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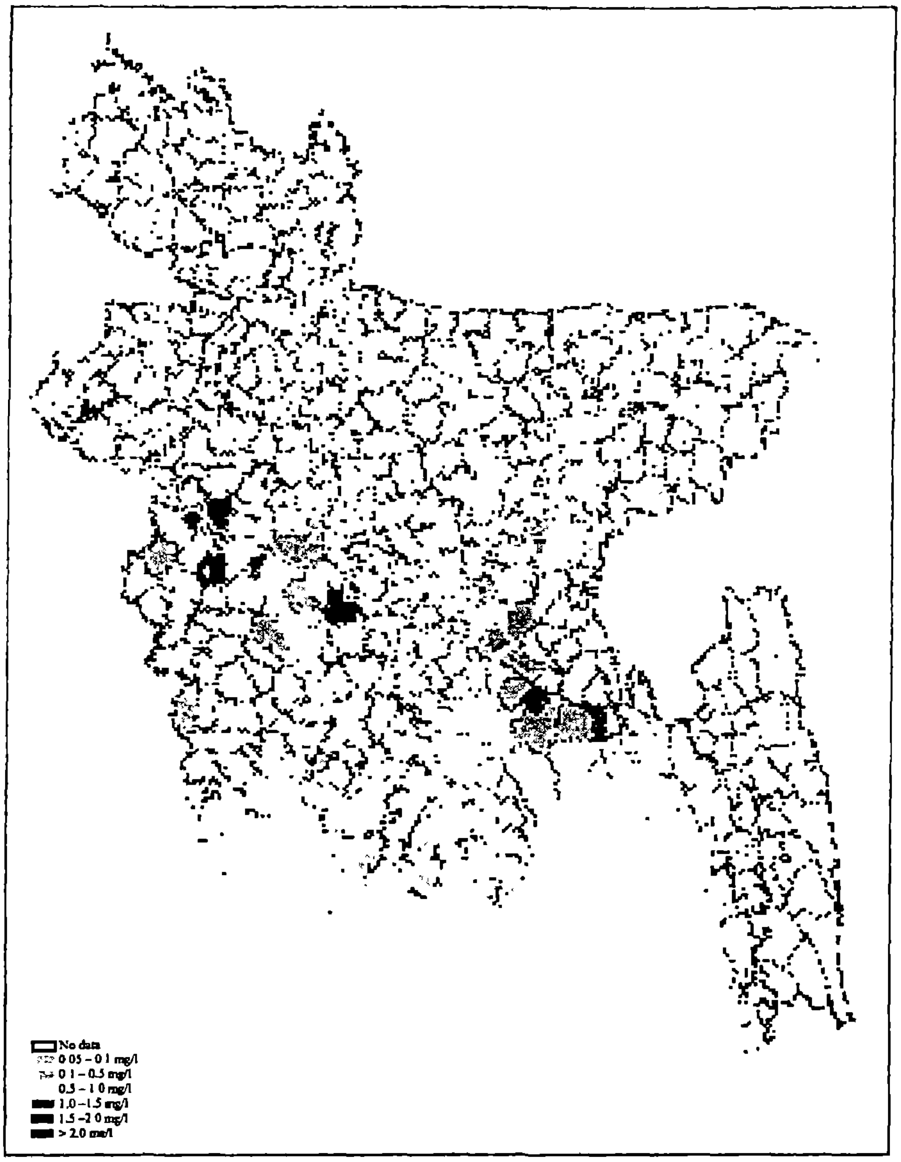

Study of low-cost arsenic mitigation technologies for application in rural Bangladesh.

Shakil Ahmed Ferdausi

M.Sc. Thesis SEE 087

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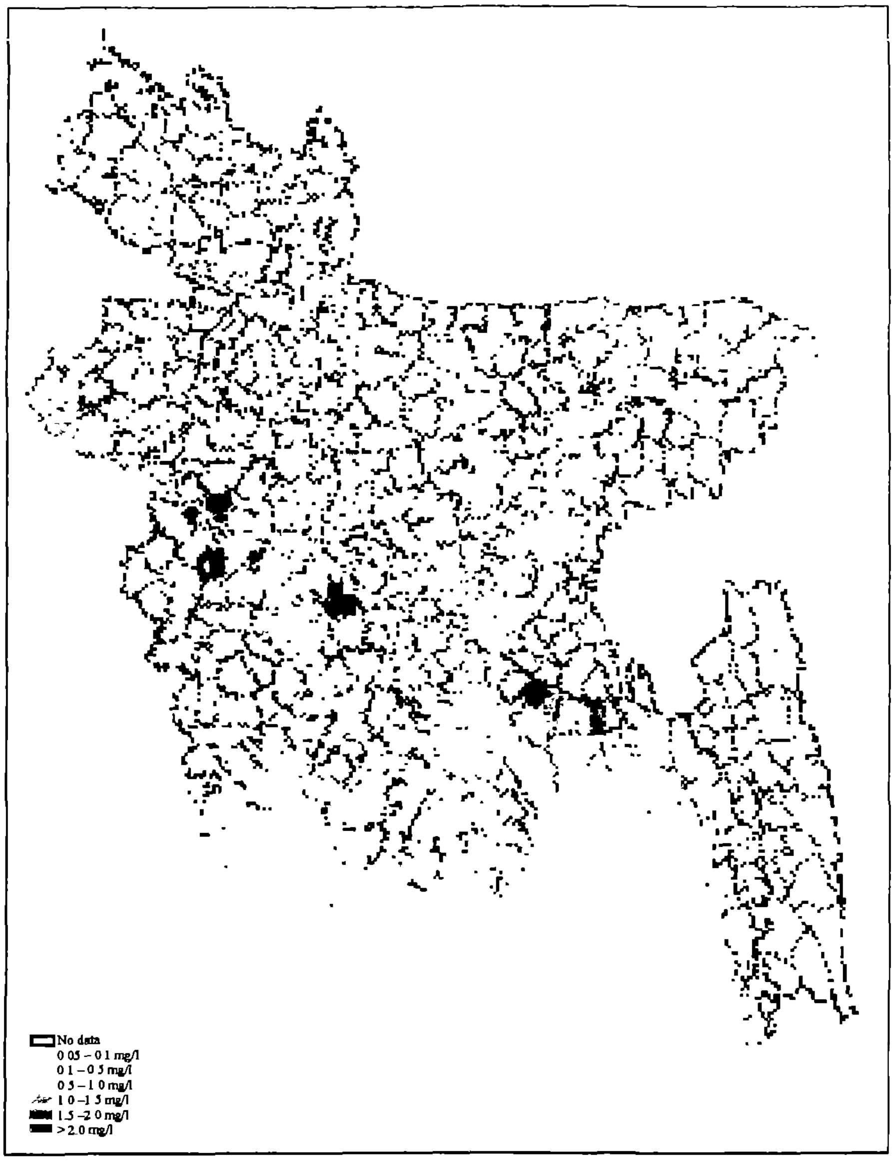

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July, 1999.

Dedication-

Millions of arsenic affected people of Bangladesh

ACKNOWLEDGEMENTS

With the deep sense of gratitude and respect I have the pleasure to express special thanks to my supervisor Prof Dr. J C Schippers for kind supervision of this study. My sincere thanks and admiration go to my mentor Ir. M W Blokland for his valuable guidance along the way. I am most sincerely indebted to him for the arrangement of financial support to carry out the study. His vision, methodical observations and keen personal attention have inspired me throughout the project work and this study Without the involvement of Ir. A. N. van Breemen, the arsenic removal part of the study have never been carried out. His meticulous, constructive and valuable guidance has helped me to apply the systematic approach in dealing with water quality problems.

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Finally, I take the opportunity to express my sincere respect to my parents for their continuos support in all aspects of my life. I am also grateful to my two sisters for their support and encouragement.

ABSTRACT

Arsenic in groundwater is posing a serious threat to the rural population of Bangladesh. In 59 out of the 64 districts of Bangladesh arsenic levels in the groundwater aquifers that are widely exploited by handpumps exceed the threshold level of 50 µg/l. Arsenic in drinking water can cause dermal changes, kidney and liver disorder, cancer, and ultimately .... death.

The objective of this research is to study some practical aspects of three promising low-cost arsenic mitigation/water supply technologies that are considered appropriate for application in rural Bangladesh These technologies include arsenic removal by alum (at household level) from existing sources, rainwater harvesting (at household level) and pond sand filtration (at community level). The research includes a literature review of available technologies for arsenic mitigation and laboratory-scale experiments for arsenic removal. It comprises the assessment of rainwater harvesting based on analysis of rainfall data by mass curve method and A_c-V_c method, and costing of the system. It covers the identification of design, construction and O&M weaknesses in the pond sand filter system based on literature review, field survey, and water quality analysis.

Arsenic removal was found dependent on the initial iron value in the water, with higher iron leading to increased arsenic removal. The arsenic removal efficiency was found to be rather independent of the initial arsenic concentration. A common dosage of alum can be selected to bring the arsenic value in water down below the Bangladesh limit of 50 µg/l. Arsenic removal was also achieved without addition of alum when raw water contained high iron The coagulation technique for arsenic removal by bucket treatment at the household level appears feasible for immediate application. Additional research on different aspects of bucket treatment is required. This concerns the effective mixing of alum in the bucket, the presence of residual aluminum and the handling of the arsenic containing sludge.

Rainwater harvesting is found technically feasible and the required storage size for a typical family would vary between 2.9 and 4.4 m^3. Socalled A_c-V_c curves can be developed for the different regions and be applied at field level by non-professionals to find the required size of storage tank. The capital cost of the storage tank is relatively high compared to other technologies, and a subsidy or micro-credit scheme would be required to enable wide-scale application of the system. Additional research is necessary to find cheaper storage vessels for application in rural Bangladesh. For now, the cement ring storage tank is found to be the most economical solution

The present design of the pond sand filter improves water quality, but fails to bring the Fecal Coli number below the standard level. It was found that the frequency of re-sanding the filter is very high This reduces treatment efficiency and complicates the O&M of the system. A design improvement is proposed for pre-treatment unit, the depth of the sand bed, and inlet and outlet structures and controls Such design modifications along with improved community participation, O&M training and procedures can improve water quality, increase the filter run time and reduce the O&M activities.

In the Bangladesh Arsenic Mitigation/Water Supply Project the selection of the appropriate technology will be by the users An algorithm to help communities in surveying and choosing from the range of appropriate low-cost technologies was developed

Keywords. Arsenic, Bangladesh, groundwater, arsenic removal, coagulation, alum, iron, jar test, rainwater harvesting, catchment, storage tank, rainfall, design, dry period, costing, pond sand filter, slow sand filter, water quality, pre-treatment, O&M, turbidity, fecal colifom

ABBREVIATIONS

AEC - Annual Equivalent Cost
AIT - Asian Institute of Technology (Thailand)
ARU - Arsenic Removal Unit
BAMWSP - Bangladesh Arsenic Mitigation Water Supply Project
BBS - Bangladesh Bureau of Statistics
BCAS - Bangladesh Center for Advanced Studies
BGS - British Geological Survey
BUET - Bangladesh University of Engineering and Technology
CI - Corrugated Iron
DANIDA - Danish International Development Agency
DPHE - Department of Public Health Engineering
DFID - Department for International Development (United Kingdom)
EPA - Environmental Protection Agency (United States)
EQS - Environmental Quality Standards
FC - Fecal Coliform
GI - Galvanized Iron
IHE - International Institute of Infrastructure, Hydraulics and Environment Engineering (Delft, The Netherlands)
lpcd - Liter per capita per day (Water demand)
MAC - Maximum Allowable Concentration
MCL - Maximum Contaminant Level
MPN - Most Probable Number (Statistical estimate for bacteriological analysis)
NGO - Non-government Organization
NIPSOM - National Institute of Preventive and Social Medicine
NTU - Nephelometric Turbidity Unit
O&M - Operation and Maintenance
PSF - Pond Sand Filter
PVC - Polyethylene Vinyl Chloride
SANDEC/EAWAG - Department of Water and Sanitation in Developing Countries/ Swiss Federal Institute for Environmental Science and Technology
SDC - Swiss Agency for Development Cooperation

SODIS	-	Solar Water Disinfection
SSF	-	Slow Sand Filter
TDS	-	Total Dissolved Solids
UNICEF	-	United Nations International Children Emergency Fund
UV	-	Ultra Violet
VSST	-	Very Shallow Shrouded Tubewell
WHO	-	World Health Organization

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1 INTRODUCTION

1.1 GENERAL

The provision of safe drinking water remains a prime target for both advanced and developing countries. By far the greatest water quality problem in developing countries is the prevalence of water-borne diseases, especially gastro-enteritis, which related to fecal pollution and inadequate hygiene. Such problems are usually related to poor quality of water sources, inadequate installation and poor hygiene. Pollution from agricultural chemicals, for example nitrate and pesticides, once considered a problem restricted to rich nations, is now also a rapidly growing problem in developing countries.

In addition to the anthropogenic sources, the natural baseline geochemistry of groundwater and surface water resulting from interaction with rocks also creates widespread health and acceptability problems in many parts of the world, mainly on a regional scale. The concentration of naturally occurring mobile elements often exceed those recommended as the maximum for potable waters, and/or their concentrations may exceed limits of general acceptability for domestic use.

Bangladesh has achieved a commendable success among the developing countries in provision of basic water supply through hand tubewells. There are an estimated 3.0 million tubewells in rural Bangladesh. About two-thirds of these tubewells were installed and owned by the private/individuals and NGOs. The remainder is publicly owned, mainly by DPHE, and operated by caretaker families. The rural water supply coverage is 90% and this coverage is presently defined as percentage of population living within 150 meters of a tubewell. It took more than 50 years to motivate the rural people to use tubewell water instead of ponds water for drinking and cooking purposes and to minimize water borne diseases, especially, diarrhoeal diseases. Rural people are now quite habituated to drink tubewell water. All people are being persuaded 'to drink tubewell water'. So, strategically groundwater are being considered as free from pathogenic microorganisms and available in adequate quantity in shallow aquifers.

In recent times arsenic in groundwater has come as a threat to the rural water supply system of Bangladesh. The problem of arsenic seems to be a looming disaster for Bangladesh.

1.2 ARSENIC CONTAMINATION IN BANGLADESH

Arsenic is not an uncommon contaminant of groundwater. It is a naturally occurring element and usually presents in the form of compounds with sulfur and with many elements. However, arsenic contamination of drinking water supplies has recently been realized as a global problem. Some of the severe cases have been documented in Taiwan, Argentina, Chile, Canada, Mongolia and Mexico. But, probably the biggest outbreak of arsenic poising has been discovered in Bangladesh and West Bengal, India.

Compared to other arsenic affected countries, the arsenic problem in Bangladesh has been detected very recently. The issue of arsenic in underground drinking water in this region was possibly first noticed in 1978 in West Bengal, India. But, Dr. K.C. Saha, School of Tropical Medicine, Calcutta presented the first official report of arsenic study in July 1983, from the water samples of tubewells having depths varying from 20m to 100m (Quadiruzzaman, 1996). Arsenic in groundwater has been found above WHO maximum permissible limit 0.05 mg/l in six districts (out of seventeen districts) of West Bengal (Das *et al.* 1995). It was doubted that groundwater of adjacent districts of Bangladesh might contain high arsenic as West Bengal and Bangladesh are in the same Bengal Delta Plain. The Department of Public Health Engineering (DPHE) arranged to test the water from 34 tubewells in August 1993 and the results showed the presence of arsenic contamination in 5 tubewells. Further investigation of DPHE and other organizations widely reported the intermittent incidents of arsenic contamination in groundwater and consequent arsenic poising of the users. A DPHE/DFID regional survey conducted in 1998 shows that 59 out of the 64 administrative districts of Bangladesh, the groundwater is contaminated with arsenic. The percentage of arsenic affected thanas (sub-districts) are 43% (Mia, 1998). An estimated 24 million people are directly exposed to the arsenic problem and 75 million are at arsenic risk of arsenic contamination. It has been reported that so far about 7000 arsenicosis affected patients are identified in the arsenic affected areas (Web page of Dainichi Consultant, 1999 cited the source BBS, Dhaka Community Hospital, NIPSOM, DPHE). The figure 1.1 shows the arsenic contaminated area of Bangladesh. However, the map is prepared with the earlier data, not showing the all affected area.

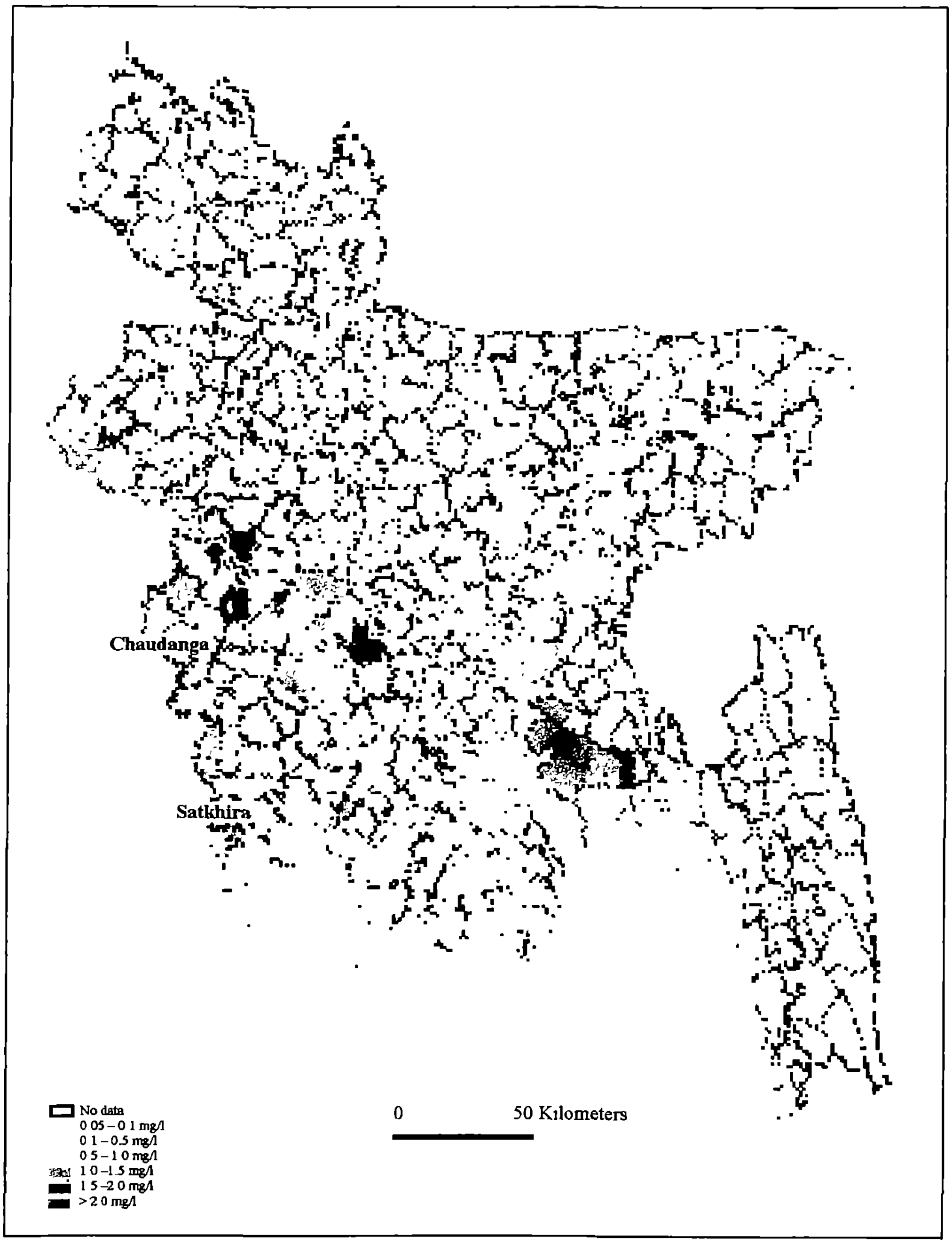

Figure 1.1: Maximum Arsenic Concentrations in Groundwater in Each Thana (Sub-District) of Bangladesh

1.3 THE NEED FOR RESEARCH

The present arsenic crisis is jeopardizing the progress made in water supply sector in the last two decades. There are two major on-site impacts of the crisis:

i) In the absence of acceptable alternatives, people are continuing to consume arsenic-contaminated water and

ii) In the absence of proper on-site water and sanitation, communities that are worried that their groundwater might be contaminated with arsenic may end up drinking pathogen contaminated surface water that is more harmful than arsenic.

There are both urgent and long-term socially acceptable technical solutions needs to address these issues in a sustainable way.

A major constraint to addressing the arsenic problem in Bangladesh is the lack of information on the extent, causes and proven remedial interventions. In general, the Government's level information on water supply and sanitation is inadequate. Although many of the country's research organizations, governmental agencies and NGOs are now engaged in data gathering, information on groundwater arsenic contamination does not cover all areas of potential contamination and is not always reliable or conclusive. Data on possible causes of groundwater poisoning are also inconclusive. However, it is now widely accepted that the source of arsenic is geological in origin. Groundwater conditions probably determine the release of arsenic and spreading via the groundwater system. Little is known about the possible geological sources or the mechanism of release and spreading within the aquifer system. The problem has so far been identified mainly in shallow aquifers at a depth up to 200 ft, but water from a number of deeper tubewells appeared to be contaminated as well.

It has been recognized that present arsenic health hazard is directly related with the drinking water. Arsenic contaminated water can be used for the other household purposes like cleaning, washing, bathing, gardening etc. without any risk of arsenic poisoning. It has been accepted that 5 lpcd arsenic 'free' safe water is required for domestic purposes, particularly drinking and food preparation. The minimum amount of drinking water required for survival in a tropical area is the range of 1.8 to 3.0 liters per day, so that another 2 to 3 liters per capita is available for other strategic uses. In the BAMWSP, a World bank assisted project targeting 4000 villagers in rural Bangladesh, arsenic mitigation measures will be taken to supply at least 5 lpcd water with an acceptable arsenic level in the arsenic contaminated area for the drinking and mainly food preparation purposes.

A simple, affordable, technically feasible and socially acceptable safe drinking water system in the rural areas of Bangladesh is very much in demand. Unfortunately, Bangladesh has mainly experience on groundwater i.e. handpump and deep tubewell. In some instances, alternative water options like rainwater harvesting and pond sand filter (PSF) are practiced in very limited way. The problem related with the water quality, long-term use and other related issues like O&M problem, social acceptability of alternative water options are still to be addressed.

1.4 GOAL OF THE STUDY

The goal of the research is to study some of the low-cost arsenic mitigation technologies for application in rural Bangladesh. The technologies include arsenic removal by alum (at household level) and alternative water sources like rainwater harvesting (at household level) and pond sand filter (at community level) for treatment of surface water.

1.5 OBJECTIVES OF THE STUDY

The objectives of the research are:

i) To analyze the potentially suitable and immediately acceptable technical options for arsenic mitigation measures in more detail.

ii) To examine the possibilities of identification of optimal alum dosing for different arsenic-iron concentrations in groundwater.

iii) To investigate the feasibility of rainwater harvesting at household level for long-term use in drinking purposes.

iv) To identify the present planning, design, construction and O&M weaknesses of pond sand filter and to propose remedial measures to overcome those.

1.6 SCOPE OF THE STUDY

The main approaches to accomplish the earlier mention objectives will be as follows:

i) General:

- Problem identification and analysis— arsenic in groundwater of Bangladesh.
- Literature review of arsenic removal technologies.
- Literature review of alternative technologies for application in rural areas.
- Analysis of the potentially suitable technologies.

ii) Arsenic Removal by Alum:

- Literature review of arsenic removal by coagulation.
- Collection and analysis of raw water from a specific area of Bangladesh to observe the iron and arsenic concentration in affected area.
- Laboratory experiments with different arsenic-iron containing water and to identify the optimal alum dosing for different iron-arsenic concentrations.

iii) Rainwater Harvesting:

- Literature review of different rainwater harvesting systems practiced in different countries for drinking purposes in detail.
- Related rainfall data collection for designing rainwater harvesting system for long-term use.
- Determination of rainwater storage volume analyzing the rainfall data.
- Comparison of different materials for rainwater storage.
- Costing of alternative options of storage tanks.

iv) Pond Sand Filter (PSF):

- Review of the literature related to small slow sand filter practiced in other developing countries.
- Review of the related reports to design and operation of pond sand filter in Bangladesh.
- Additional fieldwork to supplement the information with literatures and reports, e.g., examination of PSF operations, analyzing of water qualities, interview with stakeholders etc.
- Comparison of design and operating conditions of major components of PSF with those of SSF.

1.7 ORGANIZATION OF THE REPORT

The study report contains six chapters that can be summarized below:

Chapter One – describes the problem, research need and objectives of the study.

Chapter Two – discusses the arsenic characteristics, chemistry, guideline, probable causes of groundwater contamination, the impact of the problems. It also gives an overview of different arsenic removal technologies practiced in the different parts of the world and reviews the arsenic mitigation technologies applicable in rural Bangladesh.

Chapter Three – describes the arsenic removal technology by coagulation with its principles and the findings of previous studies. It also provides the laboratory experimental procedure with materials and methods, the findings of the experiment.

Chapter Four – illustrates the different components of the rainwater harvesting system with costing for different materials of storage tank, water quality protection, design procedure for storage tank calculation. It analyzes the rainfall pattern of Bangladesh and compares the methods for calculating storage tank volume. Finally, costing and materials of guttering and storage tanks in Bangladesh are estimated and considerations for implementing the system are discussed.

Chapter Five – compares the components of the slow sand filter and pond sand filter. It explains the filtration mechanism, identifies the technical, operation and maintenance weakness of the system and finally provides the remedial measures to improve the system.

Chapter Six – draws conclusions from the study and provides a recommendation for the technology selection at the arsenic contaminated area. It also gives some recommendations for future study.

2

REVIEW OF ARSENIC MITIGATION TECHNOLOGIES

2.1 GENERAL

This chapter reviews the arsenic removal technologies applied in the different parts of the world and low-cost arsenic mitigation measures applicable in rural Bangladesh. It comes up with a potential list of arsenic mitigation technologies, which can be applied to meet the immediate demand in the field. However, these technologies will be situation specific and should be applied with due care. This chapter also includes the general properties of arsenic, possible reason of arsenic occurrence in Bangladesh, drinking water guidelines and health hazards related to arsenic contamination etc.

2.2 GENERAL CHARACTERISTICS OF ARSENIC

Arsenic is a well-known toxic element. Arsenic has six very specific characteristics. It is called a secret poison due to its these characteristics. These are:

Box 2.1: Characteristics of Arsenic

- It is a virulent poison on acute ingestion.
- It is extremely toxic on long term exposure to very low concentrations.
- It is not visible in water and food. Even heavy contaminated water may be clear and colourless.
- It has no taste. Even heavy contaminated water may have a pleasant taste.
- It has no smell, even at deadly concentration.
- It is difficult to analyse.

Azcue & Nrjagu, 1994

2.3 GUIDELINES

There are no fixed standards for maximum permissible arsenic contaminants in drinking water. The guideline values for arsenic in drinking water established by various countries/organizations are listed in Table 2.1.

Table 2.1: Guideline values for arsenic in drinking water.

Country/Organization	*Maximum Contaminant level (MCL), μg/l*
Canada	25
USA	50
European Community (EC)	50
India	50
China	50
Taiwan	50
WHO*	10

Viraraghava *et al*, 1994 * Frederick *et al*, 1994

Although arsenic toxicity clearly depends on its chemical form, with As(III) being much more toxic than the oxidized As(V) species, the guideline value is targeted only to the total arsenic. As (III) has a high affinity for thiol (-SH) groups in proteins, causing inactivation of a variety of enzymes. On contrast, As (V) behaves very much like phosphate. Consequently, it can substitute for phosphate in normal cell reactions, interfering with normal cell functions (Frederick *et al.*, 1994).

The World Health Organization (1984) set the guideline for arsenic in drinking water at the maximum allowable concentration (MAC) of 0.05 mg/l. Recent epidemiological studies in Taiwan, where large population groups have been drinking the arsenic contaminated water for long time, have shown that arsenic may cause liver, lung, kidney, and bladder cancer in addition to the previously acknowledged risk of skin cancer. With a view to reduce the risk of getting skin cancer, and taking into consideration the practical detection limit in the available analyses, a provisional guideline value for total arsenic in drinking water of 0.01 mg/l is established by WHO in 1993. The estimated excess lifetime skin cancer risk associated with exposure to this concentration is $6x10^{-4}$. The WHO notes that "guideline values for carcinogenic substances have been computed from mathematical models that cannot be verified experimental," and "At best, these estimates must be regarded as rough estimates of cancer risk" (Frederick *et al.*, 1994). This can be simplified as one out of 1667 persons may suffer skin cancer by using 0.01 mg/l arsenic in the drinking water.

The drinking water standard for arsenic in the proposed Environmental Quality Standards (EQS) for Bangladesh is 0.05 mg/l (Hossain & Ali, 1997).

2.4 CHEMISTRY OF ARSENIC

Arsenic is a non-metal belongs to group Va of the periodic chart, which group also contains nitrogen, phosphorus, antimony and bismuth. Arsenic has atomic number of 33 and atomic mass of 74.9216. The physical appearance of arsenic resembles that of a metal, so it is referred to as a metalloid to distinguish it from a true metal. So it is referred to as a metalloid to distinguish it from a true non-metal. The stable form (element) of arsenic is crystalline, brittle and has a gray metallic luster. However, this form is not common in the environment. Arsenic is usually found combined with one or more other elements such as: oxygen, chlorine and sulfur (Pontius *et al.*, 1994, Karim *et al.*, 1997, Carmalt *et al.*, 1998).

Arsenic commonly exists in several different oxidation states: +V (arsenate), +III (arsenite), 0 (arsenic), and –III (arsine). The oxidation state (or valence state), which indicates the capacity of the atom to combine with other atoms, is used to denote the form of arsenic present (Pontius *et al.*, 1994).

Arsenic occurs in both inorganic and organic forms in natural waters. Inorganic arsenic may present in the formal oxidation states of arsenate [As(V)] and arsenite [As(III)]. The dominant arsenic species is a function of pH and redox potential. Arsenate, the thermodynamically stable form of the inorganic species in oxygen rich waters, generally predominates in surface waters. Arsenate exists in four forms in aqueous solutions: H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$ and AsO_4^{3-}. The thermodynamic prediction of the equilibrium chemistry of inorganic arsenic species are shown in Fig 2.1 (Edwards, 1994, reprinted and cited from Ferguson and Garvis, 1972).

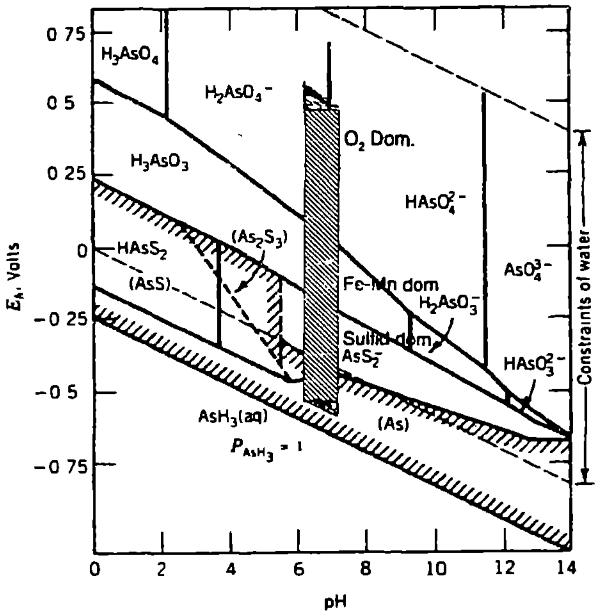

Figure 2.1 : Thermodynamic prediction of the equilibrium chemistry of inorganic arsenic species.

$HAsO_4^{2-}$ predominates from pH 7 to 11.5, indicating that this is the form most likely to occur in surface water supplies. At pH <7, $H_2AsO_4^-$ dominates. Arsenite is favored under reducing conditions, e.g., in anoxic groundwater. Arsenite is present as H_3AsO_3 in aqueous solutions; this undissociated weak acid is predominant in pH range 2-9.

Organic arsenic species occur in natural waters as a result of the use of organo-arsenical pesticides, as well as through the biomethylation mechanisms of microorganisms (Thayer 1984, Cullen 1987).

As earlier mentioned, the toxicity of arsenic depends on its chemical form. Arsenite, the trivalent inorganic species, is more toxic to biological systems than arsenate, the pentavalent species. The toxicity of organo-arsenical is lower than those of inorganic arsenic species (Cheng *et al.*, 1994).

2.5 OCCURRENCE OF ARSENIC IN GROUNDWATER

Arsenic is found widely distributed in nature, in igneous rocks and in ores in earth crust. It is ranked as the 20th most abundant element in the earth's crust. Over 245 arsenic bearing minerals have been identified which occur mainly as sulfides and which are usually associated with ores containing copper, lead, zinc, gold and silver. The most common ores are shown in Table 2.2 (Carmalt & Norman, 1998).

Table 2.2: The most common arsenic bearing ores.

Name of Ores	*Chemical Formula*
Asenopyrite	$FeAsS$
Realgar	As_4S_4 or AsS
Orpiment	As_2S_3
Arsenolite	As_2O_3
Energite	Cu_3AsS_4

The source of arsenic in the natural water is generally related to the process of leaching from geological materials and sediments derived from the arsenic bearing minerals, inputs from geothermal sources, mining wastes and landfills (Welch *et al.* 1988, Korte & Fernando, 1991). Uncontrolled anthropogenic activities such as smelting of metal ores, use of arsenical pesticides, wood preservative agents, and other various arsenicals may release arsenic directly to the environment (Battacharya *et al.*, 1997).

Occurrence of arsenic in the natural water depends on the local geology, hydrology and geo-chemical characteristics of the aquifer materials. Furthermore, the organic contents as well as the land use pattern may be important factors in controlling the natural mobility of arsenic in the alluvial underground. Under anoxic conditions the mobilization of arsenic is the reason for the overall greater risk for contamination of groundwater as compared to surface water.

2.5.1 OCCURRENCE OF ARSENIC IN GROUNDWATER OF BANGLADESH

It is now widely accepted that the source of arsenic contamination in groundwater of Bangladesh is geological in nature. Little is known about the possible geological sources or the mechanism of release and spreading within the aquifer system. Even the limited findings and present hypothesis remain to be confirmed.

Bangladesh is mainly formed of a vast thickness of alluvial and deltic sediments, which can be divided into two main parts- the recent floodplains and the terrace areas. The floodplains and the sediments beneath them are only a few thousand years old and can be classified accordingly, to which of the river system (Ganges, Brahmaputra, Tista and Meghna etc.) deposited them. The terrace areas are better known as the Madupur and Barind Tracts, and the sediments that underline them are much older than the adjacent floodplains. It has observed that most of the arsenic occurs in the youngest sediments derived from the Ganges Basin (BCAS, 1997).

A recent study conducted by the British Geological Survey team (1999) suggests that the groundwater arsenic problem in Bangladesh arises because of an unfortunate combination of three factors. These are a source of arsenic (arsenic is present in the aquifer sediments), mobilization (arsenic is released from the sediments to the groundwater) and transport (arsenic is flushed away in the natural groundwater circulation). These are explained below.

Geological source of arsenic

Previously a number of anthropogenic explanations had been for the occurrence of arsenic in groundwater. While it is possible that some may explain isolated cases of arsenic contamination, none of the anthropogenic explanations can account for the regional extent of groundwater contamination in Bangladesh and West Bengal. There is no doubt that the source of arsenic is of geological. The arsenic content of alluvial sediments in Bangladesh is usually in the range 2-10 mg/kg; slightly greater than typical sediments (2-6 mg/kg). However, it appears that an unusually large portion of the arsenic is present in a potentially soluble form. The groundwater arsenic concentrations are associated with the grey sands rather than the brown sands. The map of arsenic contaminated groundwater shows that highly contaminated areas are found in the catchments of the Ganges, Brahmaputra and Meghna rivers strongly suggesting that there are multiple source areas for the arsenic.

Mobilization of the arsenic- redox processes

Burial of the sediments, rich in organic matter, has led to the strongly reducing groundwater conditions observed. The process has been aided by the high water table and fine-grained surface layers which impede entry of air to the aquifer. Microbial oxidation of the organic carbon has depleted the dissolved oxygen in the groundwater. This is reflected by the high bicarbonate concentrations found in groundwater in recent sediments. There is a relationship between the degree of reduction of the groundwater and the arsenic concentration – the more reducing, the greater the arsenic concentration.

The highly reducing nature of the groundwater has led to the reduction of some of the arsenic to As(III) and possible desorption of arsenic since As(III) is normally less strongly sorbed by the iron oxides than As(V) under the near neutral pH groundwater conditions observed. Further reduction will lead to the partial dissolution of the poorly crystallized ferric oxide with consequent release of iron and additional arsenic. Other strongly sorbed ions, especially phosphate will also be released by iron oxide dissolution. The relatively high phosphate concentrations present in the groundwater will compete with As(V) for sorption sites and is another factor that favors high groundwater arsenic concentrations.

'Oxyhydroxide reduction' hypothesis proposed by Nickson *et al.,* 1998 explain the probable main cause of arsenic mobilization in groundwater.

Box 2.2: 'Oxyhydroxide reduction' hypothesis

Arsenic is released when arseniferous iron-oxyhydroxides are reduced in anoxic groundwater, a process that solubilises iron, and its absorbed load, and increases bicarbonate concentrations. Sedimentary iron oxyhydroxides are known to scavenge arsenic and concentrations of diagenetically available iron and arsenic correlate well in aquifer sediments.

The arsenic-rich groundwater is mostly restricted to the alluvial aquifers of the Ganges delta., so the source of arsenic-rich iron oxyhydroxides must lie in the Ganges source region upstream of Bangladesh. Weathered base-metal deposits occur in the Ganges basin (Bihar, Uttar Pradesh, and West Bengal, India), so weathering of these arsenic-rich base-metal sulphides must have supplied arsenic-rich iron oxyhydroxides to downstream Ganges sediments during Late Pleistocene-Recent times. The arsenic-rich iron oxyhydroxides are now being reduced, causing the present problem. Reduction is driven by concentrations of sedimentary organic matter up to 6%.

Transport of arsenic within the aquifers

Present groundwater movement is very slow because of the extremely low hydraulic gradients found in the delta region. Except where modified by pumping, groundwater circulation is largely confined to the shallow layers affected by local topographic features and the presence of rivers. Close to rivers, the enhanced groundwater flow may lead to a greater dispersion of arsenic along riverbanks. Annual fluctuations of the water table, typically about 5 m, will affect groundwater and arsenic movement in the shallow layers. There may have been some flushing of arsenic from the shallowest layers.

At greater depths, groundwater moves slowly in response to the low regional gradients. This is consistent with the old age of the waters. The lateral and vertical spread of contaminants is slow even without considering the retardation due to sorption. Modeling suggests that even in the most permeable layers, arsenic movement is likely to be limited to a few meters a year.

2.5.2 ARSENIC CONTENT VARIATION WITH DEPTH

The British Geological Survey team also has observed that arsenic contamination was "prominent" in shallow aquifers and "little" in deep aquifers. The samples were taken from the 41 districts out of 64 districts of Bangladesh. Altogether 2022 collected samples were analyzed in the United Kingdom collected from 252 thanas (sub-districts). On average 8 samples were collected per thana or 1 sample per 37 km^2. The sampling strategy was designed to give a uniform spatial coverage and a representative range of well types and depths.

- The median arsenic concentration was 0.0108 mg/l, just above the WHO recommended limit for arsenic in drinking water. 51% of the samples were above 0.01 mg/l (the WHO guideline value). 35% of the samples had concentrations above the Bangladesh drinking water standard of 0.05 mg/l.

- Much of Bangladesh is characterized by a two-aquifer system. A shallow aquifer typically extending from 10 to 70 m below ground level and a deeper aquifer below about 200 m. In the south the shallow aquifer is divided in two.

- The top of the shallow aquifer, at depth of less than 10 m appears to be less contaminated, and shallow wells are usually uncontaminated even in areas of otherwise high arsenic concentrations.

- Most of the very deep wells (depth greater than 200 m) had low arsenic concentrations, often significantly below 0.01 mg/l. Only 1% of these wells had arsenic concentrations above 0.05 mg/l.

- Changes, for better or worse, are likely to be slow, and if they occur, will happen over time scales of years and decades.

The importance of these findings to the rural water supply system is that, for the purpose of guiding present rural water supply system, the following low-arsenic occurrences may be assumed:

1. Where groundwater can be drawn from wells with a very shallow depth (less than 10 m), the water is likely to have an arsenic concentration less than 0.05 mg/l.

2. Where drilling of wells in deep aquifers (> 200 meters) is feasible, the water may be expected to have an arsenic concentration below 0.05 mg/l.

3. Where groundwater in the most common wells with a depth of 10 - 70 m is found to contain less than 0.05 mg arsenic/l, the source may continue to be used, and needs to be re-sampled yearly.

2.6 HEALTH HAZARDS

There are two distinct forms of arsenic poisoning— acute and chronic. Acute arsenic exposure (high concentrations ingested over a short time period) can cause a variety of adverse effects. The severity of the effect depends primarily on the level of exposure. Acute high-dose oral exposure to arsenic typically leads to gastrointestinal irritation accompanied by difficulty in swallowing, thirst, abnormally low blood pressure, and convulsions. Death may occur from cardiovascular collapse. The lethal dose to humans is estimated at 1-4 mg As /Kg for an adult. Short-term exposure to doses >500 μg As/Kg/d can cause serious blood, nervous system, gastrointestinal and other ill effects and also may lead to death (Frederick *et al.,* 1994).

Chronic exposures are due to low concentrations of arsenic and related with the drinking water contamination. The most common signs of long-term, low-level arsenic exposure from drinking water are dermal changes. Sign and symptoms of chronic arsenicosis (disease caused by drinking arsenic contaminated water) differ in manifestations in different countries. In Bangladesh skin manifestations are prime and common. The clinical manifestations are categorized in the following stages (Khan & Ahmed, 1997, Hussain, 1999).

Pre clinical stage	:	The patient shows no symptoms. Not detectable by clinical manifestation.
Initial stage	:	Blacking of some parts of the body or whole body (Melanosis)

: Thickening and roughness of the palms and soles (Keratosis)
: Redness of the conjunctiva (Conjunctivitis)
: Inflammation of the respiratory tract
: Nausea and vomiting (Gastro-enterities)

Second stage : White intermittent dots within the black area – Leucomelanosis or rain drop pigmentation (Depigmentation)
: Nodular growth on the palms and soles (Hyperkeratosis)
: Swelling of the feet and legs (Non-pitting Oedema)
: Peripheral neurophathy
: Kidney and Liver disorders

Last stage : Gangrene of the distal organs or the parts of the body
: Cancer of the skin, lungs and urinary bladder
: Kidney and Liver failure

In Bangladesh majority of the patients are found in the initial and second stages.

The palm, truck and sole of arsenicosis affected persons are shown in figure 2.2.

Melanosis of the palm **Kerotosis of the palm**

Melanosis of the trunk **Kerotosis of the sole**

Figure 2.2: Melonosis and Kerotosis of arsenicosis patients.

When arsenic is absorbed into the human body, the major portion is excreted in the urine (approximately 50%), a small portion via the faeces and through the skin, hair and nails and possibly a trace through the lungs. Even if only a small amount of arsenic is absorbed, a portion of the amount absorbed is deposited in the skin, hair and nails. Storage in these metabolically 'dead' tissues is responsible for the slow elimination rate of arsenic from the body. Arsenic in the hair, urine, and the nails has thus been used as an index for monitoring the exposure of victims to arsenic (Das *et al.,* 1995).

As earlier mentioned, arsenic contaminated water is tasteless, colorless, odorless and even clear, tangible effects of groundwater contamination usually come into light long after the actual contamination has started. It may take 1-14 years after starting to drink arsenic-contaminated water for symptoms to appear. This period depends on the amount of arsenic ingested, the length of exposure and immunity level of the person. People with poor socio-economic and nutritional status are also more vulnerable to arsenic poisoning. Most arsenic symptoms are confused with malnutrition, and it is further true that most older people, 40 years and above, deficient in vitamins A, C, and E are most susceptible to arsenic related diseases (adapted from Chowdhury, 1998).

2.7 SOCIAL IMPACTS

Although arsenicosis, is not an infectious, contagious or hereditary disease, but it creates many social problems for the victims and their families. A large number of people due to their ignorance, superstitions and lack of information, consider the disease caused by arsenic as 'curse from the God'. Patients suffering from arsenicosis are often ostracized socially as most of the people consider it like leprosy or other contagious disease. It is very difficult to arrange marriage for a young girl affected by arsenic. Some affected housewives are divorced by their husbands and even forcibly sent to their parental home with children. In fear of social problem, some affected people feel hesitation to express their illness, which ultimately will complicate their disease condition (adapted from Milton *et al.*, 1998).

2.8 ARSENIC REMOVAL: AN OVERVIEW

Effective removal of arsenic is a complicated task due to different forms of arsenic in groundwater. It requires combinations of several treatment methods. In a large-scale application, such as urban and industrial water treatment plants there are established technologies for achieving reliable separation of arsenic. However, it requires skilled staff, good monitoring equipment and a well-managed facility.

The different treatment technologies for arsenic removal can be divided into two categories. These are conventional treatment technologies and advance treatment technologies. The existing treatment processes for other purification purposes can be applied for removing arsenic. Several researches have been focused on improving the efficiency of coagulation with metal salts since these technologies are available in most of water treatment facilities. Other conventional treatment technology includes Fe-Mn oxidation and lime softening. The advance treatment technologies for arsenic removal show promising results at the laboratory. However, these methods are limited to pilot scale or small scale and mostly not yet proven at full-scale treatment plants.

Conventional Treatment Technologies

i) ***Removal by addition of a coagulant:*** Potable water treatment with coagulants has traditionally been used to reduce turbidity by removing non-settling, slowly settling solids from source water. Dissolved inorganic contaminants, such as arsenic, can also be removed during coagulation treatment with alum or ferric chloride through adsorption, occlusion, and solid-solution formation (Benefield & Morgan, 1990).

The type of coagulant, dosage and pH effect the efficiency of the process. Alum performance is slightly lower than ferric sulfate. Others were also less effective than ferric sulfate. Disposal of the contaminated coagulation sludge is a concern of this process.

ii) Fe-Mn Oxidation: According to Edwards (1994), the geochemistry of arsenic reveals that high arsenic concentrations are often correlated to high Fe(II) and/or Mn(II). During Fe(II) and Mn(II) removal the arsenic can be removed through oxidation. Fe(II) and Mn(II) leads to the formation of hydroxides that remove soluble arsenic by co-precipitation or adsorption reactions. He observed that removal of arsenic during manganese precipitation is relatively ineffective when compared with iron. In general, arsenic removal is controlled by the quantity of iron removed ($Fe(OH)_3$ formation) but is relatively independent of the quantity of manganese removed (MnOOH formation).

Rashid (1996) achieved 74% of As(III) removal by aeration of 5 mg/l of Fe(II) followed by filtration. The initial As(III) concentration of raw water was 200 µg/l. The effect of pH on As(III) removal in his study is shown in Figure 2.3.

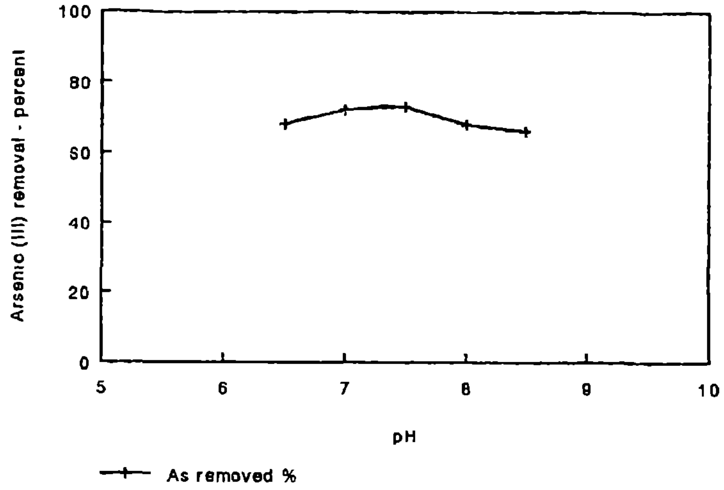

Figure 2.3: As(III) removal as a function of pH (equilibrium) by oxidation of 5 mg/l Fe(III).

iii) Lime Softening: Arsenic can be removed effectively from hard water by lime and excess lime softening treatment, with the amount of removal dependent upon the pH and the valence of the arsenic contaminant. The As(V) is more readily removed from hard water than As(III) and that removals of both forms increased with increasing pH. The results of the lime softening on well water having an initial hardness of around 300 mg/l as $CaCO_3$ are shown in Figure 2.4. At pH 10.5 and above almost 100 percent removal is possible on water spiked with 0.4 mg/l of As(V). The best removal of As(III) is about 80 percent at pH 11.1 and above. Below the optimum pH, with As(V) and As(III) removals decreased with decreasing pH, with arsenic V removals always higher than As(III) removals (Sorg & Logsdon, 1978).

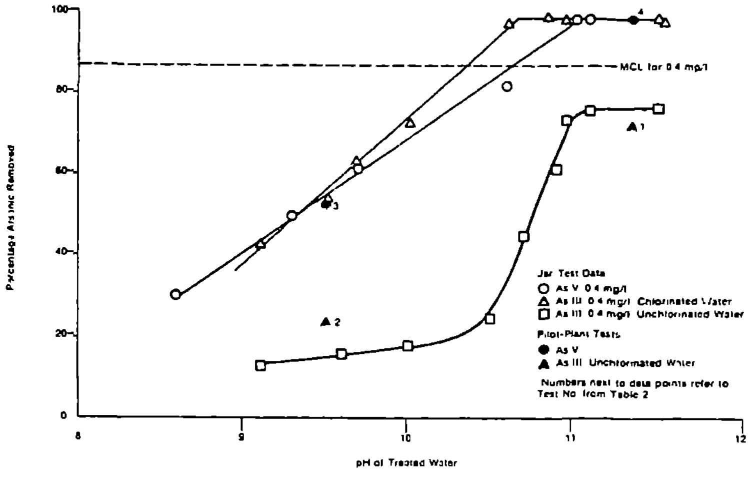

Figure 2.4: Effect of pH on arsenic removal by lime softening

McNeill and Edwards (1997) demonstrated that $Mg(OH)_2$ was very effective for sorbing arsenate, producing >90% removal in bench-scale experiments. The presence of carbonate decreases arsenate removal by $Mg(OH)_2$. Addition of a small amount of iron to waters before softening can dramatically increase arsenate removal.

Removal of arsenic compounds by absorbents, ion-exchanging materials and membrane technique.

i) ***Activated Alumina:*** Activated alumina is aluminum oxide (Al_2O_3) grains prepared in a way that the grains have high sorptive surface. The specific surface could be 200-300 m^2/g. When the water passes through packed-bed configuration of activated alumina, arsenic and other compounds in the water are absorbed at the surfaces of grains. The capacity of activated alumina for arsenic is strongly pH dependent. As(V) is effectively adsorbed in the pH range 4-7 (Gupta & Chen, 1978). Both As(III) and As(V) species are adsorbed by activated alumina. Activated alumina is highly selective towards As(V); and this strong results in regeneration problems, possibly resulting in 5 to 10 percent loss of capacity for each run (EPA, 1998).

ii) ***Activated Carbon:*** Huang & Fu (1984) carried out experiments with 15 different graded activated carbon powder to remove As(V) from water. Treatment with these activated carbons met drinking water standards (0.01 mg/l). The surface area for the activated carbons studied ranged from 550 to 1700 m^2/g, but there was no correlation between adsorption density and specific surface area in As(V) adsorption. Electrostatic attraction and the formation of specific chemical bonds were the major adsorption mechanisms. Maximum As(V) removal (61%) was occurred at pH 4 to 5.

iii) ***Iron Coated Sand:*** Iron oxide-coated sand can be prepared by mixing ferric nitrate ($Fe(NO_3)_3.9H_2O$) solution with washed and dried river sand followed by drying in oven and washing with distilled water. Joshi & Chaudhuri (1996) reported that in the laboratory study with an initial concentration of 1.0 mg/l As (III) and As(V), iron oxide-coated sand achieved the WHO provisional guideline value of 0.01 mg/l arsenic in drinking water. However, the study did not address the effect of some important factors, such as possible selectivity of As(III) and As(V) over one another for removal, water pH, concentration and type of competing anions and cations that sorb and affect surface charge of the medium or form soluble arsenic complexes.

iv) Zeolite: Ningnoni (1999) has studied the As(V) removal from groundwater by using uncontioned and conditioned natural zeolite (clinoptilolite). The conditioned zeolite performed better with the efficiency of 77.3% to 89.0% compared to 6.7% efficiency of the unconditioned one. The capacity of zeolite for As(V) uptake obtained in this study is 62 µg As(V)/g zeolite (0.0008 mmole/g), which is very low compared to the capacity of activated carbon (0.27 mmole/g) as found in a research by Rajakovic (1995).

v) Ion Exchange: It is an adsorption process similar to activated alumina, just medium is a better-defined synthetic resin with well-defined ion exchange capacity. The process is normally used for removal of specific undesirable cation or anion from water. When the water containing arsenic passing through the synthetic resin, the arsenic exchanges for the chloride ions, which is loaded at the exchange sites. Eventually it requires regeneration after the resin becomes exhausted. The principal regenerated agent is chloride, i.e., a salt solution.

Arsenic exchange

$2\mathbf{R}\text{-Cl} + HAsO_4^{2-} = \mathbf{R}_2HAsO_4 + 2Cl^-$

Regeneration

$\mathbf{R}_2HAsO_4 + 2Na^+ + 2Cl^- = 2\mathbf{R}\text{-Cl} + HAsO_4^{2-} + 2Na^+$

Where **R** stands for ion exchange resin.

Like the other arsenic removal processes, it is important that arsenic is in the +V oxidation state in order to achieve the best removal efficiency. However, the need to oxidize the As(III) could result in damaging the resin by the excess of the oxidation agents. The removal capacity is dependent on sulfate content of raw water as sulfate is exchanged before arsenic. One minor advantage of the ion exchange process is that the performance is less dependent on pH (Dahi, 1997).

vi) Membrane Techniques: Reverse osmosis, Electrodialysis and nanofiltration are membrane techniques, which have been demonstrated to be efficient in removing arsenic from water. The water shall be free from suspended solids and the arsenic in water shall be in As(V) form. Most membranes, however, can not withstand oxidizing agent.

RO can provide arsenic removal efficiencies of greater than 95 percent when operating pressure is at ideal pressure. (EPA, 1998).

These high tech methods are of no interest in developing countries like Bangladesh because of their high costs and requirement of skilled operation and maintenance.

Applicability of arsenic removal technology in Bangladesh

Arsenic removal can be achieved by using any of the methods. The best method for a specific purpose depends on the raw water quality, effluent water quality requirement, the financial conditions, available skills of staffs, monitoring equipment and system and management capabilities etc.. Unfortunately, Bangladesh has very limited experience on water treatment units. The rural water supply scheme in Bangladesh is mainly handpump based. There is no distribution network for the rural water supply system. The economical status, demographic and sociological conditions do not presently permit the installation of large-scale water treatment plant and associated transport and distribution system. Even the urban water supply system faces the problem of inefficient state-owned management, unskilled technical staff, capital shortage, inferior quality materials, inadequate power supplies etc. The arsenic removal technology for the rural area will be household based or small community based. Arsenic removal by addition coagulation and Fe-Mn oxidation can be applied in household based or small community based. The required chemicals are relatively normally available and relatively cheap comparing to the chemicals of other process.

Arsenic removal by addition of alum in a two-bucket system has been introduced recently by a project in an arsenic contaminated area. The initial result of this coagulation system shows that the household can operate and maintain the system.

2.9 ARSENIC MITIGATION TECHNOLOGIES IN BANGLADESH

As stated earlier that the arsenic contamination problem has been identified recently in Bangladesh. There is still no proven technology that can be applied at the rural area confidently. Various agencies/organizations are now working on the arsenic mitigation technologies. However, very limited technical papers are available on their research methodology and findings. It may also be pointed out that many of these arsenic mitigation technologies are still in a research or development stage, so that revisions in design may follow. Also, field level testing of technologies under different conditions and at user level is yet to be done in many cases. This paragraph is therefor concluded with section that translates the review of technologies into an advice on their immediate applicability in the rural area of Bangladesh.

2.9.1 WATER SOURCES AND THE NECESSITY OF TREATMENT

The rural water supply system in Bangladesh seeks to remedy the intake of arsenic contaminated water by the application of a variety of water supply technologies. The selection of the appropriate technology will be situation specific. The technologies are treatment of arsenic-affected groundwater, and the replacement of the arsenic-containing groundwater source by an arsenic free source. The arsenic-free sources are groundwater from other aquifers, rainwater and surface water from ponds, and if worst comes to worst, tanker truck water or bottled water.

The choice of source and related technology needs to be very carefully considered, particularly in terms of public health considerations. The categorization for the prioritization of sources is particularly relevant in this respect. For example, when moving away from arsenic-containing groundwater to surface water, one dangerous contaminant, arsenic will be replaced by another equally or more dangerous one, pathogens, the removal of which will require water treatment ranging from simple disinfection to slow sand filtration with pre-treatment. In the public health sense, a move to unpolluted groundwater or rainwater will be much less risky, as this water is free of any significant contamination. The different water sources and the associated need for water treatment is shown in table 2.3.

Table 2.3. Water sources and the need for treatment

Source of Water	***Concentration of***		***Need for Treatment to reduce***	
	Arsenic	***Pathogens***	***Arsenic***	***Pathogens***
Groundwater	>0.05 ppm	Negligible¹⁾	Yes	No ²⁾
	< 0.05 ppm	Negligible¹⁾	No	No²⁾
Rainwater	Negligible	Negligible¹⁾	No	No²⁾
Surface Water	Negligible	Significant	No	Always

1) except where water abstraction technologies have not been properly installed or maintained

2) periodic disinfection may be considered

2.9.2 CATEGORIZATION OF OPTIONS

The arsenic mitigation options can be categorized in 4 groups. These are follows:

1. ***Arsenic reduction option:*** Removal of arsenic to an acceptable level by simple treatment of water from the present source. Example - Household arsenic treatment by bucket type method.

2. ***Replacement of source option:*** Developing a source with an acceptable arsenic level. Example- A new arsenic-free well, rooftop rainwater harvesting, and pond water with adequate treatment.

3. ***Source sharing option:*** Obtaining drinking water from a neighboring unsuspected source, whilst continuing to draw for other uses from the present well. Example-

Arrange permission to take or buy a certain quantity of water from a nearby, arsenic-free well.

4. ***Imported water option:*** Getting wholesome water carried in from elsewhere. Example- Tanker truck water delivery, and bottled water.

2.9.3 ARSENIC REDUCTION OPTION

If the groundwater is contaminated with arsenic above the threshold value of 0.05 mg/l, which is most likely in wells with a depth between 10 and 70 m, then the groundwater abstraction technologies have to be combined with attached or separate arsenic removal treatment devices. Attached devices are treatment modules that are installed in, at or near the pump, while separate technologies are those where arsenic-contaminated water is carried home, and treated there. These devices are described separately below, and include both tested and untested technologies, as well as technologies subject to ongoing research.

a. Attached Devices

a.1. Iron-removal plant

Iron removal plants usually combine aeration, coagulation and filtration. They are used for iron removal but, if present, arsenic co-precipitates. The arsenic-removal efficiency improves when alum added. The plant consists of stapled gravel, sand and filtered water chambers in series, with a downward gravity water flow. It often used as community-based system. Reportedly, removal efficiency varies widely, mainly between 55% and 95% (Liang, 1998).

a.2. DANIDA – designed arsenic removal unit

The DPHE-DANIDA Urban Water and Sanitation Project has developed a prototype filter to remove arsenic from tubewells. It can serve up to 25 families or 200 individuals. This arsenic removal unit (ARU) comprises one compact unit. There are five compartments inside that unit: buffer chamber to control chemical addition, mixing chamber, aeration chamber; and chemical stock solution. The removal efficiency is reportedly 70% (from about 0.14 arsenic mg/l). Alum dosing was about 200-300 mg-alum/l.

b. Separate, Household-based Devices

b.1. Bucket type removal by coagulation

In this process, a suitable dosage of coagulant (Alum/ferrous sulfate/ferric chloride) and bleaching power are added to a plastic bucket (10 to 15 liters) containing raw water. The chemicals are mixed by fast manual stirring for a minute and slow manual stirring for half an hour. A settled floc is formed during the process of stirring. The water is kept undisturbed for about 4 hours so that the flocs settle. The supernatant water is drawn out slowly and carefully and stored for drinking purposes. It is suggested that the water should be filtered with a simple cloth filter before final use for removing the micro-sized flocs. The reduction in arsenic content varies depending on the concentration and nature of arsenic, concentration of iron, pH, hardness, contact period and type and dosages of coagulants. Addition of bleaching powder can improve the removal efficiency.

A Two-bucket system can be used for this purpose. The first one is used for mixing the coagulant and bleaching powder, floc formation and settling. The second one is for collection and storage of treated water. DPHE's Urban Water and Sanitation Project is promoting the two - bucket type method.

b.2. Chemical package treatment at household level

Different types of chemical packages have been distributed in the form of tea bags form for treating arsenic contaminated tubewell water. A strong chlorine smell was observed in a widely distributed tea bag form chemical package. It was claimed that it could bring the arsenic concentration below the WHO standard. The efficiency of the packages was not scientifically investigated and the efficiencies claimed must be viewed with caution. The people's acceptance for this method was very low, on account of the strong smell and poor palatability.

b.3. Bucket removal - Spontaneous precipitation of arsenic by storage

Arsenic can be reduced spontaneously by leaving the water undisturbed over 24 hours without adding any chemicals. Then the top portion of is separated out slowly. The arsenic removal in this method is highly depended on the composition of the water, especially the iron content. The method produces better results with high initial iron concentrations. The method is promoted by a few major agencies. Arsenic removal efficiencies using this approach are typically 20-70% which may not be sufficient to reduce the arsenic concentration to the desired level but it could at least provide an emergency option to reduce the intake of arsenic.

b.3. Cartridge filters

Filter units with cartridge filled with sorptive media or ion-exchange resins are readily available in the market. These units remove arsenic like any other dissolved ions present in water. These units are not suitable for water having high impurities and iron in water. Presence of ions having higher affinity than arsenic can quickly saturate the media requiring regeneration or replacement. The initial and operation costs are high and beyond the reach of the common people (Ahmed, 1999).

b.4. Sand-khoa (brick chip) filtration

This household filtration unit has been developed based on traditional household practices. This follows slow sand filtration technique. It consists of two or more filtration units; the units are placed one under the other. Earthen wide mouthed pits with about 15-liter capacity are used to form the filtration units. Each pot contains at least one layer of brick chips followed by layer of sand. Three pieces synthetic or nylon cloth cover the top layer, between the chips and sand layer and cover the bottom inside part of the pot. One to three small holes should be made at the bottom of the pot. The units require cleaning and disinfection at regular intervals to avoid the growth of bacteria.

This aeration-filtration unit for arsenic treatment reportedly provides 60-100% reduction of arsenic depending on the initial arsenic concentration, proportion of arsenic (III) and presence/concentration of iron.

2.9.4 SOURCE REPLACEMENT OPTION

The arsenic contaminated groundwater source can be replaced by uncontaminated groundwater source, surface water source or rainwater source. Uncontaminated groundwater source can be divided into three groups: groundwater up 10 m depth, groundwater below 200 m depth and groundwater in intermittent depth (normally 10 to 70 m).

Groundwater Source

a. Groundwater up to 10 m

a.1. Very Shallow Shrouded Tubewell (up to 10 m depth)

This is a low-cost tubewell about 8 m in depth with 2 m strainer shrouded with coarse sand. The VSST is designed to be fitted with a handpump and collects water from very shallow aquifers formed by displacement of saline water by continuous flow of accumulated fresh water. The lenses of fresh water formed by this process are found beneath old ponds in coastal area. In many areas, ponds are dry up but fresh water in shallow aquifer remains beneath the pond. Immobile preserved aquifers are also found at shallow depths at various locations in the coastal area. It is convenient method for withdrawal of fresh water in limited quantity. Identification of existence of fresh water pockets is difficult. The life span of VSST is also short.

a.2. Dugwell with handpump

Dugwells are large diameter shallow wells for ground water extraction. This used to be a common option for potable water before the success of tubewell program. Water of these dugwells have been found to contain nil or negligible arsenic (below WHO standard) in many arsenic affected areas, for example, Singair, Matlab, etc. But this water is generally highly contaminated with fecal bacteria.

A dugwell can be used with handpumps following its disinfection (chlorination), the installation of a raised, protective platform over the entire opening, and the sealing of the upper portion of the well to prevent seepage into the well of polluted water from the ground surface. This system provides nil or acceptable coliform bacteria and arsenic contamination. The disinfection/chlorination of the dugwell was required at a certain frequency. A dugwell can be lined with brick masonry, cast-in-situ concrete or pre-cast concrete rings (ringwell).

b. Groundwater more than 200 m

Deep Tubewell (locally up to 300 m)
A tubewell installed to withdraw water from deeper aquifers is called a deep tubewell. In the coastal belt, the depth of deep tubewell can go up to 300 m. It is possible to drill a deep tubewell by simple manual method in the unconsolidated soil. These tubewells are also operated by hand.

Motorized deep tubewell is another option to abstract groundwater from a greater depth. Submersible pumps are commonly used for static water levels below 30 m. These require a large diameter. Usually, submersible pumps deliver water to storage reservoirs from where water is drawn.

c. Groundwater between 10 to 70 m (other location)

The reasons and extent of the arsenic contamination is not yet clearly understood. It has been observed in many instances that an arsenic free groundwater source is identified within a limited distance from an arsenic contaminated tubewell in deeper depth (within 70 m). The installation of a new tubewell in this depth should be carried out with due attention on the water quality (level of arsenic in that water). However, there is no scientific basis on how long the newly installed tubewell will serve without arsenic contamination.

Rainwater Sources

Rainwater is pure and a preferred source of drinking water in many countries. If collected from an elevated surface such as a roof and stored in a hygienic manner it is usually suitable for drinking without treatment and is only very rarely contaminated with pathogenic organisms. The rainwater is free from arsenic contamination. The rainwater harvesting system requires a roof of a particular minimum size to collect water, and a storage tank with an adequate volume to ensure continued supply over prolonged dry periods. The monthly rainfall figures and rainfall pattern suggest that rainwater harvesting is a potential source of potable water in Bangladesh.

The most suitable rooftop surfaces are corrugated iron sheet, although tiled roofs can also be used. Thatched roofs pose problems as the runoff is lower and generally of a lower quality. Rooftop catchment systems collect rainwater precipitated on the roof using gutter and down-pipes (made of local wood, bamboo, GI or PVC) and lead it to one or more storage containers ranging from simple pots to large masonry concrete, and ferrocement tanks, or even disused, sealed wells.

A rainwater storage tank can be constructed at each house for individual household use, but communal use of rainwater is also an option, particularly where household roof are not suitable. At communal level, a tank can be constructed for few households using a single or multiple roof catchments. Also, water can be drawn from the roofs of public buildings and stored in communal tanks with public taps.

Surface Water Sources

Surface water has shown nil or negligible concentration of arsenic. But then surface water is often biologically and physically contaminated, and can only be ingested after prior treatment. Surface water in Bangladesh may be found in rivers, streams, lakes, canals, and ponds.

Ponds served as a prime drinking water source in earlier times when groundwater was not widely used and extreme care was taken to protect and maintain the ponds. After the introduction of groundwater technologies, the ponds have gradually lost their original use, and are nowadays neglected or put to other uses such as fish farming, sanitary drainage outlet, cattle watering and washing, etc.. Water drunk from this type of modern-day pond carries a high risk of diarhoeal diseases.

Pond water

Pond water will be classified here in two types: the type with little or no pollution, and the pond with limited pollution. The initial indicator used to classify a pond is the turbidity. In the course of project development, more parameters need to be determined to establish the quality of pond water and determine treatment needs.

Pond water can be used for the drinking purposes after simple treatment, if the pond is protected against the unwanted flows. There should be arrangements in place to guarantee that the pond is free from human access, livestock watering and bathing, washing clothes, garbage dumping, drainage of irrigation return flows, rainwater runoffs, sanitary runoffs, fish farming etc.. The pond that will be considered for drinking purposes with limited treatment should be filled with the rainwater only, and not be used for any other purpose. For drawing water from the pond, a mechanical device is required, so that people do not need to enter the pond and create health risks. The water can be abstracted by simple handpumps mounted on a platform constructed over or by the side of the pond.

Pond water from the cleaner ponds can be treated right at the pond, or at the household. Several simple treatment methods are available to treat this pond water. The most important objective of treatment is to bring down the presence of pathogens to acceptable levels. The Bangladesh standard for bacteriological quality of drinking water is one fecal coliform per one hundred milliliter of water (1 FC/100 ml).

a. Pond water with turbidity <1 NTU and Fecal coliform <10/100 ml

If the water quality of the pond is in the above range, the water can be used with only simple disinfection. It may be noted that this a fairly hypothetical case. In reality, very few ponds are expected to meet the above criteria.

The simple disinfection methods are as follows:

a.1. Chlorine Tablets

The easiest way to disinfect drinking water is to add chlorine tablets to it. These tablets can be bought in a chemistry or pharmacy. The tablets are quite cheap, but to use them continually will turn out to be very expensive. Therefore, their use could be limited to periods with increased risks, for instance during epidemics. If the turbidity of the surface water is within the acceptable limit, the method can be applied only during high-risk periods. This method may give a distinct taste of chlorine to the water.

a.2. Bleaching Powder

Another method to disinfect contaminated water is to add a bleaching powder solution. The volume of the bleach to be added should be given by a specified institution, like a Public Health Laboratory. It takes about one hour for the chlorine in this solution to destroy the bacteria in the water. Application of this method requires some training and some specialized tools. This method also may give a distinct taste. Bleaching powder usually loses half of its strength within a period of one year, even stored in a cool dark place.

a.3. Boiling

Boiling kills the disease-carrying organisms in water. Just bringing water to the boiling point is not sufficient to kill all microorganisms that may be present in the water. To be totally safe for consumption, water must be boiled for twenty minutes. This is quite long and expenditures on firewood or other fuel will be high in the long run. To boil water for a few minutes is any case better than not boiling it at all.

a.4. Solar disinfection (SODIS)

This technique has been developed by SANDEC/EAWAG. The principle of this technique is use solar energy to inactivate and destroy pathogenic microorganisms present in the water. The treatment basically consists in filling transparent containers with water and exposing them to fill sunlight for about five hours. This process is based on the use of solar energy only. This process has been found satisfactory to disinfect small quantities of water used for consumption.

Solar radiation can be used to disinfect any water. With dugwell water SODIS showed better results than pond water because it had lower initial bacteriological and organic pollution than pond water. The SODIS treatment process is still under study.

b. Pond water with turbidity <10 NTU and Fecal coliform <100/100 ml

The pond water quality in this range requires more treatment than only disinfection. The water can be treated at the household level with the simple treatment method. These treatment methods must be combined with any one of the disinfection processes described earlier. The simple household treatment processes are as follows:

b.1. Conventional Household Filtration

There are different types of conventional filtration units used in Bangladesh and elsewhere. Mostly, the filtration process is based on the principle of slow sand filtration. These filters usually will reduce the number of fecal coliforms and pathogenic bacteria. However, because of common negligent maintenance there are reservations about the continuous reliability of household sand filters to produce bacterially pure water.

One of the common types of household of filtration is Pitcher (Kalshi) filter. This type of filtration was used widely in the rural areas for treatment of surface water. But, this method has been phased out with the introduction of hand tubewells at the village levels in the last decades. This process can not produce completely bacteriological free water.

b.2. Commercial Household Filter

Different types of modern, mass-manufactured filtration units are available in market. One of these common units is known as the Puritas filter. Independent research results on the performance of cheap and commonly available filters for pond or ditch water treatment could not be located.

b.3. Household treatment by using alum

Alum can be used to treat the pond water at the household level. This can be done by adding alum to a bucket of water, mixing thoroughly and allowing to sit for at least 1 hour. The clear top water is separated carefully. The water is generally safe for drinking purposes, may taste acidic and bitter.

b.4. Moringa Olifera Seeds

This technique has been developed by SANDEC/EAWAG. Powder of Moringa Oliefera seed is used as coagulant to reduce the turbidity of the raw water. It has been reported that powder of two Moringa Olifera seeds can reduce the turbidity within the acceptable range within one hour. There are three types of Moringa Olifera are available in Bangladesh and the removal efficiencies may vary with the type of Moringa Olifera. This treatment process is still under study (personal communication with SDC project).

c. Pond water with turbidity 10-100 NTU

The pond sand filter at the pond site is the technical solution for the pond water containing the above turbidity.

c.1. Pond Sand Filter

A pond sand filter is a manually operated small filtration unit used to treat the adjacent pond water using the principle of slow sand filtration. Brick chip (khoa) and sand chambers are arranged in series. Water is pumped from ponds through filter piped connected to a bent PVC pipe joined to a head assembly of commonly available shallow handpumps. Ponds, which are more or less protected from indiscriminate pollution and holds water round the year, are selected for this purpose. The another suggested guideline about the pond sand filter is the salinity and iron content of the pond water must not exceeded 600 mg chloride /l and 5 mg/l respectively at the any time of the year.

2.9.5 SHARING ARRANGEMENT OPTION

It has been observed that there are large differences in the extent of contamination of the shallow tubewells in different districts, from 'hardly affected' in the northwest to 'nearly all affected' in the southeast. The pattern of arsenic contamination is irregular in the medium arsenic contamination area. Also, there may be some occasional 'hot spots' in the low arsenic contamination area, and vise-versa. Research also showed that not all the tubewells in an effected area would necessarily show a too high arsenic concentration. Also, it was concluded that changes in arsenic level are likely to be slow, and if they occur, will happen over time scales of years and decades. The implication of all this is that the users of an arsenic-contaminated well may find ways to satisfy their drinking water requirement from a nearby arsenic-free well. An arrangement may be required to allow such water collection with the owners/users of that well. The arrangement could include for paying the cost of water through flat or graded rates, or cash payment when drawing at the source (vending). Community mobilization is required in both the deprived and providing communities in this case.

2.9.6 BOTTLED WATER/TANKER WATER OPTION

These are measures with an emergency character that may however need to be implemented for a prolonged period of time. At this time, these measures are not applied in rural areas of Bangladesh, primarily because of their high cost. These means of supply must be considered however as a last resort in arsenic contaminated areas where the development of other sources is not feasible and where water sharing proves impossible. Here bulk water needs to be trucked in, or bottled water made available. Tanker trucks can collect the water from nearby municipal supplies or irrigation wells, and distribute the arsenic free safe water to a specific village to a certain time of the day. Alternatively, if available, or constructed under the project, the arsenic-free water can be deposited in a service reservoir fitted with public taps. As an alternative to tanker water, bottled water may be distributed. For this, the village shop may be stocked with bottled water. Cost recovery is an important constraint here. The cost of tanker water and bottled water may prove prohibitive, and the pricing and possible subsidization of arsenic-free water must be decided with the public health motive foremost in mind. In principle, this drinking water can be sold to the villagers through flat or graded rates, or cash payment when drawing from the source (tanker truck, service reservoir or shop). The water quality of the tanker and bottled water should be monitored regularly by the concerned authorities.

2.9.7 REVIEW OF TECHNOLOGIES

The information in the above sections of this paragraph is attempted to be captured in the overview shown in the Table 2.4.

Table 2.4. Technologies for Arsenic Mitigation in the arsenic contaminated area with, arsenic removal efficiency and applicability.

Type	*Source*	*Technology*	*Arsenic Removal Efficiency*	*Applicability in the rural water supply*
Technologies for groundwater extraction	Very Shallow Groundwater <10 m	Dug well + handpump	Zero	Suitable*
		Very shallow shrouded tubewell	Zero	Where water pocket is available
	Shallow to medium depth groundwater	Suction mode handpump	Zero	Only where As<0.05 mg/l
		Deep-set handpump	Zero	Only where As<0.05 mg/l
	Deep ground water >200 m	Manually operated handpump	Zero	Suitable*
		Motorized pump	Zero	Suitable*
Technologies for Arsenic Removal from arsenic-affected well water	Attached Devices	Iron removal plant	Variable (55-95%)	If raw water contains high iron
		DANIDA design arsenic removal unit	Variable (around 70% for As 0.14 mg/l)	-
	Separate household based devices	Bucket type removal by Coagulation	Variable (up to 100%)	Suitable (dosing is important)
		Chemical package treatment	Variable (70-100%)	No
		Bucket removal - Precipitation by storage	Highly variable (typically 20-70%)	If raw water contains high iron
		Commercial Units	Not known	-
		Sand-khoa (brick chip) filtration	Variable (60-100%)	-
Technologies for Rainwater collection and Storage	Rainwater	Rooftop rainwater harvesting system	Zero	Suitable
Technologies for treatment of pond water	Pond Water	Disinfection	Zero	NTU>1 and FC>10/100ml
		Conventional Household filtration and disinfection	Zero	NTU>10 and FC>100/100ml
		Commercially available filter and disinfection	Zero	-do-
		Household treatment by alum and disinfection	Zero	-do-
		Moringa Olifera seeds and solar disinfection	Zero	Under study
		Pond Sand Filter	Zero	Suitable, but requires improvements

* - water should tested for As concentration.

2.10 CURRENTLY ACCEPTABLE TECHNOLOGIES

A simple, affordable, technically feasible and socially acceptable safe drinking water system in the rural areas of Bangladesh is very much in demand. Unfortunately, Bangladesh' experience is limited mainly to groundwater exploitation from unsuspected sources by means of a handpump mounted tubewell. Alternative water technologies like rainwater harvesting and pond sand filters (PSF) are practiced, but only in a very limited way, and until recently, without much detailed study of technical, social, financial and other aspects. At present, triggered by the arsenic problems, many more technologies are being actively researched, however until now without much conclusive evidence regarding their efficiency and applicability.

When taking in only the experiences in Bangladesh, and considering the socio-economic and technical constraints presented by their possible application for village water supply, only a very limited number of technologies can actually be confidently promoted for the application to the arsenic contaminated areas in rural Bangladesh. These include arsenic-free groundwater abstraction (new wells), plus the importation of arsenic-free water in bottled or tanker form (only a temporary solution, and very expensive).

This selection is very limited and would not permit the use of treated pond water, rainwater, or treated groundwater. Such would ignore experiences elsewhere, and discredit long lasting but poorly documented experiences with conventional treatment in Bangladesh. It is therefore proposed to allow the qualified use of other technologies. These include a selection of technologies for the abstraction and treatment of pond water, rainwater harvesting from roof catchments, and the treatment of groundwater from arseic-affected wells. The selection has been guided primarily by an assessment of the technologies on the basis on the available information and would certainly be subject to discussion and further developments. Table 2.5 shows a list of currently acceptable technologies for immediate application in arsenic contaminated area. The table requires review and revision from time to time, on the basis of new information and insights.

Table 2.5: The Currently Acceptable Technologies

Application Options	*Household level*	*Community/ Village level*
Treat water from existing arsenic-affected groundwater source (deep or shallow well)	- Bucket chemically assisted removal (coagulation) 1) - Bucket spontaneous removal (under specified conditions 2)	No acceptable and appropriate technologies available
Start with a new arsenic-free Ground water source 3)	Well < 10 m deep: - **Very shallow shrouded Tubewell + Handpump** - **Dug well + Handpump**	Well < 10 m deep - **Very shallow shrouded Tubewell + Handpump** - **Dug well + Handpump** Well > 200m deep: - **Deep well + Handpump** - **Deepwell + motorized pump and (limited) distribution**
Start with a Rainwater source 4)	- *Individual, Household-based Rainwater Harvesting from rooftops*	- *Rainwater Harvesting from rooftops of public buildings* - *Rainwater Harvesting from house rooftops to common reservoir*
Start with a Surface water source (pond)	Pond NTU<1, FC<10/100 ml Community based Handpump abstraction, followed by household- based disinfection - *Chlorine Tablets* 5) - *Bleaching Powder* 5) - **Boiling** - Solar Disinfection (SODIS) 6) Pond NTU<10, FC<100/100 ml - Community based Handpump abstraction, followed by household treatment. (and disinfection as above) - Conventional Household filtration 7) - *Household treatment by using alum* 8) - Treatment by Moringa Oliefera seeds 9)	Pond NTU<1, FC<10/100 ml - **Handpumped abstraction** plus household-based disinfection (see left hand box) Pond NTU<10, FC<100/100 ml - **Handpumped abstraction** plus household-based treatment and disinfection (see box to left) Pond NTU<100 - *Pond sand filter* 10) and optional disinfection (see left hand box)
Share an existing source (deep or shallow well)		- *Sharing arrangement between existing and new users*
Import water	- **Bottled water**	- **Tanker water**

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Legend: **Bold-** proven in Bangladesh, *Italics- proven elsewhere and considered feasible, Italics with underlines-* Proven and used in Bangladesh, but effective only with due care, Underline- Experimental or ill-documented, but considered feasible with due care

Notes:

1 extreme caution with dosing and sludge disposal

2 actual removal water-matrix specific, effluent As may not be below standard

3 Subject to testing for As, and FC (shallow wells only) Deeper, machine drilled wells will be too costly for household use

4 Design guidelines for Bangladesh are yet to be established, periodic disinfection may be required

5 Dosing must be appropriate

6 Selection of appropriate bottle and correct placement of bottle during use are critical

7 Produces water with slightly elevated FC, must be periodically cleaned and disinfected

8 Appropriate dosing must be determined, associated risk of excess alum ingestion

9. Appropriate choice to be advised

10 Pond-sand filter needs to be re-designed to reduce present operating deficiencies

2.11 POTENTIALLY SUITABLE TECHNOLOGIES

Table 2.6 presents a list of other potentially suitable technologies, distinguishing for household level solutions and community level solutions. Some of these technologies could possibly be applied in the future.

Table 2.6: The potentially suitable, additional technologies.

Application Options	*Household level*	*Community level*
Treat water from existing source (deep or shallow well)	– Sand-Khoa filtration (aeration-filtration) – Chemical package (improvement required) – Commercially available filter - local – Commercially available household units (membrane distillation, ion exchange)	– HP + iron removal plant (aeration) – Arsenic treatment at tubewell site – DANIDA designed arsenic removal plant – Arsenic treatment inside tubewell.
Start with a Surface water source (pond)	– Commercially available filtration units- improved	– Roughing filter + Slow sand filter

BAMWSP, 1999

2.12 CAPITAL COST OF CURRENTLY ACCEPTABLE TECHNOLOGIES

An attempt is made to compare the estimated capital cost involvement of major acceptable technologies in the Table 2.7. All technologies are meant to deliver 5 liters of water per capita per day. The average family size is taken as 6. There are differences of between the technologies especially in terms of water quality, level of service (e.g., walking distance), operation and maintenance easiness, present practice, environmental factors, level community participation requirement etc. However, the comparison table is prepared only based on the capital cost, not considering other factors related to the technology selection.

Table 2.7: Capital cost of technology

Technology	*Approximate Capital Cost (Tk.)*	*No. of families*	*Approx. Capital Cost per Family (Tk.)*
Shallow, arsenic-free groundwater:			
• VSST + handpump	7,158	6	1,193
• Ringwell + handpump	56,750	30	1,891
Arsenic-contaminated groundwater			
• Arsenic removal: bucket type	1,500	1	1,500
Deep, arsenic-free groundwater:			
• Deep Tubewell (200 m) + handpump	46,028	30	1,534
• Deep Tubewell + motorized pump			
a. with 1 village-level reservoir	1,021,050	600	1,701
b with distribution to 20 cluster-level tanks	1,768,100	600	2,946
Rainwater.			
• Roof water harvesting system	7,725	1	7,725
Surface water from pond:			
• Pond sand filter	18,809	30	630

In the above table, per family capital costs have been calculated using the assumptions made above for family number using a system. The technologies have been arranged in order of the water source options. The per family cost when calculated this way vary between a low Tk. 630 for the cluster-based pond-sand filter and Tk. 7,725 for the family-based rainwater water harvesting system. Most technologies cost between Tk. 1000 and 3000. (1 US$ = Tk. 48.5).

3

ARSENIC REMOVAL BY APPLICATION OF A COAGULANT

3.1 GENERAL

It reveals from the review of the different technologies for arsenic removal that conventional coagulation is the most promising low-cost arsenic reduction technology for rural Bangladesh. It is also observed that the arsenic in the groundwater is always associated with iron in groundwater. This study has taken a limited laboratory scale experiment to study the possibilities of identification of optimal coagulation (alum) dose for different arsenic-iron value in the groundwater. The groundwater samples taken from Bangladesh have been analyzed to determine a range for arsenic and iron in the groundwater. Jar tests have been carried out with different arsenic-iron spiked water by using different alum dosages. Experiments have been also carried out to test the arsenic removal possibilities by original iron present in the water. Residual aluminum in the treated water may be concern for using alum in the treatment process. However, residual aluminum concentration has not analyzed in this study.

This chapter reviews the previous studies on arsenic removal by coagulation, describes the experimental procedure and discusses the results of the experiments.

3.2 ARSENIC REMOVAL PRINCIPLES BY COAGULATION

Coagulation is one of the most used conventional treatment processes for drinking water treatment. The process comprises addition of coagulant, mixing, flocculation (formation and growth of flocs) and removal of flocs. The hydrous oxides of aluminum and iron formed during coagulation process are strong absorbents for many trace inorganic materials including arsenic.

Addition of iron or aluminum coagulants to water can facilitate the conversation of soluble As(V) and As(III) species into soluble reaction products. These products might form through precipitation, co-precipitation, or adsorption mechanisms. Precipitation refers to the insolubilization of contaminants by exceeding a solubility product, in this case that of either $Fe(AsO_4)$ or $Al(AsO_4)$ solids. Co-precipitation is defined as an incorporation of soluble arsenic species into a growing hydroxide phase via inclusion, occlusion, or adsorption. Finally, adsorption refers to formation of surface complexes between soluble arsenic and the solid oxyhydroxide surface site (Edwards, 1994).

Alum dissolution:

$Al_2(SO_4)_3.18H_2O = 2Al^{3+} + 3SO_4^{2+} + 18H_2O$

Aluminum precipitation:

$2Al^{3+} + 6H_2O = 2Al(OH)_3 + 6H^+$

Co-precipitation:

$H_2AsO_4^- + Al(OH)_3 = Al\text{-}As\ (complex) + Other\ products$

Arsenic absorbed on aluminum hydroxide flocs as Al-As complex is removed by sedimentation. Filtration may be required to ensure complete removal of flocs (Ahmed, 1999).

Amirtharajh and O'Melia (1990) indicated that freshly precipitated amorphous aluminum hydroxide, $Al(OH)_3$ (am), is formed by the addition of alum to water. A series of hydrolysis reactions occur as intermediate reactions (Table 3.1) prior to precipitation of $Al(OH)_3$.

Table 3.1: Aluminum Equilibria

SL. No.	*Reaction*	*Log K (25°C)*
1	$Al^{3+} + H_2O = AlOH^{2+} + H^+$	-4.97
2	$AlOH^{2+} + H_2O = Al(OH)_2^+ + H^+$	-4.3
3	$Al(OH)_2^+ + H_2O = Al(OH)_3 + H^+$	-5.7
4	$Al(OH)_3 + H_2O = Al(OH)_4^- + H^+$	-8.0
5	$2Al^{3+} + 2H_2O = Al_2(OH)_2^{4+} + 2H^+$	-7.7
6	$3Al^{3+} + 4H_2O = Al_3(OH)_4^{5+} + 4H^+$	-13.94
7	$13Al^{3+} + 28H_2O = Al_{13}O_4(OH)_{24}^{7+} + 32H^+$	-98.73
8	$Al(OH)_3\ (am) = Al^{3+} + 3(HO)^-$	-31.5

Amirtharajh & O'Melia (cited from Baes & Mesmer)

These reactions illustrate that alum hydrolysis produces hydrogen ions (H^+) and hence acts like an acid and often reduce the pH of the water. The pH reduction would depend on the alkalinity of the water. For every 1 mg/l of alum that reacts to produce a precipitate of aluminum hydroxide, 0.5 mg/l of natural alkalinity expressed as $CaCO_3$ is consumed. Thus, for example, when an alum dose of 30 mg/l is used, the alkalinity required for reaction is 15 mg/l and often when treating low alkalinity waters, lime or caustic soda is added to provide the necessary alkalinity and to keep the pH conditions in the range where aluminum hydroxide precipitate may be formed and optimum coagulation occurs.

According to thermodynamic data for aluminum equlibria, aluminum is least soluble around a pH of 6.2 (Figure 3.1). Below a pH of 5.7, freshly precipitated $Al(OH)_3$ (am) can be quite soluble and polymeric species such as $Al_{13}O_4(OH)_{24}^{7+}$can predominate.

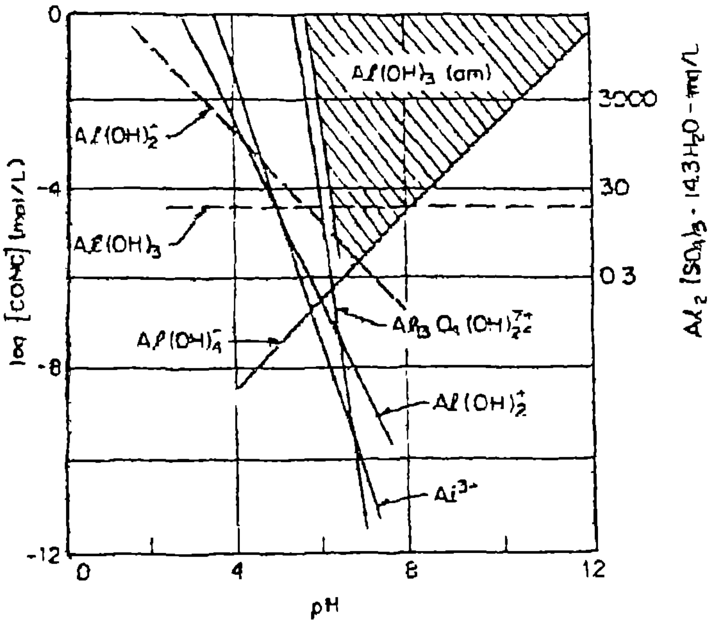


Figure 3.1: Solubility of aluminum with amorphous $Al(OH)_3$.

3.3 PREVIOUS STUDIES OF ARSENIC REMOVAL BY COAGULATION

Shen (1973) compared the ability of 20 mg/l doses of alum, ferrous sulfate, and ferric chloride to remove arsenic from well water (pH 6.8, 1.0 mg/l total arsenic) in bench-scale tests; arsenic removals of 32, 24 and 82 percent were achieved with the respective coagulants. He also observed that coagulation with $FeCl_3$ gave better removals when preceded by oxidation with chlorine. The dosages he used can be expressed in terms of Al^{3+}, Fe^{2+} and Fe^{3+} and the dosages were 1.8 mg Al^{3+}/l, 4.0 mg Fe^{2+}/l and 4.1 mg Fe^{3+}/l considering the chemical formula of alum, ferrous sulfate and ferric chloride are as $Al_2(SO_4)_3.14H_2O$, $FeSO_4.7H_2O$ and $FeCl_3.6H_2O$ respectively.

Gulledge and O'Conner (1973) spiked water with arsenic(V) and tested 10-50 mg/l alum [$Al_2(SO_4)_3$. $18H_2O$] and ferric sulfate [$Fe_2(SO_4)_3.3H_2O$] at pH 5-8 in a bench-scale study. Arsenic removal was function of pH and coagulant dose (Figure 3.2a and 3.2b). The pH dependence was much more pronounced for $Al(OH)_3$ than $Fe(OH)_3$. Arsenic adsorption on ferric hydroxide exceeded the adsorption on aluminum hydroxide, for example As(V) removal by adsorption on hydrous aluminum oxide was 93.6% (dosing 50 mg/l alum or 4.1 mg Al^{3+}/l) and on hydrous ferric oxide was 98.4% (dosing 50mg/l ferric sulfate or 12.3 mg Fe^{3+}/l). In both cases, increased coagulation dosage resulted in increased arsenic removal. As(V) adsorbed less on both $Al(OH)_3$ and $Fe(OH)_3$ at pH 8 that at a pH of 5-7. They also analyzed the arsenic lost at glassware and filter during coagulation process. The results showed that maximum 10.9% and 7.3% arsenic were lost to glassware during coagulation with aluminum sulfate and ferric sulfate respectively. Maximum 12.2% and 6.8% arsenic were lost to 0.45 µm cellulose acetate membrane filter for aluminum sulfate and ferric sulfate respectively.

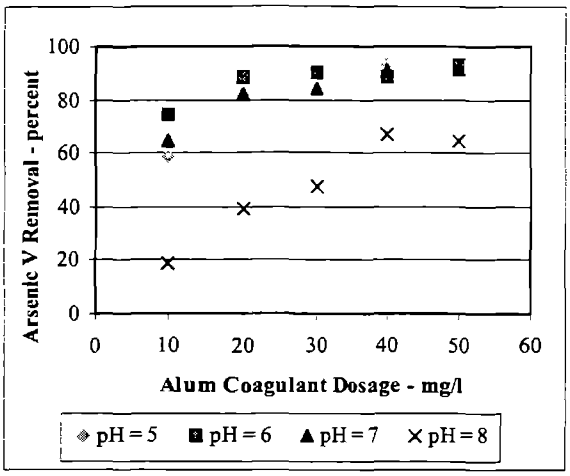


Figure 3.2a: Removal of Arsenic(V) by adsorption on hydrous aluminum oxide. (reproduction by using data)

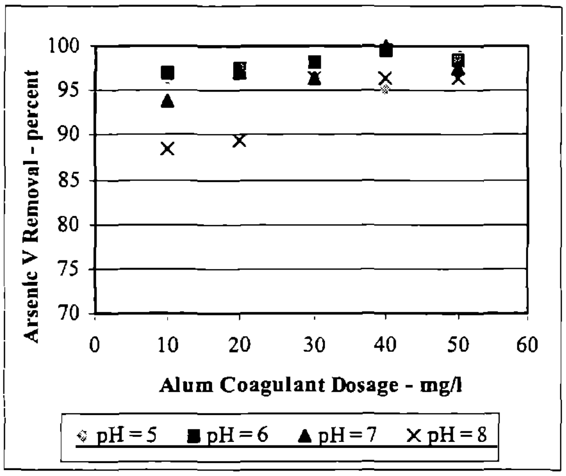


Figure 3.2b: Removal of Arsenic(V) by Adsorption on hydrous ferric oxide. (reproduction by using data)

Similar conclusions were drawn by Cheng *et al.* (1994) in treating As(V) spiked water at various pH conditions in bench, pilot and demonstration scale. According to their studies:

- $FeCl_3$ is more effective than alum when compared on an equal weight dosage basis.
- Alum is pH dependent, and the highest As(V) are achieved at pH<7.
- $FeCl_3$ coagulation is not pH-dependent between 5.5 and 7.0.
- Increasing coagulant dosage will increase As(V) removal.
- There is no correlation between turbidity removal and arsenic removal.

In their experiment the effluent was collected after being passed through a sand bed.

Cheng *et al.* also concluded that arsenic removal percentage appeared to have remained relatively constant in this study, regardless of the influent arsenic concentration. The arsenic concentration in the raw water varied from 2.2 to 128 µg/l for one plant (Figure 3.3) and from 4.4 to 13.3 µg/l for another plant.

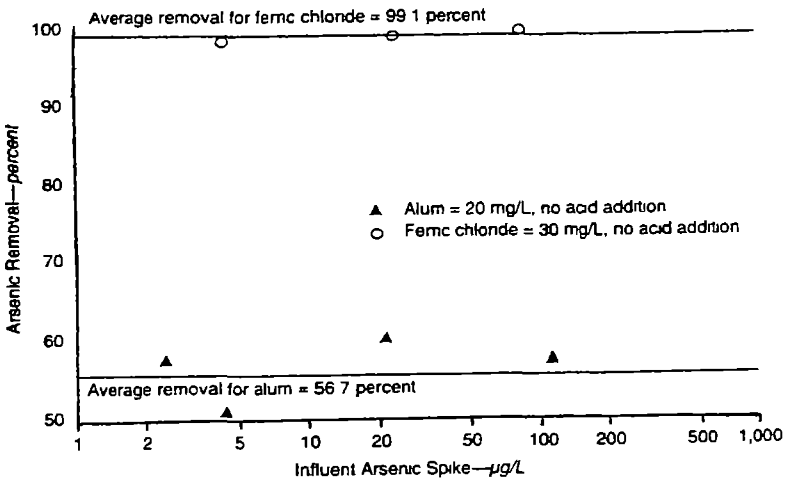


Figure 3.3: Comparative percentages of arsenic removal at varying influent arsenic spikes using alum and ferric chloride (Cheng *et al.*,1994).

Scott *et al.* (1995) evaluated the removal of naturally occurring arsenic in a full-scale conventional treatment unit. Average arsenic removals of 82, 89, 86, 94 and 96 percent were achieved when 3, 4, 5, 6.5 and 10 mg/l ferric chloride [or 18.5, 24.7, 30.8, 40.1, and 61.7 μM Fe(III)/l or 1.0, 1.4, 1.7, 2.2 and 3.4 mg Fe^{3+}/l] were used. Most of the arsenic removal (48-88 percentage) was achieved in the sedimentation basin. Alum dosages of 6 mg/l, 10 mg/l and 20 mg/l (0.6, 0.9 and 1.8 mg Al^{3+}/l) removed 23, 45 and 69 percent of the arsenic on an average. Influent arsenic concentration was ranging from 1.2 μg/l to 2.2 μg/l. On a metal-equivalent basis, Fe(III) removed more than arsenic than Al(III) in the pH range from 7.18-7.8.

Hering *et al.* (1996) conducted bench scale studies in model freshwater systems to investigate how various parameters affected arsenic removal. Under comparable conditions, better removal was observed for As(V) than As(III). The arsenic removal at pH 7 is shown in figure 3.4. Both As(V) and As(III) removal was dependent on coagulant dosages. Arsenic removal percentages were observed independent of initial arsenic concentration (2.0 to 100 μg/l). Below neutral pH values, As(III) removal was significantly decreased in the presence of sulfate. However, only a slight decrease in As(V) removal was observed. At high pH, removal of As(V) by adsorption was increased in the presence of calcium.

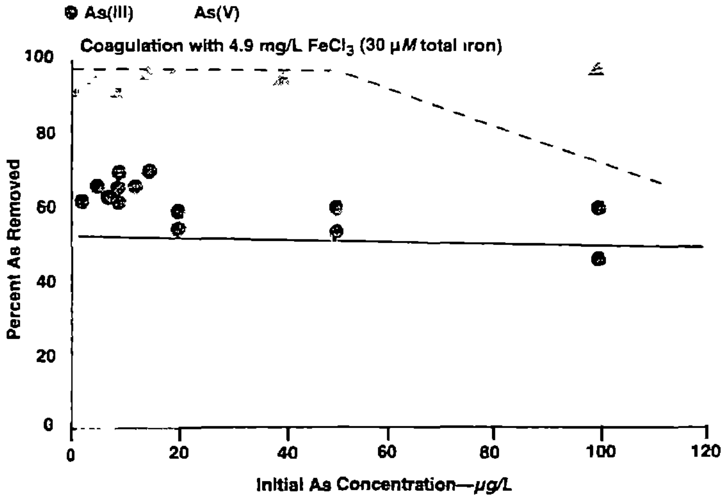


Figure 3.4: Efficiency of arsenic removal at pH 7 (Hering *et al*, 1996)

Rashid (1996) conducted batch experiments with As(III) and Fe(II) spiked water. The initial concentration of As(III) and Fe(II) were 200 μg/l and 5 mg/l respectively. He achieved 95% of As(III) removal by coagulation, when 8 mg/l Fe(III) and 12 mg/l Fe(II) is applied, followed by flocculation, sedimentation and filtration at pH 7. No oxidizing agent was used to oxidize As(III) into As(V). The process was dependent of pH (figure 3.5).

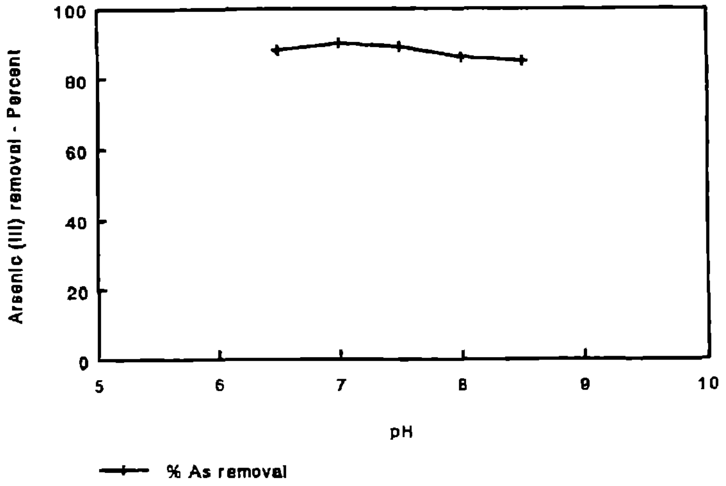


Figure 3.5: Arsenic (III) removal efficiencies as function of pH with coagulant $FeCl_3.6H_2O$ dose of 32 mg/l (or 6.6 mg Fe^{3+} /l) (Rashid, 1996).

Nath and Majumder (1997) analyzed the performance of alum in removal of arsenic with different samples of water. The performance indicated that the rate of removal of arsenic was dependent on remaining concentration of arsenic in water. Higher percentages of arsenic removal observed at higher alum and ferrous sulfate dosage. Their study results can be presented in the figure 3.6. 97% arsenic removal was observed with 60 mg/l alum dosage (5.5 mg Al^{3+}/l) at initial arsenic concentration 335 µg/l and pH 7.1. However, they were in the opinion that an optimal dosage could be derived for removal of arsenic and it is dependent on initial concentration of arsenic in groundwater.

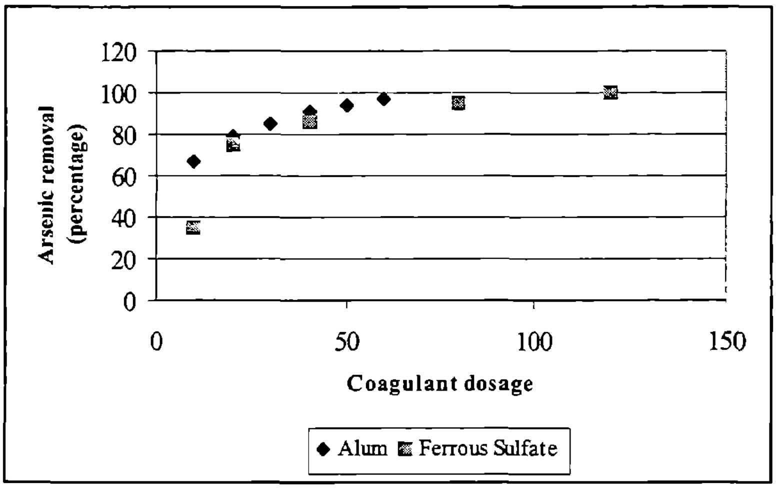


Figure 3.6: Arsenic removal efficiencies with coagulant dosages.

Dave (1997) conducted bucket type chemical treatment in the laboratory using initial arsenic concentration from 0.1 to 3.0 mg/l with As(V) as 60% and As(III) 40%. From findings, he proposed 3 types chemical packets to treat the raw water with different range of initial arsenic concentration for 12 liters water in bucket. The packets are:

Packet I for arsenic concentration 1.5 to 3.0 mg/l

Bleaching power, 20% chlorine	2.0 g
Ferric chloride	0.5 g
Fly ash	10.0 g

Packet II for arsenic concentration 0.5 to 1.5 mg/l

Bleaching power, 20% chlorine	1.0 g
Ferric chloride	0.25 g
Fly ash	7.0 g

Packet III for arsenic concentration 0.1 to 0.5 mg/l

Bleaching power, 20% chlorine	1.0 g
Ferric chloride	0.2 g
Fly ash	5.0 g

Liang (1998) carried a field study at Bangladesh on arsenic removal by bucket experiment using $FeCl_3$ $6H_2O$ and $Al_2(SO_4)_3.18H_2O$ and existing iron removal units (IRU). There was no clear correlation between the concentration of arsenic and the concentration of iron in raw groundwater, but a linear correlation was derived between the arsenic removal and the iron concentration in the raw water at the IRU. It was also fact that on simple weigh basis, $FeCl_3 6H_2O$ is about double as effective as $Al_2(SO_4)_3.18H_2O$. The use of 90 mg/l $FeCl_3 6H_2O$ (18.6 mg Fe^{3+}/l) and 200 mg/l $Al_2(SO_4)_3.18H_2O$ (16.2 mg Al^{3+}/l) were found sufficient to reduce the arsenic concentration from about 400 µg/l to 50 µg/l. However, $Fe(OH)_3$ flocs were big enough staying on the surface of the water instead of setting down to the bottom of the bucket. The appearance of red, thick $Fe(OH)_3$ flocs created fear among the illiterate people and was not found suitable due to its odd appearances. The resulting pH lies between 6.5 to 7, indicating that no adjustment of pH is required.

A DPHE-Danida Water & Sanitation Project based at Noakhali, Bangladesh has proposed bucket type arsenic removal at household level by coagulation. In that system, 4 gm (16.2 mg Al^{3+}/l) of powdered alum and 0.03 gm of powdered potassium permanganate have been added to the 20 the bucket of water having arsenic concentration from 160 µg/l to 1100 µg/l. The treated As concentration has come down to levels between 10 to 20 µg/l regardless of the initial concentration of As (DPHE/DANIDA, 1999). They have observed that 10-15 seconds stirring is sufficient for floc formation. The sludge collected on the lower bucket is emptied on weekly basis.

Conclusions:

Previous studies have been shown that conventional treatment with aluminum and iron slats can be used to remove arsenic from drinking water. The general findings of the studies are presented in the Table 3.2.

Table 3.2: Summary of the findings of previous studies on arsenic removal by coagulation (Shen (1973), Gulledge and O'Conner (1973), Cheng *et al* (1994), Scott *et al.* (1995), Hering *et al* (1996), Rashid (1996), Nath and Majumder (1997), Liang (1998) and DPHE/DANIDA (1999)).

Conditions	***Effects***
Effective coagulant	Ferric chloride and alum are found effective coagulants for arsenic removal. However, ferric chloride is more effective than alum on simple weight basis 20 mg/l alum and ferric chloride can remove 32 and 82 percent of As from water with initial arsenic concentration 1000 µg/l. On the other hand when considered as iron and aluminum as Fe^{3+}/l and Al^{3+}/l, the effectiveness is about same. 18.6 mg Fe^{3+}/l and 16.20 mg Al^{3+}/l were found sufficient to reduce the arsenic concentration from about 400 µg/l to 50 µg/l by bucket type removal at a specific location in Bangladesh.

Dosing of coagulant	Arsenic removal increases with the increase of coagulant dosages. For example- 1.8 mg Al^{3+}/l, 3.6 mg Al^{3+}/l and 10.9 mg Al^{3+}/l can remove 79.1%, 91 0% and 97 0% respectively from a water containing As 335 µg/l at pH 7.1.
Initial As concentration	Arsenic removal efficiency is less dependent on initial arsenic concentration (Figure 3.3). The mechanism is not explained. However, there is not consensus on this finding.
pH dependence	Arsenic removal is pH dependant and the pH is much more pronounced for $Al(OH)_3$ than $Fe(OH)_3$. Arsenic is best removed at pH 5 to 7 by alum.
Removal of As(III) and As(V)	As(V) is better removed than As(III). As(III) should be oxidized to As(V) for effective removal.
Major removal process	The main portion of flocs is removed by sedimentation process. 44-88% percentage can be achieved in sedimentation basin.
Effect of water matrix	Arsenic removal is affected by the water matrix that is present of sulfate, phosphate, calcium etc.. These can compete with As(V) for $Al(OH)_3$ or $Fe(OH)_3$.
Appearance of flocs	$Fe(OH)_3$ flocs are red, thick and big enough. $FeCl_3$ may not be feasible as household level due to its odd appearance to the illiterate people at rural Bangladesh.
Co-relationship between turbidity and arsenic removal	There is no direct relationship between turbidity reduction and arsenic removal.
Other factors	Glassware absorbs a substantial amount of arsenic. Maximum 10.9% and 7.3% arsenic can be lost to glassware during coagulation with aluminum sulfate and ferric sulfate respectively.

The results of the DPHE-DANIDA dosing and residual As and Al concentration should be evaluated before wide scale application.

3.4 RESIDUAL ALUMINUM IN DRINKING WATER

Whenever water is treated by alum then there is chance of residual aluminum in treating water. The current maximum limit of aluminum in drinking water of 200 µg/l has been adopted by the wide range of regulatory agencies including European Community (1980), World health Organization (1984) and US Environmental Protection Agency (1981) (Borikar, 1998). The proposed secondary maximum contamination levels for aluminum is 50 µg/l for U.S.A. (Cotruvo & Craig, 1990).

The metabolism of aluminum in human is not well understood, but it appears that inorganic aluminum is poorly absorbed and that most of the absorbed aluminum is readily excreted in urine. There is no evidence of carcinogenesis in studies using different mammals and aluminum slats. It is reported that Aluminum may cause certain neurological disorder such as 'Alzheimer disease'. In the country like Netherlands, use of alum is avoided in drinking water treatment (Borikar, 1998). However, this study did not consider the residual aluminum in the treated water due to limitation of time.

3.5 ARSENIC REMOVAL POSSIBILITIES BY NATURAL IRON

The use of naturally occurring iron precipitates in groundwater of Bangladesh is a promising method of removing arsenic by adsorption. It has been found that hand tubewell water in 65% of the area in Bangladesh contains iron in excess of 2 mg/l and in many acute problem areas, the concentration of dissolved iron is higher than 15 mg/l. Although no good correlation between concentration of iron and arsenic has been derived, iron and arsenic have been found to co-exist in groundwater. Most of the tubewell water samples satisfying Bangladesh Drinking Water standard for iron (1 mg/l) also satisfy the standard for arsenic (50 µg/L). About 50% of the samples having iron content 1-5 mg/l satisfy the standard for arsenic while 75% of the samples having iron content > 5 mg/l are unsafe for having high concentration of arsenic (Ahmed, 1999).

Precipitation with Fe(III) and subsequent filtration of the generated precipitates has proved to be an adequate method to remove As(V) from water. The binding mechanism is the most probably the adsorption of arsenate molecules to the surface of the precipitates Fe(III) hydroxide (Rashid, 1996 cited from Broho & Merkl, 1993).

Schematically, the As(III)/As(V) removal process is shown in the following diagram.

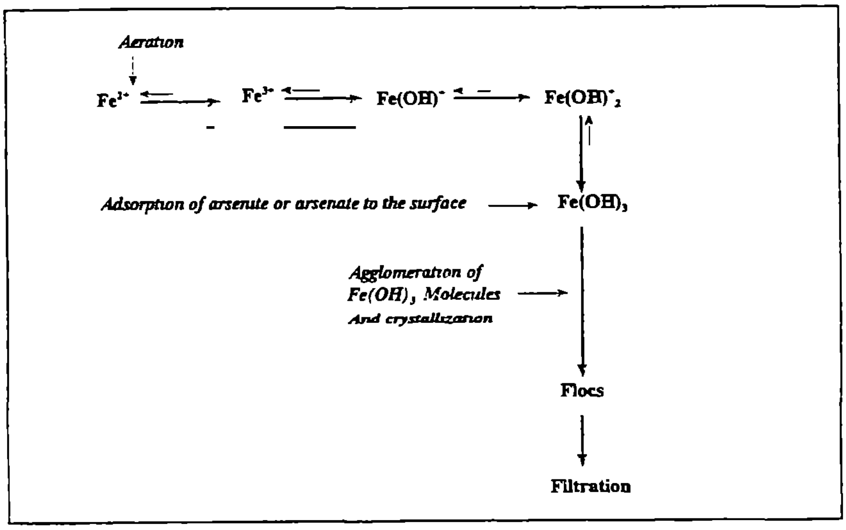


Figure 3.7: Schematic diagram, showing As(III) and As(V) removal mechanism by Fe-oxidation followed by agglomeration and filtration.

3.6 METHODOLOGY OF LABORATORY EXPERIMENTS

Identification of the optimal alum dosing for different arsenic-iron content water is the objective of laboratory experiment of this study. To achieve this objective, the following sequential activities were carried out.

- Groundwater samples collection from arsenic affected area in Bangladesh and analysis at IHE laboratory.
- Selection of the concentration of arsenic and iron in the model water.
- Jar tests with the arsenic-iron spiked water.

In addition to the above activities, jar tests were carried out without addition of coagulant to study the possibility of arsenic removal using original iron in water.

3.7 ANALYSIS OF ARSENIC CONTAMINATED WATER

To determine the arsenic concentration and iron concentration in the groundwater, water samples collected from the Bangladesh and was analyzed at IHE laboratory. The samples were collected from Chuadanga, one of the arsenic affected districts of Bangladesh with an area of 1,160 square kilometers and population of 228,000. The position of Chuadanga is 23°37' N (latitude) and 88°65' E (longitudinal) (Figure 1.1). According to the physiographic division, this area is in the inactive Ganges delta, which is composed mainly of deltic silt deposits. Stratifically this area represents the stable shelf facies boarded by the active Gangatic flood planes to the North and NorthEast and tidal deltic deposits in the south. The groundwater samples analyzed in the DPHE zonal laboratory shows that the average value arsenic concentration in the contaminated groundwater lies between 200 to 300 µg/l. Some of samples contain high arsenic concentration (more than 750 µg/l). Chaudanga is also an iron affected area. However, the iron concentrations of these arsenic affected tubewells are not available.

The analytical instruments, chemical required to test arsenic and iron is described in Annex –A1. The arsenic analysis procedure is also explained in Annex-A2.

3.7.1 RESULTS OF THE EXPERIMENTS

20 groundwater samples were collected from the 5 unions of Chaudanga districts. The samples were collected in 100 ml plastic bottles and 0.5 ml HNO_3 was added into each bottle as preservative. The samples were analyzed at the IHE laboratory within 15 days

of collection. It may noted that the standard preservative for total metal analysis is 5 ml HNO_3 per liter and the maximum holding period is 6 months.

The results of the As and Fe analysis are presented in the Table 3.3 along with the installation year and depth. The Figure 3.8 shows the iron concentration against the arsenic concentration in the groundwater.

Table 3.3: Results of water sample analysis.

Sample No.	*Name of Caretaker*	*Union*	*Installation Year*	*Depth (ft)*	*As Conc. (µg/l)*	*Fe Conc. (mg/l)*
1	Court Building	Damurduda	1998	107	110	6.5
2	Damududa Thana	Damurduda	1998	86	105	8 4
3	Md. Abdul Samad	Damurduda	1997	110	95	7
4	Md. Abdul Awadud	Damurduda	1998	55	120	3.1
5	Dil Mohammod	Damurduda	1998	127	130	4.6
6	Md Akkas Ali	Damurduda	1998	122	115	3 8
7	Mojibur Rahman	Damurduda	1997	107	210	6.3
8	School Para Mosque	Damurduda	1997	84	380	11.6
9	Hawli UP Office	Hawli	1998	90	130	3
10	Md. Lokman Munshi	Hawli	1998	100	175	1.4
11	Md. Abdul Jalil Mondal	Hawli	1997	105	180	6.9
12	Md. Abdul Sattar	Kuralgachi	1998	90	125	9
13	Md. Sultan Mondal	Kuralgachi	1997	115	125	5
14	Md Motiar Rahman	Parkrisnopur	1998	75	405	7.2
15	Md Noor Haque	Juranpur	1997	122	170	6.3
16	Md. Kamruzzaman	Juranpur	1996	138	640	25 9
17	Md. Sawkat Ali	Juranpur	1997	105	405	11.8
18	Md. Saiful Islam	Juranpur	1997	75	50	0.2
19	Md. Azizul Haque	Juranpur	1998	122	145	3.1
20	Md Zaman Uddin	Juranpur	1999	105	240	6

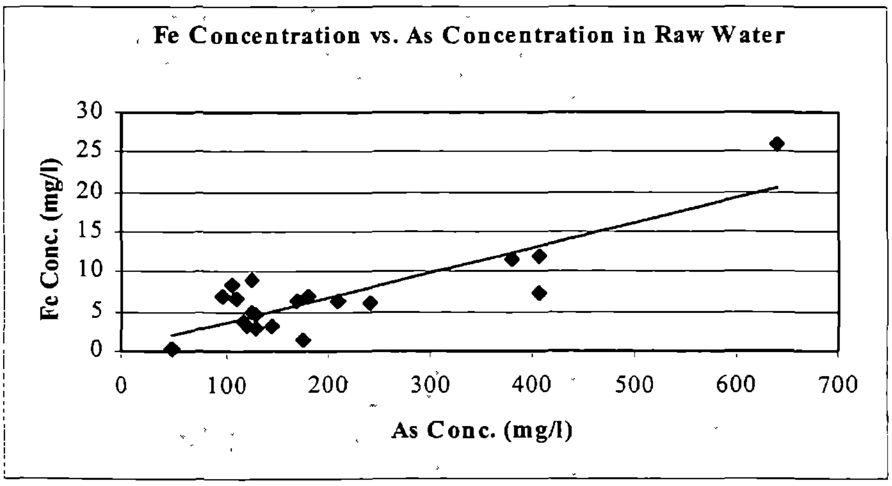


Figure 3.8: Iron concentration vs. Arsenic concentration in raw water.

It can be shown from the table that, all these tubewells has been installed in the recent years (1997-1999) with depth varies from 55 ft to 138 ft (16.76 m to 42.06 m).

The figure 3.3 shows that water containing high arsenic also contain high iron. This may be due to arsenic mediation from arseopyrites (FeAsS). However, there was no linear relationship between arsenic and iron concentration in groundwater. It is not possible to predict the arsenic concentration in a groundwater by using iron concentration. But, the presence of high iron contain associated with high arsenic contain provides an opportunity to explore the possibilities to remove the arsenic using the natural iron in groundwater.

The arsenic concentration varied from 50 µg/l to 640 µg/l and the iron concentration varied from 0.2 mg/l to 25.9 mg/l. The average arsenic concentration was 203 µg/l and average iron concentration was 6.9 mg/l.

From the basis of this result, the model water for the coagulation experiments were selected. The arsenic concentration were taken 200 µg/l, 400 µg/l and 600 µg/l. The iron concentration were taken 3 mg/l, 6 mg/l and 9 mg/l. So, 9 types model water were prepared for the experimental purposes. These are listed in Table 3.4.

Table 3.4: The concentration of As(V) and Fe(II) in model waters

SL. No.	*Concentration of As(V), µg/l*	*Concentration of Fe(II), mg/l*
1	200	3
2	400	3
3	600	3
4	200	6
5	400	6
6	600	6
7	200	9
8	400	9
9	600	9

3.8 JAR TESTS WITH ARSENIC-IRON SPIKED WATER

Jar tests were conducted with different model water (Table 3.4) having different As(V) and Fe(II) concentration. The objective was to identify the optimal alum dosing for different arsenic-iron content water.

3.8.1 EXPERIMENTAL APPARATUS AND CHEMICALS

Experimental apparatus:

- Jar test apparatus – stirring set (200 rpm): C6F VELP Scientifica
- Polyethylene and borosilicate glassware beakers- 1000 ml
- Polyethylene syringes: 10 ml
- Polyethylene containers: 100 ml, 1000 ml
- Other borosilicate glassware (volumetric flasks, pipettes, measuring flasks etc.)
- Weighing machine

Analytic instruments:

- Atomic absorption spectrometer (AAS): Perkin Elkin Elmer 1100 B with graphite furnace and HGA 300 programmer – for total arsenic analysis.
- pH meter: Metrohm 691
- Turbidity meter: DR LANGE LT4

Chemical and reagents:

- Arsenic pentaoxide, As_2O_5
- Ferrous sulfate, $Fe_2SO_4.7H_2O$
- Aluminum sulfate heytahydrate, $Al_2(SO_4)_3.14H_2O$
- Calcium hypochlorite, $Ca(OCl)_2.4H_2O$
- Sodium bicarbonate, $NaHCO_3$
- Demineralized water
- Nitric acid, HNO_3: AR grade- Merck
- Nickel nitrate, $NiNO_3$: AR grade- Merck

3.8.2 EXPERIMENTAL PROCEDURE

A series of experiments were conducted with the different model water by using the jar test equipment. To increase the buffer capacity of the model, 200 mg/l HCO_3^- was added to the water.

In the jar test, a series of 1 liter beakers was used. The beakers were filled with the model water. The model water was prepared using the stock solution of As(V) and Fe(II) and powder sodium bicarbonate just before the experiment. Aluminum sulfate (coagulant) and calcium hypochorite were added as quickly as possible in the powder form to the beakers during stirring at 200 rpm. The doses of aluminum sulfate were 60, 80, 100, 120, 140 and 160 mg/l as $Al_2SO_4,14H_2O$ (or 5.45, 7.27, 9.08, 10.9, 12.72 and 14.54 mg Al^{3+}/l). The calcium hypochorite dosage was 10 mg/l (3.3 mg Cl_2/l). The calcium hypochorite would serve three purposes in the field experiments. It would oxidize As(III) if present in that form, increase the pH of water and also act as a disinfectant. In the experiments with model water containing 200 μg/l As(V) with 6 mg/l and 9 mg/l of Fe(II), the 20 mg/l and 40 mg/l of aluminum sulfate (or 1.8 mg Al^{3+}/l and 3.6 mg Al^{3+}/l) were also used to study the effect of lower alum dose. The pH was maintained 6.9± 0.05 by adding 0.1 M of NaOH drop wisely. After 1 minute, the stirrer was set to 15 rpm and continued for 50 minutes and after that switched off. The solutions were kept undisturbed to settle down the flocs.

To study the effect of the settling time over the arsenic removal by coagulation process, one set of experiment with As(V) concentration 600 μg/l and Fe(II) concentration 3 mg/l were carried out by adding 40, 60, 80 and 100 mg/l aluminum sulfate and kept for 24 hours. The samples were taken after 1 hr, 4 hr and 24 hr. The results and related figure are shown in Annex A3. The result showed that arsenic removal increases with the settling time when we compared the absolute values. However, there was no marked improvement on arsenic removal efficiencies. The average arsenic removal for the settlement time 1 hr, 4 hr and 24 hr were 94.1%, 95.7% and 96.8%. These differences were not very significant and the samples were taken after 1 hr on further experiments.

From the settled samples, 10 ml water samples were taken from the supernatant of each beaker by 10 ml syringe. However, the samples were not filtered with 0.45 μm pore size filter paper after the settlement. An earlier experiment was carried out by filtering the supernatant with 0.45 μm glass fiber paper (GF6). The results showed that the arsenic content after the filtration was below the detection limit (detection limit – see annex A4). It may noted that Ningnoi (1999) reported for the same type of filter paper that filter paper could remove more than 70% arsenic when from a water having 95 μg/l arsenic in water. The filter paper was not used in the further experiments as such filtration is not used at the field level of Bangladesh.

A set of experiment was also carried out without addition of aluminum sulfate and calcium hypochorite to observe the arsenic removal capacity of iron present in the raw water. The model water mentioned in the table 3.3 was used along with a high concentration of Fe(II) e.g. 12 mg/l. The samples were taken after the 24 hours settlement. This longer time was provided as no oxidizing agent was used in this process.

3.8.3 ANALYSIS METHOD

The analysis of the arsenic samples carried in the same procedure described in the Annex A2.

3.8.4 EFFECT OF INITIAL IRON CONCENTRATION ON ARSENIC REDUCTION

The results of the arsenic removal with different aluminum sulfate dosing with different model water are listed in the Table 1 to Table 9 in the Annex A4.

The arsenic removal with different aluminum sulfate dosing and different initial iron concentration for initial arsenic concentration 400 μg/l and 600 μg/l are shown in the Figure 3.9 and 3.10 respectively.

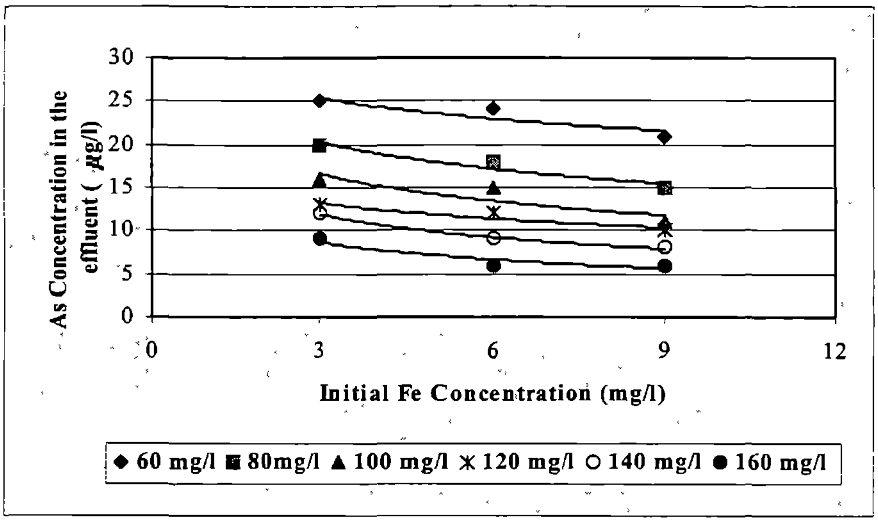


Figure 3.9: Effect of initial Fe concentration and dosing on arsenic removal with initial As concentration 400 μg/l.

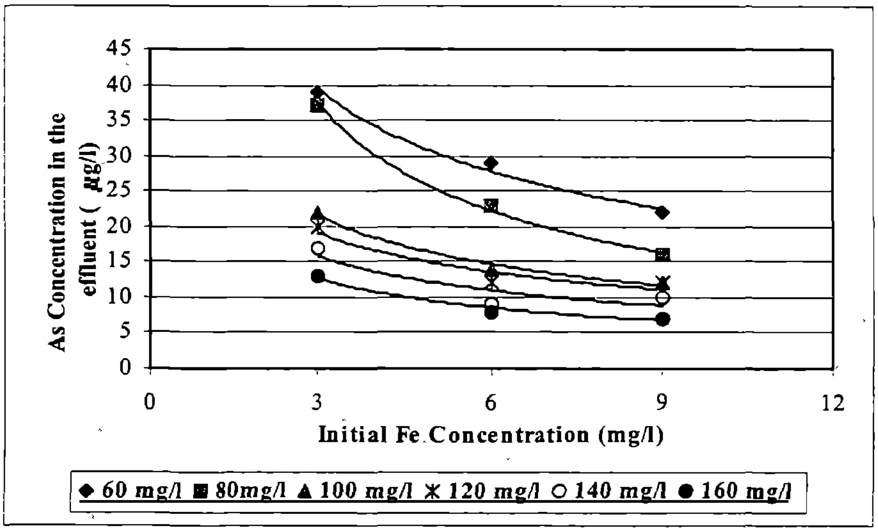
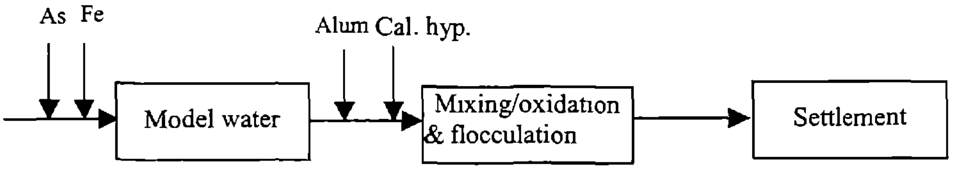


Figure 3.10: Effect of initial Fe concentration and dosing on arsenic removal with initial As concentration 600 μg/l.

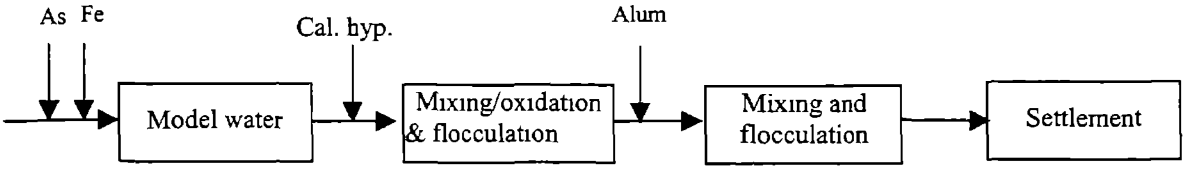
The results and figures show that arsenic removal increases with the increase of aluminum sulfate dosing and also with the initial iron concentrations. The higher As removal for higher coagulant dosages may be due to the increased amount $Al(OH)_3$ produced in the in the coagulation process which leads to formation of higher amount of Al-As (complex) in the co-precipitation process and settles at the bottom of the beaker.

The original iron present in the water is in Fe(II). This Fe(II) is oxidized by the addition of calcium hypochorite during the stirring process in jar test. The Fe(III) forms $Fe(OH)_3$ and where As(V) adsorption takes place and also Fe-As complex co-precipitation takes place and settles down at the bottom of the beaker. The higher Fe(II) produces the higher amount of $Fe(OH)_3$ which may be reasons for higher As removal with higher Fe concentration in water.

The sequence of the treatment process used in the experiments can be shown schematically as follows,



The arsenic removal may be increased if the calcium hypochlorite and alum are added in the following sequence. The iron present in the water will be first oxidized and $Fe(OH)_3$ can remove a substantial part of As. In the second stage, the As will be removed by $Al(OH)_3$.



3.8.5 EFFECT OF INITIAL ARSENIC CONCENTRATION ON ARSENIC REDUCTION

The As concentration in the effluent against the initial As concentration for initial Fe concentration 3 mg/l is shown in the Figure 3.11. The arsenic removal efficiencies for Fe concentration 3 mg/l with different dosing are also shown in Figure 3.12.

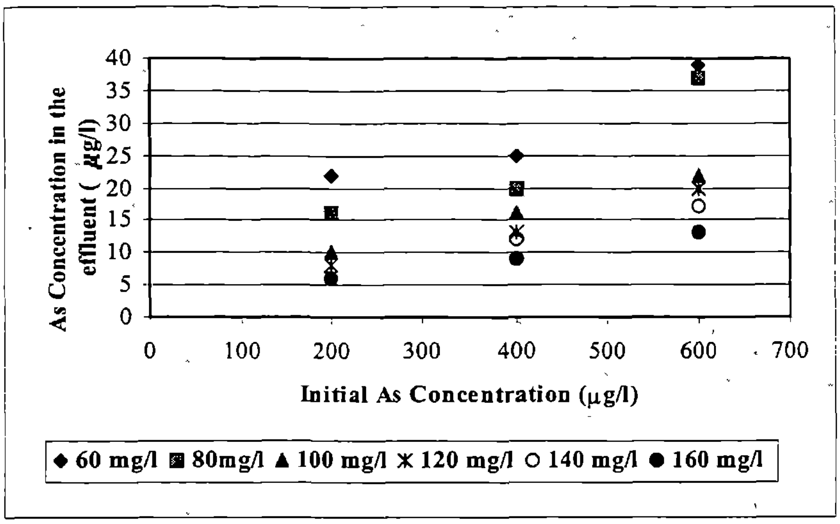


Figure 3.11: Effect of initial As concentration and dosing on arsenic removal with initial Fe concentration 3 mg/l.

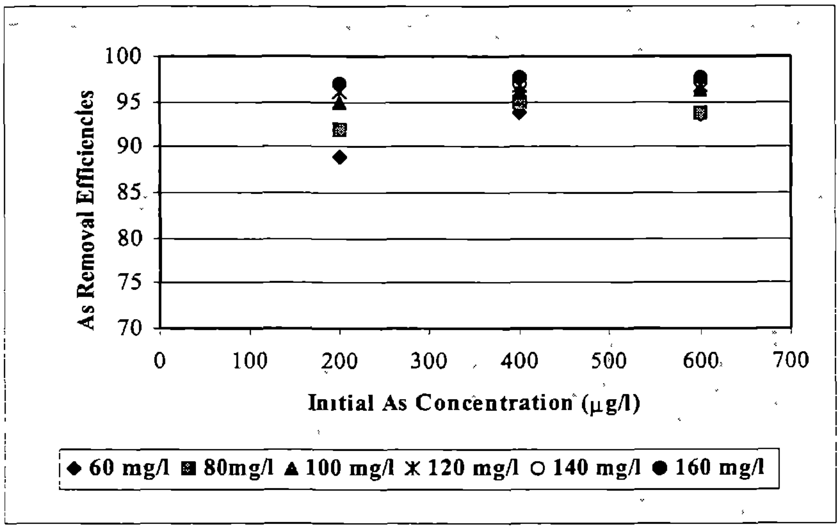


Figure 3.12: Effect of initial As concentration and dosing on arsenic removal efficiencies with initial Fe concentration 3 mg/l.

The Figure 3.11 shows that higher dosing is required to reach the WHO recommended guideline for higher concentration of arsenic. This probably due to higher $Al(OH)_3$ requirement at higher As concentration to create Al-As complex.

From Figure 3.12, it is observed that the removal efficiencies are not varied significantly with the initial arsenic concentration. This finding is analogous to the findings of Cheng *et al.* (1995) and Hering *et al.* (1996). However, they did not explain the reason behind this phenomenon.

3.8.6 IDENTIFICATION OF OPTIMAL DOSING

Identification of the optimal dosing for different arsenic-iron containing water is the objective of the laboratory experiments. The optimal dosing is expected to produce the less amounts of the waste and less amounts of residual aluminum. From the experiments, it is possible to identify the optimal dosing for the different model waters. The optimal dosing for different model waters to reduce the arsenic concentration to WHO guideline values are listed in the Table 3.5.

Table 3.5: The optimal dosing for model waters

SL. No.	*Concentration of As(V), µg/l*	*Concentration of Fe(II), mg/l*	*Optimal dosing $Al_2(SO_4)_3.14H_2O$ mg/l*	*Optimal dosing Al^{3+} mg/l*
1	200	3	100	9.1
2	400	3	160	14.6
3	600	3	180*	16.4
4	200	6	80	7.3
5	400	6	140	12.7
6	600	6	140	12.7
7	200	9	60	5.5
8	400	9	120	10.9
9	600	9	140	12.7

* Estimated

It can be concluded that from the extensive experiments with the different arsenic-iron containing water, it is possible to guide in selecting the optimal dosages. It will minimize the chemical needs in the coagulation process and reduce the load of sludge handling.

3.8.7 ARSENIC REDUCTION USING ORIGINAL IRON

The results of the experiments with original iron in raw water (without addition of coagulant and calcium hypochlorite) are illustrated in the Figure 3.13 and given in Table 1 in Annex A5.

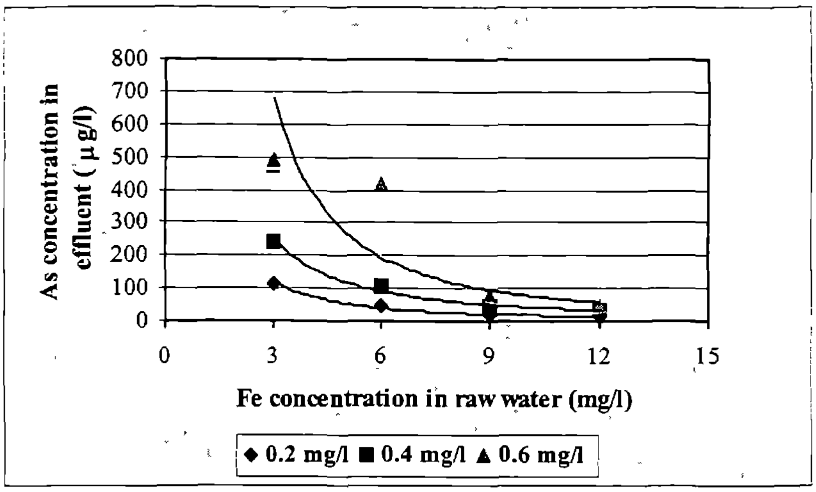


Figure 3.13: Effect of original iron concentration in raw water on arsenic removal.

The result shows that arsenic removal can be possible using the original iron present in raw water and it is dependent on the initial iron and arsenic value. The higher the initial iron value, the better the arsenic removal is achieved. The maximum 42.5%, 77%, 88% and 93% removal efficiencies are observed with the iron concentration 3 mg/l, 6 mg/l, 9 mg/l and 12 mg/l respectively. At the iron concentration value 12 mg/l, the arsenic removal efficiencies are relatively constant for initial arsenic 200 μg/l, 400 μg/l and 600 μg/l. The Bangladesh arsenic standard (50 μg/L) was obtained from initial As(V) concentration 200 μg/L, 400 μg/L and 600 μg/L when the original iron concentrations in the raw water were 6 mg/l, 9 mg/l and 12 mg/l. However, addition of oxidizing agent may improve the removal efficiencies. The arsenic removal using the original iron should be evaluated in the field by using different natural water and can be considered one the most suitable technology in different parts of Bangladesh where the groundwater contains very high iron.

3.8.8 TURBIDITY REDUCTION OVER TIME

The results of turbidity reduction over the time with different aluminum sulfate dosing for model water no. 8 (As 400 μg/L and Fe 9 mg/l) is given in Table 1 in Annex A6 and shown in the Figure 3.14.

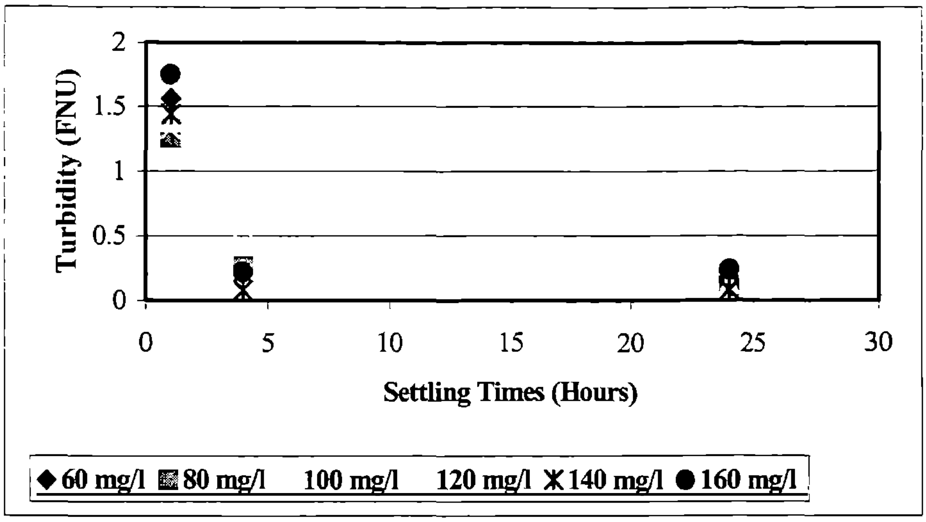


Figure 3.14: Turbidity reduction over settling time.

The figure shows that the turbidity of the treated water is very low and most of flocs were settled within 4 hours. The very low turbidity suggests that the As(V) present in the treated water was mainly in the dissolved form. There was no distinct effect of dosing on turbidity reduction. It was also no relationship between arsenic removal and turbidity. This finding is similar to the findings of Cheng *et al.* (1995).

3.9 CONCLUSIONS AND REMARKS

The experiments were carried out to identify the optimal dosing for different arsenic-iron containing water. The arsenic and iron concentrations were determined by analyzing water samples from an arsenic affected area of Bangladesh. The experiments were carried out with different model waters having different arsenic-iron concentration. The effect of the iron and other related factors were also considered in the experiments. The following conclusions are drawn on the basis of the experiments carried out in the study.

- High arsenic was associated with the high iron concentration in the groundwater of Chuadanga, Bangladesh. However, there was no direct correlation observed between arsenic and iron concentrations. The average arsenic concentration was 203 μg/l and average iron concentration was 6.9 mg/l.

- 96% As(V) was removed from water having arsenic concentration 200 μg/l and iron concentration 6 mg/l by addition of 80 mg/l aluminum sulfate (7.3 mg Al^{3+}/l) and 10 mg/l calcium hypochlorite (3.3 mg Cl_2/l). Arsenic removal increased with the increasing coagulant dosages. This is the general finding of the previous experiments.

- Presence of iron in the water enhanced the arsenic removal in the coagulation process. The residual As in the treated water was 20 µg/l, 18 µg/l and 15 µg/l for initial iron concentration 3 mg/l, 6 mg/l and 9 mg/l respectively when 80 mg/l aluminum sulfate (7.3 mg Al^{3+}/l) and 10 mg/l calcium hypochlorite (3.3 mg Cl_2/l) was added to the water having arsenic concentration 400 µg/l.

- Arsenic removal efficiency was almost constant regardless of initial arsenic concentration. The removal efficiencies were 95%, 96% and 96.3% for initial arsenic concentration 200 µg/l, 400 µg/l and 600 µg/l respectively by addition of 100 mg/l aluminum sulfate (9.08 mg Al^{3+}/l) and 10 mg/l calcium hypochlorite (3.3 mg Cl_2/l). This finding is analogous to the findings of Cheng *et al.* (1995) and Hering *et al.* (1996).

- The optimal dosing to achieve the WHO guideline can be identified for different initial arsenic-iron concentration in water (Table 3.5).

- Arsenic removal was also achieved by using the iron present in the water. The Bangladesh arsenic standard (50 µg/L) was obtained from initial As(V) concentration 200 µg/L, 400 µg/L and 600 µg/L when the initial iron concentrations were 6 mg/l, 9 mg/l and 12 mg/l.

A substantial amount of arsenic removal by addition of alum was achieved in the laboratory experiments. A dosage of 60 mg/l alum (5.5 mg Al^{3+}/l) and 10 mg/l calcium hypochlorite (3.3 mg Cl_2/l) brought the effluent arsenic concentration below the Bangladesh standard for 9 types of model water used in the laboratory experiments. It can be concluded that a standard dosing can be applied to a range of water qualities to reduce the arsenic concentration to the Bangladesh standard. Considering the water quality (only arsenic and iron) of the study location, a single standard coagulant dosing of 60 mg/l alum (5.5 mg Al^{3+}/l) and 10 mg/l calcium hypochlorite (3.3 mg Cl_2/l) can be suggested to apply for the treatment of arsenic.

However, optimal dosing can be recommended for different arsenic-iron concentrations. The optimal dosing is expected to produce the less amounts of the waste and less amounts of residual aluminum.

This technology is also attractive due to very low capital investment. The capital cost (arsenic removal by addition of coagulant bucket type treatment in the field level) includes the cost of 4 to 6 plastic buckets and same number of plastic taps. The costs of chemicals (alum and calcium hypochlorite) are low. These chemicals are readily available in the scientific shops in all towns and can be supplied to the rural areas in a small packet (the dosage to one bucket).

However, the wide-scale application of the arsenic removal by coagulation is subject to many other factors. By using alum for the treatment of arsenic containing water, we may move to another dangerous contaminant- aluminum. It is especially the case, when a high alum dosage is applied to a very low concentration of arsenic containing water. Handling the sludge produced in this process is also a major concern. The release of the heavy metals from the sludge is not clearly understood. These should be kept in mind before promoting this technology.

The experiments were carried out in a limited scale with the model water. Arsenic removal may be decreased, when natural well water is used for the experiment due to the influence of water matrix. Phosphate ions or sulfate ions present in the water can compete with As(V) on the hydroxide surface. Moreover, stirring is a major determining factor for a coagulation process. The manual stirring at the field level will reduce the arsenic removal efficiencies. However, it is possible to develop a mechanical device using locally available low-cost materials to stir the water continuously.

Where no other technology is available, arsenic removal by coagulation can be used as a potential arsenic mitigation technology for the intermediate period. It can only be confidently promoted for wide-scale application only when the further study will confirm the residual aluminum concentration is within allowable range and the sludge produced can be safely handled without endangering the environmental.

The arsenic removal using the iron present (> 6 mg/l) in the water is also appeared as a promising option for arsenic reduction. This removal can be achieved in many instances where the groundwater contains very high arsenic. Addition of oxidizing agent may improve the arsenic removal process.

4

RAINWATER HARVESTING

4.1 GENERAL

Rainwater harvesting and storage do not constitute a new technology. It has been used for domestic, agricultural, runoff control, air-conditioning etc. for a long time. Historical sources mention the use of rainwater for potable water supply some 4000 years ago in the Negev desert. Interest in the use of rainwater as an alternative or supplemental source of water for domestic water supply has been stepped up recently. It particular in developing countries where due to a number of problems, availability of adequate and potable water within easy reach is not always assured. Also, the cost of supplying water to the people through pumped, gravity or other schemes is higher than can be affordable. The rainwater harvesting is considered as a possible answers to the global water use problem, especially where surface and groundwater are limited.

Rainwater harvesting is not a common practice in Bangladesh. Only 35.5 percent households have been found to use the rainwater as drinking water source during the raining seasons in coastal areas having high salinity problems (Hussain & Ziauddin, 1989). Rainwater is considered as a potential arsenic free water source in the context of groundwater arsenic contamination.

Rainwater harvesting is the process of the interception of rainwater from the air and conveying it towards a reservoir from which the water is withdrawn for consumption. It requires adequate provision for interception, collection and storage of the water.

Rainwater is collected as it runs from roofs, or as surface runoff flowing of natural ground, roads, yards, or specially prepared ground surface catchments. Rock catchment systems can also be possible where unjoined rock outcrops provide suitable catchment surfaces. The runoff is channeled along stone and cement gutters constructed on the rock surface into reservoirs contained by concrete dams (Gould, 1991). Depending on circumstances, rainwater is collected from roofs or while running over ground surfaces. As the rainwater collected from roofs is usually quite clean, this water is best used for drinking and cooking purposes. Additional water needed for washing and watering a vegetable garden can be taken from less clean sources such as underground tank collecting surface runoff (Hofkes, 1981). Rooftop rainwater harvesting system seems suitable for Bangladesh, as the system will be designed only to supply drinking and cooking water.

In this study, am attempt is made to calculate the required storage volume for rainwater harvesting system in different parts of Bangladesh. The different low-cost materials used for storage tank construction in the other countries was reviewed and some materials are selected on the basis of cost, availability of local materials, skill, performance etc. The costs of these materials are estimated in the context of Bangladesh. The costs of different guttering materials are also estimated. The constraints of implementation of rainwater harvesting system in rural Bangladesh are identified and steps to overcome the constraints are also discussed.

4.2 COMPONENTS OF ROOFTOP RAINWATER HARVESTING SYSTEM

A typical rainwater harvesting systems mainly consist the following components (adapted from Hasse, 1989, CWSSP, 1995, Michaelides & Young, 1985, Hofkes, 1981, Lee & Visscher, 1992, Skinner & Franceys, 1992).

Suitable roof catchment

The roof of a domestic dwelling is the commonest form rainwater catchment for domestic water supply. The roofing surface should be smooth dense (hard inorganic) since this is less likely to catch and hold wind-blown dust and debris. It is preferable for a roof to be galvanized metal (corrugated plates or galvanized iron). Lead roofs and asbestos cement sheeting are unsuitable because of health concerns. Thatched roofs pose problems as the runoff is lower and generally of a low quality. It is also more difficult to fix gutters to thatched roofs. It can be used with a surface cover by plastic sheet when there is no other alternative is available.

The size of the roof will depend on the size of the house. The quantity of rainwater that can be collected through roof catchment will largely determined by the effective area of roof and local rainfall. The greater the size of the roof catchment, the smaller is the storage volume with same rainfall data.

The shape of any given catchment area has considerable influence on the catchment possibilities. Therefore different types of roofs provide different catchment possibilities. The most common roof type are flat roof, single pitch roof, double pitch roof, hip roof and tent roof. The single pitch roof is the most appropriate as the entire roof area can be drained into single gutter on the lower side and one or two down-pipes can be provided depending on the area.

Gutter & down pipe system

Gutter and down-pipe are collecting and conveying systems. Gutter is fixed with roof catchment in a gentle slope and connected to the down-pipe that ends up with the inlet of the storage tank. This connection can be made from locally available materials like bamboo and wood. However, GI and PVC provide better results. Sizing of this installation depends on roof area. It is necessary to make the joints leak-proof to reduce water losses and this can be a major problem with many of the locally produced gutters.

Flushing system

This arrangement is required to catch the first flush or bypass for flushing the roof. It prevents the contamination that results from first flush that is mixed with leaves, birds dropping, and other dirt. For small systems, simply fixing a small length of flexible hose at the end of can do this. When the roof is being flushed the flexible hoses should be taken out of storage tank inlet, and directed to a drain. Once the roof is clean this could be inserted back into the storage tank.

Filter

The sand filter is the step before the storage tank to purify the collected rainwater. Installation of a filter will certainly improve the water quality, but it will also increase the cost of the system. This filter system is not common in the rainwater harvesting system. Cloth and netting are used as screen instead of filter to reduce the cost of the system.

Storage tank

It is the most important component of rainwater harvesting system. Safe storage of rainwater throughout the year is the main objective of the storage tanks. The size of the rainwater storage depends on demand, amount and distribution of rainfall, catchment area and type.

A variety of materials have been used in different parts of the world for rainwater storage tanks. These are mainly: ferrocement tank, bamboo reinforced ferrocement tank, earthen molded ferrocement tanks, cement mortar jars, bricks tanks, brick block tanks, earthen jars, plastic vessels etc. The different type storage tanks are discussed in the section 4.3.

Device to extract water from the tank.

The device for extraction of water from the tank depends on the position of storage tank. A taps fitted at the bottom of the tank is the simplest method for extraction of water in case of ground and elevated tank. For under ground tanks, the withdrawal can be done by installing a handpump.

The components of a rainwater harvesting system are shown in Figure 4.1.

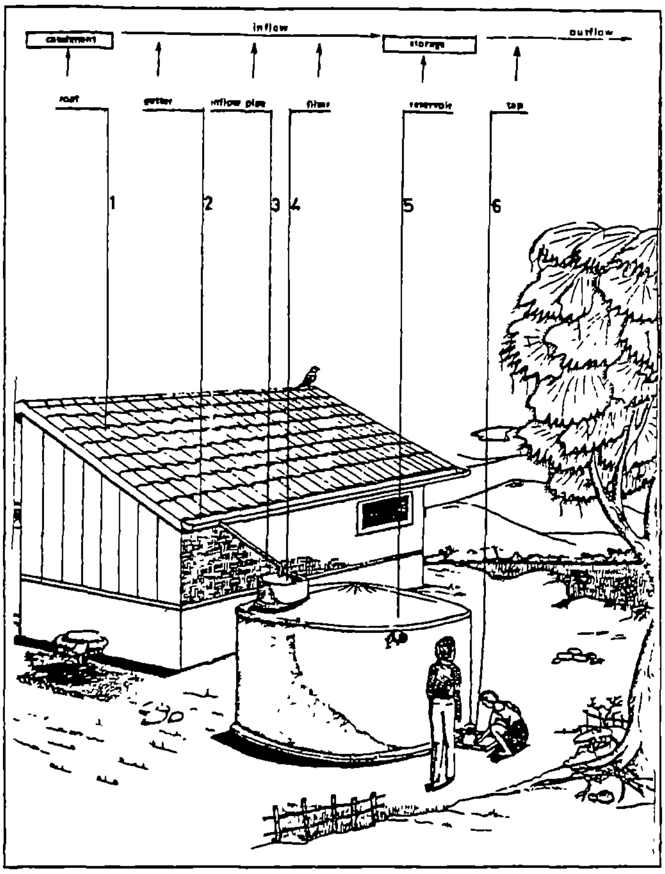


Figure 4.1: Components of a rainwater harvesting system

4.3 COSTING AND TYPES OF STORAGE TANKS

A storage tank is the most expensive component of a rainwater harvesting system. The roof is assumed to be given since it must be available for a household. The cost of the gutters or the down-pipes, which direct water to the tank is considered very little, compared to the cost of storage tank. The cost of the storage tanks mainly depends on the size and material of the rainwater storage tank. Different studies were carried out to reduce the cost of the storage using different low cost materials. The costs of different types of storage tanks used in the different parts of the world are summarized in Table 4.1a and 4.1b. The cost of the storage tank generally decreases with the increase of the size.

Table 4.1a: Costs of rainwater storage tanks in Asia (Lee & Vissher, 1990).

SL. No.	*System*	*Volume (m^3)*	*Cost ($)*	*AEC $/$m^3$*	*Country*
1	Reinforced cement jar	2	25	0 17	Thailand
2	Concrete ring	11 3	250	0.29	Thailand
3	Wire framed ferrocement	2	67	0 37	Philippines
4	Wire framed ferrocement	4	125	0 35	Philippines

AEC: Annual equivalent cost.

Table 4.1a: Costs of rainwater storage tanks in Africa (Lee & Vissher, 1990).

SL. No.	*System*	*Volume (m^3)*	*Cost ($\$$)*	*AEC $\$/m^3$*	*Country*
1	Small jar standing	1	25	0.42	Togo
2	Ferrocement standing	5.5	180	0.36	Kenya
3	Cement stave & rooftop	6	627	1.74	Togo
4	Ferrocement ball	7	168	0.27	Kenya
5	Polyethylene & rooftop	7	750	1.87	Botswana
6	Basket standing	8	250	0.35	Kenya
7	Ferrocement standing	9	221	0.27	Kenya
8	Granary standing	10	167	0.28	Togo
9	Round hut standing	10	222	0.37	Togo
10	Ferrocement standing	10	250	0.28	Kenya
11	Brick standing	10	500	0.83	Botswana
12	Ferrocement standing	10	750	1.25	Botswana
13	Ferrocement standing	13.5	630	0.52	Kenya
14	Ferrocement standing	20	925	0.77	Tanzania
15	Ferrocement standing	21	534	0.28	Kenya
16	Ferrocement standing	25	1111	0.49	Kenya
17	Ferrocement standing	30	1073	0.39	Kenya
18	Masonry standing	50	3500	0.78	Kenya
19	Ferrocement ground tank	70	1750	0.28	Kenya
20	Ferrocement ground tank	75	1937	0.29	Kenya
21	Ferrocement ground tank	78	872	0.12	Kenya
22	Ferrocement ground tank	80	2000	0.27	Kenya

AEC: Annual equivalent cost

AEC is calculated by assuming that the tanks are filled three times each year over two rainy seasons, that all water is used and that the tanks last for 30 years.

From the tables, it is clear that rainwater storage is an expensive option when compared against the groundwater abstraction by handpump. The AEC for a handpump is estimated 0.006 $\$/m^3$, whereas the lowest AEC for rainwater storage is 0.12 $\$/m^3$ for Africa and 0.17 $\$/m^3$ for Asia. However, the estimated cost for groundwater abstraction is based on the arsenic-free groundwater. The cost of the arsenic treatment will increase the AEC cost for groundwater.

The storage tanks constructed from different materials are described below.

Corrugated Iron tank

This is an industrial product manufactured in different countries. The advantages of this tank is the fast installation and also low capital cost. However, this system has a limited lifetime (8 to 15 years). Repainting is also necessary every 5 years and quality of the paint may adversely affect the quality of stored water. The corrugated iron tank is also vulnerable to manual force (Hasse, 1989). The carrying cost of manufactured tank may also be a concern in the rural context.

PVC tank

Several industrial producers offer different types of PVC foil water storage tanks. The foil is fixed inside a reinforcement mesh framework or galvanized sheet cylinders. The cost of the tank varies with the quality of the raw materials used. This type of tank is not suitable for long-term use due to influence of ultraviolet ray on PVC foil (Hasse, 1989).

Clay ring tank

Good quality of clay is readily available in many parts Africa, Asia and Latin America. Clay can be used to build suitable rainwater storage containers of limited volume. Hard-baked tiles or rings are to be preferred as building material for water storage tanks. A simple glazing technique is useful in improving the impermeability of clay pot or barrel walls (Hofkes, 1981). However, there is no evidence available on successful operation and maintenance of this type of tank in long term use.

Earthen jars (motka)

Different sizes of earthen jars are readily available in rural Bangladesh. These types of jars are called 'Motka'. Motka are generally used in the rural areas for storage of food grains. These eastern jars are also used for short-term storage of rainwater by the people of coastal area (Hussain, 1993). The main disadvantages of these jars are safe water abstraction is difficult, very vulnerable to manual force and can be produced in limited size.

Cement jars

About 9 million of cement jars were constructed and distributed during the 1980s in the mainly northeast part of Thailand. It was found that the jars were simple to construct and maintain. The use of jars for rainwater collection was also found cost-effective comparing to the other source of water (Hewison & Tunyavanich, 1990). The design is ideal for small tanks and can be used for tanks up to 2 m^3 with wire reinforcement or up to 0.5 m^3 without it. The construction procedure involves the use of a reusable form-work. This can be made using a hessian sack filled with sand, straw, sawdust, rice husks etc. for smaller jars up to 0.5 m^3. For larger jars of up to 2 m^3 reinforcement is required and either a basket or specially made cement block from-work, made from about 90 curve bricks, can be used. The form-work is placed on a precast wire reinforced circular base 3 cm thick and up to 1 m in diameter, a 5 – 7 mm of 1:2 cement/sand mortar is then carefully plastered onto from-work. Steel wire is then wrapped around the jar at about 10 cm intervals and a further layer of plaster applied. A neck is produced at the top of the jar using two concentric metal ring moulds the smaller of which can be used to cast the cover (Gould, 1991).

Concrete ring jars

This design is particularly suitable for medium sized tanks up to 6 m^3 although larger tanks than this can be built. It is an attractive option in areas where aggregate and hardcore are cheap or freely available and where wire-mesh and steel reinforcement bars needed for standard ferrocement designs are expensive.

The construction procedure basically involves using two concentric ring moulds each made from two corrugated iron sheets bolted together and having diameters of 1.9 m and 1.65 m respectively. They are placed on a 2.5 m diameter, 15 cm thick weld-mesh reinforced level concrete base laid on a 30 cm hardware foundation. Concrete (cement:sand:hardcore 1:3:3) is then poured into void between the rings and barbed wire wrapped around 12 times as reinforcement, the concrete being poured between each turn of the wire. The following day mould can be unbolted and placed on top of the first concrete ring and a second ring cast in the same way. The next day a third ring can be added and on subsequent days further rings added as required. The tank should be plastered inside twice (once with 1:2 cement, waterproof sand mix), then a roof added using fixed shutting and finally plastered outside. The tank should be cured for a week and the shuttering removed before use. A 5 m^3 tank requires about 12 bags of cement, 200 m of barbed wire and 14 man days of labor (7 skilled). The moulds can be reused up to 25 times (Gould, 1991).

Ferrocement tank

There are a number of different ferrocement designs available and large up to 200 m^3 or more can be built using ferrocement. The ferrocement tank with a factory made mould has considerable advantages where a series of tanks are to built with same size. However, this technology can only be chosen if a factory or experienced workshop provides the facilities for bending corrugated sheets and welding them neatly together. The mould can be used 10-15 times depending on the experience and careful handling of the staff. Repairing of damage is relatively easy in this system. The estimated life expectancy is 15 to 20 years. The structure must be kept moist for through out the year (Hasse, 1989).

The wire framed ferrocement tank is also particularly good for tanks with capacities between 2 m^3 and 10 m^3 but can be used for tanks up to 16 m^3 in size. The construction consists of making a frame out of steel reinforcing bars and wire mesh. This is then placed on a reinforced concrete foundation and plastered from both inside and outside simultaneously. The materials required for a 10 m^3 tank include 22 bags of cement, 40 steel reinforcing bars (9.15 m x 9 mm), 12 mm welded wire mesh (30 m x 0.9 m), 3 cubic meters of sand. This method is currently being implemented in Philippines (Gould, 1991).

Bamboo reinforced ferrocement tank

Bamboo has been introduced as reinforcement material by AIT. However, 6 mm diameter mild steel is also used for the mail skeletal. The construction procedure is similar to wire framed ferrocement tank. A study shows that the tanks constructed with bamboo reinforcement works efficiently after 5 years of operation (Chembi & Nimityongskul, 1989). However, the construction requires skill specifically handling the bamboo mesh from breakage.

Soil-cement block tank

This type of low-cost tank was studied by AIT. The estimated cost of 8.2 m^3 tank is \$135.19 and the cost of 16.25 m^3 tank is 189.25 m^3. The interlocking soil-cement blocks were produced through compression of lateritic soil mixed with 10% - 15% of cement and water (Iterbeke & Jacobus, 1988). However, field study shows that this system has leakage problems, which has made this type of tank unsuccessful (Gould, 1991).

The reinforced brickwork tank

Brick tanks are common throughout the world and have a long history. A variety of design exits and these vary according to the type and availability of bricks. The reinforced brick tank is more expensive than the ferrocement tank, although the cost per m^3 reduces with the increased capacity. It costs twice as much as a ferrocement tank. For this reasons, this tank should chosen where the capacity needed is above 30 m^3 and in all cases the life of the structure is expected to be 20 years and more (Hasse, 1989).

4.4 WATER QUALITY PROTECTION

Rainwater has virtually no bacterial content. With few exceptions, the quality of rainwater prior to interception is more consistent than that of other water sources. Some typical examples of the composition of rainwater are given in Table 4.2. A general characteristic of rainwater is its low content of dissolved solids. In this respect calcium and magnesium are of particular interest. It has been recently recognized that there is an inverse relationship between death from heart disease and the concentration of calcium and magnesium in drinking water. This problem may particularly count for rural areas in developing countries where alternative supply of calcium and magnesium through food may be inadequate (IWACO BV, 1981).

Table 4.2: Typical examples of rainwater composition (IWACO BV, 1981).

SL. No.	*Parameter*	*Amazon area, Brazil*	*North Carolina, USA*	*West Java, Indonesia*
1	Specific conductance, µS/cm	40		25
2	pH	6 5		5 6
3	Chloride (Cl^-), mg/l	1.9	0.6	3
4	Nitrate (NO_3^-), mg/l	0.1	0.6	1
5	Sulfate (SO_4^{2-}), mg/l	3	2.2	4
6	Iron (Fe), mg/l	0.6		Nil
7	Manganese (Mn), mg/l			Nil
8	Calcium (Ca^{++}), mg/l	4.3	0.65	2
9	Magnesium, (Mg^{++}), mg/l	1 1	0.15	1

It may be judged that rainwater in its composition is not likely to exceed the guideline for drinking water qualities. However, in using rainwater for drinking water supplies, it is not so much the quality of the rainwater itself is important, but rather the quality of the water as collected from roof and drawn from the storage tank in which the water is collected and stored for later consumption (Hofkes, 1981).

The sources of pollution are:

During collection of the water:

- Contamination from the catchment surface materials.
- Contamination by human beings and large animals (e.g. transmission of infection diseases)
- Remains of dead animals, birds etc.
- Accumulation of dirt, leaves, excrements of birds, small animals etc.

During storage of the water

- Entry and mixing with polluted groundwater (in case of ground storage).
- Entry of dirt, leaves, excrements of birds and small animals etc.
- Algae growth.
- Corrosion of the reservoir material.
- Transmission of disease organisms by insects or birds.

Reduction or elimination of the effects of these sources of pollution can be obtained by the following measures:

Catchment and collection

- The catchment structure must be non-toxic to the human beings.
- The surface should be smooth dense (hard inorganic) since this is less likely to catch and hold wind-blown dust and debris. It is preferable for a roof to be galvanized metal (corrugated plates or galvanized iron).
- Regular cleaning of the catchment surface, gutters and down-pipe to remove accumulated dirt etc.
- Diverting the first runoff, which contains most accumulated dirt etc.
- Placing a wire mesh over the top of the down-pipe to prevent entering of dirt etc. and possible clogging.
- Providing the catchment an even slope to prevent the formation of pools. Steeper slope will further stimulate the removal of solid waste.
- Proper selection of location of the catchment to reduce the accumulation of dirt etc.
- Filtration of the water before entering the reservoir.

Storage

- Application of watertight materials and construction of above ground reservoirs to prevent the inflow of groundwater.
- Always covering the tank to reduce the algae growth and to prevent entry of insects, dirt, leaves, excrement of birds etc. Covering the ventilation hole with mosquito netting.
- Regular cleaning of the reservoirs to remove sediments at the bottom.
- Disinfection of water by boiling and chemical disinfectants.

However, chemical disfection is discouraged due to dangers of health risks from over chlorination. One safe and simple method for improving the quality of lightly contaminated water is to exposure of small quantities (1-3 liters) to the UV radiation in strong sunlight. The techniques is also mentioned in chapter 2, section 2.9.4 (surface water - pond water a.4). The method will destroy virtually all pathogenic bacteria in relatively clear, lightly polluted water.

4.5 DESIGN PROCEDURE

The basis of the design is provided by any records of monthly rainfall measured at one or more rain gauge stations, which can be regarded as representative of the area under consideration. If no such rainfall records are available, either because there are no gauge stations in the area or because the rainfall records are too short or unreliable, then it may be possible to use the records from existing stations outside the area. This however, may introduce serious errors in the analysis (Hofkes, 1981). Shorter time intervals (e.g. weekly totals) will yield more accurate results but do increase the amount of calculations over one period with a both a time interval of one week and one month, however, show that only a limited increase in accuracy is obtained (IWACO BV, 1981). Besides that, monthly rainfall data are generally included in periodical publications of meteorological institutes and therefore more easily accessible than weekly rainfall records.

The rainfall received by a catchment area (whether a roof or ground surface) is only partly discharged toward the storage tank. A portion of the rainwater serving to wet the surface of the catchment area, is held in depressions and then lost by evaporation or infiltration in the ground.

The amount of water yielded per month by a catchment may be computed as,

$$\text{Yield} = \frac{f * A * R}{1000} \text{ m}^3/\text{month} \quad \ldots\ldots (4.1)$$

where,
A = catchment area (m^2)
R = monthly rainfall (mm)
f = catchment efficiency factor or runoff coefficient

A short low-intensity rainstorm after a long dry period is likely to evaporate for the greater part, so that the useful runoff would be very small. Conversely, during a long period of heavy rain, the runoff coefficient might be very high. However, the catchment co-efficient is taken as constant for the reasons of simplicity (Hofkes, 1981).

Field measurements indicate that the portion of rainfall that is actually harvested, ranges from about 30% for pervious, flat ground catchments to over 90% for covered, sloping-strip ground catchments and roofs of suitable materials. The factor f, thus, ranges between 0.3 to 0.9 (Table 4.3).

Table 4.3: Runoff coefficient for different catchments (Hofkes, 1981).

SL. No.	*Type of catchment*	*f*
1	Uncovered catchment surface	
1.a	Completely flat terrain	0.3
1.b	Sloping 0 – 5%	0.4
1.c	Sloping 5 – 10%	0.5
1.d	Sloping more than 10%	0.5 and more
2	Covered catchment surface	
2.a	(roof) tiles	0.8 – 0.9
2.b	Corrugated sheets	0.8 – 0.9
2.c	Concrete bitumen	0.7 – 0.8
2.d	Plastic sheets	0.7 – 0.8
3	Brick pavement	0.5 – 0.6
4	Compacted soil	0.4 – 0.5

The simplest method to determine the rainwater storage tank is to multiply the days of the longest dry period by the amount of water required per day.

$$\text{Storage volume} = \frac{D * N * Dp}{1000} \text{ m}^3 \quad \ldots\ldots (4.2)$$

where,
D = demand per capita per day in litre
N = nos. of family members
Dp = duration of dry period in days

This method gives only a rough estimate of the storage required. It does take into the variation of rainfall, catchment area and runoff coefficient. A better method of tank sizing involves the mass curve analysis method. Another systematic method for estimating storage tank volume is optimal critical catchment area-critical storage volume (A_c-V_c) method.

4.5.1 Mass Curve Analysis Method

This method involves analysis of rainfall data using mass curve technique. Successful use of this method requires a minimum of 10 years of raw data. This includes tabulating the monthly rainfall (mm), monthly supply (liters), cumulative supply (liters), monthly demand (liters), monthly amount stored (liters) and total amount stored (liters). The required tank volume (given in the seventh column) can be determined when the table is filled out. The least amount stored during the dry season is subtracted from the largest amount stored during the wet season. The difference represents the storage required for that particular year. The difference between the largest and least amounts stored in each year is calculated. The largest difference yields the tank size.

This method also can be applied graphically. However, a more accurate result is obtained from the tabulated calculations.

4.5.2 Optimal A_c-V_c Relation Method

In this method, a relationship between critical catchment area per person (m^2 per capita) and minimum storage volume provided per person serviced (m^3 per capita) is determined based on a series of n years actual monthly rainfall data and a selected frequency of periods with limited supply (calculation). This method requires a series of calculation using different formulas.

$$A_{cl} = A_{c\,min} = \frac{C*12}{f*R_{a\,min}} \ m^2/\text{capita} \quad \ldots\ldots (4.3)$$

where,

$A_{c\,min}$ = Minimum catchment area, m^2/capita

C = Monthly demand per capita, liters/month

$R_{a\,min}$ = Lowest annual rainfall over the observed period, mm/year

f = runoff coefficient

$$R_c = \frac{C}{f*A_c} \ \text{mm/month} \quad \ldots\ldots (4.4)$$

where,

R_c = Amount rainfall required per month to fulfil the required consumption (i.e., critical rainfall), m^2/capita

$$D_c = \frac{A_c * f * (R_c * N_c - \sum R_l)}{1000} \quad m^3/\text{capita} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4.5)$$

where,

D_c = Deficiency (supply – demand) in a year, m^3/capita

N_c = Nos. of dry period (month) in a year

R_l = Rainfall during the dry period, mm/month

The required storage volume (V_c) is proportional to the Dc value. The D_c value is selected based on the number of observation years (Table 4.4).

Table 4.4: Number of observation and related D_c value (IWACO BV, 1981).

Number of years- monthly rainfall data	*D_c value*
1 – 10	Largest value
10 – 20	One but largest
20 – 30	Two but largest

$$V_c = \frac{D_c}{1 - L_c * 0.5 * N_c} \quad m^3/\text{consumer} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4.6)$$

where,

V_c = storage capacity, m^3/capita

L_c = Loss factor (l/month)

The same calculations will be also carried out for subsequent catchment areas A_{c2}, A_{c3} and A_{c4}. A_{c2}, A_{c3} and A_{c4} will be calculated by the flowing formulas.

$$A_{c2} = A_{c1} + 1 \ (m^2/\text{capita}) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4.7)$$

$$A_{c3} = A_{c2} + 1 \ (m^2/\text{capita}) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4.8)$$

$$A_{c4} = A_{c3} + 1 \ (m^2/\text{capita}) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4.9)$$

The A_c and V_c values will be plotted and the best fitting curve will be drawn. This curve provides the required storage volume per capita for a specific catchment area per capita. Other way, a catchment area can be designed for a given storage volume.

4.6 RAINFALL PATTERNS IN BANGLADESH

Bangladesh is a tropical country and receives heavy rainfall due to north-easterly winds during in the rainy season. The monthly rainfall distribution of Dhaka City based on rainfall data from 1975 to 1995 is shown in Figure 4.2.

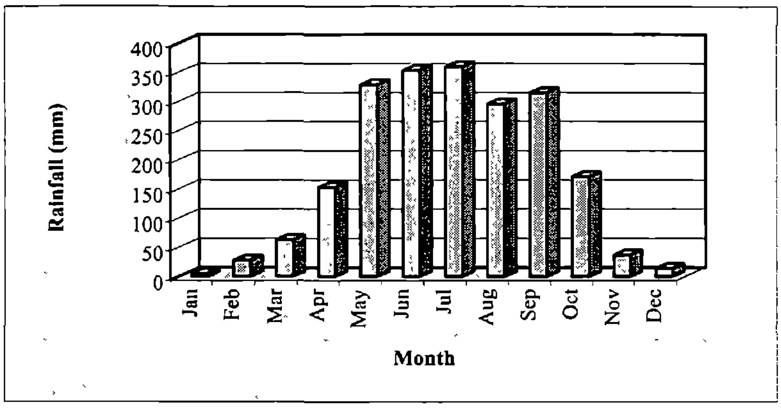


Figure 4.2: Average Monthly rainfall distribution of Dhaka City

The figure shows that the heavy rainfall only concentrated from April to October. The rainfall from November to March is very inadequate to meet the demand during the periods. So, rainwater has to be stored during rainy seasons to use the rainwater through out the year. Rainwater harvesting for long-term use was not considered a potential source due to unavailability of suitable catchment area and inconvenience of storing water over 5 months when it is compared with the hand tubewells. However, the rainwater harvesting in Bangladesh is now considered as potential alternative source under the recent groundwater contamination of arsenic.

The rainfall distribution is not uniform over the country. The normal annual rainfall varies from 1500 mm to 3000 mm. The Figure 4.3 shows that average rainfall distribution over Bangladesh.

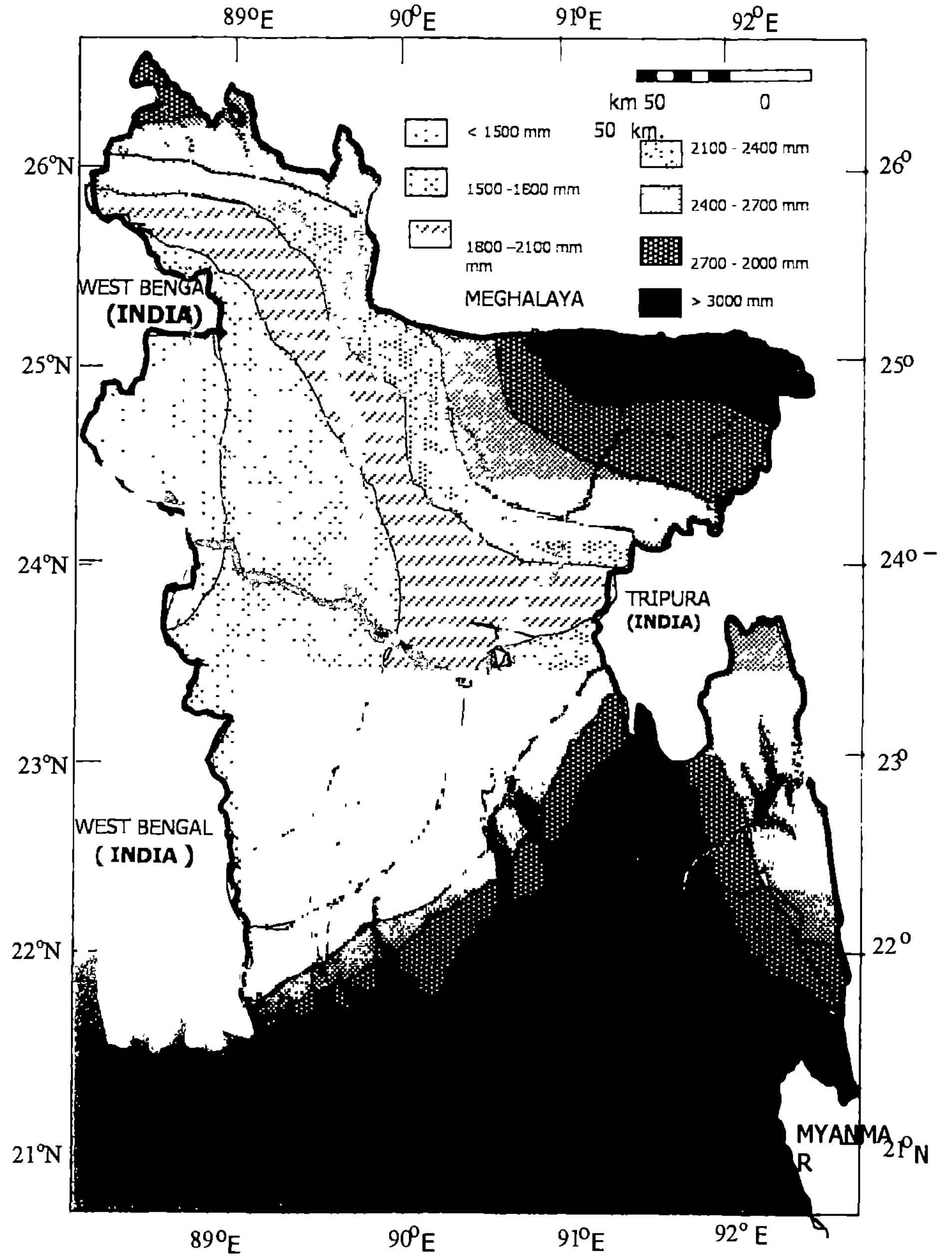


Figure 4.3: Average annual rainfall distribution over Bangladesh.

The figure shows that the north-western part of Bangladesh receives the lowest rainfall while, the eastern part of Bangladesh receives higher rainfall. However, this figure is prepared based on the average annual rainfall. In designing a rainwater harvesting system, the minimum annual rainfall has more significance than the average annual rainfall. The Figure 4.4 shows the minimum annual rainfall in the different administrative districts of Bangladesh. The maximum, minimum and average annual rainfall data are also presented administrative district wise in Table 1 Annex-B1. The calculations are carried out based on rainfall data from 1964 to 1975. These data are collected from Bangladesh Water Development Board.

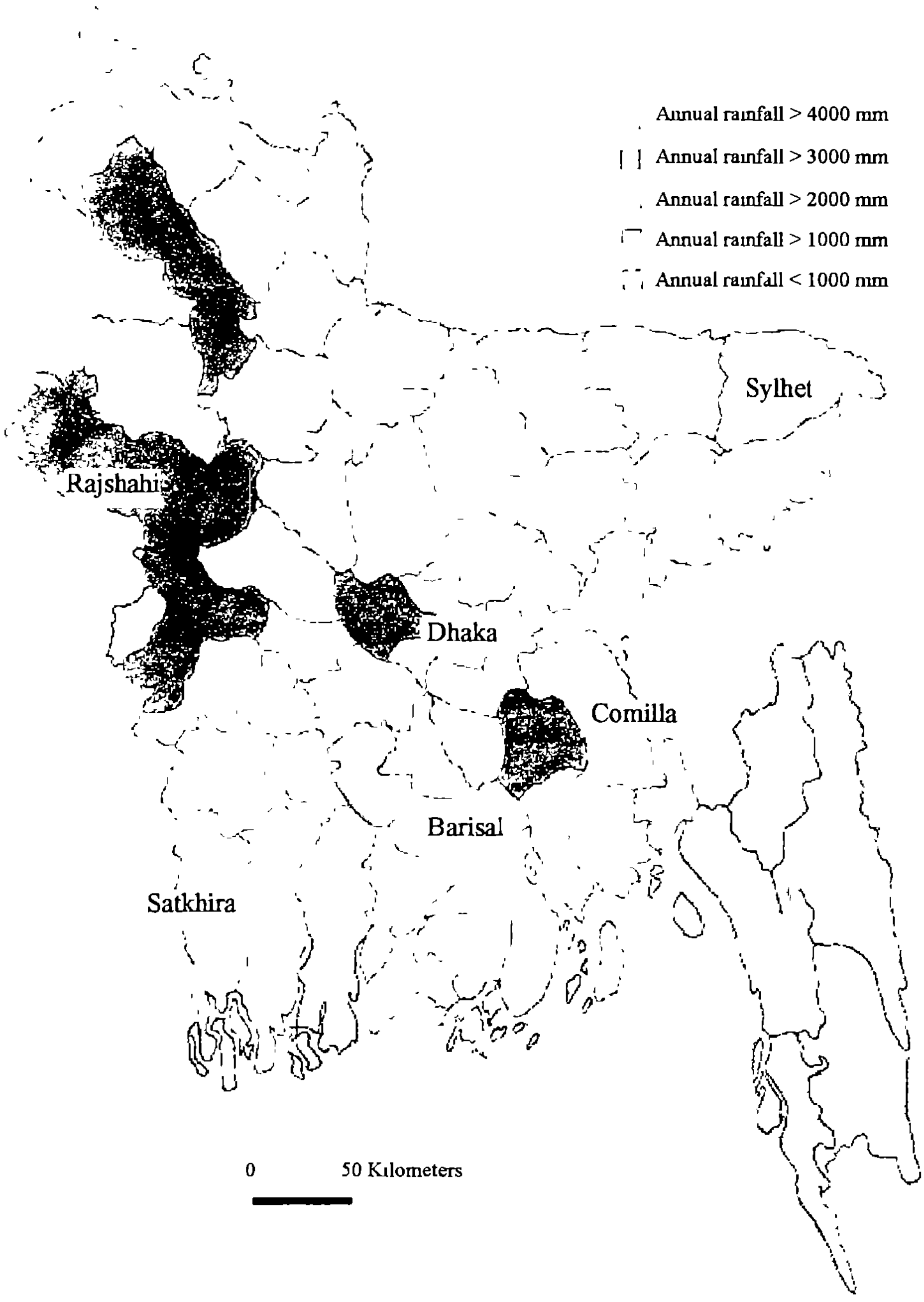


Figure 4.4: Minimum annual rainfall distribution over Bangladesh (District wise).

The numbers of districts with the different maximum, minimum and average annual rainfall are categorized in the table 4.5.

Table 4.5: Number of districts with different minimum, maximum and average annual rainfall.

SL. No.	*Minimum annual rainfall*		*Maximum annual rainfall*		*Average annual rainfall*	
	mm	*No. of districts*	*mm*	*No. of districts*	*mm*	*No. of districts*
1	> 4000	1	> 5000	3	> 5000	1
2	> 3000	0	> 4000	4	> 4000	1
3	> 2000	3	> 3000	14	> 3000	1
4	> 1000	42	> 2000	31	> 2000	26
5	< 1000	9	< 2000	3	> 1000	26

Data of 9 administrative districts was not available

The dry period has also been calculated administrative district wise. The dry period is defined as the month with rainfall below 38.13 mm. This amount of rainfall is required to meet the demand of a person (5 liter/day) from an average roof size 5 m^2 per capita. The results are shown in the Table 1 Annex-B2 and the maximum dry period is shown in Figure 4.5.

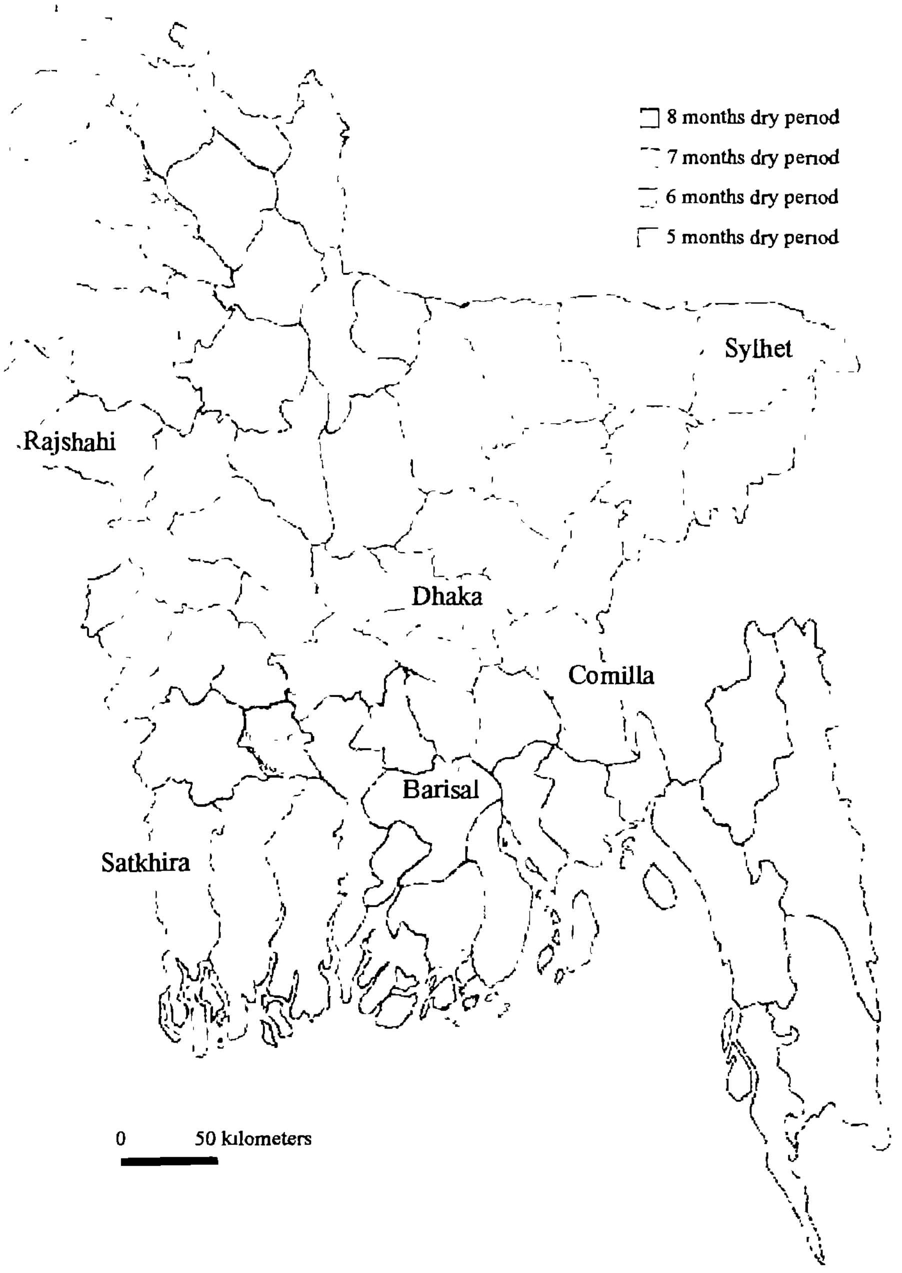


Figure 4.5: Maximum dry period over Bangladesh (District wise)

The numbers of districts with the different maximum, minimum and average dry periods are categorized in the table 4.6.

Table 4.6: Number of districts with different maximum, minimum and average dry period.

SL. No.	Maximum dry period		Minimum dry period		Average dry period	
	month	No. of districts	month	No. of districts	month	No. of districts
1	8	5	4	6	6	3
2	7	11	3	18	5	25
3	6	30	2	26	4	25
4	5	9	1	5	3	2

Data of 9 administrative districts was not available.

From the Table 4.5 and Table 4.6, six different locations from six different regions (divisions) of Bangladesh are selected to design the storage volume requirement. These six locations have different ranges of dry period and annual rainfall. The locations with annual rainfall and dry period are shown in Table 4.7.

Table 4.7: Study locations with dry period and annual rainfall.

Location	Dry period (months)			Annual rainfall (mm)		
	Max.	Min.	Avg.	Min.	Max.	Avg.
Dhaka	5	2	4	1530.8	2391.9	2025.5
Rajshahi	7	3	5	873.6	1902.1	1450.5
Comilla	6	2	3	1684.2	3558.6	2372.3
Sylhet	5	1	3	2985.7	5206.1	4202.2
Barisal	6	2	4	1670.8	3243.6	2216.4
Satkhira	7	3	4	1216.7	2415.6	1815.8

4.7 HOUSEHOLD SIZE IN BANGLADESH

Household size is one of the important parameter in designing a rainwater harvesting system specifically by using the mass curve analysis method. It is related to the total water demand, storage volume and catchment area. The household size of Bangladesh is given in Table 4.8a and 4.8b.

Table 4.8a: Distribution of household by number of persons.

Person per household	Household		Population	
	Number	Percentage	Number	Percentage
1	477582	2.5	477852	0.5
2	1411930	7.4	2823860	2.7
3	2421613	12.7	7264839	7.0
4	3164239	16.6	12656965	12.1
5	3233789	17.0	16168945	15.5
6	2746566	14.4	16479396	15.8
7	2019973	10.6	14139811	13.6
8	1344665	7.1	10757320	10.3
9	840881	4.4	7567929	7.3
10+	1358975	7.2	15848627	15.2
Total	19020483	100.0	104185544	100.0

(Population census, 1991) BBS, 1995

Table 4.8b: Distribution of household in different locality.

Person per household	*Rural area total*	*Municipality area total*	*Other urban area total*	*National total*
1	375624	56253	45975	477582
2	1143415	148748	119767	1411930
3	1972379	246812	202422	2421613
4	2576286	321459	266494	3164239
5	2636293	324733	272763	3233789
6	2243825	271538	231203	2746566
7	1654229	196870	168874	2019973
8	110847	131560	112258	1344665
9	685583	84397	70901	840881
10	425107	55347	44595	525049
11+	660972	99873	73081	833926
Average size (persons)	5.48	5 50	5 47	5.48

(Population census, 1991) BBS, 1995.

The average size of household is 5.48 persons and 57% population having household size between 4 to 7. The average household size is taken as 6 for the calculation of design storage capacity.

4.8 ROOFING MATERIALS IN BANGLADESH

Different types of roofing materials are used in Bangladesh. These include cement concrete, tiles, C.I./metal sheet, straw with or without polythene covering, Bamboo with polythene covering. The different types of roofing materials are shown in Table 4.9.

Table 4.9: Dwelling households by materials of roof.

Locality	*Straw/bamboo polythene*	*Tiles/C.I./metal sheet*	*Cement*	*Total household*
Rural area	7966388	7362318	145860	15474566
Municipality area	449828	970999	516763	1937590
Other urban area	572136	917508	118689	1608333
Bangladesh total	8988352	9250825	781312	19020489

(Population census, 1991) BBS, 1995.

From the table, it is seen that about 48% households in the rural area have tiles, C.I./metal sheet as roofing materials. However, another study carried out in 1994 projected that about 58% households in the rural area have tiles, C.I./metal sheet (BBS, 1995). For the study purpose, it can be assumed that at least 50% of households has the roofing catchment area made from suitable materials.

4.9 ROOFING SIZE IN BANGLADESH

There is no data is available on the average roof size in Bangladesh. However, a limited field survey was carried out in Chuadanga (from where the arsenic contaminated samples are collected) on the roof size. Only the household having metal sheet as roof materials were considered and the data is given in Table 4.10.

Table 4.10: Roofing size in a typical rural area.

Roof area $< 20\ m^2$	*Roof area* $20 - 40\ m^2$	*Roof area* $40 - 60\ m^2$	*Roof area* $60 - 80\ m^2$	*Roof area* $> 100\ m^2$
6	5	10	4	3

The data was collected on from the 28 households by random selection. This data may not be applicable in all rural conditions in Bangladesh. However, it provides an idea about the available catchment area. The storage capacity has been calculated using the roof size 20, 40 and 60 m^2 in method of mass curve analysis. It is also observed that the roof area i.e., housing size is related to the economic condition of the household. Moreover, economically sound families have more than one housing structures (normally two or three) in their housing premises.

4.10 STORAGE VOLUME CALCULATION

Storage volumes for six different locations have been calculated by using the 20 years rainfall data (from 1975-76 to 1994-95). The rainfall data were collected from the Bangladesh Meteorological Department.

4.10.1 Mass Curve Analysis Method

The calculation is based on the technique described on section 4.4.1. The following assumptions were used to calculate the design storage volume by using mass curve analysis method.

- The family size is 6.
- The demand is 5 liter per capita per day.
- The demand is same for the every month.
- The demand is constant from year to year.
- The rainfall pattern in future will be similar.
- The runoff coefficient is 0.8.
- Evaporation from tank is included in the runoff co-efficient.

The storage volume is calculated for roof catchment area 20, 40 and 60 m^2. The storage volume for different catchment size and location is tabulated in Table 4.11 and also shown in Figure 4.6. The calculation of storage volume by mass curve method with catchment area 40 m^2 for Rajshahi is shown in Table 4 Annex-B.

Table 4.11: Storage volume requirement with different catchment area (Mass curve analysis method).

Location	*Required storage volume (liter) for catchment area*		
	20 m^2	*40 m^2*	*60 m^2*
Dhaka	4776	4152	3528
Rajshahi	5676	5052	4428
Comilla	4936	4472	4164
Sylhet	3360	3120	2880
Barisal	4164	3828	3492
Satkhira	4488	3828	3492

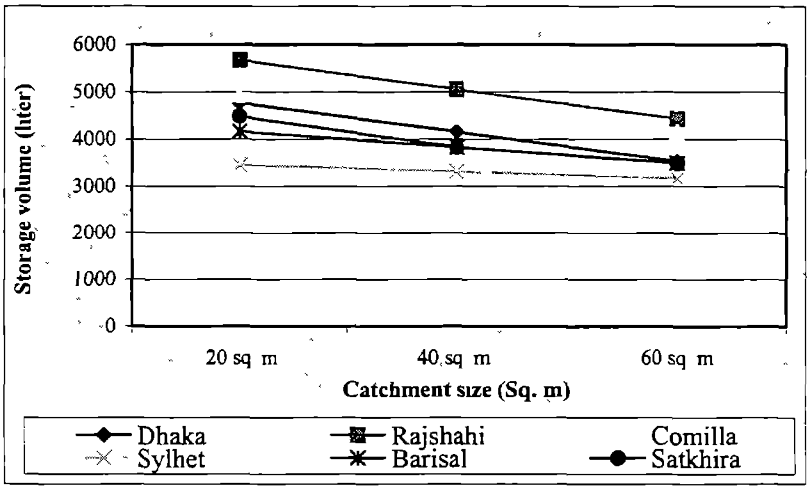


Figure 4.6: Storage volume requirement for different catchment size in different locations (mass curve analysis method)

The table shows that the maximum storage volume 5676 liters are required at Rajshahi with the catchment area of 20 m^2. For the catchment area, the minimum storage volume 3360 liters are required at Sylhet. For catchment area 60 m^2, the storage volume required for Rajshahi is 4428 liter and for Sylhet is 2880 liter. The figure shows that the relationship between catchment area and storage volume requirement varies with the location i.e., amount and pattern of rainfall.

The yearly rainfall and required storage volume for different catchment size for Rajshahi district is shown in Figure 4.7. The annual rainfalls for the year 11 (1985-86) and 14 (1988-89) were 1294 mm and 1275 mm respectively. However, the required volumes were 2160 liters and 4428 liters respectively. This variation was due to the difference in distribution of rainfall over the year.

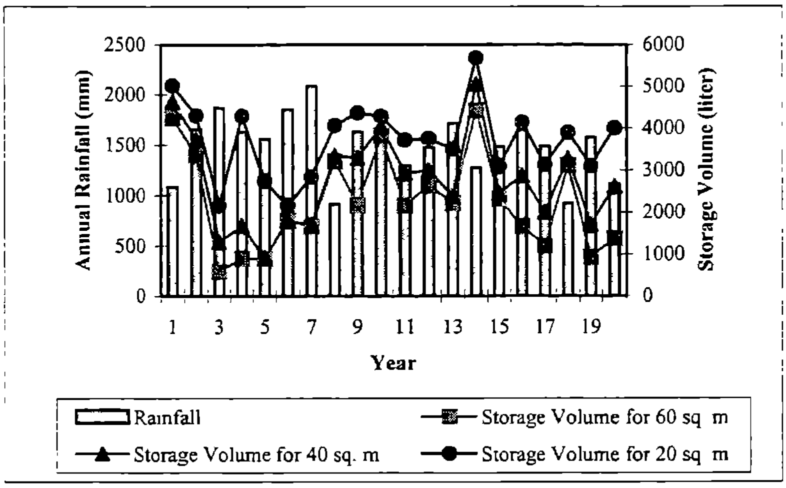


Figure 4.7: Annual rainfall and storage volume requirement for different catchment size at Rajshahi (mass curve analysis method).

4.10.2 Optimal A_c-V_c Relation Method

The optimal A_c-V_c curves were plotted for the six locations using the equations 4.3 to 4.9 described in the section 4.4.2. The following assumptions were used in calculating optimal A_c-V_c.

- The demand is 5 liter per capita per day.
- The demand is same for the every month.
- The demand is constant from year to year
- The rainfall pattern in future will be similar.
- The runoff coefficient is 0.8.
- The loss factor for stored water is taken 0.05 liter/month.

The optimal A_c-V_c curve for six locations are shown in Figure 4.8a to 4.8f. The calculations of A_c-V_c curve for Rajshahi are shown in Annex-B4.

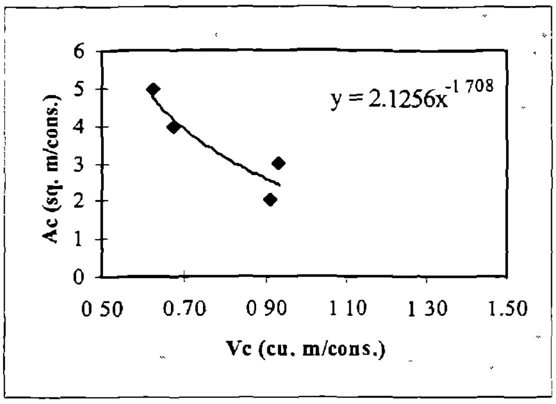


Figure 4.8a: Optimal A_c-V_c Curve for Dhaka.

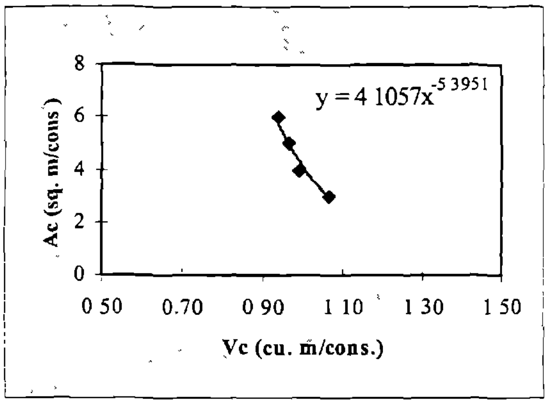


Figure 4.8b: Optimal A_c-V_c Curve for Rajshahi.

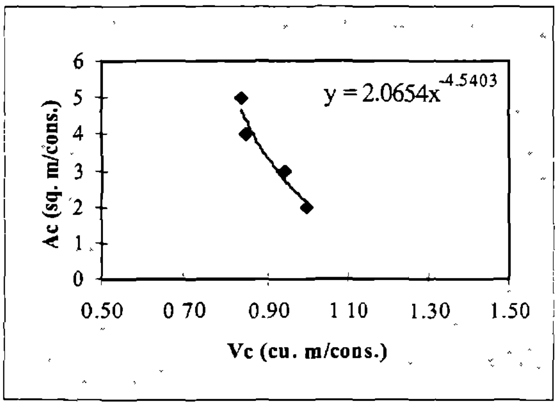


Figure 4.8 c: Optimal A_c-V_c curve for Comilla.

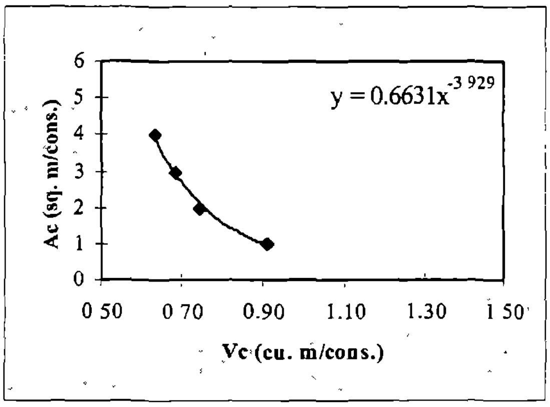


Figure 4.8d: Optimal A_c-V_c curve for Sylhet.

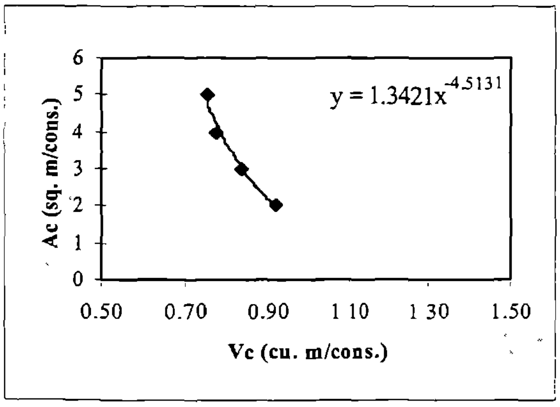


Figure 4.8e: Optimal A_c-V_c curve for Barisal.

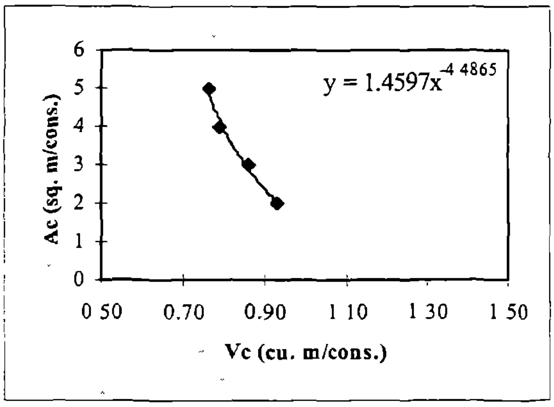


Figure 4.8f: Optimal A_c-V_c curve for Satkhira.

Using the figures and related equations, storage volumes are calculated for 6 persons with catchment sizes 20 m^2, 40 m^2 and 60 m^2 and presented in the Table 4.12.

Table 4.12: Storage volume requirement with different catchment sizes (A_c-V_c method).

Location	*Required storage volume (liters) for catchment area*		
	20 m²	***40 m²***	***60 m²***
Dhaka	4610	3073	2423
Rajshahi	6236	5484	5087
Comilla	5400	4635	4239
Sylhet	3978	3345	3008
Barisal	4905	4206	3845
Satkhira	4991	4277	3907

4.11 COMPARISON OF TWO METHODS

The results of the above two methods are compared in the Table 4.13 with respect of the results of mass curve analysis method.

Table 4.13: Comparison of the results of the two methods.

Location	*Differences in percentage*		
	20 m²	***40 m²***	***60 m²***
Dhaka	(-) 3.48	(-) 25.99	(-) 31.18
Rajshahi	9.86	8.55	14.88
Comilla	9.40	3.65	1.77
Sylhet	18.39	7.21	4.44
Barisal	17.80	9.87	10.11
Satkhira	11.20	11.73	11.88

The table shows that the design capacity calculated by A_c-V_c method requires a higher design capacity than calculated by mass curve analysis method (with exception in the case of Dhaka). The differences in these cases vary between 3.65% to 18.39% which can be acceptable. The reasons for these differences may be due to consideration of loss factor for stored water in the case of A_c-V_c method. It is also fact that A_c-V_c method does not consider the distribution of rainfall during the dry period and only considers the number of dry periods and the total rainfall during these periods.

From the figure 4.8a (for Dhaka), the best-fit line does not touch all the points. So, the related equations is not also very much representative (R^2 = 0.7879). This may be reason of inconsistent results in case of Dhaka. This problem can be solved by taking more A_c and V_c values to draw the curve, which will smoothen the curve.

The major advantage of the mass curve analysis is the simplicity in the calculation. However, the calculation is very much situation specific i.e., separate calculation is needed for the each household having different catchment area and family size.

On the other hand, the major advantage of A_c-V_c method is that this curve can be applied to each household in a specific area regardless of catchment area and household size. However, this method requires expertise for a series of calculation using 7 mathematical equations. This method gives a higher value for storage volume, which increases the reliability of the system over a long period. But, it also increases the capital cost of the system.

4.12 MATERIALS AND COSTING OF GUTTERS AND DOWN-PIPES

As stated in the section 4.2, different materials can be used as gutters and down-pipes and the requirement of amount materials depend on the roof size. The table 4.14 gives the costing of gutters and down-pipes.

Table 4.14: Costing of gutters and down-pipes

Materials	*Unit*	*Qty*	*Unit Cost (Tk.*)*	*Total cost (Tk.*)*
Bamboo made				
Material cost	No	2	60	120
Accessories	-	L.S.	-	100
Labor	self			0
Total cost				***220***
Wood made				
Material cost	cft	0.5	600	300
Accessories	-	L S.	-	200
Labor	man day	2	70	140
Total cost				***640***
PVC pipes				
Material cost	meter	8	50	400
Accessories	-	L.S.	-	200
Labor	man day	2	70	140
Total cost				***740***
G.I. pipes				
Material cost	meter	8	225	1800
Accessories	-	L.S	-	300
Labor	man day	2	70	140
Total cost				***2240***

* 48 5 Tk = 1 US$

The bamboo made gutters and down-pipes have short life span. It can work properly one rainy season. Again, leakage is a major concern in case of bamboo and wood made gutters and down pipes. The cost of G.I. pipes is very high comparing to other materials. PVC pipes are very cheap and readily available at the rural areas of Bangladesh. The PVC pipes should be used as gutters and down-pipes for rainwater harvesting system in the rural areas of Bangladesh.

4.13 MATERIALS AND COSTING OF STORAGE TANKS

From the review of the section 4.3, some potential materials for storage tank have been selected. These can be applied in different sizes in the rural Bangladesh. No fixed design or materials are selected on the basis on literature review, as these technologies require field-testing at the rural context of Bangladesh.

Table 4.15: Costing of storage tank.

Materials	*Capacity (m^3)*	*Total cost (Tk.*)*	*Per m^3 Cost (Tk.*)*
Ferrocement- molded tank	3.2	7170	2240
Ferrocement- wire framed tank	10	14040	1404
Ferrocement- bamboo reinforced tank	4.5	6660	1480
Cement jars	2.0	2800	1400
Cement ring tank	5.0	6330	1266
Brick reinforcement tank	5.0	16500	3300

* 48.5 Tk = 1 US$

Though the cost of the tanks decreases with the size of the tank, the cement ring tank seems to be the least storage tank for rural Bangladesh. The main advantage of the tank is the familiarity of the construction process. Cement rings are used and constructed widely in the rural Bangladesh for sanitary latrine construction. The ferrocement is not a common technology in Bangladesh and it requires an extensive training before construction.

The cost of earthen jars was not compared with the costing of other materials due to uncertainties regarding its applicability. However, several jars could be used together for long-term water storage. Adequate measure should be taken in water storage and especially water collection. The average cost of 0.3 m^3 earthen jars varies Tk. 250 to 350, i.e., approximately Tk. 1000/m^3.

4.14 CONSIDERATIONS FOR RWH IN RURAL BANGLADESH

The rainwater harvesting in rural Bangladesh seems as a viable alternative water source in the arsenic contaminated area of rural Bangladesh. There is adequate rainfall during the rainy season distributing from April/May to October. There is a regional variation of rainfall. Lesser storage volume is required in the western part, and a higher storage volume is required for north-western part.

The water quality is of rainwater is very high and the stored water quality is also very satisfactory when proper attention is taken. This water is free from two extreme contaminants i.e., arsenic and fecal coliform (with due care). The major advantage of the rooftop rainwater harvesting system is that the system is independent and suitable for scattered settlements. Each household can use their own separate water storage system. It is very convenient to the users especially to the women to collect water from their house premises. It saves the time of collection water from a distance source. As the system is household based, strong community cohesion is not a very prerequisite factor for rainwater harvesting.

The operation of the rainwater harvesting is easier than other water supply system. No specialized skill is necessary to operate the system. It does not require any pumping device to abstract the water. The system also requires very little maintenance work. The maintenance work is mainly cleaning the catchment area, gutters, down-pipe, storage tank etc. The storage tank can require plastering or other maintenance work normally once in five years if the storage tank is constructed properly.

The roof catchment area is often considered as a part of the housing system. The cost of the roof maintenance work should not take account as the cost the rainwater harvesting system.

However, there are some difficulties that can limit the successful application of rainwater harvesting system. The major consideration identified in the development and use of rainwater harvesting systems on a sustainable basis are discussed below with their possible remedial actions.

Economic considerations

Economic issue is crucial to the introduction of water harvesting systems to the rural Bangladesh. Table 2.13 indicates that the capital cost involvement of rainwater harvesting system per family is high compared to other water supply systems. The financial base in rural area of Bangladesh is very weak and rainwater harvesting system would not be easily affordable. About 42% of rural households have straw/bamboo polythene roofing materials, which would need to be changed to more suitable materials like corrugated iron sheet. The capital cost for a 5 m^3 cement ring tank is Tk. 6330 (US $ 130), whereas the per capita annual income in Bangladesh is US $ 342. Clearly, up-front payment in cash for a tank would present major problem for lower income groups.

Although the capital cost of rainwater harvesting is high, this some extent offset by their negligible recurrent costs. The average life expectancy of a storage tank is taken about 15 years. The cost of the system is also reduces when the free labor of the user is taken consideration.

It is possible to implement the rainwater harvesting system widely in rural Bangladesh with the external support. Government or other supporting organization can provide subsidy and establish revolving funds for the capital cost of the system. The government has done it successfully in Thailand (Gould, 1992). Lee and Visscher (1990) pointed out that the community contribution was 10 to 40% in the five African countries.

Another promising option of financing in rural Bangladesh is micro-credit scheme. Different NGOs have achieved commendable success in micro-credit scheme for income generating options. Though rainwater harvesting for drinking purposes not considered as an income generating activity, it has an indirect relation with the income generation e.g. health benefit from safe drinking water. If the cost of the storage tank could to be paid in monthly interest-free installments over the 5 years, the monthly cost for the 5 m^3 cement jar tank come to Tk. 106 which many families can afford.

Technical considerations

The rainwater harvesting system for long term use is a new technology in Bangladesh. The system requires to incorporate materials, skill and construction procedures that are compatible with the Bangladeshi conditions. Extensive training and demonstration program is essential for the construction procedure and operation and maintenance of the system.

Social considerations

The success of rainwater harvesting system program depends on the interest, enthusiasm and active support of the users. Groundwater is the major source of water supply for nearly two decades in Bangladesh. People may have negative attitude about the rainwater. The rainwater harvesting program can be implemented only when people have the willingness to use the system. Failure to involve the community in the planning, design, siting and construction of the rainwater harvesting is commonly a cause of failure of the system in many countries.

One of the important steps towards achieving successful and suitable rainwater harvesting system is to create awareness of the technology among its potential users. This can be achieved through mass media, workshop and grass root level formal and informal meetings.

The community must be involved in the planning, design, siting and construction of the rainwater harvesting. Women should be consulted about the technologies and implementation strategies and their involvement must be ensured in the program.

Training activities are required both at the project management and at the community level. The training will be towards program sustainability, community involvement, design procedure, site selection, construction of system, operation and maintenance of the system etc.

5

POND SAND FILTER

5.1 GENERAL

Pond Sand Filter (PSF), a special small scale filtering device has been used mainly in the coastal parts of Bangladesh to treat the water from rain-fed ponds. It is a manually operated treatment unit, based on the principle of slow sand filtration. Water is pumped up from the pond by a handpump and is poured into a small concrete tank, having more compartments, of which one is the filter chamber filled with the sand. Water passes through the sand filter chamber from where it flows into adjacent storage chamber. A small chamber filled with brick chips acts as a pre-treatment unit. The treated water quality depends on the efficiency of the filtration system and also on the raw water quality of the pond. Again, the water quality of the pond depends on design of the pond, the use being made of the pond by people and or livestock, and the runoff into the pond of drainage and wastewater.

It has been reported by a recent survey that more that 50% of PSFs were out of operation or malfunctioning in the study area. The water quality of the system is also questionable. This study compares the components of the system with the slow sand filter and also analyzes the water quality of PSFs. The operation and maintenance procedure is also evaluated. On the basis of these findings, a design improvement is proposed for PSF. An O&M procedure is also proposed to improve the O&M activities.

5.2 MAJOR COMPONENTS OF SSF

The major component of a PSF is a small sand filter, which operates using the principles of slow sand filtration. So, it is required to study the different components and working principle of SSF to understand the working principle of PSF and also to make comparison between PSF and SSF.

According Visscher *et. al.* (1987) and Thanh and Hettiaratchi (1982), the following are the essential components of a SSF.

A supernatant layer of raw water

The supernatant water layer provides a sufficient head of water to make the raw water pass through the filter bed, and creates a sufficient detention time during the raw water will be subjected to various physical and biological processes. An operating depth of 1.0 to 1.5 m of water must be maintained at all times above the sand level. Above the water level in the supernatant reservoir the filter walls must be carried up to form a freeboard about 0.2-0.3 m high.

A bed of fine sand

Although any inert, granular material can be used as filter medium, sand is usually selected because it is cheap, inert, durable and widely available. When placed in the filter, the sand should be free from clay, soil and organic matter. As the amounts required are large it is usual to employ ungraded sand as excavated from natural deposits. Some degree of uniformity is however, desirable in order to ensure sufficient porosity. Accordingly, sand having a uniformity coefficient between 2.0 and 3.0 and an effective size in the range of 0.15-0.35 mm should preferably be chosen.

Grain size selection is a crucial factor in filter performance. Bellay (1985) conducted 18 test runs with pilot filters at a filtration rate of 0.12 m/h and sand bed depths were 0.97 m. He concluded that total colifom bacteria removal depends on the sand grain size of the filter (Figure 5.1).

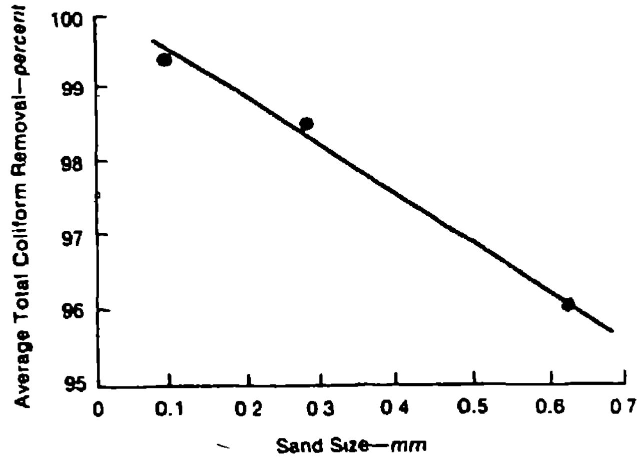


Figure 5.1 Effect of sand size on removal of total coliform bacteria in slow sand filtration (Bellamy, 1985).

Continuos sedimentation and straining of particles will gradually increase resistance in the filter skin (Figure 5.2), and after one to three months the resistance becomes too high for the filter to produce sufficient safe water. Filtration capacity can be resorted by cleaning the filter, which is done by draining off the supernatant water and removing the top 1 to 2 cm of sand bed, including the filter skin.

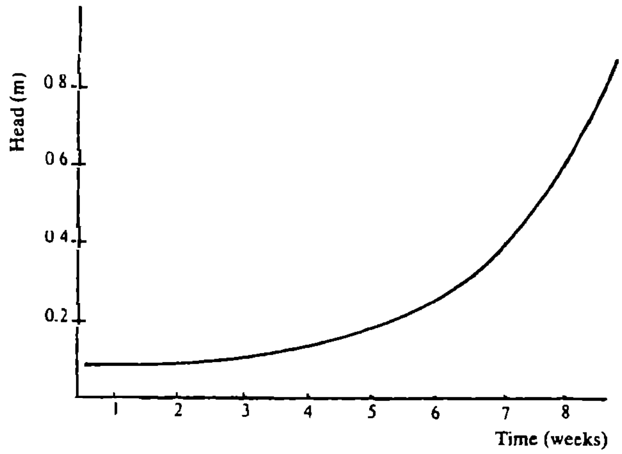


Figure 5.2 Development of resistance in the filter bed (Visscher *et al.* 1987).

For the proper functioning of the purification process a minimum bed thickness of 0.6 m should be provided. Additionally, allowance should be made for the removal of a 10-20 mm thick layer during regular filter cleaning. Therefore a total bed thickness of 1 m is recommended so that the sand will not need to be refilled more than once every few years.

Bellamy (1985) also studied the effect of sand bed depth on percent remaining on total coliform bacteria in effluent during slow sand filtration. The two plotted points are averages of 164 colifom analyses for each point (Figure 5.3).

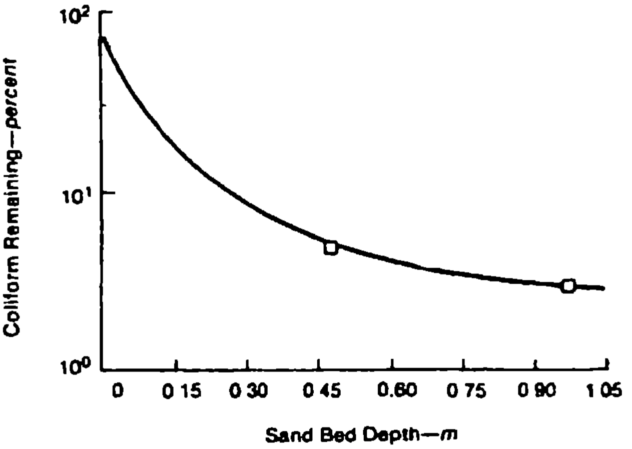


Figure 5.3 Effect of sand size on percent remaining of total coliform bacteria in effluent in slow sand filtration (Bellamy, 1985).

A system of underdrains

The underdrain system serves two purposes: firstly, it provides unobstructed passage of treated water and secondly, it supports the bed of filter medium. Usually, it consists of a main and lateral drain constructed from perforated pipes, or a false floor made of concrete blocks or bricks, and is covered with layers of graded gravel. These layers prevent the filter sand entering or blocking the underdrains and ensure uniform abstraction of the filtered water. The thickness of the underdrain system, including gravel layers, may range from 0.3 to 0.5 m, although the depth of the underdrain system will be smaller if corrugated pipes are used.

An inlet and outlet structure

The inlet structure is intended to allow water to flow into the filter without damaging the filter skin on top of the sand bed. Usually, the inlet structure is a box, which can also used to drain the supernatant water quickly.

The outlet chamber usually consists of two sections separated by a wall, on the top of which a weir placed with its overflow slightly above the top of the sand bed. This weir prevents the development of below-atmospheric pressure in the filter bed, which could lead to the formation of air bubbles underneath the biological layer. The weir also ensures that the filter operates independently of fluctuations in the level of the clear-water reservoir. By allowing the free fall of water over the weir, the oxygen concentration in the filtered water is increased and the weir chamber should therefore be suitably ventilated to facilitate aeration.

A set of filter regulation and control devices

The SSF has different controlling valves to regulate the flow of water at its different sections. The major valves are: raw water inlet valve, valve for drainage of supernatant water layer, valve for back-filling the filter bed with clean water, valve for drainage of filter bed and other outlet chamber, valve for regulation of the filtration rate, valve for delivery of treated water to waste, valve for delivery of treated water to the clear water reservoir.

5.3 MECHANISMS OF SLOW SAND FILTRATION

In slow sand filter impurities in the raw water are removed by a combination of different processes such as sedimentation, straining, adsorption, bio-chemical and bacteriological actions. The purification processes start in the supernatant water but the major parts take place on the top layer of the filter bed.

Straining removes those suspended particles that are too large to pass through the pores of the filter bed. It takes most exclusively at the surface of the filter where the impurities are retained on the top layer. This will improve the straining efficiency but also increases the resistance against the downward water flow. Periodically the accumulated impurities have to be removed by scraping off the top layer (IRC, 1981).

Sedimentation removes particulate suspended matter of finer sizes than the pore openings by precipitation upon the sides of the sand grains, in exactly the same way as in any ordinary settling tank. In such tank, however, deposits can only form on the bottom, while in slow sand filter the combined surface area of all filter grains is available (Huisman, 1989). In combination with the low rate filtration, the combined surface area provides a very low surface loading. The settling velocity will, therefore, be so high that even small particle can be completely removed.

Adsorption is the most important purification process during filtration, retaining finely divided suspended matter next to colloidal and molecular dissolved impurities. Adsorption is effected in many ways, passively when a suspended particle has contacted a sand grain and is retained on the sticky gelatinous coating formed by previously deposited bacteria and organic matter and actively by the physical action between two particles of matter and the electrostatical attraction between opposite electrical charges (Huisman, 1989).

The matter accumulated on the filter sand grains does not remain there unchanged; it is transformed by bio-chemical and bacterial activity. Soluble ferrous and manganous compounds are turned insoluble ferric and manganic oxide hydrates that become part of the coating around the sand grains. Organic matter is partly oxidized thus providing the energy needed by the bacteria for their metabolism. Another part of the organic matter is transformed into cell material, which is used for bacterial growth. Usually, the amount of organic matter in the raw water is small and provides food for only a limited bacterial population. Thus, simulations with the bacterial growth mentioned above, there will be a die-off of bacteria. Organic matter is so released. It is carried away with the water flow and again by other bacteria deeper in the filter bed. In this way the degradable organic matter originally present in the raw water is gradually broken down and transformed into inorganic compounds such as carbon dioxide, nitrate, sulfates, and phosphates. Finally, these are discharged with the filter effluent.

Microbial actions mentioned above need time to establish themselves. Hence, a ripening period of sufficient time is required. During this period bacteria from the raw water are absorbed onto filter bed grains. There, they multiply using the organic matter present in the water as food. The breakdown of organic matter takes place in many steps in each of which a particular type of bacteria is active.

For the filtration process to be effective, it is necessary that the bacteria develop and migrate to the deeper layers of the filter bed. This takes time, and variations in the filtration rate should be introduced slowly over a period of hours. In practice, it has been found that the full bacterial activity extends over a depth of about 0.6 m of filter bed so that the effective bed thickness should be not less than 0.7 m. The initial bed thickness should be 0.3-0.5 m more, to allow for a number of filter scrapings before resanding is necessary (IRC, 1981).

The most important purifying action of a slow sand filter is the removal of bacteria, including E.coli and pathogens. By the mechanisms mentioned above, but also by their own movement, bacteria adhere to the surface of the filter grains where their food is concentrated. For intestinal bacteria, the water environment is decidedly an unhealthy place, where the temperature is too low and insufficient organic matter of animal origin is available to suit their living requirements. In upper part of the filter bed, moreover, several types of predatory organisms abound, feeding on bacteria. In lower part of the filter bed bio-chemical oxidation has lowered the organic matter content so far as to starve the bacteria, which venture here. The microbiological life in a slow sand filter finally produces various antagonistic actions, such as killing or at least weakening intestinal with chemical (antibiotics) or biological poisons (viruses). The over-all effect is marked decrease in the number of E.coli and as pathogens are less likely to survive, an even larger drop in their number. The reduction of intestinal bacteria will be larger as proper flora and fauna of the slow sand filter is better developed, that is with sufficient food and not too low temperatures. As long as oxygen is available, the microbiological activity is independent of the actual content, but at lower temperatures the activity of bacteria eating protozoa and nematodes drops sharply, while on the other hand the metabolism of intestinal bacteria slows down, again increasing their chance of survival when passing the sand bed (Huisman, 1989).

5.4 MAJOR COMPONENTS OF PSF

DPHE with the collaboration of UNICEF have been and testing and promoting this type of filtering unit since 1984. The original design of PSF has been modified in different stages to overcome the problems identified at the field level. The major problems with the initial design identified at the field level were:

- Low discharge, totally inadequate to meet the demand of local people,
- A thick layer of clay forms on the surface of the sand,
- The useful capacity of the water chamber is very low (only 90 liters),
- The outlet chamber is so small that is difficult to carryout the cleaning and maintenance,

- When the filter has a low filtration rate, the water rises in the filter and as the height of the outlet water chamber is lower than the filter, unfiltered water enters the outlet water chamber.

- As the outer water chamber is not sealed at the top, there is a possibility that the filtered water becomes polluted again.

To overcome the above mentioned problems, the following modifications have been introduced in the present design (DPHE/UNICEF, 1987a).

- The internal dimensions has been increased to 5 ft x 5 ft (1.524 m x 1.524 m) for the filter bed and 5 ft 10 inch x 5 ft 10 inch (1.778 m x 1.778 m) above the filter bed. The filter bed size was formerly 4 ft x 4 ft (1.219 m x 1.219 m).

- The filter box wall height is reduced to 5 ft (1.524 m) from 6 ft 3 inch (1.905 m) to stop the possibility of entering untreated water to outlet water chamber.

- A small pre-filter chamber is introduced beneath the outlet of the handpump to reduce the turbidity load to the sand filter.

- The capacity of the storage tank for treated water is increased to 1000 liters. The storage tank has a fixed cover with a manhole for access.

- The filter chamber is covered with a lid consisting of wooden frame with corrugated iron sheet.

- The area of the platform is increased to about 28 ft^2 (2.6 m^2), which is three times larger than the original platforms. Two ½ inch (1.27 cm) outlet taps are provided for the users.

- The depth of the main filter bed varies between 1 ft 6 inch (45.72 cm) to 2 ft 6 inch (76.2 cm). There is a 1 ft (30.48 cm) layer of graded khoa (brick chips) under the filter bed.

The present PSF has now the following major components.

Handpump

A No.6 hand tubewell is used to pump up the water from the pond. A 6 ft (1.8288 m) long screen (perforated PVC pipe) is installed in the pond as floating intake. The intake is fitted with PVC pipe and is connected with handpump to feed raw water in the PSF. The floating intake is normally placed in such a way that it can abstract water from 2 ft 6 inch (76.2 cm) below the surface of the pond water. The handpump could draw 20-25 liter per minute as per standard human operation. There are 3 steps at the platform to operate the handpump.

Pre-treatment Chamber

A small pre-filter chamber, beneath the outlet of the handpump is installed to improve the raw water quality by filtration and sedimentation process. It also can improve the bacteriological quality of water. Originally coconut fiber and brick chips were used in the pre-filter. But, coconut fiber requires frequent replacement due to deterioration of its quality. Brick chips are now recommended for the filter chamber.

Sand Filter

It is the main treatment component of the Pond Sand Filter (PSF). It has a 25 ft^2 (2.32 m^2) filter bed with the normal depth of the filter sand bed varies from 9 inch (0.2286 m) to 1 ft (30.48 cm). The size of the filter sand is 0.2 – 0.35 mm with the uniformity co-efficient 1.5-1.7. There is a 1 ft (30.48 cm) thick layer of graded Khoa (brick chips) under the filter bed. This layer of brick chip acts as underdrains, which allow unobstructed passage of treated water and support the bed of filter medium. There is a layer of 3 inch (7.62 cm) concrete layer below the layer of brick chip.

The height of supernatant water is 1 ft (30.48 cm). Water, which passes through the sand filter, is collected at the base of the filter chamber from where it flows into adjacent storage chamber by a raised pipe. This raised pipe acts like a weir to maintain the minimum height of supernatant water. It helps filter bed to permanently submerge, and a minimum flow of the water to provide the micro-organisms in the filter bed with a stable flow of nutrients and oxygen. The storage tank has the effective capacity of 1000 liters. It has a fixed cover with a manhole for access.

Platform

The PSF has a platform with the dimension 5 ft 5 inch x 5 ft (2.154 m x 1.989 m). From the storage tank, the treated water is delivered through two ½ inch (1.27 cm) outlet taps for public use.

The plan and different sections of a PSF is shown in Annex C1.

5.5 SITE SELECTION CRITERIA FOR PSF

Selection of a proper site for PSF is very important to proper construction, operation and maintenance. The DPHE-UNICEF (1987b) provided a guideline for site selection of a PSF.

- The pond must be large enough to ensure that it will not dry out in the dry season.

- The salinity of the pond water must not exceed 600 ppm at any time of the year.
- The iron content of the pond water must not exceed 5 ppm at any time of the year.
- The location of the PSF should be close to a family to ensure its security. It must be freely accessible to the people.
- PSF will be constructed only when the beneficiaries show their willingness to participate and contribute in construction and take responsibility for operation and routine maintenance.

5.6 GUIDELINES FOR SELECTION OF A SURFACE WATER TREATMENT SYSTEM IN RURAL AREAS

The raw water qualities play an important role in selection of treatment processes. The guidelines given in Table 5.1 can be used to select a water treatment system, adopting slow sand filter as the main process.

Table 5.1: Guideline for the selection of a water treatment system for surface water in rural areas.

Average raw water quality	***Treatment required***
Turbidity· 0-5 NTU Faecal coliform MPN*.0 Guinea worm or schistosomiasia is not endemic.	No treatment
Turbidity· 0-5 NTU Faecal coliform MPN*:0	Slow sand filter.
Turbidity 0-20 NTU Faecal coliform MPN*:1-500	Slow sand filtration, Chlorination, if possible.
Turbidity 20-30 NTU (30 NTU for a few days) Faecal coliform MPN*·1-500	Pre-treatment advantageous; Slow sand filtration; Chlorination, if possible.
Turbidity: 20-30 NTU (30 NTU for several weeks) Faecal coliform MPN*:1-500	Pre-treatment advisable, Slow sand filtration; Chlorination, if possible
Turbidity 30-150 NTU Faecal coliform MPN*·500-5000	Pre-treatment, Slow sand filtration; Chlorination, if possible
Turbidity· 30-150 NTU Faecal coliform MPN*. >5000	Pre-treatment, Slow sand filtration, Chlorination.
Turbidity: >150 NTU	Detailed investigation and possible pilot plants study required

Visscher *et al* (1987)

Note * Faecal coliform counts per 100 ml.

Generally, roughing filter (horizontal flow or vertical flow) is used as pre-treatment filter to the slow sand filter. Horizontal flow filter has been found very effective at rural tropical communities, as construction costs are low and maintenance is minimal. The higher tropical temperatures favor biological activity within the filter. Pilot plant studies have revealed that a properly designed pre-filtration unit is capable of removing 60-70% of the suspended solids and 80% of the coliform organisms in raw water (Thanh and Hettiaratchi 1982). Horizontal roughing filter consists of different sizes coarse materials separated by wire mesh. The filter acts like compartments filled with different sizes of coarse materials. The number of the compartments and size of the coarse materials are selected based on the water quality. Three compartments with 15 mm, 10 mm and 5 mm gravel were used to as pre-treatment unit for the pond water (average turbidity 60). More than 90% turbidity and fecal coliform reduction were observed in the horizontal roughing filter (Nath *et al.,* 1992).

Ahsan (1995) worked a new pretreatment technology for highly turbid river water, called direct horizontal-flow roughing filtration, by combining the principles of direct filtration with roughing filtration process. The HRF process was improved to direct horizontal-flow roughing filtration (DHRF) by rapid mixing of small and constant amount of coagulant, typically 1 mg Al(III)/l prior to HRF. DHRF (8 m long consisting of 4 m first compartment with 20 mm diameter grains and 4 m second compartment with 8 mm diameter grains) systematically yielded good effluent quality (2-5 NTU) with raw water turbidity of 100-400 NTU. DHRF run time was 3-15 days depending on raw water turbidity, grain size and filtration rate.

The pre-treatment unit in PSF is a small filtering box, which can be considered as a rapid roughing filtration unit. This type of system is also expected to product an effluent satisfactory for slow sand filtration. The PSF has no chlorination device in the storage tank. The water is used for drinking purposes without any chlorination. As a small filter box is used for the pre-treatment and safety chlorination is not carried out in PSF, it can be concluded the expected raw water quality is turbidity < 30 NTU and Fecal coliform < 500/100 ml.

5.7 COMPARISON OF DESIGN CRITERIA OF SSF AND PSF

The design criteria of SSF and PSF are compared in the Table 5.2.

Table 5.2: Comparison of design criteria of SSF and PSF.

Criteria	*Standard of SSF*	*Standard of PSF*
Depth of supernatant water	1.0 m – 1.5 m	0.3048 m
Sand bed		
Depth	Minimum 0.6 m	0.2743 m – 0.3048 m
UC	2.0 – 3.0	1.5 – 1.7
Effective size	0.15 – 0.35	0.2 – 0.35
Thickness of Underdrain	0.3 m – 0.5 m (including gravel layers)	0.381 m
Inlet structure	Well control structure	Water falls directly over the sand filter
Weir in outlet structure	Weir on top of a brick wall in the outlet chamber	Raised pipe in storage chamber
Filtration rate	0.1 – 0.3 m/h	Not mentioned
Filter regulation and control device	Well defined controlling valves	No major controlling valves. Valves for only drainage of water
Run times	20 – 100 days	10 – 20 days
Number of filter bed	Minimum 2	1
Mode of raw water pumping	Motorized pump	Handpump

The maximum size of the filter bed of SSF is generally 200 m^2 in rural areas to ensure that cleaning can be carried out within a day. As a rule, the minimum size of a filter bed is 5 m^2, but experiments have shown that filters of less than 1 m^2 are equally efficient (Visscher *et al.*, 1987). It would appear that to reduce the cost of PSF, the design criteria for PSF has been changed from SSF though the effective removal by the mechanism of the SSF require the standard of SSF. It seems that the dimensions of supernatant water, filter bed height are reduced in proportional way to the filter bed size.

The effects of difference in design criteria shown in the above table are discussed below.

Depth of supernatant water

The depth of supernatant water is very low comparing to the standard of SSF. A minimum 1 m supernatant water layer is required to provide a sufficient head of water and to create a sufficient detention time for various physical or biological processes during passes of water through the filter.

Sand bed

The recommended sand for the PSF has a lower uniformity coefficient value than the standard value. This grades sand will provide a better removal comparing to sand with higher uniformity coefficient. However, such uniform sand might be fairly expensive. The effective size of the sand for PSF and SSF is almost same.

The major identified limitation of PSF is the limited depth of the sand bed filter. It is revealed from the filtration theory that full bacterial activity extends over a depth of about 0.6 m of filter bed so that the effective bed thickness should be not less than 0.7 m. So, it is clear that removal by bacterial activity in PSF is partly achieved.

Underdrain system

The thickness of underdrain system in PSF is with the design range of the SSF.

Inlet structure

PSF has no inlet structure; the water is allowed to flow directly from the pre-treatment chamber to top of the sand bed a PVC pipe. This direct flow of water can damage the filter skin on the top of the sand bed. It may also create a route for passes of bacteria in the filter bed to the treated water.

Weir in outlet structure

A raised 3.81 cm PVC connection pipe (sand bed to storage chamber) acts as a weir in the outlet chamber. On the other hand, in SSF a wall separates the outlet chamber into two sections and a weir is placed on the top of the wall. The PVC connection is in PSF vulnerable to manual cleaning of storage tank.

Filtration rate

The filtration rate of PSF is not mentioned in the working document of PSF. However, the suggested value for slow sand filter is 0.1 m/h to 0.3 m/h.

Filter regulation and control device

There is no device for filter regulation and control the flow in PSF. This makes the different uncertainties in operating the system and it probably effect the treated water quality.

Run times

The run time of a filtration unit depends on the raw water quality. As the small pre-treatment box in PSF does not improve the water quality especially the turbidity, the runtime of PSF is very short comparing to SSF.

Number of filter bed unit

The another major disadvantage of PSF is only one filter bed unit. After scraping of the top layer of sand, it takes time (one to two days) to reestablish the useful bacteriological layers. In SSF, at least two filter units are used to ensure safe and continuos operation and to allow one of the beds to be cleaned.

Mode of raw water pumping

The water is pumped through a handpump in PSF system, where motorized pump is used in the case of SSF. The type of supply in PSF is intermittent and there will be no supply after certain time in the night. The flow rate during night may cease all together.

5.8 OPERATIONAL STATUS OF PSFs

The one of the major problems to study the PSF is the lack of information on its operational conditions, the quality of the treated water, level of user acceptability etc. There is no independent assessment report on performance of PSF. WHO (1998), Dhaka in collaboration with DPHE and UNICEF has carried out a survey on operational status 130 PSFs. Only 63 (48.5%) PSFs were in operation and 67 (51.5%) PSFs were not in working conditions. Out of 130 PSFs surveyed, 70 handpumps were in operation and 60 (46.1%) handpumps were not in operation. 38 (29.23%) handpumps were not operable due to spare parts damaged/missing, 3 (2.3%) for pump damaged, 5 (3.8%) pumps were stolen, 8 (6.15%) for non-acceptance of PSF and 6 (4.6%) for other reasons like faulty installation. The study did not conclude any relationship between the handpumps condition and the PSF condition. It is not clear that the non-operational PSFs have the major problem only with the handpump.

The study also describes the physical condition of the different components of PSF like filter condition, pre-treatment unit, platform condition, drainage condition etc. The result shows that the connection pipe is in satisfactory condition only in 43 cases of 130. So, it is obvious that negative pressure may develop in many instances and the filter bed may become dry at the night.

The conclusions drawn form the study are as follows. Surprisingly, the study did not check the water quality of the treated or raw water.

- Users are not sufficiently aware the health benefits of drinking PSF water.
- Location of PSFs is not correctly selected in some instances.
- Supervision of construction works was not adequate.
- The C.I. sheet cover is not strong enough and delivery spout is not appropriate.
- The thickness of sand filter is reduced affecting effectiveness of PSF.
- Training and maintenance tools are not adequate.

- The ponds are not protected against the unwanted flows.

The DPHE/UNICEF (1987) showed that the coliform bacteria in the treated water were ranging from 0 to 5 in 100 ml in samples collected from 5 PSFs. Contrary to this, it is reported* that the treated water contains more than 10 colifom/100 ml of samples during most of the time of the year. However, the situation becomes even poorer and the water may contain a few hundreds fecal coliform bacteria per 100 ml which is considered as totally unacceptable quality.

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* Reported by Dr Bilquis, A H from ICDDRB in the National Conference on Coordinated Action for Arsenic Mitigation, Dhaka 1999

5.9 LOCATION OF FIELD STUDY

A field study has been carried out to supplement the available information on PSF. The objectives of the field study are to investigate physical condition of the PSF and compare with the design guidelines. The study also looks into the participation of community in operation and maintenance of PSFs. The filed study has been carried out at Shyamnagar, a Thana (sub-district) of Satkhira district (see Figure 1.1).

Satkhira is located on is 22°42' N (latitude) and 89°04' E (longitudinal). It is one of the coastal districts of Bangladesh where suitable groundwater (salinity free) is not readily available. People have been using pond water traditionally for a long time. The ponds are abundant in this region comparing to the other regions of Bangladesh. PSFs has been introduced by DPHE-UNICEF in this area from the 1985. The other available drinking water sources are VSST (very shallow shrouded tubewell) and manually operated deep tubewell. However, identification of suitable water pocket is difficult and life span of VSST is too short. Deep tubewell on the other hand is relatively expensive. In the Shyamnagar proper union, VSST and PSF are the only two available methods for drinking water supply. However, still a portion of people using the pond water directly. The pond used for drinking purposes are generally kept restricted for use of other purposes like bathing, washing of clothes, cattle bathing, fishing with chemical food. This area is not vulnerable to frequent flooding.

5.10 TECHNICAL ASPECTS OF PSFs

Reason of not operation

The field study was carried out on 13 Nos. of PSFs. 4 Nos. of PSFs was found not in operation. 2 PSFs were abandoned due to saline water intrusion in the pond from a shrimp culture field. Other 2 PSF have been temporarily out of operation. One PSF was in the premise of a charity clinic and the handpump required replacement of spares. The maintenance cost is generally paid by the charity clinic and the clinic could not repair the handpump due to shortage of fund for this purpose. However, they planned to repair it very next month. The other PSF in the premise of Water Development Board was kept out of operation due to shortage of water. The water from the pond was pumped for household use in the office campus.

Sand bed

The depth of the sand bed was found between 11 inch (27.94 cm) to 12 inch (30.48 cm) measured in the 5 PSFs. This depth was within the range defined in the PSF design.

The sand used in these filters was used from the same source - DPHE. The sand is also available in the market and some times caretaker purchased sand from the market during their need. The sand sample was taken from DPHE stock and the sieve analysis was carried out in the IHE laboratory. The sieve analysis result is given in Table 1 in Annex C2 and the grain size distribution curve is shown in figure in Figure 5.4.

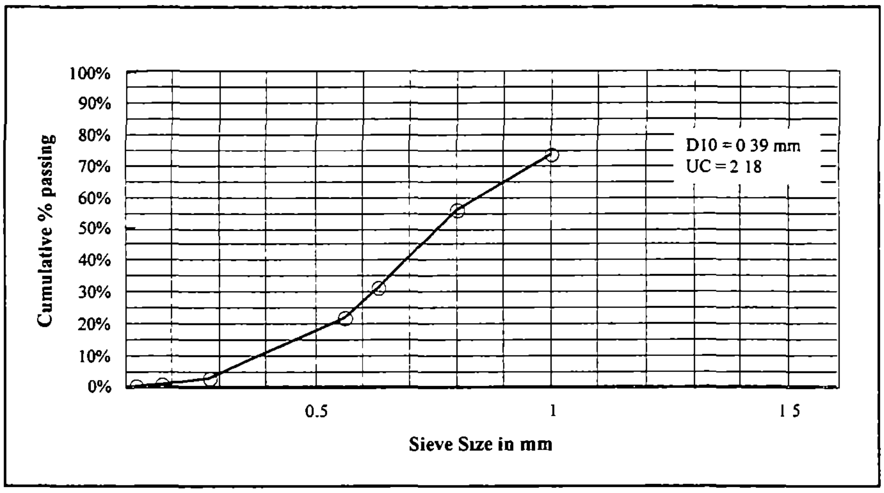


Figure 5.4: Grain size distribution of filter sand.

The uniformity coefficient was found 2.18, which higher than DPHE standard, but in the range of slow sand filter. The effective size was found 0.39, which is just in the range of DPHE guided range but above the standard given for slow sand filtration. However, 44.4% of sand was retained in the sieve size 0.8 mm and 1 mm. The removal of coliform bacteria decreases with higher value of sand grain (figure 5.1). In the physical observations of sand, it was revealed that very small sizes (larger than 1 mm) gravel was mixed with the sand. The quality of the sand was not suitable for the single treatment filtration unit. The removal efficiency of fecal coliform reduces with the increase of particle size.

Pre-treatment chamber

The size of brick chips is not defined in the design. However, DPHE suggests to use 1 inch (2.54 cm) brick chips in the pre-treatment chamber. In 3 PSFs, larger size brick chips were used. The size was more than 2½ inch (6.35 cm). These larger size brick chips can not improve the water quality. The effective surface area of filtering media decreases with the increase of the size of filtering materials.

In the horizontal flow coarse media pre-filter, 3 mm to 20 mm gravel are used (Thanh, 1982).

Raw water quality (Iron and Salinity)

The water samples from 3 ponds were collected from the inlet handpump. These 3 ponds supply water to three PSF systems. These 3 PSF plants were selected on the management point of view. The plant 1 is in the premises of DPHE thana office and DPHE office maintains it The plant 2 is in the thana parisad (sub-district council) campus and maintained by the mosque committee. The third plant is in open place, nearly the main highway and is maintained by a caretaker. The filters were running between 10 to 12 days after the last resanding.

The iron and chloride concentrations of the samples were analyzed in the DPHE zonal laboratory at Rajshahi. The results are shown in Figure 5.5a and 5.5b. The iron analysis was carried out by colorimetric method (standard method 3500-Fe) and chloride analysis was done by argentometric method (standard method 4500-Cl$^-$).

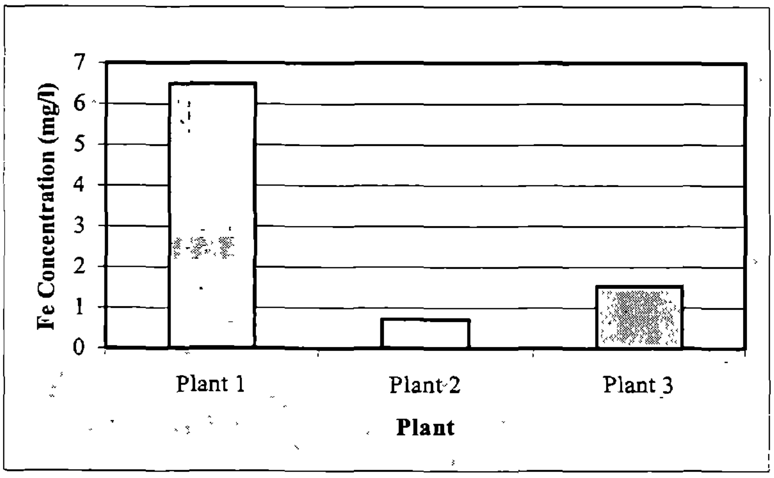


Figure 5.5a: Fe concentration tubewell (pond) water

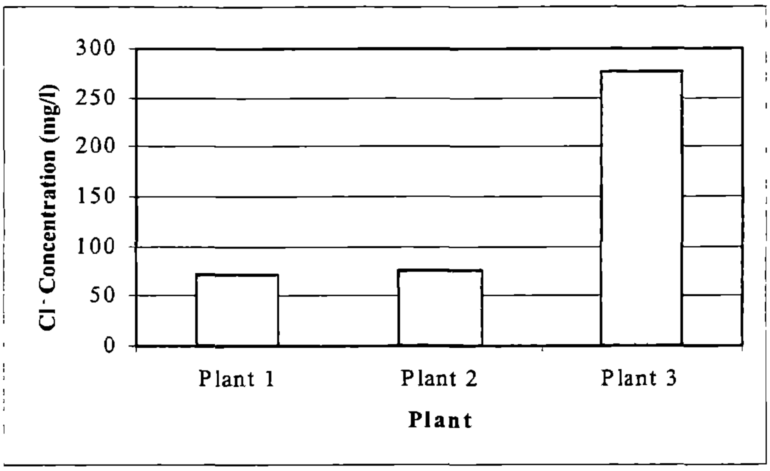


Figure 5.5b: Cl⁻ concentration tubewell (pond) water

The Fe concentration of the raw water in plant 1 was 6.5 mg/l, above the DPHE guideline (5 mg/l). The Fe concentrations of other two sources are 0.72 mg/l and 1.53 mg/l respectively.

The Cl⁻ concentration of Plant 3 is higher than that of other two plants. However, it is below the guide value (600 mg/l). The Cl⁻ concentrations of 3 plants were 72, 77 and 277 respectively.

Turbidity reduction in PSF

The water sample collected from the same 3 plants from Tubewell, from the output point of pre-treatment chamber and outlet taps for turbidity and fecal coliform analysis. The size of the brick chips in the 3 pre-treatment chamber was between 1 inch (2.54 cm). The turbidity of the samples was analyzed by turbidimeters at DPHE zonal laboratory at Rajshahi. The results of the analysis are given in Table 2 in Annex C and the turbidity reduction is shown in Figure 5.6.

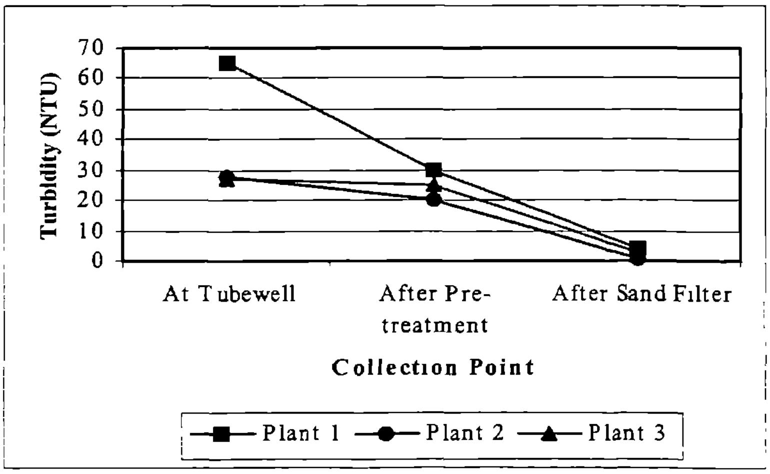


Figure 5.6: Turbidity reduction in PSF system

The maximum turbidity observed in the raw water was 65 in plant 1. The turbidity in the treated water was found 4, 1 and 3 which was the below the advisable turbidity limit (5 NTU). The removal efficiency of the pre-treatment chamber was found highly variable, ranging from 7.4% (Plant 3) to 53.85% (Plant 1). The removal efficiency of sand filter varied from 86.67% (Plant 1) to 95.0% (Plant 2). The pre-treatment chamber was not very effective in reducing the turbidity of the raw water. It increased the turbidity load in the slow sand filter.

Fecal coliform reduction in PSF

The fecal coliform test was carried out by fecal coliform membrane procedure (standard method 9222 D). The samples from each points were collected in 3 times for the coliform tests. The results of the analysis are given in Table 3 in Annex C and the coliform reduction is shown in Figure 5.7.

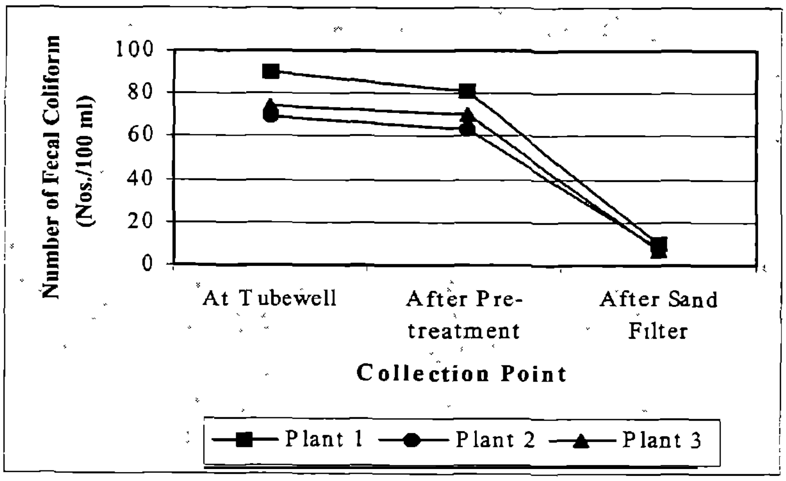


Figure 5.7: Fecal coliform reduction in PSF system

The fecal coliform in treated water was found between 7 to 10 per 100 ml. These values are higher than the guideline value (0 per 100 ml) for drinking water. However, PSFs (pre-treatment chamber and sand filter) reduced the fecal coliform by 88.41% to 90.54%. The fecal coliform reduction in the pre-treatment chamber was found very negligible (5.41 % to 10%).

Re-sanding

Re-sanding were carried out twice a month except two plants. The runtime was generally selected when filtration rate became very low. In the other two plants, re-sanding was carried out once a month, regardless of filtration rate. About 4 to 8 inches (10.14 to 20.32 cm) sand was scraped, washed in the platform, dried and again placed on the sand bed. The water in the filter box was drained out before the resanding. 2 men were required for the resanding purpose. The required time re-sanding was one working day. Users started taking water from the very next day after the re-sanding.

However, it also required another 2 to 3 days (minimum) for growth of the biological layer. So, if we consider 3 days for growth of the biological layer and 1 day for re-sanding, then 4 days were found ineffective in producing quality water for each re-sanding. For re-sanding twice a month, users can get satisfactory water only 22 days. However, it also took 2/3 days where the users or caretaker did the job. The users were collecting water from the nearby PSF or the pond during the re-sanding period of the filter.

Conclusion

The water quality samples were taken in the summer period i.e., in the dry season. The raw water quality generally decreases during the rainy seasons as runoff from the different unprotected latrines, cattle field etc are mixed with the pond water. This will also increase fecal coliform numbers in the treated water. The sand filter depth is not found adequate to reduce the fecal coliform to the guideline value. The sand grain used in the field was used not satisfactory. The sand filter is able to reduce the turbidity to the guideline value.

The runtime of PSF is very short which makes the O&M of the system very complicated. It also reduces the effective days of treated water in a month.

The performance of pre-treatment in terms of turbidity removal and fecal coliform removal was not found satisfactory. The pre-treatment system requires improvement to reduce the turbidity load and fecal coliform load in sand filter. An improved pre-treatment system will enhance the runtime of a PSF. A small horizontal roughing filter can be considered for pond sand filter. Direct horizontal roughing filter is not possible, as constant amount of coagulant addition is not possible in the manual operated PSF system.

The Fe and Cl^- concentrations in the raw water were found acceptable.

A PSF system may be out of order not due to other problems not related to the filtration problems.

A PSF can not bring the fecal coliform to the acceptable limit, but it reduces the fecal colifom level in the water. The effluent turbidity is within the acceptable limit. An improvement of the system can produce water acceptable water quality.

5.11 COMMUNITY ASPECTS OF PSFs

The role of a caretaker

The caretaker of PSF is generally the head of a family whose pond is used for the pond sand filter. He does not receive any remuneration for looking after the system. The main advantage he and his family enjoy is that the system is very close to their house.

It was observed that the caretaker had little or no knowledge about the filtration mechanism. The effects of filtration rate, sand quality, supernatant water etc. were not known to them.

Community participation

The DPHE Sub-Assistant Engineer and caretaker mainly selected the locations of the PSF. There is very limited role of the users in selecting the location of the PSF. The caretaker family and other nearby families normally paid the contribution money for the PSF.

The PSF were found accessible to the all users except one location. However, the users are very reluctant to pay the maintenance cost. The caretakers have to pursue many times to receive the money from the users. In many instances, the caretaker family bears the cost of maintenance. The users were in the opinion that water is the basic need for the existence of human life and government should bear the cost of the water. The users and the caretaker had no idea about the monthly payment system for a caretaker who will take care about the system.

It was observed that the one outlet tap in the three PSFs was kept closed due to the problems among the users in taking the water. If the two points were opened, the problems were created between the two users about pumping water in the system.

The users were generally pumping water during their collection of water. However, some users were found reluctant in pumping water if water is available from the storage tank. But, it is very difficult to quantify what percentage of users are unwilling to pump water.

The users were found satisfied with the system as the PSF produces better quality of water. The better quality of water in their terms was salinity and turbidity free water. The users had no other alternative water sources for use throughout the year.

Conclusion

Community contribution for the installation and maintenance of the PSF is very negligible. As the community was not concerned with the installation of the system and the other decision making activities, they did not the think about the sustainability of the system. There are no identified approaches for community financing to meet the recurrent cost of the system.

Adequate knowledge about the system is one of the most important factors for a successful operation and maintenance of a system. Unfortunately, caretaker did not receive any proper training on it.

Though women were the main collectors from the PSF, their role in different level of decision making were neglected.

The users require health and hygiene education as they still consuming the pond water during the re-sanding period.

5.12 PROPOSED DESIGN IMPROVEMENTS FOR PSF

It has been revealed in the study that there is still scope for design improvement to achieve potable water from a PSF system. The design improvements are limited in 5 components, keeping in mind the extra cost involvement. The proposed design improvement is shown in Figures in Annex C2. The improved components with their expected effect are described below.

Pre-treatment Chamber

<u>Present design</u> - One box with larger brick chips.

<u>Proposed design</u> - Three compartments with smaller size of gravel (or brick chips) separated by wire mesh. The size of the gravel will be ½ inch to 1 inch (12.7 mm to 25.4 mm), ¼ inch to ½ inch (6.4 mm to 12.7 mm), $^1/_8$ inch to ¼ inch (3.2 mm to 6.4 mm). Two other compartments are also used before and after the three compartments for water. The new pre-treatment unit will act as a horizontal flow roughing filter.

<u>Expected improvement</u> – The pre-treatment chamber can really contribute to the treatment process. It will decrease the turbidity load to the sand filter. So, the runtime of the sand filter will be increased. The expected runtime will be around 60 days. It will also reduce the FC due to longer detention time in the pre-treatment chamber and also due to some biological activity.

Inlet structure

<u>Present design</u> – No inlet structure.

<u>Proposed design</u> – A very small inlet structure before the sand filter.

Expected improvement – It will stop the direct falling of water to the filter sand skin and will reduce the possibilities of passing of bacteria to the treated water without treatment. It will also provide greater facilities during the re-sanding period. Presently, all the water in the filter box is drained out before the resanding. By opening the valve at the inlet structure supernatant water can be removed without disturbing the filter bed. The upper portion of the sand can be scrapped off and the sand from the stock can be laid down immediately over the filter bed. This process will less disturb the biological layer in the deeper sand filter.

Filter bed unit

Present design – One unit.

Proposed design – Two units.

Expected improvement – It will ensure safe and continuos operation and will allow one of the beds to be cleaned. The other filter bed unit can be cleaned after the few days of the first bed cleaning. The treated water from the cleaned filter bed will not be allowed to supply in the storage chamber for one day. Treated water will be discharged to outside drain, as the bacteriological quality of the filter may not be satisfactory in first day of filtration.

Filter bed

Present design – The depth of filter bed sand – 1 ft (30.48 cm).

Proposed design – The depth of filter bed sand – 2 ft 3 inch (68.58 cm).

Expected improvement – This increased filter bed will allow the full biological activity in the filter bed and will produce the acceptable quality of water. The re-sanding in the top layer (7.62 cm to 10.16 cm) will not disturbance the developed biological layer already developed in the lower filter bed. Presently, about 50 percent of the sand filter bed are scrapped off and again washed and dried sand is placed on it.

Supernatant water

Present design – The depth of supernatant water – 1 ft (30.48 cm).

Proposed design – The depth of supernatant water – 3 ft (91.44 cm).

Expected improvement – The increased water depth above the filter will provide sufficient head of water to pass through water the filter bed and sufficient detention time for various physical and biological processes.

Outlet Chamber (prevention of negative pressure in filter bed)

Present design – A raised connection pipe.

Proposed design – A brick wall.

Expected improvement – The brick wall will ensure the prevention of development of negative pressure in the filter bed. It will also ensure that filter will operate independently regardless of fluctuations in the water level in the storage tank. It can be noted that the raised PVC connection pipe was observed very vulnerable to cleaning the storage tank.

5.13 PROPOSED O&M PROCEDURE FOR PSF

Caretaker

A fixed caretaker will increase the operation and maintenance system of a PSF. The caretaker preferably not the head of the family, whose pond is used for the system .It is the general observation that the head of the family is the oldest man in the joint family. A young hardworking with the basic education should be selected for as a caretaker. The caretaker needs adequate training on the principles of the system, the O&M system and the approach of community management. The caretaker should receive a monthly remuneration (Say Tk. 1000) from the community and it will certainly offer the most effective control mechanism to ensure that operation and maintenance tasks are properly carried out. If fixed remuneration is not possible in a community, other form of compensation is also possible like provision of a toolkit and increased status etc.

The caretaker will check the water level water at the night and early in the morning and if required will pump to ensure the sufficient height of the supernatant water.

The caretaker will perform the re-sand with the voluntary labor from the community. He will also perform the minor repair of the system such as repairing of the outlet taps, replacement of spares of tubewells (e.g., buckets, cup-seal etc.).

Heath and hygiene education

The community participation and health improvement can be considerably achieved from a water supply system by a well-designed health and hygiene education program. The program will demonstrate the effect the safe water supply system and transmission of disease. The program should be taken with the consultation with the community. The type of program will motivate the users in taking responsibility of operation and maintenance system.

Water user group

A water user group will be formed for each PSF system composed of the users directly involved with the system. A more balanced gender representative body needs support from both men and women involved in the community. The user group will take decision on the operation and maintenance issues of PSF and will assist the caretaker to perform his duties. The responsibility for daily operation and maintenance like cleaning of the platform, pumping the system etc. will be distributed by the water user group.

Village water committee

The representatives from the user group of the each PSF will form a village water committee. The committee will supervise the PSFs and have a close communication with the implementing agencies. The committee will have some common accessories like the nets (sieves). For example, sand will be passed through a net with the opening of 0.4 mm. The sand passed through the net will be taken for next net having opening of 0.2 mm. The sand retained on the net will be used for the filter. The gravel size will also be identified by the similar way.

Fund Raising

The fund raising is one important activity for smooth operation and maintenance of a PSF. The community have to mobilized to contribute for the O&M of the PSF. There should be an acceptable form of fund raising system for the user group. There are several methods for fund raising for community water supply system. These are: voluntary funds, general community revenue and community revolving fund and production cooperatives. These methods are described in Annex C3.

6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following conclusions are drawn on the basis of the study carried out.

Arsenic removal by a coagulant

The coagulation technique for arsenic removal appears feasible for immediate application as alum along with calcium hypochlorite can remove a substantial amount of arsenic. The capital cost of the system is also low and chemicals are available. The arsenic removal was found dependent on the initial iron value in the water, with higher iron leading to increased arsenic removal. A common dosage of alum and calcium hypochlorite can be applied for a range of raw water to bring the arsenic value down below the Bangladesh standard. Optimal dosages can be identified and applied for different arsenic-iron concentrations for more reliable results. Arsenic removal was also achieved without addition of coagulant when raw water contained high iron. The specific findings on the experiments are below:

- High arsenic was associated with high iron concentration in the groundwater. However, there was no direct correlation between arsenic and iron in groundwater of Chuadanga, Bangladesh. The average arsenic concentration was 203 μg/l and average iron concentration was 6.9 mg/l.

- 96% As(V) was removed from water having arsenic concentration 200 μg/l and iron concentration 6 mg/l by addition of 80 mg/l aluminum sulfate (7.3 mg Al^{3+}/l) and 10 mg/l calcium hypochlorite (3.3 mg Cl_2/l).

- Presence of iron in the water enhanced the arsenic removal in the coagulation process. The residual As in the treated water was 20 μg/l, 18 μg/l and 15 μg/l for initial iron concentration 3 mg/l, 6 mg/l and 9 mg/l respectively when 80 mg/l aluminum sulfate (7.3 mg Al^{3+}/l) and 10 mg/l calcium hypochlorite (3.3 mg Cl_2/l) were added to the water having arsenic concentration 400 μg/l.

- Arsenic removal efficiency was almost constant regardless of initial arsenic concentration. The removal efficiencies were 95%, 96% and 96.3% for initial arsenic concentration 200 μg/l, 400 μg/l and 600 μg/l respectively by addition of

100 mg/l aluminum sulfate (9.1 mg Al^{3+}/l) and 10 mg/l calcium hypochlorite (3.3 mg Cl_2/l).

- The optimal dosing to achieve the WHO guideline can be identified for different initial arsenic-iron concentration in water (Table 3.5).

- Arsenic removal was also achieved by using the iron present in the water. The Bangladesh arsenic standard (50 µg/L) was obtained from initial As(V) concentration 200 µg/L, 400 µg/L and 600 µg/L when the initial iron concentrations were 6 mg/l, 9 mg/l and 12 mg/l.

Rainwater harvesting

Rainwater harvesting is found technically feasible on the basis of the prevailing rainfall pattern. 58% of household has a roof constructed from technically appropriate materials. The capital cost of the system is high. However, the recurrent cost of the system is very negligible. The system is only feasible for the low-income group if high subsidy or other financial arrangement is provided. Micro-credit system is one the attractive option for financing the storage tank, which can be pay-backed over 5 years. The other conclusions are:

- The required size of the storage tank varies from location to location due to distribution of rainfall. The required storage tank volume at Rajshahi (Avg. rainfall 1450 mm and avg. dry period 5 months) is 4.4 m^3, whereas at Sylhet (Avg. rainfall 4202 mm and avg. dry period 3 months) is 2.9 m^3 with an catchment area 60 m^2 (for 6 person in a family).

- Mass curve analysis and A_c-V_c method are both feasible for estimating the capacity. However, A_c-V_c curve can be developed for different regions and non-professionals can easily calculate the required size for different household at the field level by using it.

- The estimated cost for cement ring storage tank (Tk. 1266/m^3) is found relatively cheaper than other materials tank.

Pond sand filter

The present PSF design reduces the fecal colifom significantly, but can not bring to the standard. The operation and maintenance of the PSF is complicated specially resanding of filter bed after 15 days of operation on an average. Despite different limitations, PSF can be considered an appropriate technology where no other appropriate methods of producing potable water are available. An improvement of the PSF design may produce the desire quality of water and reduce the frequency of resanding. The specific findings are:

- PSF can reduce the turbidity (< 4 NTU) of the water within guideline value.

- The sand filter depth is not found adequate to reduce the fecal coliform to the guideline value. The FC in the treated water was found between 7 to 10 per 100 ml.

- The sand grain used in the field was not satisfactory.

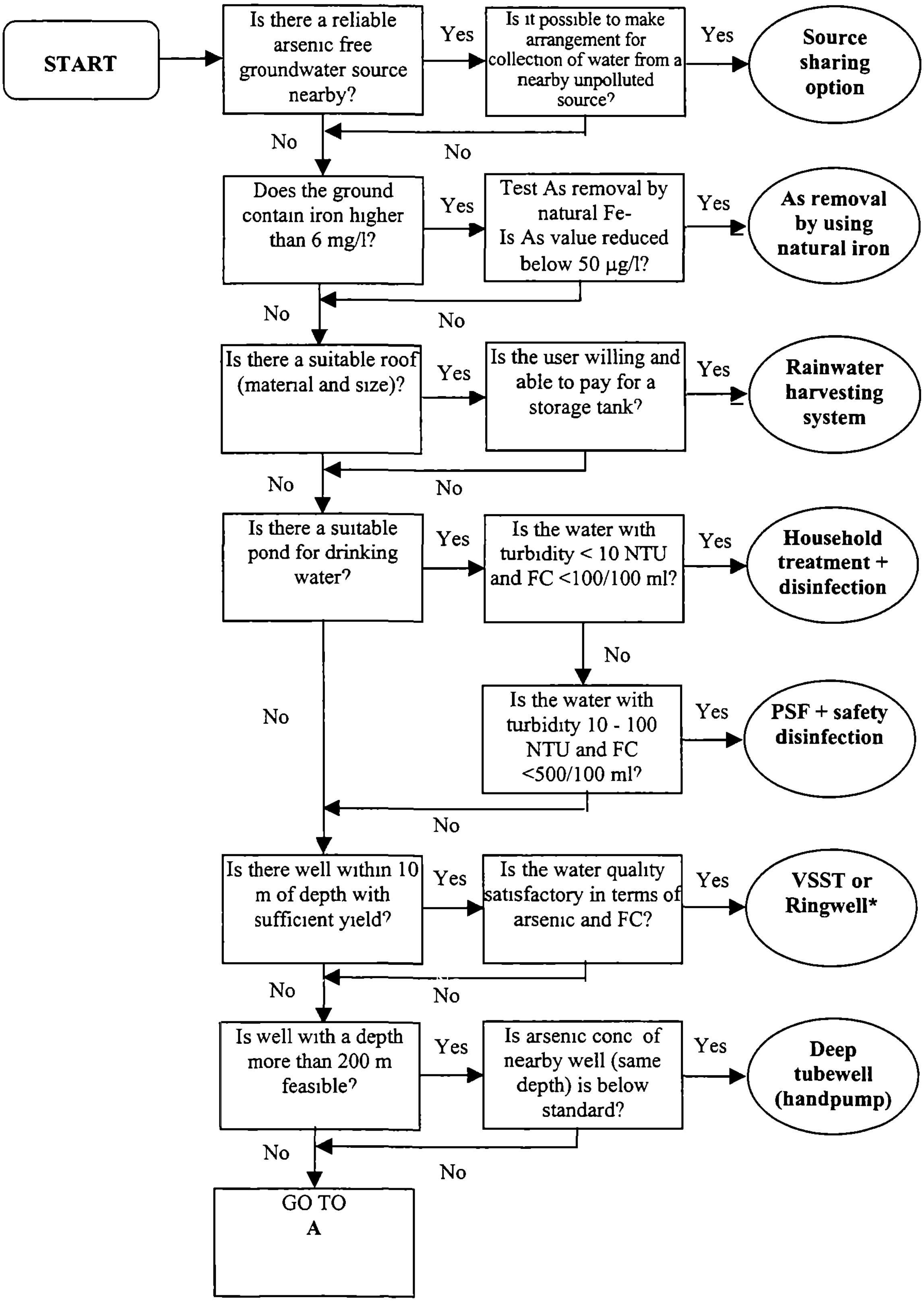
- The runtime of PSF is very short which makes the O&M of the system very complicated. It also reduces the effective days of treated water in a month.

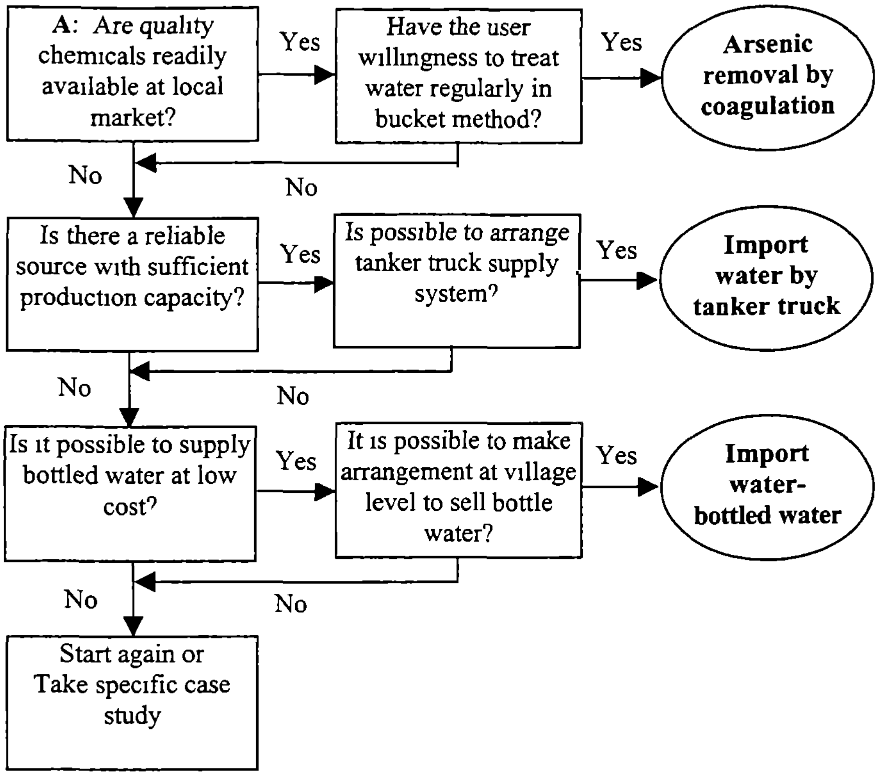
- The performance of pre-treatment chamber in terms of turbidity removal and fecal coliform removal was not found satisfactory. The pre-treatment system requires improvement to reduce the turbidity load and fecal coliform load in sand filter. An improved pre-treatment system will increase the runtime of a PSF.

- The proposed modified design is expected to improve the treated water quality, increase the filter run time and reduce the O&M activities.

6.2 RECOMMENDATIONS FOR TECHNOLOGY SELECTION

On the basis of the study, the following flow-chart is recommend to select a technology for water supply in an arsenic affected area. The assumption is that user will bear the most of the capital cost and O&M cost.





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* Handpump will be used for abstraction of water from ringwell and periodical disinfection is necessary.

6.3 RECOMMENDATIONS FOR FUTURE STUDY

The following recommendations are made for future research in this field.

<u>Arsenic removal by a coagulant</u>

- The experiments were carried out in a limited scale at the laboratory with model water. Arsenic removal may be decreased, when natural well water is used for the experiment due to the influence of water matrix. Phosphate ions or sulfate ions present in the water can compete with As(V) on the hydroxide surface. Moreover, stirring is a major determining factor for a coagulation process. The manual stirring at the field level may reduce the arsenic removal efficiency. Therefore, further studies are required at the field level with the natural water and also with manual stirring in the bucket experiments.

- Residual aluminum concentration and sludge handling are also major determining factors when considering the use of the coagulation method. These were not considered in the limited scale study. Further studies are required to investigate the residual aluminum concentration in the treated water and the release of metals from the sludge produced.

- There are further scopes to study the role of iron in arsenic removal. The arsenic removal efficiencies by iron present in the water can be compared by addition of oxidizing agent and without addition oxidizing agent. The arsenic removal by addition of coagulant can also be compared by changing the sequence of the dosing – first dosing of calcium hypochlorite and mixing, after that dosing to alum and mixing.

Rainwater harvesting

- The study does not work with the different storage tanks at the field level, as these are not presently available. Applied research is required particularly for real cost of different materials in the field, improvement of storage tank using local and low-cost materials, financing system, impact assessment, community participation, women involvement etc.

Pond sand filter

- A further study on the seasonal effect on the quality of the raw water and treated water, operational limitations especially during rainy season is necessary.

- The performance of proposed modification of pond sand filter needs to be studied at field level.

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Annex A1: ANALYTICAL INSTRUMENTS AND CHEMICALS

Analytic instruments:

- Atomic absorption spectrometer (AAS): Perkin Elkin Elmer 1100 B with graphite furnace and HGA 300 programmer – for total arsenic analysis.
- Atomic absorption spectrophotometer (Flame AAS): Perkin Elkin Elmer 3100 – for iron analysis.

Chemical and reagents:

- Demineralized water
- Nitric acid, HNO_3: AR grade- Merck
- Nickel nitrate, $NiNO_3$: AR grade- Merck
- Hydrochloric acid, HCl: AR grade- Merck

Annex A2: ARSENIC ANALYSIS METHODS

Preparation of standard solutions:

The As(V) stock solution of 1000 mg/l was prepared by dissolving 0.1534 g As_2O_5 in 100.0 ml demineralized water. This main stock solution was kept in a refrigerator. The As(V) primary standard of 10.0 mg/l was prepared from the stock solution by diluting 1.0 ml to 100.0 ml with 0.1 M HNO_3. The secondary standard of 1.0 mg/l was prepared from the primary standard. This standard was used within 2 weeks. The working standards of 0, 20, 40, 60, 80 µg/L As(V) were prepared by diluting the appropriate volumes of the secondary standards with 0.1 M HNO_3. The 0 µg/L solution was used as the blank standard. The working standard solutions were freshly prepared before experiments.

Preparation of samples:

The supernatant obtained from the As removal experiment was pre-treated with 1 M HNO_3 to adjust pH to about 2 (3 drops/10 ml sample) and with $Ni(NO_3)_2$ (100 µl/ 10 ml sample) as a matrix modifier.

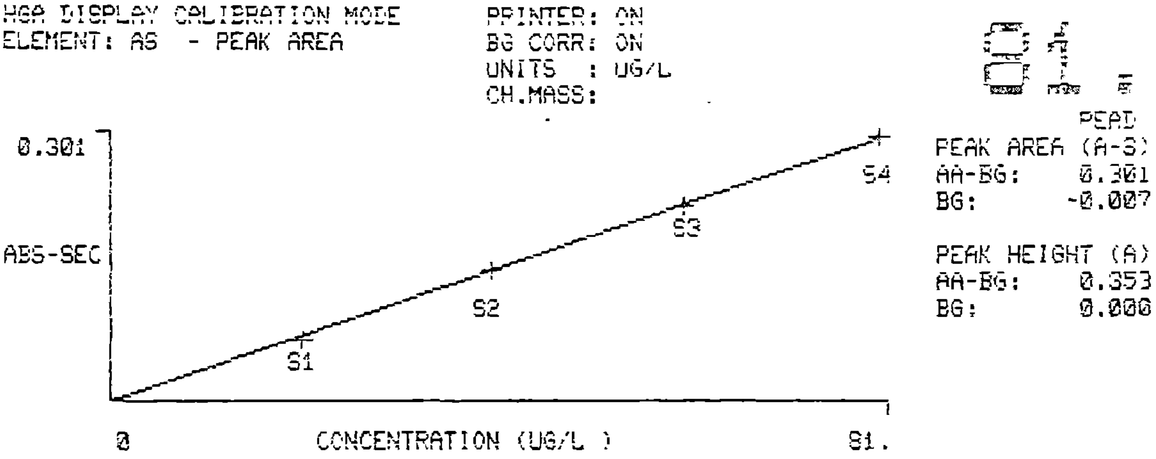
Calibration curve:

The analysis for As was carried out according to the Standard Methods (*Eaton et al., 1997*) by using AAS with graphite furnace. The temperature programme is as follows:

Step	*Temperature °C*	*Ramp °C/sec*	*Hold time sec*
1	90	5	10
2	110	10	10
3	130	10	10
4	450	10	10
5	850	10	20
6	1300	10	10
7	2300	0	5
8	30	2	2

Each standard solution (20 µl) was injected to the graphite tube of the AAS. The analysis of each standard was done in triplicate to verify the method precision. The linear analytical curve was then constructed in the AAS (plot of the average peak areas of the standard solution versus concentration of the working standards).

The calibration curve for As measurement is as follows.



```
HGA DISPLAY CALIBRATION MODE      PRINTER: ON
ELEMENT: AS  - PEAK AREA          BG CORR: ON
                                  UNITS  : UG/L
                                  CH.MASS:
                                                              READ
                                                    PEAK AREA (A-S)
                                                    AA-BG:     0.301
                                                    BG:       -0.007

                                                    PEAK HEIGHT (A)
                                                    AA-BG:     0.353
                                                    BG:        0.000
```

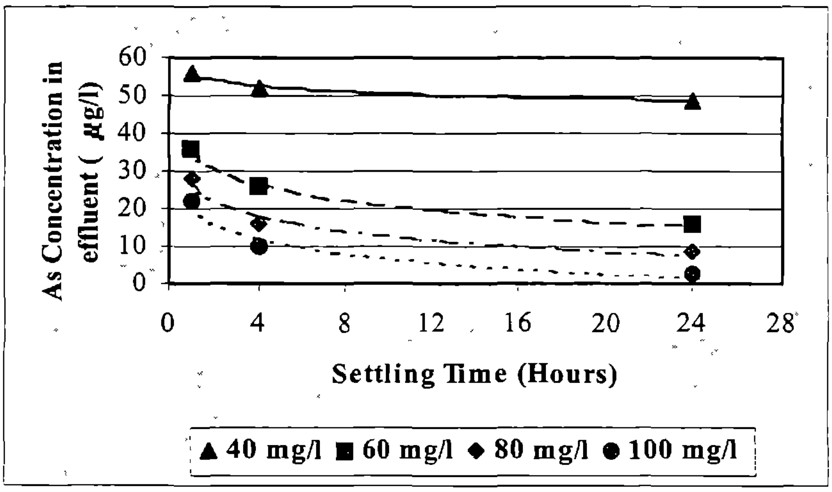
Samples analysis:

Each sample was analysed using the same procedures as the standard solutions for the calibration curve, and at least in duplicate or until reproducible results were obtained ($\leq$ 10% variation). If any result of a specific sample is not comparable to the other two results, the deviated result was discarded while calculating the average. For examples, if the results of a sample on triplicate application were found 32 µg/L, 40 µg/L and 31 µg/L, the average was taken as 31.5 µg/l, ignoring 40 µg/l. The As concentration in the sample was read directly from the AAS. For the samples with higher concentration than those of the most concentrated standard solution; these were diluted in 0.01 M HNO_3 and reanalysed.

Annex A3: Arsenic Reduction in Different Settling Time.

As Concentration in Raw Water: 600 µg/l
Fe Concentration in Raw Water. 3 mg/l
HCO_3^- Concentration in Raw Water: 200 mg/l

SL No	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2.4H_2O$ mg/l	Residual As Concentration		
			After 1 hr.	After 4 hr.	After 24 hr
1	40	10	56	52	49
2	60	10	36	26	16
3	80	10	28	16	9
4	100	10	22	10	3



Annex A4: Jar Test Results with Different Aluminum Sulfate Dosing.

Limit of detection: The limit of detection for arsenic measurement by atomic absorption spectrometer - graphite furnace method was found 6 µg/l. Ningoni (1999) reported the same limit of detection for arsenic measurement using the same apparatus.

Table 1

As Concentration in Raw Water 200 µg/l
Fe Concentration in Raw Water 3 mg/l
HCO_3^- Concentration in Raw Water. 200 mg/l
Settling Time: 1hr

Sl. No	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2\,4H_2O$ mg/l	Residual As concentration	% of As reduction
1	60	10	22	89.0
2	80	10	16	92.0
3	100	10	10	95.0
4	120	10	8	96.0
5	140	10	< 6	> 97.0
6	160	10	< 6	> 97.0

Table 2

As Concentration in Raw Water: 200 µg/l
Fe Concentration in Raw Water. 6 mg/l
HCO_3^- Concentration in Raw Water. 200 mg/l
Settling Time: 1hr

Sl. No.	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2\,4H_2O$ mg/l	Residual As concentration	% of As reduction
1	20	10	45	77.5
2	40	10	38	81.0
3	60	10	20	90.0
4	80	10	8	96.0
5	100	10	6	97.0
6	120	10	< 6	> 97
7	140	10	< 6	> 97
8	160	10	< 6	> 97

Table 3

As Concentration in Raw Water: 200 µg/l
Fe Concentration in Raw Water: 9 mg/l
HCO_3^- Concentration in Raw Water: 200 mg/l

Settling Time: 1hr

Sl. No	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2\,4H_2O$ mg/l	Residual As concentration	% of As reduction
1	20	10	41	79.5
2	40	10	20	90.0
3	60	10	8	96 0
4	80	10	6	97.0
5	100	10	< 6	> 97 0
6	120	10	< 6	> 97.0
7	140	10	< 6	> 97.0
8	160	10	< 6	> 97 0

Table 4

As Concentration in Raw Water: 400 µg/l
Fe Concentration in Raw Water: 3 mg/l
HCO_3^- Concentration in Raw Water: 200 mg/l

Settling Time. 1hr

Sl No.	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2\,4H_2O$ mg/l	Residual As concentration	% of As reduction
1	60	10	25	93 8
2	80	10	20	95 0
3	100	10	16	96.0
4	120	10	13	96.8
5	140	10	12	97.0
6	160	10	9	97.8

Table 5

As Concentration in Raw Water. 400 µg/l
Fe Concentration in Raw Water. 6 mg/l
HCO_3^- Concentration in Raw Water 200 mg/l

Settling Time: 1hr

Sl. No	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2.4H_2O$ mg/l	Residual As concentration	% of As reduction
1	60	10	24	94.0
2	80	10	18	95.5
3	100	10	15	96 3
4	120	10	12	97.0
5	140	10	9	97.8
6	160	10	6	98.5

Table 6

As Concentration in Raw Water 400 µg/l
Fe Concentration in Raw Water: 9 mg/l
HCO_3^- Concentration in Raw Water: 200 mg/l

Settling Time: 1hr

Sl No.	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2.4H_2O$ mg/l	Residual As concentration	% of As reduction
1	60	10	21	94.8
2	80	10	15	96 3
3	100	10	11	97.3
4	120	10	10	97.5
5	140	10	8	98 0
6	160	10	6	98.5

Table 7

As Concentration in Raw Water: 600 µg/l
Fe Concentration in Raw Water: 3 mg/l
HCO_3^- Concentration in Raw Water· 200 mg/l

Settling Time. 1hr

Sl. No.	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2$ $4H_2O$ mg/l	Residual As concentration	% of As reduction
1	60	10	39	93 5
2	80	10	37	93 8
3	100	10	22	96.3
4	120	10	20	96 7
5	140	10	17	97.2
6	160	10	13	97 8

Table 8

As Concentration in Raw Water 600 µg/l
Fe Concentration in Raw Water: 6 mg/l
HCO_3^- Concentration in Raw Water. 200 mg/l

Settling Time: 1hr

Sl. No	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2.4H_2O$ mg/l	Residual As concentration	% of As reduction
1	60	10	29	95.2
2	80	10	23	96.2
3	100	10	14	97.7
4	120	10	12	98.0
5	140	10	9	98.5
6	160	10	8	98.7

Table 9

As Concentration in Raw Water 600 µg/l
Fe Concentration in Raw Water 9 mg/l
HCO_3^- Concentration in Raw Water· 200 mg/l

Settling Time 1hr

Sl. No.	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2.4H_2O$ mg/l	Residual As concentration	% of As reduction
1	60	10	22	96.3
2	80	10	16	97.3
3	100	10	12	98.0
4	120	10	12	98.0
5	140	10	10	98.3
6	160	10	7	98.8

Annex A5: Jar Test Results with Original Iron in Water (Without addition of Coagulant and Calcium hypochlorite).

Fe mg/l	As 0 2 mg/l	Removal Efficiency (%)	As 0.4 mg/l	Removal Efficiency (%)	As 0 6 mg/l	Removal Efficiency (%)
3	115	42.5	240	40	490	18 33
6	46	77	105	73 75	415	30.83
9	18	91	47	88.25	76	87 33
12	14	93	32	92	46	92.33

Annex A6: Turbidity in Different Settling Time.

Table 1

As Concentration in Raw Water 400 µg/l
Fe Concentration in Raw Water 9 mg/l
HCO_3^- Concentration in Raw Water. 200 mg/l

SL. No	Dosages of Coagulant mg/l	Dosages of $Ca(OCl)_2 4H_2O$ mg/l	Turbidity (FNU)		
			After 1 hr.	After 4 hr	After 24 hr.
1	60	10	1.56	0.24	0.14
2	80	10	1.26	0.26	0.11
3	100	10	1.38	0.24	0.12
4	120	10	1.33	0.43	0.28
5	140	10	1.44	0.08	0.08
6	160	10	1.75	0.22	0.24

Annex B1: Maximum, Minimum and Average Annual Rainfall

Table 1

Sl No	Districts	Maximum Rainfall (mm)	Minimum Rainfall (mm)	Average Rainfall (mm)
1	Panchaghar	3718.9	1467.0	2237.6
2	Thakurgao	2090.3	1497.1	2131.7
3	Nilphamari	3138.6	1061.8	2001.9
4	Lalmonirhat	4068.8	1591.9	2469.1
5	Kurigram	3354.8	1609.1	2194.0
6	Rangpur	3028.1	1255.5	2098.1
7	Dinajpur	2936.4	860.7	1910.6
8	Jaypurhat	2460.7	870.3	1599.5
9	Naogaon	2137.4	1020.2	1506.2
10	Nawabganj	1815.0	507.8	1178.5
11	Rajshahi	1902.1	873.6	1450.5
12	Natore	2459.3	897.3	1580.5
13	Pabna	2036.9	1038.8	1520.7
14	Sirajganj	2304.3	1262.3	1767.8
15	Bogra	2735.0	1277.7	1762.5
16	Gaibanda	2938.2	1376.6	1910.5
17	Jamalpur	2630.1	1525.6	2076.5
18	Sherpur	2130.7	1202.8	1717.5
19	Mymensingh	3128.0	1829.8	2421.5
20	Natrokona	4285.6	1927.0	2908.5
21	Kishorganj	3515.1	1645.5	2261.2
22	Norsingdi	3566.7	1632.0	2614.1
23	Gajipur	2969.3	1519.8	2187.6
24	Tangail	2070.6	1276.6	1848.2
25	Manikganj	2507.0	922.5	1727.8
26	Rajbari	2757.3	1182.5	1670.9
27	Faridpur	2563.6	1356.7	1854.2
28	Gopalganj			
29	Madaripur	2459.7	1486.6	1954.1
30	Shariyatpur			
31	Munshiganj	5068.8	1660.7	2496.9
32	Narayanganj	2036.3	1731.0	1853.8
33	Dhaka	2391.9	1530.8	2025.5
34	Sunamganj	6988.6	4273.3	5558.7
35	Sylhet	5206.1	2985.7	4202.2
36	Mulobibazar	3381.2	2165.1	2646.1
37	Hobiganj	4243.2	1698.8	2484.3
38	Bramanbaria	2843.7	1598.6	2074.5
39	Comilla	3558.6	1684.2	2372.3
40	Chandpur	2648.2	997.3	1879.7
41	Laxmipur	3474.5	1671.7	2456.5
42	Noakhali	3177.7	1703.2	2227.1
43	Feni	4562.7	2154.5	3240.0
44	Chittagonj			

Contd

Sl. No	Districts	Highest Dry Period (Month)	Lowest Dry Period (Month)	Average Dry Period (Month)
45	Khagrachori			
46	Rangamati			
47	Bandarbon			
48	Cox'sBazar			
49	Pirojpur	2974.0	1321.8	2073.4
50	Jalokhathi	2835.1	1264.6	2145.3
51	Barisal	3243.2	1670.8	2216.4
52	Bhola	2936.6	1824.6	2393.5
53	Pothuakhali	3451.4	1903.7	2646.7
54	Barguna	3222.2	1769.2	2561.3
55	Meherpur			
56	Kustia	1802.7	972.2	1413.1
57	Chuadanga	2483.1	972.3	1500.6
58	Jinaidah	2009.6	1068.3	1506.2
59	Magura	2281.9	1200.6	1674.5
60	Jessore	2144.1	1049.3	1722.8
61	Norail	2028.5	1206.9	1637.4
62	Bagerhat			
63	Khulna	2386.6	1350.4	1854.9
64	Satkhira	2415.6	1216.7	1825.4

Annex B2: Maximum, Minimum and Average Dry Period

Table 1

Sl No	Districts	Highest Dry Period (Month)	Lowest Dry Period (Month)	Average Dry Period (Month)
1	Panchaghar	7	1	6
2	Thakurgao	7	4	5
3	Nilphamari	7	4	5
4	Lalmonirhat	6	3	5
5	Kurigram	6	3	5
6	Rangpur	6	2	5
7	Dinajpur	8	2	5
8	Jaypurhat	8	4	6
9	Naogaon	8	4	6
10	Nawabganj	8	4	5
11	Rajshahi	7	3	5
12	Natore	7	4	5
13	Pabna	7	2	5
14	Sirajganj	6	2	5
15	Bogra	6	3	5
16	Gaibanda	7	1	5
17	Jamalpur	6	3	5
18	Sherpur	7	3	5
19	Mymensingh	5	3	4
20	Natrokona	6	3	4
21	Kishorganj	5	3	4
22	Norsingdi	6	2	4
23	Gajipur	6	2	4
24	Tangail	6	2	4
25	Manikganj	6	2	4
26	Rajbari	6	3	5
27	Faridpur	6	2	4
28	Gopalganj			
29	Madaripur	6	2	4
30	Shariyatpur			
31	Munshiganj	8	3	5
32	Narayanganj	5	1	4
33	Dhaka	5	2	4
34	Sunamganj	5	2	4
35	Sylhet	5	1	3
36	Mulobibazar	5	1	4
37	Hobiganj	6	3	4
38	Bramanbaria	5	2	5
39	Comilla	6	2	3
40	Chandpur	6	2	4
41	Laxmipur	6	2	4
42	Noakhali	6	2	5
43	Feni	6	2	4
44	Chittagonj			

Contd

Sl No	Districts	Highest Dry Period (Month)	Lowest Dry Period (Month)	Average Dry Period (Month)
45	Khagrachori			
46	Rangamati			
47	Bandarbon			
48	Cox'sBazar			
49	Pirojpur	6	2	5
50	Jalokhathi	7	2	5
51	Barisal	6	2	4
52	Bhola	6	2	4
53	Pothuakhali	6	3	4
54	Barguna	6	3	4
55	Meherpur			
56	Kustia	7	3	5
57	Chuadanga	6	2	5
58	Jinaidah	6	2	5
59	Magura	6	2	4
60	Jessore	6	2	4
61	Norail	6	3	5
62	Bagerhat			
63	Khulna	5	3	4
64	Satkhira	7	3	4

Annex B3: STORAGE VOLUME CALCULATION BY MASS CURVE METHOD WITH CATCHMENT AREA 40 m^2.

Station: Rajshahi

Table 1

Roof Size = 40 sq m
Family size = 6

Month	Monthly Rainfall	Monthly Supply *Liters*	Cumulative Supply *Liters*	Monthly Demand *Liters*	Amount Stored *Liters*	Total Amount Stored *Liters*	Volume Required *Liters*
1	109	3488	3488	900	2588	2588	
2	71	2272	5760	900	1372	3960	
3	381	12192	17952	900	11292	15252	
4	179	5728	23680	900	4828	20080	
5	197	6304	29984	900	5404	25484	
6	125	4000	33984	900	3100	28584	
7	0	0	33984	900	-900	27684	
8	0	0	33984	900	-900	26784	
9	0	0	33984	900	-900	25884	
10	10	320	34304	900	-580	25304	
11	4	128	34432	900	-772	24532	
12	10	320	34752	900	-580	23952	4632
13	235	7520	42272	900	6620	30572	
14	234	7488	49760	900	6588	37160	
15	242	7744	57504	900	6844	44004	
16	389	12448	69952	900	11548	55552	
17	257	8224	78176	900	7324	62876	
18	45	1440	79616	900	540	63416	
19	1	32	79648	900	-868	62548	
20	0	0	79648	900	-900	61648	
21	4	128	79776	900	-772	60876	
22	19	608	80384	900	-292	60584	
23	0	0	80384	900	-900	59684	3732
24	229	7328	87712	900	6428	66112	
25	241	7712	95424	900	6812	72924	
26	543	17376	112800	900	16476	89400	
27	399	12768	125568	900	11868	101268	
28	157	5024	130592	900	4124	105392	
29	121	3872	134464	900	2972	108364	
30	162	5184	139648	900	4284	112648	
31	10	320	139968	900	-580	112068	
32	33	1056	141024	900	156	112224	
33	1	32	141056	900	-868	111356	1292
34	46	1472	142528	900	572	111928	
35	62	1984	144512	900	1084	113012	
36	93	2976	147488	900	2076	115088	
37	104	3328	150816	900	2428	117516	
38	492	15744	166560	900	14844	132360	

Contd

39	126	4032	170592	900	3132	135492	
40	149	4768	175360	900	3868	139360	
41	545	17440	192800	900	16540	155900	
42	92	2944	195744	900	2044	157944	
43	24	768	196512	900	-132	157812	
44	0	0	196512	900	-900	156912	
45	45	1440	197952	900	540	157452	
46	17	544	198496	900	-356	157096	
47	2	64	198560	900	-836	156260	1684
48	35	1120	199680	900	220	156480	
49	13	416	200096	900	-484	155996	
50	46	1472	201568	900	572	156568	
51	492	15744	217312	900	14844	171412	
52	275	8800	226112	900	7900	179312	
53	379	12128	238240	900	11228	190540	
54	188	6016	244256	900	5116	195656	
55	28	896	245152	900	-4	195652	
56	28	896	246048	900	-4	195648	
57	29	928	246976	900	28	195676	
58	12	384	247360	900	-516	195160	496
59	69	2208	249568	900	1308	196468	
60	0	0	249568	900	-900	195568	
61	156	4992	254560	900	4092	199660	
62	349	11168	265728	900	10268	209928	
63	281	8992	274720	900	8092	218020	
64	316	10112	284832	900	9212	227232	
65	215	6880	291712	900	5980	233212	
66	149	4768	296480	900	3868	237080	
67	0	0	296480	900	-900	236180	
68	0	0	296480	900	-900	235280	1800
69	71	2272	298752	900	1372	236652	
70	49	1568	300320	900	668	237320	
71	26	832	301152	900	-68	237252	
72	240	7680	308832	900	6780	244032	
73	290	9280	318112	900	8380	252412	
74	159	5088	323200	900	4188	256600	
75	574	18368	341568	900	17468	274068	
76	340	10880	352448	900	9980	284048	
77	398	12736	365184	900	11836	295884	
78	0	0	365184	900	-900	294984	
79	3	96	365280	900	-804	294180	1704
80	91	2912	368192	900	2012	296192	
81	0	0	368192	900	-900	295292	
82	10	320	368512	900	-580	294712	
83	80	2560	371072	900	1660	296372	
84	139	4448	375520	900	3548	299920	
85	43	1376	376896	900	476	300396	
86	260	8320	385216	900	7420	307816	

Contd

87	189	6048	391264	900	5148	312964	
88	217	6944	398208	900	6044	319008	
89	66	2112	400320	900	1212	320220	
90	38	1216	401536	900	316	320536	
91	60	1920	403456	900	1020	321556	
92	1	32	403488	900	-868	320688	
93	1	32	403520	900	-868	319820	
94	2	64	403584	900	-836	318984	
95	4	128	403712	900	-772	318212	3344
96	34	1088	404800	900	188	318400	
97	121	3872	408672	900	2972	321372	
98	65	2080	410752	900	1180	322552	
99	366	11712	422464	900	10812	333364	
100	505	16160	438624	900	15260	348624	
101	149	4768	443392	900	3868	352492	
102	358	11456	454848	900	10556	363048	
103	0	0	454848	900	-900	362148	
104	24	768	455616	900	-132	362016	
105	31	992	456608	900	92	362108	
106	1	32	456640	900	-868	361240	
107	0	0	456640	900	-900	360340	
108	10	320	456960	900	-580	359760	3288
109	94	3008	459968	900	2108	361868	
110	325	10400	470368	900	9500	371368	
111	294	9408	479776	900	8508	379876	
112	321	10272	490048	900	9372	389248	
113	297	9504	499552	900	8604	397852	
114	202	6464	506016	900	5564	403416	
115	0	0	506016	900	-900	402516	
116	0	0	506016	900	-900	401616	
117	4	128	506144	900	-772	400844	
118	7	224	506368	900	-676	400168	
119	3	96	506464	900	-804	399364	4052
120	75	2400	508864	900	1500	400864	
121	190	6080	514944	900	5180	406044	
122	232	7424	522368	900	6524	412568	
123	274	8768	531136	900	7868	420436	
124	146	4672	535808	900	3772	424208	
125	233	7456	543264	900	6556	430764	
126	77	2464	545728	900	1564	432328	
127	3	96	545824	900	-804	431524	
128	12	384	546208	900	-516	431008	
129	3	96	546304	900	-804	430204	
130	12	384	546688	900	-516	429688	
131	19	608	547296	900	-292	429396	2932
132	93	2976	550272	900	2076	431472	
133	81	2592	552864	900	1692	433164	
134	175	5600	558464	900	4700	437864	

Contd

135	262	8384	566848	900	7484	445348	
136	238	7616	574464	900	6716	452064	
137	408	13056	587520	900	12156	464220	
138	190	6080	593600	900	5180	469400	
139	27	864	594464	900	-36	469364	
140	4	128	594592	900	-772	468592	
141	0	0	594592	900	-900	467692	
142	4	128	594720	900	-772	466920	
143	12	384	595104	900	-516	466404	2996
144	76	2432	597536	900	1532	467936	
145	102	3264	600800	900	2364	470300	
146	350	11200	612000	900	10300	480600	
147	488	15616	627616	900	14716	495316	
148	400	12800	640416	900	11900	507216	
149	193	6176	646592	900	5276	512492	
150	43	1376	647968	900	476	512968	
151	5	160	648128	900	-740	512228	
152	4	128	648256	900	-772	511456	
153	1	32	648288	900	-868	510588	2380
154	30	960	649248	900	60	510648	
155	36	1152	650400	900	252	510900	
156	60	1920	652320	900	1020	511920	
157	139	4448	656768	900	3548	515468	
158	407	13024	669792	900	12124	527592	
159	301	9632	679424	900	8732	536324	
160	300	9600	689024	900	8700	545024	
161	89	2848	691872	900	1948	546972	
162	10	320	692192	900	-580	546392	
163	10	320	692512	900	-580	545812	
164	0	0	692512	900	-900	544912	
165	4	128	692640	900	-772	544140	
166	8	256	692896	900	-644	543496	
167	5	160	693056	900	-740	542756	
168	2	64	693120	900	-836	541920	**5052**
169	224	7168	700288	900	6268	548188	
170	190	6080	706368	900	5180	553368	
171	357	11424	717792	900	10524	563892	
172	117	3744	721536	900	2844	566736	
173	332	10624	732160	900	9724	576460	
174	78	2496	734656	900	1596	578056	
175	0	0	734656	900	-900	577156	
176	8	256	734912	900	-644	576512	
177	0	0	734912	900	-900	575612	2444
178	34	1088	736000	900	188	575800	
179	46	1472	737472	900	572	576372	
180	97	3104	740576	900	2204	578576	
181	301	9632	750208	900	8732	587308	
182	263	8416	758624	900	7516	594824	

Contd

183	462	14784	773408	900	13884	608708	
184	238	7616	781024	900	6716	615424	
185	180	5760	786784	900	4860	620284	
186	127	4064	790848	900	3164	623448	
187	17	544	791392	900	-356	623092	
188	0	0	791392	900	-900	622192	
189	24	768	792160	900	-132	622060	
190	0	0	792160	900	-900	621160	
191	18	576	792736	900	-324	620836	
192	20	640	793376	900	-260	620576	2872
193	157	5024	798400	900	4124	624700	
194	211	6752	805152	900	5852	630552	
195	286	9152	814304	900	8252	638804	
196	96	3072	817376	900	2172	640976	
197	511	16352	833728	900	15452	656428	
198	84	2688	836416	900	1788	658216	
199	0	0	836416	900	-900	657316	
200	92	2944	839360	900	2044	659360	
201	1	32	839392	900	-868	658492	
202	33	1056	840448	900	156	658648	
203	0	0	840448	900	-900	657748	
204	16	512	840960	900	-388	657360	2000
205	121	3872	844832	900	2972	660332	
206	85	2720	847552	900	1820	662152	
207	244	7808	855360	900	6908	669060	
208	185	5920	861280	900	5020	674080	
209	124	3968	865248	900	3068	677148	
210	29	928	866176	900	28	677176	
211	5	160	866336	900	-740	676436	
212	0	0	866336	900	-900	675536	
213	0	0	866336	900	-900	674636	
214	5	160	866496	900	-740	673896	3280
215	55	1760	868256	900	860	674756	
216	70	2240	870496	900	1340	676096	
217	65	2080	872576	900	1180	677276	
218	477	15264	887840	900	14364	691640	
219	241	7712	895552	900	6812	698452	
220	177	5664	901216	900	4764	703216	
221	316	10112	911328	900	9212	712428	
222	157	5024	916352	900	4124	716552	
223	54	1728	918080	900	828	717380	
224	0	0	918080	900	-900	716480	
225	18	576	918656	900	-324	716156	
226	36	1152	919808	900	252	716408	
227	5	160	919968	900	-740	715668	1712
228	31	992	920960	900	92	715760	
229	115	3680	924640	900	2780	718540	
230	237	7584	932224	900	6684	725224	

Contd

231	171	5472	937696	900	4572	729796	
232	206	6592	944288	900	5692	735488	
233	171	5472	949760	900	4572	740060	
234	130	4160	953920	900	3260	743320	
235	22	704	954624	900	-196	743124	
236	0	0	954624	900	-900	742224	
237	17	544	955168	900	-356	741868	
238	31	992	956160	900	92	741960	
239	9	288	956448	900	-612	741348	
240	8	256	956704	900	-644	740704	2616

The design storage volume is taken from the difference of month 162 and 168. This is the maximum storage volume requirement in the calculation and it is 5052 liters.

Annex B4: STORAGE VOLUME CALCULATION BY A_c-V_c METHOD.

Station: Rajshahi

Table 1: Monthly Rainfall data

Number	Year	Monthly Rainfall Ri mm												Annual rainfall
		M	J	J	A	S	O	N	D	J	F	M	A	Ra mm
1	1975-76	109	71	381	179	197	125	0	0	0	10	4	10	1086
2	1976-77	235	234	242	389	257	45	1	0	4	19	0	229	1655
3	1977-78	241	543	399	157	121	162	10	33	1	46	62	93	1868
4	1978-79	104	492	126	149	545	92	24	0	45	17	2	35	1631
5	1979-80	13	46	492	275	379	188	28	28	29	12	69	0	1559
6	1980-81	156	349	281	316	215	149	0	0	71	49	26	240	1852
7	1981-82	290	159	574	340	398	0	3	91	0	10	80	139	2084
8	1982-83	43	260	189	217	66	38	60	1	1	2	4	34	915
9	1983-84	121	65	366	505	149	358	0	24	31	1	0	10	1630
10	1984-85	94	325	294	321	297	202	0	0	4	7	3	75	1622
11	1985-86	190	232	274	146	233	77	3	12	3	12	19	93	1294
12	1986-87	81	175	262	238	406	190	27	4	0	4	12	76	1475
13	1987-88	102	350	488	400	193	43	5	4	1	30	36	60	1712
14	1988-89	139	407	301	300	89	10	10	0	4	8	5	2	1275
15	1989-90	224	190	357	117	332	78	0	8	0	34	46	97	1483
16	1990-91	301	263	462	238	180	127	17	0	24	0	18	20	1650
17	1991-92	157	211	286	96	511	84	0	92	1	33	0	16	1487
18	1992-93	121	85	244	185	124	29	5	0	0	5	55	70	923
19	1993-94	65	477	241	177	316	157	54	0	18	36	5	31	1577
20	1994-95	115	237	171	206	171	130	22	0	17	31	9	8	1117
	Average	145	259	322	248	259	114	13.5	14.9	12.7	18.3	22.8	66.9	*1495*

Annex B4

Ac and Rc Calculations

1	Number of years of rainfall data, n	20	
2	Consumption per consumer, C	5	lit/day
3	Rainoff co-efficient, f	0 8	
4	Minimum annual rainfall Ra $_{min}$	915	mm
5	Catchment area, Ac		
	$Ac_{min} = (C*30.5*12)/(F*Ra_{min})$	2.5	m^2/consumer
	$Ac_1 = Ac_{min}$ rounded up to the next higher integer	3	m^2/consumer
	$Ac_2 = Ac_1 + 1$	4	m^2/consumer
	$Ac_3 = Ac_2 + 1$	5	m^2/consumer
	$Ac_4 = Ac_3 + 1$	6	m^2/consumer
6	Critical rainfall, $Rc = (C*30.5)/(F*Ac)$		mm/month
	Rc_1	63 54	mm/month
	Rc_2	47 66	mm/month
	Rc_3	38.13	mm/month
	Rc_4	31 77	mm/month

Annex B4

Table 2a: Calculation of Dc for Ac_1

Ac_1 = 3 m^2/consumer

Rc_1 = 63 54 mm/month

Pc	Nc	Ri (mm/month)									Σ Ri	Nc * Rc	Nc * Rc - Σ Ri	Dc
		1	2	3	4	5	6	7	8	9	mm	mm	mm	m^3/cons
1	6	29	0	0	0	10	4				43	381.24	338.24	0 81
2	7	10	45	1	0	4	19	0			79	444.78	365.78	0 88
3	5	10	33	1	46	62					152	317 7	165 7	0 40
4	5	24	0	45	17	2					88	317.7	229 7	0 55
5	7	35	13	46	28	28	29	12			191	444.78	253.78	0.61
6	5	0	0	0	49	26					75	317.7	242.7	0.58
7	4	0	3	0	10						13	254.16	241.16	0.58
8	7	43	38	60	1	1	2	4			149	444.78	295 78	0.71
9	6	34	0	24	31	1	0				90	381.24	291.24	0.70
10	6	10	0	0	4	7	3				24	381.24	357.24	0 86
11	5	3	12	2	12	19					48	317.7	269 7	0.65
12	5	27	4	0	4	12					47	317.7	270 7	0.65
13	6	43	5	4	1	30	36				119	381.24	262.24	0.63
14	8	60	10	10	10	0	4	8	5		107	508.32	401.32	0.96
15	6	2	0	8	0	34	46				90	381.24	291.24	0.70
16	5	17	0	24	0	18					59	317 7	258.7	0.62
17	5	0	0	1	33	0					34	317.7	283 7	0.68
18	7	16	29	5	0	0	5	55			110	444.78	334.78	0.80
19	5	54	0	18	36	5					113	317.7	204.7	0 49
20	6	31	22	0	17	31	9				110	381.24	271.24	0 65

Number of years of rainfall data, N = 20
Largest Dc = 0.96
Second largest Dc = 0 88
So, the Dc = 0 88

Annex B4

Table 2b: Calculation of Dc for Ac_2

Ac_2 = 4 m^2/consumer

Rc_2 = 47 66 mm/month

Pc	Nc	Ri (mm/month)									$\sum$ Ri	Nc * Rc	Nc * Rc - $\sum$ Ri	Dc
		1	2	3	4	5	6	7	8	9	mm	mm	mm	m^3/cons.
1	6	29	0	0	0	10	4				43	285 96	242.96	0 78
2	7	10	45	1	0	4	19	0			79	333 62	254.62	0 81
3	4	10	33	1	46						90	190 64	100.64	0 32
4	5	24	0	45	17	2					88	238 3	150.3	0.48
5	7	35	13	46	28	28	29	12			191	333.62	142 62	0 46
6	4	0	0	0	26						26	190.64	164 64	0 53
7	4	0	3	0	10						13	190.64	177.64	0 57
8	6	43	38	1	1	2	4				89	285.96	196 96	0 63
9	6	34	0	24	31	1	0				90	285.96	195 96	0.63
10	6	10	0	0	4	7	3				24	285 96	261 96	0 84
11	5	3	12	2	12	19					48	238.3	190.3	0 61
12	5	27	4	0	4	12					47	238.3	191.3	0.61
13	6	43	5	4	1	30	36				119	285 96	166.96	0 53
14	7	10	10	10	0	4	8	5			47	333 62	286.62	0.92
15	6	2	0	8	0	34	46				90	285 96	195.96	0.63
16	5	17	0	24	0	18					59	238.3	179.3	0.57
17	5	0	0	1	33	0					34	238 3	204.3	0.65
18	6	16	29	5	0	0	5				55	285 96	230.96	0.74
19	4	0	18	36	5						59	190.64	131 64	0 42
20	6	31	22	0	17	31	9				110	285 96	175.96	0 56

Number of years of rainfall data, N = 20
Largest Dc = 0.92
Second largest Dc = 0 84
So, the Dc = 0.84

Annex B4

Table 2c: Calculation of Dc for Ac_3

Ac_3 = 5 m^2/consumer

Rc_3 = 38.13 mm/month

Pc	Nc	Ri (mm/month)									$\sum$ Ri	Nc * Rc	Nc * Rc - $\sum$ Ri	Dc
		1	2	3	4	5	6	7	8	9	mm	mm	mm	m^3/cons.
1	6	29	0	0	0	10	4				43	228.78	185.78	0.74
2	6	10	1	0	4	19	0				34	228.78	194.78	0.78
3	3	10	33	1							44	114.39	70.39	0.28
4	4	24	0	17	2						43	152.52	109.52	0.44
5	6	35	13	28	28	29	12				145	228.78	83.78	0.34
6	4	0	0	0	26						26	152.52	126.52	0.51
7	4	0	3	0	10						13	152.52	139.52	0.56
8	5	38	1	1	2	4					46	190.65	144.65	0.58
9	6	34	0	24	31	1	0				90	228.78	138.78	0.56
10	6	10	0	0	4	7	3				24	228.78	204.78	0.82
11	5	3	12	2	12	19					48	190.65	142.65	0.57
12	5	27	4	0	4	12					47	190.65	143.65	0.57
13	5	5	4	1	30	36					76	190.65	114.65	0.46
14	7	10	10	10	0	4	8	5			47	266.91	219.91	0.88
15	5	2	0	8	0	34					44	190.65	146.65	0.59
16	5	17	0	24	0	18					59	190.65	131.65	0.53
17	5	0	0	1	33	0					34	190.65	156.65	0.63
18	6	16	29	5	0	0	5				55	228.78	173.78	0.70
19	4	0	18	36	5						59	152.52	93.52	0.37
20	6	31	22	0	17	31	9				110	228.78	118.78	0.48

Number of years of rainfall data, N = 20
Largest Dc = 0.88
Second largest Dc = 0.82
So, the Dc = 0.82

Annex B4

Table 2d: Calculation of Dc for Ac$_4$

Ac$_4$ = 6 m^2/consumer

Rc$_4$ = 31.77 mm/month

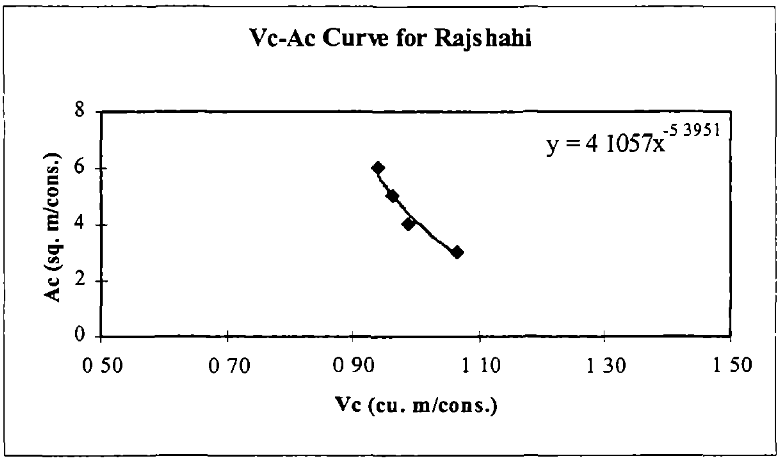
Pc	Nc	Ri (mm/month)									$\sum$ Ri	Nc * Rc	Nc * Rc - $\sum$ Ri	Dc
		1	2	3	4	5	6	7	8	9	mm	mm	mm	m^3/cons.
1	6	29	0	0	0	10	4				43	190.62	147.62	0.71
2	6	10	1	0	4	19	0				34	190.62	156.62	0.75
3	2	10	1								11	63.54	52.54	0.25
4	4	24	0	17	2						43	127.08	84.08	0.40
5	5	13	28	28	29	12					110	158.85	48.85	0.23
6	4	0	0	0	26						26	127 08	101 08	0.49
7	4	0	3	0	10						13	127.08	114.08	0.55
8	4	1	1	2	4						8	127 08	119.08	0.57
9	5	0	24	31	1	0					56	158.85	102.85	0.49
10	6	10	0	0	4	7	3				24	190.62	166.62	0.80
11	5	3	12	2	12	19					48	158.85	110.85	0.53
12	5	27	4	0	4	12					47	158.85	111.85	0.54
13	4	5	4	1	30						40	127.08	87.08	0.42
14	7	10	10	10	0	4	8	5			47	222.39	175.39	0.84
15	4	2	0	8	0						10	127.08	117.08	0.56
16	5	17	0	24	0	18					59	158.85	99.85	0.48
17	4	0	0	1	0						1	127.08	126.08	0.61
18	6	16	29	5	0	0	5				55	190.62	135.62	0 65
19	3	0	18	5							23	95.31	72.31	0.35
20	6	31	22	0	17	31	9				110	190.62	80 62	0.39

Number of years of rainfall data, N = 20
Largest Dc = 0.84
Second largest Dc = 0 80
So, the Dc = 0 80

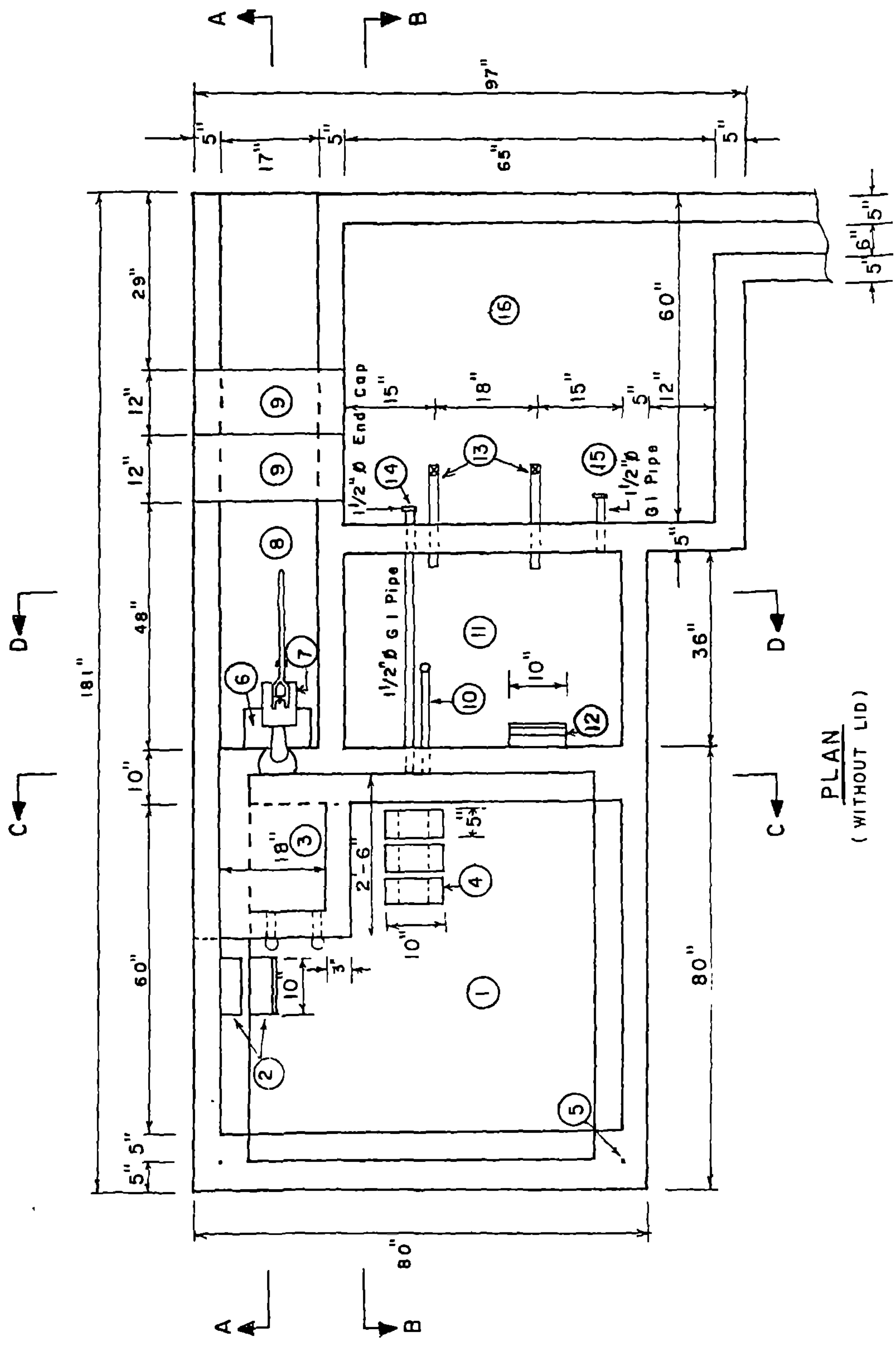
Annex B4

Table 3: Calculation of Vc

Calculatıon no	Ac m^2/consumer	Dc m^3/consumer	Nc	Vc m^3/consumer
1	3	0.88	7	1.07
2	4	0.84	6	0.99
3	5	0 82	6	0.96
4	6	0.8	6	0 94

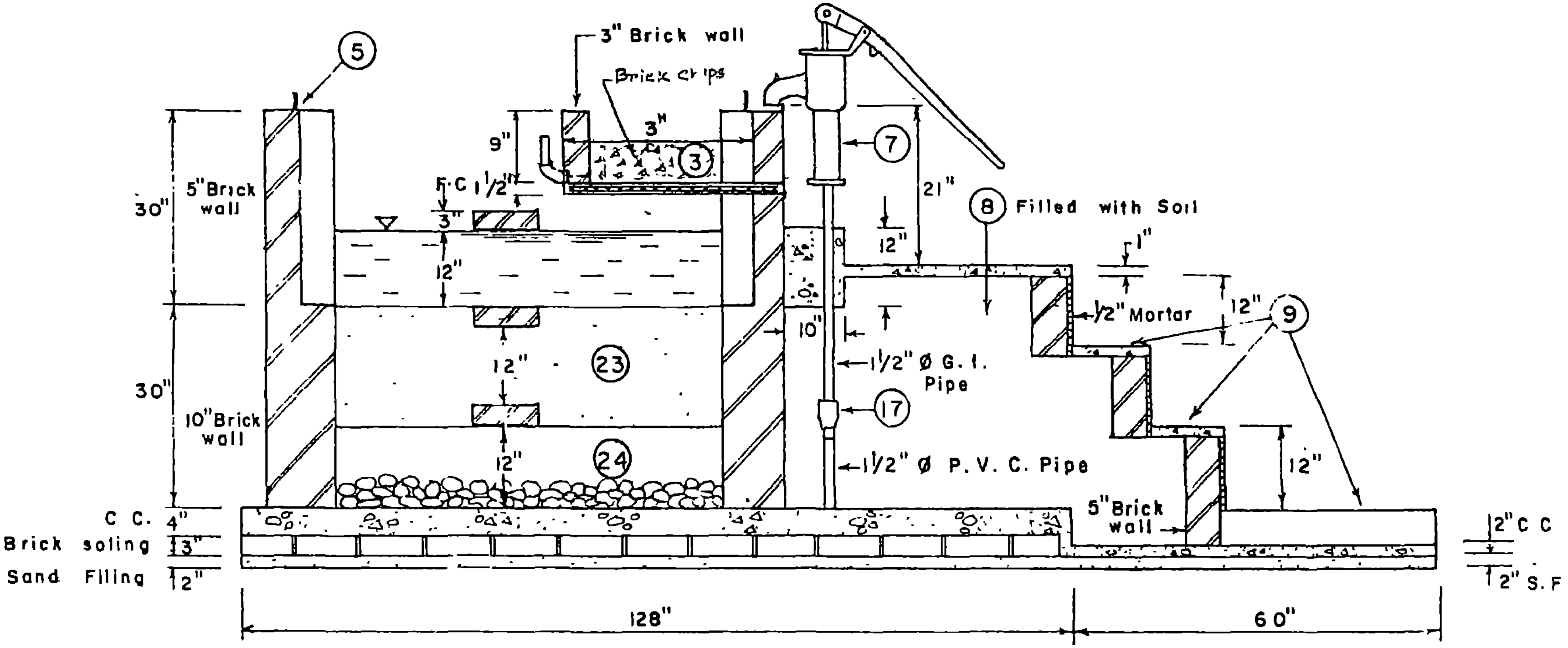


Annex C1: PLANS AND DIFFERENT SECTIONS OF PSF



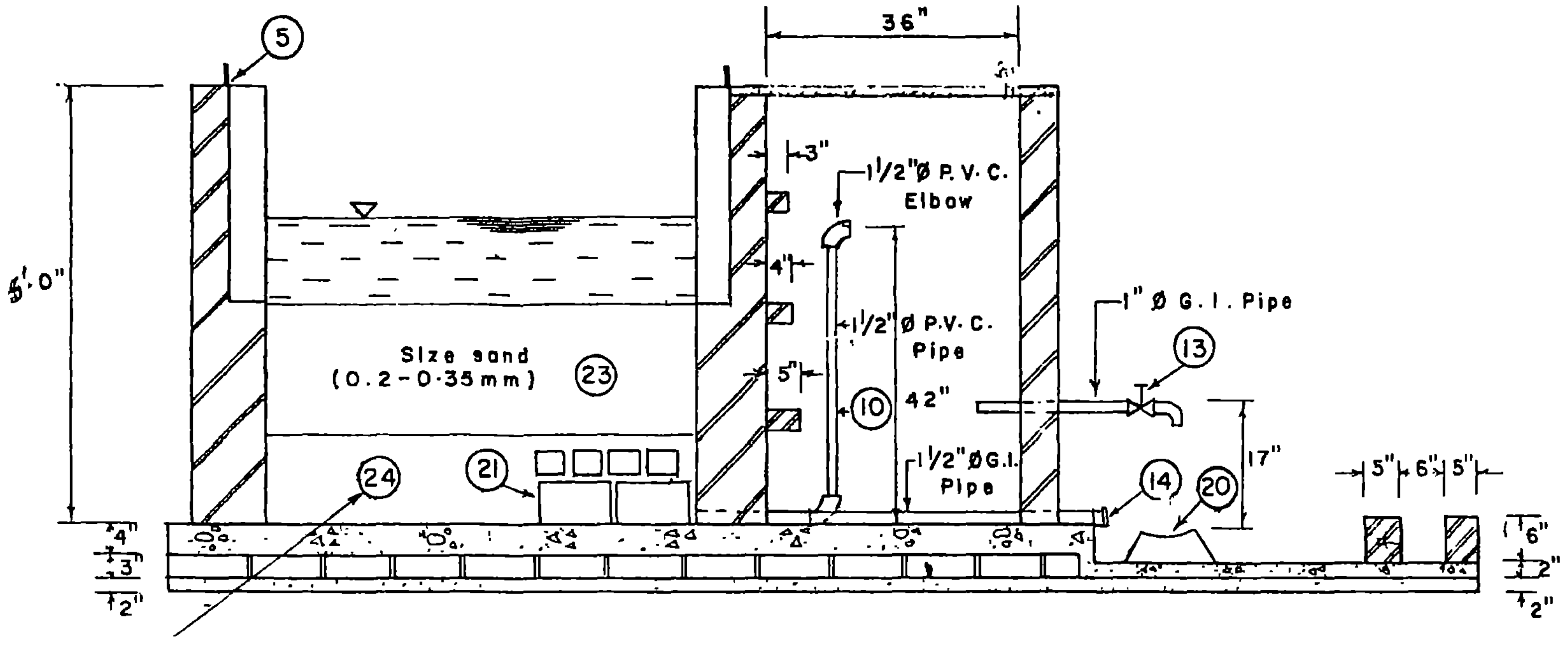
PLAN
(WITHOUT LID)

Annex C1



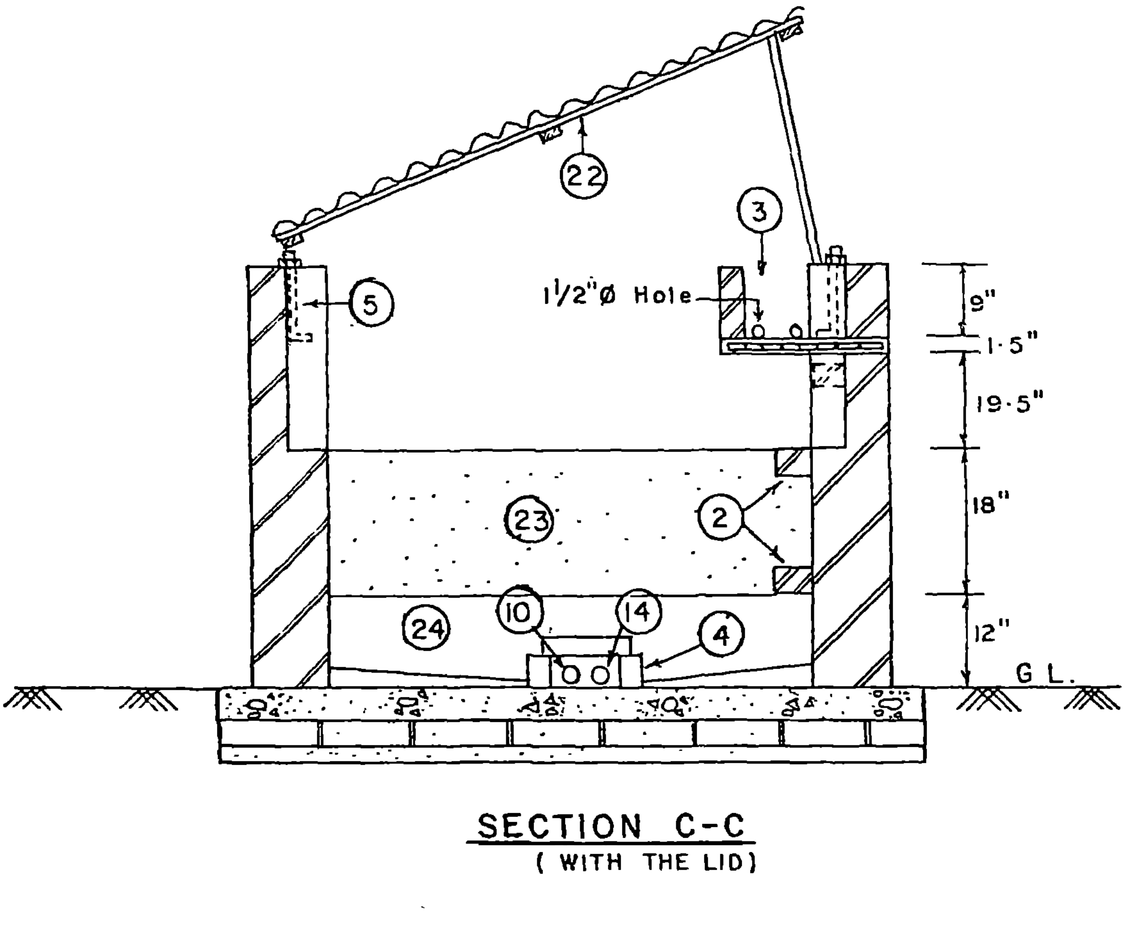
SECTION A-A

Annex C1



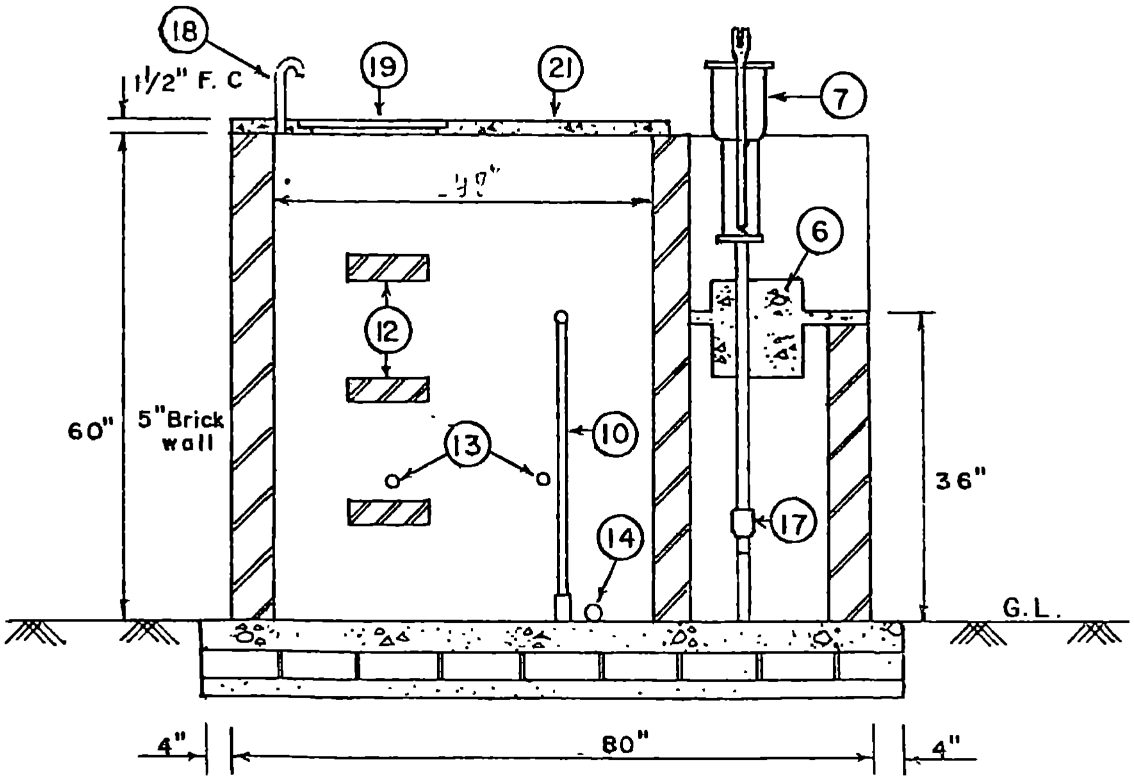
SECTION B-B

Annex C1



SECTION C-C
(WITH THE LID)

Annex C1



SECTION D-D

(WITH THE FIXED COVER)

Annex C1

① SAND FILTER (S.F.)
② STEPS
③ PRE-FILTER CHAMBER
④ BRICK TUNNEL
⑤ BOLT
⑥ CONCRETE PILLAR OR BLOCK
⑦ HAND PUMP
⑧ RAISED PLATFORM
⑨ BRICK FOOT STEPS TO PUMP
⑩ CONNECTION PIPE (S.F. TO S.T.)
⑪ STORAGE TANK (S.T.)
⑫ BRICK STEPS DOWN TO FILTER & C. W. CHEMBER
⑬ DELIVERY PIPE & C. I. TAPS
⑭ S.F. WASHOUT PIPE
⑮ S.T. WASHOUT PIPE
⑯ PLATFORM
⑰ P.V.C. ADAPTOR
⑱ VENT PIPE
⑲ MANHOLE
⑳ PITCHER SEAT
㉑ FIXED COVER
㉒ S.F. LID
㉓ SAND BED (0·2 – 0·35 mm)
㉔ GRADED KHOA ($\frac{1''}{8} - \frac{1''}{4}$; $\frac{1''}{4} - \frac{1''}{2}$; $\frac{1''}{2} - 1''$; $1'' - 2''$, 3-Loyers)

Annex C2: TEST RESULTS

Table 1: Sieve Analysis of Sand

Aperture size mm	Weight of Sieve gms	Weight of Sieve & Sand	Weight of Sand gms	% Retained	Cumulative % Retained	Cumulative % Passing
1	467.6	513.5	45.9	26.4%	26.4%	73.6%
0.8	439.2	469.7	30.5	17.6%	44.0%	56.0%
0.63	445.8	488.6	42.8	24.7%	68.7%	31.3%
0.56	441.7	458.6	16.9	9 7%	78.4%	21.6%
0.28	394.2	426.7	32.5	18.7%	97.1%	2.9%
0.18	400.1	403.1	3.0	1.7%	98.8%	1.2%
0.125	403.9	404.9	1.0	0.6%	99.4%	0.6%
Pan	438.1	439.1	1.0	0.6%	100.0%	0.0%
Total			173.6	100.0%		

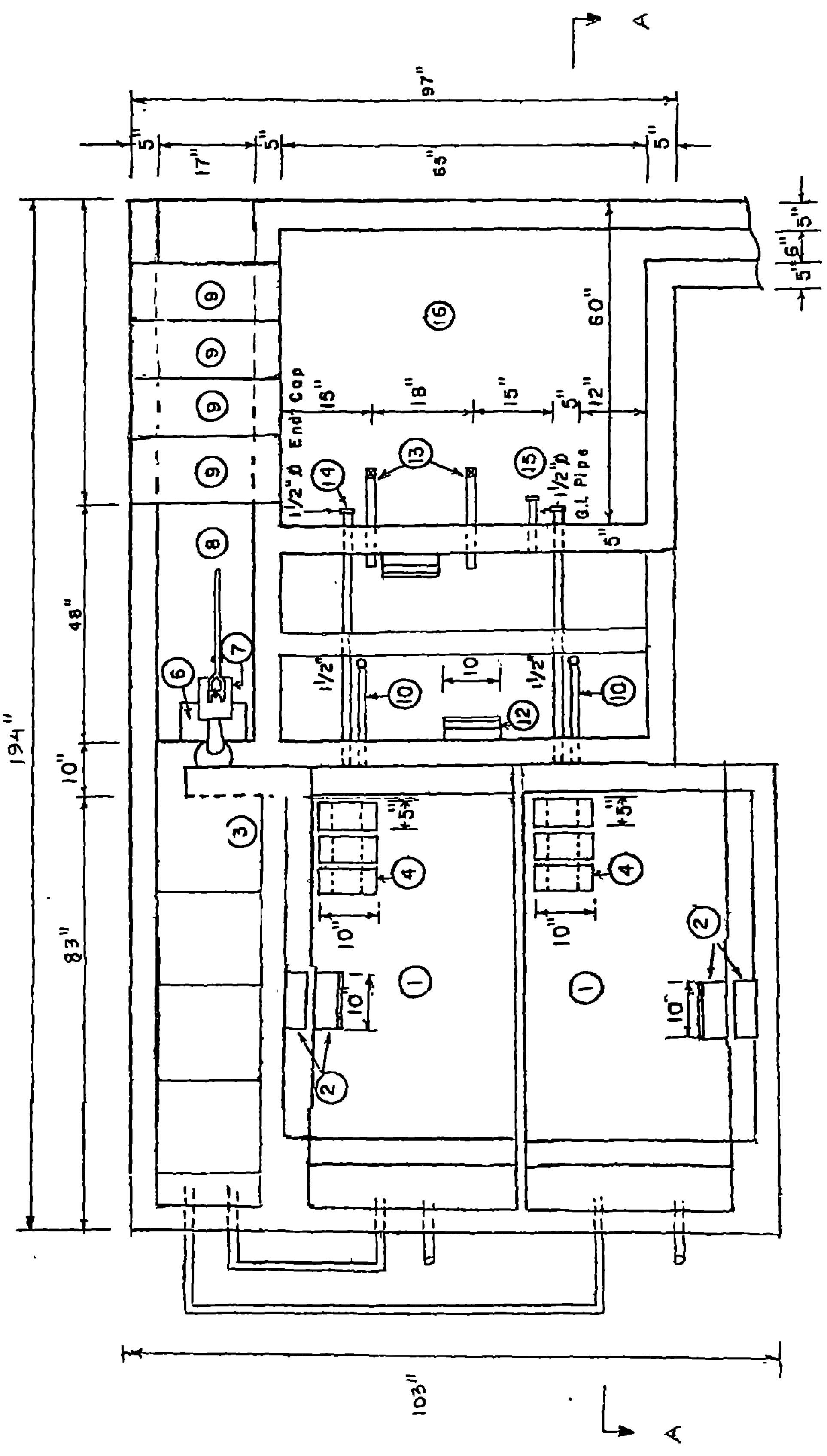
Table 2: Turbidity reduction in PSF plants

Plant No	At Tubewell	After Pre-treatment	After Sand Filter
Plant 1	65	30	4
Plant 2	28	20	1
Plant 3	27	25	3

Table 3: Fecal coliform reduction in PSF plants

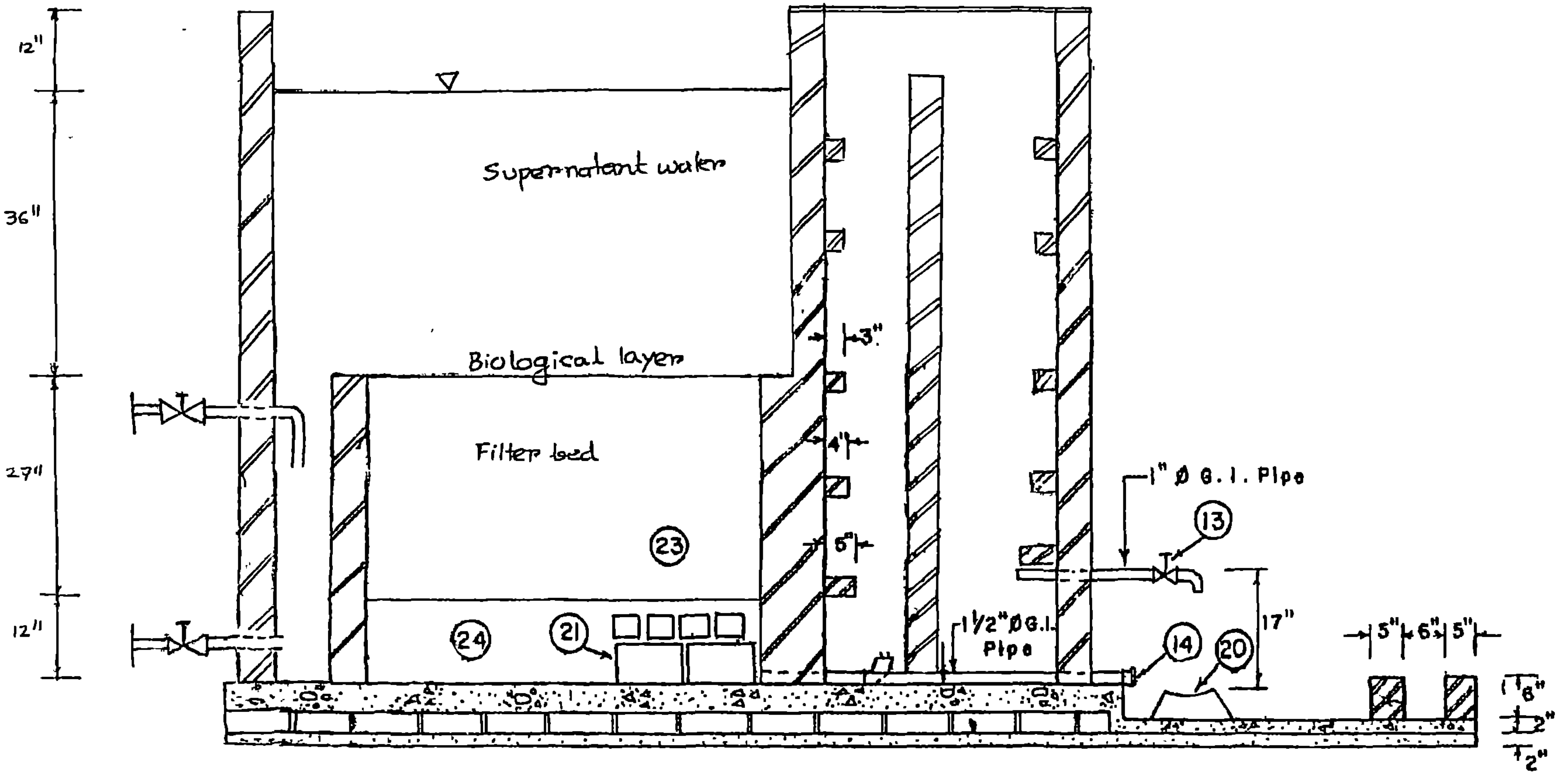
Plant No.	At Tubewell	After Pre-treatment	After Sand Filter
Plant 1	92, 82, 95 (90)	78, 80, 85 (81)	10, 12, 9 (10)
Plant 2	70, 65, 70 (69)	65, 65, 60 (63)	8, 6, 11 (8)
Plant 3	78, 74, 74 (75)	68, 68, 73 (70)	9, 5, 6 (7)

Annex C3: MODIFIED PLAN AND SECTIONS OF PSF



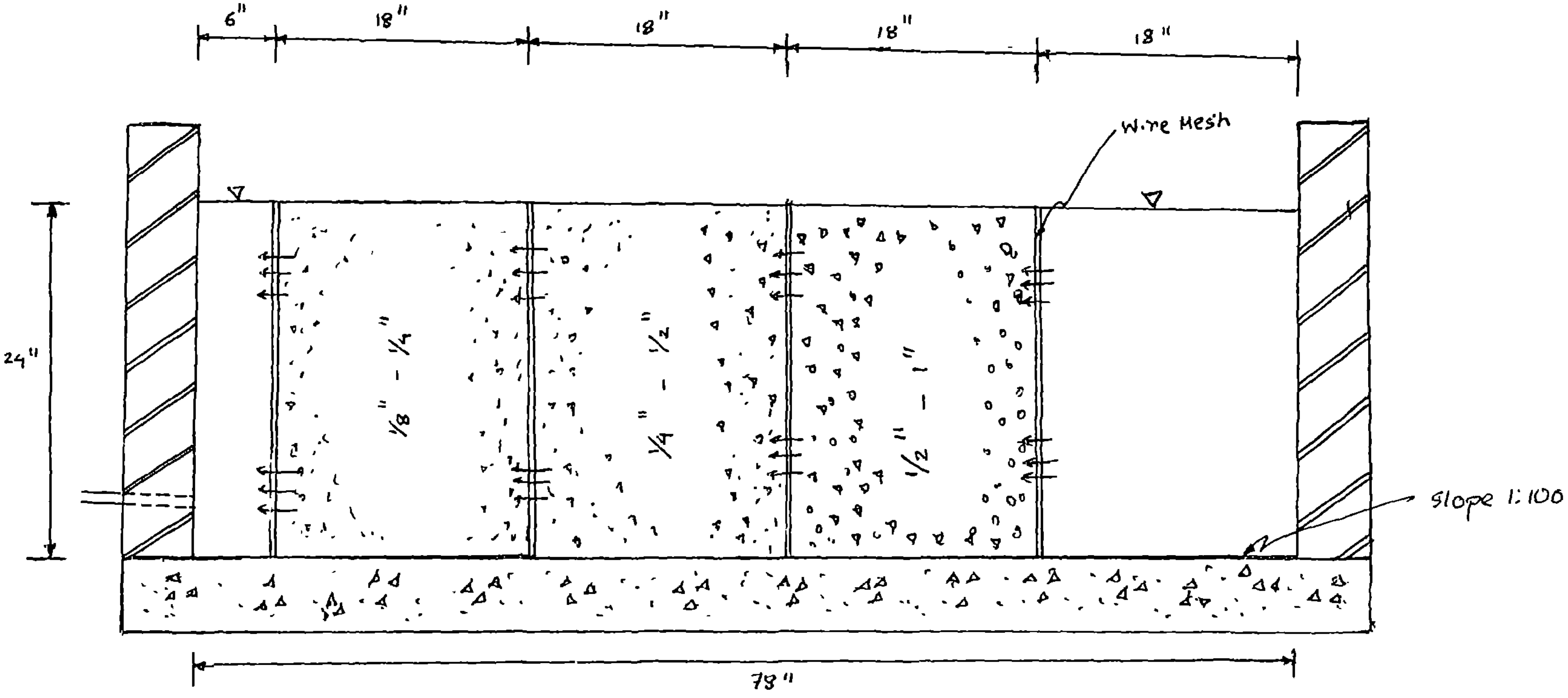
PLAN

Annex C3



SECTION A-A

Annex C3



SECTION OF PRE-TREATMENT CHAMBER

Annex C4: METHODS OF COMMUNITY RAISING

Voluntary Funds

With incidental fund-raisings, local leaders or a community group collect voluntary contributions for the construction, repair and expansion of the community water supply. Funds are collected at public meetings, bazaars, lotteries, festivals, and similar social activities, or through door-to-door collections.

The total amount that can be collected in this way is uncertain when the size of the contributions is left to be decided by individual households. Setting a target for the period to be provided for and dividing this target by the estimated number of user households can help. Each household then has a yardstick with which to set its personal contribution

Annual voluntary fund-raising for maintenance can be a good solution in communities with seasonal income. In farming communities for example, a special campaign can be organized to raise money for the running costs of the community water supply at the time when the cash crops have been sold. The amount of money that needs to be raised should of course not to be large. An advantage is also reduction of work for the local organization, as it needs to come into action for fund collection only once a year. This can be done at the time when agricultural work is slackening and traditionally much attention is paid to social activities.

A limitation of the system is that there is no link with actual water use. Households, which use large quantities of water for domestic and perhaps also productive purposes such as livestock and vegetables, may not pay in proportion or may even evade payment completely. The system is therefore only suitable when there is enough social control in the community to ensure that all user households pay a voluntary contribution in accordance to their capacity and benefits received.

General Community Revenue

Some communities jointly own and mange communal enterprises, such as a communal field for a cash crop, a village shop or flour mill. The profit made on these enterprises, or community funds generated by other means (e.g. levies on crops, cattle sales, or business) are used to pay for other community expenditures, such as maintenance and repair of a public standpost system.

A precondition for this type of financing is that all households have more or less equal access to the improved water supply. Otherwise the less fortunate households will quite rightly object that the service is paid for from funds to which they also contribute.

A disadvantage of relying on general community revenue is that the availability of funds for the water system depends on the income and profits from the other enterprises. The enterprises may fluctuate considerably in their results and also need their own investments. One option is to try and expand the number and variety of sources of community revenue, so that risks are more divided.

Community Revolving Fund

Another interesting way to involve the community in the financing of community water supplies is a community-based revolving fund. Starting capital may come from a government donation or the issue of shares to individual shareholders. Often there is an upper limit to the number of shares each household may buy. This prevents wealth accumulating in the hands of a few families, and decision-making becoming dominated by the wealthier fund-members.

Using the initial capital, loans are given to individual households or groups to start small enterprises or improve housing and sanitation. Upon repayment new loans are given to other members, according to the decisions of the group. Repayment of loans plus interest makes it possible to give a greater number of new loans to others. The community may also use the capital to setup communal enterprises, such as a community shop or a work yard producing building blocks, latrine slabs and other building materials. In this way, community income slowly grows until it becomes possible to finance some basic service. One of these services may be safe water. Common characteristics of successful revolving village funds are strong leadership, high village unity, a high level of participation, diversified sources of income, diversified services, compensation for fund managers, external inputs, including technical and organizational training, periodic review and support visits, and good return of investments.

Despite initial skepticism, experience with loan repayment by low-income households is very positive. Women in particular have gained outstanding repayment records in many countries. Contributing factors are the intimate knowledge which small communities or neighborhoods have of their members' capacities and reliability, the creation of group liability and control, and the strong motivation to make life better for the children.

Production Co-operatives

Sometimes, an improved water supply is established and run by a group of households rather than the community as whole. The water supply serves either the group or the whole community. One type of group is a production co-operative. Its members contribute regular payments in cash or kind, or buy shares. The resulting fund is used to finance co-operative enterprises or give loans to individual members.

Once the group has got sufficient revenue, the members frequently decide to use part of their funds to finance basic services for the group, such as water supply and household latrines. The fund is used to pay all or part of the construction costs, or to establish a maintenance fund for an externally financed system. Because social services to members usually come in a later stage, co-operatives are already well organized by the time that they start a water supply project Their earlier experience with social organization and financial management is also good proof of their capacity to administer a small water system.

A special form of a co-operative approach to an improved water supply is a saving club. Each member of the club (often a women's group) makes a small regular contribution to a communal fund. These contributions can be in cash or in kind In some groups, for example, members save a handful of rice every day When enough rice has been collected it is sold to increase the funds of the group, e.g. by hiring themselves out for agricultural labor during peak season The group's savings are paid out to each member in turn to finance a major acquisition, e.g. a corrugated iron roof with gutter and rainwater collection tank. In this way the women have succeeded in assisting each other to make important improvements for family hygiene and labor reduction. In other cases, the groups have initiated and contributed financially to the improvement of the community water supply, and have also succeeded in mobilizing help the men.