| σ | Conductivity |

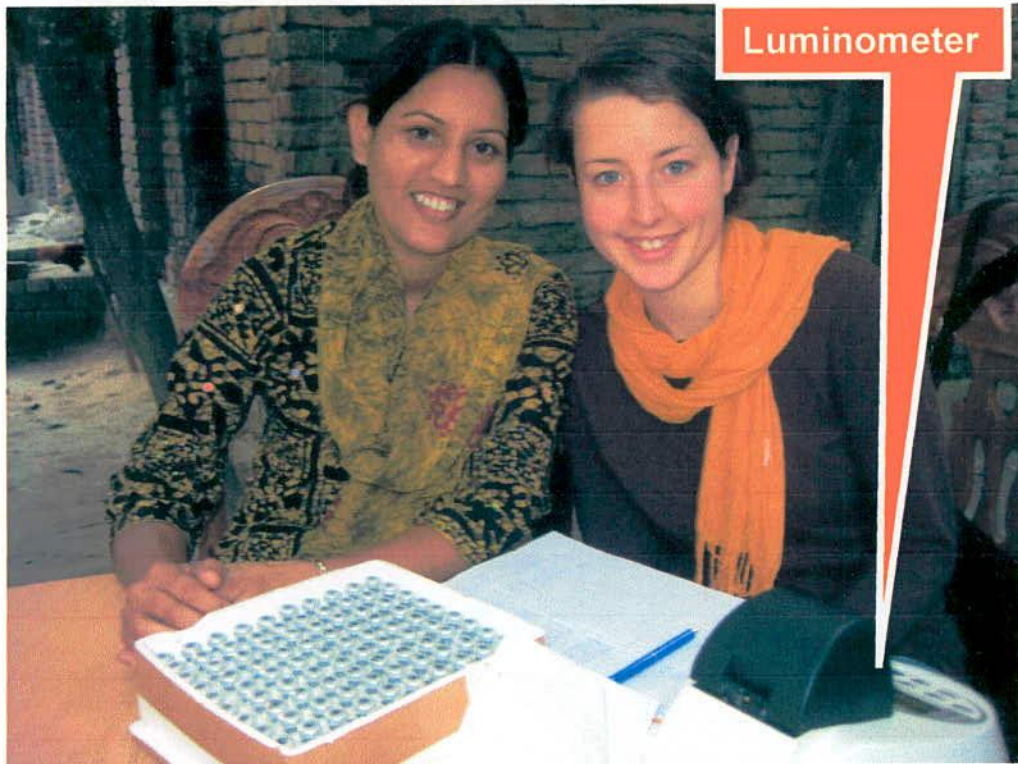**Collection of water samples from different tube wells**



Biosensor test

Merck field test kit
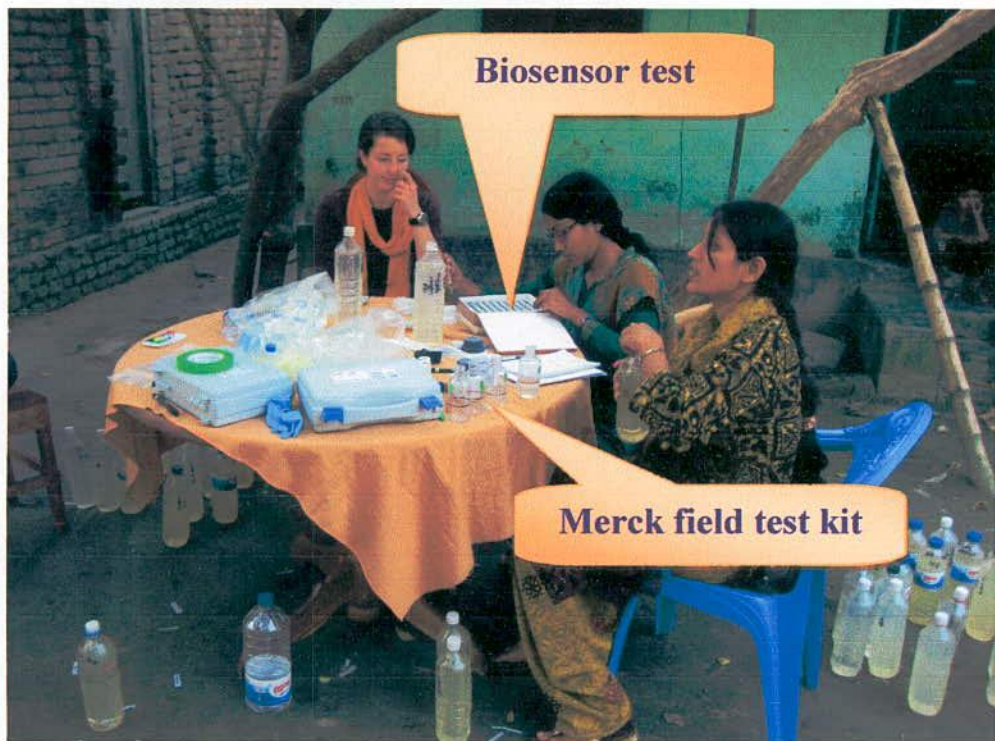
**Investigation of water sample by Biosensor test and Merck field test kit**
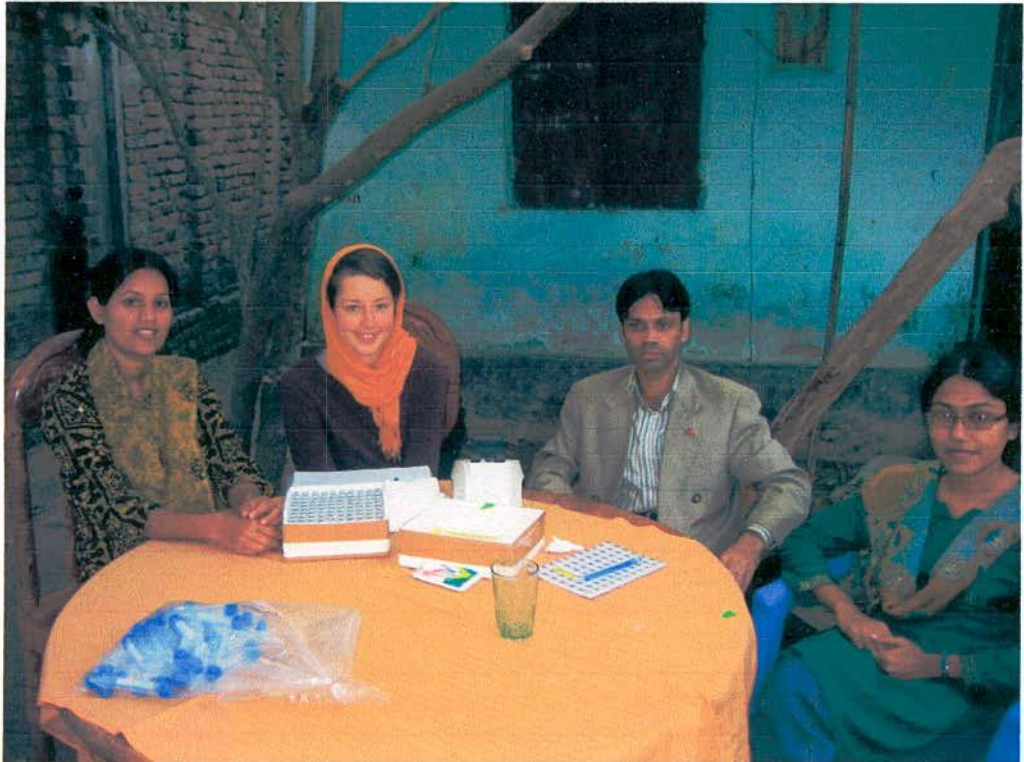
**After Incubation we are waiting for the result**



**We are collecting the results**

**Waiting for biosensor test**



**Discussion about the results**