ASSESSMENT OF MSF MODEL FOR SUSTAINABLE DRINKING WATER SOLUTION TO RURAL COMMUNITY OF ARSENIC AFFECTED REGION IN WEST BENGAL

A thesis submitted towards partial fulfilment of the requirements for the degree of Master of Engineering in Water Resources and Hydraulic Engineering.

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"Assessment of MSF Model for Sustainable Drinking Water Solution to Rural Community of Arsenic Affected Region in West Bengal"** is bonafide work carried out by **S M Hidayetullah** under our supervision and guidance for partial fulfilment of the requirement of Master of Engineering (Water Resources & Hydraulic Engineering) in School of Water Resources Engineering, during the academic session 2020-2022.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned does not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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DECLARATION

I hereby declare that this thesis contains a literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Water Resources & Hydraulic Engineering degree during the academic session 2020-2022.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

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Abstract

Clean water is essential for health and the living in general for humans. For some people the access of clean and fresh water is a simplicity but for others, the lack of clean water, especially in rural areas creates one of the biggest humanitarian problems in the world today. For example, a child under the age of five dies every 20 seconds today, due to water-related diseases. For areas with widespread poverty and poor living conditions, it has shown that the access of clean water is a fundamental factor in order to increase the living situation and for the area to start develop. UNESCO claims that is possible to extinguish about 10 % of all diseases worldwide by implementing water treatment methods and sanitation facilities in vulnerable areas in order to improve the water quality. And reports from WHO and UNESCO shows that there is a clear connection between access to clean water and economic growth for a developing country.

One of the oldest methods of water treatment is slow sand filtration (SSF) and HRF unit. The main advantage of MSF being its simplicity in design, have low capital cost, and ability to separate fine solids particles over prolonged periods (high solids retention capacity) without the addition of chemicals. The MSF unit in this study is a simple three-chamber system filled with sand and gravel and activated carbon and one tank is working as a water reservoir tank. Under suitable circumstances, this type of slow sand filter is a very effective water treatment method for purifying the water with both mechanical and biological processes.

In rural area village chatra, we have studied their economic condition and drinking water-related issues. Considering the village situation, we have set up a MSF unit so that they can operate this unit with low maintenance cost as most of the villagers have low monthly income.

For continued development of the SSF project it’s recommended to fill the filters with finer sand grains (0,2 – 0,45 mm), to at least a sand height of 40 cm, to spread more knowledge about maintenance of the filters and to continue to keep a regularly contact with the households to monitoring the status of the filters and also to maintain the relation between the household and the authority. The flexible and modular design options inherent to SSF systems, along with the modifications in expanded application, make SSFs highly attractive for potable water treatment in rural and remote regions.

Keywords: slow sand filtration, rural water quality, potable water treatment, aeration system, biological activated carbon filtration.

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ABBREVIATION:

MSF- Multi-Stage Filtration

MDGs- Millennium Development Goals

SSF- slow sand filtration

HRF-horizontal roughing filter

UV- Ultra Violet

TDS- Total dissolved solids

GAC- granular activated carbon

NTU- Nephelometric turbidity unit

SS- Suspended Solids

BAC- Biological Activated Carbon

BF- Biofiltration

TDPW- Tank Dewatering Produced Water

DGF- Dynamic Gravel Filter

ABF - Arsenic Biosand Filter,

CF-UGF - Coagulation and Flocculation in Up Flow Gravel Filters

MF- Microfiltration

UF- Ultrafiltration

NF- Nano-filtration

BDOC- Biodegradable Dissolved Organic Carbon

EBCT- Empty-Bed Contact Time

THMs- Trihalomethanes

MCL- Maximum Contaminant Level

THMFP - Trihalomethanes Formation Potential

DIGF- Dynamic Intake Gravel Filter

SYMBOLS

º: Degrees

ºC: Celsius degrees

cm: centimeter

d10: effective size diameter

d_{60}: 60% passing diameter

dc: collector size or grain diameter, grain size

log: logarithm

m: meter

Re: Reynolds number

Uc: uniformity coefficient

Eps: Emerging Pollutant

Chapter 1

1. Introduction

1.1 Background of the study:

In the rural areas of West Bengal's North 24-Parganas district, 95% of the total drinking water supply is met by groundwater (Rahman et al. 2003). Yet, many aquifers particularly along the southern border with Bangladesh are subject to arsenic contamination. The adverse health effects of arsenic in drinking water are unambiguous among scholars (WHO 2010; Ravenscroft et al. 2009; Yoshida et al. 2004; Rahman et al. 2003; Smith et al. 1992) and include "cardiovascular (heart failure) problems, gastrointestinal problems (burning lips, painful swallowing, thirst, nausea, and severe abdominal colic), haematological effects (anaemia and leucopenia), hepatic effects, renal effects, neurological effects (headache, lethargy, mental confusion, hallucination, seizures and coma), dermal effects (skin disorder, hyper-keratosis) and carcinogenic effects (lung cancer)" (Elangovan and Chalakh 2006). Poor health conditions caused by arsenic contamination increase the risk of poverty and socio-economic limitations such as exclusion and marginalization.

One of the areas where people lack access to the safe drinking water supply is the Rasui in the North 24-Parganas district close to India's border with Bangladesh. Aquifers in the vicinity of the Rasuii are known to be affected by arsenic contamination (Figure 10, p.15). Nevertheless, untreated groundwater from shallow tube wells remains the prevalent source of water for drinking and other purposes. Hence, there is a need for the implementation of a sustainable drinking water supply scheme that eliminates the health risk for affected inhabitants. Since the data for water supply and sanitation were limited, it was necessary to explore drinking water supply-related needs and assets of the target community in order to determine the most adequate drinking water treatment technology.

Current days surface water also becoming polluted due to different emerging pollutants. Emerging Pollutants (EPs) are a group of substances which are relatively "new" in science. Up to now, around 700 EPs have been detected by the NORMAN Network group during the last 10 years. But some of them have been undetected for years and some are new in water analysis. The most important groups of EPs are Pharmaceuticals, Industrial chemicals, Consumption products, Pesticides and Biocides, Nanomaterials etc.

1.2 Worldwide research activities on Emerging Pollutants:

Nowadays there are several large research projects on EPs. They are shown in Table 1.

Project Name/ Time duration	Domain	Key aspects
Norman 2005	**Europe**	a) Enhance the exchange of information and collection of data on emerging environmental substances b) Encourage the validation and harmonization of common measurement methods and monitoring tools so that the demands of risk assessors can be better met. c) Ensure that knowledge of emerging pollutants is maintained and developed by stimulating coordinated, interdisciplinary projects on problem-oriented research and knowledge transfer to address identified needs d) Organizes expert group meetings, workshops, databases and methods validation exercises
Riskwa N/s	**Germany**	a) Include many other projects as TRANSRISK, SAUBER+, RISK Ident, Schussen AktivPlus b) Promote characterization-and management of risks, new technologies for emissions management, communication and education arrangements, identification of pollutants.
Solutions 2013-2018	**Europe**	a) common denominators and causal links between changes in society and climate, use of chemicals in materials and emissions of pollutants b) aim to predict future emerging pollutants – based on scenarios for developments in society.
Scarce 2009-2014	**Europe**	a) Assessing and predicting the effects on water quantity and quality in Iberian rivers caused by global change. b) Define the long-term patterns and actual mechanisms that operate in the hydrology, water quality, habitat dynamics, and ecosystem structure and function of Mediterranean watersheds.

1.3 Occurrence of EPs in Indian Waters:

In India, the contribution of emerging contaminants in the aquatic environment comprises of 57% pesticides, 17% pharmaceuticals, 15% surfactants, 7% personal care products and 5% phthalates (Gani & Khazmi 2016). Several studies ascertained the presence of Active pharmaceutical ingredients (API), personal care products (PCP), pesticides, endocrine-disrupting chemicals (EDC) and artificial sweeteners (ASW) in surface water bodies.

1.4 History of Arsenic Contamination in South Asia:

Unofficial accounts of arsenic-related diseases in North-24-Parganas date back to the late 70s (Rahman et al. 2003). Officially, arsenic poisoning through drinking water was observed in North 24-Parganas and three other districts of West Bengal in the early 1980's (Elangovan and Chalakh

2006; Chakraborti et al. 2002) and in 1988, the WHO published a bulletin on arsenic contamination of groundwater in Bengal (Chakraborti et al. 2015). From 1992 onwards, the faculty of Environmental Studies (SOES) of Jadavpur University in Kolkata Systematically screened people for arsenic-related diseases. The results were shared with the World Health Organisation (WHO), the United Nations Children's Fund (UNICEF) and the government of Bangladesh. In 1993, Bangladesh's government acknowledged arsenic contamination of tube wells.

Even though West Bengal hosted an international conference on arsenic contamination in 1995, little attention was being paid to the issue (Chakraborti et al. 2015). In 1996, (Mandal 1996) published an often-quoted paper which dubbed arsenic contamination of groundwater in seven districts of West Bengal "the biggest arsenic calamity in the world". A similar narrative was adopted by (Smith et al. 2000) who called arsenic contamination of groundwater in Bangladesh the "largest poisoning of a population in history". Still, many years later, it is often stated that insufficient remedial action is initiated (Ravenscroft et al. 2009; Chakraborti et al. 2015).

1.5 Arsenic Contamination in West Bengal and North 24-Parganas:

The Ganga-Brahmaputra delta at the apex of the Bay of Bengal comprises the south of West Bengal as well as Bangladesh and is South Asia's most affected area with regard to arsenic contamination of groundwater (Elangovan and Chalakh 2006). In this area alone, 136 million people are at risk of groundwater with arsenic concentrations above 50 μg/L (Chowdhury et al. 2001). Approximately 50 percent and 43 percent of Bangladesh's (Khan et al. 2003) and West Bengal's (Chakraborti et al. 2009; Chowdhury et al. 2000) population are at risk of ar-senic contamination of drinking water respectively9. In West Bengal, at least 107 blocks in 42 districts are affected by arsenic contamination of groundwater (Chowdhury et al. 2000; Roy-chowdhury 2010).

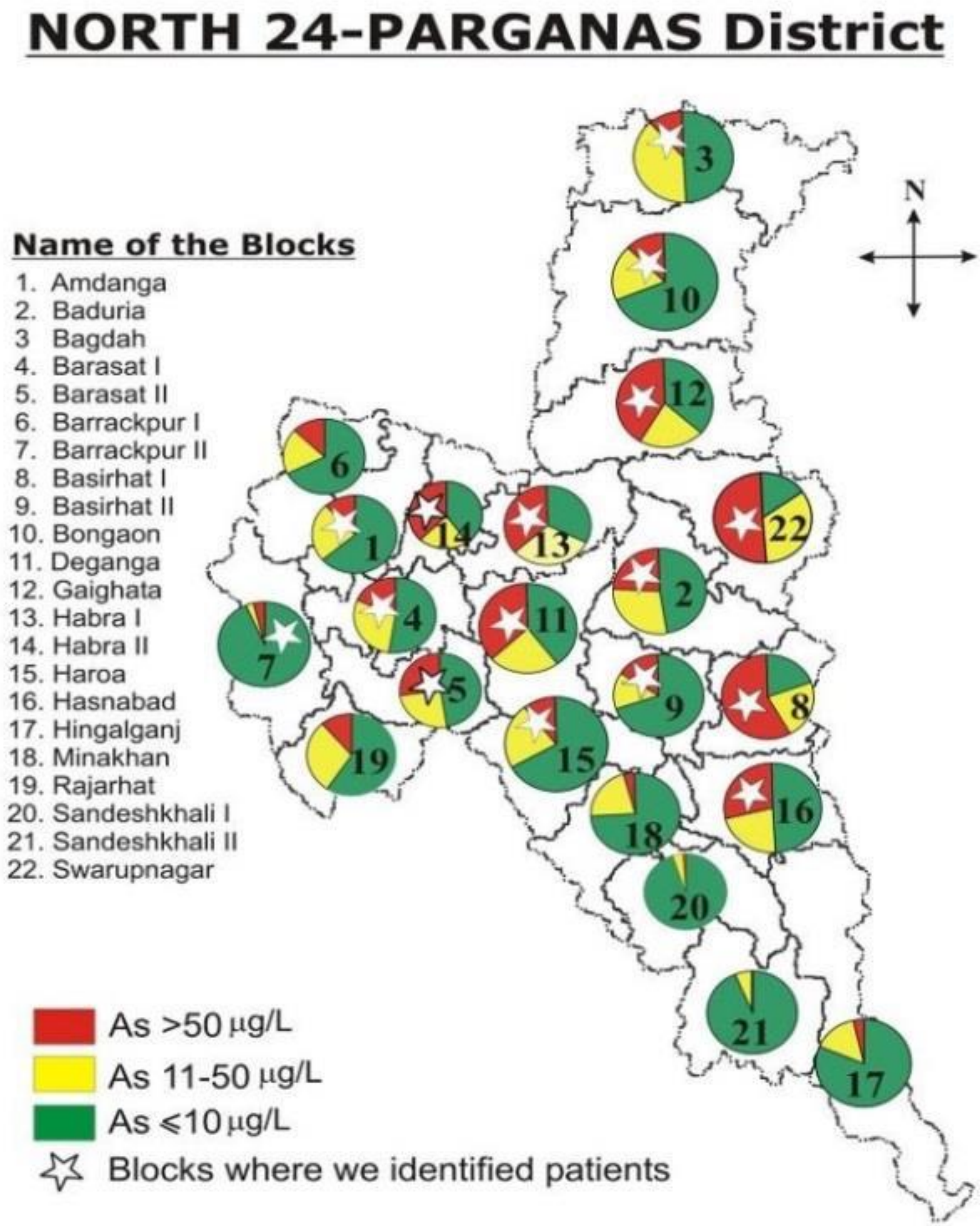


Figure 1: Arsenic contamination in North 24-Parganas. The Gram Panchayat Chatra is situated within the Baduria CDB (Source: SOESJU 2016).

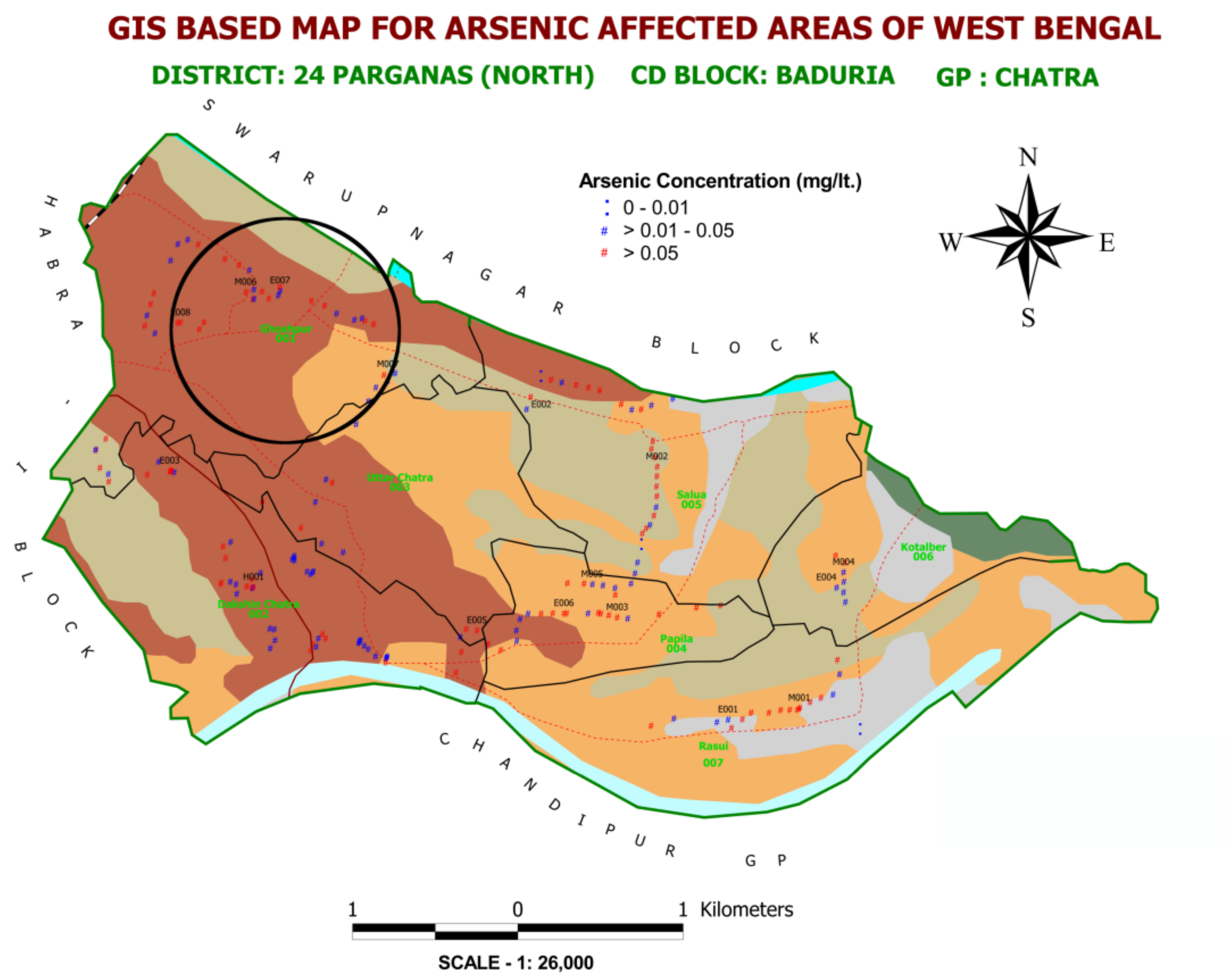


Figure 2: Arsenic contamination of public tube wells in Ghoshpur (outlined in black). Blue and red hash charac-ters indicate public tube wells with arsenic contamination of more than 10 and up to 50 µg/L as well as more than 50 µg/L, respectively. Modified from (WBPHED 2014).

1.6 Exposure to Arsenic:

As many as 200,000 self-constructed hand tube wells with a depth of 10 to 15 metres exist in North 24-Parganas alone and around 1.33 million in West Bengal in total (Chakraborti et al. 2009; Rahman et al. 2003). Ninety-five percent and 70 percent of North 24-Pargans' rural inhabitants rely on groundwater from hand tube wells for drinking and cooking, respectively (Rahman et al. 2003). Thousands of large-diameter tube wells with a depth of more than 100 metres and a pumping capacity of 20 m^3/h were constructed by the PHED (Ravenscroft et al. 2009). Arsenic in drinking water is colourless, tasteless, and odourless and thus, for consumers difficult to detect (Yoshida et al. 2004). In addition, food contributes to arsenic exposure if arsenic contaminated tube well water is used for irrigation or cooking (Sharma et al. 2014; Santra et al. 2013; Brammer and Ravenscroft 2009; Ravenscroft et al. 2009; Williams et al. 2006).

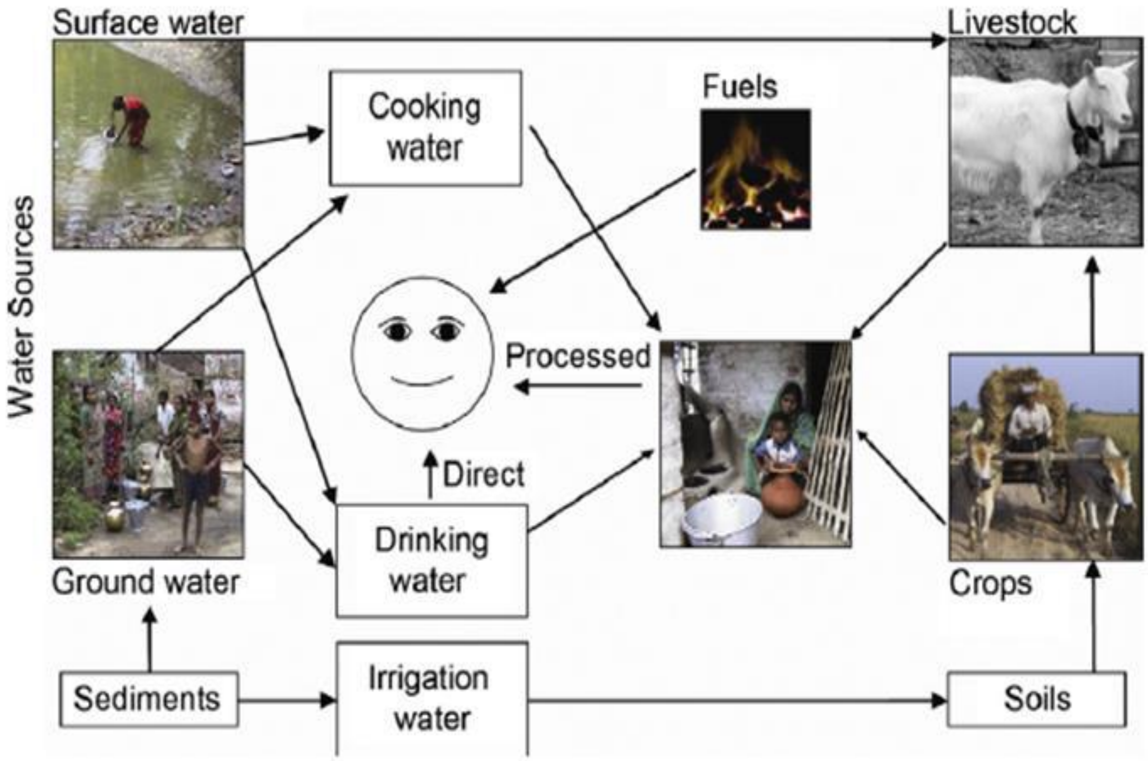


Figure 3: Possible ways of human exposure to arsenic (Sharma et al. 2014).

1.6.1 Health Impact of Arsenic in West Bengal and North 24-Parganas:

Arsenic in drinking water is absorbed by the gastrointestinal tract from where it enters other body compartments. The toxicity of arsenic in the human body is a function of arsenic intake and arsenic degradation (WHO 2008) and the cumulative intake of arsenic poses a threat to human health (Yoshida et al. 2004).

The evidence of a link between elevated levels of arsenic in drinking water and cancer is described by the WHO as overwhelming (WHO 2008). Other symptoms of arsenic poisoning or Arsenicosis include "dermal changes (pigmentation, hyperkeratosis, and ulceration), respiratory, pulmonary, cardiovascular, gastrointestinal, haematological, hepatic, renal, neurological, development, reproductive, immunological, genotoxic, mutagenic, and carcinogenetic effects" (Mandal et al. 2001). The latency of Arsenicosis is high. Some symptoms only emerge after years and the death rate from Arsenicosis is likely to still peak in the future (WHO 2010; Flanagan et al. 2012).

Arsenic-related diseases have been classified and summarized by (Sun et al. 2014) into genotoxic, cytotoxic and epidemiological diseases (Figure 12, p.19). Epidemiological dermatological disorders are the most commonly observed clinical pictures of Arsenicosis. They indicate internal health damages and have been observed at exposure levels below the WHO guideline of 10 µg/L (Yoshida et al. 2004). Their occurrence in North 24-Parganas has been studied by Rahman 2003. Two thousand, two hundred seventy-four out of 33,000 test-ed people showed dermatological disorders and during a follow-up study, many of the affected villagers suffered from serious diseases such as cancer (Rahman et al. 2013; Rah-man et al. 2003).

Out of 21,000 samples, 56%, 89% and 87% were subclinically affected and showed elevated levels of arsenic in hair, nail and urine respectively (Rahman et al. 2003). The link between elevated levels of arsenic in hair, nails and urine and arsenic contamination of tube well water has been confirmed by Roy chowdhury (2010). Studies on chronic arsenic exposure in utero and in early childhood suggest an increased risk of foetal loss, infant death, reduced birth weight and impaired cognitive function in children, as well as significantly higher risks of impaired lung function, renal cancer and death from lung cancer, lung disease and acute myocardial infarction later in life. In general, children have been found to be more susceptible to arsenic poisoning but usually do not show arsenic skin lesions (Rahman et al. 2003; Chowdhury et al. 2001; Chowdhury et al. 2000).

1.6.2 Mitigation Strategies:

Arsenic mitigation approaches can be classified into: (1) use of uncontaminated parts of an aquifer (2) treatment of arsenic-contaminated water or (3) development of surface water sources. For each approach, however no single best technological solution exists and local social, environmental and economic aspects of a specific location always need to be considered (Ravenscroft et al. 2009; Curry et al. 2000). Any mitigation strategy should be accompanied by awareness campaigns and water quality monitoring programs which ensure that exposure to arsenic has ceased (Smith et al. 2000).

1.7 Benefits of Multistage Filtration and the need for research in rural areas:

Multi-Stage Filtration (MSF) is an integrated solution for improving community water supply in rural communities and small to medium-sized towns. Although it has been implemented in some areas and piloted in others, MSF as a technological package remains unknown in many countries. MSF was developed in the 1990s by researchers in Colombia where it is now being applied on a larger scale and some efforts were made to support wider dissemination and further development, particularly in Latin America. The Millennium Development Goals (MDGs) require improved interventions in the water and sanitation sector. This challenge includes the need to improve water quality in many countries. MSF is one of the more interesting options, and perhaps the only solution for many community water supply systems. The challenge includes the need to improve existing systems, particularly the many slow sand filtration (SSF) systems around the world that do not perform well because of a lack of pre-treatment. These systems need to be converted into MSF systems for better performance.

It is important to use water treatment technology that is appropriate for the local condition. The developing world used surface water as a source of water for small communities. Sanitary risk associated with surface water is becoming greater due to poor protection of water sources and inadequate wastewater and solid waste management. Surface water may also show unpredictable and erratic changes in quality due to runoff during rainy periods. This is a critical problem for water works operators. Surface water may carry considerable sanitary risk and require treatment to remove or remove disease-causing organisms. This risk is lower for well-protected sources in the hilly region than for lowland rivers in populated areas.

The use of sand and gravel as filter media for water supplies can be split into three basic filter types: slow sand filter, Rapid filters and roughing filters.

Apart from desalination and reverse osmosis, SSF is perhaps the most effective single treatment for purifying drinking water supplies. They are used on large scale as part of the water supply for small cities, as part of the system for small villages, and on a much smaller scale they can be adopted for use in individual households.

Slow sand filter is the oldest water treatment technique used in water supply system for small communities for treating surface water with relatively low levels of contamination. If surface water contains more turbidity, then it is problematic to use of SSF, so in that case we can use rapid sand filter with coagulation treatment unit. But in case of rapid sand filter micro-organism removal will be 80%-90%, which is risk for drinking water purpose. So, we have to use such arrangement which will reduce maximum threat.

SSF has two important limitations. Firstly, poor water quality may exceed treatment capacity if high turbidity levels lead to premature clogging of filters, or if colour levels exceed removal capacity. (Colour in water is a marker for organic compounds which can react with chlorination processes to produce harmful and carcinogenic substances. Excessive coloration of water can also make it unacceptable to communities.) Secondly, the biological nature of SSF treatment requires a continuous flow of the water to ensure a continuous supply of oxygen and nutrients. Treatment is negatively affected by low temperature, low nutrient concentration or low levels of dissolved oxygen.

To reduce problems associated with these limitations, research was initiated into the development of pre-treatment systems to improve water quality before it reaches the SSF. For this purpose, we can use a multistage filtration unit to treat the water. The technology of multi-stage filtration (MSF) presented in this chapter is a combination of a horizontal roughing filter (HRF) and slow sand filter (SSF). This combination allows the treatment of water with considerable levels of contamination, well above the levels that can be treated by SSF alone. MSF retains the advantage of SSF in that it is a robust and reliable treatment method that can be maintained by operators with low levels of formal education. It is much better suited than chemical water treatment to the condition in rural communities and small and medium-size communities. Other treatment processes such as simple sedimentation, screens, and aeration system can precede MSF technology. Wherever possible, terminal disinfection needs to be included as a safety barrier after the MSF.

1.8 Research Gap:

Current days water pollution due to emerging pollutant is a great threat to human health. In India most of emerging pollutants are due to pesticide which is used in agricultural field. Study have been done for removal of Eps from water in Europe, Germany. But in India, we did not see too much research related to the removal of Eps. Also study of efficiency of multistage filtration unit in the removal of the emerging pollutants is a new topic. In this study, we have also determined the increase in efficiency of dissolved oxygen level due to inclination of aeration system in different angle and due to different flow rate.

1.9 Research Objectives:

The main objective of this study is to design a sustainable energy efficient surface water treatment unit (MSF) and assessment of its efficiency for removing Emerging contaminants and water quality parameters.

Specific objectives to meet this goal were to:

- Determine the performance of multistage filtration, particularly with respect to the removal of physical and chemical and bacteriological parameters, with increased raw water turbidity, low water temperatures, and increased hydraulic loadings rate.
- Determine an increase in the efficiency of dissolved oxygen with different sloping angles and different flow rates. How with a decreased flow rate dissolved oxygen level will increase? Also determine, how to DO level will increase with a sloping angle.

Another objective is to gather the needs of drinking water requirements of study area and evaluates the qualitative and quantitative data on water scenario including the condition of surface and sub-surface water sources of rural study area of North 24 pgs, West Bengal

1.10 The Study Area:

The area under consideration in this research is Rasui a village of North 24 Parganas district in West Bengal. The geographical location of Rasui village is 88°48'08.5"N, 22°50'00.0"E. The Rasui village has population of 704 of which 365 are males while 339 are females as per Population Census 2011. Rasui village has lower literacy rate compared to West Bengal. In 2011, literacy rate of Rasui village was 67.83 % compared to 76.26 % of West Bengal. In Rasui Male literacy stands at 77.71 % while the female literacy rate was 57.09 %. In Rasui village population of children with age 0-6 is 101 which makes up 14.35 % of total population of village. Average Sex Ratio of Rasui village is 929 which is lower than West Bengal state average of 950. Child Sex Ratio for the Rasui as per census is 980, higher than West Bengal average of 956.

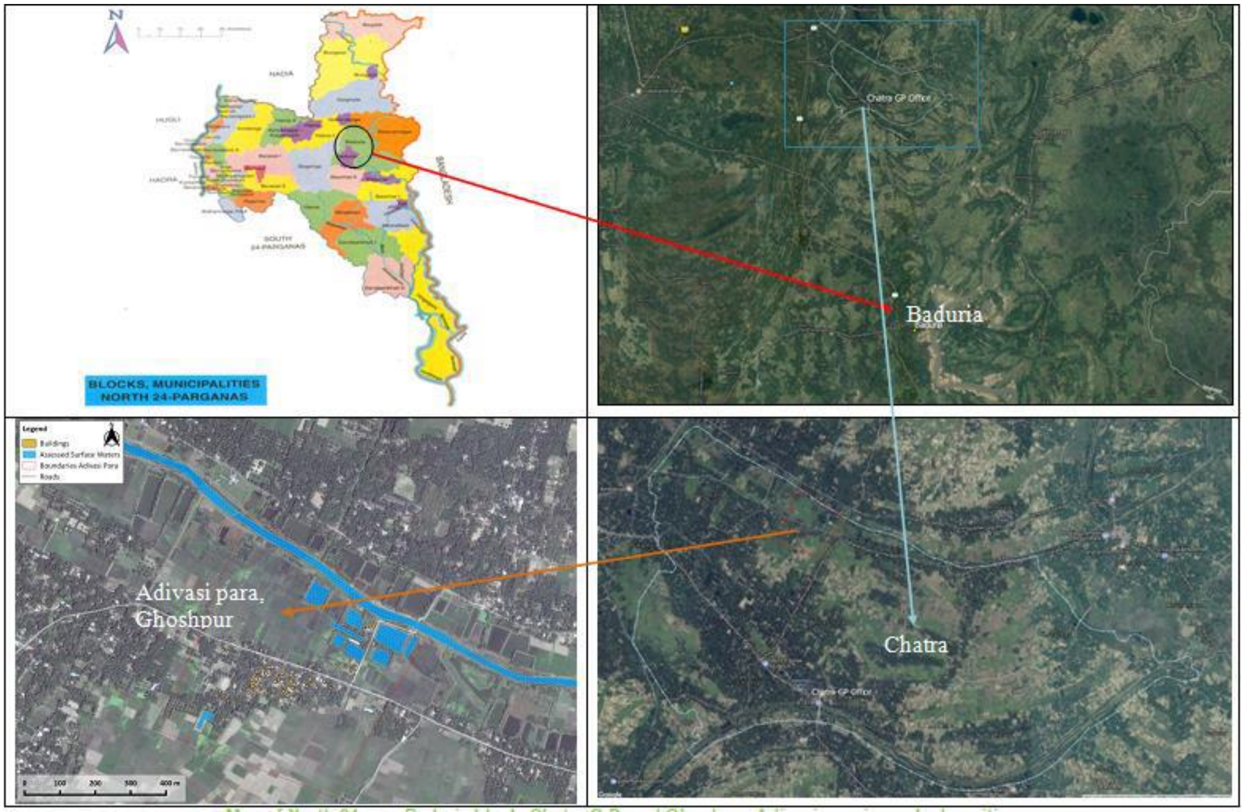


Figure 4: Tangible map of study area

1.11 Research Approach:

After a thorough literature review, research needs were defined and one model pilot system was commissioned on the Jadavpur University campus lab and another pilot system is set up in the village Rasui. Model pilot system fed with raw water from the pond near fluvial lab of Jadavpur University. The pilot plant has set up in the village fed with water from a canal. We also set up a cascade-type aerator before the sand filter. checking the efficiency of aerator to increase dissolved oxygen lebel in water.

1.12 Reason for choosing MSF unit:

Source water is polluted due to the presence of turbidity, iron, arsenic, pathogenic bacteria and odour problem. Villagers' monthly income is very less so we have to set up such a unit that has low maintenance and operational cost. The unit will be such which can be operated by them easily. Also, it is important to use water treatment technology that is appropriate for the local condition. That's why we chose the MSF unit which will satisfy all these conditions. we set up a MSF unit for small village Rasui in North 24 parganas.

1.13 Outline of The Thesis:

Drinking water facility, condition, pollution status, economical background of villagers, cause of water pollution etc. assessment done in this project and a sustainable MSF unit developed. This research work consists of five chapters. Chapter 2 contains literature review of different similar nature of national and international scenarios of MSF units. Chapter 3 describes needs assessments survey water aspect. Chapter 4 describes details theory of slow sand filter, horizontal roughing filter and multistage filtration unit. Chapter 5 presents the methodology and experimental design of different filtration techniques. Chapter 6 contains result and discussion part. Chapter 7 ends with conclusion and recommendation.

Chapter 2

2. Literature review

Mushila et.al (2016) studied on evaluation of the performance of HRF units by way of their removal efficiencies for the various water quality parameters under varied raw water conditions. In order to meet this objective a pilot plant unit was designed and operated. The pilot plant was set up at Moi University Water Treatment Works in Kesses Division, which is about 36 kilometers South East of Eldoret town in Kenya. The response of the respective HRF units in removal of selected parameters guiding drinking water quality such as microbiological (Faecal and Total coliform), Turbidity, Suspended Solids (SS), dissolved iron and Manganese was investigated. He found that removal efficiency of HRF unit was 86 percent for turbidity and 85 percent for Suspended Solids removal. With respect to microbiological raw water quality improvement, HRF units reduced Fecal coliforms load by 36 percent and Total coliforms load by 38 percent respectively. They observed that connecting the HRF units in series yielded very high efficiencies in terms of Turbidity and Suspended solids, removal recording levels as high as 98 percent.

Shawn A. Cleary et.al (2005) studied on multistage filtration consisting of roughing filter followed by slow sand filter was set up in northern climates with reference to the Ontario Safe Drinking Water Act. Testing was conducted on two different pilot multistage filtration systems and fed with water from the Grand River, a municipally and agriculturally impacted river in Southern Ontario. One system featured pre-ozonation and post-granular activated carbon (GAC) stages, and shallower bed depths in the roughing filter and slow sand filter. The other system featured deeper bed depths in the roughing filter and slow sand filter, two parallel roughing filters of different design for comparison, and a second stage of slow sand filtration for increased robustness. Removal of turbidity, total coliforms, and fecal coliforms under a range of influent turbidities (1 to >100 NTU), water temperatures (2 to 20^{o}C), and hydraulic loading rates (0.2 to 0.8m/h) were investigated. In addition, the slow sand filters in each pilot system were challenged with high concentrations of inactivated Cryptosporidium parvumoocysts. They found that effluent turbidity was mostly below 0.5 NTU during periods of stable influent turbidity (no runoff events) and a hydraulic loading of 0.4m/h also reduced coliforms to≤2MPN/100 mL in 80% measurements with influent levels as high as 2400MPN/100mL. Overall, it is concluded that the system appears to have great potential as safe and reliable treatment alternative for small and non-municipal water systems, in communities that are depends upon surface water sources.

Gamila E. et.al (1999) examined the potential of some roughing filter media, prepared from locally available materials in removing organic matter and turbidity from surface water and testing the efficiency of roughing filter followed by slow sand filter in minimizing the suspended load on the subsequent water treatment steps. Filter media consisted of three layers of gravel, showing 84–100% removal for green algae, blue-green algae, diatoms, total algal count, bacterial count (at 22 and 37˚C), total coliforms, fecal coliform, fecal streptococci, yeast and Candida albicans. It is found that after using only slow sand filter turbidity removed up to 83% and by using a combination of slow sand filter followed by roughing filter turbidity removal efficiency reached up to 92%. It is concluded that esthetic quality of the filtered water point of view, the results of the analyzed physico-chemical parameters showed no change before and after the use of the roughing and slow sand filters.

Mathias Osterdahl et.al (2015) studied on SSFs which consists of a simple two-tank system where one tank is filled with sand and gravel and the other tank is working as a water reservoir tank and it is done in rural areas in Colombia the filters were most effective against turbidity and some filters reduced coliform bacteria very effectively. The study showed that many filters could reduce some of the chemical and biological parameters but no filter produced water according to the recommended drinking standard. For continued development of the SSF project it's recommended to fill the filters with finer sand grains (0.2 – 0.45 mm), to at least a sand height of 40 cm.

Ann M. Gottinger et.al (2010) studied on slow sand filters (SSFs) as well as two case studies from the province of Saskatchewan, Canada in which an optimized technology has been successfully designed and implemented to produce high quality potable water for very small populations. The SSFs designed and tested in Saskatchewan are modular polyethylene systems that include pre and post treatment processes such as ozone oxidation, roughing, and biological activated carbon (BAC) filters to provide significant reductions in turbidity, heavy metals, colour, and organics. The system successfully removes manganese from concentrations as high as 0.8 mg/L to below the acceptable limit of 0.05 mg/L and Iron from concentrations 0.3 mg/L to<0.005 mg/L. Modified SSF systems have proven to produce exceptional quality water despite operating in cold temperatures, encountering a variety of contaminants, and in highly variable water conditions with minimum operational costs or maintenance making them a suitable alternative for many rural and remote communities.

GM Ochieng et.al (2014) examined verification of Wegelin's design criteria for horizontal flow roughing filters (HRFs) with alternative filter material. This is done based on gravel as a filter medium and two other possible alternative filter media, namely broken burnt bricks and charcoal maize cobs. The pilot plant was monitored for a continuous 85 days from commissioning till the end of the project. Results showed that in general, filters filled with charcoal maize cobs and broken burnt bricks were off model prediction by 13% compared to gravel's 15%. The performances also varied in both low- and high-peak periods. It is concluded that the Wegelin's design criteria should be used as a guideline step followed by actual field and laboratory tests to establish the actual filter design parameters in line with the filter media in use and the quality of the raw water to be treated.

Celia Charron et.al (2015) examined on a Case Study of a Multi-Stage Filtration System for Remote and Northern Communities in Canada. A pilot multi-stage filtration system for water treatment was operated at two sites with phosphorous nutrient limited (C: N: P of 546:24:1 w/w) and nutrient rich (C: N: P of 6.3:1.6:1 w/w) source waters. The system had two parallel treatment trains: Train 1 consisted of pre-ozonation, roughing filtration and slow sand filtration (SSF); and Train 2 consisted of pre-ozonation, roughing filtration and biofiltration (BF). Raw water turbidity values ranged from 0.2 to 70 NTU. It is observed that SSF effluent turbidity ranged between 0.2 to 17 NTU, while the BF effluent turbidity ranged from 0.1 to 60 NTU. It is found that Nutrient limited conditions give result in low DOC removals for both the biofilter and slow sand filter operating in parallel. A low ozone dosage of 1.55 mg O_3/mg DOC improved the DOC removal (8.27% for the SSF and 10.3% for the BF) compared to un-ozonated conditions (5% for the SSF and 6.34% for the BF) and Nutrient rich conditions resulted the highest DOC removal for the biofilter occurred during low ozone dosing conditions (26.1% at a dose of 1.9 mg O_3/mg DOC) and the highest removal for the slow sand filter occurred during high ozone dosing conditions (26.1% at a dose of 3.45 mg O_3/mg DOC). Overall, it is concluded that Nutrient rich conditions give higher DOC removals for both the biofilter and slow sand filter operating in parallel under low and high ozone doses, compared to the nutrient limited conditions.

B.A.Clarke MSc et.al (1999) studied on performance of a multi-stage treatment system, comprising shallow up flow gravel pre-filters and fabric-enhanced slow sand filters, was investigated both in service and during cleaning operations in a UK-based research project. The multi-stage system was found to be achieving substantial levels of microbial and physical improvement of the raw water obtained from the river Umuvumba. They found removal efficiency of both turbidity and suspended solids levels of typically between 60% and 75% and significant level of microbiological treatment was achieved by the triple-stage pre-filters, with fecal coliform removal in the range 80–90%. It is concluded that multi-stage filtration, comprising up flow gravel pre-filters and enhanced slow sand filters, is perceived as offering a reliable water treatment system for small community applications in the developing country like India.

Mtsweni Sphesihle et.al (2016) research aims at providing both social and scientific information on the importance of greywater reuse and recycling as an alternate source to aid water demand management under South African conditions. The approach to this research work was divided into two main thrusts: the first was to gain an understanding of the public attitudes towards the idea of reusing greywater that is usually perceived as wastewater which pose health concerns. The second was to provide an understanding of typical greywater quality in a peri-urban community in Durban, South Africa as well as investigate the suitability of a horizontal roughing filtration system in reducing pollutant strength of contaminants found in greywater for non-potable reuse applications. He found that a small percentage (<20%) are agree with re use of grey water and higher percentage of respondents (>60%) disagree that the reuse of grey water could negatively impact on public health. It was observed that 90% turbidity and 63% Chemical Oxygen Demand reduction was achieved over the entire duration of operation of the horizontal roughing filter. It was also observed that the removal efficiency was significantly higher in the compartment with the smallest filter media size and the removal efficiency was significantly higher at lower filtration rates.

Tommy Ngai et.al (2003) studied on design of an appropriate household drinking water filter for rural area in Nepal. A household-level drinking water filter (Arsenic Biosand Filter, ABF) was developed at Massachusetts Institute of Technology to simultaneously remove arsenic and pathogens from tubewell water. On the basis of three-month study from September 2002 to January 2003 the performance of the filter under various setups are evaluated, and investigated long-term removal efficiencies, to improve the filter design, and to implement the filter in arsenic affected villages. The Arsenic Biosand Filter was found to be effective in removing arsenic up to 93%, total coliform 58%, E.Coli 64%, and iron is greater than 93%.It was observed that high flowrate (avg14 L/hr), simple operation, minimal maintenance, as well as the clean-looking and good-tasting water coming out from the filters. That’s why the filter is durable and permanent solution to their drinking water problems.

M.P. Ormad et.al (2007) studied the effectiveness of the treatments commonly used in drinking water plants in Spain to degrade 44 pesticides systematically detected in the Ebro River Basin. The pesticides studied are: alachlor, aldrin, ametryn, atrazine, chlorfenvinfos, chlorpyrifos, 3,4-dichloroaniline, dicofol, dieldrin, dimethoate, diuron, metholachlor, methoxychlor, molinate, parathion methyl, parathion ethyl, prometon, prometryn, propazine, simazine, terbuthylazine, terbutryn, tetradifon and trifluralin, pp' -DDD, op' -DDE, op' –DDT etc. The techniques applied are: preoxidation by chlorine or ozone, chemical precipitation with aluminum sulphate and activated carbon adsorption. Oxidation by chlorine removes 60% of the studied pesticides, although combining this technique with a coagulation-flocculation-decantation process is more effective. The disadvantage of this treatment is the formation of trihalo methane. Oxidation by ozone removes 70% of the studied pesticides. Although combination with a subsequent coagulation-flocculation-decantation process does not improve the efficiency of the process, combination with an activated-carbon absorption process gives rise to 90% removal of the studied pesticides. This technique was found to be the most efficient among the techniques studied for degrading the majority of the studied pesticides.

Matiar Rahman Mondol et.al (2009) studied the adverse effects of presence of iron, manganese and arsenic in ground water in Bangladesh. They constructed seven numbers of multistage filtration units (MSFU) in Sirajgonj,Comilla and Jessore (three different hydro-geological conditions) to investigate the effectiveness of multistage filtration in removing iron, manganese and arsenic from groundwater of Bangladesh. The MSFU, which is attached to a tube well, has three chambers, 1st chamber (Aerator plus Down-flow Flocculator), 2nd chamber (Sedimentation plus Up-flow Roughing Filter) and 3rd chamber (Down-flow Roughing Filter). Water entering the first chamber is distributed uniformly over the whole bed of course media through a porous thin Ferro-cement plate placed on the top, resulting strip out of CO2 and increase of pH value for the oxidation of soluble iron. They achieved removal efficiency of arsenic up to 91 %, also manganese removal efficiency upto85 % and iron removal efficiency achieved up to 97% without using any chemicals. It is recommended that Length of filter run between cleaning should be maximum 3 - 4 weeks. MSFU will be cleaned when flow from the outlet of URF chamber will reduce by 45-50% of the tube well flow.

P. Akshay et.al (2020) developed a handy personal, water purifier, which is a ubiquitous, cost-effective access to healthy potable water for humans. This portable water purifier is a multi-stage filter constituted of a fabric filter, graphene-oxide coated sand filter, vetiver grass filter, and a UV filtration system. It shows drastic reductions (more than 50%) in the total dissolved solids (TDS), hardness, chloride and calcium ions. This paper proposes an innovative, inexpensive and eco-friendly method for water purification. Implementation of this filtration unit in India is expected to serve as an efficient and affordable appliance for daily consumption of water.

Monalisa Franco et.al (2012) studied on water treatment by multistage filtration system with natural coagulant from moringaoleifera seeds. It is the evaluation of a pilot multistage filtration system (MSF) with different natural coagulant dosages, 131 mg/l and 106 mg/l. The system was comprised by a dynamic pre-filter unit, two up flow filters in parallel and four slow filters in parallel, and in one of the four filters had the filter media altered. The performance was evaluated by monitoring some water quality parameters such as: turbidity, apparent color and slow filter load loss. They found pre-filtration without applying the coagulant suspension had 62% efficiency in removing turbidity and apparent color of the water. After The application of dosage of 131 mg/l turbidity removal efficiency becomes 89% and apparent color removal 86%. Also, after application of dosage of 106 mg/l turbidity removal efficiency becomes 99% and apparent color removal 98%. The steps employed in pre-filter and slow filter, respectively, proved to be efficient in removing turbidity and apparent color of the water, through the MSF system.

L.D.Sánchez et.al (2015) explored the design criteria, the operation and maintenance (O&M) practices, and the performance of a study of four full-scale up flow gravel filters that are part of full-scale multi-stage filtration which is selected near to Cali, Colombia. It was found that most design criteria and O&M procedures are following the recommendations as presented in the literature but several diversions were also identified. It was also found that removal efficiencies were on the low side when compared to the literature, possibly because of the good influent quality water that was treated. Cleaning efficiency was analyzed and found that about 90% of the retained solids were removed in two drainage cycles; the remaining 10% is probably removed during surface cleaning of the gravel bed. Overall, it is concluded that an adjustment of the design criteria and O&M procedures is needed to enhance system performance. This includes drainage system design, surface cleaning by weir, and filter bed cleaning to allow a reduction in cleaning cycles and an improvement in operation control.

R.C. Medeiros et.al (2020) set up a dynamic gravel filter (DGF) as a pre-treatment to household slow-sand filters (HSSFs). DGFs (with and without a non-woven blanket on top of the gravel layer) followed by HSSFs were tested. DGFs operated with a filtration rate of 3.21 m^3/m^2*d and HSSFs with 1.52 m^3 /m^2*d. Influent water contained kaolinite, humic acid and suspension of coliforms and protozoa. It was found that removal of turbidity is >60%, E.coliup to 1.78 log, Giardia cysts and Cryptosporidium oocysts up to 3.15 log and 2.24 log, respectively. The non-woven blanket was shown as an important physical barrier to remove solids, E. coli and protozoa. HMSFs with a non-woven blanket is a clear example of the multi-barrier concept, in which there is more than one treatment stage to improve water quality, with gradual removal of particles and microorganisms.

L.D.Sanchez et.al (2012) assessed the operational and design aspects of coagulation and flocculation in up flow gravel filters (CF-UGF) in a multi-stage filtration (MSF) plant.CF-UGF units improve the performance of MSF considerably, when the system operates with turbidity above 30 NTU. It highly reduced the particulate matter load in SSF and therewith avoids short filter runs and prevents early interruption in SSF operations. They found the removal efficiency of turbidity in the CF-UGF with coagulant in between 85 and 96 %, whereas the average efficiency without coagulant dosing was 46 % (range: 21–76 %). Operating with coagulant also improves the removal efficiency for total coliforms, E-coli and HPC. It is concluded that combining CF-UGF with MSF greatly contributed to the removal efficiency of the system without negatively affecting the biological activity of the treatment system in terms of the efficiency of microorganism removal in the UGF and SSF when coagulant was used.

Mehrdad Ebrahimi et.al (2012) studied on evaluation of a multistage treatment process of oilfield produced water generated from tank dewatering with different ceramic membranes. They focused on the characterization of permeate flux using various ceramic microfiltration (MF), ultrafiltration (UF,) and Nano-filtration (NF) membranes as potential techniques for efficient treatment of tank dewatering produced water (TDPW). It was found that total removal percentage of oil content in between 45% to 93% for MF and 80% to 99.5% for UF followed by NF, while TOC removal ranged from 3% to 26% for MF and 13% to 60% for UF followed by NF. It is concluded that the investigated membrane processes (single and combined MF, UF and NF) are excellent techniques to remove oil from oilfield produced water.

Chapter 3

3. Needs Assessments Study

This document has been compiled with the aim of gather and evaluates the qualitative and quantitative data on water scenario including the condition of surface and sub-surface water sources. The report includes social and financial condition of inhabitants of the project location under SDWP which is supported by the SDWP team funded by Indienhilfe e.V. herrsching. The evaluation and description in this document comprise of all Drinking Water-Related Needs, Problems, and areas of Concern of the community. The report may be used for further implementation of distribution network of water supply under Safe Drinking Water Project.

During needs assessment survey, 148 among 152 households were interviewed with prepared questionnaires (given in figure 6). The information of water scenario and status of health, hygiene, economy was collected and interpreted. As per analyzed information, major inhabitants are associated with daily labour and agriculturally based works. 74% households are belonging to low-income group and earn less than 7000 per month. Most of households have their own tube well but due to bad quality, water is not uses for drinking and cooking purposes. The inhabitants rely on community tube well for which family head have to travel for more than 5 minutes for collecting drinking and cooking water. The inhabitants are also suffering in monsoon as the area get waterlogged for 3-4 months. A perennial river called Padma is situated near the location which is affected with brackish water during summer time due to high tidal effect. Majority have own toilet system but no proper/poor hygiene facility is observed. Latrines are majorly situated at unsafe distance from tube well which is susceptible to bacterial contamination in Groundwater. No proper drainage facility is observed in the project area where inhabitants are used to build small pit/doba near tube well to store and infiltrate the wastewater into the ground. The incidence of water-related diseases is approximately bimonthly and peaks during rainy season. Average 26 days are lost for this illness and 2% of monthly income are spend for medicine. Information of on-going safe drinking water project was shared during the interviews and respondents are happy and willing to support the project. Inhabitants are interested to participate in awareness events and Water User Group meeting for collecting more information on treatment technology and water supply. The daily combined drinking and cooking water requirement is 8 LPCD which is sufficient for providing safe water to all inhabitants under project area as per daily capacity of water treatment plant. All inhabitants are willing to collect water from standpost & treatment plant and interested to get household connection. Lack of knowledge of Arsenic pollution, safe water usage and practices, water quality standards and organic and eco-friendly practices is observed on which SDWP team can build capacity of the community in future awareness and knowledge dissemination events.

Figure 5: Interview with community member.

3.1 Selected Target group for water supply

Target beneficiary community is a poor community in Chatra in West Bengal's North 24-Parganas district. The neighborhood is home to a minority community and has a population count of approximately 650 individuals. Depending upon baseline survey, the treatment plant has been designed for supplying 10KLD safe drinking water and riverside private area has been selected for construction of this treatment unit. Other target stakeholders for setting up a community-based water supply in the framework of an international cooperation project are local authorities, like the panchayat and its staff, local companies contracted to do construction activities and local NGOs which interact with the beneficiaries and facilitate local organization processes.

Figure 6: GIS Map of project area with pond Location at Parupara, Rasui.

3.2 Selected Target group for water supply during implementation

During implementation of drinking water supply in Rasui Paruipara, cluster of minority and socially backward communities have been identified which suffer from unavailability of safe drinking water. The targeted beneficiaries were considered from four communities: Paruipara, Halderpara, Daspara and Mollapara. Paruipara is considered as a most vulnerable community among these and mostly suffering from drinking water-related problems. The study was conducted among 152 households located in the above-mentioned area situated under Baduria Block of North 24 Parganas and survey was conducted in January, 2022. The above-mentioned areas are geographically low land regions surrounded by river Padma & Yamuna.

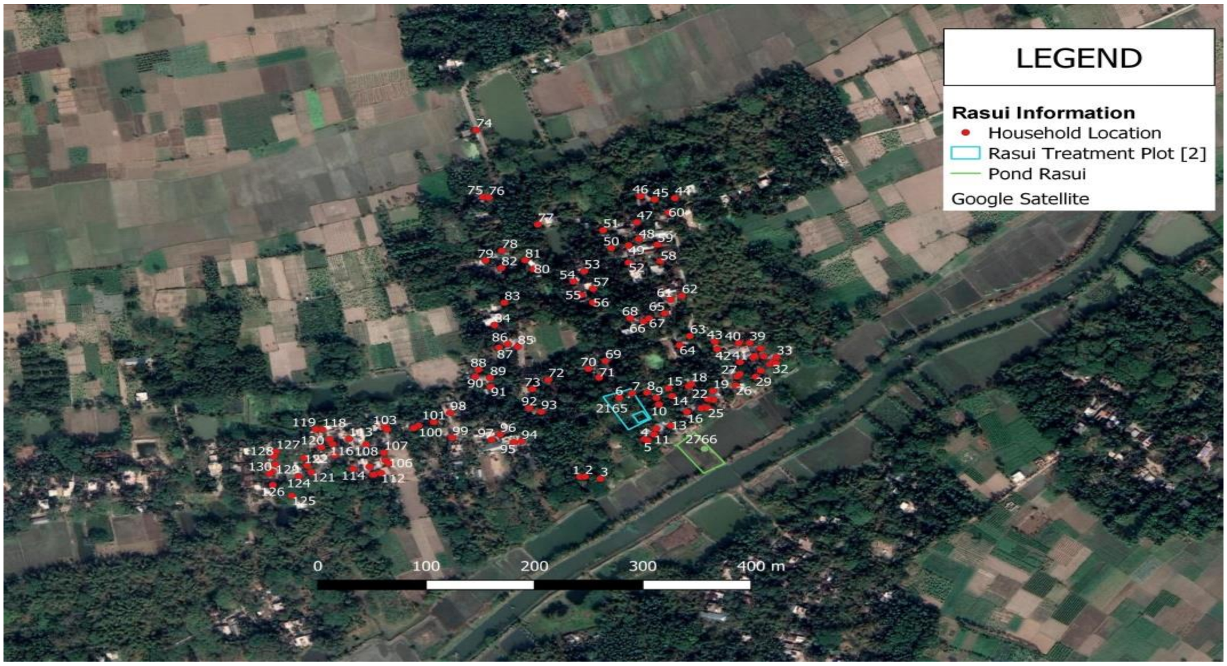


Figure 7: GIS map of community household Rasui.

3.3 Results (Need assessments)

The study area consists of 152 households and an estimated 610 inhabitants. One-hundred forty-eight households were surveyed and interviewed. The most prevalent house-hold size in the study area is 4 individuals and the mean household size is 5 (Figure 4).49% of the inhabitants are females and 51% are males. All respondents stated to have always lived within the community.

Majority of respondents are belonging to SC (Schedule Caste) community (54%), followed by General Category (31%) and OBC (Other Backward Class) (25%).

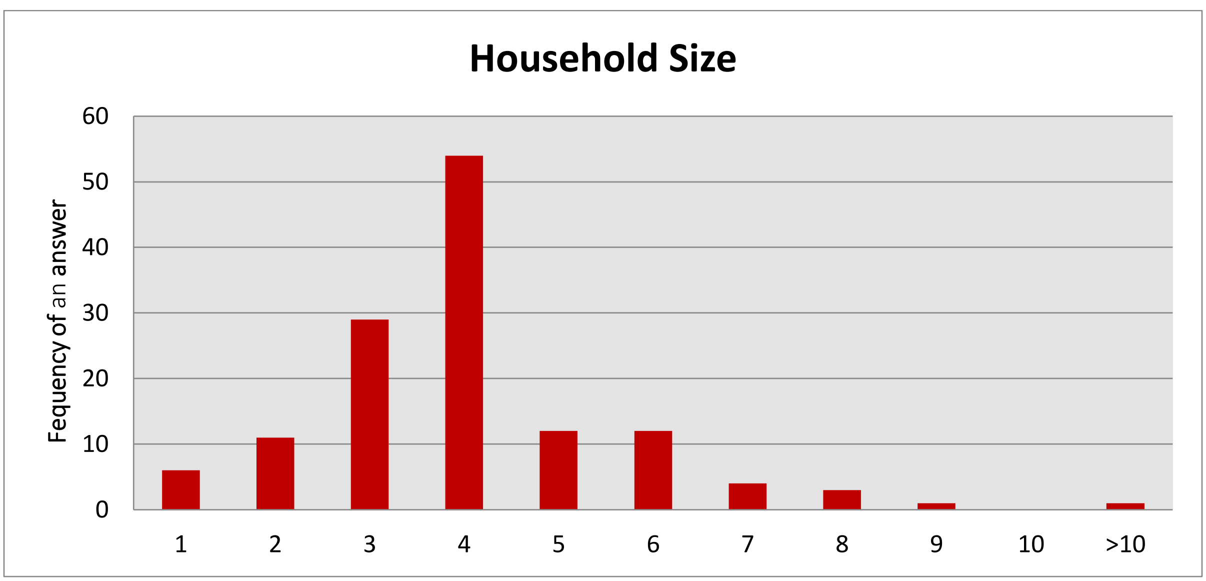


Figure 8: The size of households within the village.

3.3.1 Community Assets:

3.3.1.1 Social capital

Since agriculture is the most important economic sector in the area, 35% of participants are working as daily worker and 28% of inhabitants are involved with farming. Besides from the agricultural works, Daily labours also include bricklayers, material carrying and other physical labourers. Very few inhabitants are associated with building works like mason (3%) and metal & carpentry works (1%). 10% households are associated with small business like sell vegetables & fruits, work at grocery shop, salon and stitching. Due to COVID responses, 3% respondents remain unemployed in this community.

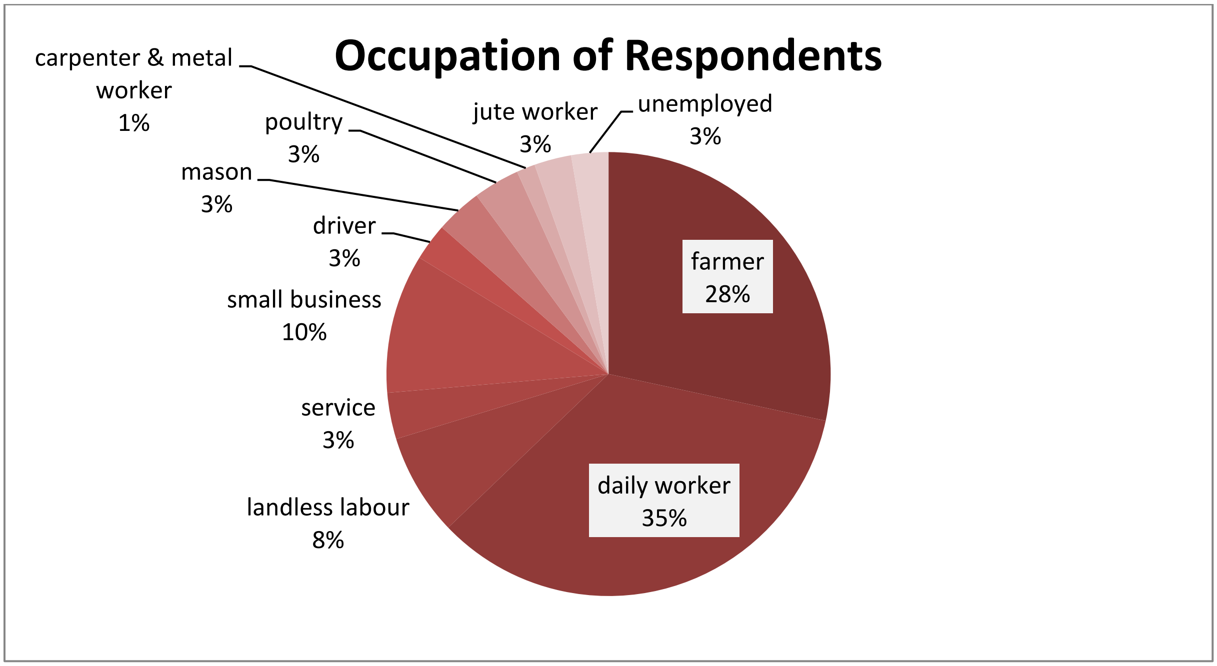
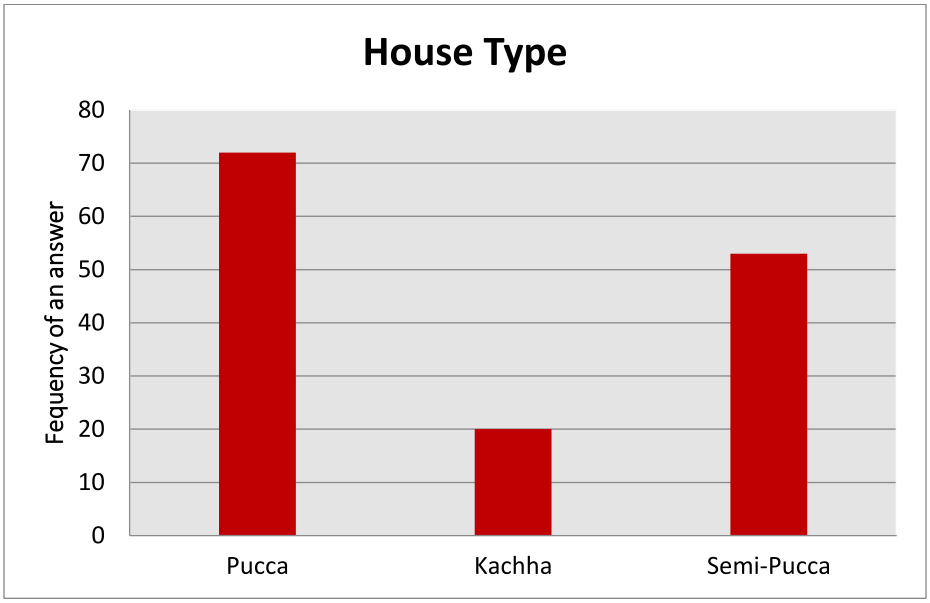


Figure 9: The type of occupation which respondents stated

3.3.1.2 House Type

As per observations, 50% respondent's houses are made by concrete and brick (Pucca). In remaining parts, 36% houses are semi-pucca (roof with tiles or tins and brickwalls) and 14% houses are kaccha.



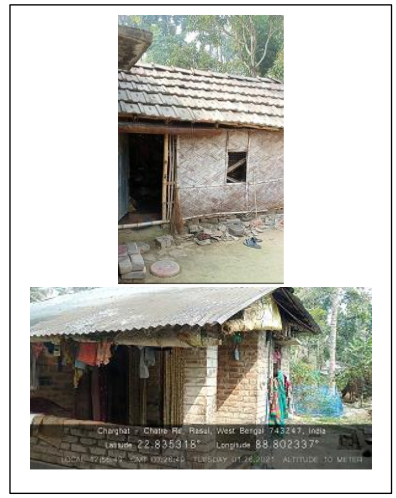


Figure 10: House type of Respondents

3.3.1.3 Financial and built capital

The mean monthly income of the respondents is 6100(SD=5211, figure 7). Overall, the income is highly dispersed, which is attributable to the respondents' occupation. Few respondents (9%) claimed to earn 10,000 INR/month or more while some of them (4%) earn 2,000 INR/month or less.

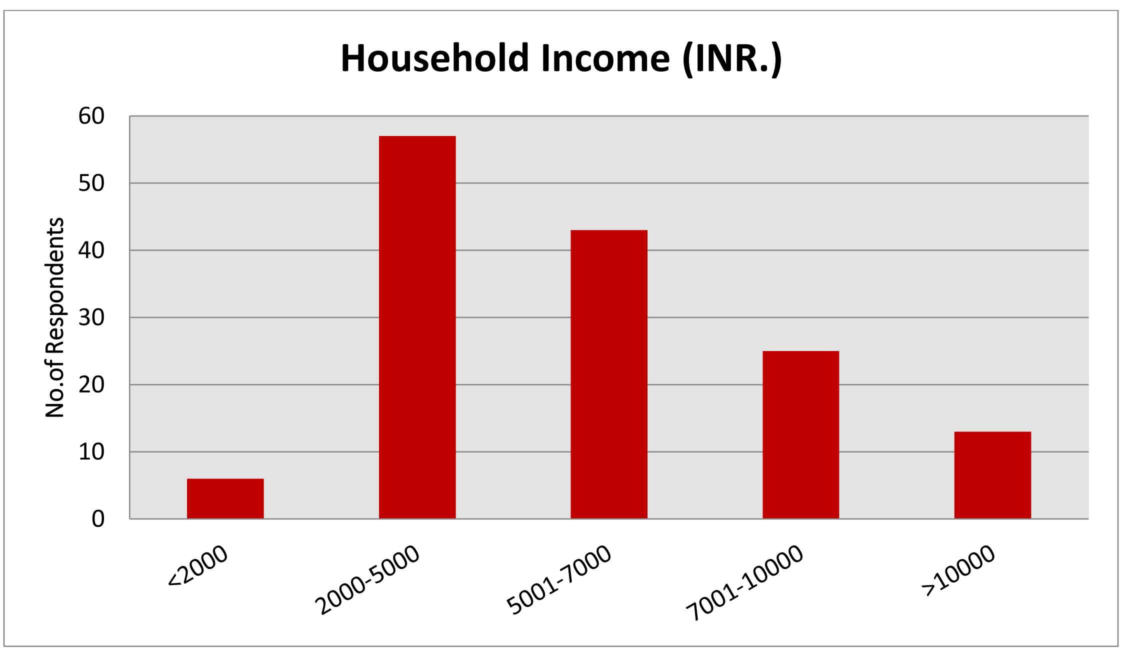


Figure 11: The income of the respondents

3.3.2 Water Scenario of the study area

3.3.2.1 Status of River Water

Surface waters are abundant in West Bengal which becomes visitble through many ponds which exist within the community and its vicinity. A perennial River (Padma River) is situated at southern side of community which connects to Icchamati River.

During the rainy season vast parts of the land adjacent to the community specially paruipara are inundated. According to most of the respondent (77%), during the rainy season vast parts of the land adjacent to the community are flooded. Average height of water 1.25ft (SD=1.17ft) (Fig. 9) above the ground level during flooding. So, it concludes that a high amount of surface water exists in this area and people have to live in waterlogged condition during monsoon time. Accordingly, the utilization of surface water should be a viable option for drinking water supply if within year variations are addressed through storage management. Most respondents don't experience a limitation in how much water they can withdrawal from their tube well but the estimated values for different water uses was collected and analysed in the water survey.

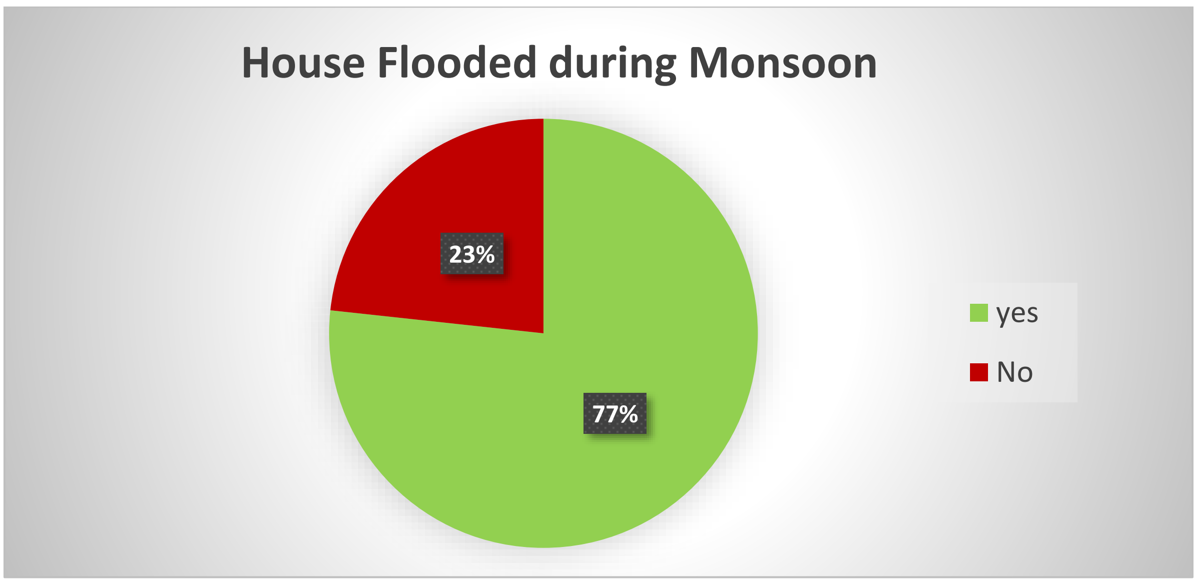


Figure 12: House Flooded during Monsoon

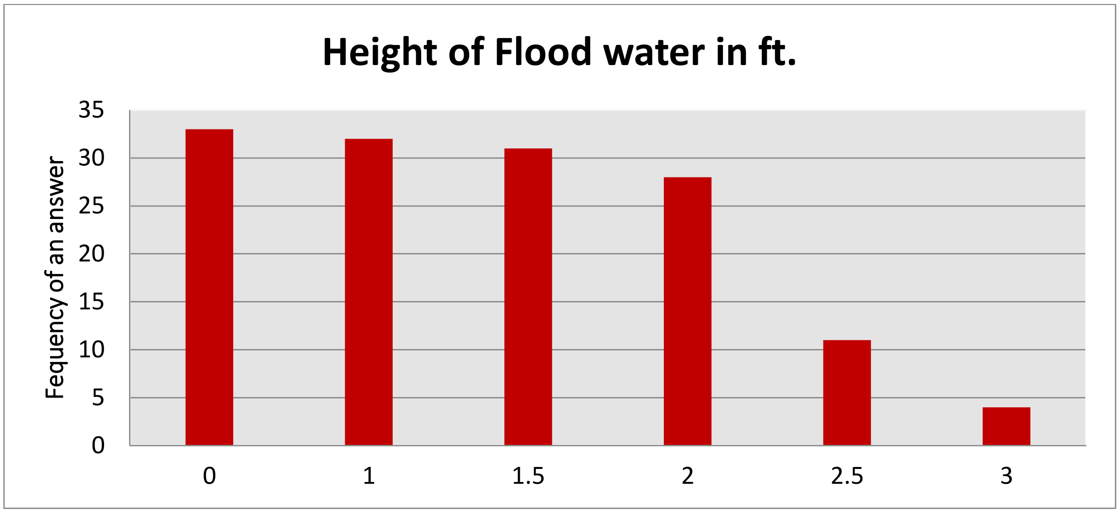


Figure 13: Height of water during flood

3.3.2.2 Status of Tube wells

Currently, the main source for drinking water is groundwater from private tube wells. As per physical verification by surveyors, 81% respondents have their own tube wells and remaining respondents are using the tube wells of neighbour for daily purposes. According to the respondents, the mean depth of their tube well is 18.5 meters (SD=16.5m, minimum=6m, maximum=61m) (Fig. 10) and most of the tube wells are flooded during rainy season so during this time drinking water is not hygienic.

The terrain is flat and for being in low land near river line, the water table of the tube wells is within 2m from Ground water during monsoon time.

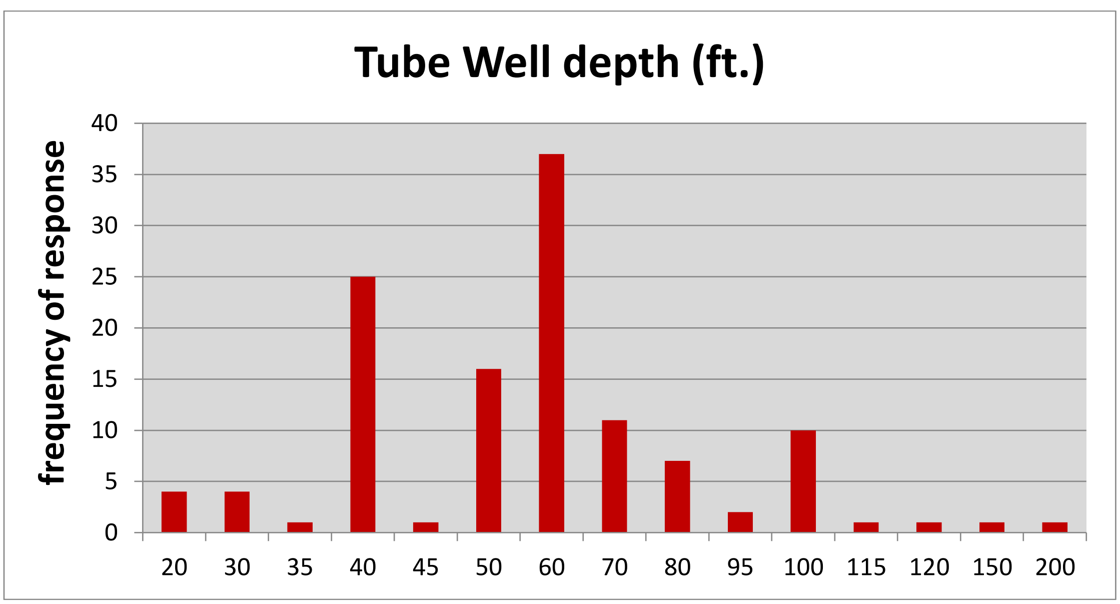


Figure 14: Depth of tube well water

3.3.3 Sanitation and hygiene scenario:

3.3.3.1 Sanitation facility assessment

Among the respondents 20% use toilet sharing with relatives, 71 % use Pit Latrine and 6% use Sanitary with Septic Tank and 3% have no toilet and used to open defecation. Among the respondents most of them (94%) don't have any water source near toilet and 6% have water facility near toilet.

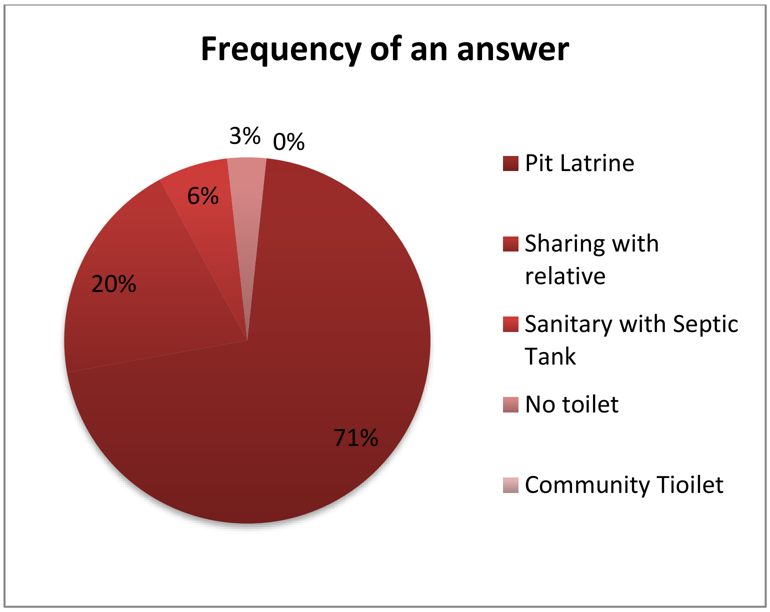


Figure 15: The respondents' sanitation facility

3.3.3.2 Household Drainage Type assessment:

Among the respondents' major portions (68%) have no household drainage system, 16% respondents have kachha drainage system, 8% respondents use pucca and semi-pucca drainage system respectively. 77% respondents said house flooded during monsoon. It is concluded that the area is flooded prone, figure 10. In the maximum household's small pit/doba was excavated to collect the wastewater from tube well and infiltrate into the soil strata.

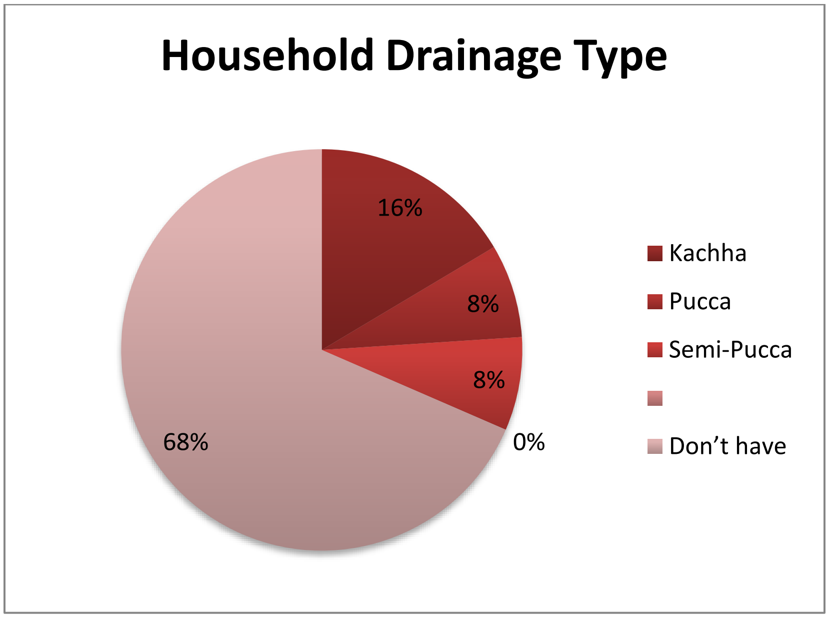


Figure 16: Household drainage type

3.3.3.3 Safe Distance to Tube well and Latrine

On average, the respondent's tube wells were located at three to ten meters (the most prevalent distance) distance from their shelter (SD=4.41; Figure 13). As per National regulations safe distance latrines Water, the the pit can be located at a minimum distance of 33 ft. from the water source if the distance between the bottom of the pit and ground water table is less than 2m during any part of the year. The results show that maximum households don't have safe latrine distance and which cause for contaminated groundwater.

During the survey it was noticed at many sites that due to lack of proper knowledge & awareness toilets or pit toilets are not being installed by maintaining the safe distance measurement between a water point. Furthermore, people/community are not aware about the facts that water borne diseases are caused by improper sanitation system

Respondents are usually transported in buckets and bottles, while other water uses (personal hygiene, laundry, bathing) is directly performed at the source.

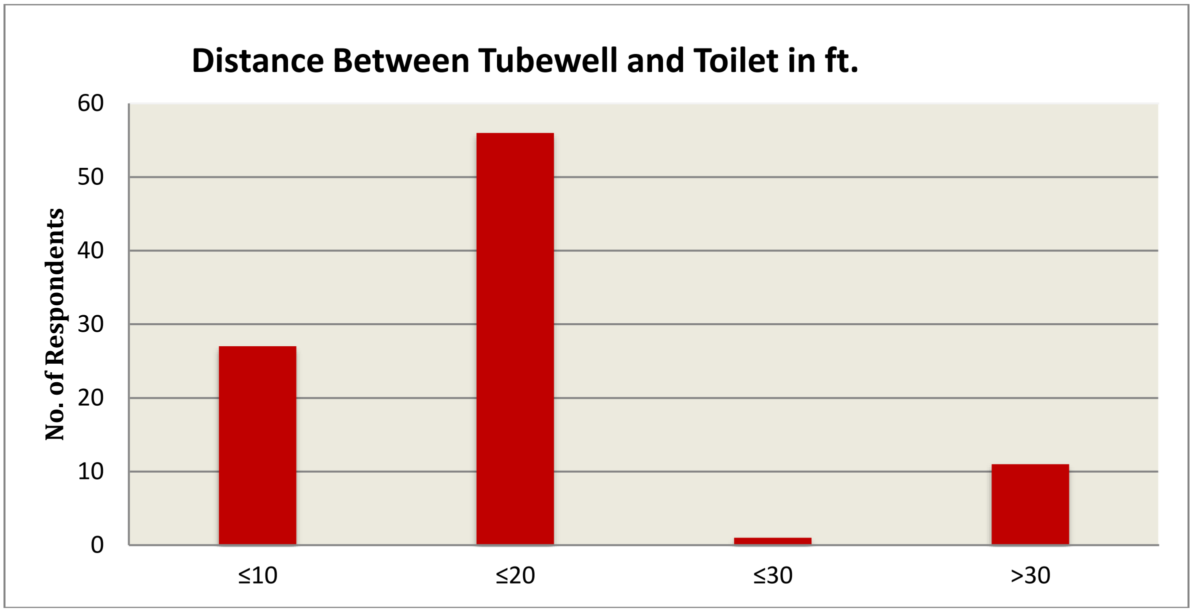


Figure 17: The distance between the respondents' toilet and their tube well

In case of every housholds, it is observed that Tubewell are not connected to the drainage system. In all cases, waste water from tubewells are stored in nearest pit/dhoba and infiltrated to ground.

3.3.4 Drinking Water-Related Needs, Problems and Areas of Concern

3.3.4.1 Groundwater Quality assessment:

Among the 148 households 145 households use tube well water. Among the respondents 62% said water quality of tube well is bad and 12% said that water quality is good. 26% respondents said not bad (Figure 14). 7.5% respondents have informed about the testing of water quality of their tubewell but results of condition of Water quality is still unknown. Only one respondent has information of water quality which show the arsenic contamination in own tube well.

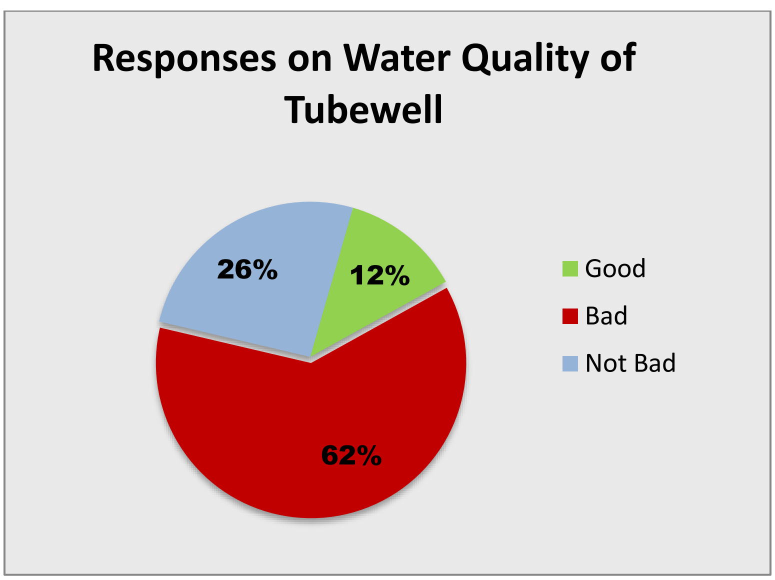


Figure 18: Tube well water quality

For the point of using tube wells, major respondents have to fetch drinking water from the community tube well at Halderpara which is far away from the community (700 m). Respondents are using contaminated tube wells for high distance for alternative sources.

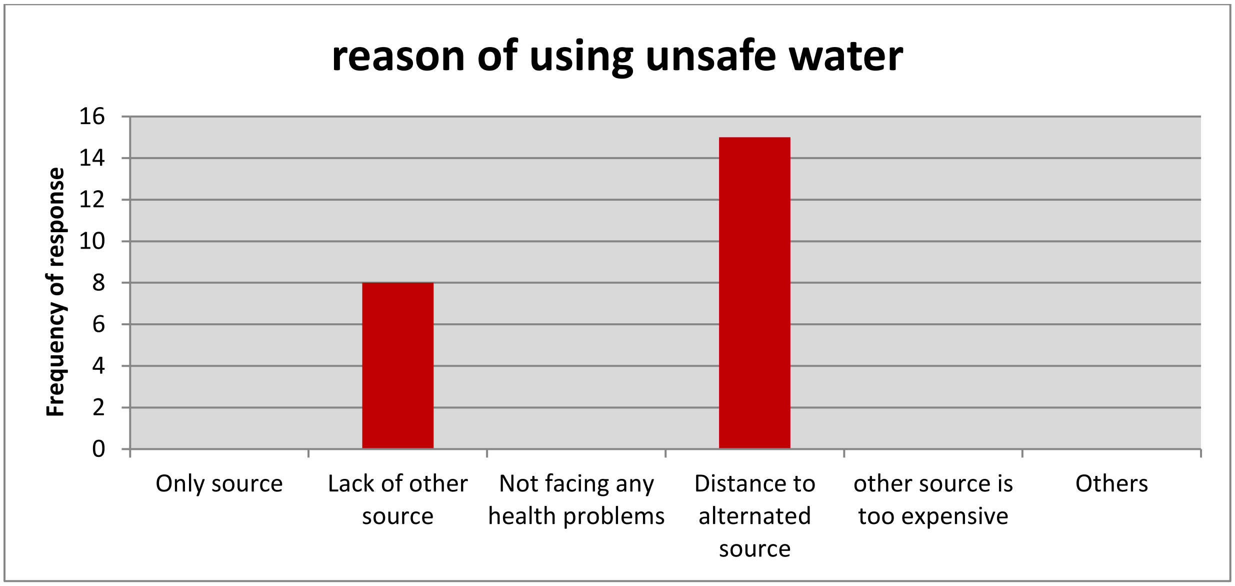


Figure 19: reason of using unsafe water.

3.3.4.2 Cause of the pollution of Ground water:

Water available for drinking purpose is polluted due to many reasons which includes. On the Groundwater quality, only 12% respondents consider the tube well water is unsafe for drinking. But most of respondents is carrying drinking and cooking water from another tube well. As per responses from the participants, Presence of Iron (43%), Repulsive Odour (28%), due to turbidity (14%), Presence of Pathogens (2.8%), Presence of Bacteria (5.7%), Leachate into tube well from stagnated water (2.86%) and Presence of Arsenic (2.86%) is responsible for pollution. Though unsafe then also reason of using that water because of Lack of other source according to 35% and 65% said alternate source is far away. 40% people don't hear about arsenic pollution and 60% know about this. Lack of information of Arsenic pollution and water quality in Groundwater is observed during the survey.

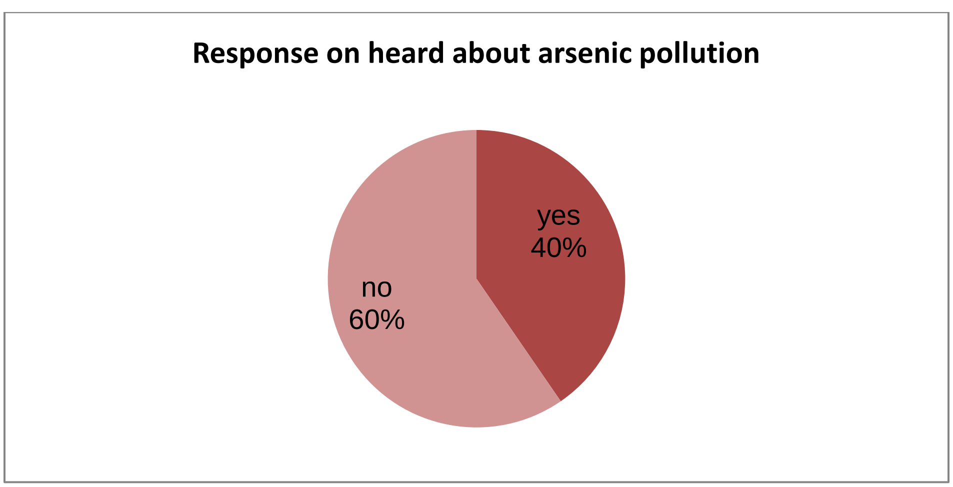


Figure 20: response on arsenic pollution

3.3.4.3 Quality assessment of river water:

Among the respondents 79% said that river is saline and most of the salinity comes during April-May (Figure 17). According to 19% respondents, river is not saline and salinity less during May-June months. 2% respondents have no idea about the salinity (figure 18).

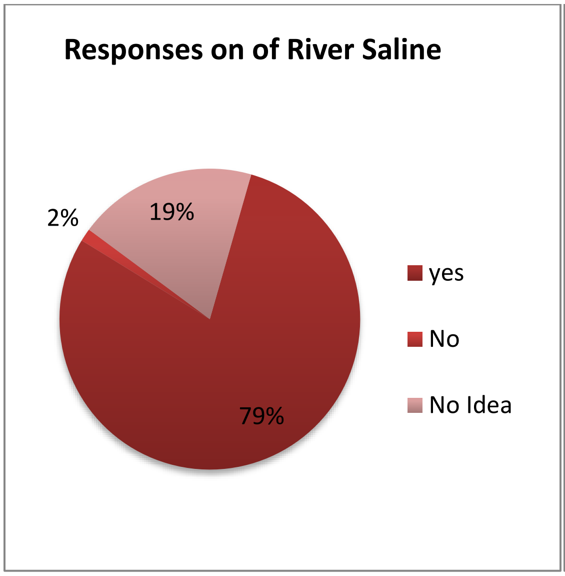


Figure 21: River salinity

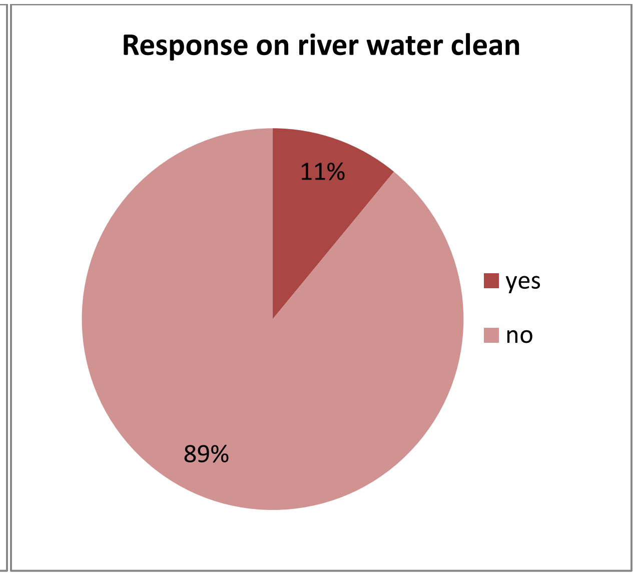


Figure 22: Cleanliness of river water

According to most (89%) of the respondent's river water is not clean and 11% said river water is clean (figure 17).

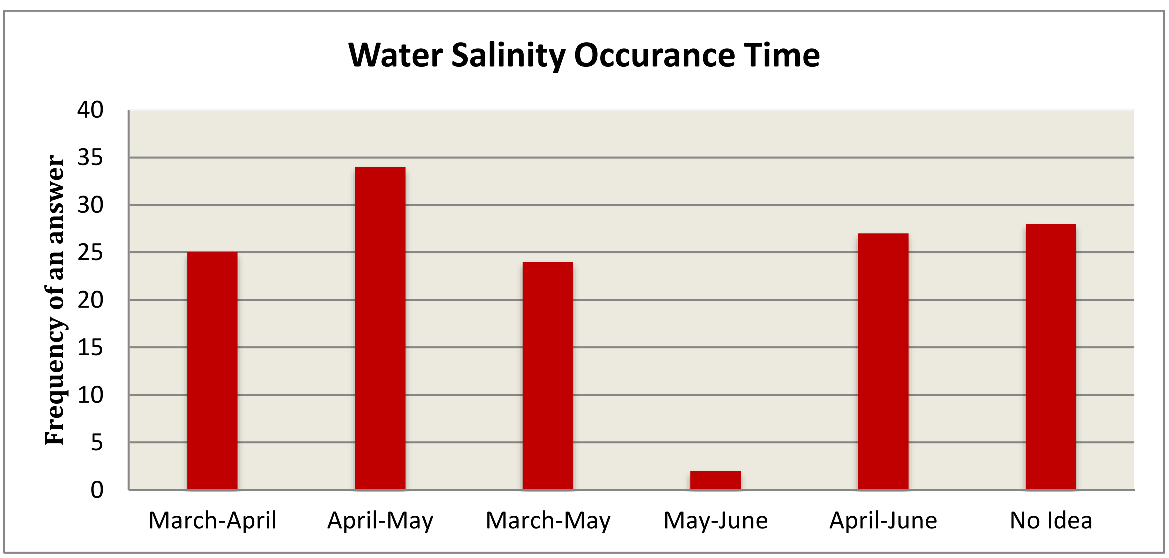


Figure 23: Water salinity occurrence time

According to respondents, River water is polluted due to presence of different parameters. Majority of the respondents shared the cause for river due to aquaculture (40.3%), jute rotting

(44.7%), Rotted Hyacinth (8.8%). It is noted that respondents are aware out degradation of River due to massive hatcheries and fish farming along with the river stretch.

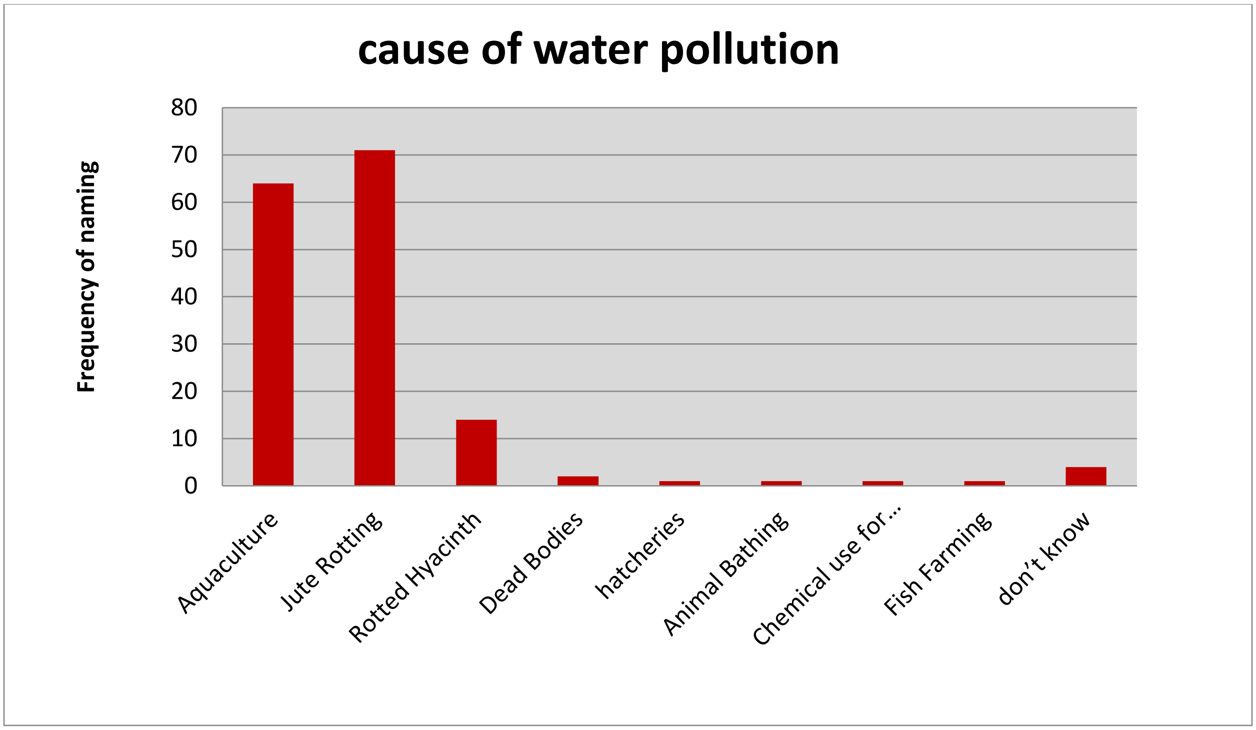


Figure 24: cause of water pollution

3.3.4.4 Water Scarcity problem:

According to 63% respondents are suffering from water scarcity during summer time (Fig. 21). 36% respondent said water scarcity stays 1 to 3 months (March to May) (Fig. 22).

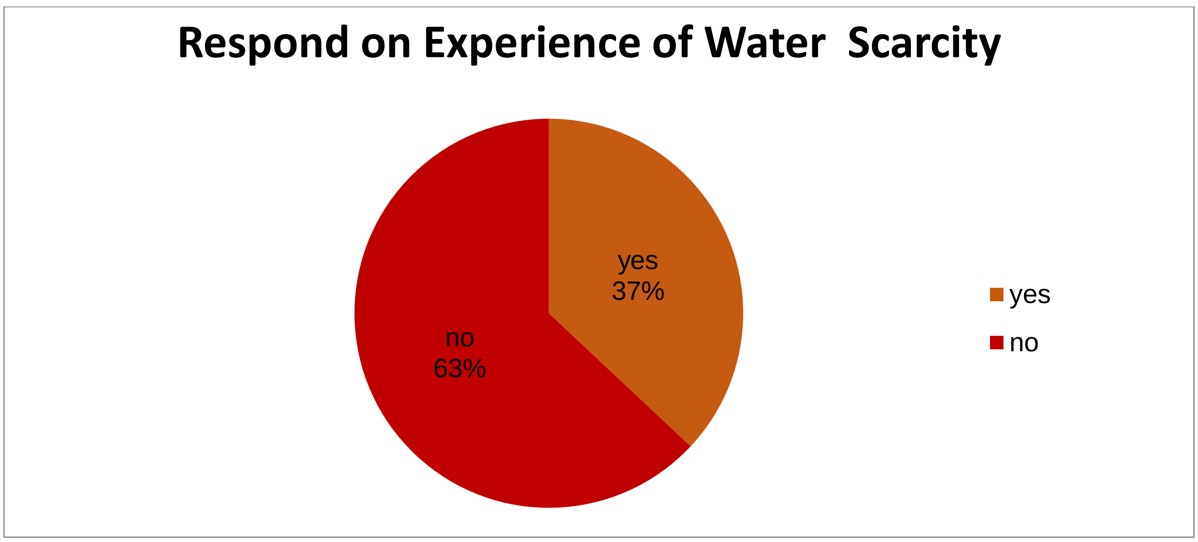


Figure 25: experience of water scarcity

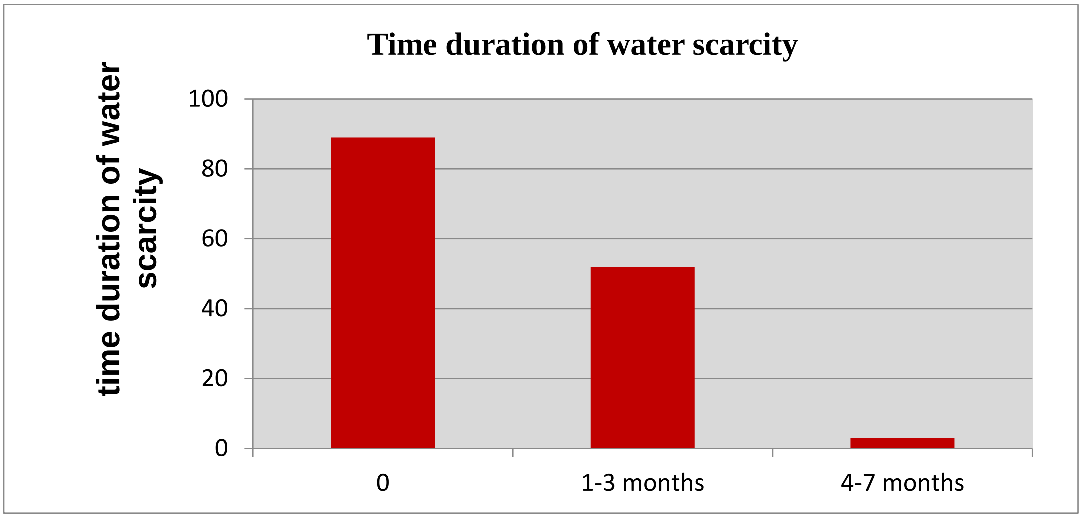


Figure 26: Time duration of water scarcity

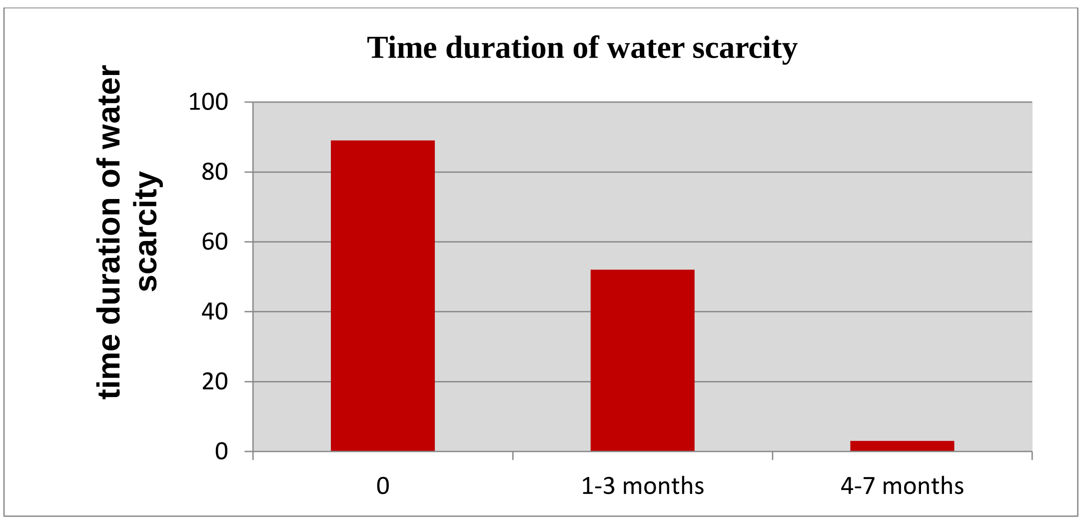


Figure 27: Time duration of water scarcity

3.3.5 Water Consumption for different purpose

3.3.5.1 Drinking and cooking water quantity

According to the respondents, the mean water consumption for combined Cooking and drinking purposes is 8 LPCD (SD=5.85, Figure 23), in which the requirement for drinking water is average 3.5 Liter and for cooking water is average 4.5 Liter for daily use for per person. The drinking water treatment has capacity of 10KLD per day which enable to provide sufficient clean water for the targeted population.

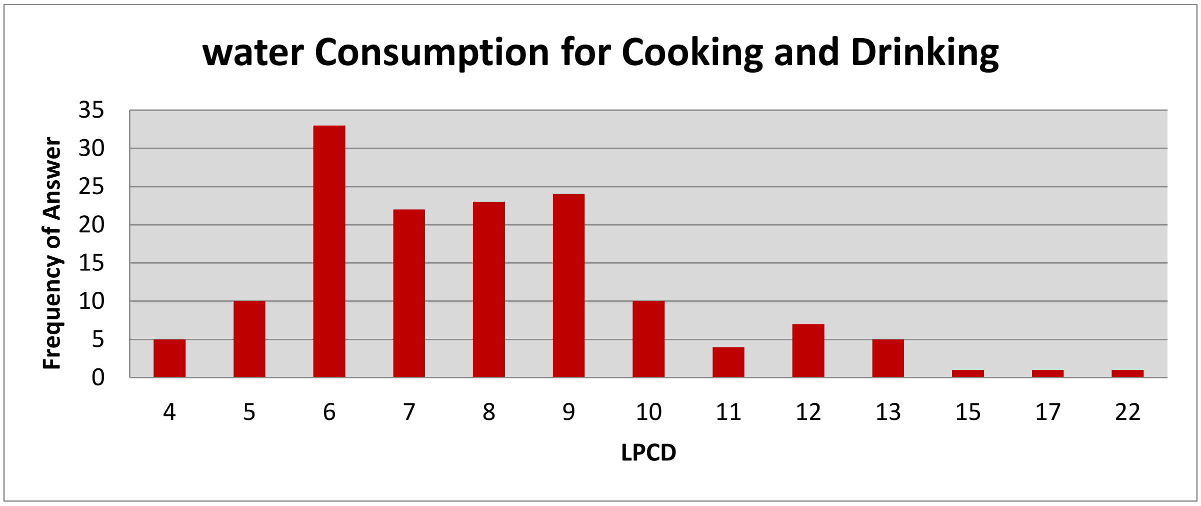


Figure 28: water Consumption for Cooking and Drinking

3.3.5.2 Quantity of water for other purposes

According to the respondent's water requirement for Washing and cleaning purpose 29 LPCD (SD=13.78, Figure 24). However, the obtained average may be an overestimation because of unaccounted uses of tubewell water. In some cases, two respondents use water from pond and river for cleaning and washing purposes due to easily available water sources. Among these respondents, 78 participants are using livestock (cow, goat, pig, and hen) for alternative livelihood. Water consumption for animal husbandry is about avg. 59 LPCD (SD=139.82, Figure 25).

In the project area, very few responses (8%) of water consumption are noted for gardening purposes and use water from tubewell average 58 LPCD (SD=82.81). For Irrigation purposes, 23 respondents have own shallow pump and extract groundwater during dry period. Water consumption of irrigation is average 2119 LPCD (SD=1639.79, Figure 26). The variation of average water consumption is observed due to different agricultural land types, crop patterns and land areas of each respondent.

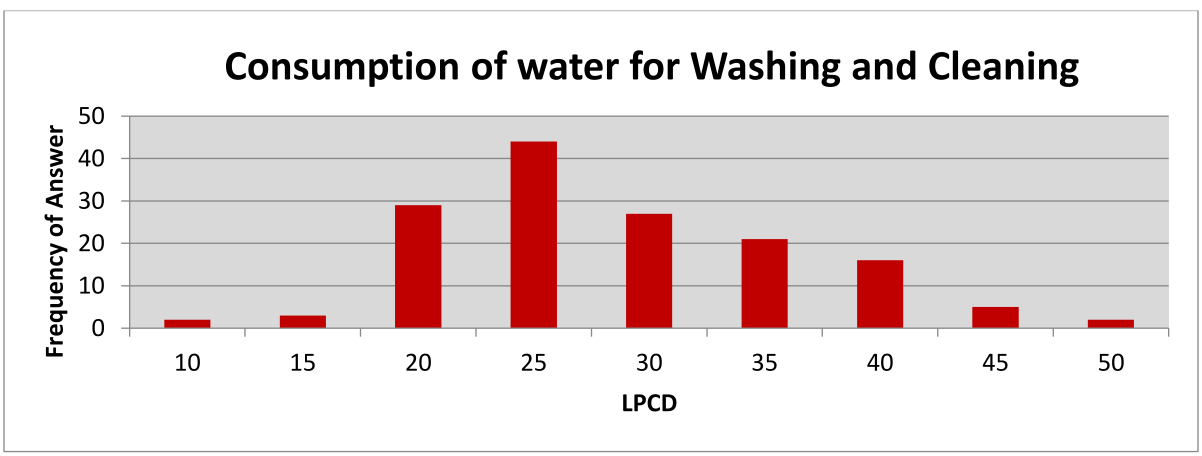


Figure 29: Consumption of water for Washing and Cleaning

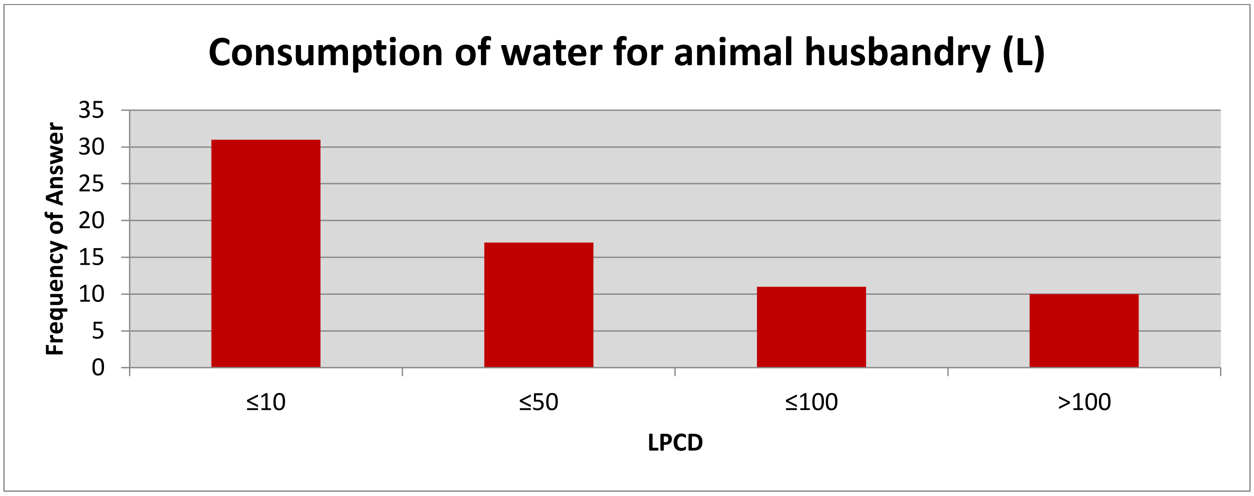


Figure 30: Consumption of water for animal husbandry

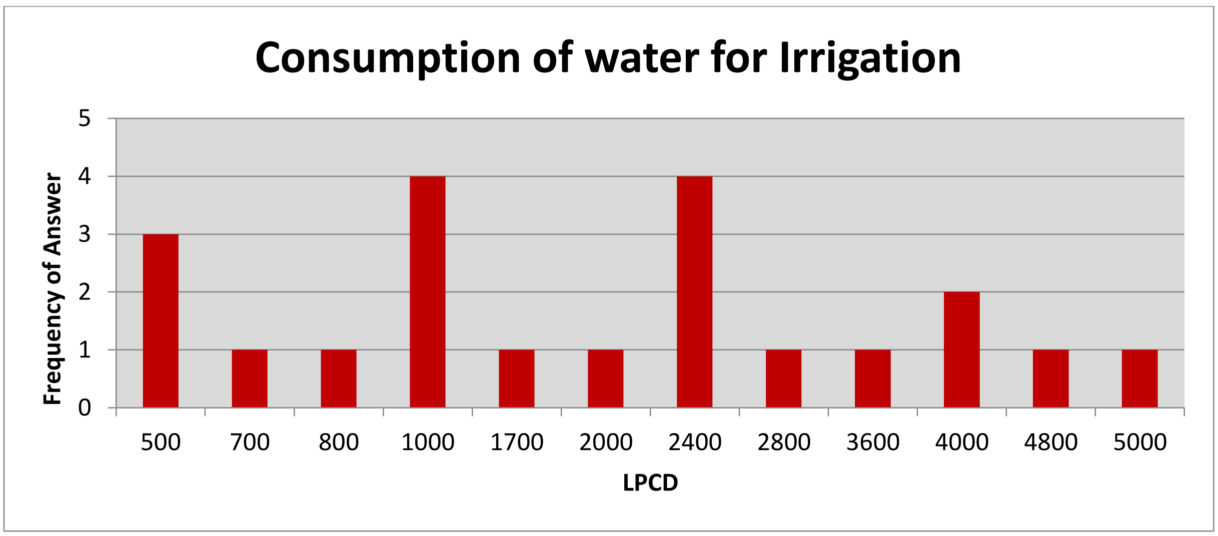


Figure 31: Consumption of water for Irrigation

3.3.6 Community health

As per survey, 87% respondents are suffering from waterborne diseases. The most prevalent diseases in the community are Gastritis (49%), Indigestion (28%), stomach problems (13%), skin disease (4%), Nausea (4%), Diarrhea (2%) (Figure 27). During survey, it has prevailed that respondent are not aware of water borne diseases and therefore surveyors have to explain the different types of waterborne diseases with detailing.

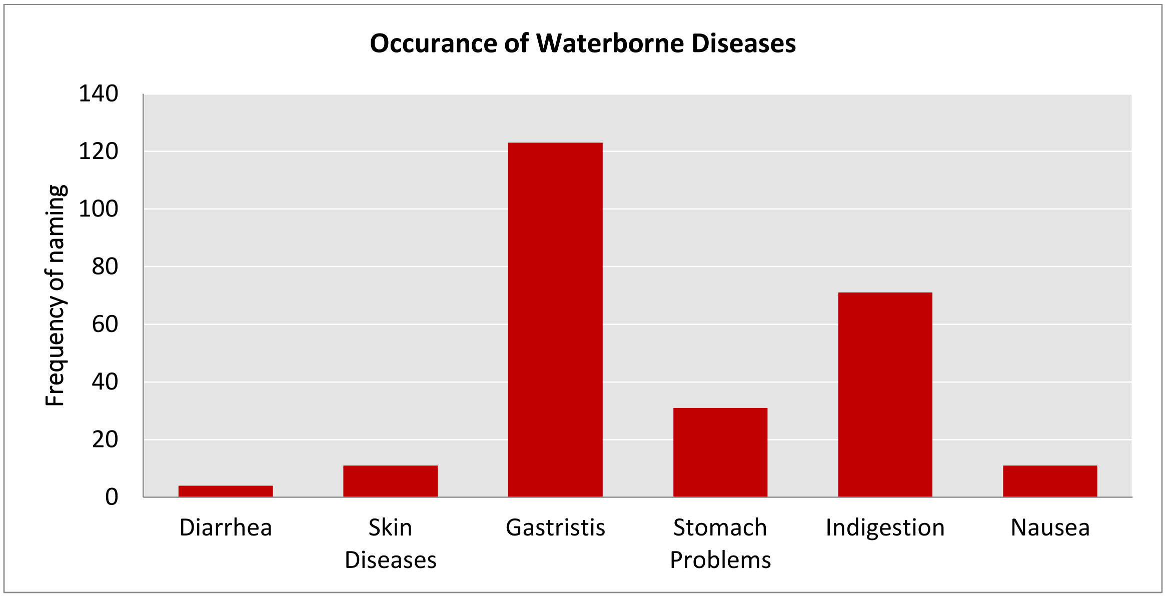


Figure 32: occurrence of waterborne disease

According to respondents, the incidence of water-related diseases is approximately bimonthly and peaks during rainy season. On average, respondents claimed to be sick 26 days per year (SD=16.76, Figure 26).

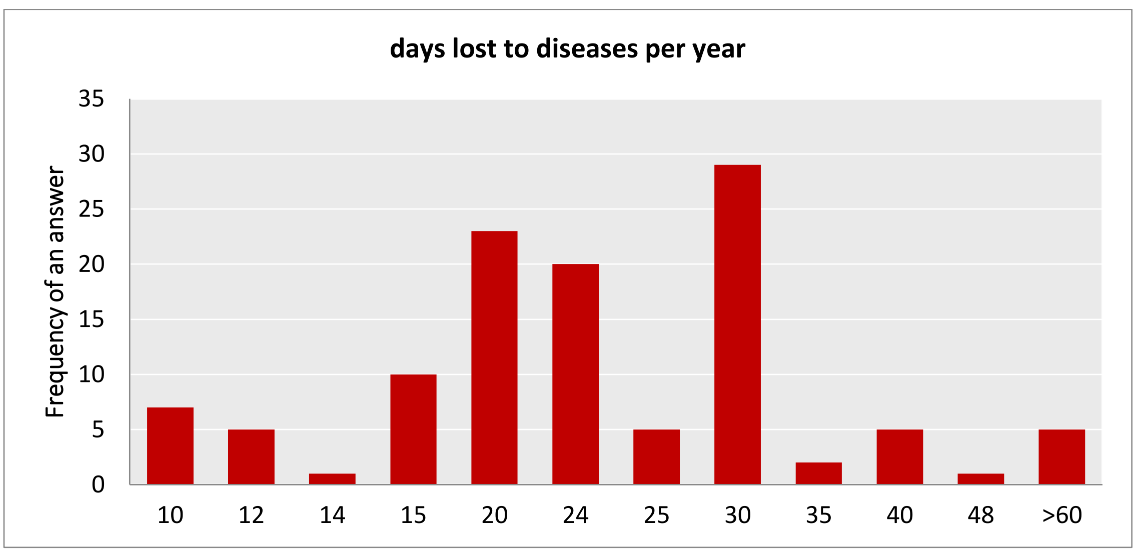


Figure 33: days lost per year for diseases

The mean yearly expenditure on medication is 1642 INR (SD=1208.3; Figure 29) which presents about 2.25% of the average monthly income. The respondents unanimously reported that water sanitation and health education have never been offered in the community.

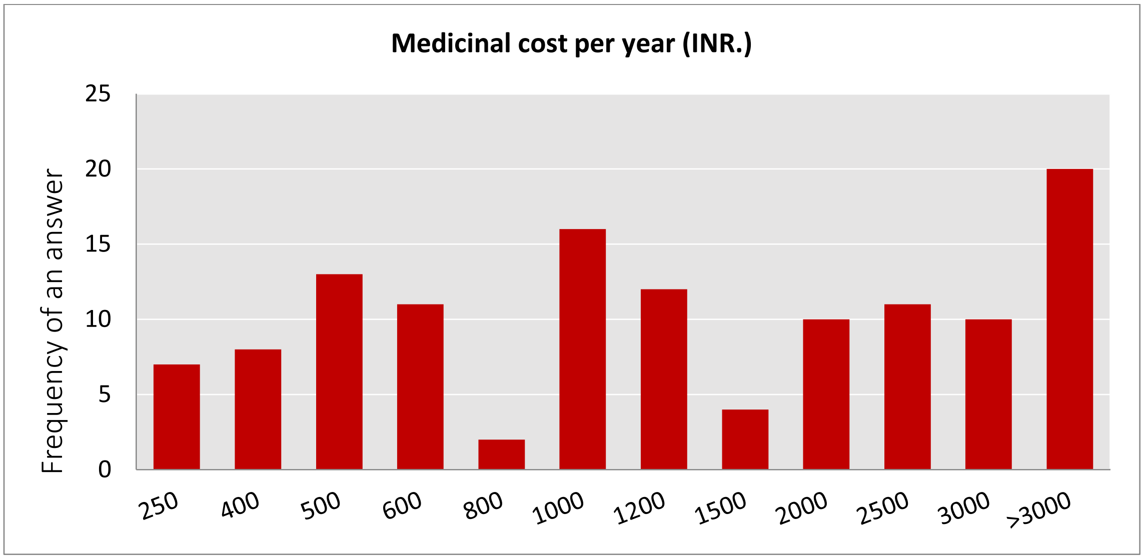


Figure 34: Medical expenses per year

3.3.7 Organic and Eco-friendly practices

Organic and Eco-friendly practices is essential for maintain the surface water quality as well environmental and ecological balance of project area. In the context of catchment area protection, eco-friendly practices reduce the contaminant level of water bodies which also reduce the change of biodiversity and ecological imbalance like rapid growth of algal bloom.

According to respondents 46.6% respondents only heard, 15.1% respondents know & heard, 14.4% said they know about this organic farming, heard and practice this organic farming and 24% have no idea about this organic farming given in figure 30.

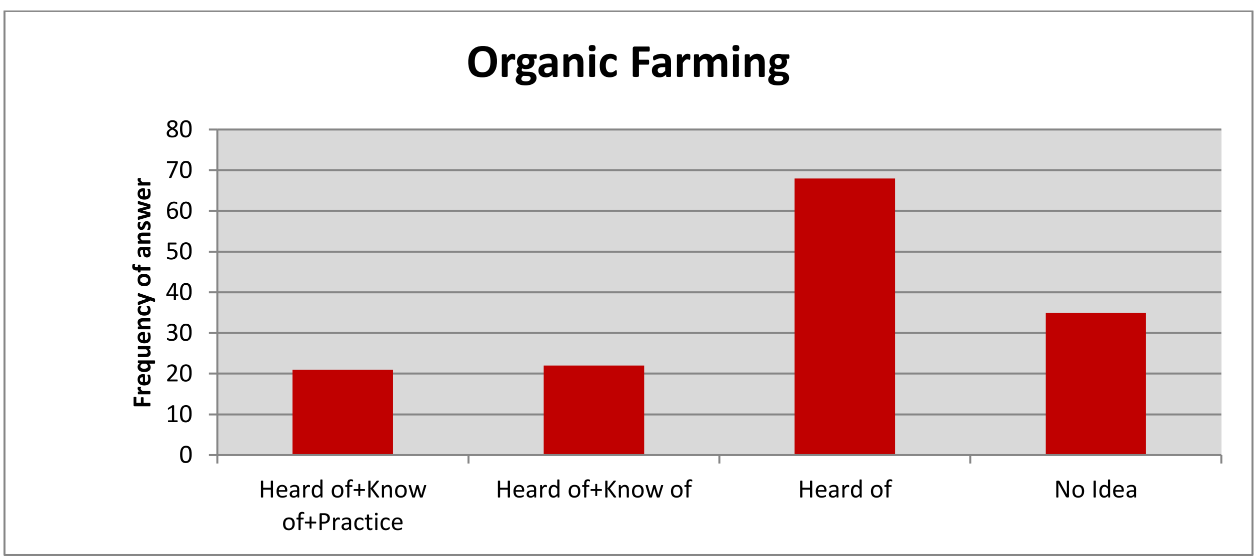


Figure 35: knowledge of organic farming

Organic aquaculture aims at the maintenance of the sustainability of the system by restricting the introduction of harmful substances that adversely alter the ecosystem. Organic aquaculture is a process of sustainable cultural practices based on long term ecologically and environmentally sound practices. These practices help in raising aquatic products in a humane manner that is sustainable and also pollution-free. According to the respondents, most of the people (82%) don't have any idea about the organic fish farming, 17% people heard about this and only 1% people heard and know about organic fish farming given in figure 31.

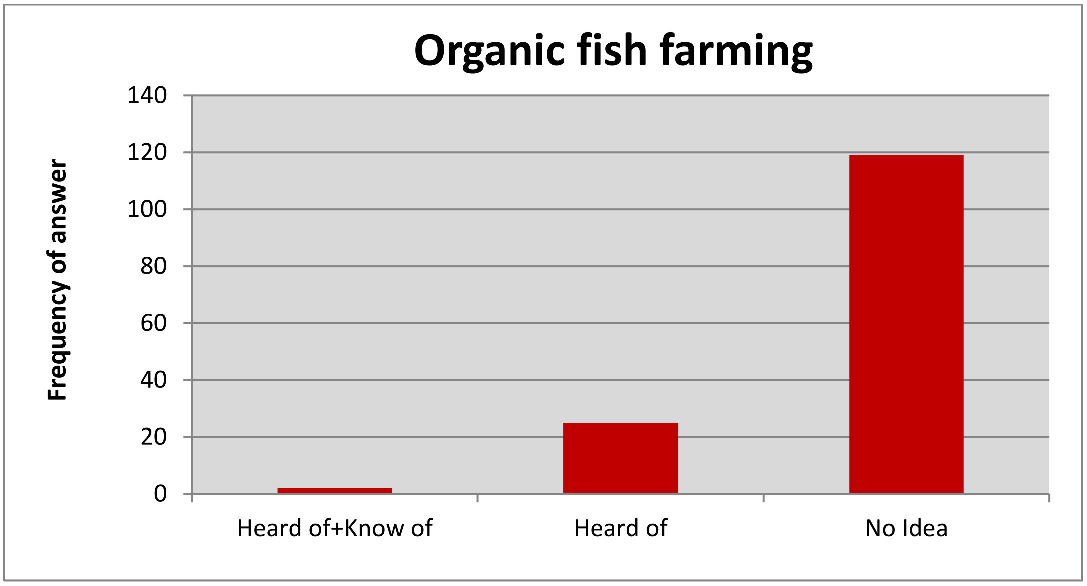


Figure 36: knowledge of organic fish farming

According to 57% respondents don't have any idea about non-toxic pesticide, 27% heard about non-toxic pesticides, 10% heard and know about this and only 5% heard, know and practice the use of non-toxic pesticides given in figure 32.

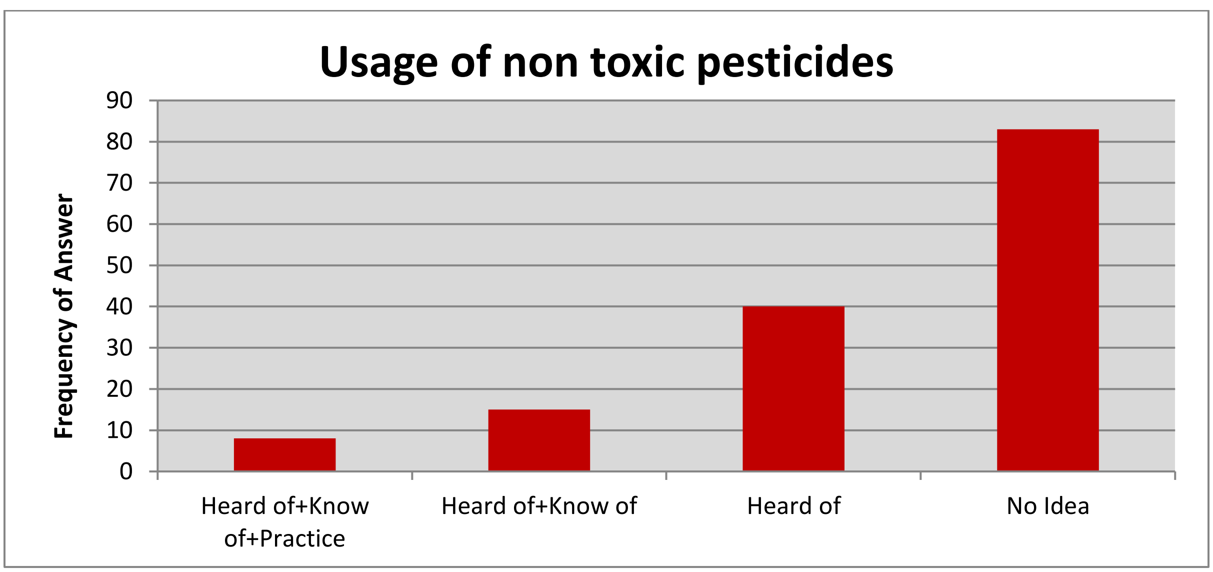


Figure 37: Usage of non-toxic pesticides

On the context of other information like knowledge of construction wetlands, wastewater treatment and sewerage networks, participants have no idea about these systems. For the sustainability of water treatment and catchment area protection, knowledge sharing and awareness programme on these topics will be helpful and effective in upcoming and future events.

3.3.8 Community Drinking Water Sources and Water Safety

Among the villagers' largest people have to fetch the drinking water from other community tube well and bad odor and quality most of them are not depended on own tube well. 97% carried respondents to carry drinking water by cycle or with any other means (Figure 33). Carrying of drinking water to the house is majorly conducted by Male head and Female head of the family (Figure 34). Among the respondents, 17% use to carry drinking water 2-3 times in a week, 72% used to carry water daily and 7% responds use to carry several times in a day (Figure 35). 18% villagers carried water from Halderpara TW, 3.5% carried from TW at Rasui Primary School, 1.4% carried from Chatra Bazar, 1.4% use Neighbour TW and 2.8% have own TW (Figure 36).

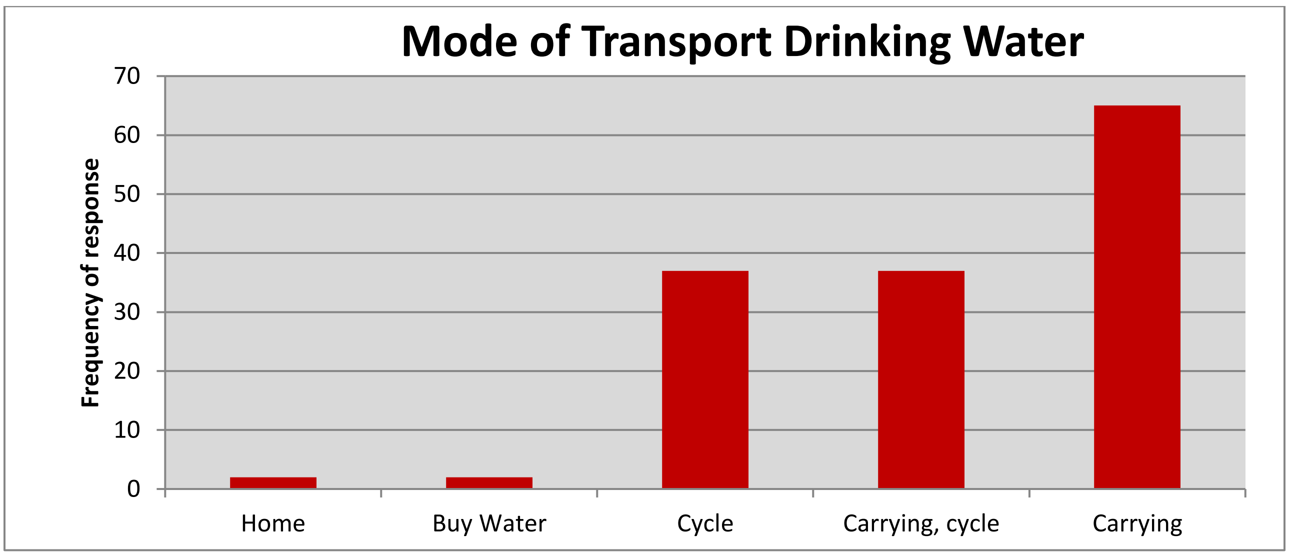


Figure 38: Mode of transportation of drinking water

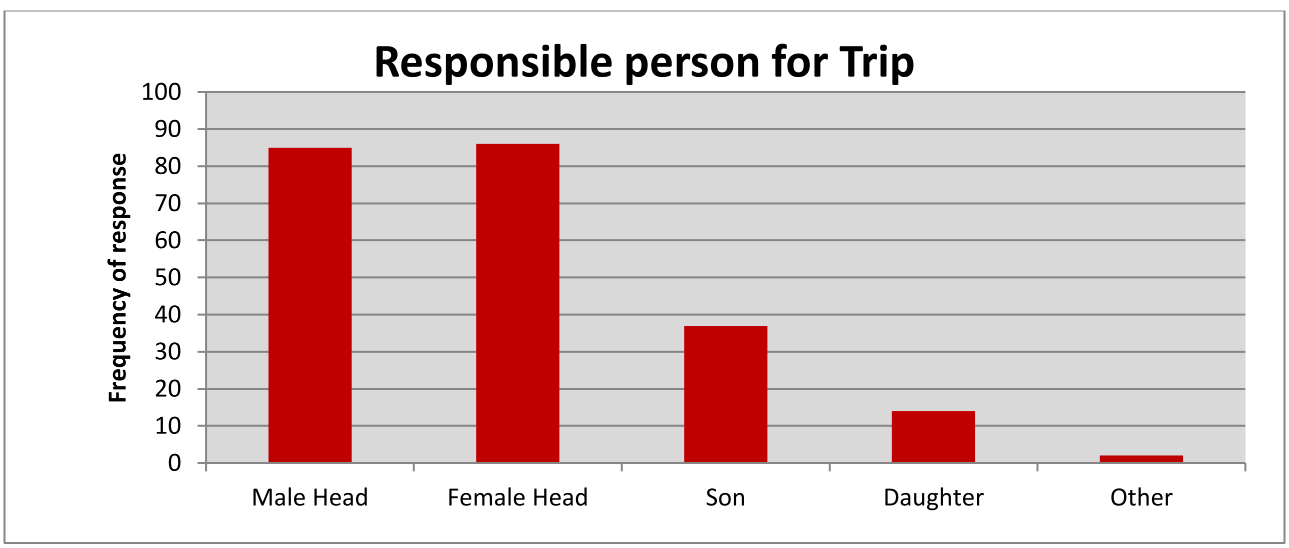


Figure 39: Responsible person for Trip

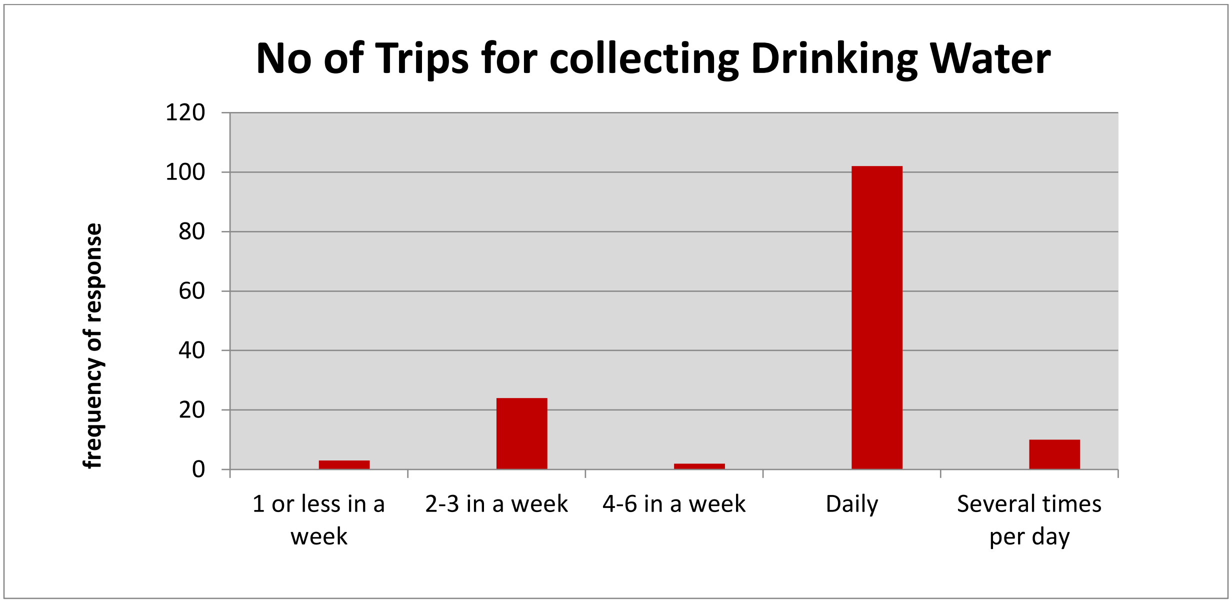


Figure 40: No of Trips for collecting Drinking water.

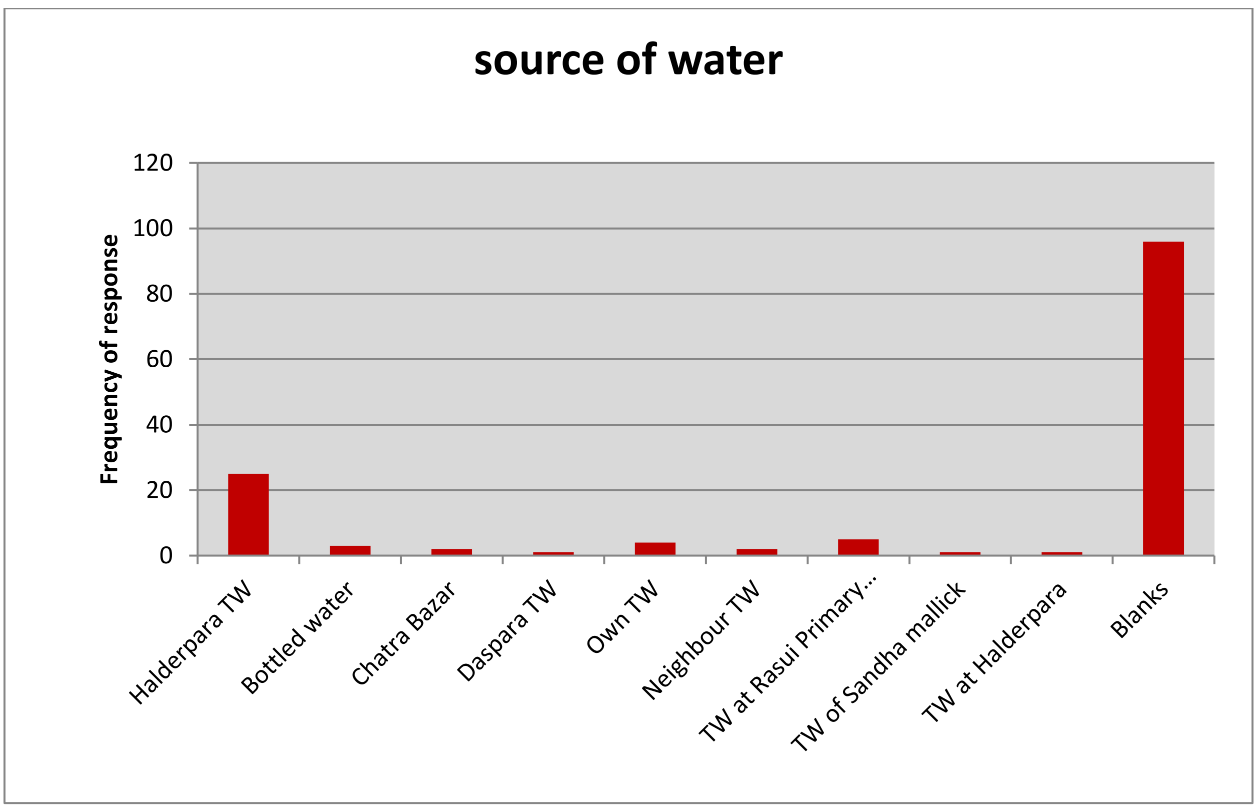


Figure 41: Source of drinking water

Villagers use different safety measure, 47% respondents said use Strain with cloth, 7% used to do boiling, 3% use filter and 44% respondents do not use any safety measures shown in Fig. 37.

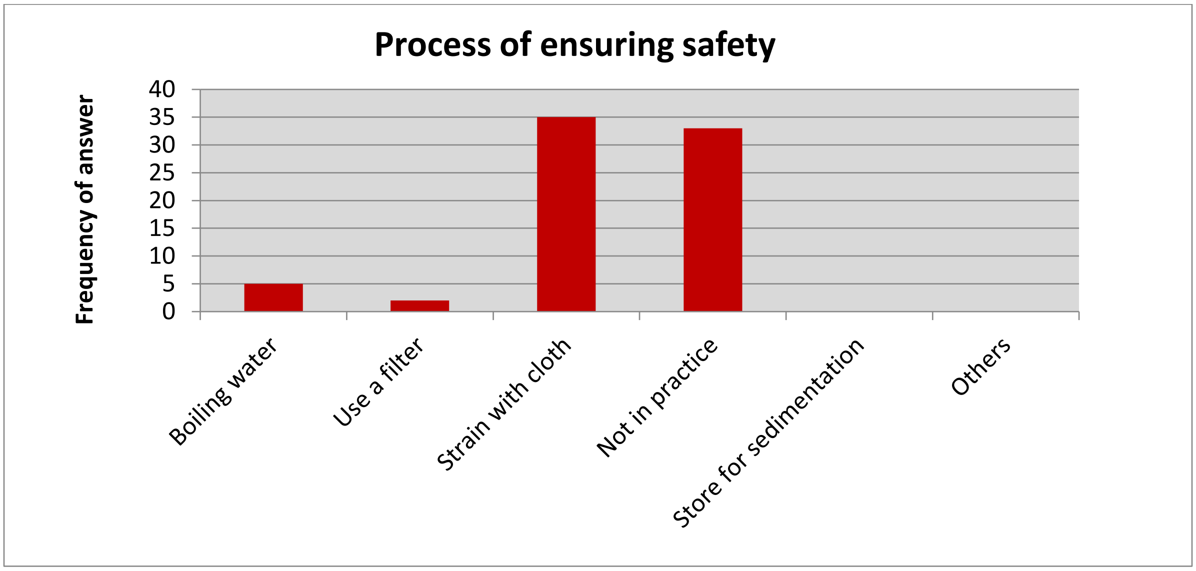


Figure 42: Process of ensuring safety

During Survey, it was identified that all respondents are aware of benefits of using safe water. Many benefits of using safe water were explained by the surveyors. Most of respondents are agreed that better health and longer life expectancy can be achieved with safe drinking water usage. (Fig. 35).

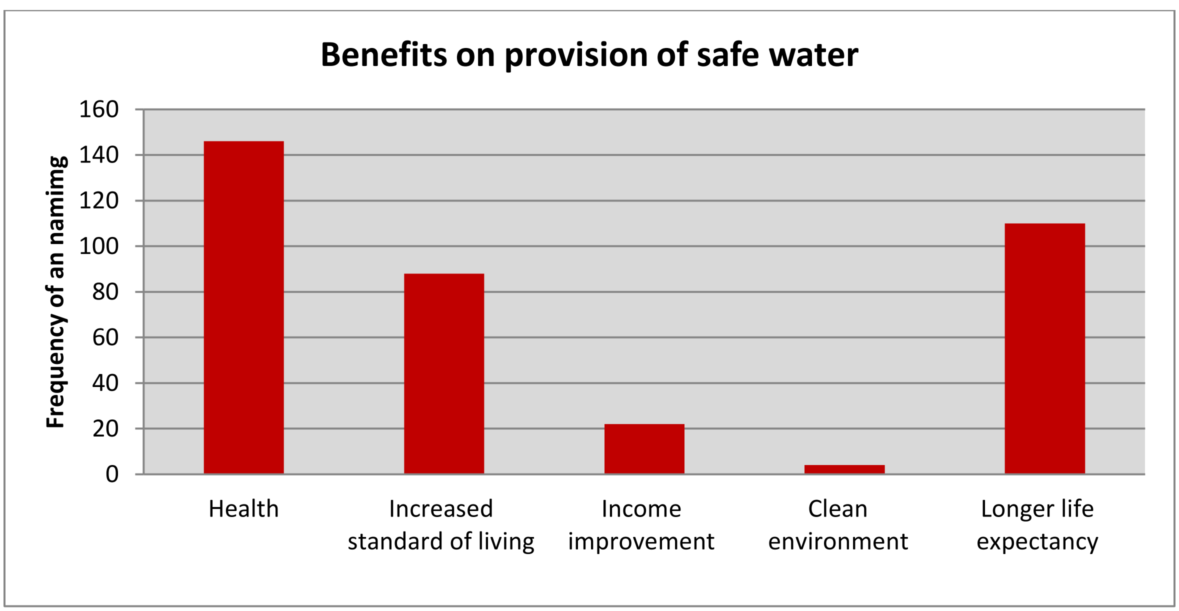


Figure 43: Benefits on provision of safe water

3.3.9 Information of Safe Drinking Water Project

During the needs assessment survey on water aspects, it was informed that construction of a surface water-based treatment plant under water supply is ongoing and team had explained about the components of each treatment units like, DyGF, HRF, SSF, ACF, Disinfection and its functionalities as per queries from the respondents.

On the point of using water from treatment plant, 146 household among 148 household show their willingness to use water from treatment plant and stand post (Fig. 39).

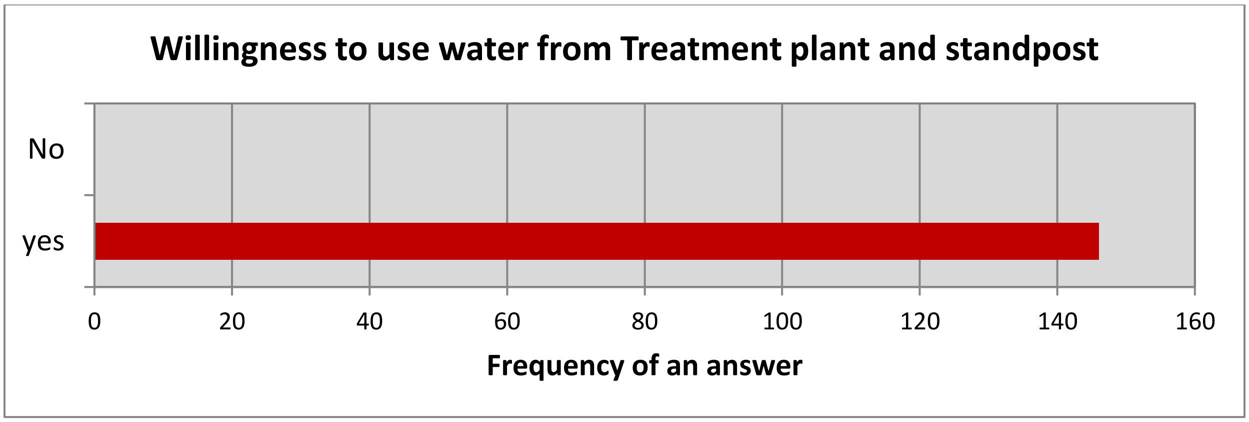


Figure 44: Willingness to use water from Treatment plant and stand post

Villagers are willing to support for implementation of drinking water plant. Among the respondents 26% said they will help by providing labor, 2% said will help by providing electrician, 68% will give advice, 1% will provide plumber and 3% will help with masonry (Fig.40)

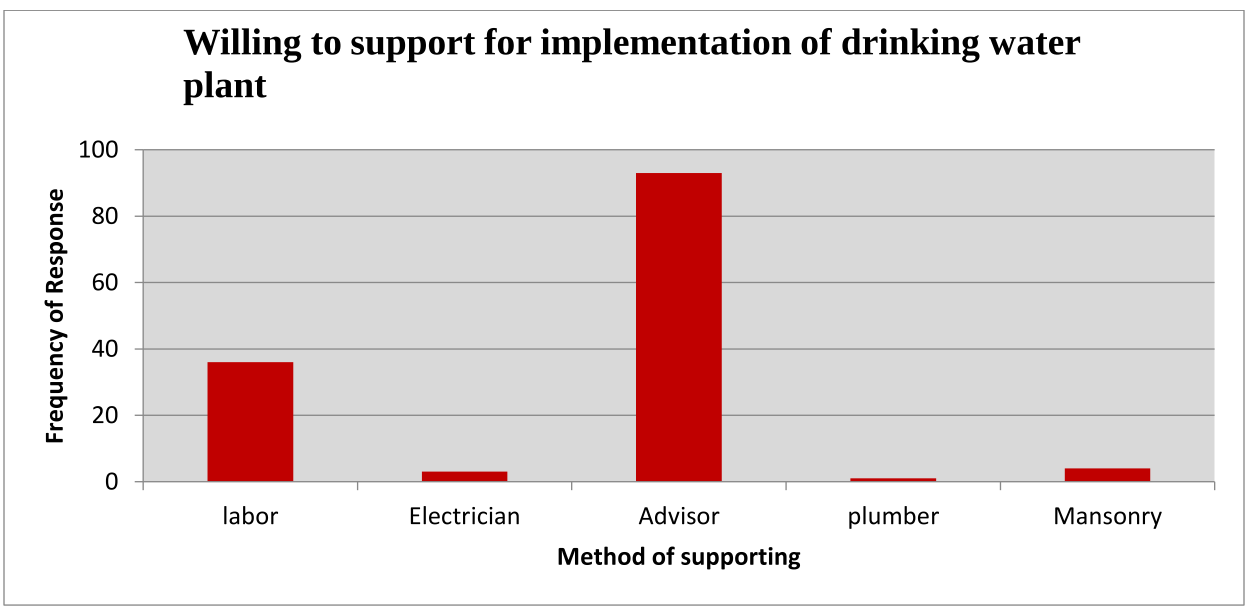


Figure 45: Method of supporting for drinking water plant

3.4.10 Additional Findings

- Sixty Percent of Respondents are not aware of the arsenic contamination of their community. Most of them are not using their tube wells for drinking purposes due to bad odour and high iron content.
- The age of tube wells within the community ranges from 1 to 40 years and does not serve as an indicator of a tube well's operational status. If the findings of arsenic contamination of drinking water in the area are to be confirmed, tube well users are likely to have been exposed for a long time
- Water supply infrastructure which was constructed by the government appears to be completely dysfunctional and has to depend on community tube well.
- Most respondents report that they want to improve their housing, and communication facility and educate their children
- During the survey it was observed that the majority of the poor households at Paruipara still do not have access to clean water to a toilet, nor do they practice hygienic behaviors due to a lack of awareness & poor socioeconomic status
- Although the majority of respondents (56%) know about the surface water supply system in Kolkata and North 24 pgs but have not been able to visit any plant and have not seen any surface water-based treatment plant in the local block and panchayat.
- Respondents are quite positive towards the implementation of treatment plant.

Chapter 4

4. Development of Theoretical Concepts on Water Treatment Technology

4.1 Reviews on the different the treatment unit:

4.1.1 Aeration: it is generally used for groundwater and removes undesirable gases. It can also remove volatile illiquid like phenols & humic acids. It removes iron and manganese & it also increases the acidity of water. There is a different process which is used for aeration are discussed below:

- **Spray nozzle:** very costly and high efficiency.
- **Cascade aerator:** in the aeration process, the cheapest method is the cascade method.
- **Diffused air aerator:** water absorbs oxygen from compressed air and colour, odour and taste are removed.
- **Trickling bed or tray tower aerator:** it is used in small-scale industries where discharge is less.

4.1.2 Sedimentation: it is used to removed suspended solids. It is two types:

- **Plain sedimentation:** discrete particles will remove here.
- **Sedimentation with coagulation:** coagulant is used to agglomerate the colloidal particle.

4.1.3 Flocculation: slow mixing or agitation process in which destabilized colloidal particles are brought into intimate contact.

4.1.4 Filtration: economically effective in controlling guinea worm disease.

The use of sand and gravel as filter media for water supplies can be split into three basic filter types: slow sand filters, rapid filters, and roughing filters.

- **Slow sand filter:** In this filter particle size varies between 0.2 to 0.3 mm. In case of high turbidity, it is not used. Bacteria removal efficiency is 98-99%. Its required a high initial cost and low maintenance cost. Its construction is simple.
- **Rapid sand filters:** These filters use coarser sand than slow sand filters and the effective size of the filter media is usually greater than 0.55 mm. The flow rates are normally between 4 and 21 m/h. These filters do not remove disease-causing entities as efficiently as slow sand filters and usually need a post-filtration chlorination process. Flocculation and coagulation are sometimes used as pre-treatments. Bacteria removal efficiency is 80-90%.
- **Roughing sand filter:** These filters are used to remove suspended solids by passing the water through material that is much coarser than that used in slow sand filtration or rapid sand filters. The filter material is usually graded so that the water passes through coarse (25mm), medium, and then fine (5 mm) sand. Flow rates are often in the region of 0.3 – 0.6 m/h (i.e 300 – 600 l/h) per m2 of filter surface area.

Table 2: comparison of slow sand filters and rapid sand filters.

	Rapid Sand Filtration	Slow Sand Filtration
Improvement of water quality	With pre-treated water, filtrate quality is possible that has 1 NTU turbidity, 90% removal of coliforms, 50-90 %removal of cryptosporidium and Giardia cysts, 10 % removal of colour,5 % removal of total organic content.	With raw water, a filtrate quality is possible that has less than 1 NTU turbidity, 95 % removal of coliforms,99 % removal of cryptosporidium and Giardia cysts, 75 % removal of ccolor10 % removal of total organic content.
Flow rate	Rate of filtration range between (3000-6000) $l/m^2/hr$	Rate of filtration range between (100-200) $l/m^2/hr$
Filtration medium	The effective size of sand is>0.55mm and the uniformity coefficient is between 1.2-1.6	Effective size of sand (0.15-0.35) mm and uniformity coefficient in between 3-5
Cleaning required	Cleaned through backwashing (using 2-5% of total filter water) and the process takes 15-30 min and a period of cleaning 1-3 days.	Frequency of cleaning (1-3) months.
Pre-treatment	Usually, necessary including coagulation and flocculation followed by sedimentation.	Plain sedimentation and roughing filters may be used to reduce the turbidity to below 20 NTU and Preferably below 5 NTU. Flocculation should not be used
Post-treatment	Chlorination is usually required.	Chlorination to be on the safe side
Filtration mechanism	Sedimentation, adsorption, straining, Chemical and microbiological processes.	Sedimentation, adsorption, straining, Chemical and microbiological processes.
Main filtering mechanism	Physical special adsorption	Microbractial
Principal Advantages	Substantially reduces pathogenic bacteria, viruses, and cysts, to produce potable water without further treatment. No machinery required.	Relatively small and compact.
Principle Disadvantages	Can only effectively treat low turbidity Water.	Cannot produce potable water without further treatment. Backwashing water is required for cleaning the filter, this usually involves pumps.

4.1.5 Disinfection: the process of destruction or inactivation of harmful micro-organisms in water either by physical or chemical process. There are the different processes which is used for disinfection are:

- **Physical process:** by boiling, by UV rays.
- **Chemical process:**
    - oxidizing agents (Cl, Br, I_2, O_3, $KMnO_4$, H_2O_2)
    - Metal ions (Ag, Cu)
    - Alkalis(pH>11) and acids (pH<3) (detrimental to bacteria)

4.2 Different parameters which cause pollution in drinking water:

Water contains different water quality parameters like physical and chemical water quality parameters.

4.2.1 Physical water quality parameter:

- Suspended solid: the problem of suspended solid comes only in surface water, not in groundwater.
- Turbidity: it is due to the presence of suspended or dissolve solid in water.
- Colour: organic compounds present in water may cause colour problems.
- Taste and Odour: taste and odour are caused by dissolved gasses. Algae secretes oily substances that may result in bad taste & odour.

4.2.2 Chemical water quality parameter:

- **Total dissolved solids:** major source of TDS is sodium, calcium, magnesium, sulphate, chloride, silica etc.
- **Alkalinity:** alkalinity in drinking water is caused due to the presence of carbonate, Bi-carbonate and Hydroxyl ion.
- **pH:** if pH is less than 6.5 and more than 8.5 then that water cause health issue in drinking water. Also, acidic water causes corrosion & alkaline water causes incrustation of pipe.
- **Hardness:** it represents the concentration of multivalent metallic cations in solution. Excessive hardness is objectionable because: great deal of soap is required for washing clothes; scale is formed in boilers in hot water heating system, incrustation of pipelines and plumbing fixures.

4.2.3 Biological water quality parameter: It includes Bacteria coli, and Escherichia Coli. The Presence of those in water indicates water is polluted due to pathogenic bacteria. Due to the presence of pathogenic bacteria in drinking water, many water-borne diseases occurred. Some water borne disease describe below:

Water borne diseases:

Diseases caused due to bacteria is Typhoid fever, Cholera, Bacillary Dysentery etc. Protozoa caused amoebic dysentery. The virus caused jaundice, poliomyelitis, infectious etc.

4.3 Slow Sand Filters

Slow sand filters use sand with effective sizes of 0.15 - 0.35 mm to remove a large percentage of coliforms, cryptosporidium and Giardia cysts. They operate most effectively at a flow rate of 0.1 – 0.3 m/h (or m3/h/m2).

These filters use physical processes such as sedimentation, adsorption and straining to remove fine particles as well as microbiological processes to remove organic material and bacteria. Because of the slow filter rates, the raw water sits above the sand for several hours before passing through it, various oxidation reactions break down organic material during this time. Algae, that grows on the sand surface, consumes this oxidized organic material and releases oxygen back into the water.

Roughing filters and sedimentation are often used as pre-treatments to reduce the turbidity of the raw water and therefore reduce the rate at which the slow sand filter becomes clogged. Some aeration, to increase the oxygen content of the raw water, is also desirable.

The flow of raw water through the filter should be continuous, however small-scale filters, for use in individual households, have been designed to work intermittently (i.e. a few hours a day). These have been widely used in several countries around the World.

4.3.1 The Basic Design of Slow Sand Filters

The Stages in a Slow Sand Filtration System

There are several important stages in a slow sand filtration system:

- Pre-treatment – one or more of the following:
    a) sedimentation tank
    b) roughing filter
    c) aeration
- The sand beds
- ·Under drainage, protected by a gravel pack
- A flow-regulating valve
- Weir
- Chlorination (if applicable)
- Storage Tank

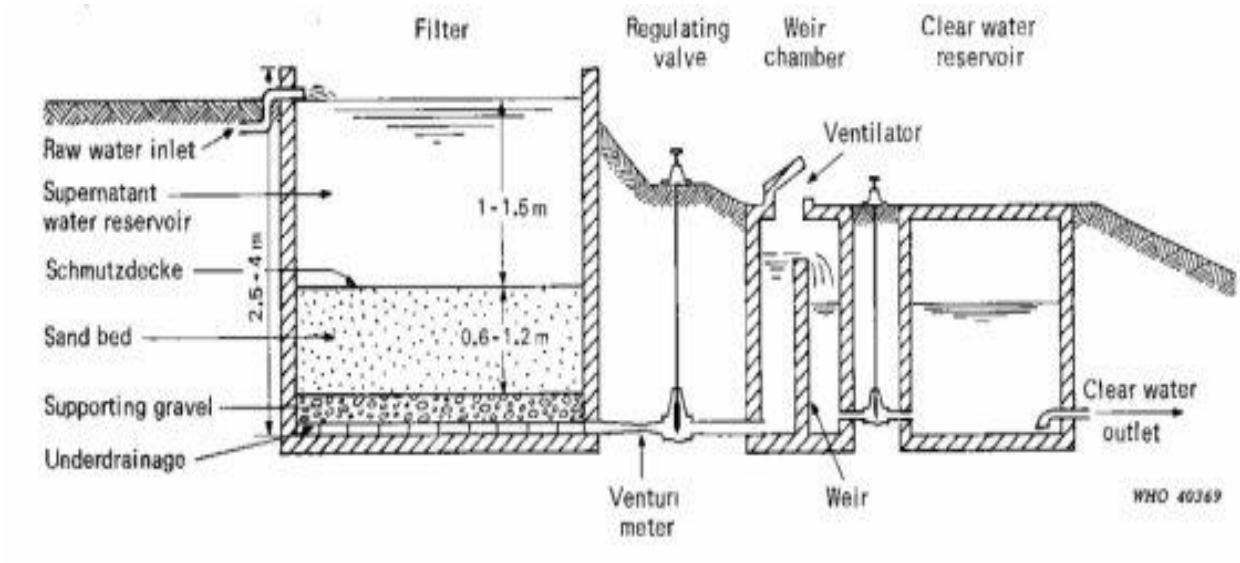


Figure 46: Show the basic design principles used in a slow sand filter.

4.3.2 Design characteristics of the slow sand filtration units

In an SSF treatment plant, at least two units should operate in parallel for continuous supply. A unit basically consists of a structure that contains the following components: Flow control and drainage systems, supernatant water layer, and filter bed.

❖ **Flow control systems:** Controlling the flow in SSF units is necessary to maintain the proper filtration rate through the filter bed and the submergence of the media under all conditions of operation. Abrupt filtration rate increases should be avoided. Two types of flow rate control are used outlet and Inlet. In an outlet, the controlled filter supernatant water level is kept close to the maximum desired level above the filter bed. To control the flow rate, the outlet valve is gradually opened to compensate for the increase in the head loss over the filter media. This is the usual control method in Europe and has been adopted in some of the units built in the Americas (Pardón and Lloyd, 1994; Tanner and Baker, 1994). The storage capacity above the sand bed provides for some equalization of the influent water quality, sedimentation of heavier particles, and time for some biological activity (Fox et al, 1994), as well as some buffer capacity. In inlet-controlled filters, the increase in head loss is compensated by an increase in the height of the supernatant water. Di Bernardo and Alcocer (1996) found similar performance in terms of effluent water quality, head loss in the filtering bed and filter run times for inlet and outlet control SSF units run in parallel, with filtration velocities in the range of 0.13 to 0.5 mh^{-1}. In the inlet flow control option, the inlet box should allow flow control, and excess energy dissipation to protect the filtering bed from scouring; facilitate flow distribution to the SSF units filtering in parallel, and permit possible overflow.

The drainage system consists of a principal drain with lateral branches usually constructed in perforated pipes; brickwork or tiles and covered with a layer of graded gravel and a layer of course sand. The drainage system of SSF has to comply with the following functions:

- To support the filter material and prevent it from being drained from the filter;
- To ensure uniform abstraction of the water over the filter unit;
- To allow for the backfilling of the filter and drive out possible air pockets.

The main drain should discharge the filtered water freely at atmospheric pressure in the outlet box. A flow indicator is required at both inlet and outlet sides of the units to facilitate operational procedures and to verify water balance, as an indication of possible water losses in the main filtering boxes. The outlet weir is also necessary to maintain the supernatant water layer above the maximum level of sand, protecting biological activity, preventing pressure drops in the filter bed, and ensuring the functioning of the units independently of the level fluctuations in the contact or storage tanks.

- **Supernatant water layer:** The layer of supernatant water provides the static head necessary for the passage of water through the sand bed. In a clean bed the initial head loss is usually below 0.1 m and gradually increases until the maximum level is reached. In units with outlet control, the variations of the supernatant depth for small systems have been reported in the range of 0.6 to 1.2 m (Pyper and Logsdon, 1991). At the Weesperkaspel plant in Amsterdam, where the SSF units deal with highly pretreated water, the average supernatant water height is 2 m (Kors et al, 1996). Filter shading may contribute to improving filter runs if significant production of filter blocking algae is happening on the filter skin or in the supernatant water layer (Haarhoff and Cleasby (1991), but few definitive advantages in terms of filtrate quality have been reported (Di Bernardo, 1993).
- **Filter bed:** The adequate selection of sand includes size grading, characterized by the effective size diameter d10, and the uniformity coefficient, $U_c=d_{60}/d_{10}$. Huisman and Wood (1974) advise that d10 should be small enough to produce safe water and to prevent penetration of clogging matter to such depth that it can't be removed by surface scraping. 30 Bellamy (1985) reports a total coliform removal reduction from 99.4% at d_{10} of 0.1mm to 96% at d_{10} of 0.6mm. Di Bernardo and Escobar (1996) studied four pilot units in parallel having sand with d10 values in the range of 0.21 to 0.23 mm, and u_c values of 2.24, 2.85, 4.20, and 4.29. The tested filtration rates were 0.1, 0.2 and 0.25 mh^{-1}. For the lower velocities (0.1 and 0.2 mh^{-1}), the pilot units with higher u_c values had longer filter runs, deeper dirty penetration, and better effluent quality in terms of turbidity, apparent color, total iron and number of particles. The higher quality seems to be associated with a greater amount of data after the maturation period in the filters having sand with greater u_c values. Van der Hoek et al (1996) studied the impact of grain size and filtration rate on operation and performance in SSFs in Amsterdam. They fed four pilot units with highly pretreated surface waters. Two different filter rates were applied to two different filter sand types (d_{10-90}=0.19-0.35 mm and d_{10-90}=0.25-0.84 mm). All the units were producing water within the Amsterdam Water Supply standards. The filters with the smaller grain size showed slightly better performance with respect to the filtrate, and presented a shorter filtration rate, as predicted by filtration theory. However, these results also show that pretreatment in this case practically overrides the effect of grain size and filtration rate on the SSF performance. Deeper sand beds should result in improved removal of particles. However, due to the development of the filter skin and the biological activity concentrated mainly in the upper sand layers, particle removal is more effectively accomplished in this part of the SSF units. After a field survey Lloyd (1974) found evidence showing the significance of the uppermost 5-10 cm of SSF as the functional zone in purification at a filtration rate of 0.15 mh^{-1}, where around 1 log reduction of mesophilic and thermophilic bacteria usually takes place. For the same grain size grading, this functional zone increases with higher filtration rates, although population quantities and densities tend to decrease for the most active protozoa predators. Bellamy et al (1985) found in their pilot units that 93 per cent of the total coliforms were removed in the top 0.5m bed depth and 95 per cent above 1.0m bed depth. Experimental

evidence like this supports the practice of having a minimum sand depth above 0.3 to 0.5 m in the SSF units to achieve more than one log reduction of indicator bacteria. This is relevant for small systems working with low flow rates (0.1 to 0.2 mh^{-1}), but having to filter at higher rates during short periods due to their lower buffering capacity when one of the units is out of operation. The sand to be put into the SSF units should be clean, and free of clay, earth and organic material (Visscher et al 1987; Ives, 1990). The presence of dust or fine material produces high initial head losses and seems to limit the essential development of an active and effective microbial population in the filter bed. Placing dirty sand in the filter may interfere with the treatment process and makes it necessary to remove the sand earlier for correct washing.

There are several important elements that should be observed when constructing slow sand filters:

- The raw water supply feeding the filter should be able to maintain a constant head of water above the filter bed, thus there will be a constant pressure pushing water through the filter. The raw water source must therefore be able to supply a flow rate greater than the flow rate through the filter.
- The filter bed (normally sand) should be at least 0.6 m deep and should contain sand of an appropriate size and size distribution.
- The under-drainage system must support the filter bed while providing the minimum resistance to flow.
- The resistance of the filter bed will increase during use as the pores between sand grains become blocked by the material being removed from the raw water. The flow rate through the bed should be controlled by a regulating value placed in a pipe after the filter. The amount of head above the filter should not be used to regulate flow.
- A weir should be placed in the system between the filter and the storage tank. The weir ensures that if the raw water supply fails the filter bed can't run dry. As the filter is used the resistance of the sand bed surface increase due to clogging, the weir ensures that it is impossible for the top of the sand bed to run dry even if water can drain out of the bottom of the bed faster than it can pass through the surface.

4.3.3 Filtration Mechanism in Slow Sand Filters

Several mechanisms for the removal of turbidity, bacteria, viruses, and organic matter operate in slow sand filters. These can be broken down into two broad groups: physical and mechanical; and biological. Slow sand filters differ from rapid sand filters and roughing filters in the biological processes predominate.

4.3.3.1 Physical and Mechanical Processes

Straining is perhaps the most obvious process whereby particles can be removed from water flowing through a sand bed; that is, particles that are too large to fit through the pores between sand grains become lodged and are therefore removed from the water.

- However, rapid sand filters have been shown to trap particles that are far smaller than the pores. For example, sand grains with diameters of 0.5-1.0 mm will have pores that are approximately 0.1 mm in diameter but can remove particles with sizes of 0.01 mm and bacteria with sizes of 0.001 mm. Since these observations have been made using rapid sand filters the removal mechanism is physical rather than biological.

There are two important factors that must occur when particles are physically removed from the water. Firstly, a particle must move into contact with a sand grain (transport) and secondly the particle must become attached to it (attachment).

❖ **Transport**

Because of the slow flow rates, many of the larger solid particles will settle out in the head of water above the sand bed. The processes that occur within the sand bed can be summarized as followed:

- Interception– the water flows so that particles move close enough to a sand grain to become attached.
- Diffusion– random Brownian motion brings particles close to grains.
- Sedimentation– gravitational forces move particles downwards onto the top surfaces of grains.
- Hydrodynamic– particles in a velocity gradient (i.e. where water is flowing around a grain) often develop a rotation that provides lateral forces that move particles out of the water stream and into contact with sand grains.

❖ **Attachment**

These processes involve electrostatic and molecular (Van der Waals) forces that are similar to those that occur in coagulation. These attractions are sensitive to the surface charges on the sand grains and therefore the pH of the raw water. For example, virus removal occurs more readily in Low pH environments and for normal sand, E.Coli removal is most efficient in water with pH 5.

4.3.3.2 Biological Action

Slow sand filters have small flow rates hence most solid particles are removed in the top 0.5 to 2 cm of sand. This top layer of sand develops into a biologically active area. Known as the schmutzdecke (this translates roughly from German as 'dirty layer'). While most of the biological activity occurs in this region some activity continues down to a depth of about 0.5 m, although faster flow rates will carry organic food, that sustains bacteria, even deeper into the sand bed.

The Schmutzdecke is perhaps the single most important feature of the slow sand filter and is a sticky reddish-brown layer consisting of decomposing organic matter, iron, manganese, and silica. It acts as a fine filter to remove fine colloidal particles from the raw water and is also the initial layer of bioactivity. The schmutzdecke takes a while to form and ripen; this may take 2 – 3 weeks depending on the temperature and the biological content (bacteria and organic material) of the raw water. Once the schmutzdecke started functioning, should remain undisturbed until the filter has to be cleaned – probably 2 – 20 weeks. After cleaning, where the top 1 cm of sand is removed, the schmutzdecke will take a few days to ripen. The schmutzdecke is effective against intestinal bacteria because the temperature is lower than body temperature and there is little appropriate food. Also, there are predatory organisms present at the top of the filter bed.

The effectiveness of the schmutzdecke relies on there being adequate food (organic material in the raw water), a high enough oxygen content, and a sufficient water temperature. The following points should be observed when operating a slow sand filter:

- The sand must be kept wet to keep the essential micro-organisms alive in the biological zone.
- The biological zone needs food, therefore raw water should be continually fed in and the filter should be run continuously.
- The biological zone needs adequate oxygen for the metabolism of biodegradable components and the consumption of photogenes. If the oxygen content of the filter drops too far anaerobic decomposition occurs producing hydrogen sulphide, ammonia and other products that affect the taste and odour of the water.

The oxygen content of the filter should be above 3 mg/l to ensure anaerobic conditions are avoided within the filter. To maintain the oxygen level in the filter:

- Ensure there is a continual flow of water through the filter.
- Provide an aeration treatment before, or as, the raw water enters the filter.
- Do not have an excessive head of water above the sand bed.

The biological layer becomes less effective at lower temperatures. When the air temperature drops to below 2°C for any prolonged period the filter should be covered to prevent heat loss or chlorination should be used on the filtered water as a safeguard.

4.3.3.3 Algae

Algae may grow in the rivers, lakes, storage reservoirs, or even in the supernatant of the SSF. The presence of algae in moderate quantities is usually beneficial for the functioning of the SSF units. Most algae are retained by the SSF, but under certain conditions occasional and significant algae growth or algae blooms may develop. This massive growth may cause a quick reduction of the permeability of the filtering bed, greatly reducing the filter run. Algae may also play an important role in the production of high concentrations of soluble and biodegradable organics in the water, which may create smell and taste problems, and contribute to microbial growth in the distribution system.

4.3.4 Conditions that inhibit or reduce the efficiency of the treatment process

Various circumstances can interfere with the treatment process in the SSF units and prevent the expected efficiencies from being obtained. Some of these are related to the short filter runs. Other important inhibiting conditions are low temperatures, low nutrient content, and low dissolved oxygen content.

i. **Temperatures:** A low temperature increases the viscosity of water and reduces the biochemical activity in the sand bed, affecting the treatment efficiency. E. coli removal may be reduced from 99 to 50% when the temperature falls from 20ºC to 2ºC (Huisman and Wood 1974). The strategy in countries that face cold periods during the year has been to cover the filters or to build underground to prevent the freezing of the units and reduce the impact of low temperatures which, of course, has considerable economic implications.
ii. **Nutrients:** The microorganisms active in the sand bed require nutrients such as carbon, nitrogen, phosphorus, and sulphur for their metabolism and growth. The humic and fulvic acids are rich in carbon but low in the other elements (Spencer and Collins, 1991). This

may be part of the explanation for the low removal of natural color in SSF treating water sources that are well protected. Bellamy et al. 1985 report that adding nutrients permits increasing the biological activity in experimental SSF units, and improves the removal efficiency for turbidity and for microbiological contamination.

iii. **Dissolved oxygen**: When the flow velocities and the dissolved oxygen level in the water source are low, particularly if this is combined with a high amount of biodegradable material, the oxygen in the water can be depleted resulting in anaerobic conditions in the filter skin (Joshi et al., 1982). This anaerobic condition in the filter must be avoided because it may create serious water quality problems such as bad smell and taste, as well as re-suspension of heavy metals with implications of aesthetic nature or interference with the final disinfection stage.

4.3.5 Limitations of Slow Sand Filtration:

- The main drawback of slow sand filtration is its inability to treat high turbidity surface water without the rapid development of head loss and frequent clogging of the filter. Ellis (1985) stated the common belief that "high turbidity in surface waters was the original reason that slow sand filtration had to be rejected in many areas. Most surface waters may reach a turbidity of 30-50 NTU, after heavy runoff it may be reached to 200 NTU (Barrett el al. 1991). It is suggested that slow sand filtration operates best with raw water turbidity below 10 NTU, and can manage peaks up to 50 NTU for one or two days without incurring major increases in head loss (Galvis et al. 1992). However, if the turbidity is consistently as high as 50 NTU, the filter will clog and require frequent cleaning, resulting in inadequate filter run times between cleanings. Furthermore, frequent cleaning of the filter disrupts the biological equilibrium in the filter media and does not allow enough time for biological maturation between cleanings (Galvis et al., 1992), leading to increased risk of pathogen breakthrough.
- The physical process of clogging the filter can also have a detrimental effect on effluent quality. The accumulation of particles in the top of the sand bed results in a decrease in pore size and a subsequent increase in interstitial water velocity. As the interstitial velocity increases, the shearing of the deposited particles increases. This results in the penetration of particles into deeper regions of the filter, and an increased risk of particle breakthrough in the effluent (Huck et al., 2001). In addition, the accumulation of solids can smother bioactive sites in the media, reducing the ability of bacterial predators to prey on harmful bacteria and pathogens (Lloyd, 1974).
- Excessive algal matter in the influent (Cleasby 1991)) can also clog filters and require frequent cleaning. High algal concentrations in the influent can also produce taste and odour problems in the effluent. In addition, the presence of excessive algae may increase the pH and cause precipitation of calcium and magnesium in the filter bed, resulting in an increase in interstitial velocity and a decrease in filter efficiency (Galvis et al., 1992).
- Slow sand filters are also susceptible to sudden fluctuations in raw water quality, such as sudden increases in solids loading. The biological community in slow sand filters is very dynamic and can adapt to prevailing raw water conditions. However, surface water is prone to sudden fluctuations in water quality due to precipitation events or pollution, thus

the biological community in the filter is liable to be upset (Huisman and Wood, 1974). This, in turn, may disrupt the treatment efficiency of the filter.

- Another drawback of slow sand filtration is its limited ability to treat stable suspensions of fine colloidal matter. The colloidal matter is much too fine, stable, and numerous to be completely removed by slow sand filtration alone colloidalidal matter is usually derived from clay; it ranges in diameter from 0.3 to 1 µm and exists in suspension due to its negative charge (Montgomery, 1985). Many surface water sources have a high percentage of colloidal matter. For example, an examination of water from a reservoir in Dar es Salaam found 50% of particles less than 1 µm (Boller, 1993). Furthermore, Ingallinella et al. (1998) examined surface water where 50% of the particles were below 0.5 µm in size.
- In slow sand filtration experiments, Bellamy et al. (1985a) found poor removals of turbidity, in the range of 27 to 39%, due to the presence of colloidal clay. However, particles ranging in size from 6.35 to 12.7 µm were effectively reduced by 96.8-98%. Similarly, Fogel et al. (1993) found poor turbidity removals of 55% due to a high amount of colloidal matter in the source water, in which 34.4% of all particles were less than 5 µm in diameter.
- The stable behaviour of colloidal suspensions can be even more pronounced in the presence of negatively charged humic matter, which absorbs to particle surfaces and prevent particle contact. Ahsan et al. (1996) found that absorbed humic compounds can increase electrostatic repulsion between particles or cause steric hindrance. Indeed, tests have confirmed that attachment efficiency between suspended particles is reduced in the presence of humic matter (Tipping et al., 1982; Jekel, 1986). Conversely, the presence of Ca^{2+} or Na^{+} in the water can absorb to the surface of the particle and destabilize a suspension (Collins et al., 1994b).
- Slow sand filters are also poor in removing colour. Colour is a surrogate measure of organics and an aesthetic measure of water quality. The dissolved fraction of colour is referred to as true colour. Colour is mainly caused by the presence of organic humic substances (Montgomery, 1985). Due to the stabilizing nature of humic substances on dissolved particles, it is expected that colour is difficult to remove in slow sand filters. Ellis (1985) found that the average expected removal of true colour in slow sand filters is 30%. In fact, the common reason for the declining use of slow sand filtration in the United Kingdom is its limited ability in removing organic colour and dissolved organic carbon (Lambert and Graham, 1995).
- Another important limitation of slow sand filtration is its reduced treatment efficiency at low water temperatures. Huisman and Wood (1974), Schuler et al. (1988), Bellamy et al. (1985c), Burman (1962), and Fogel et al. (1993) all report decreased removal efficiencies at lower temperatures, due to decreased microbiological activity and biological treatment. For example, Huisman and Wood (1974) found that the removal of Escherichia coli (E.Coli) reduced from 99% to 50% when the temperature decreased from 20^{o}C to 2^{o}C. Ellis (1985) found similar deficiencies in removal, and attributed it to lower predation activity of protozoa at lower temperatures.
- Furthermore, Burman (1962) found 99% removal of E.Coli and coliform bacteria throughout most of the year in a northern climate, but during persistent cold weather removals decreased to 41% and 88%, respectively. Similarly, Bellamy et al. (1985c) found

that removal of total coliform bacteria reduced from 97% at 17^{o}C to 87% at 5^{o}C, and removal of standard plate count bacteria reduced from 99.9% at 17^{o}C to 90% at 2^{o}C. On the other hand, despite a low temperature of 5^{o}C, Poynter and Slade (1977) still found 99.6% and 99.5% removals of coliform bacteria and E.Coli, respectively. The variation in results from these authors could be site-specific. Perhaps bacteria removals are less affected by temperature in water that is higher in organic content, resulting in higher biomass levels.

- Inadequate nutrient loadings, such as dissolved oxygen and organics, can also limit the performance of slow sand filtration. Aerobic microorganisms in the biomass require an adequate supply of oxygen, carbon, nitrogen, and phosphate for metabolic activity and growth. It is recommended that aerobic biological activity can only be sustained with a minimum dissolved oxygen level of 0.5 mg/L (Visscher et al., 1987), however, it should ideally not drop below 3 mg/L (Ellis, 1985).

Finally, from an engineering perspective, a disadvantage of slow sand filtration is its low hydraulic loading rates, forcing the requirements for larger filter areas and higher capital construction costs.

4.3.6 Operational Factors Affecting Removal in Slow Sand Filtration:

Slow sand filtration is proven to achieve excellent removals of pathogenic bacteria, protozoa, viruses, suspended solids, and turbidity. However, removal efficiency is highly dependent on the physical and operational characteristics of the filter including the media size, bed depth, filtration rate, biological maturity of the filter, and cleaning practices.

Generally, there are similarities in the findings of many authors, who report a decrease in filter efficiency with increased media size, increased filtration rate, decreased bed depth, and decreased biological maturity of the sand bed.

A smaller media is favoured due to its increased filtration efficiency. Ellis (1985) reports improved bacteria removals with smaller media. Although, the impact of media size on filter performance largely depends on the size distribution and surface chemistry of the particulate matter in the source water. For example, if there are a high proportion of solids in the water with a relatively large particle diameter, they are more likely to be removed, even in larger media. On the other hand, a high proportion of smaller size particles possessing a negative surface charge are more difficult to remove, especially in larger media.

Van der Hoek et al. (1996) documents a varied response from several authors regarding the effect of media size on slow sand filter performance. Interestingly, Bellamy et al. (1985c) reported that an increase in effective sand size did not necessarily result in poor filter performance. An increase in effective media diameter from 0.128 mm to 0.615 mm resulted in only a small decrease in bacteria removals from 99.4% to 96%. Likewise, Van der Hoek et al. (1996) found that the use of a smaller range of grain size (d_{10}=0.19) resulted in only slightly better filtrate quality than a larger range of grain size (d_{10}=0.25). More importantly, however, a shorter filter run length was observed with the smaller media.

Although a larger media may be desired for longer filter runs, it also allows deeper penetration of schmutzdecke and more sand would need to be removed during cleaning to restore headloss to initial values (Bellamy et al., 1985c). This may significantly reduce treatment efficiency after cleaning, leading to an increased risk of pathogen breakthrough.

For example, Burman (1962) found that cleaning of the slow sand filter lead to a reduction in the removal of E.Coli from 99 to 94%, although removal of coliform bacteria was unaffected. Burman (1962) also found that removal of chlorine-resistant spore forming bacilli ranged from 81 to 88%, and after cleaning these removals dropped from 81 to 73%. Bellamy et al. (1985a) found that cleaning or replacing the sand resulted in a 1 log decrease in bacteria removal efficiency.

Thus, a good compromise is to use a larger effective media diameter, but preserve filtration efficiency by using a media with a relatively low uniformity coefficient (UC). A lower UC ensures that there is not a high proportion of sand that is too fine, which would lead to premature clogging, and not a high proportion of sand that is too large, which would reduce filtration efficiency (Goitom, 1990).

The filtration rate is another important factor affecting removal in slow sand filters. In particular, sedimentation and biological mechanisms are dependent on the filtration rate (Ellis, 1985). This is because a lower filtration allows less turbulent conditions in the sand interstices and facilitates gravitational sedimentation, reduces fluid shear on deposited particles, and increases the hydraulic retention time in biologically active regions of the filter.

As expected, Poynter and Slade (1977) found that the removal of viruses decreased with an increased filtration rate. In addition, Muhammad et al. (1996) found that colour removals, which depend mostly on sedimentation, were significantly decreased at higher filtration rates. This confirms that biological treatment and sedimentation are indeed influenced by filtration rate.

Interestingly, Huisman (1977) reported that a higher filtration rate increases the organic loading rate, which results in higher substrate availability and forces microorganisms to live deeper than 300-400 mm in the sand bed, leading to the potential breakthrough of bacteria. In some cases, however, filtration rate does not have an effect on bacteria removals. For example, Poynter and Slade (1977) found that increasing the filtration rate from 0.2 m/h to 0.4 m/h had no effect on removals of coliform bacteria and E.Coli.

Bed depth is also an important parameter for slow sand filter performance. The minimum depth for good turbidity and coliform bacteria removal is 300 mm, but 600 mm is necessary for removal of all viruses, and perhaps to complete the oxidation of ammonia (Ellis, 1985). Likewise, the removal of colour can be significantly increased at bed depths greater than 400 mm (Muhammad et al., 1996).

Bellamy et al. (1985c) found good removals of bacteria with reduced bed depth. In this study, coliform removals dropped from 97% to only 95% by reducing the bed depth from 0.97 m to 0.48 m. This is because most of the biomass and biological treatment occurs in the upper portion of the sand bed. In fact, Williams (1987) found that all bacteria reduction occurs in the top 20 cm of the filter bed. In this study, 1 log removal of faecal coliforms was achieved after 5 cm depth and another 1.3 log removal after 20 cm depth, for a total of 2.3 log removal (99.5%). Overall, bed depth is more important for the removal of smaller particles, including viruses, colloidal matter, and colour; and less significant for the removal of bacteria.

The biological maturity of the filter also has an important influence on removal efficiency. Basically, if the length of filter run is short and cleaning is frequent, the biological layer will never have enough to time to re-establish equilibrium and maturity. Cleasby et al. (1984b) found that the removal of coliform bacteria increased from 95% to greater than 99% as the filter matured. Likewise, Bellamy et al. (1985a) found that Giardia removal was 98% in new sand, where in biologically mature sand, removal was 3 to 4 logs. Thus, the importance of lengthy filter runs, which allow plenty of time for maturation, cannot be overstated.

4.3.7 Performance of Slow Sand Filtration:

Slow sand filtration produces an effluent low in turbidity, free of impurities and more importantly, virtually free of bacteria, entero-viruses and protozoa (Galvis et al., 1988).Galvis et al. (1998) and Galvis et al. (2002) compiled typical removal efficiencies for slow sand filters from the work of several authors such as Bellamy et al. (1985c), Ellis (1985), Huck (1987), Rachwal et al. (1988), Haarhoff and Cleasby (1991), Hrubec et al. (1991), and Fox et al. (1994). These removal efficiencies are shown in Table 2.2. The original figure was amended to include the results from the work of Cleasby et al. (1984b) and Huisman and Wood (1974). Most of the results are from slow sand filters operating at temperatures above 5ºC, filtration rates between 0.04 and 0.2 m/h, bed depths above 0.5 m, and effective media diameters between 0.15 and 0.3 mm.

Table 3: Typical Removal Efficiencies for Slow Sand Filtration

Parameter	Effluent or Removal Efficiency	Comments
Turbidity	< 1 NTU	Treatment efficiency depends on quantity nature, and distribution of particles.
Coliform bacteria	> 99%	Treatment efficiency mostly depends on the biological maturity of the filter.
Entero bacteria	90 to 99.9%	Treatment efficiency affected by temperature, filtration rate, media size, bed depth, and cleaning practices.
Entero viruses and Giardia	99 to 99.99%	Effect of cleaning practices on removal efficiency in a biologically mature bed is minimal
True colour	25 to 40%	Colour is associated with organic material and humic acids. Average 30% removal.
Total organic carbon (TOC)	< 15 - 25%	
Dissolved organic carbon (DOC)	5 - 40%	Mean 16%
Biodegradeable dissolved organic carbon (BDOC)	46 - 75%	Mean 60%

Assimilable organic carbon (AOC)	14 - 40%	Mean 26%
UV absorbance (254 nm)	5 - 35%	Mean 16-18%
Trihalomethane (THM)	< 25%	
Iron and manganese	30 to 90%	Fe levels > 1 mg/L reduce filter run length due to precipitation and filter clogging.

Adopted from Galvis et al. (1998/2002)

4.3.8 Ozone and Slow Sand Filtration

Ozonation before slow sand filtration can have a positive influence on slow sand filter treatment performance, microbiology, and NOM transformation (Eighmy et al., 1993). As slow sand filtration alone is only capable of removing 5-25% of NOM (McMeen and Benjamin, 1996), pre-ozonation is important for achieving good removals of NOM from surface water.

Generally, ozone increases the biodegradability of NOM, hence increasing biological activity in the filter and increasing the removal of BOM. It works by oxidizing long-chain molecular substances into more easily biodegradable short chain molecular substances. More specifically, Eighmy et al. (1993) found that ozonation of NOM produced low molecular weight substances capable of supporting bacterial growth consisting of obligate aerobic bacteria or facultative anaerobic bacteria with “robust and diverse heterotrophic capacities” Eighmy et al. (1993).

Thus, pre-ozonation increases the BDOC content of NOM increases removal of UV absorbance, and also transforms NOM into more hydrophilic forms, which have a lesser potential for THM formation (Eighmy et al., 1993). Mogren et al. (1990) studied the ozonation of different source waters and found that it increased the BDOC fraction of water from 30 to 60%, 10 to 40%, or 0 to 20%, depending on the characteristics of the source water. This indicates that ozonation is effective in increasing the biodegradability of NOM.

Gould et al. (1984) found NPDOC and UV absorbance removals of 15 to 25% and 39 to 54%, respectively; in pre-ozonated slow sand filter effluent. The ozone dose was 3 to 5 mg O_3/L and the slow sand filtration rate was 0.14 m/h. comparatively, non-ozonated slow sand filter effluent had removals of only 9 to 14% and 11 to 15%, respectively.

Similarly, Zabel (1985) found NPDOC and UV absorbance removals of 35 and 70%, respectively, operating at an ozone dose of 5 mg O_3/L and filtration rate of 0.25 m/h. Whereas, whereas non-ozonated slow sand filters had NPDOC and UV absorbance removals of only 12 and 16%.

Rachwal et al. (1988) found similar trends in the removal of UV absorbance, but more importantly, found that most of the removal occurred during pre-ozonation, as the slow sand filter contributed only 10% of removal. This is confirmed by Eighmy et al. (1993), who report that ozonation of NOM reduces UV absorbance of the source water likely through oxidation of aromatic compounds.

Ellis (1985) found that removal of BOM in pre-ozonated slow sand filter effluent was 75%, compared to 50% achieved by slow sand filtration alone. In addition, removal of TOC in pre-ozonated slow sand filter effluent was 35%, compared to 15% achieved by slow sand filtration alone.

The effects of ozonation on TOC reduction are even more profound during the winter when TOC removal by slow sand filtration alone is generally poor (Seger and Rothman, 1996). Seger and Rothman (1996) found that the reduction of TOC in cold water (<8^{o}C) improved by 220% with pre-ozonation, compared to an improvement of 75% in warm water (>8^{o}C). Thus, pre-ozonation is especially important during cold water conditions for optimal removal of NOM in the slow sand filter.

4.3.8.1 Removal of Colour with Ozonation

Ozonation is also used for the removal of true colour, as slow sand filtration typically only achieves 30% removal. Greaves et al. (1988) found that pre-ozonation removed true color by 74% followed by an additional 20% removal by slow sand filtration. Comparing ozonated and non-ozonated slow sand filter effluent, Cable and Jones (1996) found a 52% removal of true color compared to 19% in non-ozonated effluent. In the case of color removal, ozonation alone is responsible for most of the removal, due to the alteration of the chemical bonds in humic materials, "leading to a reduction in the conjugation of the molecules" (Cable and Jones, 1996).

4.3.8.2 The Effect of Ozone on Filter Run Length

Another advantage of pre-ozonation is extended slow sand filter run times. Rachwal et al. (1988) found that filter run times were extended due to the oxidation of filter blocking algae. This phenomenon is likely more significant in tropical regions or during the warmer seasons of northern regions.

Conversely, Eighmy et al. (1993) found that pre-ozonation reduced filter run times, most likely due to increased biomass development in the filter. In this case, a larger media with more biomass storage capacity can be used to extend filter run times.

4.3.9 Removal of Disinfection By-Products with Slow Sand Filtration

4.3.9.1 Removal of Trihalomethanes

Chlorination has been used throughout the 20th century to prevent the transmission of waterborne diseases. Recently, however, there is a large concern over the formation of chlorination by-products, such as trihalomethanes (THMs), which pose a cancer risk in humans.

THMs are formed when a chlorine-based chemical oxidant reacts with organic matter in water. The USEPA has stipulated a maximum contaminant level (MCL) of 80µg/L for total THMs

(USEPA, 1998a). Filtration is very important for the removal of THM pre-cursor material and the reduction of THM formation potential (THMFP) during the post-chlorination stage.

Eighmy and Collins (1988) found that removal of THMFP in slow sand filtration ranged from 9-27% in the winter and 14-27% in the fall. The improved removals in the fall were attributed to the increased growth of biomass in warmer water temperatures. Eighmy and Collins (1988) found a direct correlation between the amount of biomass concentration and the removal of THMFP. For example, filters cleaned with the biomass conserving harrowing method, as opposed to scraping, had significantly higher removals of THMFP.

In pre-ozonated water, Eighmy et al. (1993) found even better removals of THMFP, 40 to 70%, compared to 10 to 15% removal in conventional systems. They used ozone doses of 2 to 6 mg/L and found that the increased THMFP removal was due to both direct oxidation and enhanced biological treatment.

Cable and Jones (1996) also found improved removals of THMFP with pre-ozonation, averaging 50% for ozonated effluent compared to 28% for non-ozonated effluent. They also found good linear correlations between THMFP and true color or TOC. This suggests that true color and TOC are reasonable surrogates for predicting THMFP.

Overall, the removal of THMFP is enhanced with higher water temperatures and pre-ozonation.

4.3.9.2 Removal of Ozonation By-Products

Although pre-ozonation is very effective in aiding the removal of BOM, it may, unfortunately, result in the formation of DBPs or ozonation by-products (OBPs) that are harmful to human health. Examples of OBPs are low molecular weight aldehydes and organic acids, including formaldehyde and acetaldehyde, as well as bromate. Bromate, a suspected carcinogen, is formed when bromine is present in the water. The concentration of bromate that is formed during ozonation depends on the ozone dose, contact time, and pH (Kimber, 2003). The current MCL of bromate is 10µg/L (USEPA, 1998a).

Fortunately, biological processes can be very efficient in removing OBPs. Eighmy et al. (1993) found that formaldehyde and acetaldehyde were readily removed to below detection limits during slow sand filtration.

However, the removal of some ODPs is highly dependent upon EBCT. Melin and Odegaard (2000) found that the removal of ODPs increased with increasing EBCT and the optimal EBCT was around 20 minutes. This contact time could easily be achieved in the biologically active regions of a slow sand filter.

There is very little information available on the removal of bromate by slow sand filtration, but it is expected that increased EBCT will result in optimal removals.

4.3.10 Post-Treatment with Granular Activated Carbon Filtration

Granular activated carbon (GAC) is a common adsorbent used in drinking water treatment for the removal of dissolved organic matter and humic substances, THM precursor material, taste and odor compounds, pesticides, and ozonation by-products.

GAC has a large surface area consisting of macropores and micropores, which have a large adsorptive capacity. It is also capable of supporting a high amount of biomass, which is sheltered from fluid shear forces. One problem with biomass supporting GAC filters, however, is that biomass can detach from the media and be net producer of bacteria (Uhl and Gimbel, 1996).

GAC filters can be operated as a post-slow sand filtration treatment step, just before disinfection, or as a layer within the slow sand filter. This adds robustness to the process, as GAC can provide additional removal of true color, colloidal matter, and THMFP, beyond that which is capable in slow sand filtration alone.

For example, GAC filters operated at slow filtration rates have been reported to remove greater than 90% of organic precursor materials (Fox et al., 1984). More impressively, Eighmy and Collins (1988) found organic precursor removals of greater than 75% in a GAC amended slow sand filter with a GAC depth of only 7.6 cm above the sand bed.

Mallevaille and Duguet (1988) found that GAC filters operated at a filtration rate of 0.625 m/h (EBCT of 14.4 min.) removed an additional 15% of TOC after a 10% removal by slow sand filtration, giving a total TOC removal of 25%.

Dussert and Tramposch (1996) summarized the results from many authors regarding the removal of AOC, ozonation by-products, DOC, TOC, and THMFP in GAC filters, and found removals of 42-57%, 73-90%, 17%, 29%, and 21-40%, respectively.

Thus, post-treatment with GAC filtration can provide a significant amount of additional treatment, beyond that which is capable of slow sand filtration alone. Furthermore, it is an important treatment barrier in the multi-barrier approach to water treatment.

4.4 Horizontal Roughing Filtration:

Gravel filtration has been used in water treatment since the early 1800s, when it was first used in Scotland (Baker, 1948) to pre-treat water before slow sand filtration. Gravel filtration soon disappeared due to the advent of chemical and mechanical water treatment but resurfaced in the 1970s and 1980s mainly in developing countries to pre-treat high turbidity water before slow sand filtration (Collins et al., 1994b). As roughing filters do not require sophisticated mechanical equipment or the use of coagulants (Wegelin and Schertenleib, 1993), they are a sustainable method of pre-treatment in rural areas.

Briefly, roughing filters consist of several gravel media layers ranging in size from 20 mm down to 4 mm (Wegelin and Schertenleib, 1993), in the direction of flow. There are several types of roughing filters, which are shown in Figure 2.3. Generally, they are classified based on the direction of flow (flow, downflow, or horizontal flow) and the depth of media layers in the direction of flow. The selection of the roughing filters depends on the raw water characteristics and the operation and maintenance requirements (Galvis et al., 1993).

4.4.1 Basics design process of Horizontal roughing flow filter

A horizontal-flow Roughing Filter (HRF) consists of a horizontal filter box with 3 or 4 compartments of decreasing length separated by baffles, in which water flows horizontally. Each compartment is filled with gravel, with the coarsest media in the first compartment and the finest media in the compartment. The advantage of HRF is its extended bed lengths and solid storage capacity, resulting in less cleaning frequency than up-flow roughing filters. It is also more suitable for treating very high Suspended solids concentrations. The disadvantage of the HRF is its large space requirements. The horizontal flow roughing filter is commonly applied with SSF, especially in developing countries. To date, the most comprehensive model applied in HRF design is based on wegelin design criteria founded on the "1/3 -2/3" filter theory (wegelin, 1986; 1996).

- **Wegelin design criteria of HRF:**

Wegelin design criteria is founded on the "1/3-2/3" filter theory and is still to date the most comprehensive model applied in design of Roughing Filters (Wegelin, 1986; 1996). The filter theory is based on Suspended Solids (SS) reduction. The "1/3-2/3" filter theory is classified as conceptual. The investigations of Wegelin et al (1996) describe this theory as follows; by logic or experience, a particle in water can bypass a gravel grain either on the left or right or settle on its surface. Hence the chance to fall on the grain is 1/3. However, the process continues, as there is a second, third and many other gravel grains to settle on. This theory has been used to formulate models, which give a simple elucidation of the removal kinetics of the Roughing Filters and hence further used to describe the filter efficiencies in the design of Horizontal-flow Roughing Filters. The mathematical exercise description of this theory, clearly proves that solid matter separation by filtration can be described by an exponential equation. Based on Fick's law and other established filter theories, the filter efficiency can be expressed by the filter coefficient λ.

$(dc/dx) = -\lambda c$………………………………………………………………………………. (1)

Where,

C= solid concentrations.

X=filter depth.

λ== Coefficient of proportionality also known as filter coefficient.

Equation (1) states that the removal of suspended particles is proportional to the concentration of the particles present in water. Assuming the total filter length as a multi-tore reactor consisting of a series of smaller filter cells, the performance of an HRF can be calculated on the basis of the filter cell test results. Neglecting straining mechanisms and further assuming surface chemical conditions to be constant, the total suspended solids (SS) concentration after an element Δx can be estimated by the following expression;

$C_{out}=\Sigma C_{i(in)}e^{-\lambda i\Delta x}$…………………………………………………………………. (2)

Where;

C_i = concentration of particles of size d_{pi}

Δx = the length of the experimental filter cell.

λ_i = filter coefficient for each filter cell. Equation

(2) Shows that in knowing the inlet SS concentration, the filter coefficient, and the filter depth (length), the outlet SS concentration can be easily predicted and consequently the filter performance efficiency. This aids in filter design. According to Wegelin (1986; 1996), the effluent quality for an n number of compartments is given by the following expression;

$C_e = C_0 * E_1 * E_2 * .... * E_n$... (3)

Where;

C_o= concentration in the HRF influent.

C_e = concentration in the HRF effluent.

E= are the filtration "efficiencies" for i=1,2......n compartments respectively.

The basic expression for the above relationship is;

$C_e = C_o e^{-\lambda L}$

Where;

L= is the length of filter.

λ = is the coefficient of filtration (also known as filter coefficient).

Where;

L= is the length of filter

B λ= is the coefficient of filtration (also known as filter coefficient).

The filter efficiency is given by:

$E = C_e/C_o = e^{-\lambda L}$... (5)

Co=Ce*E... (6)

The values of Ei (i = 1, 2… n) are obtained from tables as developed by Wegelin (see mentioned reference for further details).

4.2.2 Mechanisms of Removal in Roughing Filtration

The most influential mechanisms of removal in roughing filters are gravitational sedimentation, interception, and diffusion. The principal mechanism, as recognized by many authors, is gravitational sedimentation, where the settling velocity of the waterborne particle is greater than the hydrodynamic forces of the water flow.

Sedimentation and interception are most influential for particles greater than 1 µm, and the removal efficiency due to these mechanisms increases with increasing particle size (Collins et al., 1994b). Diffusion is the most influential removal mechanism for particles less than 1 µm, and the removal efficiency of diffusion increases with decreasing particle size (Collins et al, 1994b).

The roughing filter can be considered a sedimentation basin, where the filter media provides a large surface area and short settling distances for discrete and flocculant particle settling (Wegelin et al., 1986). In conventional sedimentation basins, particles have to reach a settling distance of 1 to 3 metres, whereas in roughing filters, the interstitial settling distance to the gravel surface is only a few millimetres (Wegelin and Schertenleib, 1993). Particles deposit onto media grains in dome-like formations. Eventually, particle accumulations drift and are allowed to migrate freely through the large pore spaces towards the bottom of the roughing filter (Boller, 1993). Thus, most particle accumulation occurs in the bottom of the filter.

Compared to rapid filters with smaller media, roughing filters contain less collectors of a larger media size per unit volume, resulting in lower filtration efficiencies (Boller, 1993). Boller (1993) suggests that filter efficiencies similar to rapid filters can only be achieved in media less than 3 mm in diameter, where forces other than gravity become important. However, the advantage of the larger media in roughing filters is that it allows a higher probability of impaction, resulting in higher solids deposits. In addition, particles that are retained in solids deposits will act as additional collectors, increasing the interception of subsequent passing particles (Saidam and Butler, 1996). It is possible that as solids accumulate in the filter and interstitial pore space becomes smaller, interception and straining play an increasingly important role in removal (Saidam and Butler, 1996).

Furthermore, in rapid sand filters, the effects of van der Waals and double-layer forces on particle removal are more significant with decreasing media diameters and increasing particle diameters (Boller, 1993). However, in roughing filters with media diameters generally greater than 5 mm, these forces are negligible (Boller, 1993). Overall, although filtration is not as efficient as rapid filters, solids storage capacity is much larger in roughing filters and headloss develops at a much lower rate, leading to very long filter run times (Boller, 1993).

The secondary mechanisms of particle removal in roughing filters are adsorption to biomass and biological degradation of captured particles (Schulz and Okun, 1984). Organic particles that are retained by the filter are assimilated into a sticky gelatinous biofilm on the media surfaces (Saidam and Butler, 1996). This sticky biofilm, otherwise known as zoogloea, further assimilates organic particles or adsorbs inert particles (Huisman and Wood, 1974). In fact, Collins et al. (1994b) found improved treatment with algae-ripened media compared to clean media. This suggests that the sticky nature of algae assists in particle attachment and solids retention.

It is important to note that, in absence of biomass, adsorption to clean media is not a significant mechanism in roughing filters. Wegelin (1996) found that removals were not greatly influenced by the surface properties of the filter media. This is confirmed by Mbwette and Wegelin (1989) who found that the shape and surface texture of roughing filter media has a negligible influence on filtration coefficient.

4.4.3 Factors Affecting Removal in Roughing Filters

The principal design parameters for roughing filtration are bed depth, filtration rate, and media size (Collins et al., 1994a). Generally, treatment performance increases with decreasing media size, increasing surface area, decreasing filtration rate, and increasing bed depth. In addition, the characteristics of the particulate matter, such as size and nature (organic or inorganic), have a significant influence on its removal in roughing filters.

Bed depth is the most influential design variable (Collins et al., 1994b). As particles deposit in the filter bed, pore spaces become smaller and the solid deposits are subjected to higher shear forces, causing detachment and penetration of detached solids deeper into the filter bed. Thus, it is important to maximize the bed depth to capture particles that penetrate deeper into the filter.

Filtration rate also has a significant influence on particle removal. Good removals in roughing filters are best achieved with low filtration rates (Boller, 1993). Boller (1993) suggests that low filtration rates are critical to retain particles that are gravitationally deposited or attached to the upper side of the media. It is important to maintain laminar flow conditions in the pores to limit the fluid shear stress on solids deposits. In Figure 2.6, Wegelin (1996) shows that removal efficiency increases with decreasing Reynolds Number (R_e). For example, removal of turbidity was 40% at a R_e of 8, whereas removal was greater than 80% at R_e less than 3. (Reprinted by permission of the Swiss Centre for Development Cooperation in Technology and Management (SKAT), from Surface Water Treatment by Roughing Filters: A Design, Construction, and Operation Manual (Sandec Report No. 2/96), by Wegelin, M., SKAT, 1996).

Furthermore, Wegelin et al. (1986) found that at increased filtration rates (2 m/h), coarse particles penetrated deeper into the bed, clogged the finer gravel media, and decreased the filter efficiency, resulting in more particle breakthrough. However, at 0.5 m/h, the bulk of the solid matter was retained by the coarse gravel, leaving the finer gravel sections unloaded. Whereas, at 1 m/h there was a good distribution of solids loading throughout the bed.

When treating high turbidity water, Wegelin (1983) found it necessary to use a filtration rate between 0.5 and 1 m/h to meet the influent requirements for slow sand filtration. In fact, a significant improvement in roughing filter removal efficiency was observed at filtration rates below 2 m/h, compared to over 2 m/h. In addition, Boller (1993) found that the removal of colloidal particles could only be achieved with filtration rates lower than 2 m/h, preferable lower than 1 m/h.

The media size is another important design variable. Gravity sedimentation on course media is more pronounced than in finer media, where a higher interstitial turbulence limits the gravitational accumulation of particulate matter (Clarke et al., 1996a).

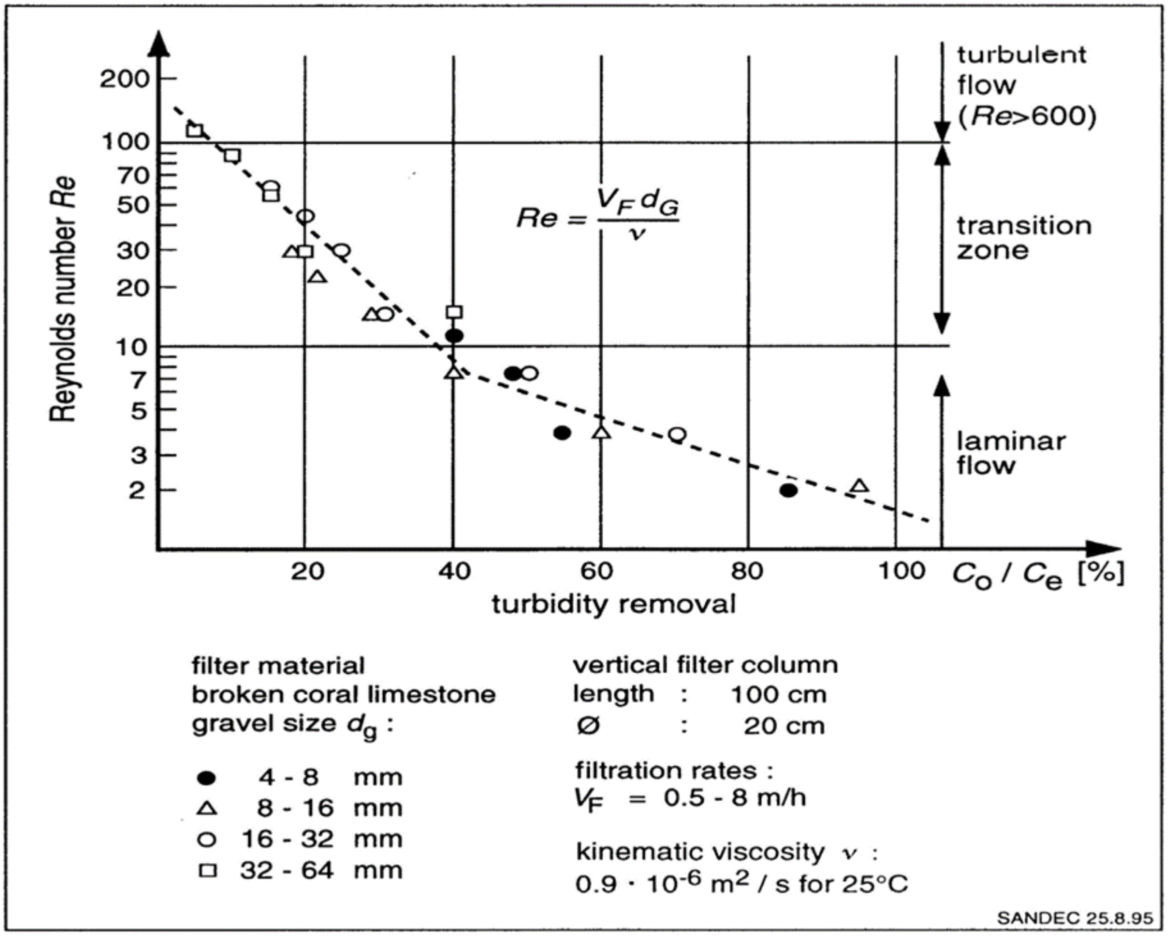


Figure 47: Removal Efficiency vs. Reynold Number in Roughing Filter.

Removal of particulate matter in roughing filters is also dependent on the particle characteristics. Thus, it is important to study the characteristics of the given source water when designing a roughing filter for a particular location. For example, Collins et al. (1994a) found that the removal of mineral particles (denser, less sticky, and less uniformly sized particles) is most influenced by bed depth, followed by media size and filtration rate, in order of decreasing.

importance. Conversely, the removal of organic particles similar to algae (less dense, more sticky, more uniformly size particles) is most influenced by filtration rate, followed by media size and filter length in order of decreasing importance.

In addition, Collins et al. (1994a) found that sedimentation of particles was improved in the presence of “sticky” algal particles, which tend to aggregate with other particles and settle out faster. On the other hand, sedimentation of particles was compromised in the presence of stabilizing humic materials.

Furthermore, Wegelin et al. (1986) found that coarse particles are removed more efficiently and only smaller particles penetrate deeper into the roughing filter bed. However, near end of filter run, coarse particles penetrate deeper and smaller particles may breakthrough in the effluent.

The direction of flow can also have an impact on roughing filter performance. Particle trajectory models suggest that horizontal pores are more efficient particle collectors than vertical pores (Boller, 1993). In fact, particles 5 µm in diameter are three to four times more likely to become deposited in horizontal pores than vertical pores. Thus, it is suggested that horizontal filtration is more efficient than vertical filtration in sedimentation. In addition,

Boller (1993) found that the use of smaller media (less than 4 µm in diameter) is not able to reach the same amount of solids deposits as larger media, without incurring a large headloss.

Finally, filtration efficiencies of roughing filters tend to decrease with time as particles are deposited in the filter, resulting in increased interstitial velocity due to decreasing pore space (Boller, 1993). In fact, the removal performance of roughing filters is constant until a critical solids deposit is reached, after which the filter coefficient decreases towards zero and may drop

to negative values (Boller, 1993). Negative filter coefficient indicates a breakthrough or "washout" or solids in the effluent. Thus, roughing filters should not be operated past the point of critical solids deposit (Boller, 1993).

Overall, roughing filter performance depends on influent solids concentration, particle-size distribution, media size, bed depth, and filtration rate (Boller, 1993). Boller (1993) suggests that filter design becomes an "art" when attempting to determine the optimal combination of media size and bed depth for a particular source water. The ultimate goal of the design is to distribute the solids loading and headloss development evenly throughout the filter.

4.4.4 Performance of Roughing Filtration

In the following section, performance results from a number of roughing filtration studies are presented. The main parameters discussed are removal of turbidity, suspended solids, colour, DOC, metals, algae, and bacteria. This is followed by a performance comparison of the different types of roughing filters.

4.4.4.1 Removal of Turbidity

Roughing filters are capable of excellent removals of turbidity. Upflow roughing filters can achieve removals between 50 and 90% (Wegelin et al., 1998). The higher removal efficiencies are achievable with higher solids loading (Collins et al., 1994a). The effluent that is produced by roughing filters is well within the limitations of slow sand filtration. For example, Barrett et al. (1991) found that roughing filters reduced the turbidity from 150 NTU down to 15 NTU.

Clarke et al. (1996a) found removals of 60-75% turbidity from a 3-stage URFS, where particles down to a lower measurement limit of 0.75 µm were progressively removed across the filters. It is unclear, however, whether any particles smaller than 0.75 µm were removed. Most impressively, the roughing filter was able to attenuate sudden turbidity peaks and facilitate successful operation of the downstream slow sand filter even when the source water turbidity was continuously greater than 10 NTU for up to 3 months. It was reported that most of the attenuation of the turbidity peaks occurred in the coarsest media fraction (40 mm diameter).

As removal efficiency is a function of the influent loading, significantly low removals can result from treating low turbidity water, especially in the presence of colloidal matter. For example, Galvis et al. (1992) found that for raw water turbidities less than 10 NTU and high amounts of colloidal particles below 0.5 µm, particle removal was only 0-40%. Thus, removal efficiencies in roughing filters are largely dependent on influent loadings.

4.4.4.2 Removal of Suspended Solids

In tropical areas, rivers receiving monsoon runoff can reach suspended solids concentrations of 30,000 mg/L. These solids are mostly inorganic in nature and 80-90% of particles may be below 20 µm in size (Rajapakse and Ives, 1990). Thus, roughing filters are important for protecting slow sand filters from such high solids loadings. Generally, roughing filters can reduce suspended solids concentrations to below 25 mg/L (Rajapakse and Ives, 1990). Wegelin et al (1998) reports removals of 90% with influent concentrations of 50-200 mg/L, and between 50 and 90% with influent concentrations of 5-50 mg/L.

Most impressively, Rajapakse and Ives (1990) reported that, at a filtration rate of 0.72 m/h, roughing filtration reduced an influent suspended solids concentration of 5,000 mg/L to less than 1 mg/L.

4.4.4.3 Removal of Colour:

Removal of dissolved colour or true colour in roughing filters has not been well documented. As colour is related to humic substances, it is expected that true colour exists in a relatively stable suspension and is more difficult to remove. Indeed, Collins et al. (1994b) reports that removal of true colour in roughing filters compares favourably to removals achieved by slow sand filtration. Wegelin et al. (1998) reports true colour removals in the range of 20 to 50%.

On the other hand, there have been numerous reports of removals of apparent colour, which is the colour attributable to un-dissolved particulate matter. Wolters et al. (1989) and Barrett et al. (1991) both found removal of apparent colour to be 45 to 80%.

As colour is often used as a surrogate parameter for organic matter, the removal of DOC is expected to compare favourably to removals of true colour. Indeed, Wegelin and Schertenleib (1993) found 15% removal of DOC in roughing filters, which is similar to removals of true colour in roughing filters.

4.4.4.4 Removal of Metals

Removal of metals in roughing filters is not well documented. However, Bernardo (1988) found significant reductions of iron and manganese in roughing filters. Wegelin et al. (1998) reports around 50% removal of iron and manganese. In addition, Wegelin and Schertenleib (1993) found 50% removal of heavy metals in roughing filters.

4.4.4.5 Removal of Algae

Many authors, such as Galvis et al. (1992) and Wegelin and Schertenleib (1993), report operational problems caused by the clogging of slow sand filters with algae. Thus, roughing filters can play an important role in reducing the algal load on slow sand filters and increasing the filter run length. Barrett et al. (1991) found that algal removal in roughing filters is in the range of 30-80%.

4.4.4.6 Removal of Bacteria

Traditionally, roughing filters have not been viewed as valuable contributors to the removal of bacteria. This is because their original purpose was to reduce solids loading on slow sand filters. However, in recent decades the microbiological performance of roughing filters has been recognized.

The results show that roughing filters are not only important from an operational point of view, but also integral in providing a robust approach to water treatment. For example, Clarke et al. (1996b) found that fecal coliform removals were in the range of 80-90%, and suggested that roughing filters play a significant role in the multi-barrier approach to pathogen removal.

Wegelin et al. (1998) reports removals of fecal coliforms in the range of 0.65 to 2.5 log units. The higher removals are achieved with higher levels of bacterial contamination (Wegelin et al., 1998). For example, Barrett el al. (1991) found peak coliform bacteria removals of 90%, and found that higher reductions were associated with higher influent turbidity loadings. Wegelin and Schertenleib (1993) found even higher bacteria removals of 90 to 99%.

In addition, performance does not seem to be affected by sudden changes in influent conditions. For example, Clarke et al. (1996a) found that removal of bacteria phage was similar under sudden surges of influent turbidity, compared to during periods of stable influent turbidity.

Generally, roughing filters are capable of reducing influent bacteria to levels that are easily treatable with slow sand filtration. For example, Barrett et al. (1991) studied an upflow roughing filter that reduced coliforms from 16,000 colonies/100 mL down to 1,680/100 mL. Furthermore, Wegelin and Schertenleib (1993) studied a HRF that reduced E. Coli from 200- 1,000/100 mL to 10-30/100 mL.

Overall, roughing filters are important for adding robustness to the process of bacteria removal in multistage filters. Not only do they protect the slow sand filter from premature clogging and potential pathogen breakthrough, they provide significant pre-treatment of bacteria, and reduce influent contamination to levels that are easily treatable by slow sand filtration.

4.5 Multistage Filtration

4.5.1 Addressing the Limitations of Slow Sand Filters with Multistage Filtration:

A proven treatment method to cope with many of the limitations of slow sand filtration is multistage filtration (MSF). MSF is a robust, multi-barrier treatment method, which consists of pre-treatment with roughing filtration followed by slow sand filtration. Although, in recent years the addition of pre-ozonation and granular activated carbon (GAC) filtration stages have been practiced. MSF can consistently provide effluent water quality that exceeds the capabilities and limitations of slow sand filtration alone. Furthermore, Galvis et al. (1998) advocate that MSF is suitable for rural communities of small to medium size and remote areas in northern climates (Galvis et al., 1998).

A diagram depicting the multi-barrier treatment concept is shown in Figure 2.2. In the diagram, the surface water undergoes a step-by-step treatment process. In the pre-treatment or roughing stage, the larger-sized particles (mainly suspended inorganic matter) are efficiently removed while the smaller particles (pathogens, bacteria, suspended solids, etc.) are gradually reduced. In the main treatment or slow sand filtration stage, the smaller particles are completely removed. Thus, particulate matter and pathogenic microorganisms face a series of treatment barriers throughout the treatment system. As the water becomes progressively cleaner in the direction of flow, it becomes increasingly difficult for pathogens to penetrate through the multi-barrier treatment system.

Thus, a multi-barrier approach to water treatment, such as that provided by multistage filtration is recommended for providing a reliable source of drinking water that is consistently safe for human consumption.

4.5.2 Performance of Multistage Filtration:

- **The Success of Multistage Filtration in Columbia:**

Multistage filtration (MSF) has had particular success in Columbia where there are about 50 full scale systems in operation, and 10 of them have been in operation since the 1980s (Galvis and Visscher, 1999). In most of these systems, the local consumers of the water supply cover the low operational and maintenance costs.

Galvis and Visscher (1999) compared the performance of two different MSF systems in Columbia, one of them treating water from a heavily polluted river and the other treating a less polluted surface water. Both MSF systems provided similar effluent levels of turbidity, fecal coliforms, and colour. This suggests that MSF treatment "can adapt itself to the type of raw water and the concentration of contamination" (Galvis and Visscher, 1999), and higher removal efficiency results when using raw water sources that are more polluted. For example, MSF achieved a 2.5 log removal of fecal coliforms with raw water levels of 330 FCU/100 mL. In contrast, MSF achieved a 4.6 log removal of fecal coliforms with raw water levels of 44,500 FCU/100 mL (Galvis and Visscher, 1999).

One of the main limitations of slow sand filtration is its inability to effectively treat high levels of colloidal matter and true colour. Galvis and Visscher (1999) studied the efficiency of MSF in removing colour from heavily polluted surface water, with raw water colour ranging between 63 and 93 TCU. Due to the high raw water colour, removal efficiencies were high (between 86 and 89%), resulting in a SSF effluent between 8.2 and 12 TCU, and below 15 TCU between 77 and 96% of the time.

In addition, Galvis and Visscher (1999) report filter run times of 46 to 178 days, which far exceed slow sand filter run times of one to four weeks.

- **The Success of Multistage Filtration in North America:**

Recently, there has been increasing interest and use of MSF for surface water treatment in small communities throughout North America. Lecraw et al. (2004) documents the performance of MSF in a number of onsite pilot studies and full-scale plants. The process includes pre-ozonation for colour and organics removal, roughing filtration, and slow sand filtration. In some cases, a post-GAC filter was used for additional removal of colour and organics. Generally, the process has been used with raw water turbidities and colour ranging from <1 to 10 NTU (with spikes greater than 30 NTU) and <5 to 60 TCU, respectively (LeCraw et al., 2004). Typical effluent turbidities and colour ranged from <0.1 to 0.2 NTU and <5 TCU, respectively.

A summary of the results from several MSF systems, both pilot scale and full scale, is shown in Table 2.4. In each location, the effluent turbidity and colour was lower than the regulatory requirements of the SWTR. These results are promising for small communities that are looking for a simple and cost-effective treatment method. Thus far, MSF has proven to be a reliable treatment technology in several cold climate locations throughout North America.

Throughout the world and North America, small communities in rural areas often rely on contaminated surface water for their drinking water supply. As a result, numerous water- related outbreaks due to inappropriate small system treatment technologies have led to a growing need for a simple, reliable, and sustainable treatment technology.

Slow sand filtration is a proven, economical, and sustainable technology for rural drinking water treatment. It is a simple technology that is capable of achieving high standards of treatment without the use of chemicals and labour-intensive operations and maintenance. However, the process is highly sensitive to raw water turbidity where high turbidity levels can lead to frequent clogging.

Chapter 5

5. Methodology

In this chapter, to achieve various activities of the study objectives are discussed and the various activities carried out in the study are shown through the flow chart in Fig. 47.

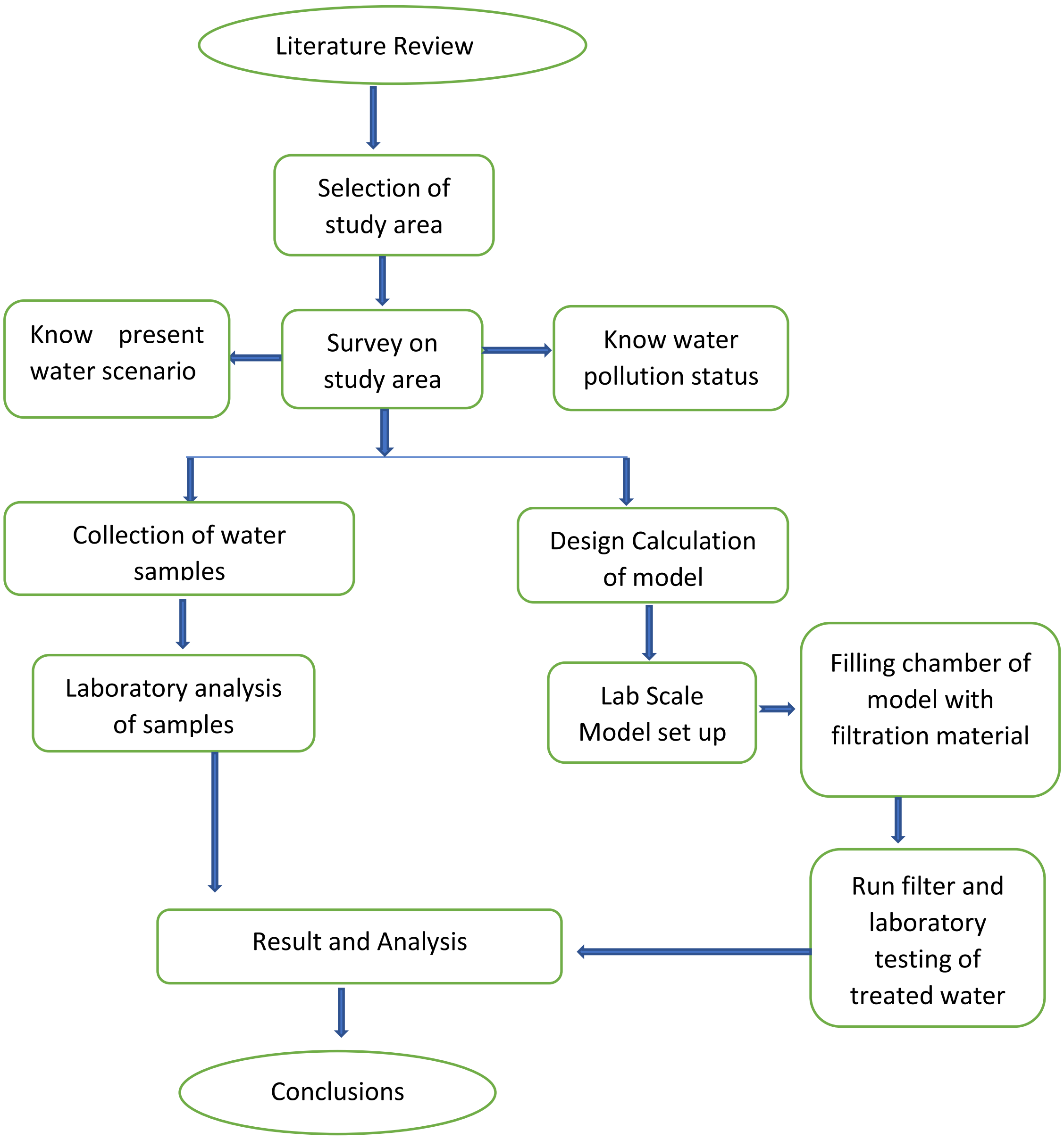


Figure 48: Showing the Methodology chart

Firstly, done a survey of the water-related needs of the target area's inhabitants and a technology assessment based on multiple criteria analysis to determine the most suited technological options for drinking water supply implementation. After assessments we came to know there is a lack of pure drinking water, so we want to set up a multistage filtration unit for the villagers. And we also set up one model MSF unit in our Jadavpur university campus lab which will run with pond water near the fluvial lab.

The pilot plant has been set up in Rasui village fed with water from canal. We have installed a pump with this water supplied to DIGF chamber then goes to buffer filter. After that water will pass through HRF. Then water will go through aeration system to increase the dissolved oxygen level in water. After that water is filtered with SSF and then goes to clean water tank (shown in figure 48).

Figure 49: Different stages of filtration unit.

5.1 Scope Definition:

The needs assessment served as a baseline assessment to obtain the most important information on drinking water-related needs and assets of the target area. The need assessment was conducted at three levels:

- For the entire community
- For each household.
- For the existing water supply system

For each category, an individual set of questionnaires was prepared and verified time and again. The following questions were addressed by the needs assessment:

- What are the geographic, demographic, and socioeconomic framework conditions in the target area?
- What is Rasui's current water quality as well as water quantity issues and drinking water-related needs?
    - What is the sanitation condition? How far is the sanitation unit from the drinking water supply system?
    - What is the most common disease they suffer from? How many days do they lose due to it? How much money do they spend?
    - How much water do they need for their daily need like drinking, food preparation, washing, etc.?
- What community assets exist that could be supportive of the implementation of a community-based safe drinking water supply?
    - What is the catchment condition surrounding the water supply system?
    - How much money they are willing to pay if a plant is set up at their community for its operation and maintenance?

5.2 Community Needs Assessment:

The categories of community need that are subject to assessment are determined by the scope of the needs assessment: facilitating the implementation of a sustainable community-based drinking water treatment plant for the Adivasi para Ghoshpur. Important indicators to cover the gap between the current and desired state of water supply on different societal levels (e.g. individual, family, community) are quantitative and qualitative demand for water for drinking, cooking, hygiene, laundry, and domestic animals and its actual availability. Additionally, coverage of drinking water-related needs is essential to identify gaps between the current and desired state of the drinking water supply. Knowledge of the status quo of drinking water supply was established through the assessment of existing tube wells (quantity, quality, access, distance) and water needs on a household level.

5.3 Execution:

5.3.1 Lab Scale Model set up:

Set up a piolet model in our lab which consists of an overhead storage tank, aeration tank and a multistage filter. The aeration process is used a cascade-type aerator. The filter consists of three chambers filled with different sizes of sand medium. At bottom of each chamber have a gravel layer of height up to 0.06m, and above this layer have a sand layer height of height 0.6m. After that, we have three chambers ACF. Among these, two chambers filled with an activated carbon layer of height 0.6m and below activated carbon consist gravel layer of height 0.06m. and one ACF chamber only consists gravel layer of height 0.06m. We installed a reciprocating pump for supplying water from the pond to the storage tank. we set up a storage tank of volume 300lt from which water will first go to the cascade aerator and then into the sand filter and then goes to ACF.

- **Gravel Specification:** gravel used in the bottom layer up to 0.07m of size varies from 4.75mm to 30mm. after sieving with a different sieve which is retained in 4.75mm and passing through 30mm sieve is used. At the bottom layer grave size 20-30 mm is used. in the 2nd layer 10-20 mm is used then in the 3rd layer 5-10mm gravel size is used.

- **Sand specification:** sand used in SSF has a uniformity coefficient generally in the range of 2-3. Effective particle size varies between 0.2-0.45mm. At first, we have done sieving with different sieve sizes of ranges 150μm to 450μm. The sand is used which is retained in 150μm and passed through 450μm.Then filled into the sand filter for 0.6m depth above the gravel layer.
- **Granular Activated Carbon:** Granular activated carbon (GAC) is commonly used for removing organic constituents and residual disinfectants in water supplies and maintaining desired colour and odour for drinking water. We used Nut Shell type activated carbon whose iodine number 1000, Molasses number 0, Abrasion number 67, Bulk Density as packed LB/CF 29-30, volume activity 0. Size of activated carbon used in our ACF ranges between 1mm to 3mm. After washing this activated carbon, we poured in to the filter chamber.

Figure 50: Lab Scale model of MSF unit

Figure 51: Sand filling in SSF

Figure 52: Cascade Type aerator

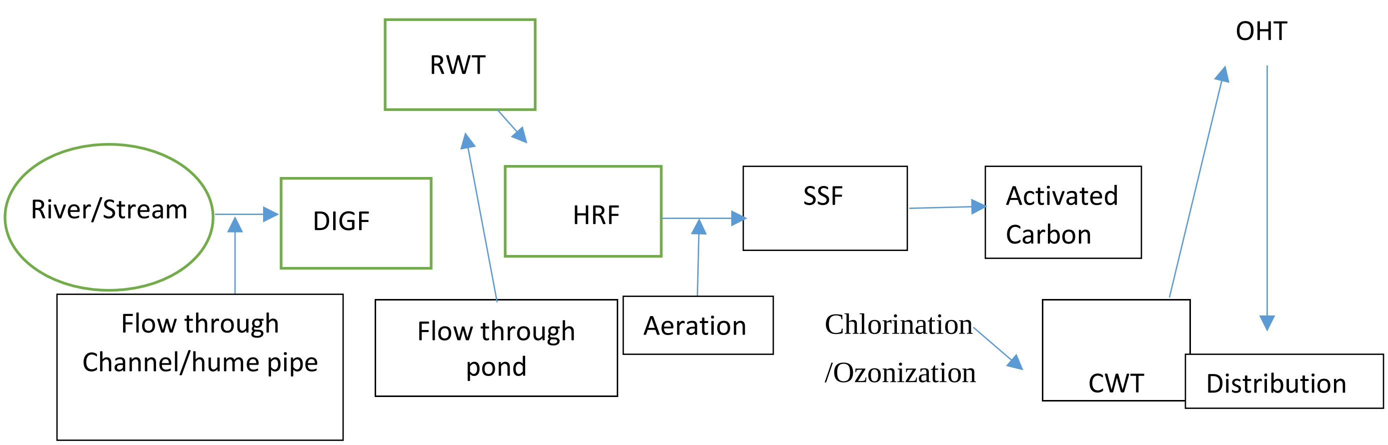
Figure 53: Washing of Activated carbon

5.3.2 Filter Run Procedure:

A Monoblock pump is used to lift water from the pond the near fluvial lab to our storage tank. In storage tank consists of 3 flow control valves which control the rate of flow. From the storage tank water flows through 3 different stairs with three different flow rates, 1st chamber with 5lt/h, 2nd chamber with 10lt/h, and 3rd chamber with a flow rate 15lt/h. The water is aerated by means of a cascade Aeration process before being treated through a Slow Sand Filter (SSF). After treatment with SSF, the water flows through an Activated Carbon Filter (ACF) and is collected in the tank. we collect water samples from different stages and test that water.

5.4 EXPERIMENTAL DESIGN

5.4.1 Flow Diagram of Multistage Filtration



- **Flow Procedure:**

Water from the river flows through a Dynamic Intake Gravel Filter (DIGF) combined with a channel/hume pipe which leads to a pond. The channel/hume pipe is located at such depth that continuous water supply from the river is maintained. Further the water will be pumped out of the pond and stored in a Raw Water Tank (RWT) in order to provide sufficient head pressure for the gravity-based treatment process. From there the raw water flows through a Horizontal Roughing Filter (HRF) that serves as a pre-treatment step. In the following, the water is aerated by means of a cascade Aeration process before being treated through a Slow Sand Filter (SSF). After treatment with SSF, the water flows through an Activated Carbon Filter (ACF) and is collected in the Clear Water Tank (CWT). In this tank the water is chlorinated and further pumped to the Overhead tank (OHT). Form this tank the water is supplied to the stand posts /households. Every treatment unit has two chambers in parallel and is dimensioned to be able to treat double the amount of water as compared to its standard capacity. This is required for maintenance of the system.

5.4.2 Design of Pre-Treatment plant

5.4.2.1 Horizontal Roughing Filter

Output Flow rate (Q_{HO}) =0.33 m^3/day = 0.0138 m^3/hr

Filtration Rate (V_{Hf}) = 0.3 m/hr (Range= 0.3-1.5 m/hr)

Filter Area= (Q_{HO}/ V_{Hf}) = Q_{HO}/ ($B_h \times h_h$)

= (0.0125/0.5) m^2

=0.046 m^2

0.0154 m^2 for each chamber

Providing 3 chambers area of 0.02 m^2

Filter Depth (h_h)= 0.2 m

Filter Width (W_h) = 0.02/0.2m = 0.1 m

Considered four compartment of gravel size 10 mm, 5 mm, 3 mm and 2 mm are placed accordingly,

So, L1 = 1m for 10 mm Gravel

L2 = 0.5m for 5 mm Gravel

L3 = 0.3 m for 3 mm Gravel

L4 = 0.2 m for 2 mm Gravel

So, Filter Length (L_h) = L_1+ L_2+ L_3+L_4 =2 m

Filter Depth (H_h) = 0.2 m (Range =0.8-1.2 m)

Average Drainage velocity (V_{hd})= 60 m/hr (range= 60-90 m/hr)

Drainage Rate (Q_{hd})= V_{hd} × (L_h× W_h)

= 60×2×0.0125 m3/h

=1.5 m3/h =0.025 m^3/min

For cleaning gravel of HRF 0.025 m^3/min flow rate will be required

Now, Considered Head loss = 0.05 m

Total Depth of HRF (H_h) = h_h + Head loss +free Board = 0.2+ 0.05+0.05m = 0.3 m

Roughing filter Dimension (L_h× W_h ×H_h)

= (2 × 0.0125× 1.1) m for each chamber which include 4 compartments of different size of Gravel.

5.4.2.2 Design of Slow Sand Filter

Required Output flow (Q_{SO}): 300LD = 0.3 m^3/day

Consider Loss= 10% =0.1

Input Flow (Q_{si}) = 0.3 + (0.3*0.1) = 0.33m^3/day = (0.33/24) m^3/hr = 0.01375 m^3/hr

Consider Filtration Rate (V_{SF})= 0.1 m/hr (Range: 0.1-0.2 m/hr)

Cross Sectional Area (A_F) = Q_{si} / V_{SF} = 0.01375/0.1 m^2

=0.1375 m^2=0.15m^2(provided)

Providing 3 chambers area of each 0.06 m^2

Filter Length (L_S) =0.5 m

Filter Width (W_S) = 0.06/0.5 = 0.12 m

Height of Sand Layer (h_S) = 0.6 m

Sand volume in filter= (0.5*0.12*0.6) = 0.036 m^3 for each chamber

Height of Gravel layer under Sand (h_{sg}) = 0.07 m

Gravel Volume in Filter= 0.5×0.12 × 0.07 m^3 = **0.0042m^3** for each chamber

Maximum height of supernatant water over sand layer=0.4m

Total Depth (H) = $h_S + h_g + H_s$ +Freeboard = (0.6+ 0.07+ 0.4 + 0.03) = 1.1 m

Slow Sand Filter Dimension (Inner) = (L×B×H) **= (0.5 × 0.12× 1.1)** m^3 for each chamber

Sand Selection

Uniform Coefficient (C_U)= 3-5

Effective particle size(d_s)=0.2-0.35 mm

5.4.2.3 Aeration Process

Required Dissolved Oxygen= 6 mg/L
Total Amount of Water=0.3 KLD= 300 L/D

- **Cascade Aeration:**

Aeration efficiency

E= $\frac{C_d - C_u}{C_s - C_u}$………..

Where C_d = Concentration of dissolved oxygen in the downstream of hydraulic structure

C_u = Concentration of dissolved oxygen in the upstream of hydraulic structure

C_s =Saturated level of dissolved oxygen for a given ambient conditions

mass transfer similitude to adjust aeration efficiency to 20^0C and denoted as E_{20}

$E_{20} = 1-(1-E)^{(1/f)}$

Where $f = 1.0+0.02103(T-20) + 8.261\times10^{-5}(T-20)^2$

Now, taken average temperature= 31ºC

So, $f = 1.0+0.02103(31-20) + 8.261\times10^{-5}(31-20)^2$

= 1.2413

Now, C_d =6 mg/L, C_u =1 mg/L, C_s = 7.4 mg/L for 31ºC (Maximum Dissolved Oxygen Concentration Saturation Table),

So, E = (6-1)/ (7.4-1) = 0.781

So, $E_{20} = 1-(1-0.781)^{(1/1.2413)} = 0.7058$

The conditions given by Chanson, 2002 for a nappe flow over the stepped cascades,

dc/h ≤ 0.89 - (h/l); 0.06 ≤ (h/l) ≤ 1.8 and > 0.02 m

Where, dc = $(q_w^2/g)^{1/3}$ = critical depth in a rectangular prismatic channel (m), q_w is hydraulic loading rate (m^3/ m of width /day); h is step height (m); l is step length (m)

Now Flow=0.33 m^3/day =0.0137 m^3/hr (taken 24 hr of running) = 0.000003805 m^3/sec

Taken platform Width =0.36 m, Length= 0.12 m

Cross-sectional Area= 0.0432 m^2

hydraulic loading rate (q_w) = (0.000003805/0.0432) =0.0000881 m^3/sec/m^2

Now assume step height = 0.05 m

So, d_C =0.000925 m

So, l = 0.057 m, (Hence ok)

Consider Step length= 0.10 m

Consider 10 steps, Total Height (H) =0.05×10= 0.50 m

Size of each step is =(0.10*0.12*0.05) m

Total Length (L) =0.10×10 =1 m

5.4.2.4 Activated Carbon Process

Granular activated carbon (GAC) is commonly used for removing organic constituents and residual disinfectants in water supplies and maintain desired colour and odour for drinking water.

Table 4: Typical Properties of Granular Activated Carbon

	Bituminous	**Sub-bituminous**	**Lignite**	**Nut Shell**
Iodine Number	1,000-1,100	800-900	600	1,000
Molasses Number	235	230	300	0
Abrasion Number	80-90	75	60	97
Bulk Density as packed LB/CF	26-28	25-26	23	29-30
Volume Activity	26,000	25,000	13,800	0

For good water treatment, Iodine Number should be in the range of 900-1050

Abrasion Number should be more than 70 for vigorous back washing

Selected Granular Activated Carbon is Nutshell Type and provided mesh of 12×40 which measures 1mm particle size,

As per design considerations,

Minimum column diameter (D_{AC}) to avoid channeling of more than 70 times of effective size

$$= 70 \times 1 \text{ mm} = 70 \text{ mm} = 7\text{cm}$$

The superficial contact time (minutes) = Carbon Volume (m^3) × 60 (min/hr)/ Flow rate(m^3/hr)

Now consider superficial contact time = 20 minutes (Ranges 6-30minutes)

Carbon Volume (V_{AC}) = Contact Time × Flow rate/60

$$=20*0.01375/60= 0.00458 \text{ m}^3$$

So, providing 3 chambers of 0.0015 m^3 granulated activated carbon.

Linear Velocity (m/h) **=** Flow rate (m^3/hr) /Surface area

Considered Linear velocity =0.3 m/hr

Surface Area of GAC = Flow rate / Linear velocity

= 0.00458/0.3 m^2 =0.01527 m^2 (flow rate divided in 3 as for providing 3 chambers, 0.01375/3)

So, Surface Area (a_{AC}) = 0.015 m^2 per chamber

Diameter of Activated Carbon column (d_{AC}) = (A_{AC} ×4/)

$$= (0.015\times4/) \text{ m} = 0.138 \text{ m}$$

Now, provide 0.17 m or 17 cm dia. Activated carbon column,

So, Design Surface Area (A_{AC}) = $\pi \times 0.17^2/4$ = 0.0227 m^2

Height of column (H_{AC}) = (V_{AC} /A_{AC}) = (0.015 /0.0227) =0.67 m

Provide 0.7 m for Activated Carbon Column height

Ratio activated carbon bed/column diameter (H_{AC} /D_{AC}) = (0.7/.14) = 5

Provided Activated carbon volume (V_{AC}) = H_{AC} × A_{AC} =0.7 ×0.0227= 0.01589 m^3

Contact Time = 0.015 × 60/0.01589 min =57 min

Considered Head Loss=

using the equation provided by the excel sheet:

Head Loss (HL_{AC}) = V_F x h_{AC}/hydraulic conductivity of filter media k

= 0.3 m/h x 0.7 m/36 (m/h) = 0.085 m

Height of Gravel Support (G_{AC})= 0.06 m

Total Height of Activated Carbon Filter= H_{AC} + G_{AC} + free board+ Head Loss

=0.7 +0.06+ 0.075+0.085 = 0.92 m

Now, backwashed and drained density of Activated Carbon = 425 kg/m^3

Total Activated Carbon required= 425 × **0.01589** = 6.7 kg for each column

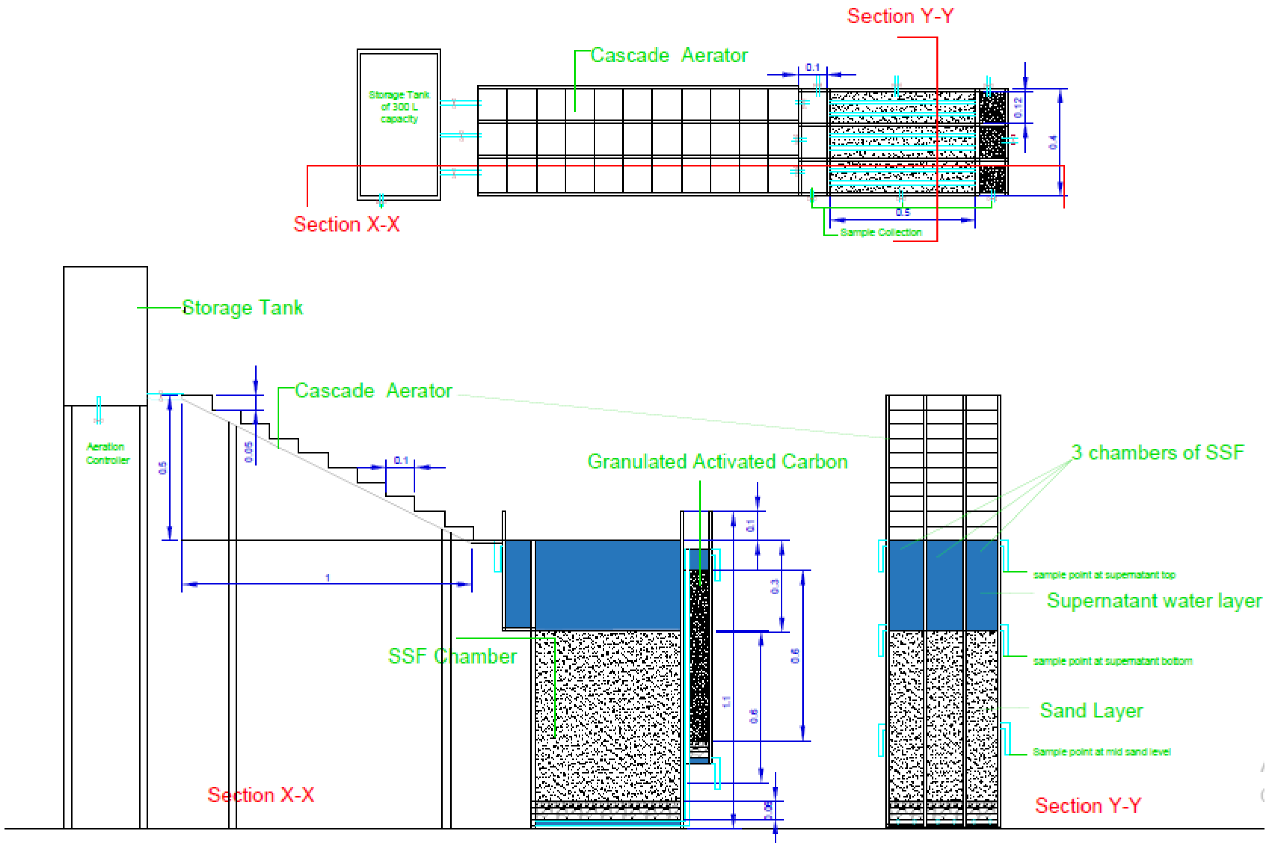


Figure 54: Model Diagram

Chapter 6

6. Result and Discussion:

6.1 Aeration Efficiency: A cascade-type aerator has been set up and measured to increase dissolved oxygen efficiency with different slope angles with different steps.

Observation: At slope angle=20.6°

Flow Rate (lt/h)	Efficiency at step 10	Efficiency at step 8	Efficiency at step 6	Efficiency at step 4	Efficiency at step 2
5	89.08	75.98	71.18	64	52.29
10	82.59	72.54	70.67	57.27	43.04
15	77.99	69.64	65.76	51.08	39.48
20	75.68	67.48	54.24	40.29	27.77

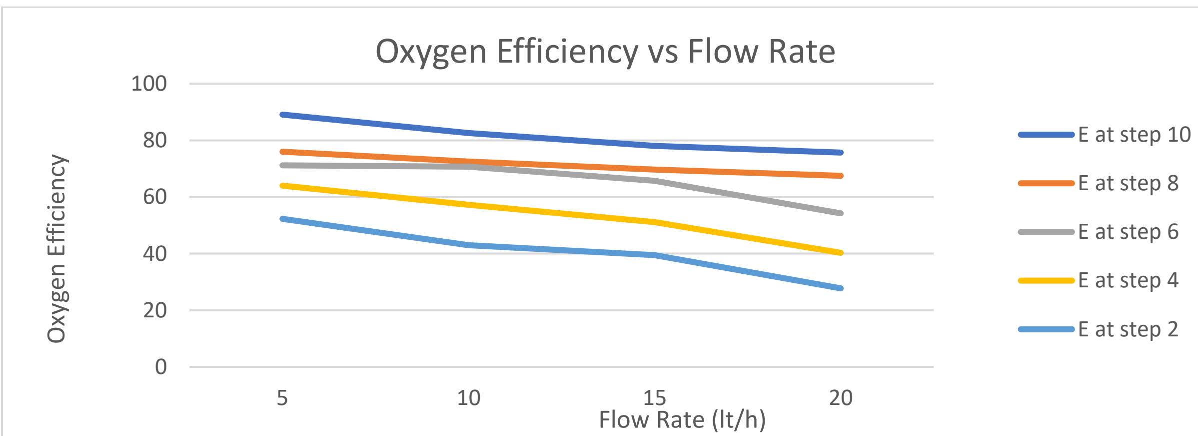


Figure 55: Oxygen Efficiency vs Flow Rate

6.2: Raw Water Test Result: Raw water sample was collected for a different date from the pond near the fluvial lab. After testing the sample, got the avg. test result given in table 4.

Table 5: Raw Water Test Result

Sl. No.	Parameter	Avg. value of 5 days sample Test Result	unit
1.	Turbidity	4.37-5.4	NTU
2.	TDS	710-738	mg/l
3.	pH	7.66	
4.	Phosphate	0.07-0.1	mg/l
5.	Nitrate	1.672-1.9	mg/l
6.	Sulphate	22.8-25	mg/l

7.	Iron	0.32-0.41	mg/l
8.	Colour	<5	Hazen Units
9.	Odour	Agreeable	

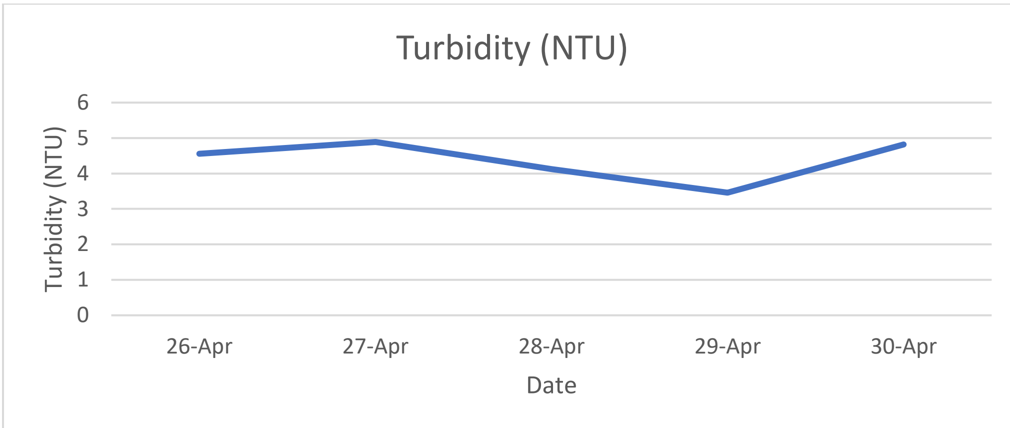


Figure 56: Variation of Turbidity of raw water

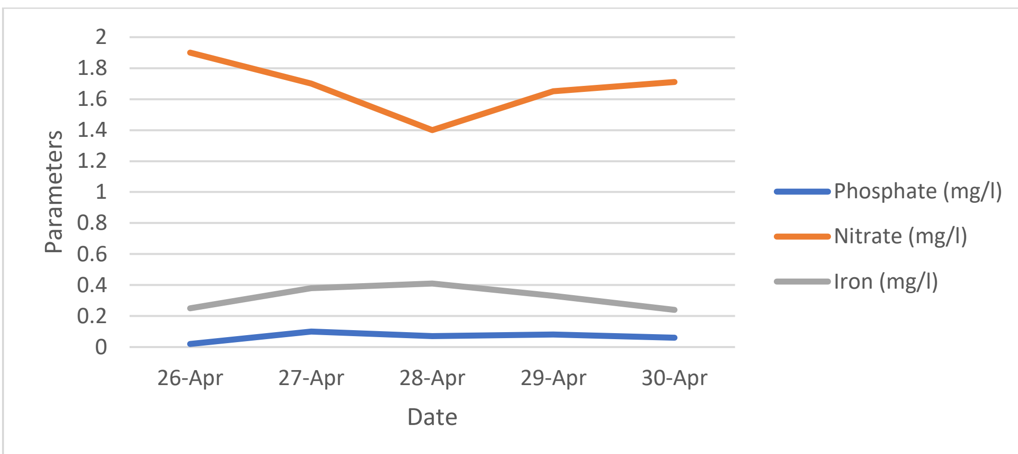


Figure 57: Variation of different parameters test result with date

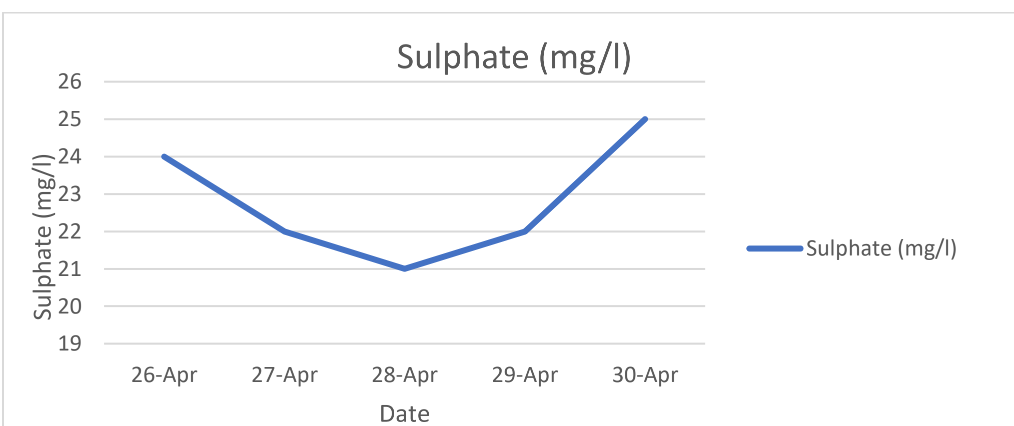


Figure 58: Variation of Sulphate in raw water

6.3: Treated Water Test Result after SSF & ACF: The model filter was run for 3 days and collected sample water after SSF &ACF. After testing, the test result comes out given in the table below.

Table 6: Removal Efficiency of different parameters

Sl. No	Parameters	Unit	Avg. value of 5 days sample Test Result	Treated water Sample Test Result after SSF	Treated water Sample Test Result after ACF	Removal efficiency after SSF	Removal efficiency after ACF	Overall Efficiency	Desirable limit	Permissible limit
1	Turbidity	NTU	4.37-5.4	1.18-1.4	0.7-1.1	73%-74%	40.67%-21.48%	84%-79.63%	1	5
2	TDS	mg/l	710-738	655-687	636-661	7.746%-6.9%	2.9%-3.78%	10.42%-10.43%	500	2000
3	pH		7.66	8.02	8.4					6.5-8.5
5	Phosphate	mg/l	0.07-0.1	0.03-0.06	0.02-.03	57.1%-40%	33.33%-50%	71.4%-70%		
6	Nitrate	mg/l	1.672-1.9	0.89-1.1	0.71-.87	46.77%-42.10%	20.2%-20.9%	57.54%-54.21%	45	45
7	Sulphate	mg/l	22.8-25	16.1-19.3	14.3-16.2	29.3%-22.8%	11.18%-16%	37.2%-35.2%	200	400
8	Iron	mg/l	0.32-0.41	0.22-0.33	0.1-0.18	31.25%-19.5%	54%-45%	68.75%-56.1%	1	1
9	Colour	Hazen Units	<5	<5	<5				5	15
10	Odour		Agreeable	Agreeable	Agreeable					
11	Total Hardness (as CaCO3)	mg/l	160		120			25%	200	600

12	Chloride (as Cl)	mg/l	293		196.31			33%	250	1000
13	TSS)	(mg/L	12		8.04			33%		

Overall Turbidity removal efficiency with this MSF model is nearly 82%. Turbidity present in raw water is within Permissible limit after treatment it is within desirable limit.

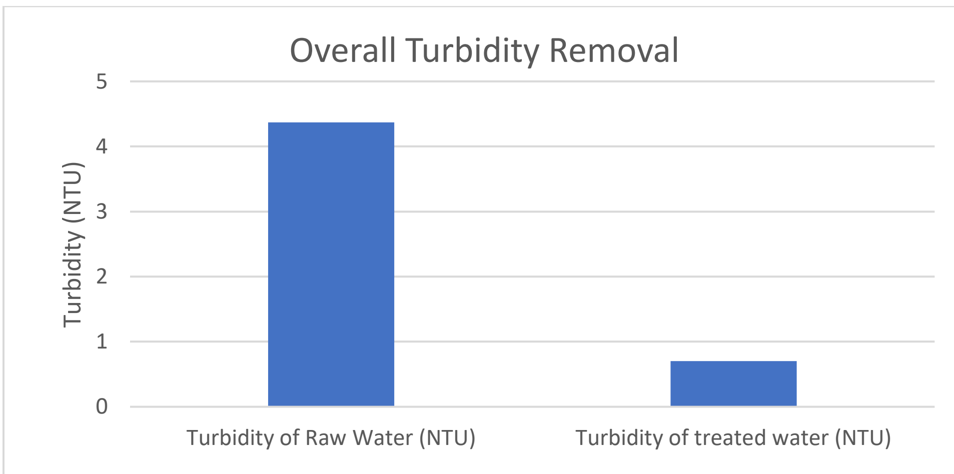


Figure 59: Shows overall turbidity removal in MSF model

Overall TDS removal efficiency with this MSF model is nearly 10%. TDS present in raw water is more than desirable limit after treatment it is also more than desirable limit.

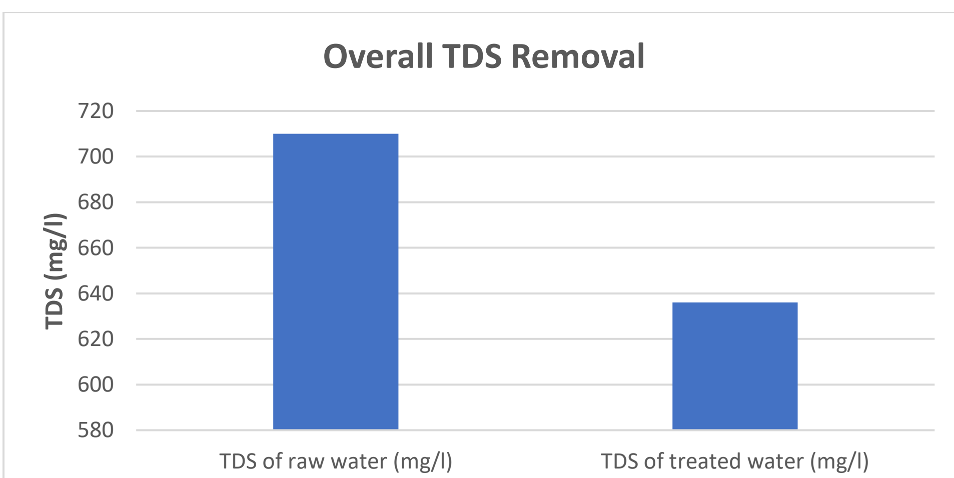


Figure 60: Shows overall TDS removal in MSF model

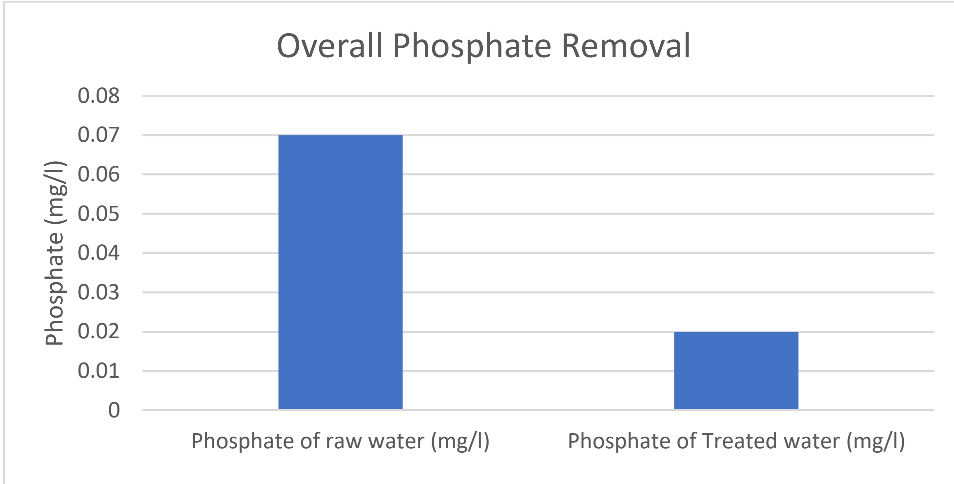


Figure 61: Shows overall Phosphate removal in MSF model

Overall Nitrate removal efficiency with this MSF model is nearly 56%. Nitrate present in raw water and treated water sample is within desirable limit.

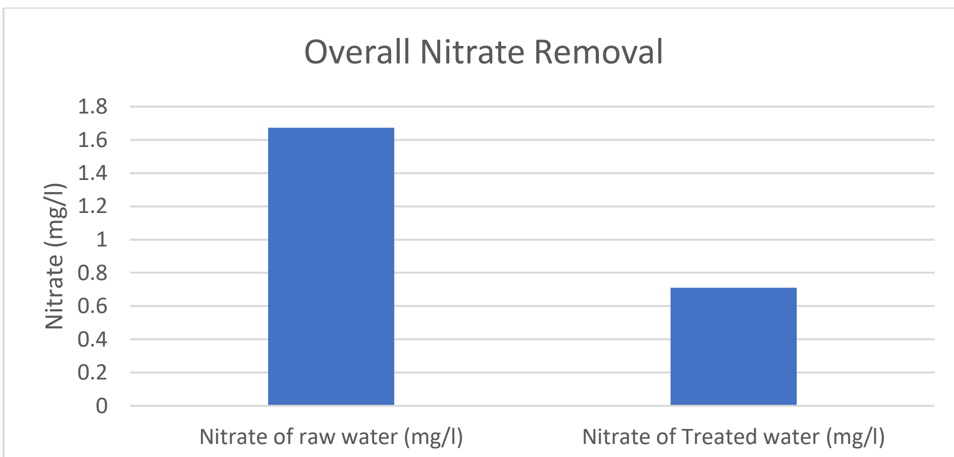


Figure 62: Shows overall Nitrate removal in MSF model

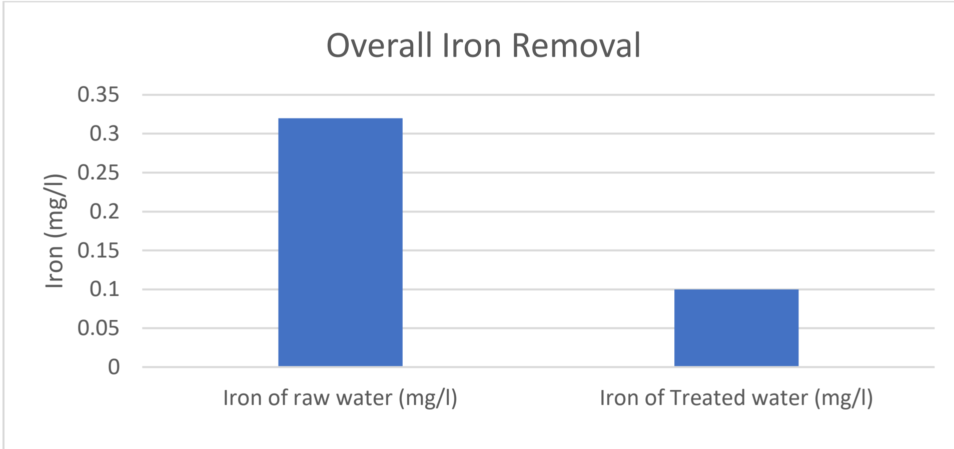


Figure 63: Shows overall Iron removal in MSF model

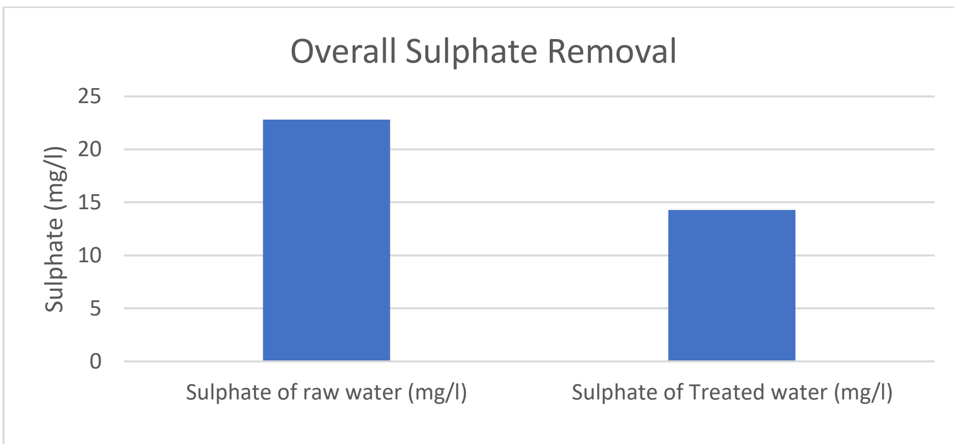


Figure 64: Shows overall Sulphate removal in the MSF model

6.4: Pesticide removal efficiency in treated water: pesticide present in pond water and removal after treatment is measured with Gas chromatography–mass spectrometry. Pesticide removal in MSF model filter given in the below table

Table 7: Removal Efficiency of Pesticide

Water Quality Parameters (µg/l) (Pesticides)	Raw water sample test result	Treated water sample test result	Efficiency	Desirable Limit
α-BHC	BDL	BDL	BDL	0.01
β-BHC	0.006	0.0015	75%	0.04
γ-BHC	0.019	0.00627	67%	0.04
δ-BHC	0.023	0.00759	67%	2

Heptachlor	0.245	0.0294	88%	0.4
Aldrin	0.089	0.00267	97%	0.03
Heptachlor Epoxide	0.878	**0.25462**	71%	0.2
α-Endosulfan	BDL	BDL	BDL	0.4
p,p' DDE	BDL	BDL	BDL	1
Dieldrin	0.023	BDL	BDL	0.3
Endrin	BDL	BDL	BDL	0.6
p,p' DDD	BDL	BDL	BDL	1
Endrin aldehyde	0.148	0.0814	45%	0.6
4-4' DDT	BDL	BDL	BDL	1
Methoxychlor	BDL	BDL	BDL	0.4
Endosulfan Sulphate	BDL	BDL	BDL	0.4
Endosulfan-II	BDL	BDL	BDL	0.4

Different type of pesticide present in pond water, among them some are below detectable limit. β-BHC pesticides removal efficiency with this MSF model is nearly 75% that is shown in Fig. 65.

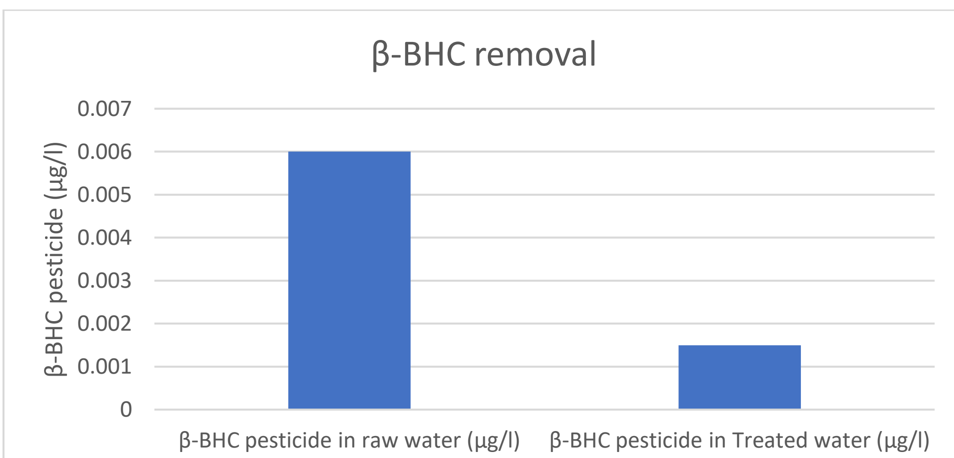


Figure 65: Shows β-BHC removal in the MSF model

γ-BHC pesticides removal efficiency with this MSF model is nearly 67%. γ-BHC pesticides present in raw water is within desirable limit after treatment it is also within desirable limit.

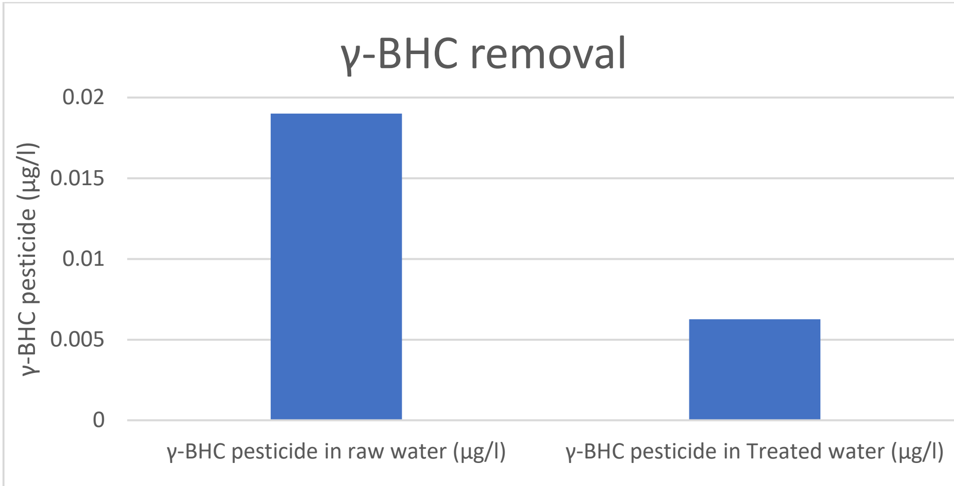


Figure 66: Shows γ-BHC removal in the MSF model

Heptachlor pesticides removal efficiency with this MSF model is nearly 88%. Heptachlor pesticides present in raw water is within desirable limit after treatment it is also within desirable limit

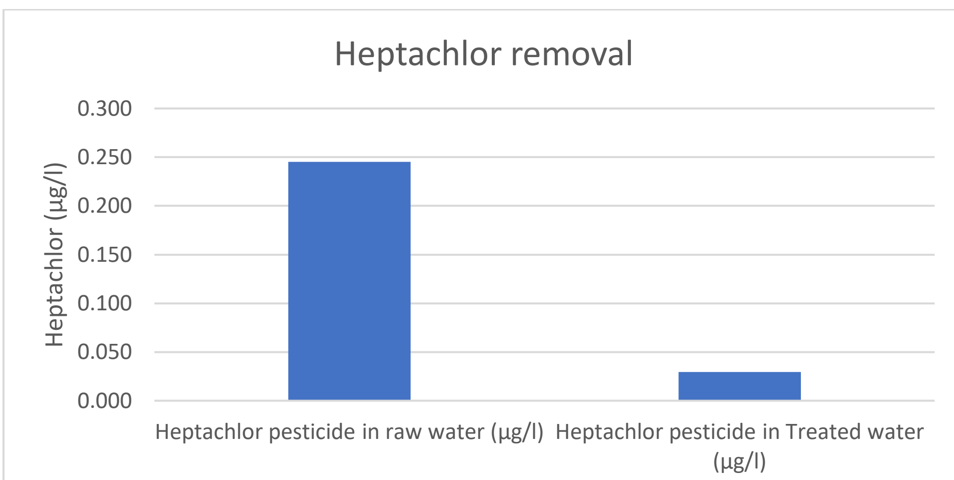


Figure 67: Shows Heptachlor removal in the MSF model

Aldrin pesticides removal efficiency with this MSF model is nearly 97% (Fig. 68). Aldrin pesticides present in raw water is more than desirable limit after treatment it is within desirable limit.

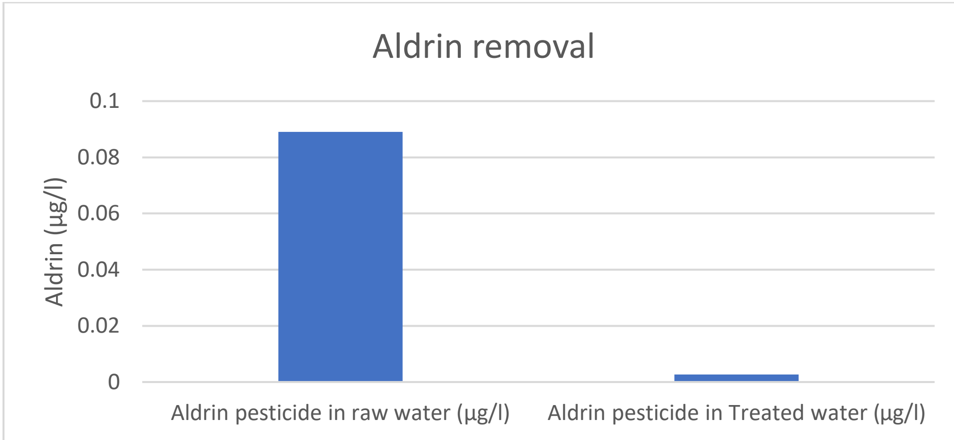


Figure 68: Shows Aldrin removal in the MSF model

Endrin aldehyde pesticides removal efficiency with this MSF model is nearly 45% (Fig. 69). Endrin aldehyde pesticides present in raw water is more than desirable limit after treatment it is within desirable limit.

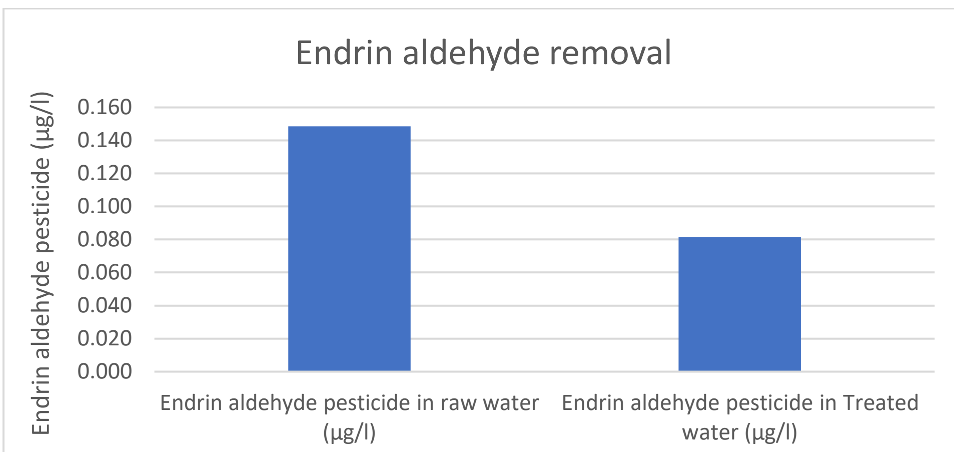


Figure 69: Shows Endrin aldehyde removal in the MSF model

Heptachlor Epoxide pesticides removal efficiency with this MSF model is nearly 71% (Fig. 70). Heptachlor Epoxide pesticides present in raw water is more than desirable limit after treatment it is also more than desirable limit.

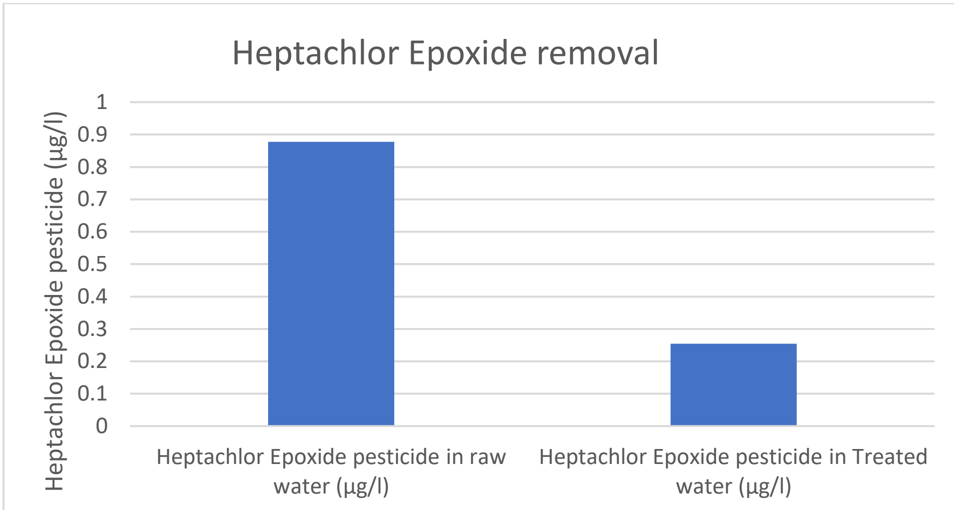


Figure 70: Shows Heptachlor Epoxide removal in the MSF model

Chapter 7

Conclusions:

The purpose of the present study is to check the removal efficiency of different physical and chemical parameters present in surface water with the MSF model. Also checking the efficiency of cascade type aerator to increase the dissolved oxygen level before flow entering into SSF model. It has been observed that theoretical efficiency is nearly the same as practical efficiency and also observed that with a decreased flow rate dissolved oxygen level got increases. Another observation that has been noticed is that with an increase in slope angle dissolved oxygen level got increased.

Trial run of the Filter is measured with a different flow rate (0.085 $m^3/m^2/hr$, 0.165 $m^3/m^2/hr$, 0.25 $m^3/m^2/hr$, 0.33 $m^3/m^2/hr$) which satisfies the general flow rate (0.1-0.2 $m^3/m^2/hr$) condition of SSF. When the filter is run with a flow rate of 0.085 $m^3/m^2/hr$, step 10 and slope angle of 20.6°, aeration efficiency is nearly 89.08% and Dissolved oxygen level in water reached to 6.65 (mg/l) which is favorable for SSF.

From all the experimental results and data, it can be concluded that overall turbidity removal with MSF is nearly 84%. Phosphate and iron removal efficiency are consecutively 71% and 68%. Emerging pollutant (pesticide) removal efficiency is also good.

Limitation:

The model filter was not able to run for more than two weeks due to the short time, with this limited time data it can't say clearly how our filter is efficient to remove all physical and chemical parameters. Overall efficiency in removing TDS is not so good. It was not able to check the effect of change of flow rate in removing efficiency.

Recommendation:

The model filter needs to run for more time and should collect a more treated water sample from the different stages. Then it is required to check the removal efficiency of our filter model. Also, it needs to check the removal efficiency of other variety of Eps present in surface water.

Further investigate if horizontal roughing filter is added before SSF how turbidity and other parameters will removed.

Investigate the impact of a 'dynamic' roughing filter prior to the multistage filter to protect the system from solids overloading during extreme events of high turbidity.

After changing the flow rate how our filter efficiency will be changed, need to be checked. Also, we have to check the efficiency to remove fecal coliform bacteria if present in raw water.

Chapter 8

8. References

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