CONTAMINATION OF DUGWELL WATER AND ITS CONTROL

A Thesis

By

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DECLARATION

I hereby certify that the research work embodied in this thesis has been performed by the author under the supervision of Dr. A. B. M. Badruzzaman, Professor of the Department of Civil Engineering, BUET. Neither this thesis nor any part of it has been submitted or is being concurrently submitted elsewhere for any other purpose (except for publications).

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ABSTRACT

Water quality studies conducted so far have shown that dug wells have reduced arsenic ingestion but exposed population to high levels of health risk from microbial contamination. This study aims at understanding the nature of contamination of dugwell water and decontamination by in-situ chemical disinfection. For preliminary water quality analysis, dugwells were selected from Sirajdikhan, Singair, Daudkandi and Sharsha upazilas. After preliminary water quality analysis, two dugwells with high microbial contamination from Sirajdikhan and one dugwell with high arsenic content from Sharsha were selected for decontamination study.

Natural growth/decay of total coliform and faecal coliform was studied in the laboratory and break point chlorine dose was determined for the samples under consideration. Then, starting from the break point dose, different doses were applied to the dugwell water in the laboratory and the chlorine dose for complete removal of coliforms from the water was determined. The effect of chlorination on other water quality parameters like arsenic, ammonia, manganese, iron, turbidity, etc. was also studied in the laboratory. Chlorination was performed in each of the selected dugwells and continued for a couple of days. Water samples were collected from each of the dugwells both before and after chlorination and analyzed for selected water quality parameters on each day of chlorination. Finally, recharge capacity of 51 dugwells in Sharsha upazila was studied and user acceptability surveyed at Sirajdikhan.

Rate of microbial decay in the dugwell water has been found to be significantly high (maximum of 0.455/day). The negative or very low Eh (-102 mV) and low dissolved oxygen (0 mg/l) of dug well water are not favourable for oxidation of iron, arsenic and odour producing substances. Dissolved arsenic (as high as 0.14 mg/l at Sharsha), iron (as high as 10 mg/l at Daudkandi) and manganese (as high as 1.48 mg/l at Sirajdikhan) were present in dugwells. There was hardly any difference between the water quality of open and closed dug wells and the efforts made for keeping the dug wells open seemed futile. The improved dugwells produce an average of 2.09 m^3/day of water in the wet season and 0.58 m^3/day of water in the dry season, which are inadequate to meet the requirements.

Residual chlorine in the range between 0.5 to 1 mg/l destroyed all coliforms. However, the chlorine level quickly decreased with the inflow of new groundwater in the dug well and rendered the well vulnerable to renewed contamination. Chlorine dosing increased redox potential of dug well water from soluble reducing fields to highly oxidizing fields in Eh-ph phase-stability diagrams of both Fe and As. Although, the oxidizing condition prevails in the DW, following chlorination, the As and Fe concentration increased in the collected samples which is contradictory to the theory. However, this might have happened as the Fe flocs formed due to oxidized condition settling downward being pumped directly through the uptake pipe and thus, increasing the Fe and As level in the samples. This dynamic flow condition might have caused the effects opposite to those found in theory as well as in the laboratory. In spite of some aesthetic water quality problems, dug well water appeared to be acceptable to most of the respondents at Sirajdikhan. Most of the people in the study areas had no complain about drinking chlorinated water at the levels of 0.5 – 1.0 mg/l of residual chlorine in water. But, intermittent dosing of chlorine even at an interval of once a day has been found to be ineffective in maintaining the coliform to desired level of zero.

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ABBREVIATIONS

AAN	Asia Arsenic Network
APSU	Arsenic Policy Support Unit
BAMWSP	Bangladesh Arsenic Mitigation Water Supply Project
BDS	Bangladesh Standard
DALY	Disability Adjusted Life Years
DASCOH	Development Association for self-reliance, Communication and Health
DBP	Disinfection By Product
DCH	Dhaka Community Hospital
DFID	Department for International Development
DO	Dissolved Oxygen
DPHE	Department of Public Health Engineering
DW	Dug Well
DWW	Dhaka Water Works
FC	Faecal Coliform
GoB	Government of Bangladesh
IDE	International Development Enterprise
IRC	International Referral Centre (Water and Sanitation)
ITN	International Training Network
JICA	Japan International Cooperation Agency
NIPSOM	National Institute for Preventive and Social Medicine
ORP	Oxidation Reduction Potential
RAAMO I	Rapid Assessment of Arsenic Mitigation Options phase I
RAAMO II	Rapid Assessment of Arsenic Mitigation Options phase II
SORAS	Solar Oxidation for Removal of Arsenic
TC	Total Coliform
THM	Tri Halo Methanes
TTC	Thermo Tolerant Coliform
UNICEF	United Nations Children's Emergency Fund

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the context of very high prevalence of diarrhoeal diseases in Bangladesh, bacteriological quality received priority as a criterion for drinking water supply. Groundwater is normally free from pathogenic microorganisms and available in adequate quantity in shallow aquifers for development of low-cost tubewell based water supply for scattered rural population. Bangladesh achieved a remarkable success by providing 97% of the rural population with bacteriologically safe tubewell water. About 10 million private and public tubewells have been installed for water supply in the country. Unfortunately, when the rural people have developed the habit of drinking tubewell water, arsenic in excess of acceptable limit has been found in tubewell water in most parts of Bangladesh. Groundwater based water supply programs that provide "safe' drinking water in order to control diseases like diarrhoea, dysentery, typhoid, cholera and hepatitis have exposed population to arsenic related health problems.

Arsenic contamination of groundwater has rendered at least 2.5 million shallow tubewell unsafe for water supply and exposed about 30 million people to arsenic exceeding Bangladesh Standard for arsenic in drinking water. There are 8,540 villages in Bangladesh where more that 80% tubewells used as only source of drinking water are contaminated with arsenic. A total of 38,430 cases of arsenicosis has been identified under National screening program (BAMWSP, 2005). Considering the urgency and gravity of the problem, alternative sources of drinking water supply are being installed in arsenic affected areas under arsenic mitigation programs without due considerations to relative health risk of these options. In the *Implementation Plan for Arsenic Mitigation in Bangladesh*, dug well has been given priority among other options for water supply in the rural areas (GOB, 2004).

Dug wells provide both groundwater withdrawal and storage. Because of the storage capacity, water can be temporarily withdrawn at a higher rate than the recharge in the well. The storage effect is particularly important when the users take the water mostly at peak rates during few hours in the morning and the evening (IRC, 1981). When shallow tubewell water was found to be contaminated with arsenic, dug well water in the same areas were relatively free from arsenic contamination. This observation attracted the policy makers, who were desperately looking for an alternative arsenic-safe water supply. The concept of improved dug well was brought in as an alternative option of water supply in arsenic affected areas. The mechanism of producing water of low arsenic and other dissolved minerals concentration by dug wells are not fully known. The following explanations were attributed to the low arsenic content of dug well water:

- The oxidation of dug well water due to its exposure to open air and agitation during water withdrawal can cause precipitation of dissolved arsenic and iron.
- Photo-oxidation of impurities in dug well including arsenic and iron in the presence of sunlight may facilitate precipitation of iron and arsenic and reduction of microbial pollution of water.
- The presence of air and aerated water in well can oxidize the soils around dug wells and infiltration of water into wells through this oxidized soil can significantly reduce the concentration of arsenic in well water.
- Dug wells accumulate groundwater from top layer of a water table which is replenished each year by arsenic safe rain and surface waters by percolation through aerated zone of the soil. The fresh recharges also have diluting effects on contaminated groundwater (Ahmed, 2001).

In a completely closed dug well from all sides, the inflow of water is actuated by suction created due to withdrawal of water from the well. If aeration is controlling process of decontamination of well water, sanitary protection may adversely affect the quality of well water. Extensive research to understand the mechanism of dearsination of well water and the effects of sanitary protection of well on chemical quality of water is needed.

Many organizations have started sinking dug wells in arsenic affected areas. The major organizations and programs involved in arsenic mitigation have constructed a large number of dug wells in their program areas in Bangladesh. A recent survey shows that BAMWSP, DCH, NGOF, AAN, World Vision, IDE, DPHE-Danida, BRDB, DPHE-GOB IV have constructed 5,626 dug wells as an option for arsenic mitigation by the end of December, 2004 (APSU, 2005a). Water quality studies conducted so far have shown that dug wells have reduced arsenic ingestion but exposed population to high levels of health risk from microbial contamination. Thermotolerant coliforms (TTC) have been found in 94% dugwells by Arsenic Project Support Unit (APSU 2004), 74% by Dhaka Community Hospital (DCH, 2003), 40% by Development Association for self- reliance, Communication and Health (DASCOH, 2004), 90% by National Institute for Preventive & Social Medicine (NIPSOM, 2003), and in most of the dug wells by Japan International Cooperation Agency/ Asian Arsenic Network (JICA/AAN 2004). E. coli to a level of up to 85% was found in dug wells by confirmatory tests (APSU, 2004). It has also been observed that bacterial contamination greatly increases in the rainy season probably due to inflow on contaminated water in well (APSU, 2005b). Microbial contamination of dug well has also been reported by Smith et al (2003) in West Bengal. On the other hand arsenic contamination exceeding Bangladesh Standard of 0.05 mg/L has been observed in 3% of dug well studied by APSU (2004), 2 % by DASCOH (2003), 3% by DCH (2003), 15% by NIPSOM (2003) and 43% by JICA-AAN (2004). Apart from arsenic and microbial contamination, high levels of colour, turbidity, ammonia, iron, manganese were found in dug well water. The median and mean disease burdens of drinking dug water are 397 and 239 Disability Adjusted Life Years (DALYs)/1000 as compared to 9.1 and 9 DALYs/1000 in case of tubewell water (APSU, 2004).

In spite of high level of contamination, dug well will continue to be used as a traditional source of water supply in some areas and as an alternative option in arsenic mitigation in areas with limited technological choices. The Implementation Plan for Arsenic Mitigation in Bangladesh has put emphasis on conducting extensive research on improvement of dug well technology. The available information are

based on the monitoring of dug well constructed under different programs as alternative option for arsenic mitigation. These studies have revealed enough information to understand the magnitude of the problem but practically no research has been conducted to understand the cause of the problems and prescribe possible solution.

The oxidation reduction potential (ORP) of the dug well determines whether the oxidation or reduction state prevails in dug well water. This influences the presence of arsenic, iron, manganese, bad smell, colour, turbidity, taste and other undesirable characteristics commonly reported in dug well water. It is extremely difficult to erect sanitary protection in open dug well. If oxidizing condition does not prevail even in open dug well, the efforts to keep dug well open maintaining adequate sanitary protection are futile exercise. The death/growth dynamics of microbial population in dug well water are not known. These characteristics of dug well water regulate the concentration of microbes in water and provide information of rate of inflow of microbes in dug well

In this context, the arsenic mitigation programs promoting dug well as an alternative water supply option need a better understanding of the nature and causes of contamination and practical method of decontamination, particularly elimination/reduction of microbial load from drinking dug well water. This study is designed to understand the health-related water quality problems associated with water supply from dug well, reasons for such problems and potentials for control of contamination by disinfection of dug well for improvement of water quality and health benefit.

1.2 OBJECTIVES

In quest of safe water supply from dug well, this study aims at understanding the nature of contamination of dugwell water and decontamination by in-situ chemical disinfection.

The specific objectives of this research are as follows:

1. An assessment of level and nature of contamination of dug well water with special emphasis on arsenic and microbial contamination.
2. Finding out the possible reasons for presence and absence of different contaminants in dug well water.
3. An understanding of natural and chemical induced death dynamics of Faecal coliform as well as reduction in arsenic content in dug well water.
4. An evaluation of effectiveness of in-situ disinfection in eliminating/reducing bacterial and arsenic contamination of dug well water.
5. Knowing about People's willingness to drink chlorinated water at residual chlorine concentrations required for disinfection of dug well water.

1.3 RATIONALE OF THE RESEARCH

The use of dug well as an alternative water supply option for arsenic mitigation requires improved understanding of the nature and extent of contamination, natural and chemical induced decontamination of dug well water. This research has been targeted to investigate some of the poorly understood issues of this traditional water supply system in the present context of its revival as an important water supply technology in Bangladesh and India. Analysis of dug well water for relevant water quality parameters in different areas of Bangladesh will add additional information to the existing data base and help understanding water quality problem better.

Dug well water is in the interface between ground water and surface water and oxidation of open dug well water by air is considered to be the main mechanism of transforming ground water of high mineral content into surface water of low hardness, arsenic, iron, manganese etc. With this understanding in mind, improved dug wells have been constructed with adequate top opening for aeration of dug well water. This study with extensive measurement of ORP will provide enough new information about the oxidizing and reducing states of dug well water in both open and closed dug wells. This information will help to understand the rational of keeping the dug well open when sanitary protection is a big problem for dug wells.

Some of the implementation and monitoring programs have already revealed that level of microbial contamination of dug well water is quite high and sanitary protection erected for dug wells are ineffective in the control of contamination. In this context, chemical disinfection of dug well has received due attention for improvement of safety of dug well water. This study will reveal the effectiveness of in-situ chlorination in reducing microbial, arsenic, manganese, iron and other contamination, dose required for disinfection of dug well and frequency of chemical dosing required for safe water supply from dugwell. The study of growth/ death dynamics of microbial population in dug well water in this research will provide a pertinent information about the rate of inflow, growth and removal by natural decay of microbes in the dug well water environment.

The rural people are not habituated to drink chlorinated water. If the dose requirement of disinfection is high, the smell of residual chlorine may not be acceptable to the rural people. The study to be conducted on consumers of chlorinated water in a command area of a dug well will reveal people's acceptability of disinfected water.

1.4 ORGANIZATION OF THE THESIS

The introduction to the problem, objectives and rational of the study have been described in this first chapter of the thesis. The second chapter provides a review of the theoretical aspects of the studies conducted to realize the objectives of this thesis and findings of previous studies on dug wells. The procedure of works conducted under this research including selection of sites of dug wells, sampling of water and analytical methodologies of the research has been discussed in the third chapter under the heading experimental works. The experimental results along with analysis and discussion on results are presented in chapter four entitled experimental results and discussion. Finally the conclusions and recommendations of this research are presented in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORICAL DEVELOPMENT

Dug well is the oldest method of groundwater withdrawal for water supplies. Wells were used in many countries in ancient time for abstraction of ground water. About 2100 B.C, near the end of 11th Dynasty, one leader of Mentuhotep's Egyptian forces reported sinking of 14 wells with an army of 3,000 men. Some four centuries later Senacharib used pulleys to raise water. One of the earliest Biblical references to ground water is the story of Moses smiting a rock with his rod and bringing forth a fountain of water. Moses got married to a girl whose father owned a well. The skill shown in the construction of Joseph's well at Cairo has made it one of the best known of the ancient wells. Dug into solid rock, the well was built in two lifts- an upper lift 165 feet deep and 18 by 24 feet across, and a lower lift exceeding another 130 feet to a total depth of 295 feet (Edward E. Johnson, Inc., 1972). Reminiscence of dug wells are still found in Egypt and India. Wells were also known to have been used at remote period in ancient Greece and Italy and artesian wells were sunk in China in very early times. Ancient China possessed the deepest well in the world as it was known to be 1500 ft. deep. In ancient Greece and Egypt deep wells as deep as 300 ft. below ground level and wells ranging in depth from 100 ft. to 200 ft even now exist in India (Aziz, 1975). Hand dug wells reached to a depth of 60m in some areas of the African countries, sometimes penetrating hard rock zones (IRC, 1988).

The Dhaka Water Supply System initiated as early as 1874 through construction of Dhaka Water Works (DWW) which supplied water through narrow water distribution mains, street hydrants and house connection to elites and well-to-do of the then Dhaka City (now old Dhaka). The remaining population of Dhaka had dug well as the source of their water supply. Dug wells and protected ponds were the main source of rural water supply in India and Bangladesh before schemes for the collection of groundwater through hand pump tubewells for community water

supplies were taken up as early as 1928. Gradually traditional dug wells were replaced by tubewells that provided greater convenience and protection from contamination. Some traditional dug wells are still found even after invasion of tubewells in massive scale in urban and rural areas of Bangladesh.

Dug wells are still in use in many countries of the world for domestic water supply. The flow in a dug wells is actuated by lowering of water table in the well due to withdrawal of water. Usually no special equipment or skill is required for the construction of dug wells. For construction by manual digging, the wells are required to be at least 1.2 metres in diameter. Large diameter wells are constructed for community water supplies. The depth of the well is dependent on the depth of the water table and its seasonal fluctuations. Wells are constructed at least 1m deeper than the lowest water table. Community dug wells can be deeper to provide larger surface area for the entry of water to meet higher water demand. Private dug wells are less that 10m deep but dug wells for communal use are usually 20-30 meters deep.

2.2 DUG WELLS IN BANGLADESH

In Bangladesh, dug well was first used for groundwater withdrawal for water supply. In its simplest form, dug well is a shallow hole dug down into the water table. In the Chittagong hilly areas, Sylhet and northern parts of Bangladesh, construction of hand pump tubewells is not always possible due to adverse hydro geological and stony soil conditions. Construction of dug wells is a good option for water supply in these areas. A large number of dug wells are found operating in those areas. Dug wells are not successful in many areas of Bangladesh having thick impermeable surface layer. In areas with thick clayey soil, dug wells do not produce enough water to meet the requirements. Again in areas having very low water table and areas with loose sand and silt, there may be difficulty in construction as well as withdrawal of water. Although tube wells in Bangladesh have replaced traditional dug wells in most places, about 1.3 million people in both urban and rural areas are still dependent on dug well for drinking water supply in Bangladesh (GOB, 2002).

It is very difficult to protect the water of the dug well from bacterial contamination. Percolation of contaminated used water is the most common route of pollution of well water. Bacteria are found in upper soil layers and in most streams, lakes and ponds; in addition, there can be concentrated bacteria sources such as inefficient septic systems, farm animals and storm runoff. There are several ways in which bacteria actually get into a well, the routes of contamination delineated by American Ground Water Trust (2003) are summarized below:

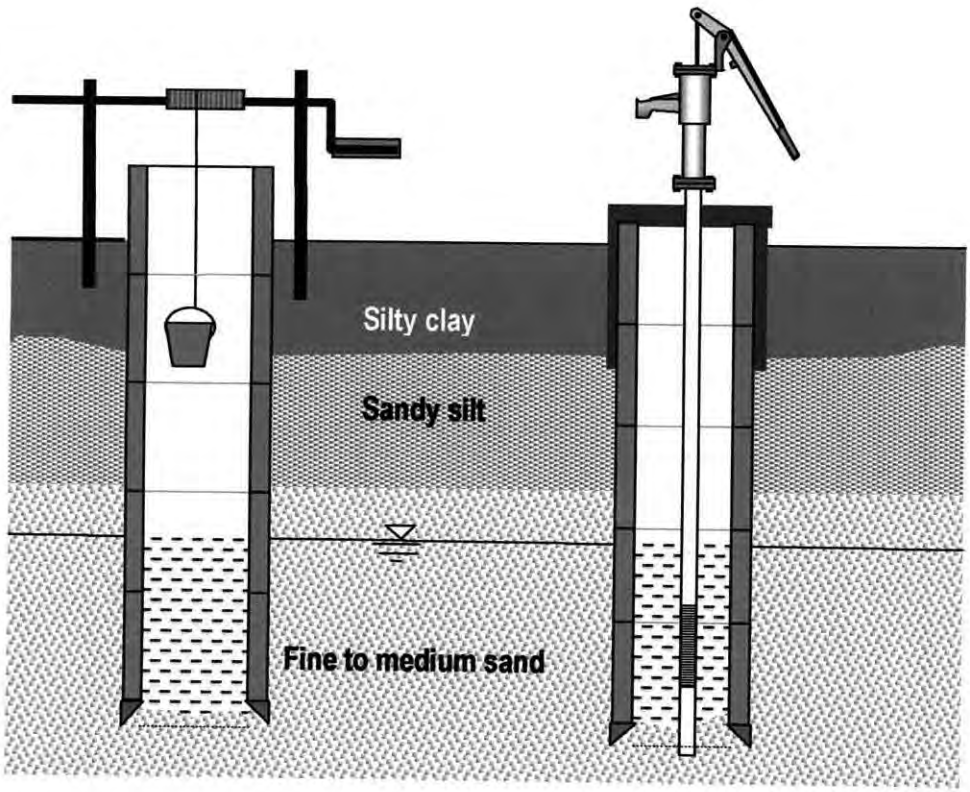
- Any shallow or dug well that is constructed from boards, bricks or stone is vulnerable to surface water contamination. Dug wells, with their water in contact with saturated soil layers, are particularly at risk because bacteria affected water can seep straight into the well. Insect infestation is very difficult to prevent in large diameter wells.
- If a drilled or bored well has casing (liner) that has not been properly sealed, bacteria from the upper soil layers may "leak" down into the well. In such cases, surface water or contaminated ground water may move vertically downward contaminating high quality aquifers.
- In the event of a flood or storm runoff, surface water could enter the top of the well if the casing does not extend far enough above the ground or if there is no watertight seal on the well casing. Wells that are in pits below ground level, in driveways or lawns, may be especially vulnerable to such pounding.
- Over time, old well casings may rust through, leaving holes near the ground surface where water can seep in and contaminate deeper ground water.
- Well casing can become cracked. Once there is a direct connection to the surface layers, bacterial infection may result. Earthquakes, subsidence and settling around the well, or impact damage from farm implements or snow plows, can make a well susceptible to contamination.
- Well bacteria can be introduced into a well when it is drilled, or when a pump is installed or serviced. Contractors must ensure that their equipment is decontaminated between jobs to prevent transporting infection from well to well. Pump installers often lay the pump, pipe and cable out on the ground before installation in the well. This practice is unwise because it can allow bacteria from the ground surface to adhere to the well equipment and enter

the well. Water wells should be sanitized after any service or installation work.

- Wells may become infected when ground water levels rise above normal and extend up to soil levels where bacteria are present. This can occur (1) in times of exceptional rainfall, (2) if major long-term water use by a nearby irrigation or municipal well ceases [ground water levels then begin to rise much higher than at the time of original well construction], or (3) when road construction, mining operations or dam construction lead to water level changes in wells.

The upper part of the well lining and the space between the wall and soil require proper sealing. The construction of an apron around the well can prevent entry of contaminated used water at the well site by seepage into the well. Water in a dug well is very easily contaminated if the well is open and the water is drawn using bucket and rope. A satisfactory safeguarding of bacteriological safety of water from a well can only be obtained if the well top is completely sealed with a water tight slab on which a hand pump is mounted to draw the water (IRC, 1981). A conventional dug well and a dug well with sanitary protection sunk in most common soil strata in Bangladesh are shown in Fig. 2.1.

In the areas with loose sand and silt, difficulties were encountered in the construction of dug well due to sand boiling. Land subsidence around dug well during or after construction and rapid filling up of constructed dug well are common problems in those areas. Large fluctuation of water tables in some areas causes dry up dug well in the dry seasons and makes many of the dug wells inoperative. The Implementation Plan for Arsenic Mitigation in Bangladesh, 2004 recommends the use of flexible pipe with a float at the lower end of the hand pump instead of strainer at a fixed depth to minimize the adverse effect of sand boiling and many dug wells adopted this technology without much benefit.



(a) Conventional Dug Well (b) Well with Sanitary Protection

Fig. 2.1: Conventional and Sanitary Protected Dug Wells (Ahmed and Rahman, 2003)

2.2.1 Open Dug Well

These dug wells are in an open place with no cover. These types are primitive ones with the wrong conception that these dug wells have no chance of external contamination. These conventional dug wells are kept open to allow entry of air and light. Open, unprotected dug wells are common especially in rural areas. Usually the peripheral wall is 2 to 3 ft. higher above ground to prevent entry of used water in the dug well as shown in Fig. 2.2. The water from the dug well is raised by bucket with a long rope. Rope of the bucket is

Fig. 2.2 : Open Dug Well

sometimes run over a pulley system as shown in Fig. 2.1 to facilitate raising of water with minimum effort. Open dug well water has the maximum exposure to air and sunlight but it is exposed to easy contamination. Dug wells can become contaminated from spilled water, animal excreta and objects thrown into the well. Dirt, leaves of trees and other substances blown by air can easily enter into the well to contaminate water. Water used to be drawn using bucket and rope from these wells which in fact increase the chance of external contamination (Fig. 2.2). Dug wells in this condition pose a major risk to public health and help to spread diseases such as guinea worm, typhoid, cholera, hepatitis A and many diarrhoeal diseases.

2.2.2 Covered Dug Well

Closed dug wells are constructed to avoid easy contamination. It was felt that dropping of pollutants from outside is the main source of contamination of open dug well. The wells are covered with space for passing air and sun light in side. Depending on the cover type, these can be of several types. Some dug wells have removable CI Sheet covers which can be removed very easily (Fig. 2.3)

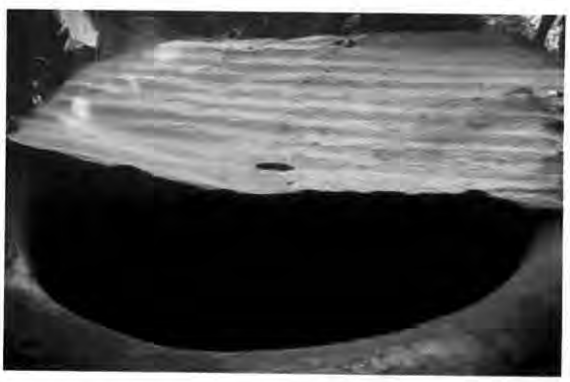


Fig. 2.3: Dug well with removable CI Sheet cover

The top of the dug well is closed to provide better sanitary protection. The water of the well is collected through a hand pump fixed either on the top of the slab or by the side of the well as shown in Fig. 2.4. Collection of water using a hand pump operating on suction mode is shown in Fig. 2.4. A pipe on the top of the slab is provided for aeration of the well. The top of the pipe is sometimes

Fig. 2.4 : Water Collection from a Closed Dug/Ring Well by Tubewell

bent so that no body can easily drop anything inside the well.

Fig. 2.5: Dug Well with Removable Concrete Cover

Some dug wells have concrete covers which are not removable easily. These dug wells contain small windows along the sides with mosquito nets (Fig. 2.5) and also contain vent pipes upon the concrete cover. Small openings are kept under the slab for entry of air. The openings are provided with mosquito net or wire mesh to prevent dropping of materials from outside. This type of closed well is considered as a substitute of the tube well as the hand pump of the tubewell used to raise water gives the feeling that people are using a hand pump tube well. Plat forms of adequate size are constructed around the pump to facilitate on-site use of water. These types of closed dug wells are in operation in the hilly areas of Bangladesh. Some people believe that the top pipe provided for ventilation of the well is not adequate to aerate the well water. Bad smell in some dug well water is sometimes attributed to lack of aeration of water.

2.2.3 Improved Dug Well

The National Policy for Arsenic Mitigation 2004 and Implementation Plan for Arsenic Mitigation in Bangladesh (GOB, 2004) recommended improved dug well as an option for arsenic mitigation. The improved dug well shall have the facilities for entry of air and sunlight in the well. The improved dug well has a cover or roof supported on frame above the head wall of the well.

The general requirements of an improved dug well are given below:

- Usually lined with brick masonry, or concrete rings; should be about 1.0 to 1.2 m in diameter.

- Wells should be at least 1.0 to 1.5 m deeper than the lowest water table in the driest month.
- Private dug wells are less than 10m deep but dug wells for communal use are usually 20-30 meters deep.
- Soil exploration needed before digging the well.
- The well lining should be extended at least 0.5m above the ground to form a 'head wall' around the outer rim of the well.
- A concrete apron, about 2 m in width, should be constructed on the ground surface extending all around the outer rim of the well.
- Water in the well should be chlorinated for disinfection after construction.
- The well should be located 10 m away from latrine or dumping ground of waste if any around.
- Hand pump connected with a pipe to the well should be used to drag water instead of rope & bucket.
- Top of the well should be covered with wire mesh.

The Schematic diagram of an improved dug well is shown in Fig. 2.6. Improved dug well, as recommended in the Implementation Plan for Arsenic Mitigation in Bangladesh, can be constructed in almost all areas of the country except in areas with loose soil, in areas with more than 15 metre consolidated clay layer, in tidal zones of the coastal areas and in areas of stony hills (GOB, 2004).

The open space between the head wall and roof allows entry of air an sunlight in the well. Usually a wire mesh is provided around the open space to prevent entry of air blown tree leaves and dropping of foreign materials in the well. Additional protection by mosquito nets around the open spaces is common in rural areas. Tube well pumps are installed by the side of the well to raise water from the well. Photograph of an improved dug well constructed in a rural area of Bangladesh is shown in Fig 2.7.

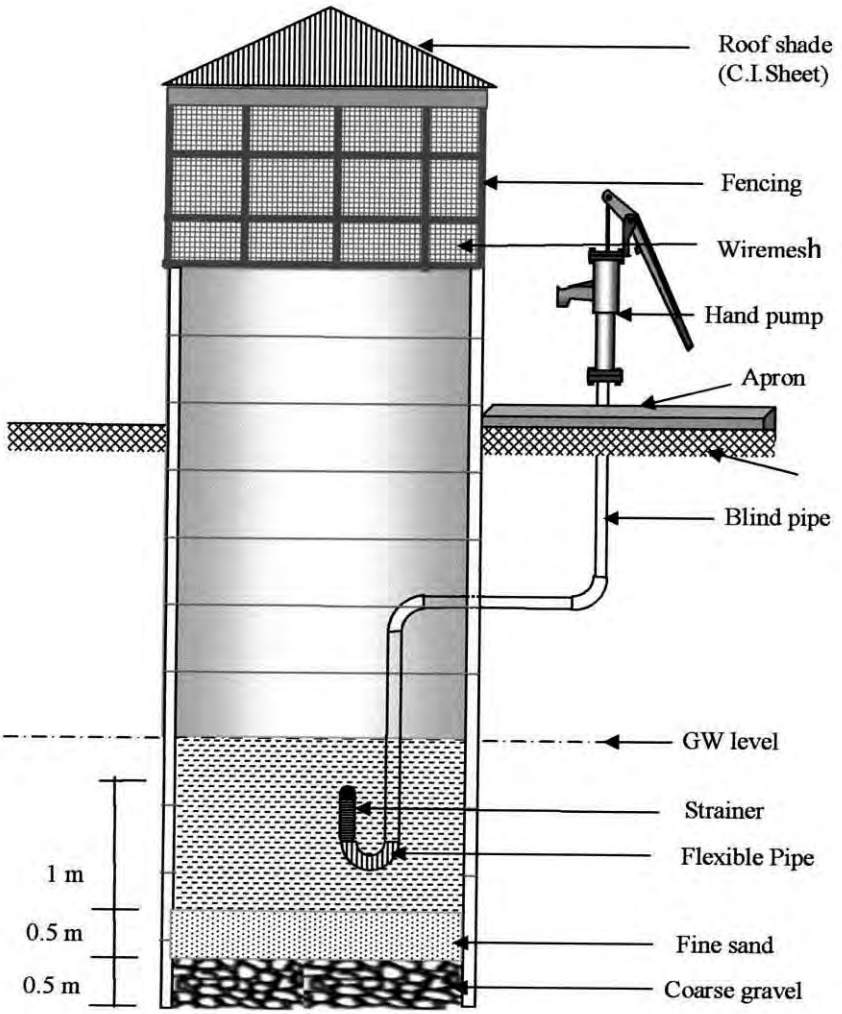


Fig. 2.6 : Schematic Diagram of an Improved Dug Well

Fig. 2.7: An Improved Dug Well

2.2.4 Recharge of Dug Well

Inflow of water in a dug well occurs when water level in the well falls below the surface level of the aquifer surrounding the well due to withdrawal of water. In an improved dug well, water mainly enter into the well through the bottom of the well. The vertical sides are protected by rings and usually sealed to avoid contamination. The rate of flow of water or rate of increase of water level, dh/dt in the dug well shown in Fig. 2.8. is proportional to the head difference between the water level in the well and the surface of the aquifer, h :

$$\text{i.e. } dh/dt = Kh \quad \ldots \quad \ldots \quad \ldots \quad (2.1)$$

where K is the recharge rate constant, per hour, which is primarily dependent on permeability of soil. The Equation 2.1 can be rearranged as :

$$dh/h = Kdt \quad \ldots\ldots\ldots (2.2)$$

Integrating the above Equation 2.2 between the limit, when t = 0, h = H, and when t = t and h = h_t:

$$\text{Log } (h_t/H) = K\,t \ldots\ldots\ldots (2.3)$$

Where H is the initial difference in water level in the well and aquifer surface level outside the well.

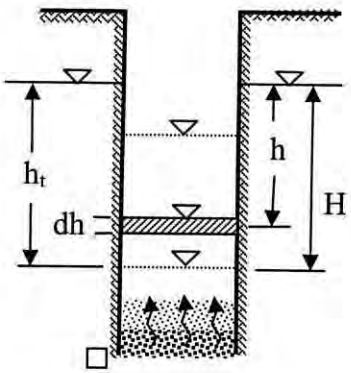


Fig. 2.8: Inflow of Water in a Dug Well

The value of recharge rate constant K of a dug well can be calculated by observing the water levels in the dug well at a definite time interval with reference to aquifer surface level. The equation 2.3 can be used to estimate the water level or quantity of water available in a the dug well after a definite period of time and the safe pumping rate at different water levels in different seasons of the year.

2.2.5 Abstraction of Water

Water is withdrawn from traditional dug well by rope and bucket which is considered to be a route of microbial contamination. An improved sanitary dug well

is covered and has no easy access to water. A pump is recommended to withdraw water from improved dug well. Different types of pumps have been installed to draw water from the covered dug wells:

Suction mode hand pump of No. 6 Tubewell

Manually operated Row pump

Tara force mode hand pump

Motorized pump

Dug wells with suction mode hand pumps are shown in Figs. 2.1, 2.4, 2.6 and 2.7. The suction mode hand pump of No.6 tubewell is the common pump used for lifting water from dug well. It can be installed outside the dug well for higher stability and is suitable for improved dug well which do not have a concrete slab for installation of pump directly on the well. Dug well with a Row pump is shown in Fig. 2.9. A Row pump operates under suction mode and produces water continuously on rotating a wheel attached to a handle as shown in Fig. 2.8. The rotating wheel pulls a rope connected to circular pistons that move upward through a pipe. The water is pushed upward through the pipe by piston and discharged through a spout for collection by users. A Row pump has to be installed directly on the well.

Fig. 2.9: Dug well with Row pump

The Tara pump is a force mode pump used to raise water when the water level falls below the sectional limit of about 24 ft. The piston is set below the water level and the water is pulled up by direct action for release through the spout. A dug well with a Tara pump is shown in Fig. 2.10. The Tara pump works well when water level in the dug well falls below 20 ft. from ground level in the dry season. The direct action

Fig. 2.10: Dug well with Tara pump

Tara pump cannot be installed out side the well; hence a strong concrete slab is required on the well for erection of this pump.

Water level in the dug well fluctuates widely between rainy and flood season. Again the bottom of the well is gradually silted up mainly due to entry of settleable soil materials with water and the process of silting up of the dug well is very high due to sand leakage/boiling in many areas. Under this conditions, a fixed strainer/screen as shown in Fig. 2.1b in many wells is either clogged or unable to collect water of best quality from dug well. The Implementation Plan for Arsenic Mitigation in Bangladesh (GOB, 2004) suggests introduction of flexible pipe with a float to collect water from a certain depth below water surface. The flexible pipe as shown in Fig. 2.6 allows vertical movement of the strainer with fluctuation of water level in the well. Photograph of a float in an improved dug well is shown in Fig. 2.11. Some movement of the float during pumping of the well helps aeration of dug well water.

Fig. 2.11: A Float in Operation in an Improved Dug well

Motorized pumps have been used in Bangladesh to raise water from community dug well to overhead water tanks for piped water supply.

2.3 OXIDATION OF DUG WELL WATER

Oxidation of dug well water is considered to be the main mechanism of improvement of quality of dug well water. Although dug wells derive ground water from top layer of the aquifer, it is believed that oxidation of well water by air removes arsenic, iron, manganese etc. that remain in soluble in water under reduced state. Oxidation of water also derives out the bad smell and improves taste of water. In this context, the study of oxidation reduction potential (ORP) and mechanism of oxidation of dug well water became important in this study.

2.3.1 Oxidation Reduction Potential

Arsenic and iron are redox sensitive elements. Arsenate [As(V)] and Arsenite [As(III)] are common oxidation states of arsenic in water. The mobility of arsenic is controlled, in large part, by oxidation-reduction (redox) transformations. The valence in which arsenic exists is related to both pH and the oxidation-reduction (or redox) potentials, *Eh*. The electron activity at equilibrium, pE, is used interchangeably with *Eh*. These parameters are related by:

$$pE = (F/2.3\ RT)\ Eh \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

where T is the absolute temperature, and F and R are the Faraday and Gas constants, respectively. Thus at 25°C, 2.3RT/F = 0.059 V and $pE = Eh/0.059$. The equation linking arsenic speciation to pH and pE are readily available. However, *Eh* versus *p*H diagrams, which indicate the predominant soluble species and relevant solids, are the most concise way of presenting this information (Ali and Ahmed, 2003). The Eh-pH diagram for As at 25°C and 1 atmospheric pressure with total arsenic 10^{-5} M and total sulphur 10^{-3} M is shown in figure 2.12. Solid species are enclosed in parenthesis in cross-hatched area, which indicates solubility less than $10^{-5.3}$ M is shown in Fig.2.12(Montgomery, 1985).

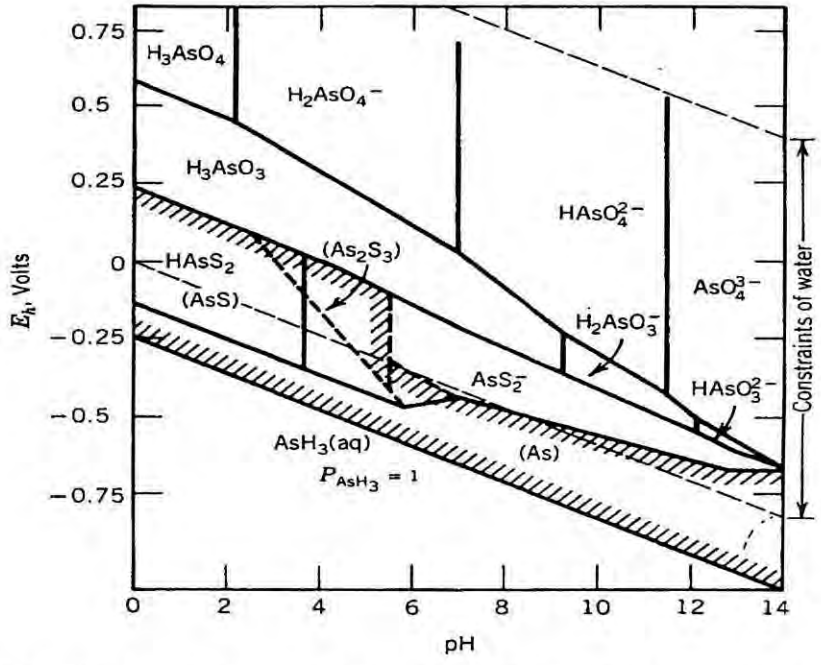


Fig. 2.12: The Eh-pH Diagram for As at 25°C and 1 Atmospheric Pressure

The diagram represents equilibrium conditions of arsenic under various redox potentials. Well-aerated surface waters would tend to induce high *Eh* values, therefore, any arsenic present should be in the arsenate [As(V)] form. Mildly reducing conditions, such as can be found in groundwater, should produce arsenite [As(III)]. By determining the *p*H and *Eh* of water, it is possible to determine which species of arsenic will be prevalent.

Similarly, the phase stability diagram for the solubility of iron minerals in water with respect to Eh and pH is shown in Fig. 2.13. In natural condition, surface water saturated with dissolved oxygen and nearly neutral pH remains in the stability field of ferric hydroxide showing very low dissolved iron in water. On the other hand, groundwater is close to the boundary between the soluble ferrous iron ($Fe2^{+}$) and insoluble ferric iron [$Fe(OH)_3$]. A change in water chemistry can increase or decrease the solubility of iron significantly.

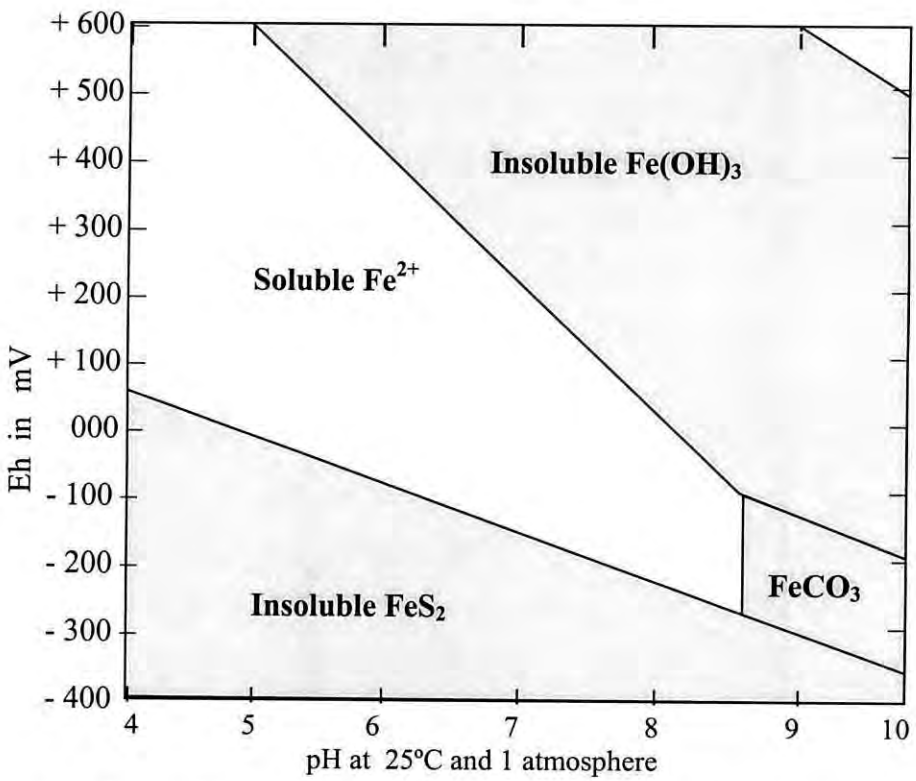


Fig. 2.13: Phase-stability Diagram for Solubility of Iron

An increase in acidity by dissolution of carbon dioxide or presence of organic acid from peat in ground water can increase solubility of iron appreciably. Presence of organic matter in saturated soils can cause deoxygenation of percolating or stored water in the ground and the groundwater becomes devoid of oxygen resulting in a reduction of Eh. Low pH and negative Eh cause dissolution of iron and arsenic from soil and increase dissolve arsenic and iron in water. This is considered as the main mechanism of arsenic contamination as well as high iron content in groundwater in Bangladesh and India. An anoxic ground water with negative Eh and low pH can hold very high levels of arsenic. However, further reduction of Eh can again make both iron and arsenic insoluble through chemical reaction with sulphur as shown in Fig. 2.12 and Fig.2.13.

When groundwater is pumped out, the pH of water increases with the escape of carbondioxide to atmosphere at lower pressure. Eh of the water also increases with the oxygenation in the atmosphere and stability of ground water enter in the field of ferric hydroxide. The insoluble ferric hydroxide also absorbs oxidized arsenic (arsenate) and settles down. Traditional dug wells are exposed to atmospheric oxygen and it is believed that oxygenation of dug well water causes a reduction in both iron and arsenic. Therefore, greater emphasis is given to keep the dug well exposed to atmosphere. On the other hand, sanitary protection of open dug well is extremely difficult. The study of Eh-pH stability fields of dug well water is important to understand the effectiveness of open dug wells in improving the quality of water.

2.3.2 Oxidation Reactions

As stated earlier, arsenate is dominant in oxygenated water while arsenite is dominant in non-oxygenated water. Although thermodynamics can provide an accurate prediction of possible changes in a given non-equilibrium conditions, they give no insight to the rate at which those changes will occur. While As(III) and As(V) acid-base reactions can be assumed to occur instantaneously, changes between oxidation states require indeterminate time periods in natural waters. For instance,

the conversion of As(III) to As(V) in oxygenated water is thermodynamically favoured, yet the transformation takes days, weeks or months depending on the specific conditions. The reduction of As(V) to As(III) is similarly kinetically constrained. This is the reason why As(V) can be found in some anoxic waters (Dahi, 1997). This process is however also known to be facilitated through catalysis and require bacterial mediation.

In strongly acidic or alkaline solutions, the presence of copper salts, carbon, certain catalysts and higher temperatures can increase the arsenic oxidation rate (Ferguson and Davis, 1972). Catalytic oxidation of arsenic can be achieved by powered active carbon and dissolved oxygen in stirred reactors. The rate of oxidation can be described by a first-order equation.

The effective removal of arsenic from water requires the complete oxidation of As(III), especially if the drinking water standard is low. There are various means of oxidation available, but in drinking water treatment there are important considerations such as the limited list of safe chemicals, the residuals of oxidants, oxidation by-products and the oxidation of other inorganic and organic compounds. In the oxidation processes with dosing of chemicals, effective oxidants are free chlorine, hypochlorite, ozone, permanganate, and hydrogen per oxide/Fe^{2+} (Fenton's reagent), but not the chloramines (Frank and Clifford, 1986). These oxidants can directly transform As(III) to As(V) in the absence of oxygen. Chlorine is widely used for oxidation purpose, but may lead to chlorinated by-products, namely trihalomethanes (THMs), from reactions with natural organic matter. Ozone, widely used in surface water treatment for oxidation and disinfection, is quite effective but is not feasible for a specific application with As(III) oxidation. The most feasible oxidants are potassium permanganate and Fenton's reagent (H_2O_2/Fe^{2+}). Permanganate oxidizes As(III), ferrous and manganese ions specifically and quickly. Chlorine and permanganate are able to oxidize arsenic (III) to (V) within a very short time, e.g., half an hour or even few minutes (Dahi, 1997).

Arsenious acid oxidation by most common oxidants are shown in the following reactions (Dahi, 1997):

$$H_3AsO_3 + \tfrac{1}{2} O_2 = H_2AsO_4^- + 2H^+$$

$$H_3AsO_3 + HClO = H_2AsO_4^- + 2H^+ + Cl^-$$

$$H_3AsO_3 + 2/3MnO_4^- = H_2AsO_4^- + 2/3MnO_2 + 1/3H^+ + 1/3H_2O$$

Ferrous oxides [$Fe(OH)_2$] present in groundwater is also oxidized to $Fe(OH)_3$ in presence of oxygen in the air:

$$Fe(OH)_2 + O_2 = Fe(OH)_3$$

Arsenic in the form of As(V) can also be immobilized by coprecipitation or adsorption by hydrous iron oxides . The possible reactions (Mok and Wai, 1994; Hering et al., 1996) of arsenate with hydrous iron oxide are shown below where [$\equiv FeOH^o$] represents oxide surface site.

$$Fe(OH)_3\,(s) + H_3AsO_4 \rightarrow FeAsO_4.2H_2O + H_2O$$

$$\equiv FeOH^o + AsO_4^{3-} + 3\,H^+ \rightarrow \equiv FeH_2AsO_4 + H_2O$$

$$\equiv FeOH^o + AsO_4^{3-} + 2\,H^+ \rightarrow \equiv FeHAsO_4^- + H_2O$$

Immobilization of arsenic by hydrous iron oxide, as shown in above equations requires oxidation of arsenic species into As(V) form for higher efficiency. The iron precipitates [$Fe(OH)_3$] formed by oxidation of dissolved iron [$Fe(OH)_2$] present in groundwater, as discussed above, have the affinity for the adsorption of arsenic. Only aeration and settling of tubewell water rich in dissolved iron has been found to remove up to 25 percent of arsenic. This process is often referred to as "passive sedimentation" (Ahmed and Ali, 2003).

2.3.3 Photochemical Oxidation of Arsenic

Besides oxidation with chemical dosing, photo-oxidation using either UV or solar light has been used for converting arsenite to arsenate. Khoe et al. (1997) developed

and patented an As-removal procedure using addition of Fe(II, III) followed by exposure to UV or solar light to accelerate oxidation of As(III). Here iron is used both as photo-absorber and co-precipitator. This procedure was initially developed to treat acidic mining effluents. Efforts to enhance As(III) photo-oxidation at higher pH values are being made, e.g., by adding S(VI) (Khoe et al., 1999).

Another arsenic removal technology – SORAS (Solar Oxidation and Removal of Arsenic), is also based on photochemical oxidation of As(III) followed by precipitation or filtration of As(V) adsorbed on Fe(III) oxides. In this method water in transparent bottles are irradiated with sunlight for oxidation of As(III) to As(V). Lemon juice was found to be most effective in enhancing the photochemical oxidation of As(III). A small amount of lemon juice is used in this process so that the pH of water (which is buffered by the presence of bicarbonate) is not changed (Wegelin et al., 1999).

UV irradiation for As(III) oxidation requires high-pressure mercury lamps with an emission spectrum between 190 and 254 nm; low -pressure mercury lamps, with their main line at 254 nm, are ineffective. The rate of oxidation can also be described by a first order rate equation, but the rate constants are considerably higher compared to the activated carbon catalysis. Nearly complete oxidation can be achieved within 30 to 60 seconds but with a high-energy input of 3 to 4 kWh/m^3 treated water (Jekel, 1994).

2.4 MICROBIAL DECAY IN NATURAL WATER

2.4.1 General

The survival, fate and distribution of bacteria and other organisms in natural waters depend on the particular type of water body (i.e., stream, estuary, lake) and associated phenomena that influence the growth, death and other losses of organisms. The factors that influence the kinetic behaviour of the communicable disease organisms and the indicator organisms can be conveniently classified into

three categories: physical, physiochemical and biochemical-biological factors. Physical factors include temperature, salinity, sunlight, sedimentation, adsorption, flocculation and re-suspension of particulates with associated sorbed organisms. The physicochemical factors are pH, osmotic effects, chemical toxicity, and redox potential. Biochemical-biological factors include predation, nutrient deficiencies, contact opportunity and biological extraction and competitive life. The growth and death of microorganisms in dug well water are regulated by these physical, physicochemical and biological-biochemical factors.

2.4.2 Main Factors Influencing Microbial Decay

Temperature

Of the physical factors affecting microbial growth in any environment, one of the most influential in the selection of species is temperature. Microorganisms possess no means of controlling internal temperature, and the temperature within the cell is therefore determined by the external temperature. Each organism is able to grow only within a specific range of temperatures. Fortunately, many human pathogens, having adapted to an environment of the human body where the temperature is constant, are stenothermal and incapable of growing at temperatures more than a few degrees lower or higher than 37° C. This prevents their proliferation in surface and ground waters or in such waste treatment facilities as oxidation ponds, activated sludge tanks, and trickling filters. Temperature affects many of the factors that influences the survival of coliform in natural water bodies. In general, rates of biochemical reactions, and thus microbial growth rates, tend to increase as temperature rise. High growth rates place added demands on nutrient reserves which may not be renewed in dilute, natural systems, leading to an increase in death rates.

pH

Both acidity and alkalinity increase the bacterial death rate in laboratory tests, but under stream conditions the specific contribution of pH is not definable except when there is pronounced deviation from neutrality.

Effect of Nutrient

The dividing line between starvation and nutrients for multiplication is ill defined in the stream environment. Seldom is stream pollution of such character and magnitude as to simulate sufficient growth for a net change in death rate to be detectable in the stream environment.

Sedimentation and Adsorption

Adsorption, coagulation and flocculation may affect coliform disappearance rate, although few quantitative data are available. Adsorption refers to the attachment of coliform organisms to suspended particles. Coagulation refers to the coalescence of bacteria into clumps, and flocculation refers to the formation of soft loose aggregates incorporating much water. According to Mitchell and Chamberlin (1978) early investigation by several workers has demonstrated that clays tend to absorb coliform more than do silt and sands. This is, of course, commonly the case with sorbed substances. As Mitchell and Chamberlin point out, the nature and stability of coliform aggregates incorporating other particulate matter depends to a very large extent upon the physiochemical nature of the particles. Ganon et al. (1983) found that 90 to 96 percent of the coliforms entering a lake from upland watersheds were associated with 0.45 to 5 μm particles. Sedimentation may be a major mechanism responsible for the disappearance of faecal coliform bacteria from surface waters (Mitchell and Chamberlin, 1978; Gannon et al., 1983). Cells settle from the water column as discrete entities and as part of larger aggregates of faecal material, storm water debris and other suspended solids (Schillinger and Gannon, 1982). Gannon et al. (1983) observed that viable faecal coliform bacteria accumulated at the sediment surface in Ford lake, Mich., and concluded that sedimentation played an important role in the overall disappearance of faecal coliform bacteria from the water column. However, turbid conditions associated with high stream runoff usually show a net increase in bacterial concentration by virtue of contamination flushed by surface wash from the drainage area. Subsequent sedimentation with adsorption or entrapment on the receding hydrograph may induce a decrease in bacterial concentration to a point below that expected for the time of passage in the death rate.

Contact Opportunity and Biological Extraction

Small shallow streams afford greater biological contact opportunity for bacterial extraction than large, deep rivers, and they usually show higher death rates.

Effect of Competitive Life

Perhaps one of the most potent factors beyond the element of time of passage in the death rate of coliform bacteria in the stream environment is the presence of competitive life. The natural biological life of rivers is much too rugged for the survival of organisms whose normal habitat is the shelter of the intestinal tract of man and other warm blooded animals. That competition from other biological life plays a significant role is evidenced in the greatly retarded death rate of coliform bacteria placed in sterile water in comparison with the death rate of coliform bacteria placed in natural fresh water or sea water.

Effect of Salinity

Most of the investigations of effect of sea water on the death rate of coliform are based on laboratory results as it is difficult to measure reliably the time of exposure in the open ocean. However in the river environment interest is in the brackish waters formed by large fresh water rivers discharging into an ocean. Since 100% sea water has a specific gravity of 1.03, a mixture of sea water and fresh water extends upstream a considerable distance to a point of 100% freshwater, the stretch in between comprises the brackish reach. A further complicating factor is the web and flood translation induced by tides.

Effect of Sunlight

The degree of penetration of sunlight into the water column have a significant effect on many areas of water quality including bacteriological effect. Bactericidal effects are strongest in the ultraviolet region (near 260 nm; in coliform mortality (Fujioka et al., 1981; McCambridge and McMeekin, 1981). In fact, visible wavelengths may take on particular significance in natural streams because (i) u.v. wavelengths represent a small fraction (<3%) of total incident radiation (Lantrip, 1983) and (ii)

u.v. radiation is rapidly attenuated in the water column, especially when dissolved organic matter is present.

The effect of sunlight on the decay of faecal coliform has been evaluated in a variety of studies including the work of Gameson and Gould (1974). According to them

$$K_{BO}(t) = \alpha I_O(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.5)$$

Where K_{BO} (day^{-1}) is the decay rate at the surface, α is a proportionality constant, and $I_O(t)$ is the solar radiation in $cal/cm^2.hr$. From the data of Gameson and Gould α is approximately unity.

However, it must be recognized that solar radiation varies with depth as function of the light extinction coefficient. The two principal mechanisms for the extinction of solar radiation are absorption and scattering. In the former, short wave energy is transferred to long wave energy. The presence of particles in the water may also absorb the light. Scattering in water is the effect of reflection and diffraction by particles and in pure water due to small density fluctuations and other factors.

The degree of solar radiation penetration, therefore, depends on several factors: non-volatile suspended solids, organic detritus, and living particulates such as phytoplankton. The intensity of solar radiation and its angle with respect to the water surface are also important. Further, different regions of the incoming solar radiation spectrum (i.e., from infrared to ultraviolet) may be selectively absorbed or scattered.

The penetration (or conversely its extinction) of incoming solar radiation can be described by introducing the extinction coefficient. It has been observed that the extinction o flight is proportional to the light at any depth. Therefore, a differential equation that expresses this observation is

$$\frac{dI}{dz} = - K_e I \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.6)$$

where I is the solar radiation in cal/cm^2.min, z is the depth in m, K_e is the overall extinction coefficient in metre^{-1}. The above equation when solved for the boundary condition $I = I_O$ at $z = 0$, becomes:

$$I = I_O \exp(- K_e z) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.7)$$

By integrating the above equation and using the result in Gameson and Gould equation , the depth averaged effect of sunlight on decay rate can be shown to be

$$\alpha I_O (t) [1 - \exp(- K_e H)] / K_e H \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.8)$$

Where H is the depth in m over which the average is taken and K_e (m^{-1}) is the vertical light extinction coefficient.

Effect of Bottom Sediments as Reservoir of Organisms

It is known for quite some time that organisms in the microscopic range can adhere to particles dispersed in water and waste water. Thus, the discharge of bacteria and viruses to natural waters may result in the sorption of such organisms to particles. As the particles settle into bottom sediments, microorganisms can survive in the sediments for longer periods of time than in the overlying water column. Hence samples of bottom sediment yield more bacteriological evidence of the degree of faecal pollution than either water or oysters. Since the sediment may include large concentrations of microorganisms, the re-suspension of such sediment and subsequent desorption may be an important source of contamination in the overlying waters.

2.4.3 Kinetics of Survival of Faecal Coliform

The fate of bacteria in an unfavourable environment was first studied by Chick (1910). She stated that bacteria die at a constant rate, ie., a given percentage of residual population dies during each successive time unit. The mathematical formulation is as follows:

$$\frac{dB}{dt} = KB \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.9)$$

$$\Rightarrow \log_e \frac{B}{B_0} = -Kt$$

$$\Rightarrow \log_{10} \frac{B}{B_0} = -K_1 t$$

where B_O is the initial number, B is the residual after any time t, and K_1 is the reaction, or death rate.

A substantial body of laboratory and field investigation strongly suggests that the survival of pathogens and non-pathogens of special interest in stream sanitation approximate Chick's law.

2.5 CHEMICAL PROCESS OF DISINFECTION

2.5.1 General

The safety and palatability of water is often hinge upon the elimination or destruction of two groups of living organisms.

(a) the pathogenic bacteria and other micro-organisms that may infect man through his use of contaminated water, and

(b) the algae and related water-booms that may render water aesthetically unfit for human consumption with the creation of taste, odour, colour and other associated problems.

The term sterilization means killing of all organisms present in water. It is impracticable to attempt to kill all water-organisms within technical and financial limitation (Military Engineering Services,1932). The practicable objective is particularly to destroy pathogenic microorganisms called disinfection, and generally to eliminate those organisms capable of multiplication in water mains with the

consequent development of taste, odour and objectionable forms. Hence, in water works practices, the term used is disinfection, means the killing of pathogenic bacteria present in water to prevent water-borne diseases.

2.5.2 Disinfectants

Chlorine

Chlorine and its compounds, such as hypochlorite of lime $Ca(OCl_2)$, and sodium hypochlorite (NaOCl) are widely used for disinfection and addition of chloride (free) or its compound in water is termed as chlorination. Chloride of lime or bleaching powder or hypochlorite of lime are commercially available having 33 percent of free available chlorine when fresh. Sodium hypochlorite has 15 percent available chlorine.

Ozone

Ozone (O_3) is sometimes, used as a disinfectant. Passage of electric spark through air will cause triatomic oxygen termed as ozone has the third atom loosely bound. It has the capability or readily splitting up into oxygen molecule and nascent oxygen. Releasing ozone in water will disinfect it and will reduce the organic matter present in it through the action of nascent oxygen.

Lime

Use of lime in softening water showed incidentally that requisite quantity of lime would also disinfect. Experiment has shown that addition of lime in polluted waters to absorb CO_2 has also reduced coliforms 99.67 percent in 5 hrs.

Ultraviolet Light

Ultraviolet invisible rays are very effective in killing all types of bacteria and spores. The process of disinfection is costlier than chlorination but produce no taste and odour. Ultraviolet rays are not effective for turbid and coloured water exceeding 15 mg/l.

Heat

Heat alone is an excellent disinfectant. But heated water cannot be supplied to the public, rather instruction can only be given to use heated water.

2.5.3 Theory of Disinfection

The primary purpose of addition of chlorine to water is to destroy bacteria and other microorganisms. In early period of chlorination of water, the hypothesis, generally held was that the chlorine reacts directly with water to produce nascent oxygen (AWWA,1951).

$$H_2O + Cl_2 = 2\,HCl + O$$

This nascent oxygen has certain bactericidal effect by its action on the cells. This theory has been found fallacious in as much as it has been demonstrated that the bactericidal effect is not proportional to the concentration of nascent oxygen. The belief generally accepted is that the cell wall structure and the cell contents contain protein and amino groups with which the chlorine reacts. This action alters the chemical characteristics of cell contents and destroys life and may cause disinfection of cell structure (Phelps, 1945). Some works by Green and Stumpf as described by Fair and Gayer(1954) indicate that the primary reaction is one between chlorine and a certain enzyme, essential for the bacterial reproduction. It was found that the power of glucose oxidization by the bacterial cell is lost, the bacterial cell die and bacteria once inactivated by chlorine cannot be reactivated.

In absence of organic matter capable of oxidation or chlorination the germicidal reaction proceeds more rapidly with the increases in H^+ concentration, that is, with more undissociated hypochlorus acid. Specific reaction possibly with amine and chains which characterize protein molecule takes place. On the other hand, presence of oxydizable organic matter reduces chlorine concentration to the detriment of the germicidal reaction. The both oxidization and germicidal reactions are speeded up in more acid and retarded in alkaline water. At pH = 10 disinfection reaction almost ceases.

2.5.4 Chemical Reactions

When elementary chlorine is dissolved in water it react in the following way

$$Cl_2 + H_2O \Leftrightarrow HOCl + HCl$$

It is a reversible reaction free acids, HOCl, HCl further dissociates.

$$HCL \Leftrightarrow H^+ + Cl^-$$

$$HOCl \Leftrightarrow H^+ + OCl^-$$

Hypochlorous acid is a weak acid and its dissociation is controlled by the pH of water. Chlorine compound, $Ca(OCl)_2$ or NaOCl dissociates with the formation of hypochlorous ion.

$$Ca(OCl)_2 \Leftrightarrow Ca^{++} + 2OCl^-$$

$$NaOCl \Leftrightarrow Na^+ + OCl^-$$

The above reactions are dependent on the pH of water. At lower pH (below 5.0), the chlorine present as molecular chlorine at pH 5.0 to 6.0, the chlorine exist almost entirely as hypochlorous acid and above pH 6.0, hypochlorous ions are present and predominate above pH 7.5.

2.5.5 Chlorine Demand and Residual Chlorine

Chlorine demand is defined as "the differences between the amount of chlorine added to water and the amount of chlorine (free available and combined available) remaining at the end of a specific contact period" (AWWA,1951). The chlorine remaining at the end of a specific contact period is known as chlorine residual. In the figure 2.14, a hypothetical time concentration curve of the chlorine demand ten minutes after the application of initial dose, the residual chlorine is measured.

The loss indicates 10 minutes demand. As the chlorine concentration and speed of disinfection are linearly related, the ordinate of the curve could represent actual

speed of disinfection rather than the concentration, then the area of this curve would represent the total disinfection.

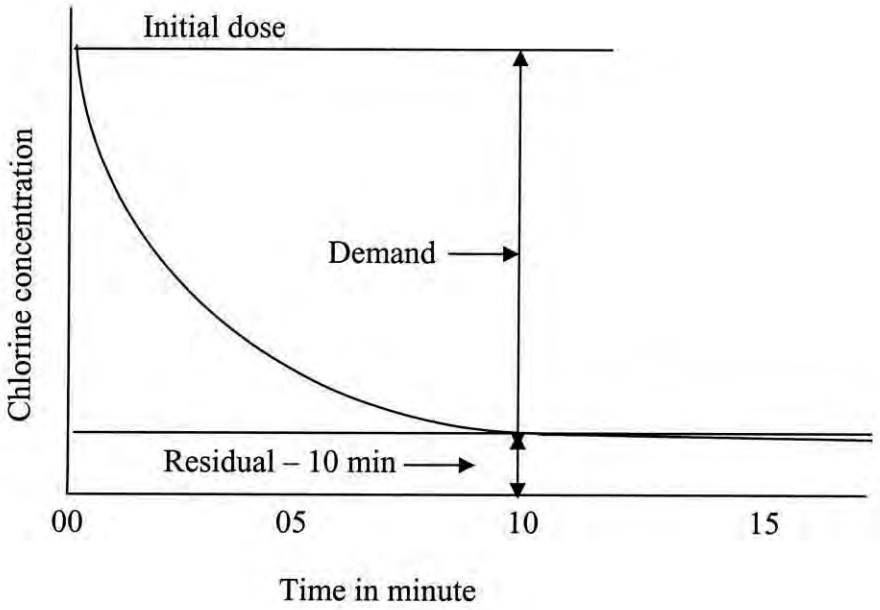


Fig. 2.14: Chlorine Demand and Chlorine Residual

2.5.6 Available Chlorine

The chlorine existing in water as hypochlorous acid, hypochlorite ion and molecular chlorine is defined as free available chlorine (Aziz,1975). Chlorine is very active element. When it is added in water as free chlorine, it will combine with organic and inorganic matter and oxidize some organic and inorganic compounds. Free available Cl_2 reacts with substances such as phenol and ammonia to form chlorine-substitute or chlorinated products, chlorophenol, chloramines.

$$C_6H_6OH + Cl_2 = C_6H_5OH\ Cl + HCl$$

$$NH_3 + Cl_2 = NH_2Cl + HCl$$

$$NH_2Cl + Cl_2 = NHCl_2 + HCl$$

$$NHCl_2 + Cl_2 = NCl_3 + HCl$$

The chloramines are less active than hypochlorous acid, hence the formation of chlorinated products reduces the activity considerably. Available free chlorine also reacts with organic compounds containing Nitrogen (such as protein, and amino acid) to form chlorine derivatives. The chloramines and chlorine derivatives have a lower oxidizing potential than that of free available chlorine but the chlorine combined in these forms are still available for chemical reactions. That chlorine existing in water in chemical combination with ammonia, or organic nitrogen compounds is defined as combined available chlorine.

2.5.7 Break Point Chlorination

The break point chlorination means the chlorination of water to the extent that chlorine combination tastes and odours have been avoided, and other tastes and odours due to other substances which can be oxidized by chlorine have been eliminated, and that the chlorine available for further disinfection is free available chlorine. A chlorine applied and the residual chlorine of a natural water is represented by a curve shown in Fig. 2.15. In chlorination for disinfection of drinking water, this curve is prepared for a water to estimate the chlorine required for break point chlorination of that water.

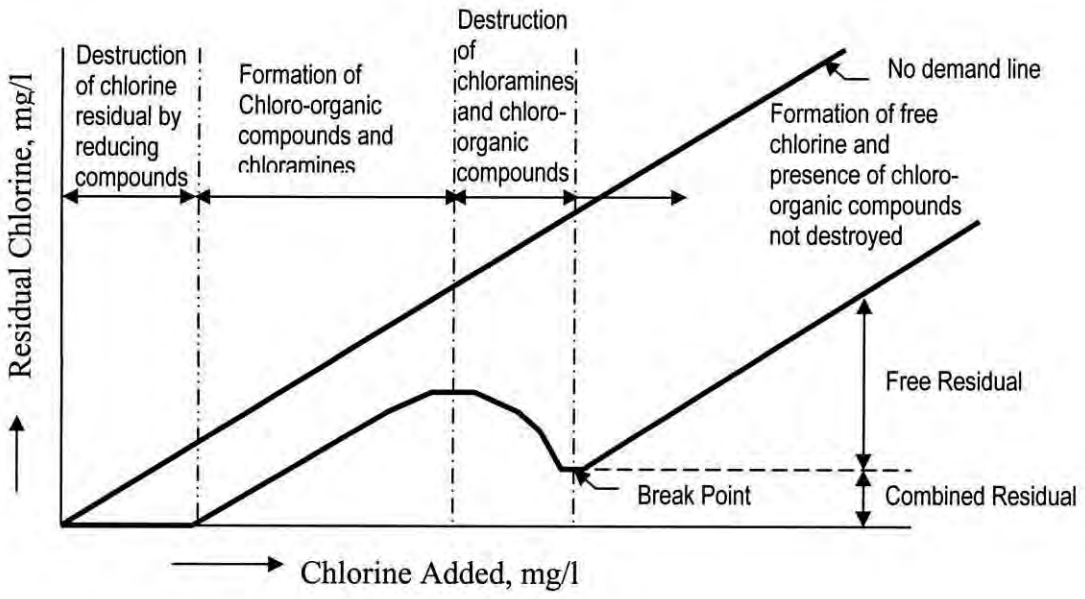


Fig. 2.15: The Chlorine Break Point

In the Fig. 2.15 the curve is the residual chlorine curve and the straight line is the no demand curve. The difference of the curves is chlorine demand. Natural water may contain substances, those of phenolic or amino nature which consume chlorine, and may start at a later point instead of origin showing an initial demand. With the addition of chlorine, chloramines and chlorine derivatives concentration increases showing a peak residual. With the further application of chlorine the reactions are completed and the end products do not react with titrating agent to show residual chlorine, thus residual chlorine decreases with the application of more chlorine until the break point is reached when the chlorine applied remains as free residual and the curve shown an increase in residual gaining the slope of the no demand curve. The residual chlorine curve shows a minimum at break point where the chloramine and free residual are in equal proportion. The chlorine for break point chlorination is to be applied slightly above the break point.

2.5.8 Factors Affecting Disinfection

The efficiency of disinfection depends on the following factors:

- The nature and concentration of organism in water to be destroyed
- The nature and amount of disinfecting agent
- The characteristics of water
- pH and temperature of water
- The time of concentration

The dose of a disinfectant is adjusted based on the above factors (Aziz, 1975)

2.6 QUANTITATIVE HEALTH RISK ASSESSMENT

The World Health Organization recommends the use of Quantitative Health Risk Assessment (QHRA) in the framework for safe drinking water (WHO, 2004). The QHRA provides the over all disease burden of a water supply and is used to establish health based target in Water Safety Plan (WSP) adopted by WHO as most effective means of consistently ensuring the safety of drinking water (WHO, 2004). QHRA

has been used in Bangladesh to compare the disease burden of alternative water supply option for arsenic Mitigation (APSU, 2004 and APSU, 2005b).

The potential risk associated with drinking water and for each type of contaminant (chemical or biological) can be expressed in terms of infections per person per year for a particular disease or as DALYs (Disability Adjusted Life Years). DALYs are preferred because they provide single health outcome parameters that can aggregate the many possible health outcomes arising from any or a range of single or multiple hazardous agents and via different exposure pathways (Deere et al., 2004).

DALY involves three different components to be considered (Deere et al., 2004)

- Likelihood of infection or incidence of illness by pathogens or harmful chemicals
- The severity of the infection or health hazard
- Duration of exposure

For example, a specific type of pathogen (eg. Cryptosporidium parvum), if ingested, can cause mild diarrhoea with a probability given infection of 7.1%, a severity of 0.067 (a value in between 1 and 0) and a duration of 7 days (Havelaar and Melse, 2003).

So, DALY for mild diarrhoea per infection is:

$$0.067 * \frac{7}{365} * \frac{7.1}{100} = 9.1 \times 10^{-5} \text{ yr.}$$

There can be hundreds of pathogens and other contaminants in water. It is not possible to deal with every pathogen or chemical. Hence, only some index pathogens are chosen representing specific group of pathogens.

Selection criteria of these index pathogens include (Deere et al., 2004):

- Waterborne transmission in an established route
- High relative mortality or morbidity
- High prevalence in a particular system considered

- High persistence in environment and in many cases to some treatment options.

The selection of index pathogens keeps the quantitative risk assessment more manageable and focuses on the 'worst case' pathogens contributing the most of disease burdens. Estimated disease burden attributable to index pathogens gives an estimate of the overall disease burden from all pathogens.

The WHO recommended index pathogens are (WHO, 2004).

- Rotavirus (as an index of viral waterborne pathogens)
- Escherichia Coli 0157 (an index of bacteria)
- Cryptosporidium parvum (and index of protozoan pathogens)

The choice of index pathogens should be based on background information, testing and possible epidemiological data, if available.

The hazardous chemicals are chosen based on hazards, extent of impact and occurrence. For example, in acute arsenic affected areas arsenic could be chosen as a hazardous chemical; in urban areas where chlorination is in excess, risk due to chlorine overdose could be considered; impact of heavy metals should be considered where they have significant impact.

In the RAAMO studies carried out by ITN-BUET in 2004-2005, a model was developed for health risk or disease burden of drinking water expressed in DALYs considering three index pathogens (Rota Virus, ETEC and Cryptosporidium Parvum) and one toxic chemical (arsenic) in drinking water (APSU, 2004 and APSU, 2005b). The model takes arsenic and TTC (Thrermo-tolerant Coliform)/FC concentration as input and gives output in DALYs for arsenic and bacteriological contamination induced disease burden.

2.7 PREVIOUS WORKS

Arsenic Policy Support Unit (APSU) conducted extensive studies on water quality of dug wells in the dry season in 2004 and arrived at the following conclusions (APSU, 2004):

- Microbial contamination of dug well water was very high and in some wells the level of contamination was higher than that of contaminated surface water. Only 6 percent DWs were found free from microbial contamination.
- The level of contamination of DW water suggests that dug well water needs disinfection for safe operation as an alternative water supply option for arsenic mitigation.
- E. coli contamination was found in DW water samples, particularly in water with high level of TTC. The average ratio of E.coli to TTC was calculated as 0.3. Although only a few numbers of samples were tested for E.coli count, the presence of E. coli is of remarkable sanitary significance.
- Three percent of dugwell water exceeded the BDS of 50 μg/L for arsenic and 25% exceeded the WHOGV of 10 μg/L. The men arsenic content of DW water was found to be 8 μg/L. This study further confirmed that DWs in all locations and in all intensity of use are not arsenic-safe.
- Iron and Manganese were present in dug wells in excess of BDS and WHOGV for iron and manganese. The concentration of nitrate in DW exceeded BDS in 8 percent cases. Ammonia in excess of BDS was present in half of the dug wells (50% of dug wells) while 8% of dug well water exceed BDS for nitrate. About 28 percent of DW water had TDS higher than BDS and WHOGV.
- About 79 percent of the respondent provided with a dug well see dug well as a permanent solution to the arsenic problem.

Further APSU studies in wet season of 2005 under phase-II revealed that the level of contamination increased drastically in the wet season. More than 50% of the dug wells showed a TTC count more than 500 cfu in the wet season as compared to 3% contaminated to that level in the dry season. Inflow of contaminated surface water in the rainy season may be the cause of such an increase in the level of contamination of dug well water. In contrast, a visible improvement in the chemical quality including arsenic content of DW water was observed in the rainy season. Dilution of top layer of the aquifer by infiltration of rain and surface waters of low mineral content may be the cause of improvement of chemical quality of water of dug wells.

The disease burden increased in the wet season with the greater deterioration of microbial water quality as compared to some improvement of arsenic content of water of both DW (APSU, 2005).

IRC (1981) suggested that the water in the well should be chlorinated for disinfection, after the well has been completed and this should be repeated at regular intervals.

Japan International Cooperation Agency and Asian Arsenic Network constructed 51 dug wells in Sharsha Upazila and was astonished to find 45% of the dug well water containing arsenic exceeding Bangladesh Standard of 50 µg/L although it was generally believed that dug well water was free from arsenic. Apart from arsenic, bad smell, small insects, Coliform and E. Coli bacteria and high iron were found in may dug wells (JICA/AAN, 2004). Five dug wells were abandoned for not yielding enough water and producing water of very bad water. The remaining dug well were used for water supply after aeration and filtration through sand and gravel filters as shown in Fig. 2. 6. Aeration and slow sand and gravel filtration and chlorination reduced arsenic, coliform bacteria and other pollutants to acceptable levels.

JICA and UNICEF completed water quality monitoring of all alternative water supply options installed Jessore district (JICA and UNICEF, 2005). Out of 108 dug wells only 69 were found operational and the reasons for abandonment of dug well were listed as non-availability of water in the dry season, bad taste, arsenic contamination, soil collapse around the well and flood. Of these 96 dug well the water quality of 17 wells were improved through installation of sand filtration and chlorination facilities. Water quality survey showed that only 12 percent of unimproved dug well and 94 percent of improved dug wells met the Bangladesh Standards of FC, As and Mn The concentrations of FC, As and Mn varied from 0-100 cfu/100ml (Mean 4.69 cfu/100ml) , 0 -263 mg/L (Mean 15.42mg/L) and 0-1.88 mg/L (Mean 0.38 mg/L) respectively. The FC count of all the modified dug wells met the requirement of zero coliform of BDS due to post chlorination of filtered dug well water.

Resenboom (2004) stated that the proportion of dug wells affected by arsenic levels was invariably lower (11%) than the overall percentage of affected wells (66%) in 15 Upazilas of Bangladesh surveyed by UNICEF. The primary explanation of low arsenic contamination of dug well given by him was that redox conditions that sensitize arsenic release, are different around a dug well open to atmosphere are likely to be different from those around a tubewell of the same depth. He also mentioned that in exchange for low arsenic, users may get high levels of bacterial contamination from dug wells and substituting the acute effects of microbial contamination for chronic effects of arsenic is a bad idea.

Dhaka Community Hospital (DCH, 2003) conducted water quality analysis of 39 dug wells in Sirajdikan Upazila in Munshigonj district and found bacterial contamination in 74% and 80% dug wells in the first and last surveys respectively. Arsenic contamination was found in 3% of the dug wells exceeding BDS and 13% dug wells exceeding WHO GV for drinking water. Iron and manganese exceeding BDS were found in water of most of dug wells.

Water quality analysis of 40 dug wells in Rajoir, Chapai Nowabgonj and Satura was made by National Institute for Preventive and Social Medicine and Others (NIPSOM & Others, 2003) and found 15-50 percent dug well depending on the area contaminated with arsenic, and 43 -65 percent wells with iron exceeding BDS of 1 mg/L and 39 to 89 % wells having coliform bacteria exceeding permissible limits. In terms of physical quality, water of dug wells was observed to be clear in most of the cases. However, in dry season, the dug wells, which contained little water, were found to be turbid. Few dug well water had disagreeable smell, in some areas 30% of the dug well water had bad smell and users did not like those wells.

Smith et al. (2003) conducted pilot scale study on disinfection of dug well water using potassium permanganate (KMnO4). Arsenic reduced from 27 µg/L to below detection limit of 10 µg/L and Total Coliform reduced from 240 to 0. Although arsenic content of water showed no detectable increase in concentration, Total

Coliform reappeared but in lower number. The turbidity of water also increased after disinfection. Disinfection by potassium permanganate was considered not feasible for many problems.

Crisp et al. (2003) made an assessment of safe water options for villages in Bangladesh and concluded that a dug well, appeared to be the best option in arsenic affected villages, since the technology is simple, cheap and relatively well proven. They opined that dug well with water distribution system may be economically viable without external aid and sustainable for more than half the affected villages. However, quality of dug well water was not taken into consideration in this assessment.

DASCOH (2004) evaluated water quality of 129 newly constructed and renovated dug wells and found that the percentages of dug wells that meet the Bangladesh Standards for Drinking water for Arsenic, Faecal Coliform, Iron, turbidity were 98%, 61%, 48% and 87% respectively and Concluded that dug well with hand pump, being a socially accepted low-cost option, could be a potentially arsenic safe option provided only if the microbial contamination could be managed.

Sikder and Khan studied the performance of sanitary dug well as an alternative safe water option under action research program and encountered sand boiling and land subsidence in the construction of wells. Arsenic and manganese concentrations of the dug wells constructed under action research were found within acceptable level but the wells showed high bacterial count and dissolved iron. A filtration unit was added to sanitary dug well to remove iron, turbidity and bacterial load. The levels of iron were reduced to acceptable level but the filtration process could not completely remove faecal coliform as required by BDS for drinking water.

2.8 SUMMARY OF REVIEW

The previous works clearly show that arsenic contamination of dug well water is relatively low but microbial contamination is very high. The concentrations of iron,

manganese, ammonia and dissolved solids are also high in many dug wells. Aesthetic water qualities of dug well water such as turbidity, colour and smell are also unacceptably high. The inferior quality of dug well water particularly the presence of arsenic in some dug well was a surprise and high bacterial contamination was equally frustrating to decision makers and promoters of dug wells. All these findings are the result of studies conducted to evaluate the quality of the dug well water but no attempt has been made to investigate the reasons for such water quality and give an acceptable explanation supported by experimental results.

Disinfection of dug well water is obviously an option to reduce the microbial contamination and render the water suitable for drinking. Disinfection by chlorination may also reduce the dissolved minerals through oxidation. Effectiveness of in-situ disinfection of dug wells by chlorination is required to be explored. Dug well water appears to be generally acceptable to the rural population but acceptability of the chlorinated water in the rural context is not known.

CHAPTER 3

EXPERIMENTAL APPROACH

3.1 THE STUDY AREA

Dug wells have been installed by different organization in various parts of Bangladesh. Dug wells from four Upazilas have been selected for this study. These are Sirajdikhan in Munshigonj district, Singair in Manikgonj district, Daudkandi in Comilla district and Sharsha in Jessore district. The geographical locations of these districts are shown in Fig. 3.1.

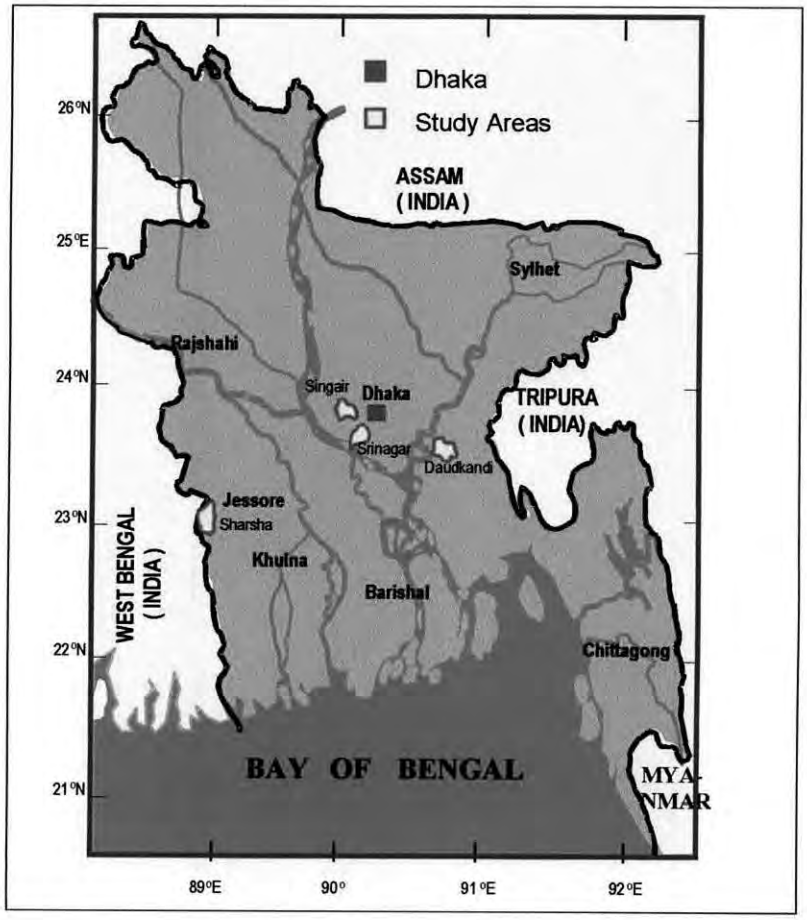


Fig. 3.1 : Locations of Study Areas

For the analysis of water quality of dug wells, samples were collected from six dug wells in Singair Upazila of Manikganj district and four dug wells in Daudkandi Upazila of Comilla district and five dug well from Srinagaor in Munshigonj district. Water quality of five dug wells from Sharsha upazila was also included in the analysis. Dugwells in Sharsha were installed by Asia Arsenic Network (AAN), those in Srinagar were installed by Dhaka Community Hospital (DCH) and those in Daudkandi and Singair were installed by Bangladesh Arsenic Mitigation Water Supply Project (BAMWASP). Baseline water quality analysis was carried out for these 20 dug wells. Three areas selected for sampling of dug wells as shown in Fig. 3.1 are close to Dhaka so that each area could be covered from Dhaka by day trip.

Dhaka Community Hospital (DCH) has installed 39 dugwells in Sirajdikhan Upazila in Munshigonj district under the UNICEF funding. Sirajdikhan is easily accessible from Dhaka, hence apart from water quality analysis two dug wells from this Upazila have been selected for decontamination study. These dugwells represent dugwells with high microbial contamination reported in literature. Arsenic in the dug wells around Dhaka was found to be comparatively low. Well documented dugwells with high arsenic content were reported in Sharsha Upazila in Jessore district. In order to achieve the objectives of this study, one well with high arsenic in Sharsha was also taken for in-situ decontamination through chlorination. One of the dugwells selected for chlorination in Sirajdikhan was a closed dug well. Another one in Sirajdikhan and one dug well in Sharsha with high arsenic selected for disinfection by chlorination were of improved form of dugwells.

Asia Arsenic Network (AAN) has installed 51 dugwells in Sharsha Upazila under JICA-AAN funding. The AAN first reported the presence of arsenic in dug well water and it was confirmed by other research organizations including BUET and Jadavpur University in Calcutta. Previously dug well water was considered arsenic free and it was reported as such in the Implementation Plan for Arsenic Mitigation in Bangladesh (GoB, 2004). Performance of dug wells as an alternative water supply technology is well documented for Sharsha Upazila (JICA-AAN, 2004).

3.2 SAMPLE COLLECTION

Samples were collected and measurement of some parameters was carried out in-situ in the field and some in the laboratory. The in-situ measurements of pH, temperature, dissolved oxygen, conductivity and oxidation reduction potential (ORP) of the dug well water were determined by portable dissolved oxygen meter, pH meter, thermometer, portable dissolved oxygen meter, conductivity meter and Eh meter respectively. Measurement of in-situ water quality parameters was made with minimum contact with air as some of these water quality parameters are greatly altered by oxidation.

In the field water samples were collected without letting those come in contact of air. The open end of a plastic bag, devoid of air, was tied with one end of a glass or plastic tube inserted in the plastic bag. The spout of the tubewell was kept closed with one hand while sampling bag was kept ready in the other. Another person started pumping of the tubewell and continued for some time to ensure adequate pumping through the well head. The free end of the tube of the sampling bag was then inserted through the fingers of the hand closing the spout and water was allowed to flow in the sampling bag. When it was filled with water, the tube was taken out and the mouth of the bag was closed by pulling the tube out. The probes were then inserted in bag containing water without allowing air to get in during measurement. As an alternative method, the spout of the tube well was sealed with polythene bag and the tubewell was pumped for some time to purge the well through the top opening of the tubewell. The heads of the probes were then inserted and immersed in the water though the opening of the top of the head for measurement of above mentioned parameters.

The samples for the laboratory analysis were collected after pumping the well for a while. Before filling the containers with samples, the containers were rinsed two to three times with the water being collected. The samples for bacterial count were collected in the sterilized bags following the procedure specified in standard method for collection of bacteriological samples. Avoidance of secondary contamination was

given due importance in bacteriological sample collection. The sterilized bags were carried in an ice box in the field to keep the coliform concentration unaltered.

The samples in the sterilized bags were prepared for incubation of the microorganisms (total and faecal coliform) immediately after returning to the laboratory. Determination of the other physical and chemical parameters of the water samples was carried out within 24 hours of collection of samples.

3.3 MEASUREMENT OF WATER QUALITY PARAMETERS

Samples were collected from the dug wells located in the sampling areas. In situ measurement was carried out for pH, dissolved oxygen, temperature, conductivity and ORP for all the samples. Baseline analyses were carried out for the parameters like total coliform, faecal coliform, turbidity, ammonia, phosphate, nitrate, arsenic, iron and manganese for all the samples. Two dugwells from Ichhapura and Rashunia union in Sirajdikhan Upazila were found to be contaminated with coliform (both faecal and total) at relatively higher concentrations. Moreover, Ecoli was detected in water from these two samples. These two dugwells were selected for in-depth analysis related to the objectives of this study.

Turbidity of the samples was measured using DR LANGE turbidimeter. Iron content in the samples was determined by comparison with the colour produced by standard iron solutions. Ammonia Nitrogen (NH_3-N) and Nitrate Nitrogen (NO_3-N) were determined by the Nessler method and Cadmium Reduction method respectively using the DR/2010 Spectrophotometer. Total Organic Carbon was measured only for the selected dugwells of Sirajdikhan and using HACH method. Phosphate and Manganese in the samples were also determined using the HACH DR/2010 Spectrophotometer. Arsenic concentration in the samples was determined by Electro Thermal (Graphite Furnace) Atomic Absorption Spectrometric Method using a Shimadzu AA6800.

For Coliform analysis, Membrane Filter method (APHA, 1985) was used. Incubation was done at 44 ± 0.5 °C for faecal coliforms and at 37 ± 0.5 °C for total

coliforms. Incubation was done for 18-24 hours. Colonies of total coliform bacteria are of golden colour and those of faecal coliform are of blue colour as shown in figures 3.2 and 3.3 respectively.

Figure 3.2: Colonies of Total Coliform

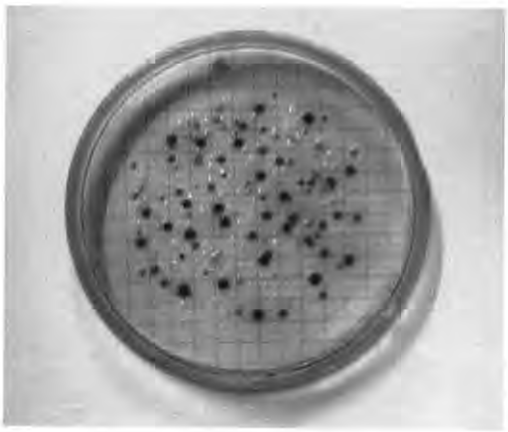


Figure 3.3: Colonies of Faecal Coliform

3.4 BACTERIAL GROWTH/DECAY STUDY IN THE LABORATORY

Samples were collected from the selected dug wells of Sirajdikhan in two 6 litre jars and transported to the laboratory. The first TC and FC counts representing initial counts were performed soon after reaching the laboratory. Then the sampling containers full with samples were kept buried to neck with soils to simulate the field condition of dug wells and to keep the water cooler than the ambient temperature. Then the natural decay/growth rate was observed for total coliforms and faecal coliforms withdrawing representative samples from the jar after 1, 2, 3, 4, 6 and 10 days. The growth/decay of bacteria in laboratory condition was analyzed using the theoretical growth/decay dynamics described in section 2.4.

3.5 LABORATORY ANALYSIS OF CHLORINE DOSING

Break point chlorination was performed for the samples after adding predetermined doses of chlorine and measuring residual chlorine adopting DPD method using HACH DR/2010 Spectrophotometer. The break point was found after plotting chlorine applied versus residual chlorine. The laboratory trial of chlorine dosing for

application in the dug wells was made in the laboratory by applying break point dose of chlorine in one litre of sample of each of the dugwells selected for chlorination. The samples were taken in separate 1 litre beakers and kept open to air. After the application of the dose, samples were collected in separate sets from each of the beakers after 15 minutes, 30 minutes, 1 hour and 24 hours of contact time with chlorine and analyzed for the presence of coliforms.

Some coliforms were detected even at doses equal to break point dosing of the samples. As a result, chlorine doses were increased above break point and samples were analyzed for the presence of coliforms after predetermined contact time. The chlorine doses at which no coliforms were found in the samples were selected as doses for field application. The concentrations of ammonia, iron, manganese and arsenic were determined after application of chlorine in the laboratory to see the effect of chlorination on these parameters of dugwell water.

3.6 FIELD DOSING OF CHLORINE

Volume of the water in the dug wells were measured at first by measuring the depth of water in the well and diameter of the well. The required amounts of bleaching powder were calculated to apply the chlorine doses as determined in laboratory trial for complete removal of coliform bacteria. The bleaching powder was then dissolved in a bucket of water as shown in Fig. 3.4 and the water was poured in the dugwells through the opening as shown in Fig. 3.5.

A bucket of water was pumped out of the well and poured back in the dugwell to accelerate the mixing of chlorine in dugwell water. After 1 hour of the application of bleaching solution, the water of the dug well was tested for residual chlorine using HACH colour comparator. Addition of bleaching solution to the dug well water was continued until residual chlorine in the range of 0.5 to 1 mg/l was obtained. Chlorination was continued everyday in Sharsha dug well and at two/three day's interval in Sirajdikhan dug wells for two weeks.

Figure 3.4: Mixing of bleaching powder with DW water

Figure 3.5: Pouring of bleaching powder mixed water into the dug well

On each day of chlorination, samples were collected from the dug wells before and after application of bleaching powder for coliform analysis and lab analysis of selected parameters like arsenic, iron, ammonia, manganese, nitrate, colour and turbidity. In-situ analysis of the parameters like dissolved oxygen, pH, conductivity and redox potential before and after application of bleaching powder were carried out as discussed above.

The preferred method of in situ determination of pH, Redox Potential (Eh) and Dissolved Oxygen of dug well water is to measure using appropriate probes in the dugwell water. But the cables of the probes were not long enough to carry out this procedure. Thus, the water was needed to be collected without bringing in contact with air. This was done in two ways. As discussed earlier, dugwell water was collected without contact with air by pumping the dugwell closing the spout by hand and releasing water mostly through the top opening and some through the spout. After some time, an empty plastic bag (no air inside) was filled through a plastic tube inserted one end in the bag and other end in the spout hand used for closing the spout. During the process of water collection, pumping was continued. Now, the pH, Eh and DO were measured by inserting probes inside the bag without allowing oxygen to enter the bag or come in contact with water. This method of collection of water is shown in Fig. 3.6 and measurement of Eh of collected water is shown in Fig. 3.7.

Figure 3.6: Collection of water in bags without air contact

Figure 3.7: Measuring of Eh by inserting probe inside the bag

Another method was followed for cross checking the measurement of pH, Eh and DO. Water was discharged through the top of the head of the hand pump by closing the spout and pumping the well. When water from the well reached the top of the pump, the pumping of the tubewell was stopped. Then the probe was inserted through the top opening. The stabilized readings were recorded as the appropriate data. This method is shown in Fig. 3.8.

Figure 3.8: Measuring of Eh by inserting probe inside the top opening

3.7 AVAILABILITY OF DUGWELL WATER

The availability of dug well water of adequate quantity in different seasons in the year is an important issue for dug well based water supply. There are complaints from many areas against inadequate supply of dugwell water in the dry season. Pumping test of 50 dug wells was conducted by the AAN in the Sharsha Upazila during the wet season. This was done by extracting old water and by estimating the volume of water accumulating in each well in one day. The measurements taken

during pumping out of all the water in dug wells and after one day provide information to calculate the water availability from these wells. These data were used to calculate the quantity of available water in the wet and dry seasons for water supply. The quantity of water accumulated in a dug well is also required to estimate the theoretical quantity of bleaching powder required for disinfection each day and the retention time available for oxidation of dug well water through aeration.

3.8 QUESTIONNAIRE SURVEY

Among the two dug wells under study in Sirajdikhan area, 16 households use the water of one of the dug wells for drinking purpose in Abirpara village and 8 households use the water of the another dug well for drinking in Purbo Shialdi village. After application of bleaching powder solution as disinfectant into the dug wells, 12 out of 16 households in Abirpara and 8 out of 8 households in Purbo Shialdi were surveyed to determine the acceptability of the chlorinated water among the users. The questionnaire used in the survey is attached in Appendix-B.

CHAPTER 4

ASSESSMENT OF CONTAMINATION OF DUGWELL WATER

4.1 WATER QUALITY

Contamination of dugwell water was assessed in terms of the presence of parameters in excess of the drinking water standards. Those parameters were given prime importance which are directly related to health and are present in high concentrations in dugwells.

4.1.1 General

Analysis of important water quality parameters of selected twenty dug wells from four Upazilas was conducted under this study. The results of water quality analysis are presented in Table A1 in the Appendix. The minimum median, mean and maximum values of the major water quality parameters are summarized in Table 4.1.

Table 4.1: Minimum, Median, Mean and Maximum Values of Water Quality Parameters of Twenty Dug Wells under study

Water Quality Parameters		WHO GV	BDS	Min Value	Median Value	Mean Value	Max Value	Standard Deviation
Microbial	Total Coliform/100mL	0	0	60	1100	1063	1800	476.04
	Faecal Coliform/100ml	0	0	0	80	358	1000	407.5
Chemical	Arsenic , mg/l	0.01	0.05	<0.001	0.0095	0.026	0.14	40.82
	Ammonia-N, mg/L	0.5	1.5	0.29	0.71	1.0	2.75	0.81
	Iron, mg/L	0.3	1.0	0.07	1.2	2.66	10	3.12
	Manganese, mg/L	0.4	0.1	0.01	0.85	0.96	1.93	0.56
	Nitrate-N, mg/L	10	50	0.1	0.3	1.03	3.63	1.07
	Eh, mV	-	-	-102	-42	-28.85	85	55.22
	pH	-	6.5-8.5	6.47	6.94	7.04	7.84	0.32
Physical	Turbidity, NTU	5	10	4	17.35	26.96	86	24.39
	Colour, PtCo	15	15	4	22	53.84	395	104.34
	TDS, mg/L	1000	1000	282	474	730.2	2133	535.56
	DO, mg/L	-	6	0	1.07	1.02	2.87	0.85

The two most important water quality parameters involving health risk in Bangladesh are arsenic and microbial water quality. The other water quality parameters measured under this study are not present in high concentrations in dug well water to pose a great health risk but directly or indirectly affect acceptability of water by the consumers. From the summary results in Table 4.1, it is found that the median and mean values differ widely in cases of almost all water quality parameters like coliform, turbidity, electrical conductivity, iron, manganese, arsenic, ammonia, nitrate etc. indicating an unequal distribution of frequency of variations within the ranges of maximum and minimum values.

The percentage of samples of dug well water that exceeded the Bangladesh Standards (BDS) for Drinking Water (GOB, 1997) and WHO Guideline Values (WHO GV) for the major water quality tested are presented in Table 4.2. APSU (2004 and 2005b) has conduced extensive analysis of dug well waters for assessment of quality under RAAMO I and RAAMO II studies. The results of water quality analysis made under RAAMO-I and RAAMO-II are also compared in the Table 4.2. Dhaka Community Hospital (DCH, 2003), Japan International Cooperation Agency/Asian Arsenic Network (JICA/AAN, 2004), Development Association for Self-reliance, Communication and Health (DASCOH, 2004) have conduced analysis of dug well waters for assessment of quality and presented similar results.

Table 4.2: Dug well water exceeding BDS and WHOGV

WATER QUALITY PARAMETERS	RAAMO I 36 DWS		RAAMO II 36 DWS		PRESENT STUDY 20 DWS	
	% DW Exceeding		% DW Exceeding		% DW Exceeding	
	WHO GV	BDS	WHO GV	BDS	WHO GV	BDS
Arsenic	25	3	15.15	0	40	10
FC	94	94	90.9	90.9	87	87
Iron	61	22	24.24	15.2	80	50
Manganese	75	75	-	-	95	95
Ammonia-N	11	50	17.65	55.9	40	55
Nitrate-N	8	8	0	14.7	0	0

WATER QUALITY PARAMETERS	RAAMO I 36 DWS		RAAMO II 36 DWS		PRESENT STUDY 20 DWS	
	% DW Exceeding		% DW Exceeding		% DW Exceeding	
	WHO GV	BDS	WHO GV	BDS	WHO GV	BDS
Turbidity	39	28	30.3	12.1	80	75
Colour	44	44	-	-	41.67	41.67
TDS	28	28	47.1	47.1	20	20

4.1.2 Microbiological Quality

4.1.2.1 Faecal coliforms

Faecal coliform (FC) was found in 87% of the dug wells. The highest count of 1000 cfu/100ml was found in the dug wells of Uttar Elliotganj union of Daudkandi Upazila. The median and mean values of faecal coliform of dug well water samples were 80 and 358 cfu/100ml, respectively.

In RAAMO-I study, FC was found in 94% of the DWs, the highest counts (TNTC) were all located in one Upazila (Gomastapur). Possible reasons for very high TTC count were that the water was raised from DW by rope and bucket. This method is more prone to contamination by users (hands etc) and therefore results in higher levels of contamination. In RAAMO-II study conducted in rainy season, the dug wells were found to be highly contaminated by TTC. This abrupt rise in coliform concentration is attributed to continuous inflow of water during rainy season. The bacteriological quality of DW water reported by the RAAMO studies is compared with level of contamination found in this study and presented in Figure 4.1. The microbial contamination of dug well water found in this study is higher that that found under RAAMO-I but lower than RAAMO-II (Fig. 4.1).

DCH analyzed faecal coliforms for dug wells in Sirajdikhan Upazila in Munshigonj district. Faecal coliform was found in 74% of the dug wells. The highest count of 2000 cfu/100ml was found in the dug well of Baraipara village of Malkanagar union.

The lowest contamination of dug well water by faecal coliform was reported by JICA and UNICEF (2005); only 7% dug wells were found contaminated with faecal coliform. The highest concentration of 100 cfu/100ml was found in Jhikargachha Upazila. The other 3 contaminated dug wells are in Jhikargachha and 1 in Monirampur Upazila. This low level of contamination of these dug wells in Jessore district was due to the fact that many of dug wells constructed by AAN had attached sand filtration and chlorination units for treatment of dug well water.

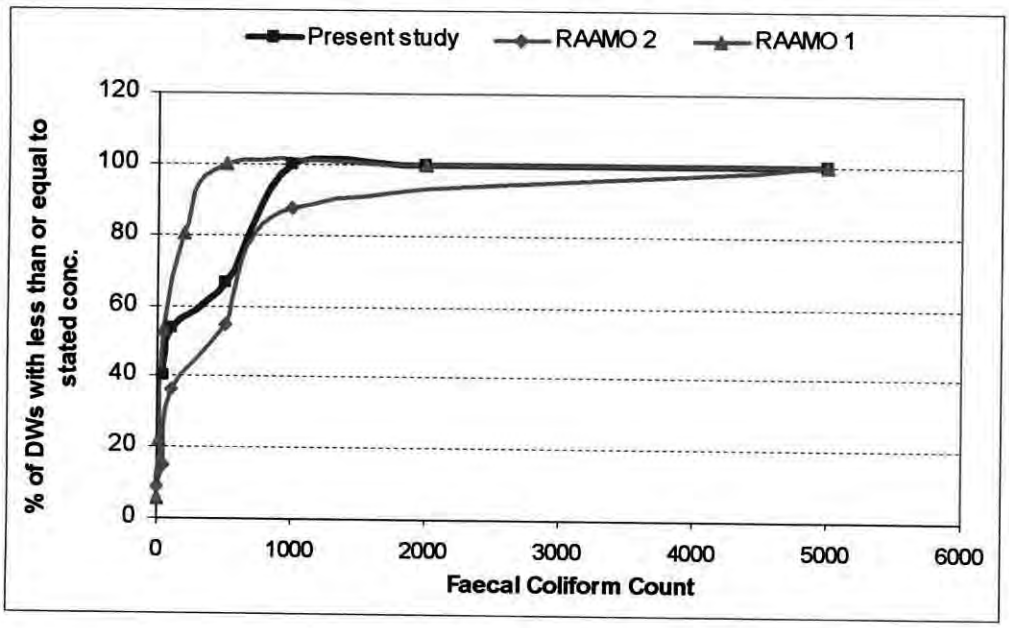


Figure 4.1: Comparison of Level of Bacterial Contamination found in Dug well for faecal coliform

Figure 4.1 shows that the bacterial contamination of DW water found in this study is within range of the studies conducted by APSU. RAAMO-II study shows the highest concentration of faecal coliforms with the highest value of 5000 cfu/100 ml and having 50% of the dug wells with a FC count above 500 cfu/100 ml. All the studies except JICA and UNICEF Study reported the presence of high level of microbial contamination of DW water and most studies found only about 5-20 percent DW free from microbial contamination.

4.1.2.2 Total coliforms

Analysis was also carried out for total coliform (TC) under present study. Mean and median values of total coliform concentrations are 1063 and 1100 cfu/100ml

respectively. The level of contamination of dug well water by TC is shown in Figure 4.2.

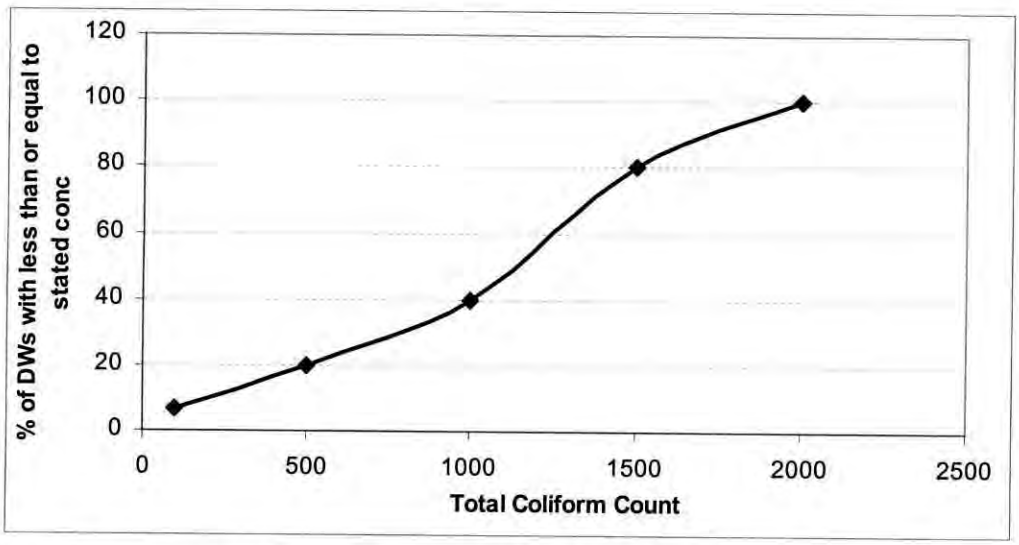


Figure 4.2: Level of contamination by TC in the DWs under present study

Figure 4.2 shows that 80% of the dug wells contain TC concentration above 500 cfu/ 100 ml with an indication of presence of different types of coliforms. However, all coliform bacteria may not be of faecal origin, hence do not indicate feacal pollution.

4.1.3 Chemical parameters

4.1.3.1 Arsenic

In the DWs sampled, 10% exceeded BDS and 40% exceeded the WHOGV for drinking water. The RAAMO-I study showed 3% DWs exceeding BDS. However, RAAMO-II study showed none of the DWs to exceed BDS, which might be due to dilution effect during rains. The mean value of arsenic for dug wells water found in this study is 26.42 ppb. The distribution of arsenic contamination of DW water as reported by the RAAMO-I, RAAMO-II and present study are shown in Figure 4.3. It appears that the level of arsenic contamination found in this study is higher than that of the RAAMO-I and RAAMO-II. This is due to the fact that some dug wells with high arsenic in Sharsha Upazial in Jessore district are included in this study. The arsenic content of dug well water in three other Upazilas studied in this work are comparable with RAAMO studies.

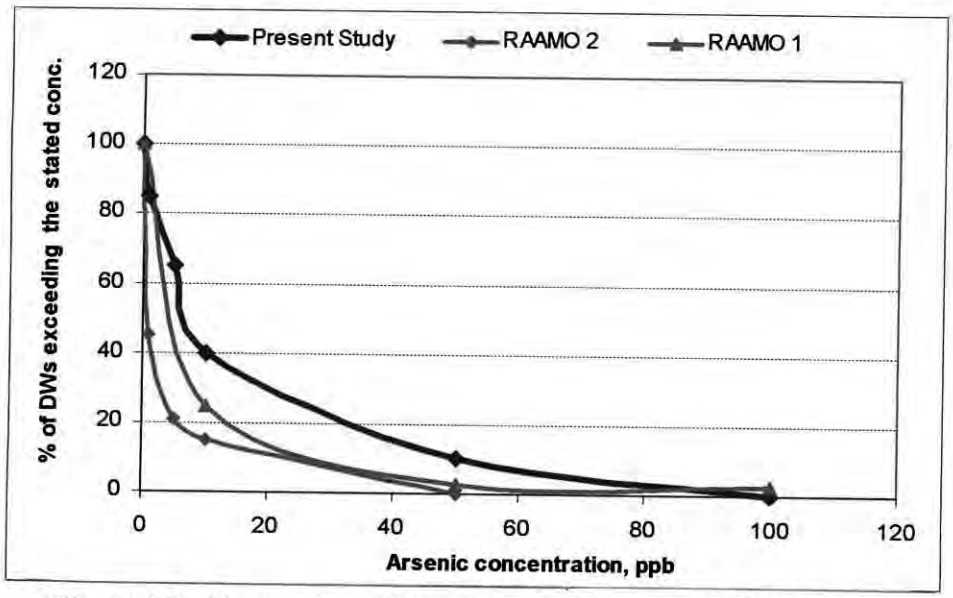


Figure 4.3: Comparison of Arsenic contamination of DW Water

DCH found arsenic concentration above Bangladesh standard only in one dug well in Char Farshail village of Balur Char union. About 4% of the dugwells under JICA and UNICEF (2005) study were found to have arsenic exceeding Bangladesh standard. The dug well with highest concentration (263 ppb) is found in Jhikargachha Upazila. However, 14 dug wells constituting 17% of the total under JICA and UNICEF study were found to be contaminated with arsenic exceeding WHO provisional GV for drinking water. The presence of arsenic in dug well water confirms that DWs in some locations can be arsenic contaminated and are not universally arsenic-safe.

4.1.3.2 Nitrate and Ammonia

The main sources of nitrate in shallow aquifers are leachate from agricultural land and decomposing organic matter buried in soil or from pit latrines (APSU, 2004). The water quality analysis present study shows that none of the DWs exceed the BDS and moreover, the mean and maximum concentration found were 0.71 and 3.74 mg/l respectively are far below the acceptable level in drinking water. RAAMO-I study showed the concentrations of NO_3-N in about 97% of the DW water but only 8% among those contained NO_3-N exceeding BDS and in RAAMO-II study, 14.7% exceeded the BDS. DCH study found concentration of NO_3-N in almost all of the

dug wells but only 3 dug wells or 8% of the total dug wells contain NO_3-N above Bangladesh Standard of 10 mg/l.

Ammonia contamination in dug wells was observed on a large scale in present study. As high as 55% of dug wells were found to contain ammonia above Bangladesh Standard of 0.5 mg/l and 40% exceed the WHO GV of 1.5 mg/l. The mean and median values are 1.0 and 0.71 mg/l, respectively, both of which are above BDS. Large variation of concentration was observed even within an area. Area wise variation in concentration of NH_3-N for 20 dugwells under present study is presented in table 4.3.

Table 4.3: Area wise variation of Ammonia under present study

Area	No of DWs Under present study	Concentration of NH_3-N, mg/l	
		Minimum concentration	Maximum concentration
Sirajdikhan	5	0.15	1.29
Manikgonj	6	0.129	1.822
Daudkandi	4	0.29	2.36
Sharsha	5	0.83	2.75

Figure 4.4 gives the distribution of Ammonia concentration under present study.

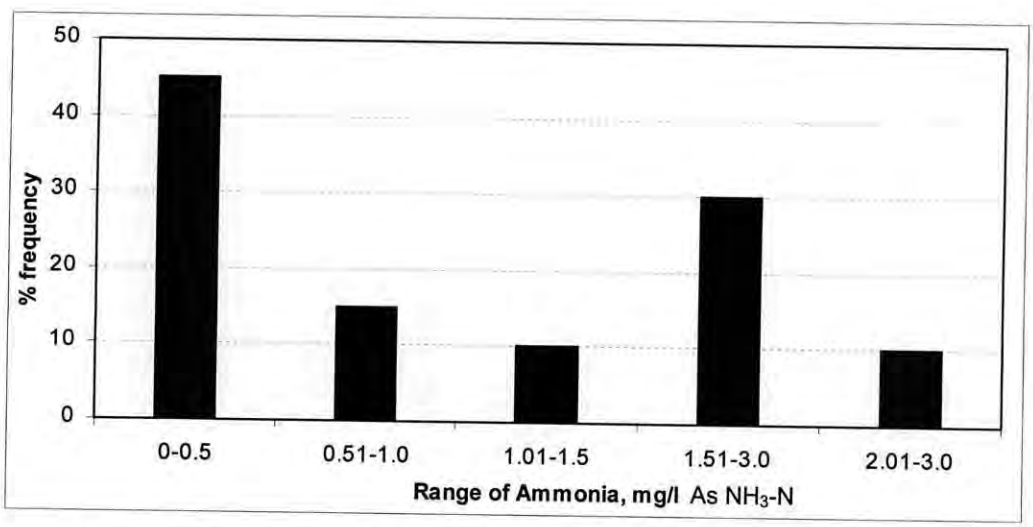


Fig. 4.4: Distribution of Ammonia in Dug Well Water (present study)

In RAAMO-I study, about 50% DWs contained NH_3-N above the BDS and 11% exceeded WHO GV. In RAAMO-II study, 56% DWs exceeded the BDS for ammonia. JICA and UNICEF (2005) found 29% dug wells to contain ammonia above Bangladesh standard of 0.5 mg/l and 19% exceed the WHO GV of 1.5 mg/l.

4.1.3.3 Iron

According to present study, the mean and median concentrations of iron are 2.66 and 1.2 mg/l respectively both of which exceed the BDS of 1 mg/l. Accordingly, 50% DWs exceeded the BDS and 80% exceeded the WHO GV. In RAAMO-I, only 22% of samples exceeded the BDS of 1 mg/l. However, over 60% of DWs exceeded WHO GV of 0.3 mg/l for iron. RAAMO-II study revealed that above 24% dug wells exceeded the WHO GV and 15% dug wells exceed the BDS. AAN study reveals that above 40% dug wells exceed the WHO GV and 30% dug wells exceed the BDS. But DCH shows more alarming situation. In Sirajdikhan, as much as 97% dug wells exceed WHO GV and around 85% dug wells exceed BDS, among which 42% dug wells have iron concentrations greater than 10 mg/l. In Daudkandi, dug well waters had iron concentrations greater than 10 mg/l. Under present study, no single area had uniform or similar concentration of iron in all the dugwells in that area. The variation is shown in table 4.4.

Table 4.4: Area wise variation of Iron under present study

Area	No of DWs Under present study	Concentration of Fe, mg/l	
		Minimum concentration	Maximum concentration
Sirajdikhan	5	1.0	7.0
Manikgonj	6	0.07	9.0
Daudkandi	4	0.1	10
Sharsha	5	0.35	6.04

The distribution of iron under present study in DWs is shown in Figure 4.5. Iron has no known effect on health, but adversely affects aesthetic quality of water and may cause problems in other domestic uses of water.

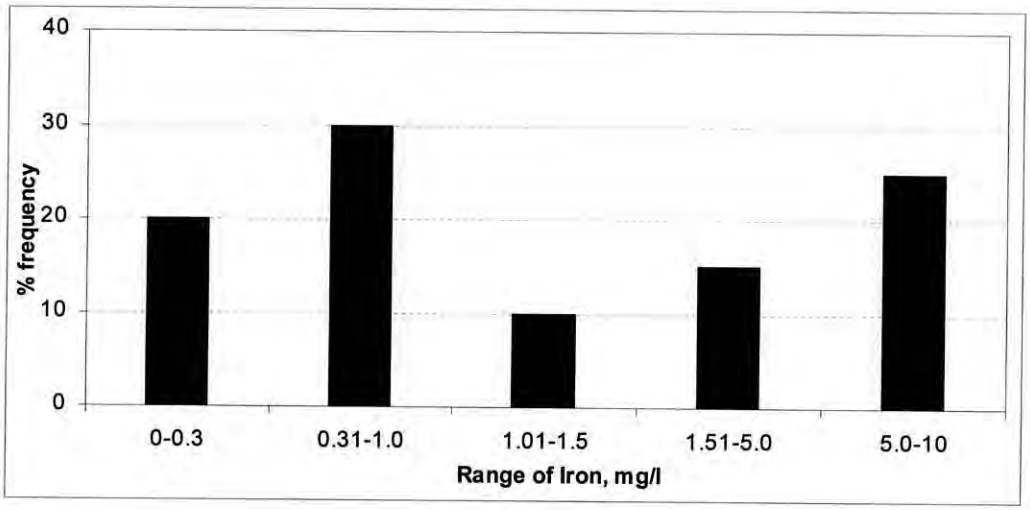


Fig. 4.5: Distribution of Iron in Dug Well Water (present study)

4.1.3.4 Manganese

Manganese was present in all DW water in relatively high concentrations and both the mean and median values exceeded the BDS and WHOGV of 0.1 mg/l. According to present study, 95% of the DWs exceeded the standards for drinking water. Only one dugwell had manganese concentration below drinking water standard which was in Daudkandi. Highest concentration of 1.93 mg/l was found in Manikgonj. The other dugwells under study had manganese concentrations within the range of 0.5-1.5 mg/l. RAAMO-I study showed similar results. Among the dug wells under DCH study, 69% exceeded the BDS and WHOGV for manganese. Among JICA and UNICEF dug wells 62% exceeded the BDS and 25% exceeded the health based WHOGV. The distribution of manganese under present study is shown in Figure 4.6.

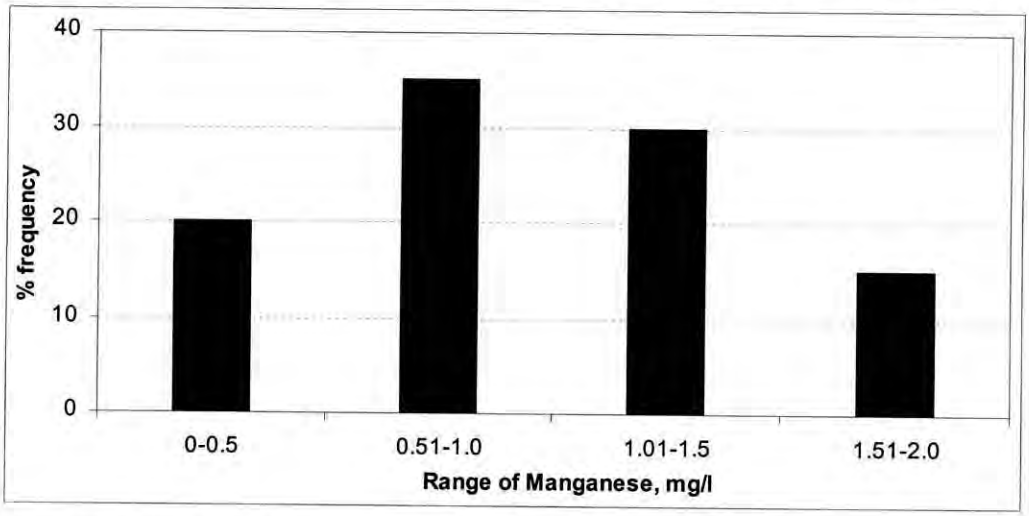


Fig. 4.6: Distribution of Manganese in Dug Well Water (present study)

4.1.3.5 Phosphate

The concentration of phosphate in DW water was determined in this study. This water quality parameter have adverse effects on treatment of water particularly removal of arsenic from ground water. The concentration of phosphate in DW waters was within BDS acceptable limit of 6 mg/l. RAAMO-I also found phosphate in dug well water within the acceptable level for drinking water.

4.1.3.6 Total Organic Carbon

Analysis of total organic carbon was performed only for the two DWs of Sirajdikhan which were selected for decontamination study and thus not documented in the water quality study of all the DWs. Very low concentration of TOC was found in these DWs. DW1 of Sirajdikhan had 1.3 mg/l of TOC and DW2 of Sirajdikhan had 2.9 mg/l of TOC.

4.1.4 Physical Parameters

4.1.4.1 Total Dissolved Solids

The total dissolved solids (TDS) and conductivity (EC) of DW samples show that 20% of the DWs exceed the BDS and WHOGV of 1000 mg/l. These DWs with high TDS were three DWs from Sirajdikhan and one DW from Daudkandi. In RAAMO-I study, the TDS of DW was poor and the value of TDS exceeding BDS is observed in 28% cases. Whereas, in RAAMO-II study, the TDS exceeding BDS is observed in 47% cases, understandably, due to ingress of suspended impurities with the inflow of rain water . The variation of TDS and conductivity maintains more or less same pattern as they are interrelated water quality parameters. In JICA and UNICEF study, only 4% dug wells exceeded the standard for TDS.

4.1.4.2 pH

The mean pH value of all the samples of dug well water was found to be 7.04, which is very close to neutral water. In RAAMO-I study, the median value for pH was 7.1, which was also closer to neutral water. The pH values of dug wells did not vary much and was found within the range of 6.4 – 7.9. The lowest pH observed was, 5.41

in JICA and UNICEF study in a dug well of Jhikargacha union and the highest pH of 11.04 has been observed in DCH study in a dug well of Malkanagar union.

4.1.4.3 Turbidity

In this study the turbidity of dug well water was found to be very high. The mean and median values of turbidity were 27 and 17 NTU, respectively, which are well above the BDS value of 10 NTU. In this study, 75% of DW water exceeded the acceptable value, whereas 28% exceeded the acceptable value in RAAMO-I study and 12% exceeded the acceptable value in RAAMO-II study. In case of JICA and UNICEF study, 26% exceeded the acceptable value of turbidity. Under present study, all the DWs of Sharsha and Sirajdikhan exceeded the standard for turbidity. Even the variation within a single upazila is such that Daudkandi showed lowest turbidity of 4.9 NTU for one DW and highest turbidity of 86 NTU for another one. Similiarly, Manikganj showed lowest turbidity of 4 NTU and highest of 78 NTU.

4.1.4.4 Hardness

All the dug wells, except one, had hardness within BDS of 500 mg/l as $CaCO_3$. The DW exceeding the standard for hardness was in Daudkandi and hardness was found to be 606 mg/l as $CaCO_3$. Dug wells are usually recharged by ground water from the top surface of the aquifer, which is diluted by rain and surface water sources of low mineral content. Thus, hardness is found less in DW water than that of natural ground water.

4.1.4.5 Colour

Analysis of colour for water samples from DWs under present study revealed that around 42% of the DWs failed to meet Bangladesh Standard for colour similar to RAAMO-I study, in which 44% of dug well water exceeded BDS for colour. High colour in dugwell water may be attributed to the presence of decaying organic substances and higher concentration of iron in water. High colour in water is important for the aesthetic quality of water.

4.1.4.6 Odour

Odour was examined by smell in the field. The odour of water was generally not objectionable. It appeared that smell in DW water varied from place to place and probably related to the presence of organic matters in soil.

4.1.4.7 Temperature

The temperature of water at the water-points ranged between 26°C and 29°C during the study period. Temperature of water of dug well, to some extent, is regulated by the ambient temperature. In the other studies conducted in winter, a temperature as low as 17°C was observed.

4.1.4.8 Dissolved Oxygen

Dissolved oxygen in dug well water ranging from 0 mg/L (Singair) to 2.87 mg/l (Sharsha) with median value 1.07 mg/l and mean value of 1.02 mg/l was found in this study. This DO levels are very low as compared to the saturation DO levels corresponding to temperatures of dug well water mentioned in Section 4.1.4.5. The distribution of DO for the twenty dug wells under present study along with saturation level 7.45 mg/L at average temperature of dug well is shown in Fig. 4.7. In JICA/AAN Study (2004), the dissolved oxygen found in dug well water ranged between 0.88 and 3.08 mg/L.

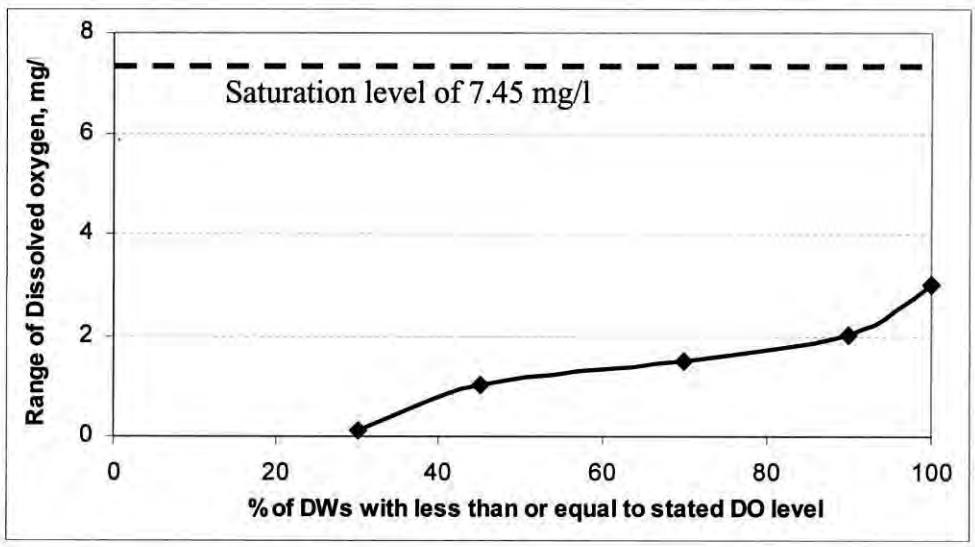


Fig. 4.7: Distribution of DO in Dug Well Water (present study)

Oxidation of impurities in dug well water at this level of oxygen is very low. The entry of air for oxidation of water is facilitated in improved dugwells by keeping the wells open. But, sanitary protection of open dug wells is a difficult practice to maintain. Although some movement of water surface by the float was observed during pumping, the oxygen level in dug well water was too low. It may be due to the fact that more carbon dioxide formed by stabilization of organics in and around dug wells may accumulate, instead of air, near the surface of water of dug well. Carbon dioxide, with density 1.9768 g/L at NTP, will tend to accumulate above water of dug well replacing lighter air of density 1.2928 g/L. This indeed will interfere with oxidation of dug well water.

4.2 OXIDATION REDUCTION POTENTIAL (ORP)

The solubility of arsenic and iron is dependent on the state of oxidation of these two elements in water, which on the other hand depends on oxidation reduction potential (ORP) or Eh value of the water. The Eh-pH diagram of dug well water is considered very important to observe the effectiveness of aeration in oxidizing the water of improved dug wells constructed in Bangladesh. In-situ Eh and pH of the dug wells were measured as described in chapter 3. Apart from these dug wells, Eh and pH values were collected for another 46 dug wells of Sharsha Upazila constructed under AAN. The ORP values with corresponding pH values were plotted on the Eh-pH diagram for As at 25°C and 1 atmospheric pressure with total arsenic 10^{-5} M and total sulphur 10^{-3} M as shown in Fig. 4.8. pH values were also plotted on phase stability diagram of Iron as shown in Fig. 4.9.

Figure 4.8 shows that only around 25% of the total DW water samples fall in the oxidized field of arsenate and the rest remain in the soluble arsenite range. The ORP of about 50% dugwells is negative. This indicates that water in most of the DWs does not promote oxidation of arsenic, which was supposed to have oxidized due to aeration in improved DWs.

Figure 4.9 shows that all the DWs fall in the soluble range (Fe^{++}) of iron. Two values fall in the insoluble sulphide range, which indicate that the water in this two dug

wells is highly reducing and can form ferrous sulphide in presence of sulphur. Thus, oxidation of iron does not happen at all in the improved DWs.

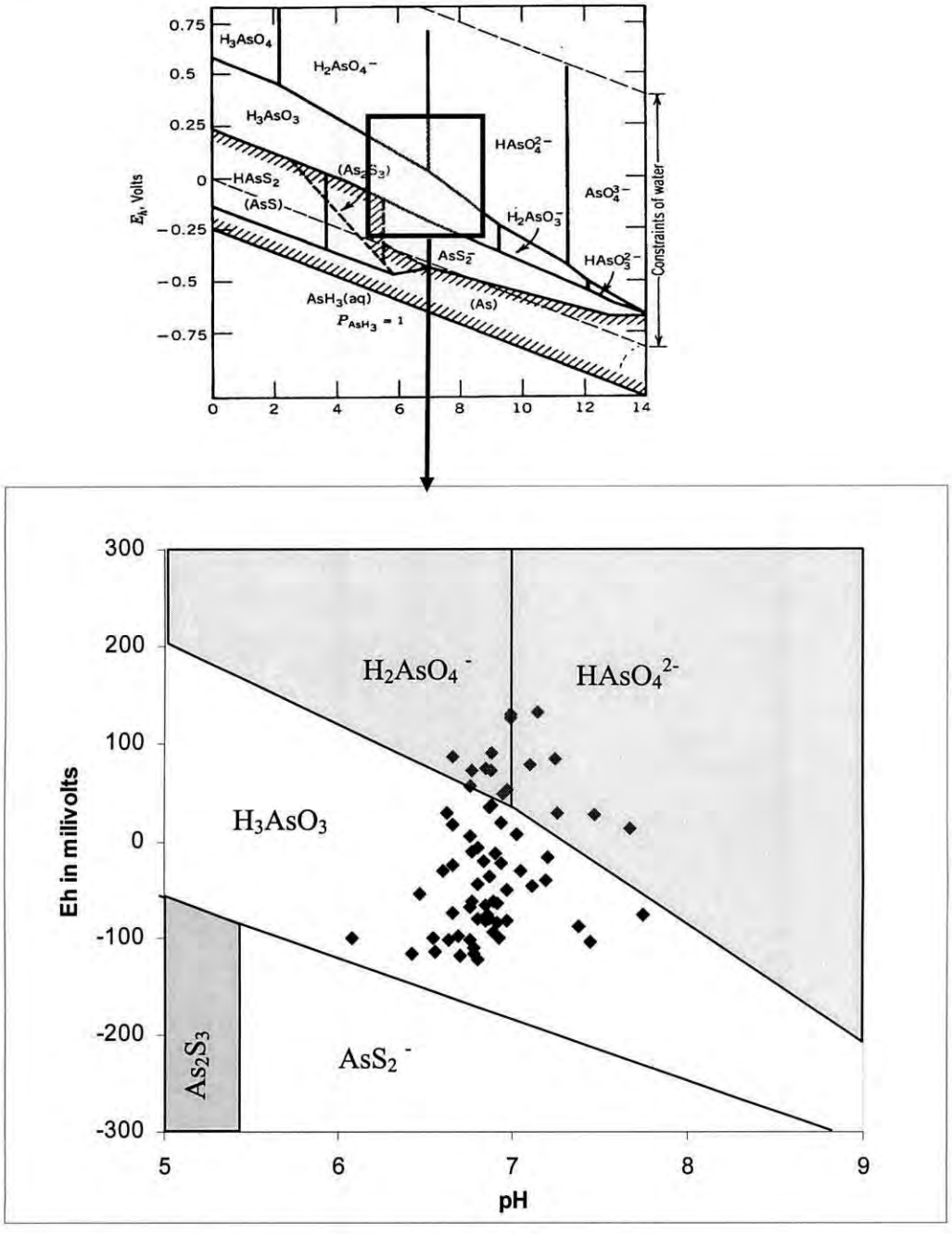


Figure 4.8: Eh-pH Plots of Dug Well Water in Phase-stability Diagram for Solubility of Arsenic (at 25°C and 1 atmospheric pressure with total arsenic 10^{-5} M and total sulphur 10^{-3} M)

It was expected that oxidation of iron into ferric form would form precipitation of iron flocs and it would adsorb oxidized arsenate and settle together. However, it is evident from Figs. 4.8 and 4.9 that dugwell water is not favourable for oxidation of

iron and arsenic. Iron and arsenic removal by co-precipitation and passive sedimentation is observed in stored aerated water. But in dug well water, this phenomenon is not likely to work due to low dissolved oxygen and mostly negative redox potential. The low DO and Eh value indicates that there is no remarkable difference between ground water and dug well water. This may be the reason for high iron, manganese and sometimes presence of arsenic in dug well water. Whatever improvement observed in respect of arsenic content of dug well water as compared to shallow tubewell water in the same location, is due to dilution of ground water in very shallow aquifer by rain and surface waters.

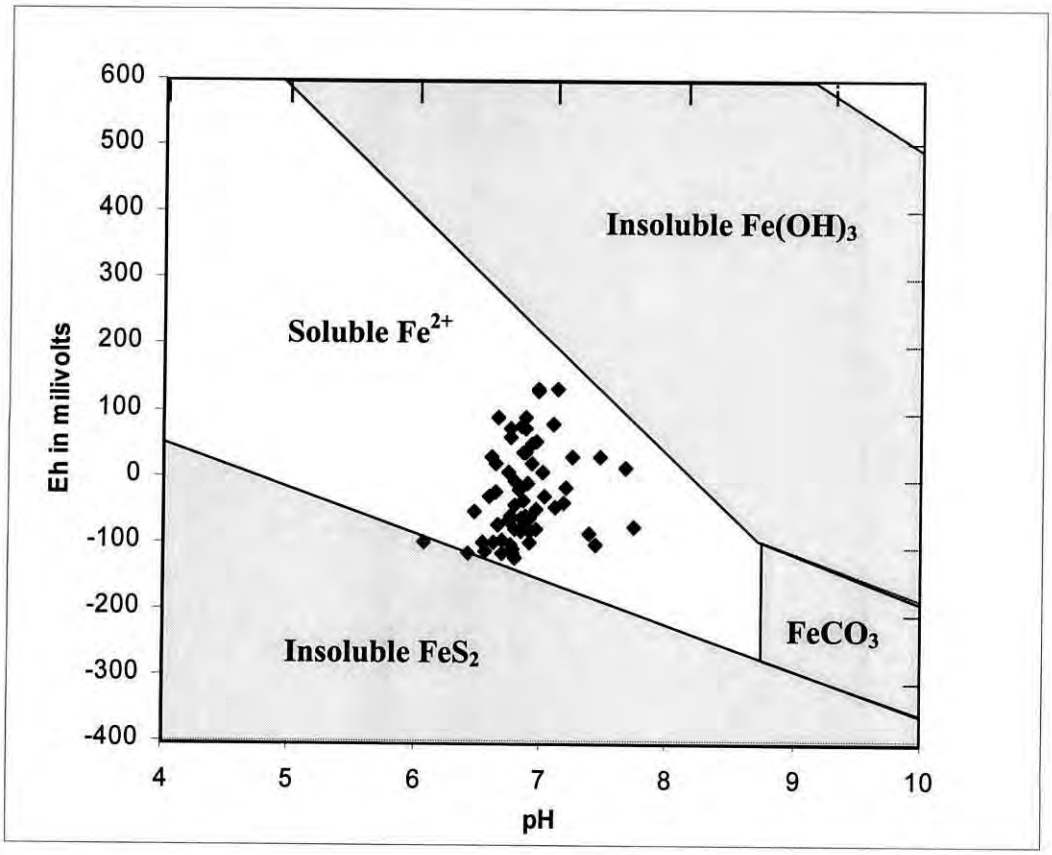


Figure 4.9: Eh-pH Plots of Dug Well Water in Phase-stability Diagram for Solubility of Iron

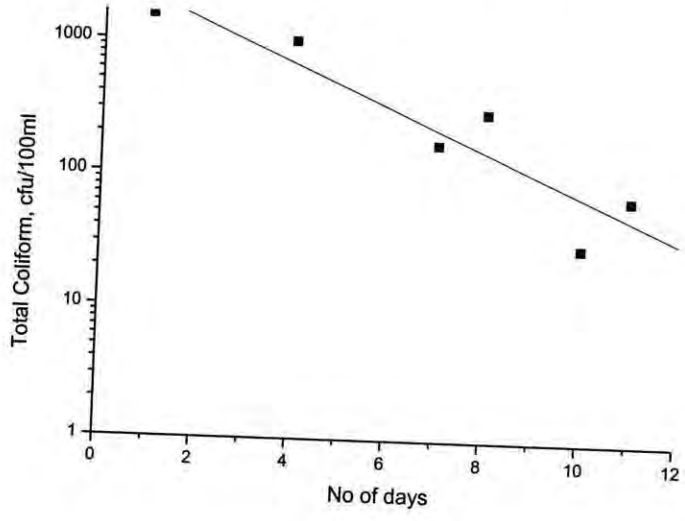
4.3 DECAY/GROWTH OF BACTERIA

Natural decay of bacteria is a highly variable phenomenon. Different external conditions influence the observed decay pattern. Additional parameters of interest are estimates of the time required for 90 percent die–off (T90), 99 percent die-off

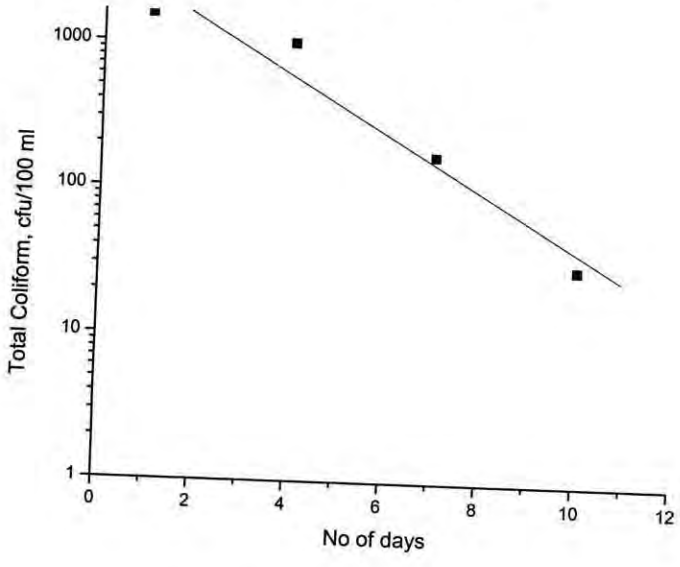
(T99), and 99.9 percent die-off (T99.9). These percentages correspond to 1- log, 2-log, and 3-log removals, respectively. From a broader perspective, T90 is used to represent inactivation rates in the development of inactivation models.

4.3.1 Total Coliform

Total Coliform dies in the unfavourable environment in dugwell water. The decay patterns for a water sample from DW1 are plotted in Fig. 4.10.



(a) Decay including re-growth



(b) Decay Excluding re-growth

Figure 4.10: Decay of Total Coliforms in Water from DW1

The important findings of the decay/growth study of total coliform are as follows:

- The decay coefficient is 0.16/day.
- The data indicate that 65% of the total coliform remained after 3 days, less than 15% remained after 6 days and less than 5% remained after 10 days. This means that the decay rate is slow at the very initial stage and then it is rapid and highest beyond 3 days upto 7 days. Then the decay gets slower after 10 days.
- Inactivation time or time required for 90% die-off is 7.01 days.
- Re-growth of bacteria was observed in the data set. There was a period of rapid die-off from day 0 to day 7, after which bacteria re-growth occurred and again at day 11 some re-growth occurred (Figure 4.8a). The plot represents the net/effective faecal coliform decay rate, since it takes the effect of bacterial re-growth into account.
- Exclusion of the re-growth phase (figure 4.8b) yields a decay coefficient of 0.2/day and an inactivation time of 6.4 days for a 1-log reduction of influent concentrations. This time is faster than that computed using the net/effective decay coefficient (7.01 days).

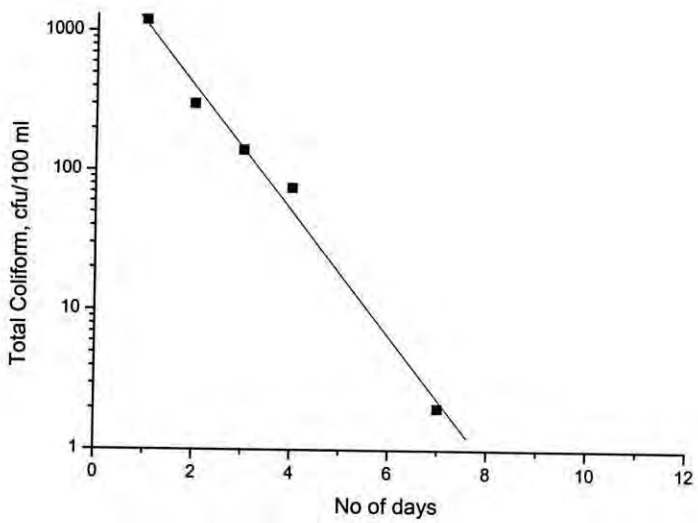


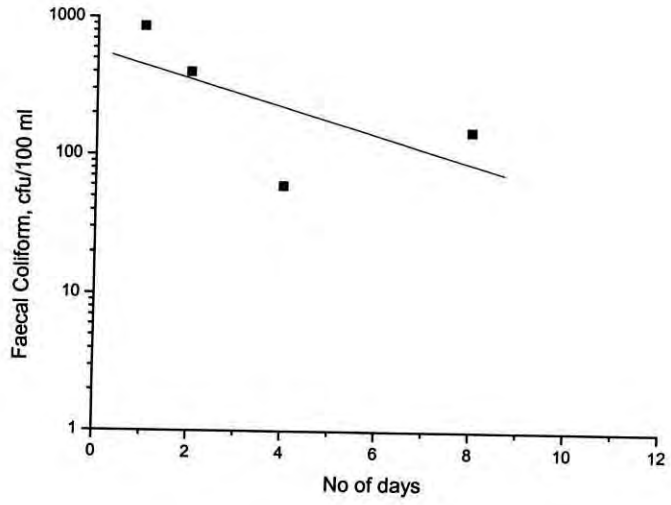
Figure 4.11: Decay of Total Coliforms for DW2

The findings of Total Coliform decay for sample 2 collected from DW2 is given below:

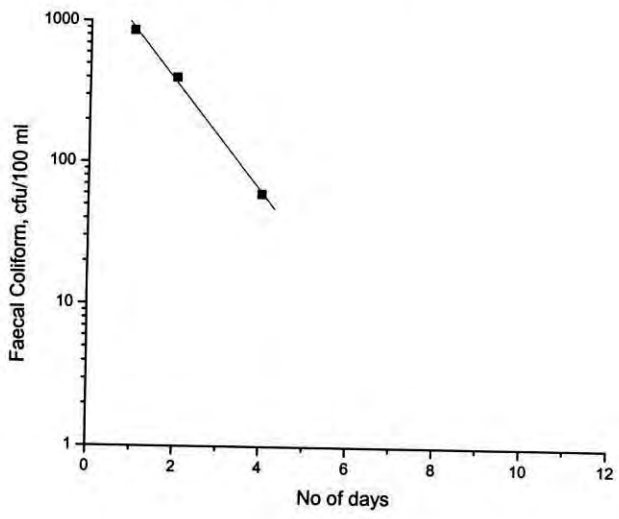
- The decay coefficient is 0.455/day.

- The data indicate that 25% of the total coliform remained after 2 days, 11% remained after 3 days and 6% remained after 4 days. Complete reduction of total coliform occurs after 7 days. Thus, initial reduction of total coliforms is rapid for this dug well water.
- Inactivation time or time required for 90% die-off is 3.03 days (Figure 4.11)
- Re-growth was not observed for this sample.

4.3.2 Faecal Coliform



(a) Including re-growth



(b) Excluding re-growth

Figure 4.12: Decay of Faecal Coliforms for DW1

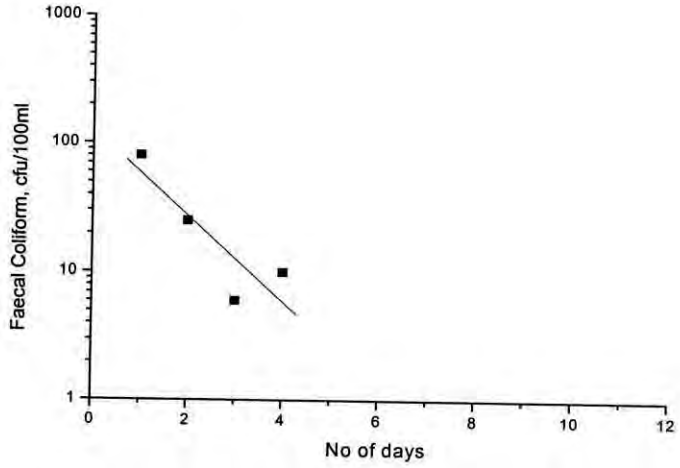
The findings of Faecal Coliform decay for sample from DW1are as follows:

- The decay coefficient is 0.1/day.
- The data indicate that 47% of the total FC remained after 2 days, less than 7% remained after 4 days and the count was nil after 10 days with a sudden re-growth after 8 days. This means that the decay rate is slow at the very initial stage and then it increased in later stage.
- Inactivation time or time required for 90% die-off is around 8 days (figure 4.12a).
- Re-growth of bacteria was observed after 8 days (Figure 4.12a). A decay coefficient of 0.39/day and an inactivation time of 3.5 days were calculated excluding the re-growth phase as shown in Figure 4.12b. Thus, the decay rate gets more than doubled if there was no re-growth.

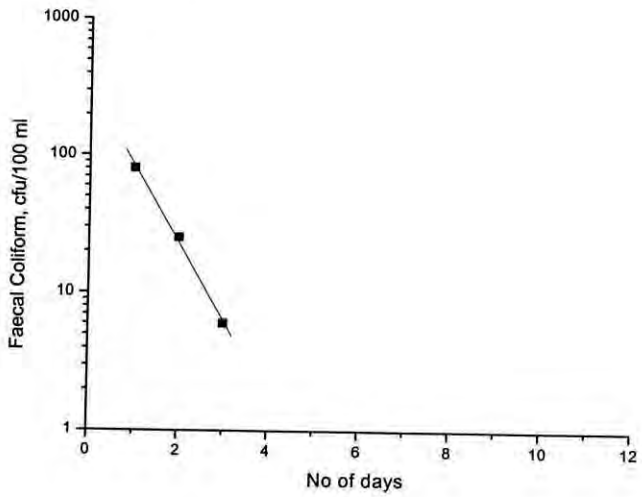
The decay pattern for faecal coliform for DW2 is shown in figure 4.13.

The findings of Faecal Coliform decay for DW 2 are as follows:

- The decay coefficient is 0.32/day
- The data indicate that 32% of the total FC remained after 2 days, 7.5% remained after 3 days and the count was nil after 5 days with a sudden regrowth after 4 days. This means that the decay rate is slow at the very initial stage and then it increases rapidly resulting to zero coliform only within 5 days.
- Inactivation time or time required for 90% die off is around 3.5 days.
- Re-growth of bacteria was observed after 4 days (Figure 4.13a). Excluding the re-growth phase, figure 4.13b yields a decay coefficient as high as 0.55/day and an inactivation time of 2.3 days. Thus, the decay rate occurs much faster if re-growth does not take place.



(a) Including re-growth



(b) Excluding re-growth

Figure 4.13: Decay of Faecal Colifoms for DW2

The study of bacterial decay/growth dynamics in dug well water shows that there is an overall decay of TC and FC population in dug well water, although some growths were noted at different stages. The decay dynamics in two dug well waters examined in this study are considerably different. The bacterial decay is regulated by water quality in a complicated manner, which cannot be correlated by studying decay dynamics of a few samples. Some growth of microorganism is not unusual but there may be some sampling errors. Entry of flocculated bacteria in the sample may show high bacterial count of bacteria, although the average count may be lower. It is,

however, confirmed from this study that bacteria die-off in dug well water at considerably high rates. In an environment of continuous decay of FC and TC in dug wells, the high level of microbial contamination can only happen when there is continuous inflow of these bacteria in the dug well.

CHAPTER 5

CONTROL OF CONTAMINATION OF DUGWELL WATER

5.1 CHLORINATION OF DUG WELL WATER

5.1.1 Break Point Chlorination

Break point chlorination of water samples from DW1 and DW2 was conducted in the laboratory to estimate the chlorine requirement for the chlorination of dug wells. Chlorine was added in incremental doses to the water of the dug wells. Break points for both of the dug well water samples were found within the range of 0.5 mg/l to 0.6 mg/l (Figure 5.1and Figure 5.2). It means that beyond this concentration of chlorine, free chlorine is available for disinfection.

It may be observed that residual chlorine curve after break point is neither at 45° angle with the x-axis nor is it parallel to the no demand curve. It may be due to the presence of slow oxidizing substances or impurities oxidized at higher chlorine dosage in the dug well water. This may require additional chlorine for the presence of free available chlorine for effective disinfection of dug well water.

Figure 5.1 shows that free residual chlorine can be obtained beyond the applied chlorine concentration of 0.5 mg/l. After applying slightly higher chlorine dose (0.6 mg/l) than the break point dose to DW-1 sample in laboratory condition, total coliform disappeared initially, but reappeared after 24 hours of contact time. This may be due to reduction of residual chlorine by oxidation of slow oxidizing substance in dug well water. The bacteria that take shelter in suspended particles in dug well water may reappear again. The chlorine was then applied at a dose, double of the break point (1 mg/l) dose. In this case, the coliforms did not appear within 24 hours of contact time.

Figure 5.2 shows the break point for the DW-2 sample which is 0.57 mg/l. Therefore, 0.6 mg/l of chlorine dose was also applied to this sample in laboratory condition and total coliform was found after 1 hour of contact time. Then 1.2 mg/l of

dose was applied and no coliform was detected within 24 hours of contact time. This result corroborated the action regarding application of chlorine dose to the natural dug well water at a dose at least double of break point chlorine dose

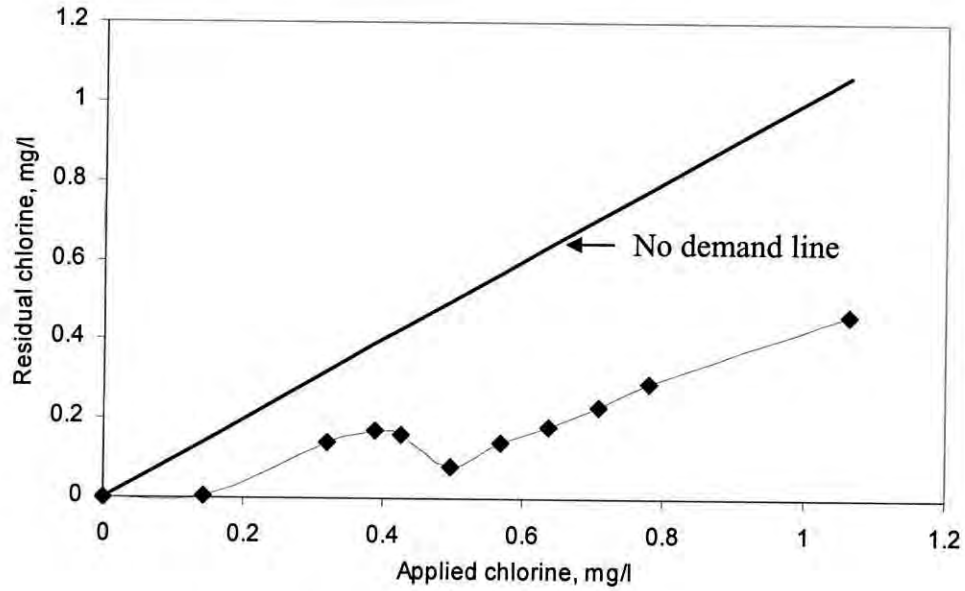


Figure 5.1: Break point curve for DW1

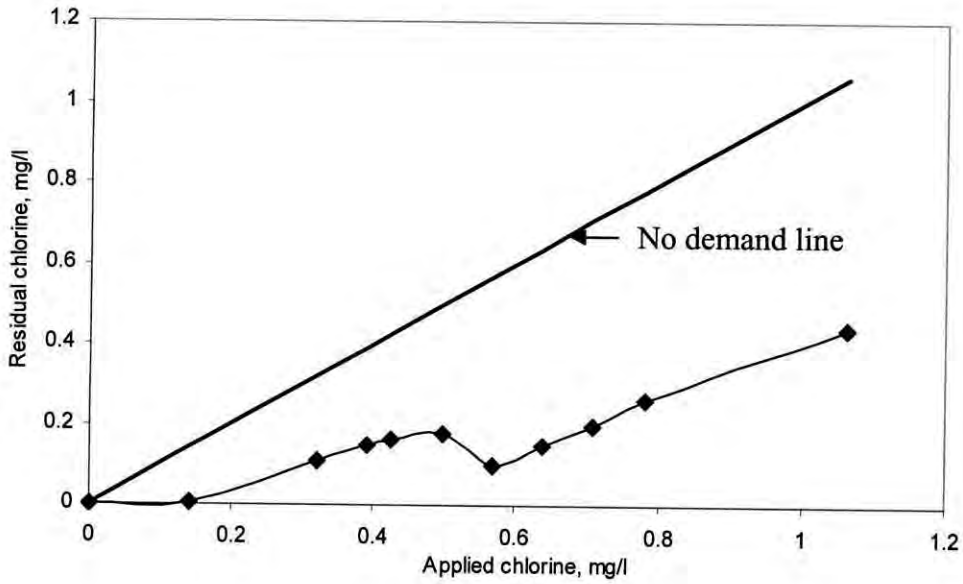


Figure 5.2: Break point curve for DW 2

5.1.2 Laboratory Chlorination of Dug Well Water

Laboratory simulation of chlorination was done to observe the effect of chlorination on water quality of dug wells. A Sharsha dug well with high arsenic content was

included with the two dug wells from Sirajdikhan in this phase of the study. Dug well water in the field is continuously enriched with new water into the well thus disrupting the effect of the applied chlorine on water quality parameters. Thus the water quality in the dug well water is in dynamic condition and unsuitable for study of effects of chlorination. Water sample from each of the dugwells was collected and chlorinated at a dose higher than the BP but not exceeding 1 mg/L and kept undisturbed for at least 24 hours. The selected water quality parameters were analysed before and after chlorination. The results are presented in Table 5.1.

Table 5.1: Effect of Chlorination on DW water in laboratory

Parameters	DW1-Sirajdikhan		DW2- Sirajdikhan		DW3- Sharsha	
	Before dosing	After dosing	Before dosing	After dosing	Before dosing	After dosing
FC (cfu/ml)	50	0	300	0	0	0
TC (cfu/ml)	200	0	500	0	25000	0
Arsenic (ppb)	6.1	0	5.6	0.72	129	21.1
Manganese (mg/l)	1.48	0.98	0.69	0.67	0.95	0.75
Ammonia (mg/l)	1.45	0.94	0.69	0.55	1.54	1.25
Iron (mg/l)	8	0.4	2.9	1.6	5.5	0.07
Turbidity (mg/l)	47	1.51	14.5	1.23	26	0.62
Color, (PtCo)	395	25	57	4	40	12

5.1.2.1 Coliform Bacteria

Both total and faecal coliform concentrations were reduced to zero after applying chlorine dose in the laboratory. Thus, disinfection of DW water with chlorine dosing was found very effective in destruction of bacteria.

5.1.2.2 Arsenic

Significant reduction of arsenic concentration was found after chlorine dosing and keeping it open condition. As high as 129 ppb initial concentration was reduced to 21 ppb for the dug well water from Sharsha. This might be attributed to the fact that, the principles of co-precipitation and passive sedimentation of oxidized arsenic were effective in lowering the levels of arsenic of dug well water. Figure 5.3 shows the

effect of lab chlorination on arsenic concentration of the 3 DWs. The oxidation of arsenic was evident from increase of Eh value in field in Eh-pH diagrams after chlorination (Fig. 5.13).

5.1.2.3 Iron

Reduction of iron was also significant after chlorination. Two samples from Sirajdikhan and one from Sharsha showed 95%, 46% and 98% reduction of iron, respectively and resulting concentrations were well below the BDS for two samples. The effects of lab chlorination on iron concentrations of the DWs are shown in figure 5.4. Chlorination of dug well water increased the Eh and changed ORP of the water from soluble field to insoluble field in phase stability diagram for iron (Fig. 5.14).

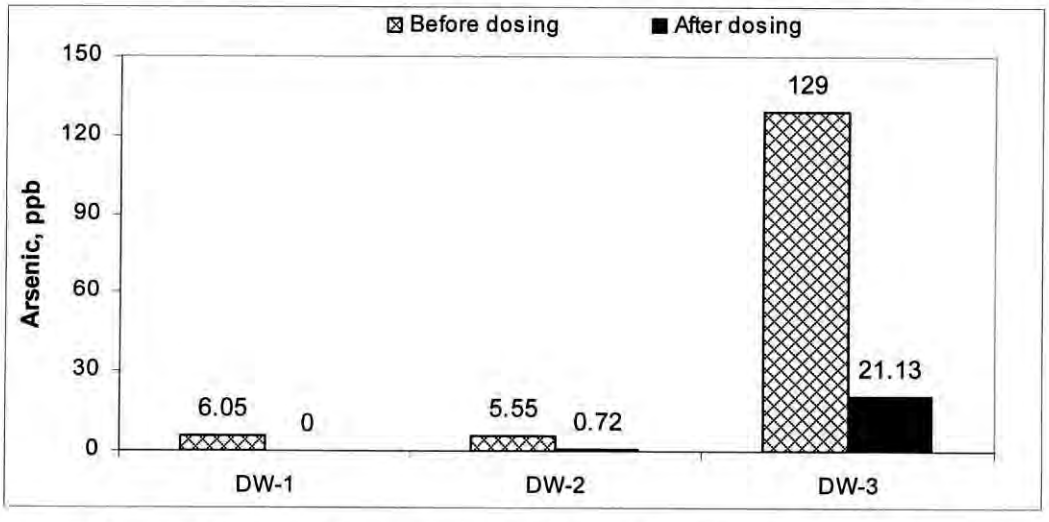


Fig. 5.3: Reduction of Arsenic by Chlorination of Dug Well Water

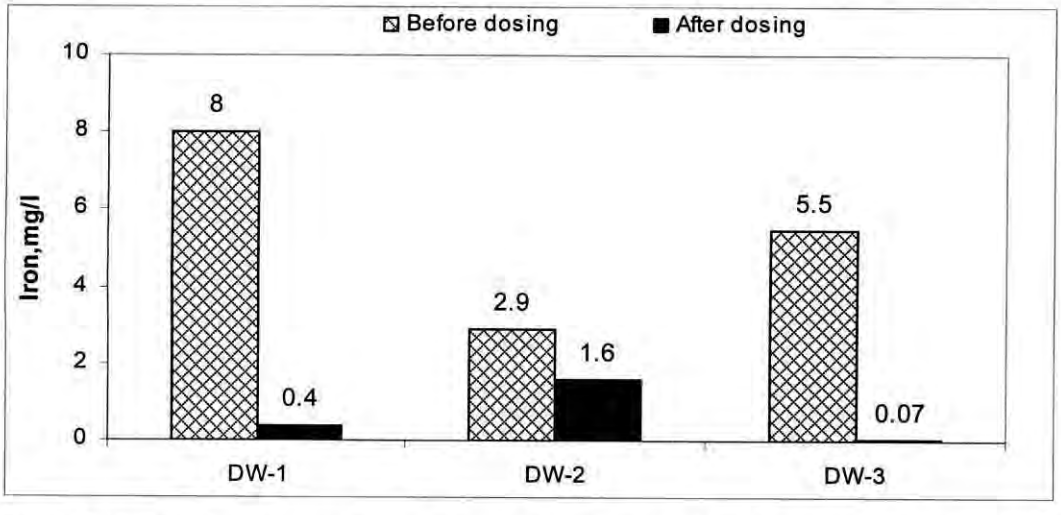


Fig. 5.4: Reduction of Iron by Chlorination of Dug Well Water in the Laboratory

5.1.2.4 Ammonia

Reduction of ammonia was not that prominent after chlorination, which ranged from 18% - 35%. Although chlorine directly reacts with ammonia, the reduction was not very high. The resulting concentrations of ammonia for all three DWs were still above Bangladesh Standard of 0.5 mg/l. The effect of lab chlorination on ammonia concentration of the DWs is shown in Figure 5.5.

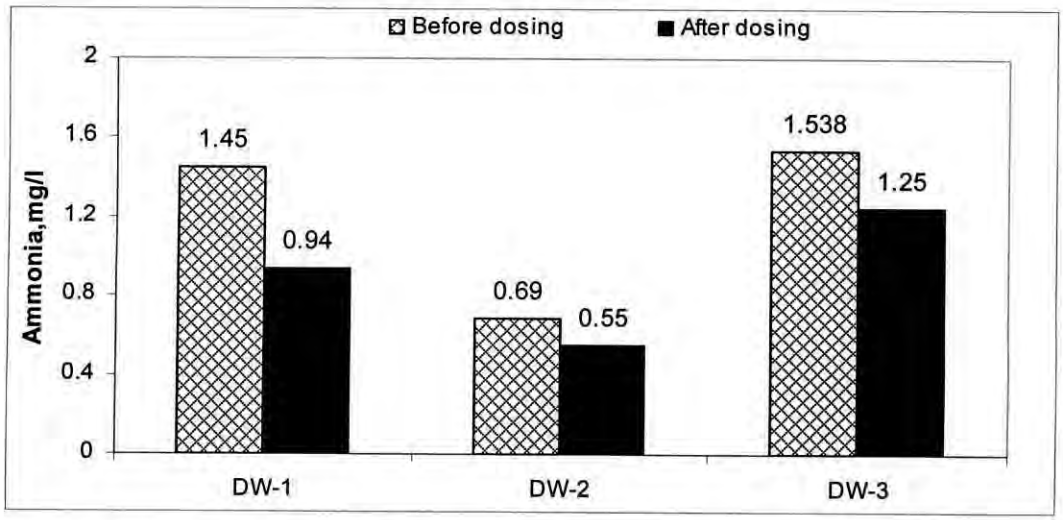


Fig. 5.5: Effect of Lab. Chlorination on Reduction of Ammonia of Dug Well Water

5.1.2.5 Manganese

Manganese did not reduce significantly upon chlorine dosing. One sample from Sirajdikhan showed 33% reduction and the one from Sharsha showed 21% reduction.

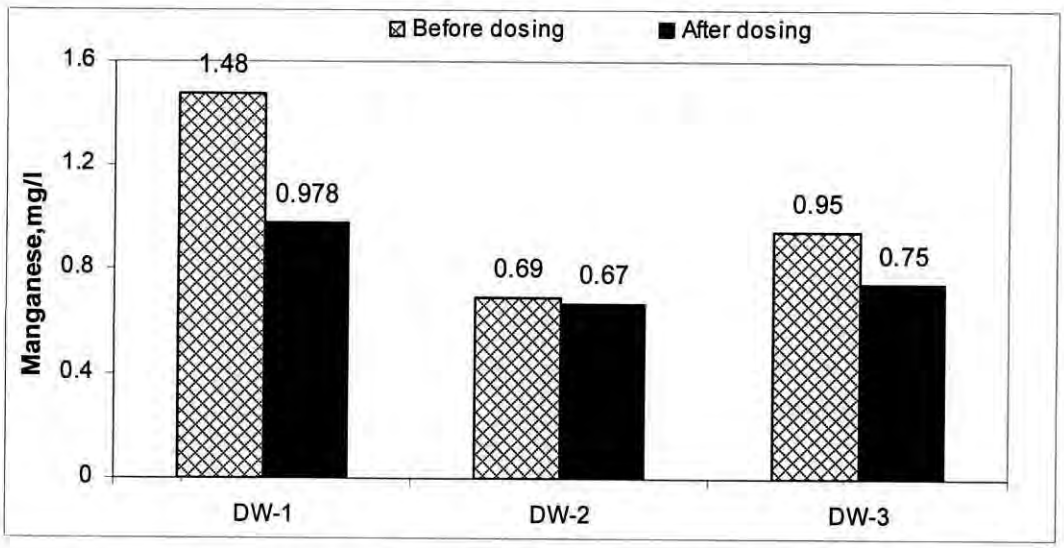


Fig. 5.6: Effect of Lab. Chlorination on Manganese of Dug Well Water

The other from Sirajdikhan showed only 3% reduction. The effect of chlorination on manganese concentration is shown in (Figure 5.6)

5.1.2.6 Turbidity

Turbidity reduced drastically after chlorination. Over 90% reduction of turbidity resulted following chlorination and retention in the laboratory. The resulting values were far below the BDS standard of 10 NTU. This reduction of turbidity is attributed to oxidation and settling of substances suspended in the DW water samples. The effect of chlorination on turbidity is shown in Figure 5.7.

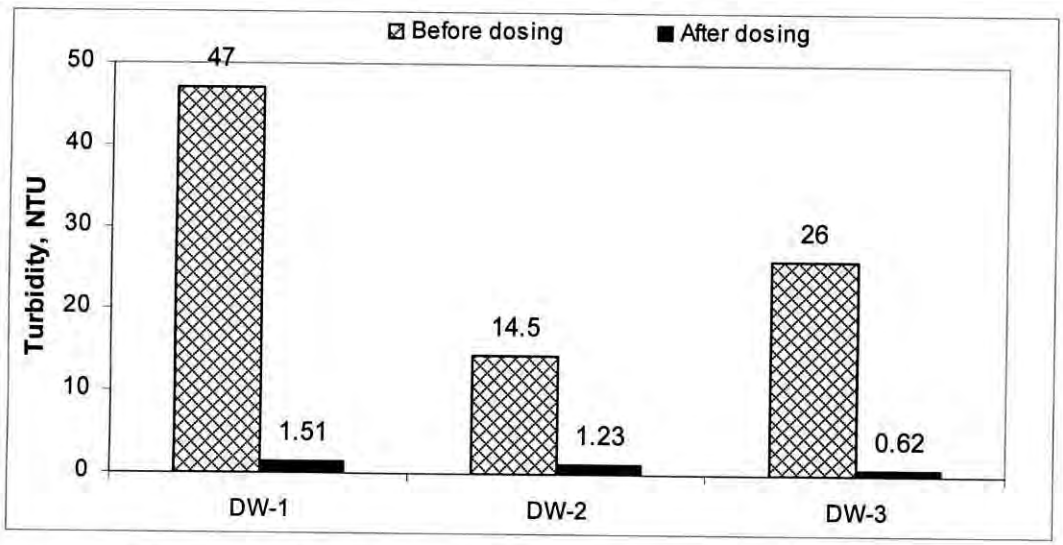


Fig. 5.7: Effect of Lab. Chlorination on Turbidity of Dug Well Water

5.1.3 In-situ Chlorination of Dugwell

Three selected dug wells were chlorinated with intermittent dosage at least for two weeks primarily for disinfection and to observe possible improvement of other water quality parameters. Application of chlorine in the field in the form of bleaching powder did not produce any residual chlorine at a concentration twice the break point value as was found in the laboratory. A chlorine dose several times higher than BP dose was required for each dug well to achieve residual chlorine of 0.5 to 1 mg/L in water. Field dosing produced varied results for each of the dug wells. The average changes in water quality parameters are shown in 5.2.

Table 5.2: Effect of chlorination on average water quality parameters of DW

Parameters	DW1-Sirajdikhan		DW2-Sirajdikhan		DW-3-Sharsha	
	Before dosing	After dosing	Before dosing	After dosing	Before dosing	After dosing
FC (cfu/ml)	800	91	80	42	-	0
TC (cfu/ml)	1200	173	500	84	25000	20
Arsenic (ppb)	-	-	-	-	132	132
Manganese (mg/l)	1.285	1.045	0.505	0.43	1.017	0.941
Ammonia (mg/l)	0.86	0.38	0.63	0.364	2.982	2.802
Iron (mg/l)	4.15	6.8	2.44	3.16	3.83	6.24
Turbidity (mg/l)	24.53	21.14	10.38	14.86	28.8	56.6
ORP (milivolt)	-44	598	-7	412	-62	469

5.1.3.1 Coliform Bacteria

The chlorine dosing and resulting changes in residual chlorine and coliform bacteria for DW1, DW2 and DW3 are shown in Fig. 5.8, Fig. 5.9 and Fig 5.10 respectively. The changes in the residual chlorine and coliform between the doses are considered straight line, which may not be the case. As stated earlier, the chlorine dose required to produce the desired residual chlorine is several times higher than that required for water only in each dug well. It indicates that there is much chlorine consuming substances in the dug well. The chlorine requirement decreased in the subsequent application as readily oxidizing substances in the dug well decreased. However, the chlorine requirement suddenly increased after heavy rainfall from 8th day. Rainwater caused a sudden increase in water level by about 2 ft. in the dug well with inflow of many impurities from surrounding.

Both total and faecal coliform concentrations were found nil or close to nil after each application of chlorine dose with a residual equal to or greater than 0.5 mg/l, in the

wells. Thus, the applied chlorine is at first being used to react with the organic compounds and then the unused portion is being used for disinfection. The residual chlorine, as obtained from laboratory disinfection of dug well water, is required to be at least 0.5 mg/l for the destruction of pathogens. Everyday before dosing, no residual chlorine could be detected but coliforms were found in much reduced number as compared to initial concentrations. It was apparent that coliforms appeared with the reduction and disappearance of residual chlorine in the dug well.

Reappearance of total coliform was found prominent in each case. The presence of faecal coliform was nil or only a few in numbers in each of the wells. The residual chlorine was mainly utilized by the freshly recharged water in the dug wells. It is estimated that each day the quantity of water recharged is utilized by the users of the dug well. Hence the residual chlorine is likely to approach to nearly zero after each day.

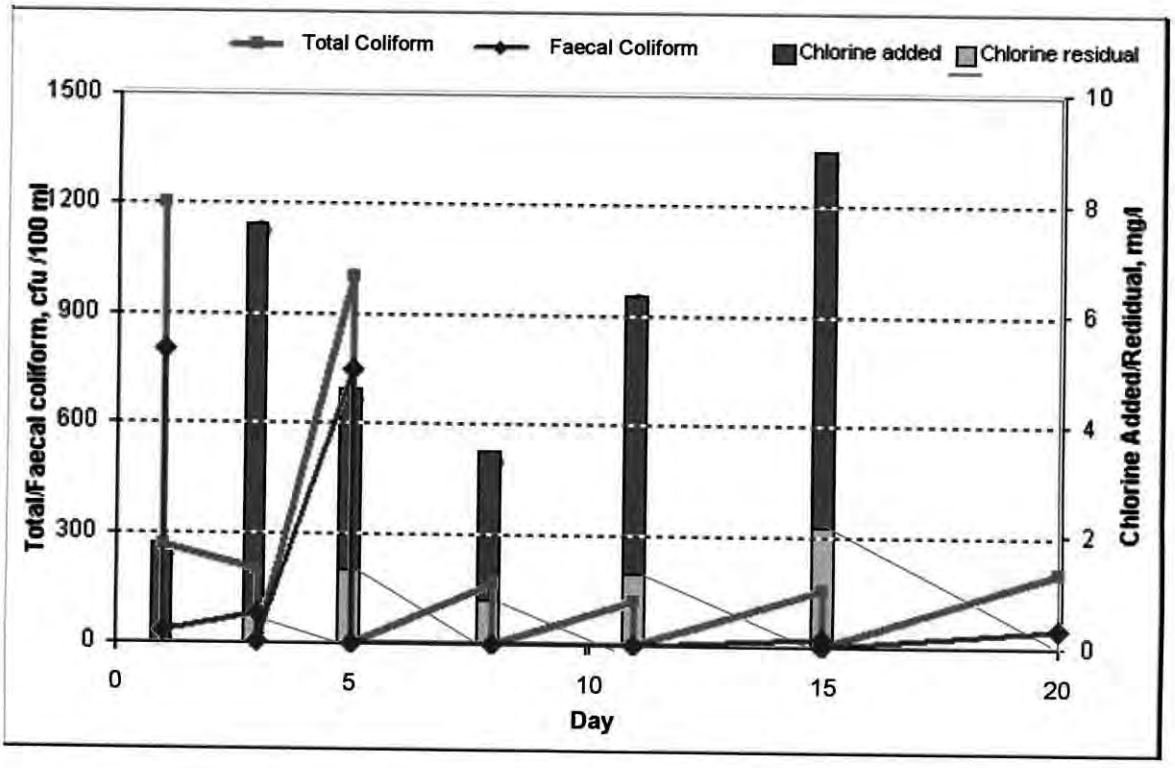


Figure 5.8: TC and FC concentrations with Chlorine dose and residual chlorine in DW 1 (Sirajdikhan)

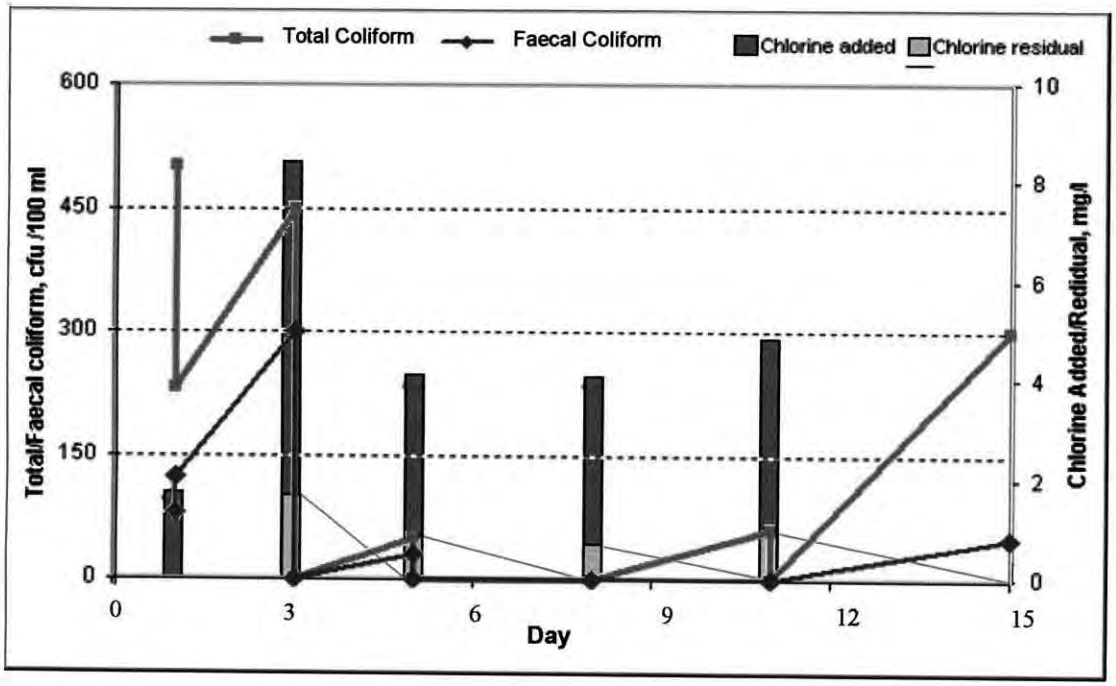


Figure 5.9: TC and FC Concentrations with Chlorine dose and Residual Chlorine in DW2 (Sirajdikhan)

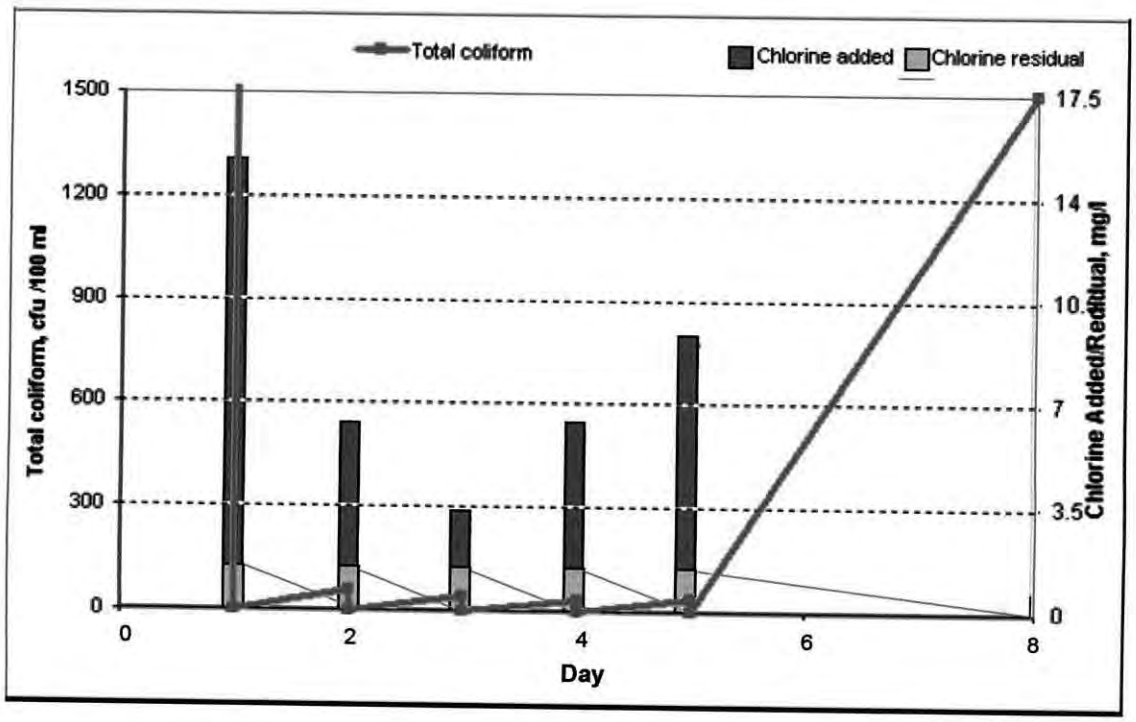


Figure 5.10: TC and FC concentrations with Chlorine dose and Residual chlorine in DW3 (Sharsha)

Figure 5.10 shows the typical phenomenon in the Sharsha DW upon chlorination. The initial count of total coliform, which is not shown here, is 25000 cfu/100 ml and the chlorine dosing has successfully reduced it to zero. Some bacteria reappeared at the end of each day with the reduction of residual chlorine (to near zero) , which disappeared when chlorine is added. But, after 5th day when chlorine dosing is stopped, the concentration jumps up to a concentration as high as 1500 cfu/100 ml in 3 days. The same phenomenon was repeated during almost every episode application of chlorine and for all dug wells. The total coliforms disappear after chlorine application but they reappear when the residual chlorine decreases to concentration not lethal to coliforms. When chlorination was discontinued at the end, the bacterial population shoot up rapidly to reach the initial concentration. The detailed results of chlorination are given in tables A2, A3 and A4 of Appendix A. In two cases of chlorination of DW1, TC values show nil but presence of FC is shown. This might be due to sampling error and external contamination during analysis. This is obvious from several days of chlorine dosing that continuous chlorination is essential for complete destruction of pathogens as bacteriological contamination seems to be caused by seepage of contaminated water from the surrounding area. Therefore, the added dose has to be increased in wet season as new water is mixed with the DW water undergoing disinfection.

5.1.3.2 Arsenic

Arsenic concentration did not decrease after chlorination of dug wells in the field, although it significantly decreased in laboratory. The arsenic state in the dugwells falls in the high oxidizing redox environment after chlorination (Fig. 5.13). This environment is actually favourable for oxidation of arsenic and thus reduction of arsenic from the dugwell water by passive sedimentation. But, the reduction is not observed practically which might be due to the fact that continuous upflow of water inside the well created a dynamic condition (Fig. 5.11) unfavourable for sedimentation of As-Fe microflocs likely to be formed after chlorination. These flocs have a downward settling velocity which is hindered by the upflow velocity of water created due to continuous withdrawal of water through handpump. Pumping of water creates agitation in the well water and the flocs do not get the opportunity to settle at the

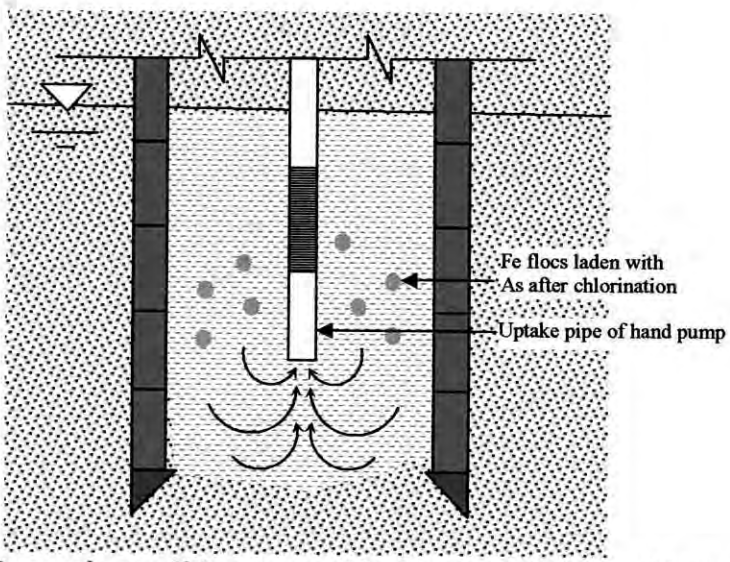


Figure 5.11: Dynamic condition created inside the DW after chlorination

bottom. To achieve sedimentation of flocs, the dug well would better be kept undisturbed for a considerable amount of time just after chlorination.

5.1.3.3 Ammonia

Reduction of ammonia was 56% on an average for DW1, 42% for DW2 and even as low as 6% for DW3. The resulting concentrations of ammonia for the DWs after 4 days were mostly within BDS of 0.5 mg/l except the Sharsha DW which showed unusually larger concentration of ammonia. Reduction of ammonia was also insignificant for DW3. The effect of field chlorination on ammonia concentration of the DW1 and DW2 are shown in figure 5.12a and 5.12b.

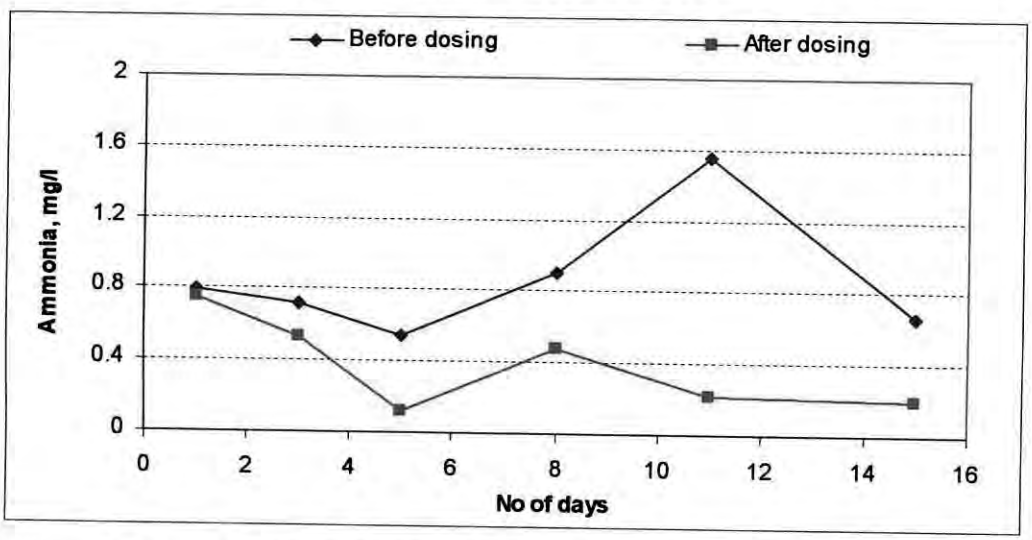


Figure 5.12a: Effect of chlorination on ammonia concentration for DW 1 (Sirajdikhan)

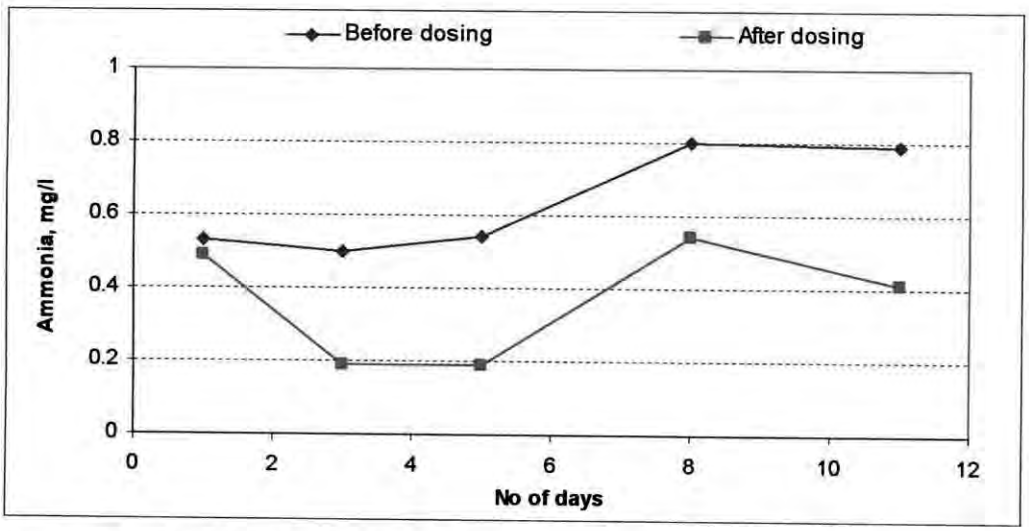


Figure 5.12b: Effect of chlorination on ammonia concentration for DW2 (Sirajdikhan)

5.1.3.4 Iron

Change in iron concentration was remarkable. In stead of expected decreasing trend, the concentration of iron increased most of the times after dosing. This situation is difficult to explain, but internal flow phenomenon might be the reason which happens in the case of arsenic. The application of disinfectant creates a downward settling velocity of iron flocs and there is continuous up flow of water in the dug well due to withdrawal of water by pumping (Fig. 5.11). The settling microflocs of iron and upflow of recharged water at some level inside the well may create increased concentrations of iron similar to sludge blanket in water treatment by sedimentation. When water is collected after chlorine dosing, water from the greater intensity level comes out of the well. Since Arsenic is also adsorbed on iron flocs, some increase in concentration of arsenic with iron was also found after chlorination (Table 5.2).

5.1.3.5 Manganese

Manganese did not reduce significantly upon chlorine dosing. On an average, the reduction was around 19%, 15% and 7% for DW1, DW2 and DW3 respectively. But the important fact is that field chlorination did not decrease the manganese level even close to the BDS standard of 0.1 mg/l. The average manganese concentration after chlorination of dug well was still 4 to 10 times higher than BDS level. The effect of chlorination on manganese concentration is shown in figures 5.13a, 5.13b and 5.13c.

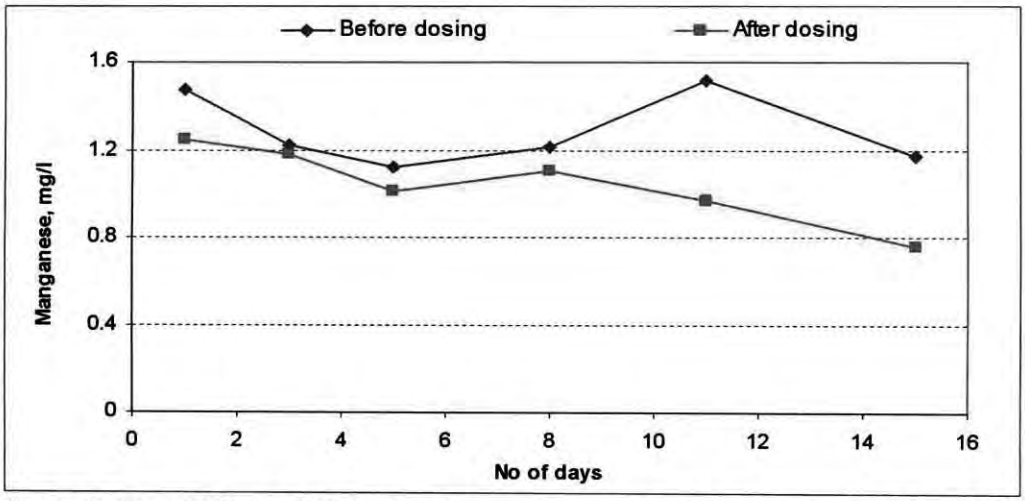


Figure 5.13a: Effect of Chlorination on Manganese Concentration for DW 1 (Sirajdikhan)

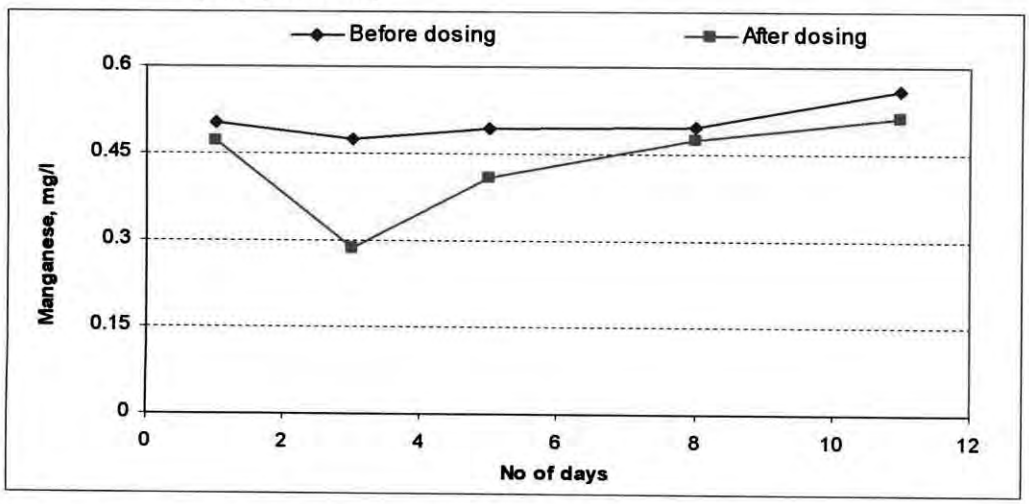


Figure 5.13b: Effect of chlorination on manganese concentration for DW 2 (Sirajdikhan)

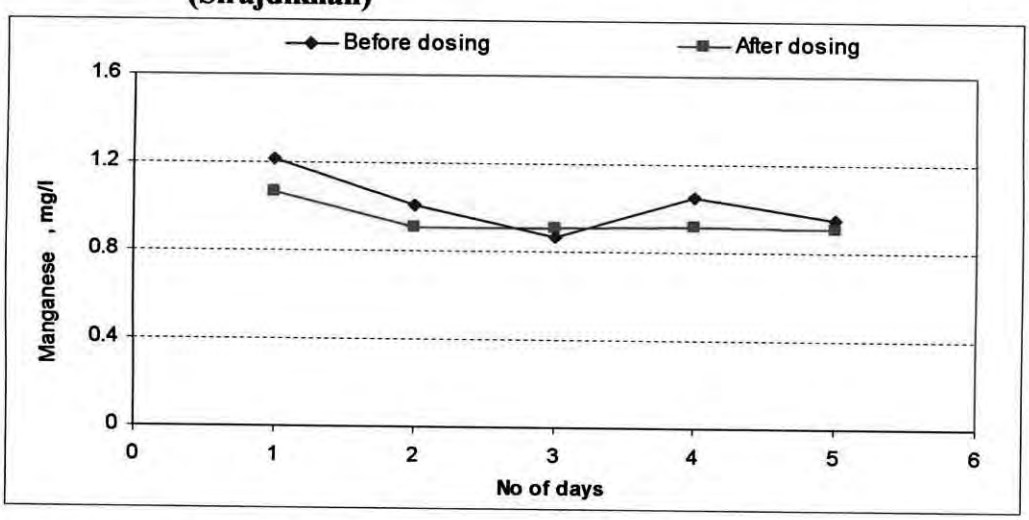


Figure 5.13c: Effect of chlorination on Manganese concentration for DW3 (Sharsha)

5.1.3.6 Turbidity

Turbidity reduced after inadequate chlorination and after allowing the water to settle in stagnant condition for a day. But most of the times, mixing of bleaching powder in larger concentration, in order to get sufficient amount of residual chlorine, turbidity of water increased. In fact, the residual of bleaching powder, on release of chlorine in water becomes lime, which remains suspended in water to cause increased turbidity.

5.1.3.7 Odour

The water of dug wells under investigation was found to have little smell before chlorination, which got lighter after chlorination. When larger dose of chlorine was applied, smell of bleaching powder resulted and the usual smell of the dug well water disappeared.

5.1.3.8 Colour

Colour of dug well water reduced always after chlorination. The range of reduction was 33% to 90%. During rains, initial colour concentration of 96 PtCo was reduced to 4 PtCo after chlorination. Chlorine rapidly reacts with organic extracts that cause true colour.

5.1.3.9 Oxidation Reduction Potential

ORP was measured before and after chlorination for each of the dug wells and drastic change in Eh value was observed. All three dug wells had negative Eh values prior to chlorine dosing and, the values increased to very high positive values after dosing. Figure 5.14 shows the plot of ORP values before and after chlorination on Eh-pH diagram of arsenic.

Figure 4.26 shows that Eh values of all the samples of DWs fall within the insoluble arsenate range after chlorination. Thus, frequent chlorination might result in reduction of arsenic values in dug wells. Similar result is observed when Eh values are plotted on iron phase solubility diagram in Fig. 5.15. The water environment changed to oxidizing in nature.

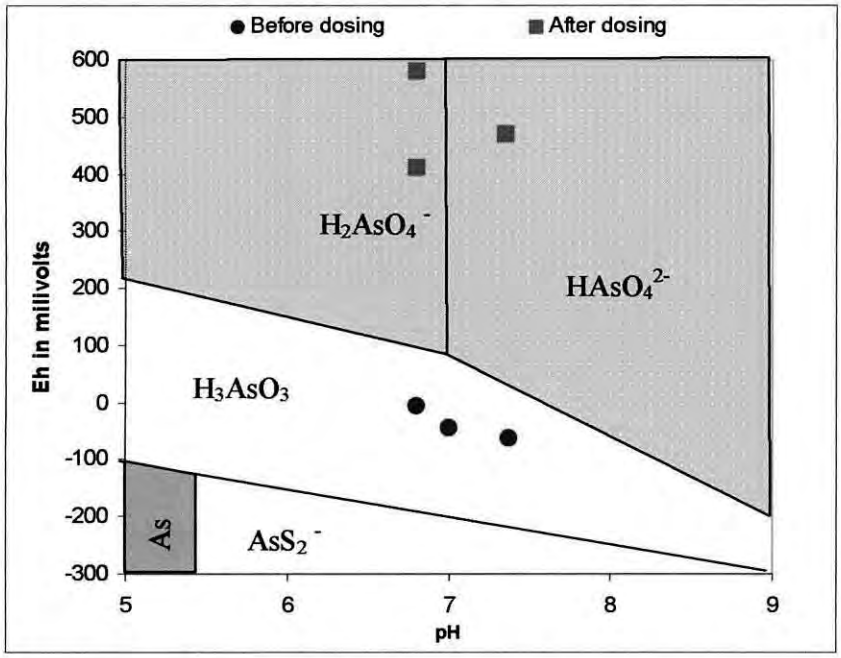


Figure 5.14: ORP values before and after chlorination on arsenic Phase Solubility Diagram (at 25°C and 1 atmospheric pressure with total arsenic 10^{-5} M and total sulphur 10^{-3} M)

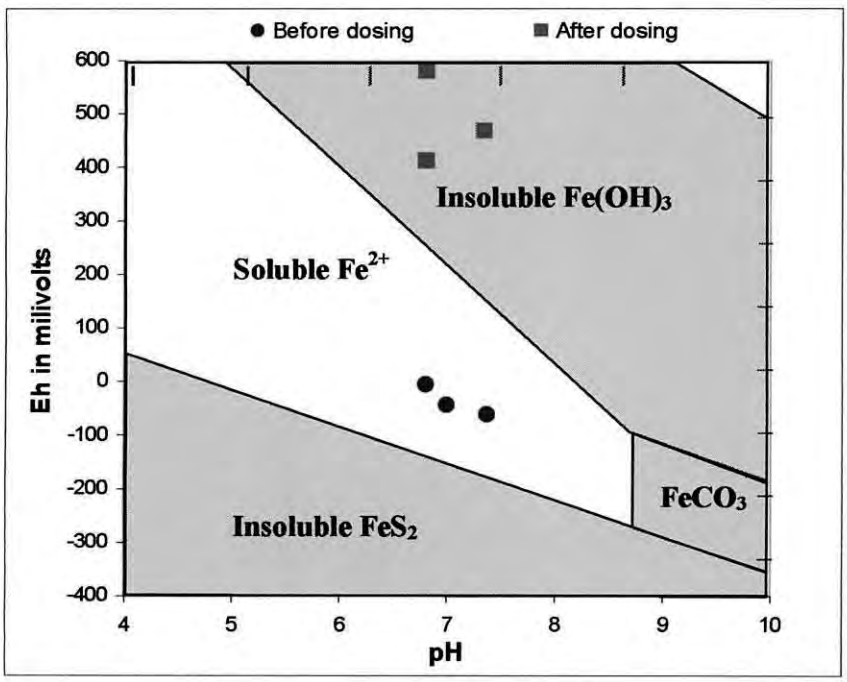


Figure 5.15: ORP values before and after Chlorination on Iron Phase Solubility Diagram

Figs. 5.14 and 5.15 show that both iron and arsenic species are likely to be oxidized which creates an environment for removal of those. Batch treatment of waters from

each dug well in the laboratory exhibited excellent removal of iron and arsenic. But in the operating dug wells as stated earlier, the concentrations of both iron and arsenic increased. The flow phenomenon in the dug wells might have resulted in increased concentration of both iron and arsenic. Further in-depth investigation is needed to give a satisfactory explanation to this interesting observation.

5.1.3.10 Findings of Chlorination of Dug Well

The major findings of in-situ chlorination of dug wells are summarized below:

- The chlorine required for disinfection of dug well is several times higher than the chlorine required for BP chlorination of dug well water. Chlorine requirement is reduced in the subsequent application, but it increased after rain fall. The excess chlorine is required for oxidation of readily oxidizable substance in the well.
- Residual chlorine in the range between 0.5 to 1 mg/L can destroy all coliforms, but chlorine level quickly decreases with the inflow of new groundwater in the dug well and render the well vulnerable to renewed contamination. As a result, intermittent chlorination cannot guarantee complete safety of water.
- A method of continuous chlorination, with dose adjusted to water withdrawal, is needed to maintain desired level of residual chlorine for destruction of coliforms and make the dug well water completely safe for drinking purpose.
- Chlorination elevates ORP of dug well water and makes it favourable for oxidizing of arsenic, iron, manganese etc., but no reduction of these mineral was achieved because of dynamic nature of water in the dug well.

5.2 AVAILABILITY OF WATER

Pumping out of water from dug wells results in lowering of water level in the wells, and the wells get refilled after a reasonable period of time. The rate of inflow in a dug well is dependent on the head difference between inside and outside of the well and permeability of aquifer in which the dug well has been constructed. AAN dried up old water of 51 Dug wells in Sharsha upazila for re-commissioning the well and

recorded the volume of water accumulated in the dug wells after a definite interval of time. These data were analyzed to estimate the quantity of water available in 24 hours for supply to the consumers. From the change in water level of these dug wells, volumes of water likely to be produced by the dug wells in 24 hours have been calculated using the equation developed in Section 2.2.4. The availability of water was calculated for wet period and also for the dry period assuming two water depths of 1 m and 1.5 m during dry period as recommended in the Implementation of Plan for Arsenic Mitigation in Bangladesh (GOB, 2004). Computation of the quantities of water production in 24 hours is shown in Tables A6 and A7 of Appendix-A and results are presented in Figure 5.16.

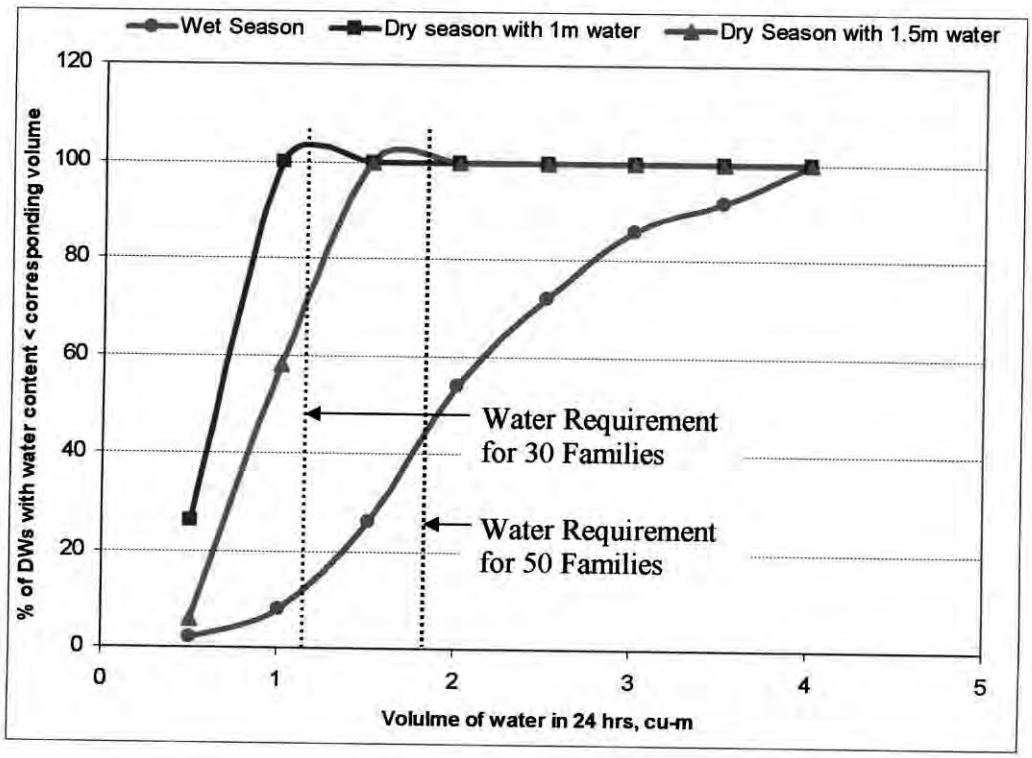


Figure 5.16: Water content of DWs after 24 hours of recharge period (Sharsha)

On an average, 2.09 m^3/day of water can be produced in wells in the wet season and in dry season the volumes of water available are 0.58 m^3/day for 1 m of water depth and 0.87 m^3/day for 1.5 m of water depth in the wells. The average rate of dug well filling is 0.08 m per hour. On an average a dug well can supply water to 15 families in dry season and 55 families in wet season at a rate of 7.5 L per person per day or

37.5 L per family per day. However, the actual requirement of water for all domestic purposes in the rural context is 50 L per capita per day (Ahmed and Rahman, 2004)

According to Implementation Plan for Arsenic Mitigation (GOB, 2004), a source shall be provided for drinking and cooking water (7.5 lpcd) for 50 families under emergency program and 30 families under mid-term program. A dug well to meet this requirement will have to produce 1.875 m^3/day of water for emergency program and 1.125 m^3/day of water under mid-term program. It may be observed that about 42% wells in wet season cannot meet this requirement and no well can meet this emergency requirement in dry season. While 12 % wells in wet season and 72% wells in dry season with 1.5m water depth and 100% wells in dry season with 1 m depth fail to meet the requirement of mid-term program. It appears from this study that availability of water in the dry season is a big problem in dug well based water supply.

5.3 HEALTH RISK

Health risk of dug well based water supply has been assessed using the model developed under RAAMO-1 (APSU, 2004). The model estimates risk associated with the presence of Thermotolerant/faecal coliform and arsenic in drinking water. The estimated health risks of water of 2 dug wells before chlorination, wells after chlorination and wells with average water quality during the period of intermittent chlorination are presented in Table 5.3. The faecal coliform of DW3 situated in Shasha Upazila could not be transported and analyzed in the laboratory within reasonable time. Total Coliforms of this dug well was analyzed in the AAN Laboratory in Jessore.

Table 5.3: Estimated Health Risk of Dug Well Water before and after Chlorination

Dug Wells	Health Risk in DALYs		
	Before Chlorination	1 hour after Chlorination	Before subsequent Chlorination (after 2 days)
DW1	757	9.87	330
DW2	374	9.71	231

It has been observed that health risk can be tremendously reduced by chlorination of dug well water. In case of intermittent chlorination, health benefit reduces with the reappearance of faecal coliform when the residual chlorine decreases to zero. The benefit can be sustained if a method of continuous chlorination according to requirements can be devised. In-situ chlorination of dug well is generally discouraged for its undesirable by product some of which are carcinogenic. The two DWs of Sirajdikhan had low concentration of organic carbon and formation of trihalo methanes or DBPs upon chlorination were also in small amounts. However, WHO (2004) states that the risks to health from disinfection by-products (DBPs) are small in comparison to risks associated with inadequate disinfection and it is important that disinfection not be compromised in attempting to control such by-products.

5.4 ACCEPTABILITY OF THE USERS

People are generally reluctant to consider unusual interventions in their daily practice and altering of habits having maintained for a long period of time. But, arsenic problem in Bangladesh has rendered people helpless about their existing practice of drinking water from tube wells which have been marked red for having elevated levels of arsenic. In fact, it had taken many years to motivate people to drink tube well water and 97% coverage in this respect had been achieved before the problem of arsenic got focused upon. Now, alternative options of drinking water are being supplied to the rural people to get access to safe water and people are also aware about arsenic problem these days which makes them eager to switch on to a new option to protect them.

Dug well water containing microbial contamination needs to be disinfected while being taken by the users. The acceptability of disinfected water of dug well by the users in not known. Because application of disinfectant incorporates different taste and smell to the dug well water other than those found naturally in the water of dug wells. Thus it is required to be known whether the disinfected water would be consumed by the previous users of the dug well or not. A questionnaire survey was

conducted in the command area of Sirajdikhan among the users (20 families) of the two dug wells under study which were disinfected by chlorine.

Only 30% of the users have been drinking the water of dug wells for more than 1 year and 10% for less than 6 months. The rest and the major portion of the people have been drinking dug well water for 6 months to one year. But DCH has installed the dug wells in the year 2003, which means that both the dug wells are in operation since one and a half year to two years. This suggests that some people in the community did not use the dug well water for a long time since its installation. Furthermore, dugwell water is still not universally accepted for drinking purpose may be due to smell and taste.

However, during problem identification, none of the users consuming dug well water mentioned it to be the cause of any kind of disease and most of them ranked the dug well water as acceptable in respect of smell, taste and odour. It appeared that motivation during installation of dug well was very effective in making dug well acceptable to the people where other safe options are not available. Only 10% of the users termed the dug well water as unsatisfactory and the rest 90% termed it as good. The satisfaction level varied according to Figure 5.17. The 50% of the users, not highly satisfied, specified bad smell as the problem of water.

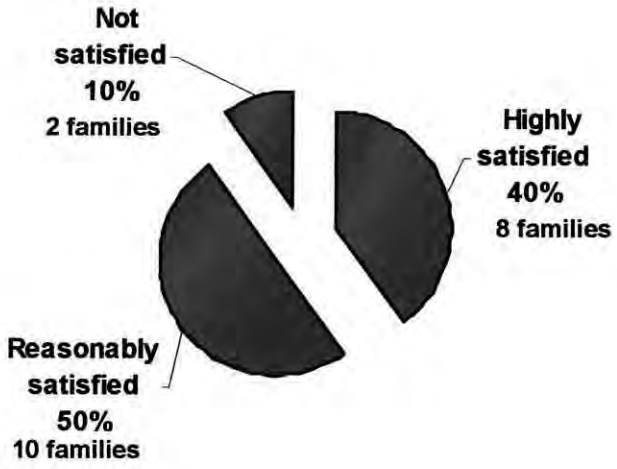


Figure 5.17: User satisfaction about dug well water at Sirajdikhan

The usage of the well water as shown in Fig. 5.18 reveals that uses of dug well water are limited to drinking and cooking. About 85% users use dug well water for drinking and cooking purpose and none use it for bathing as they use nearby ponds for that purpose. As all of the users consume dug well water via drinking and cooking, the microbial contamination is of prime importance.

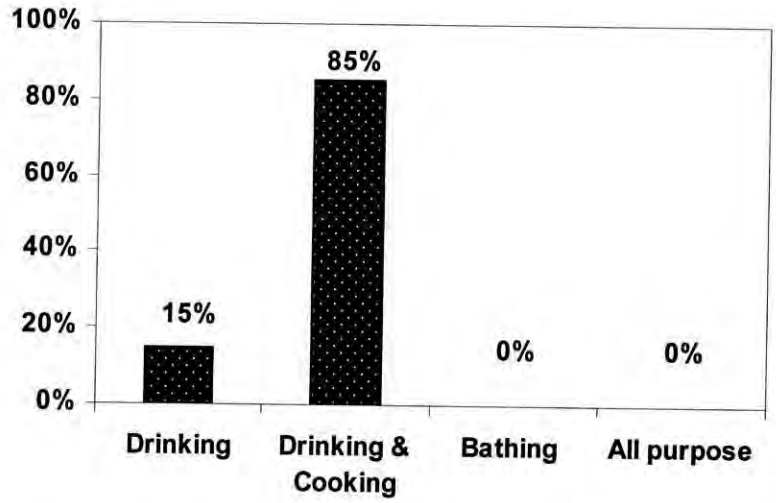


Figure 5.18: Usage of Dug well water at Sirajdikhan

Only 10% of the respondents did not like the dug well water disinfected by adding bleaching powder solution. One of them objected to the bad smell and the other complained that the water did not seem attractive to drink. But both of these respondents were willing to drink the water from the same dug well when they knew that disinfected water by chlorine would better protect their health. Actually, perception of the users about a given intervention is a very important factor in establishing a technology. Figure 5.19 gives the distribution of willingness to use the dug well water for different purposes.

Most of the people at Sirajdikhan were reluctant to use the dug well water for washing their utensils because of smell produced through application of bleaching powder. Other than this, people using the DWs at Sirajdikhan under study were willing to use dug well water disinfected by chlorine where other safe water options were unavailable.

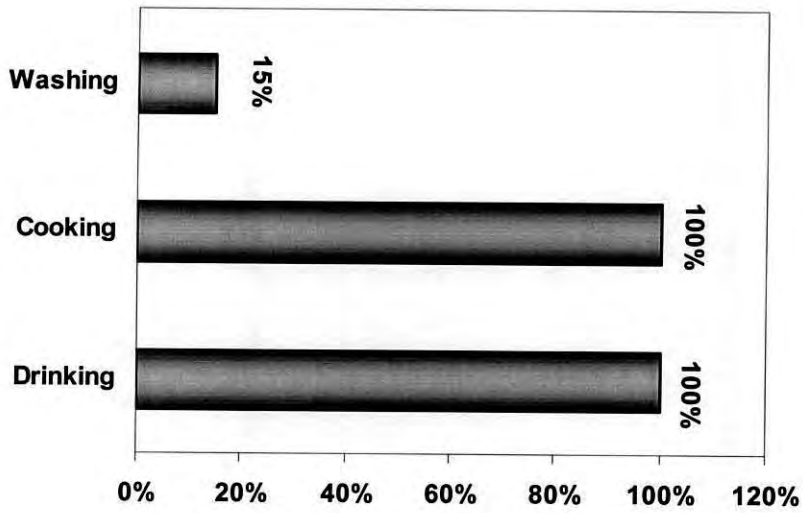


Figure 5.19: Willingness to Use the Dug Well Water for Different Purposes At Sirajdikhan

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Microbial contamination of dug well water is very high and needs effective interventions to improve the quality of water to acceptable level. Disinfection by chlorination seemed effective in laboratory in terms of reduction of coliform, arsenic, iron, manganese and ammonia. But in situ disinfection produced alarming results upon chlorination. Microbial contamination reduced by chlorination, but arsenic and iron concentration increased making the disinfection a futile exercise. Although, the oxidizing condition prevails in the DW, following chlorination, the As and Fe concentration increased in the collected samples which is contradictory to the theory. However, this might have happened as the Fe flocs formed due to oxidized condition settling downward being pumped directly through the uptake pipe and thus, increasing the Fe and As level in the samples. This dynamic flow condition might have caused the effects opposite to those found in theory as well as in the laboratory. The presence of other health related water quality parameters like arsenic and manganese is comparatively low. However, these can be significantly high depending on the location and rate of withdraw of water from the dug well. The proportion of dug wells is also high with high iron, TDS, turbidity, colour and odour. These parameters greatly affect aesthetic quality and adversely influence acceptability of water. High iron, manganese, TDS, colour, turbidity, ammonia and bad smell are all characteristic qualities of shallow ground water. The quality of dug well water is, therefore, far from well aerated surface water and more inclined toward quality of shallow groundwater that feed the dug well.

The environment of dug well water, like other sources of water, is not favourable for survival of coliform bacteria. The net decay of coliform bacteria in dug well water has been confirmed by incubation in a comparative environment in the laboratory and rate of decay has been found to be significantly high. It can be inferred from the

results that there is a fresh and continuous input of microorganism in the dug well and the level of microbial contamination is regulated by the rate of inflow and decay of microorganism in dug well. Prevention of inflow of microorganism or in-situ destruction can improve the microbial quality of dug well water.

The presence of iron, manganese, arsenic and odour in dug well water is due to the fact that aeration of open dug well is not adequate in improving these water quality parameters. The negative or very low Eh and low dissolved oxygen of dug well water are not favourable for oxidation of iron, arsenic and odour producing substances. Small retention time due to high withdrawal of water and poor aeration due to smaller diameters of improved dug wells may be the cause for insignificant difference between dug well water and ground water at the similar depth. Hence, the degree of improvement in respect of dissolved minerals, observed in dug well water compared to shallow tubewell water at the same location, is due to dilution of water of the upper layer of aquifer by fresh recharges from surface and rainwater of low mineral content. There is hardly any difference between the quality of open and closed dug well and the efforts made for keeping the improved dug well open seem futile.

Recharge capacity of most of the dug wells is not satisfactory. The average recovery rate per day was found 74% of the static water level of the dugwells and the static level of water was not that high in most of the dug wells. The improved dugwells produce an average of 2.09 m^3/day of water in the wet season and 0.58 m^3/day of water in the dry season, which can supply only drinking and cooking water to 55 and 15 households in the wet and dry seasons, respectively. An improved dug well, as a water point, is unable to supply adequate water to meet the requirements of emergency and mid-term programs in the dry season as envisaged in the Implementation Plan for Arsenic Mitigation in Bangladesh. The retention time of water in all dug well is less than a day due to low productivity of the wells.

The in-situ chlorine requirement to raise the residual chlorine level above break point is several time higher than the chlorine required for breakpoint chlorination of dug

well water in the laboratory. This indicates the presence of significant amount of chlorine consuming substances within dug wells. However, the requirements of excess chlorine gradually reduce in subsequent chlorine dosing of the dug well water. Chlorine requirement significantly increases after the rainfall in the area. This is due to sudden increase in the inflow of chlorine consuming substances and volume of water in the dug well.

Residual chlorine in the range between 0.5 to 1 mg/L can destroy all coliforms. However, the chlorine level quickly decreases with the inflow of new groundwater in the dug well and render the well vulnerable to renewed contamination. As a result, coliform bacteria reappears, but in reduced number, if chlorine dosing is stopped for one or two days. Intermittent chlorination, therefore, cannot guarantee safe water. A method of continuous chlorination with dose adjusted to water withdrawal is needed to maintain desired level of residual chlorine for destruction of coliforms.

Chlorine dosing increases ORP of dug well water from soluble reducing fields to highly oxidizing insoluble fields in Eh-pH phase-stability diagrams of both iron and arsenic. A significant reduction of iron, arsenic, manganese and ammonia as expected was found in chlorinated dug well water in the laboratory. However, no reduction of these important constituents of water except ammonia was observed in the field (dugwells). It appeared that precipitates of iron and manganese settled well with adsorption of oxidized arsenic in stagnant chlorinated dug well water in the laboratory, but a continuous uptake of ground water from the aquifer by pumping prevented sedimentation of microflocs in dug well water. However, the possibility of oxidation was significantly retarded due to reduction of residual chlorine with time. The reduction of ammonia in dug well was due to direct reaction with chlorine in dug well.

Chlorination can effectively improve microbial quality and can significantly reduce health risk associated with ingestion of dug well water. Intermittent chlorination is unable to sustain this health benefit due to reappearance of microbial population with reduction of residual chlorine.

In spite of some aesthetic water quality problem, dug well water appears to be acceptable to most of the rural population where other safe water options are not available. Motivation during installation of dug well was very effective in making dug well acceptable to the people. People use dug well water for drinking and cooking only. Microbial water quality is not a visible problem and as such does not affect acceptability until the possible health effects like arsenic are communicated. Most of the people in the study area (Sirajdikhan) had no complain about drinking chlorinated water at the levels of 0.5 – 1.0 mg/l of residual chlorine in water. Few respondents were not willing to drink chlorinated water for smell of chlorine in water. But they also agreed to drink chlorinated water when they were made aware of the possible health benefits of microbial contamination free drinking water.

6.2 RECOMMENDATIONS FOR FURTHER STUDY

The study was conducted over a short duration in selected areas of Bangladesh. Quality of dug well water has been found to vary from region to region. The study of this nature is required to be conducted with statistically representative samples of dug wells from areas representing all hydrogeological regions of Bangladesh.

In this study, it was not possible to maintain the residual chlorine in dug well at desirable level during the interval between chorine dosing. The free chlorine soon started disappearing after dosing due to continuous recharge of ground water in the dug well having high chlorine demand as the levels of water abstraction from the wells were high. As a result, the coliform bacteria reappeared with the reduction and complete depletion of free available chlorine in the dug well. This study should be continued with the development of a system of continuous chlorination of dug well with dose adjusted to water withdrawal from the well to understand the technical feasibility of well sanitation by chlorination.

Intermittent dosing of chlorine even at an interval of once a day has been found to be ineffective in maintaining the coliform to desired level of zero. Pot chlorination has been recommended in many literatures for continuous release of chorine in dug well

water. The effectiveness of pot chlorination as a mechanism for continuous dosing of chlorine in dug well water should be explored.

Oxidation of iron and arsenic by chlorine should improve water quality and excellent reductions of iron and arsenic were observed in chlorinated dug well water in the laboratory. But chlorination has not been found effective in reducing iron and arsenic in dugwell, rather an increase in both iron and arsenic in chlorinated dug wells was noted. The reasons for such interesting behaviour need in-depth investigation. And study should be carried out taking samples from the top water level of DW by bucket after chlorination without pumping the water to see whether pumping created the dynamic condition inside the well thus disrupting the settling of As-Fe microflocs. Another practice should be carried out by keeping the DW water undisturbed after chlorination for a long period of time to let the sedimentation take place. Collection of water from DW and chlorination at home might also be recommended.

There might be DWs in many other areas with high concentration of total organic carbon (TOC). Disinfection by products like Tri Halo Methanes would be a problem for these DWs upon chlorination. Assessment of the level of formation of these harmful products should be carried out to lower the health risk associated.

There are other chemicals like potassium permanganate (K_2MnO_4) which have been used for oxidation and disinfection of water in Bangladesh. Effectiveness of potassium permanganate in oxidation and disinfection of dug well water may be evaluated.

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APPENDIX-A

Table A1: Water Quality results for the Dugwells

DW	Upazila	Union	Village	pH	Turbidity	Alkalinity	Hardness	Conductivity	TDS	ORP	DO	TC	FC	E.coli	As	Fe	NH3-N	NO3-N	NO2-N	PO4	Mn	Color
-	-	-	-	-	*NTU*	*as CaCO3*	*as CaCO3*	*us/cm*	*mg/l*	*mv*	*mg/l*	*no/100ml*	*no/100ml*	*no/100ml*	*ppb*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*PtCo*
DW-1	Sirajdikhan	Rashunia	Daniapara	7.84	11.2	184	212	798	1684	-17	0.86	500	8	0	1.73	1	0.15	0.3	0.008	0.39	0.55	-
DW-2	Sirajdikhan	Isapura	Purboshialdi	7.03	61.4	284	392	1011	2133	-62	1.05	950	8	0	7.04	7	1.29	0.2	0.01	0.46	1.44	-
DW-3	Sirajdikhan	Isapura	Purboshialdi	7.19	11.8	265	282	908	594	-44	1.27	1540	860	40	<1	1	0.58	0.1	0.014	0.24	1.47	395
DW-4	Sirajdikhan	Rashunia	Abirpara	7.44	17.7	194	176	431	282	-7	1.65	1200	80	160	1.38	1.4	0.38	0.1	0.008	0.67	0.5	57
DW-5	Sirajdikhan	Rashunia	Abirpara	7.52	22.1	135	128	730	1540	-66	2.05	1000	8	0	4.29	1.9	0.38	0.2	0.012	0.74	1.45	-
DW-6	Manikgonj	Singair	Chargram	7.19	5	20	156	698	320	-40	0	1050	0	-	6.66	0.2	0.129	0.1	-	0.72	0.12	14
DW-7	Manikgonj	Singair	Chargram	6.87	10.4	41	238	889	413	35	0	400	20	-	9.46	1	1.82	0.1	-	1.1	0.63	4
DW-8	Manikgonj	Singair	Madhya Chargram	6.94	2.6	30	616	1560	738	48	0	1250	80	-	<1	0.1	0.227	0.6	-	1.21	0.58	5
DW-9	Manikgonj	Singair	Chargram	6.91	29	22.5	216	702	324	-65	0	1100	600	-	3.3	4	1.822	0.1	-	0.85	1.28	13
DW-10	Manikgonj	Singair	Uttar Chargram	6.88	4	45.5	488	2050	978	36	0	800	400	-	<1	0.07	0.29	0.4	-	2.55	0.43	22
DW-11	Manikgonj	Singair	Azimpur	6.86	78	28.5	346	1042	483	-77	0	60	0	-	13.87	9	0.448	0.2	-	0.31	1.93	25
DW-12	Daudkandi	Uttar Elliotganj	Kusiara	6.89	86	409	304	992	458	-95	0.55	1800	1000	-	38.79	10	1.42	0.1	-	0.217	0.68	71
DW-13	Daudkandi	Uttar Elliotganj	Khoshkandi	6.93	9.5	606	812	2920	1409	-23	1.08	1500	1000	-	14.22	0.8	2.36	0.3	-	1.393	0.42	34
DW-14	Daudkandi	Purba Gauripur	Dhitpur	7.24	4.9	230	210	585	268	85	1.89	1600	400	-	7.24	0.1	0.29	2.4	-	0.311	0.01	21
DW-15	Daudkandi	Purba Gauripur	Jinglatoli	6.77	16.5	346	230	891	409	-10	0.95	1200	900	-	7.12	1.4	0.5	0.9	-	0.171	1.55	28
DW-16	Sharsha	-	Dhantara	7.38	35	-	322	932	436	-88	1.76	-	-	-	140	6.04	1.55	3.4	-	2.72	1.5	-
DW-17	Sharsha	-	Shibnathpur	6.85	33	-	324	1010	465	-83	1.88	-	-	-	122	1.52	2.75	1.6	-	3.63	1.6	11
DW-18	Sharsha	-	Shibnathpur	6.63	42	-	396	855	395	-102	1.25	-	-	-	19	5.4	1.95	3.1	-	1.56	1.4	-
DW-19	Sharsha	-	Kadamtala	6.47	17	--	332	1305	604	-54	1.27	-	-	-	32	0.96	0.87	1.1	-	0.42	0.9	-
DW-20	Sharsha	-	Kadamtala	6.97	42	-	388	1459	671	52	2.87	-	-	-	21	0.35	0.83	2.1	-	1.03	0.8	-

Table A2: Results of Chlorination on arsenic contaminated Dugwell-1 in Sirajdikhan

Date	Status	BP dose	Chlorine added	Rsidual Chlorine	Temp	pH	DO	Conductivity	ORP	Turbidity	TS	TDS	NH3-N	NO3-N	Mn	Fe	Color	TC	FC	REMARKS
-	-	*Liter*	*mg/l*	*mg/l*	°C		*mg/l*	*uS/cm*	*mV*	*NTU*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*Pt Co*	No/ 100 ml	No/ 100 ml	
17.06.05	Before dosing	-	-	0	27.8	6.89	-	908	-	25.1	594	594	0.79	0.1	1.47	1.7	-	1200	800	For 8' WL
	After dosing	3.5	1.53	0.05		6.86	-	903	-	13.3	608	595	0.75	0.1	1.25	4.8	-	263	143	1600L Vol of Water
19.06.05	Before dosing	-	-	0	27.6	-	0.7	826	-	11.4	-	-	0.717	0.1	1.22	5	6	200	80	-
	After dosing	17	7.44	0.5		-	0.8	826	-	23	-	-	0.528	0.1	1.18	4	4	0	5*	-
21.06.05	Before dosing	-	-	0	-	-	-	-	-	7.26	-	-	0.54	-	1.12	1.2	-	1000	750	-
	After dosing	10	4.38	1.2	-	-	-	-	-	16.3	-	-	0.12	-	1.01	4	-	0	2*	-
24.06.05	Before dosing	-	-	0	-	-	-	-	-	16.9	-	-	0.9	-	1.21	4	-	160	0	-
	After dosing	7.5	3.28	0.7	-	-	-	-	-	11.1	-	-	0.48	-	1.1	2.8	-	0	0	-
27.06.05	Before dosing	-	-	0	26.7	7	1.3	-	-44	-	-	-	1.55	-	1.52	4.6	96	120	0	Rained and WL
	After dosing	15	6.18	1.5		6.8	1.8	-	598	-	-	-	0.22	-	0.97	7.2	4	0	0	rose 6"
1.07.05	Before dosing	-	-	0	26.2	-	0.4	637	-70	62	-	-	0.662	-	1.17	8.4	19	150	20	Rained and WL
	After dosing	25	8.75	2.2		-	0.9	682	557	42	-	-	0.192	-	0.76	18	5	0	0	Rose 2'

* Sampling error might have resulted in presence of FC though TC count shows nil

N.B: Bleaching powder contains 70% free chlorine.

Table A3: Results of Chlorination on arsenic contaminated Dugwell-2 in Sirajdikhan

Date	Status	BP dose	Chlorine added	Rsidual Chlorine	Temp	pH	DO	Conductivity	ORP	Turbidity	TS	TDS	NH3-N	NO3-N	Mn	Fe	Color	TC	FC	REMARKS
-	-	-	*mg/l*	*mg/l*	°C		*mg/l*	*uS/cm*	*mV*	*NTU*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*Pt Co*	No/ 100 ml	No/ 100 ml	-
17.06.05	Before dosing	-	-	0	26.9	6.89	-	431	-	6.63	282	261	0.53	0.1	0.503	1	-	500	80	For 5' WL
	After dosing	3.0 liter	1.54	0.04		6.85	-	429	-	6.03	282	276	0.49	0.1	0.47	3.2	-	147	49	1365L Vol of Water
19.06.05	Before dosing	-	-	0	26.4	-	0.5	444	-	3.1	-	-	0.498	0.2	0.474	5.5	10	500	300	-
	After dosing	16 liter	8.21	1.5		-	0.71	429	-	17.7	-	-	0.19	0.2	0.286	3.8	1	0	0	-
21.06.05	Before dosing	-	-	0	-	-	-	-	-	21.6	-	-	0.54	-	0.493	1.3	-	50	30	-
	After dosing	7.5 liter	3.85	0.7	-	-	-	-	-	18.8	-	-	0.19	-	0.408	3	-	0	0	-
24.06.05	Before dosing	-	-	0	-	-	-	-	-	10.2	-	-	0.8	-	0.497	2.4	-	0	0	-
	After dosing	7.5 liter	3.85	0.5	-	-	-	-	-	16.9	-	-	0.54	-	0.473	3	-	0	0	-
27.06.05	Before dosing	-	-	0	25.6	6.8	1.65	-	-7	-	-	-	0.79	-	0.558	2	45	60	0	Rained and WL
	After dosing	10 liter	4.67	0.8		6.8	2.77	-	412	-	-	-	0.41	-	0.512	2.8	5	0	0	rose 6"

N.B: Bleaching powder contains 70% free chlorine.

Table A4: Results of Chlorination on arsenic contaminated Dugwell in Sharsha

Date of Analysis	Sampling Time	Dosing	Applied Bleaching	Applied Chlorine	pH	Conductivity (µS/cm)	TDS (mg/l)	Temperature (Centegrate)		Turbidity (NTU)	DO (mg/l)	ORP (mV)	PO^{3-}_4 (mg/l)	NO^{-}_3 (mg/l)	NH^{+}_4 (mg/l)	Total Hardness (mg/l)	Free Chlorine (mg/l)	Mn (mg/l)	Fe (mg/l)	As (mg/l)	Total Coliform (cfu/100ml)
				mg/l				Water	Air												
6-Jul-05	10:50	Before	0	0	7.37	947	436	29.3	31.0	41	0.20	-62	1.73	1.6	3.18	340	0	1.219	4.380	0.132	$2.5X10^4$
	13:40	After	70g/1.4M^3	15	7.35	1020	458	29.4	31.0	78	0.61	469	-	-	2.16	418	1	1.065	6.530	0.159	0
7-Jul-05	11:00	Before	0	0	7.20	993	457	28.0	31.0	33	0.41	3	-	-	2.24	428	0.2	1.009	3.175	0.079	60
	13:45	After	26g/1.3M^3	6	7.30	1004	464	28.0	31.0	68	0.41	385	-	-	2.77	418	1	0.907	5.965	0.139	0
8-Jul-05	11:30	Before	0	0	6.93	1007	460	28.6	31.0	26	0.41	-49	-	-	2.69	448	0	0.867	3.185	0.088	42
	13:00	After	13.5g/1.35M^3	3	7.07	1022	465	28.7	31.0	40	0.41	106	-	-	2.62	436	1	0.909	5.310	0.129	0
9-Jul-05	11:30	Before	0	0	7.15	1012	464	27.6	32.0	18	0.20	-68	-	-	3.33	428	0.05	1.050	3.810	0.129	30
	14:00	After	28g/1.4M^3	6	7.20	1007	465	27.7	32.0	36	0.20	233	-	-	3.12	416	1	0.915	5.605	0.147	0
10-Jul-05	11:00	Before	0	0	7.07	1005	468	27.7	31.5	26	0.20	-78	-	-	3.47	448	0.05	0.947	4.595	0.130	35
	13:10	After	33g/1.1M^3	9	7.39	1019	473	27.7	31.5	61	0.41	220	-	-	3.34	418	1	0.907	7.805	0.189	0
13-Jul-05	11:30	Not added	0g/1.5M^3	0	8.37	967	449	27.5	28.0	67	0.12	-40	-	-	3.06	408	0	0.993	3.790	0.106	$1.5X10^3$
17-Jul-05	12:15	Not added	0g/1.8M^3	0	7.94	1044	477	28.6	33	56	0.12	-99	2.16	2.7	4.12	436	0	1.108	6.950	0.186	$5.0X10^3$

N.B: Bleaching powder contains 30% free chlorine.

Table A5: Water Quality results before and after laboratory chlorination

DW	Dosing	Turbidity	Color	pH	Conductivity	TDS	As	Mn	NH3-N	Fe
		NTU	*PtCo*	-	*us/cm*	*mg/l*	*ppb*	*mg/l*	*mg/l*	*mg/l*
DW-1	Before	47	395	6.8	1162	532	6.05	1.48	1.45	8
	After	1.51	25	7.46	1163	542	0	0.978	0.94	0.4
DW-2	Before	14.5	57	6.77	616	289	5.55	0.69	0.69	2.9
	After	1.23	4	8.1	471	218	0.72	0.67	0.55	1.6
DW-3	Before	26	11	7.09	1022	465	129	0.95	1.538	5.5
	After	0.62	12	7.81	591	273	21.13	0.75	1.25	0.07

Table A6: Recharge of DWs after pumping in Sharsha (Wet season)

DW No	Pump Operation		Pump period	Water level (m) first day				Water level 2nd day			K Value	WL height for 24 hr duration	Water depth	Water content
	Start	End		Bottom	SW. Level	APW level	APW-SWL	Water level	WL-SWL	duration				
	Time	Time	Minutes	m	m	m	m	m	m	Hours		m	m	Cu-m
1	12:30	12:58	28	8.9	3.85	8.85	5	5.92	2.07	20.33	0.04	1.77	3.23	2.54
2	12:07	12:22	15	6.7	3.85	6.55	2.7	5.27	1.42	21.22	0.03	1.31	1.39	1.09
3	10:40	11:05	25	8.7	4.05	8.4	4.35	5.94	1.89	22.83	0.04	1.81	2.54	1.99
4	9:25	10:05	40	8.6	4.2	7.6	3.4	5.19	0.99	24.17	0.05	1.00	2.40	1.89
5	1:14	1:30	16	9.6	6.73	9.55	2.82	7.45	0.72	21.08	0.06	0.60	2.22	1.75
6	4:23	4:43	20	7.64	3.86	7.6	3.74	4.81	0.95	18.2	0.08	0.61	3.13	2.45
7	1:00	1:35	35	9.1	6.4	9.05	2.65	7.13	0.73	21.75	0.06	0.64	2.01	1.58
8	1:58	2:25	27	8.94	6.14	7.47	1.33	6.18	0.04	21.33	0.16	0.03	1.30	1.02
9	2:50	3:30	40	8.73	3.85	8.7	4.85	4.13	0.28	20.58	0.14	0.17	4.68	3.67
10	4:23	4:43	20	9.32	5.2	8.9	3.7	6.53	1.33	19.62	0.05	1.06	2.64	2.07
11	9:30	10:05	35	7.62	5.1	7.52	2.42	5.27	0.17	24	0.11	0.17	2.25	1.77
12	10:20	11:00	40	9.9	6.84	9.9	3.06	8.43	1.59	21.67	0.03	1.48	1.58	1.24
13	11:46	12:10	24	7.22	4.1	7.22	3.12	4.22	0.12	23	0.14	0.10	3.02	2.37
14	2:45	3:55	70	10.45	5.1	10.2	5.1	6.25	1.15	21.75	0.07	0.99	4.11	3.23
15	12:25	1:45	20	9.52	4.84	8.05	3.21	5.8	0.96	23.58	0.05	0.94	2.27	1.78
16	11:35	11:55	20	7.75	5.37	7.65	2.28	5.57	0.2	24.83	0.10	0.22	2.06	1.62
17	12:10	12:53	43	8.75	5.08	7.84	2.76	5.69	0.61	23.28	0.06	0.58	2.18	1.71
18	1:25	2:14	49	9.35	5.09	8.75	3.66	5.9	0.81	22.27	0.07	0.72	2.94	2.31
19	10:55	11:20	25	7.5	4.39	7.4	3.01	5.76	1.37	25.67	0.03	1.44	1.57	1.23
20	9:45	10:10	25	8.9	5.7	8.8	3.1	7.09	1.39	24.5	0.03	1.41	1.69	1.32
21	10:35	11:08	33	9.35	5.4	9.3	3.9	8.84	3.44	25.45	0.00	3.46	0.44	0.34
22	10:08	10:18	10	4.75	2.44	4.66	2.22	2.62	0.18	27.7	0.09	0.25	1.97	1.55
23	11:42	12:22	40	9.75	3.65	9.7	6.05	6.14	2.49	24.63	0.04	2.55	3.50	2.75
24	1:30	2:00	30	7.71	4.5	7.46	2.96	5.08	0.58	21.17	0.08	0.47	2.49	1.96
25	11:30	12:00	30	8.72	5.41	8.58	3.17	5.43	0.02	22.08	0.23	0.01	3.16	2.48

DW No	Pump Operation		Pump period	Water level (m) first day				Water level 2nd day			K Value	WL height for 24 hr duration	Water depth	Water content
	Start	End		Bottom	SW. Level	APW level	APW-SWL	Water level	WL-SWL	duration				
	Time	Time	Minutes	m	m	m	m	m	m	Hours		m	m	Cu-m
26	12:35	1:05	30	9.12	5.75	9.12	3.37	6.83	1.08	21.25	0.05	0.93	2.44	1.91
27	2:40	3:30	20	7.6	4.5	7.5	3	4.65	0.15	19.17	0.16	0.07	2.93	2.30
28	9:50	10:55	65	10.49	5.32	10.32	5	7.9	2.58	22.58	0.03	2.47	2.53	1.98
29	1:02	1:15	13	7.09	5.15	7	1.85	6	0.85	26	0.03	0.90	0.95	0.74
30	1:35	1:51	16	8.55	5.58	8.5	2.92	6.21	0.63	25.82	0.06	0.70	2.22	1.74
31	12:53	1:04	11	7.8	5.55	7.56	2.01	5.75	0.2	26.1	0.09	0.24	1.77	1.39
32	1:25	1:37	12	8	5.24	7.95	2.71	5.98	0.74	25.75	0.05	0.81	1.90	1.49
33	11:37	12:00	23	9.7	5.1	9.6	4.5	5.85	0.75	26.33	0.07	0.88	3.62	2.84
34	10:16	10:32	16	8.3	5.4	8.27	2.87	6.04	0.64	24.13	0.06	0.65	2.22	1.75
35	9:35	9:50	15	9.9	6.57	9.7	3.13	7.44	0.87	24.58	0.05	0.90	2.23	1.75
36	11:30	11:45	15	6.2	2.63	6.2	3.57	4.94	2.31	25.58	0.02	2.37	1.20	0.94
37	12:05	12:35	30	8.3	3.4	8.2	4.8	3.7	0.3	24.96	0.11	0.33	4.47	3.51
38	9:37	10:00	23	7.6	3.18	7.23	4.05	3.79	0.61	26.25	0.07	0.72	3.33	2.62
39	10:25	10:45	20	7.62	3.76	7.62	3.86	3.8	0.04	25.08	0.18	0.05	3.81	2.99
40	11:43	12:00	17	8.68	3.13	8.68	5.55	5.67	2.54	23.33	0.03	2.48	3.07	2.41
41	11:00	11:24	24	7.52	2.45	7.52	5.07	3.53	1.08	24.1	0.06	1.09	3.98	3.13
42	12:24	12:40	16	6.2	2.13	6.2	4.07	4.76	2.63	24.5	0.02	2.65	1.42	1.11
43	9:46	10:20	34	7.75	2.28	7.6	5.32	3.5	1.22	25.42	0.06	1.32	4.00	3.14
44	9:10	9:35	25	6.54	2.41	6.54	4.13	2.45	0.04	25.92	0.18	0.06	4.07	3.20
45	9:44	10:25	41	10	5.02	9.85	4.83	5.18	0.16	21.25	0.16	0.10	4.73	3.71
46	10:42	11:05	23	9.15	4.75	9.05	4.3	6.18	1.43	22.96	0.05	1.36	2.94	2.31
47	11:10	11:20	10	5.45	2.88	5.4	2.52	4.21	1.33	24.83	0.03	1.36	1.16	0.91
48	11:36	11:57	21	7.8	2.55	7.75	5.2	3.55	1	24.47	0.07	1.03	4.17	3.27
49	12:15	12:30	15	6.8	3.76	6.73	2.97	3.82	0.06	24.13	0.16	0.06	2.91	2.28
50	12:16	12:51	35	8.03	2.5	8	5.5	3.49	0.99	22.98	0.07	0.92	4.58	3.60

SW = Static Water Level ; APW = After Pumping Water Level ; WL = Water Level.

Table A7: Recharge of DWs after pumping in Sharsha (Dry season)

DW No	Pump Operation		Pump period	Water level (M) first day				2nd day			K Value	APW – SW = 1 m			APW – SW = 1.5 m		
	Start	End		Bottom	SW. Level	APW level	APW-SW	Water level	WL-SW	duration		WL height for 24 hr duration	Water depth	Water content	WL height for 24 hr duration	Water depth	Water content
	Time	Time	Minutes	m	m	m	m	m	m	Hours		m	m	Cu-m	m	m	Cu-m
1	12:30	12:58	28	8.9	3.85	8.85	5	5.92	2.07	20.33	0.04	0.35	0.65	0.51	0.53	0.97	0.76
2	12:07	12:22	15	6.7	3.85	6.55	2.7	5.27	1.42	21.22	0.03	0.48	0.52	0.41	0.73	0.77	0.61
3	10:40	11:05	25	8.7	4.05	8.4	4.35	5.94	1.89	22.83	0.04	0.42	0.58	0.46	0.62	0.88	0.69
4	9:25	10:05	40	8.6	4.2	7.6	3.4	5.19	0.99	24.17	0.05	0.29	0.71	0.55	0.44	1.06	0.83
5	1:14	1:30	16	9.6	6.73	9.55	2.82	7.45	0.72	21.08	0.06	0.21	0.79	0.62	0.32	1.18	0.93
6	4:23	4:43	20	7.64	3.86	7.6	3.74	4.81	0.95	18.2	0.08	0.16	0.84	0.66	0.25	1.25	0.98
7	1:00	1:35	35	9.1	6.4	9.05	2.65	7.13	0.73	21.75	0.06	0.24	0.76	0.60	0.36	1.14	0.89
8	1:58	2:25	27	8.94	6.14	7.47	1.33	6.18	0.04	21.33	0.16	0.02	0.98	0.77	0.03	1.47	1.15
9	2:50	3:30	40	8.73	3.85	8.7	4.85	4.13	0.28	20.58	0.14	0.04	0.96	0.76	0.05	1.45	1.14
10	4:23	4:43	20	9.32	5.2	8.9	3.7	6.53	1.33	19.62	0.05	0.29	0.71	0.56	0.43	1.07	0.84
11	9:30	10:05	35	7.62	5.1	7.52	2.42	5.27	0.17	24	0.11	0.07	0.93	0.73	0.11	1.39	1.09
12	10:20	11:00	40	9.9	6.84	9.9	3.06	8.43	1.59	21.67	0.03	0.48	0.52	0.40	0.73	0.77	0.61
13	11:46	12:10	24	7.22	4.1	7.22	3.12	4.22	0.12	23	0.14	0.03	0.97	0.76	0.05	1.45	1.14
14	2:45	3:55	70	10.5	5.1	10.2	5.1	6.25	1.15	21.75	0.07	0.19	0.81	0.63	0.29	1.21	0.95
15	12:25	1:45	20	9.52	4.84	8.05	3.21	5.8	0.96	23.58	0.05	0.29	0.71	0.56	0.44	1.06	0.83
16	11:35	11:55	20	7.75	5.37	7.65	2.28	5.57	0.2	24.83	0.10	0.10	0.90	0.71	0.14	1.36	1.07
17	12:10	12:53	43	8.75	5.08	7.84	2.76	5.69	0.61	23.28	0.06	0.21	0.79	0.62	0.32	1.18	0.93
18	1:25	2:14	49	9.35	5.09	8.75	3.66	5.9	0.81	22.27	0.07	0.20	0.80	0.63	0.30	1.20	0.95
19	10:55	11:20	25	7.5	4.39	7.4	3.01	5.76	1.37	25.67	0.03	0.48	0.52	0.41	0.72	0.78	0.61
20	9:45	10:10	25	8.9	5.7	8.8	3.1	7.09	1.39	24.5	0.03	0.46	0.54	0.43	0.68	0.82	0.64
21	10:35	11:08	33	9.35	5.4	9.3	3.9	8.84	3.44	25.45	0.00	0.89	0.11	0.09	1.33	0.17	0.13
22	10:08	10:18	10	4.75	2.44	4.66	2.22	2.62	0.18	27.7	0.09	0.11	0.89	0.70	0.17	1.33	1.04
23	11:42	12:22	40	9.75	3.65	9.7	6.05	6.14	2.49	24.63	0.04	0.42	0.58	0.45	0.63	0.87	0.68
24	1:30	2:00	30	7.71	4.5	7.46	2.96	5.08	0.58	21.17	0.08	0.16	0.84	0.66	0.24	1.26	0.99
25	11:30	12:00	30	8.72	5.41	8.58	3.17	5.43	0.02	22.08	0.23	0.00	1.00	0.78	0.01	1.49	1.17

DW No	Pump Operation		Pump period	Water level (M) first day				2nd day			K Value	APW – SW = 1 m			APW – SW = 1.5 m		
	Start	End		Bottom	SW. Level	APW level	APW-SW	Water level	WL-SW	duration		WL height for 24 hr duration	Water depth	Water content	WL height for 24 hr duration	Water depth	Water content
	Time	Time	Minutes	m	m	m	m	m	m	Hours		m	m	Cu-m	m	m	Cu-m
26	12:35	1:05	30	9.12	5.75	9.12	3.37	6.83	1.08	21.25	0.05	0.28	0.72	0.57	0.41	1.09	0.85
27	2:40	3:30	20	7.6	4.5	7.5	3	4.65	0.15	19.17	0.16	0.02	0.98	0.77	0.04	1.46	1.15
28	9:50	10:55	65	10.5	5.32	10.32	5	7.9	2.58	22.58	0.03	0.49	0.51	0.40	0.74	0.76	0.59
29	1:02	1:15	13	7.09	5.15	7	1.85	6	0.85	26	0.03	0.49	0.51	0.40	0.73	0.77	0.60
30	1:35	1:51	16	8.55	5.58	8.5	2.92	6.21	0.63	25.82	0.06	0.24	0.76	0.60	0.36	1.14	0.89
31	12:53	1:04	11	7.8	5.55	7.56	2.01	5.75	0.2	26.1	0.09	0.12	0.88	0.69	0.18	1.32	1.04
32	1:25	1:37	12	8	5.24	7.95	2.71	5.98	0.74	25.75	0.05	0.30	0.70	0.55	0.45	1.05	0.83
33	11:37	12:00	23	9.7	5.1	9.6	4.5	5.85	0.75	26.33	0.07	0.20	0.80	0.63	0.29	1.21	0.95
34	10:16	10:32	16	8.3	5.4	8.27	2.87	6.04	0.64	24.13	0.06	0.22	0.78	0.61	0.34	1.16	0.91
35	9:35	9:50	15	9.9	6.57	9.7	3.13	7.44	0.87	24.58	0.05	0.29	0.71	0.56	0.43	1.07	0.84
36	11:30	11:45	15	6.2	2.63	6.2	3.57	4.94	2.31	25.58	0.02	0.66	0.34	0.26	1.00	0.50	0.39
37	12:05	12:35	30	8.3	3.4	8.2	4.8	3.7	0.3	24.96	0.11	0.07	0.93	0.73	0.10	1.40	1.10
38	9:37	10:00	23	7.6	3.18	7.23	4.05	3.79	0.61	26.25	0.07	0.18	0.82	0.65	0.27	1.23	0.97
39	10:25	10:45	20	7.62	3.76	7.62	3.86	3.8	0.04	25.08	0.18	0.01	0.99	0.78	0.02	1.48	1.16
40	11:43	12:00	17	8.68	3.13	8.68	5.55	5.67	2.54	23.33	0.03	0.45	0.55	0.43	0.67	0.83	0.65
41	11:00	11:24	24	7.52	2.45	7.52	5.07	3.53	1.08	24.1	0.06	0.21	0.79	0.62	0.32	1.18	0.93
42	12:24	12:40	16	6.2	2.13	6.2	4.07	4.76	2.63	24.5	0.02	0.65	0.35	0.27	0.98	0.52	0.41
43	9:46	10:20	34	7.75	2.28	7.6	5.32	3.5	1.22	25.42	0.06	0.25	0.75	0.59	0.37	1.13	0.88
44	9:10	9:35	25	6.54	2.41	6.54	4.13	2.45	0.04	25.92	0.18	0.01	0.99	0.77	0.02	1.48	1.16
45	9:44	10:25	41	10	5.02	9.85	4.83	5.18	0.16	21.25	0.16	0.02	0.98	0.77	0.03	1.47	1.15
46	10:42	11:05	23	9.15	4.75	9.05	4.3	6.18	1.43	22.96	0.05	0.32	0.68	0.54	0.47	1.03	0.80
47	11:10	11:20	10	5.45	2.88	5.4	2.52	4.21	1.33	24.83	0.03	0.54	0.46	0.36	0.81	0.69	0.54
48	11:36	11:57	21	7.8	2.55	7.75	5.2	3.55	1	24.47	0.07	0.20	0.80	0.63	0.30	1.20	0.94
49	12:15	12:30	15	6.8	3.76	6.73	2.97	3.82	0.06	24.13	0.16	0.02	0.98	0.77	0.03	1.47	1.15
50	12:16	12:51	35	8.03	2.5	8	5.5	3.49	0.99	22.98	0.07	0.17	0.83	0.65	0.25	1.25	0.98

SW = Static Water Level ; APW = After Pumping Water Level ; WL = Water Level.

APPENDIX-B

QUESTIONNAIRE ON DISINFECTION OF DUG WELL

I. Particulars of the Dug Well

1. Location:

Village: Union:

Upazila: District:

2. No. of Household Served:

II. Questionnaire (Please Tick the appropriate circle)

1. How long have you been drinking water from Dug Well?

O 6 months O 6 Months - 1 Yr. O 1yr.- 2 yr. O More then 2 yr.

2. How are the smell, taste and odour of dug well water?

O Good O Moderate O Acceptable O not acceptable

3. What are the uses of dugwell water ?

O Drinking O Drinking & cooking O bathing O all purposes

4. Has anybody fallen sick of any of the diseases after drinking DW water?

O No O Yes

If yes, tick the disease or diseases below

O Diarrhoea O Dysentery O Typhoid O Paratyphoid O Jaundice

O Skin diseases O other (specify)

5. Is the surrounding of the dug well kept clean on a regular basis?

O Always O Often kept clean O Sometimes O Never

6. Do you know that bleaching powder solution or chlorine can be used to disinfect of purify your dug well water?

O Yes O No

7. Are you satisfied with dug well water?

O Highly satisfies O Reasonably satisfied O Not satisfied

If Not satisfied, what is the reason ?

O Bad smell O Color O Taste

If bad smell, did smell disappear after adding bleaching powder?

O Yes O Partly reduced O No O Yes, but small of chlorine added

8. **Did you ever treat dug well water before drinking by boiling or using filter ?**

O Yes O No

9. **Do you like water purified by adding solution of bleaching powder in dug well**

O Yes O No.

If the answer to Question No. 9 is no, Why ?

O Bad smell O Bad Taste O Not attractive for drinking

If the answer to question No 9 is no,

Would you like to drink it, if you know that dug well water purified by bleaching powder protects your health better from diseases?

O Yes O No

9. **Would you use dug well water purified by bleaching powder for cooking ?**

O Yes O No

If No, why?

O Bad smell O Bad taste O Afraid of unknown effects

10. **Would you use dug well water purified by bleaching powder for bathing and washing purposes?**

O Yes O No

If No, why?

O Bad smell O Afraid of falling hair O Irritation O Afraid of unknown effects

Name of the water user (Respondent) : _____

Address: Village _____ Union _____

Upazila _____ District _____