Performance and Reliability Analysis of a Multi-Stage Filtration (MSF) System in the Treatment of Urban Pond Water: A Case Study of Kolkata City

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Submitted by

DIPIKA PODDER
Roll No: MRWRE24018
Reg. No.: **163871 of 2022 - 2023**

Under the guidance of

PROF. (DR.) ASIS MAZUMDAR
Professor of Water Resources Engineering
School Of Water Resources Engineering, Jadavpur University

Dr. GOURAB BANERJEE
Assistant Professor
School of Water Resources Engineering, Jadavpur University

School of Water Resources Engineering
M.E. (Water Resources & Hydraulic Engineering) course affiliated to
Faculty of Engineering & Technology
Jadavpur University
Kolkata 700032, India
2024

M.E. (Water Resources & Hydraulic Engineering) course affiliated to
Faculty of Engineering and Technology
Jadavpur University Kolkata, India

Certificate of Recommendation

This is to certify that the thesis entitled "**Performance and Reliability Analysis of a Multi-Stage Filtration (MSF) System in the Treatment of Urban Pond Water: A Case Study of Kolkata City**" is a bonafide work carried out by **Ms. Dipika Podder** our supervision and guidance for partial fulfilment of the requirementfor the Post Graduate Degree of Master of Engineering in Water Resources & Hydraulic Engineering during the academic session 2022-2024.

THESIS ADVISOR
Prof. (Dr.) Asis Mazumdar
Director & Professor
of Water Resource Engineering
School of Water Resources Engineering
Jadavpur University

THESIS ADVISOR
Dr. Gourab Banerjee
Assistant Professor
School of Water Resources Engineering
Jadavpur University
Kolkata-700032

DIRECTOR
Prof. (Dr.) Asis Mazumdar
School of Water Resources Engineering
Jadavpur University

DEAN
Faculty of Interdisciplinary Studies, Law & Management
Jadavpur University

M.E. (Water Resources & Hydraulic Engineering) course affiliated to
Faculty of Engineering and Technology
Jadavpur University Kolkata, India

CERTIFICATE OF APPROVAL **

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

Committee of Final Examination

for the evaluation of the thesis

****** Only in case the thesis is approved

DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my **Master of Engineering** in **Water Resources & Hydraulic Engineering** in the Faculty of Interdisciplinary Studies, Jadavpur University during academic session 2022-2024.

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

I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

NAME : **DIPIKA PODDER**

ROLL NUMBER : **M4WRE24018**

THESIS TITLE : **Performance and Reliability Analysis of a Multi-Stage Filtration (MSF) System in the Treatment of Urban Pond Water: A Case Study of Kolkata City**

SIGNATURE :

DATE :

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Date :

DIPIKA PODDER

Roll No M4WRE24018

ABSTRACT

This research evaluates the critical missing data optimization during water filtration. The research offers valuable insights for improving water quality and managing excess parameters in this location. Filtration constitutes a fundamental component of most water treatment systems, with filtration emerging as a novel and promising method for filtering potable water in developing regions. This research Optimization by providing a detailed analysis of interpolation methods for handling missing turbidity data and their implications for Multi-Stage Filtration processes. It mainly explores the application of interpolation techniques (Linear Interpolation) to address the issue of missing turbidity data in Filtration Model. Turbidity, a key parameter in assessing water quality, often suffers from incomplete data sets due to Missing data, data transmission errors, or other disruptions. Missing data can significantly impact the accuracy of water quality assessments and subsequent decision-making processes. The study integrates this interpolation approach with a filtration model that employs a Multi-Stage Filtration system, incorporating a Slow Sand Filter as a key component. The study found that the SSF model was effective in removing turbidity, with an overall removal efficiency of about 91%. The study also highlighted the importance of sand depth in increasing the removal efficiency of the SSF model. Based on the findings, a field-scale SSF unit was designed for a critical point identified in the study. Future research could also explore the integration of interpolation with advanced statistical and machine learning techniques to further enhance the accuracy and robustness of missing data estimation. Water samples were collected daily from both the inlet water tank and outlet pipe for laboratory analysis parameters such as Turbidity, pH, TDS, DO etc. Jadavpur University Jheel's water is highly contaminated in high turbidity which may have effects on the health of local inhabitants and aquatic ecosystems, which is almost removed in Multi Stage Filtration Model. interpolation proves to be an indispensable tool for handling missing data, and its significance in future studies cannot be overstated so the study concludes that Interpolation is the best process if any of day's data are missing or disrupt.

Keywords: Multistage Filtration, Interpolation, Water treatment, SSF, Turbidity, Error analysis,

ABBREVIATIONS

DOC: Dissolved Organic Carbon MSF: Multi-Stage Filtration SSF: Slow Sand Filter

GAC: Granular Activated Carbon

HRF: Horizontal Roughing Filter

TDS: Total Dissolved Solids

FC: Fecal coliform

UV: Ultra Violet

NTU: Nephelometric turbidity unit

SS: Suspended Solids

BAC: Biological Activated Carbon

BF: Bio-Filtration

MF: Micro-filtration

UF: Ultra-filtration

NF: Nano-filtration

BDOC: Biodegradable Dissolved Organic Carbon

ASSF: Aerated Slow Sand Filter

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CHAPTER: 1

INTRODUCTION

CHAPTER: 1

INTRODUCTION

1.1. HISTORICAL BACKGROUND

Surface water may also show unpredictable and erratic changes in quality due to run-off during rainy periods. This is a critical problem for waterworks operators, for example, in some Andean and Caribbean countries where 80% of water supply systems depend on surface water (Foster et al, 1987; Colombian Development Department, 1998). Surface watermay carry considerable sanitary risk and require treatment to remove or reduce disease causing organisms. This risk is lower for well protected sources in the mountains than for lowland rivers in populated areas. Fresh clean water is a basic necessity for life on earth. Theamount of freshwater available has been on a rapid decline. Preserving the quality of freshwater is important for the survival of human life. Most of the diseases can be prevented through the access of freshwater. The World Health Organization (WHO) has estimated that 842 000 deaths occur every year due to unsafe water supply, sanitation and hygiene, mostly in low-income countries. The global burden of diarrheal disease from inadequate potable water, sanitation and hygiene (WASH) was estimated for 145 low- and middle income countries (LMICs) for the year 2012.

Water treatment originally focused on improving the aesthetic qualities of drinking water. Methods to improve the taste and odour of drinking water were recorded as early as 4000 B.C. Ancient Sanskrit and Greek writings recommended water treatment methods such as filtering through charcoal, exposing to sunlight, boiling, and straining. Visible cloudiness (later termed as Turbidity) was the driving force behind the earliest water treatments, as manysource waters contained particles that had an objectionable taste and appearance. To clarify water, the Egyptians reportedly used the chemical alum as early as 1500 B.C. to cause suspended particles to settle out of water. During the 1700s, filtration was established as an effective means of removing particles from water, although the degree of clarity achieved was not measurable at that time. By the early 1800s, slow sand filtration was beginning to be used regularly in Europe. During the mid to late 1800s, scientists gained a greater understanding of the sources and effects of drinking water contaminants, especially those thatwere not visible to the naked eye. In 1855, epidemiologist Dr. John Snow proved that cholerawas a waterborne disease by linking an outbreak of illness in London to a public well that was contaminated by sewage. In the late 1880s, Louis Pasteur demonstrated the “germ theory” of disease, which explained how microscopic organisms (microbes) could transmit disease through media like water.

During the late nineteenth and early twentieth century, concerns regarding drinking water quality continued to focus mostly on disease causing microbes (pathogens) in public water supplies. Scientists discovered that turbidity was not only an aesthetic problem; particles in source water, such as faecal matter. As a result, the design of most drinking water treatment systems were built during the early 1900s was driven by the need to reduce turbidity, thereby removing microbial contaminants that were causing typhoid, dysentery, and cholera

epidemics. To reduce turbidity, some water systems began to use slow sand filtration. While filtration was a fairly effective treatment method for reducing turbidity, it was disinfectants like chlorine that played the largest role in reducing the number of waterborne disease outbreaks in the early 1900s. In 1908, chlorine was used for the first time as a primary disinfectant of drinking water in Jersey City, New Jersey. The use of other disinfectants such as ozone also began in Europe around this time.

By the late 1960s it became apparent that the aesthetic problems, pathogens, and chemicals identified by the Public Health Service were not the only drinking water quality concerns. Industrial and agricultural advances and the creation of new man-made chemicals also had negative impacts on the environment and public health. Many of these new chemicals were finding their way into water supplies through factory discharges, street and farm field runoff, and leaking underground storage and disposal tanks. Although treatment techniques such as aeration, flocculation, and granular activated carbon adsorption (for removal of organic contaminants) existed at the time, they were either underutilized by water systems or ineffective at removing some new contaminants.

According to a 2007 World Health Organization (WHO) report, 1.1 billion people lack access to an improved drinking water supply, 88 percent of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, and 1.8 million people die from diarrheal diseases each year. The WHO estimates that 94 percent of these diarrheal cases are preventable through modifications to the environment, including access to safe water. Simple techniques for treating water at home, such as chlorination, filters, and solar disinfection, and storing it in safe containers could save a huge number of lives each year. Reducing deaths from waterborne diseases is a major public health goal in developing countries.

Slow sand filtration (SSF) is the oldest water treatment technique used in water supply systems and has been successfully implemented in northern Europe and North America for treating surface water with relatively low levels of contamination (Rachwal et al, 1988; Simsand Slezak, 1991). Experience with SSF has not been successful In Latin American countriessuch as Brazil (Hespanhol, 1969; Di Bernardo, et al., 1999), Peru (Canepa, 1982; Pardón, 1989) and Colombia, where high turbidity levels in the rivers caused premature clogging of the filters, resulting in the need for frequent cleaning and the ultimate abandonment of many systems.

This failure contributed to increased worldwide interest in Rapid Sand Filtration (RSF) of chemically coagulated water. RSF has evolved quickly during past decades and Latin American engineers have made important contributions to upgrading the processes and simplifying the equipment, making operation and maintenance (O&M) less complex, and reducing investment and operational costs (Arboleda, 1993; Di Bernardo, 1993). However, O&M remains demanding and the purchase, transport, storage, and correct dosage with chemical compounds is complex and costly. This technology is better suited to larger treatment plants since the administrative and technical challenges limit its wider application in community water supply for small and medium sized rural communities and municipalities. Even modern compact automated RF plants are subject to the same O&M problems.

1.2. STUDY SETUP

The present study has conducted on a model which is situated in Fluvial Hydraulics Laboratory, School of Water Resources Engineering, Jadavpur University Kolkata. The water body, commonly referred to as "Jadavpur University Jheel," serves as a reservoir for rainwater harvesting and is the primary source of surface water supply. The pond is rectangular in shape, spanning approximately 147.8 meters in length and 43.2 meters in breadth. The city lies about 136.79 kilometres (86 miles) away from the sea and 4.57–6.09 metres (15–20 feet) above the mean sea level [Imperial Gazetteer of India, 1984] which is shown in **Fig: 1.2.** According to the Census of India [2011], Kolkata had 4.5 million population with density 24,252 persons per Km2.The annual mean temperature is 26.8 °C (80°F) and monthly mean temperatures ranges from 19 °C to 30 °C (67°F to 86°F).
Maximum rainfall occurs during the month of August (306 mm) and the average annual total is 1,582 mm [District Census Handbook, 2001].

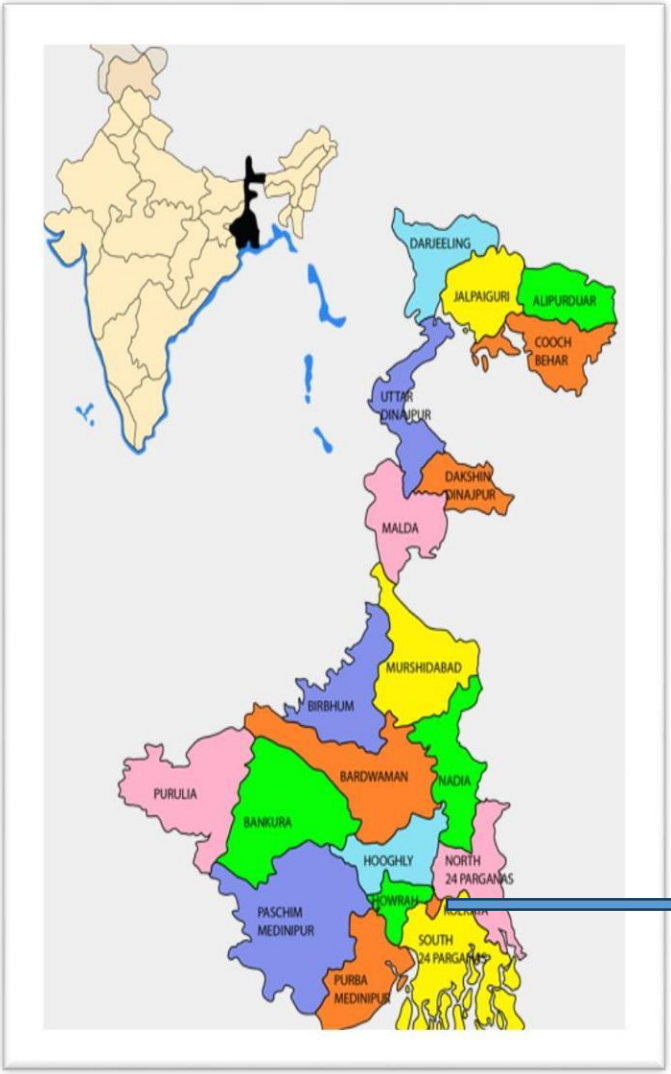


Figure 1.1 Map of India and West Bengal

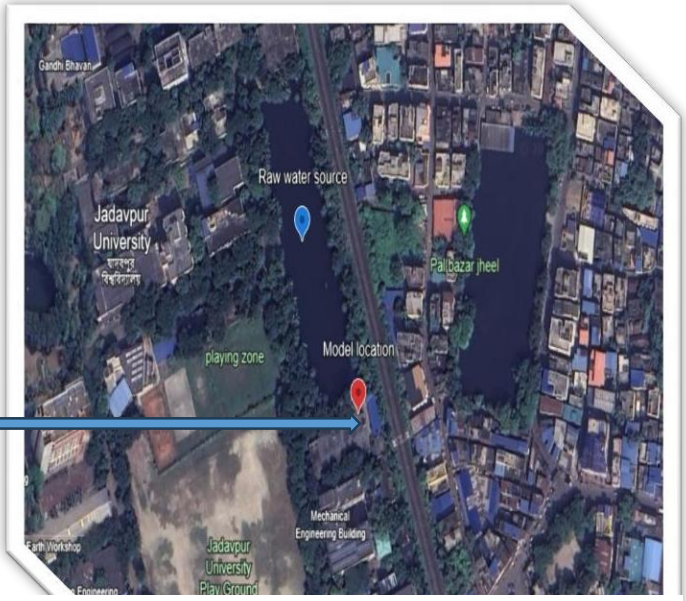


Figure1.2 Location of Model

1.3. RESEARCH GAP

While there is a substantial body of literature on multi stage filtration (MSF) for water treatment, there exists a research gap related to the efficiency across diverse contaminants and performance in variable conditions. Multi-stage filters may not effectively remove emerging contaminants such as pharmaceuticals, personal care products, and micro plastics. Research is needed to assess and enhance their effectiveness in removing these contaminants. Filters often face challenges in treating water with a complex mixture of pollutants. There is a gap in understanding how different stages interact to address multiple types of contaminants simultaneously. The performance of multi-stage filters under varying environmental conditions, such as changes in temperature, turbidity, and organic load, requires further investigation. Many studies are conducted under controlled conditions; there is a need for

research in real-world scenarios to understand how multi-stage filters perform in actual field settings, especially in urban and industrial contexts. Addressing these research gaps can lead to significant improvements in the design, efficiency, reliability, and sustainability of multi- stage filtration systems. It will enhance our understanding of how these systems can be optimized for diverse applications and environmental conditions, ultimately contributing to better water quality and resource management.

1.4. RESEARCH OBJECTIVE

The primary goal of this research was to demonstrate the performance reliability of multistage filtration for treatment of pond water in Jadavpur University jheel, Kolkata. Specific objectives to meet this goal were to:

- **Investigate the reliability of multi-stage filters:** Examine and document common failure modes and operational issues associated with multi-stage filters, such as clogging, fouling, and media degradation. Analyze how different operational conditions, such as varying flow rates and contaminant loads, affect the reliability and performance of multi-stage filters.

- **Recommendations for optimization and improvement**: Based on the findings, provide recommendations for optimizing the performance of multi-stage filters, including design improvements and operational strategies.

- **Evaluate the efficiency of multi-stage filters:** Measure the effectiveness of multi-stage filters in removing a range of contaminants, including organic compounds, inorganic substances, heavy metals, and microbial contaminants.

- **Propose Strategies for Improving Reliability and Longevity: Offer** strategies for improving the reliability and longevity of multi-stage filters, including maintenance practices and design modifications.

The research objectives outlined above focus on comprehensively evaluating the performance and reliability of multi-stage filters in drinking water purification. By addressing these objectives, the study aims to enhance the effectiveness and sustainability of multi-stage filtration systems, contributing to improved drinking water quality and more reliable water treatment solutions.

1.5. METHODOLOGY ADOPTED FOR THE RESEARCH

The overall research methodology is mainly divided into five components: Literature Review for Identification of goal and objective, Collection of the information of the present situation by primary survey and secondary survey, Data Presentation and Organisation of data analysis, Development of a method and design of multi stage filtration (MSF) system. The system consist of horizontal roughing filter (HRF) then cascade aerator then slow sand filter (SSF) andat the last activated carbon filter (ACF). The process encompassed sample collection from all the component of filtration system and characterization, followed by the construction of the MSF model. Continuous monitoring of parameters such as turbidity, suspended solids, and head loss development took place. Subsequently, collected data underwent rigorous statisticalanalysis, enabling a comprehensive evaluation of the system's capacity to evaluate the performance and reliability of MSF water filtration system in urban pond water treatment.

1.6. PROPOSE OUTCOMES

The proposed outcomes of a study on the **Performance and Reliability of Multi-Stage Filters in Drinking Water Purification** aim to provide comprehensive insights into various aspects of multi-stage filtration systems. These outcomes are intended to inform both the academic community and practical applications in water treatment. Here are the key proposed outcomes:

- **Reliability assessment:** Insights into how varying flow rates, contaminant loads, and other operational conditions affect the reliability of multi-stage filters.
- **Practical implementation insights**: Evaluation of the practicality of deploying multi-stage filters in different settings, including urban, rural, and resource-constrained environments. Includes challenges and solutions for installation and operation.
- **Performance Enhancement Strategies:** Recommendations for improving the performance of multi-stage filters, including design modifications and operational strategies.
- **Advancing Academic Knowledge**: Contributions to the academic understanding of multi-stage filtration systems, including new insights into their performance, reliability, and technological advancements.

By addressing these outcomes, the study will contribute to improving the effectiveness, durability, and economic feasibility of multi-stage filtration systems, ultimately enhancing the quality of drinking water and advancing water treatment technologies.

1.7. OUTLINE OF THE THESIS

The thesis consists of six chapters. Chapter 2 contains a literature review of national and international research of this similar topic. Chapter 3 describes the theory of multistage filtration (MSF) of drinking pond water in kolkata city. Chapter 4 illustrates the research methodology. Chapter 6 describes the results and discussions. The conclusion has been given in Chapter 6. References are given at the end of the dissertation.

CHAPTER: 2

LITERATURE REVIEW

CHAPTER: 2
LITERATURE REVIEW

A literature review discusses published information in a particular subject area, and sometimes information in a particular subject area within a certain time period.
Literature review can be just a simple summary of the sources, but it usually has an organizational pattern and combines both summary and synthesis. A summary is a recap of the important information of the source, but a synthesis is a re-organization, or a reshuffling, of that information. It might give a new interpretation of old material or combine new with old interpretations. Or it might trace the intellectual progression of the field, including major debates. And depending on the situation, the literature review may evaluate the sources and advise the reader on the most pertinent or relevant.

International Review

Schreiber et al. 2024, aimed to study in this study evaluated to remove 13 pesticide from the drinking water. Among the tested water treatment methods, reverse osmosis and activated carbon are the best options for removal of organic contaminants from water sources; both treatments achieved 100% pesticide removal in a continuous water flow. Mixed bed resin and ultraviolet radiation have shown an removal potential. Absolute, ozonator, pleated, etc showed low efficiency and should not be used to remove pesticides. Membrane filters, in general, showed low efficiency and should, therefore, not be used for this purpose.

Azat et al. 2023, discussed most important aspect of SSF for developing and less-developed countries is its function as a biological filter. SSF's function is to treat raw water in the form of diluted wastewater where high temperature and access to nutrients probably mean a high growth rate of microbes and algae but probably also high predation and high efficiency of the SSF. However, factors that may adversely affect the removal of microbiological constituents are mainly low temperature, high and intermittent flow rates,

reduced sand depth, filter immaturity, and various filter amendments.

Ormad et al. 2008, discuss about Degrade 44 pesticides systematically detected in the Ebro River Basin. The techniques applied are: pre oxidation by chlorine or ozone, chemical precipitation with aluminium 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. 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 pesticide.

Guchi et al. 2015, discussed slow sand filtration has been recognized as an appropriate technology for drinking water treatment in rural areas, and is recognized as a suitable filtration technology for removing water borne pathogens and reducing turbidity. To reduce the incidence and prevalence of diarrhoeal diseases, improvements in the availability, quantity, and quality of water, improved sanitation, and general personal and environmental

hygiene are required. The majority of people in developing countries do not have access to piped drinking water and must carry; transport and store water within their homes and in theprocess the quality of water may deteriorate.

Christopher et al. 2022, In This paper examines how slow-sand filtration could actually be used to improve drinking water qualities in rural areas Which Results showed reductions in faecal coliform count of about 95% in the filtered water. The test result showed that the filtered water was saline free having no salt, Dissolved Solid: 500mg/l. Turbidity: maximumof 5. From the result of the test; it was found out that the PH value of the filtered water was very low compared to WHO standard. Slow sand filter must be cleaned when the fine sand becomes clogged, which is measured by the head loss.

Obalowu et al. 2019, worked upon slow sand filter with granular carbon for water purification. Water samples were collected from Asa River. The water sample was poured into the water filter. The filter has a capacity for producing 15.25 litres/h of clean water. Theslow sand filter has a capacity of producing 15.25 litres/h of clean water that is safe for consumption without causing. Diseases to man. The filter reduced the turbidity by 86.42% from 6.7 NTU for non-filtered (raw water) to 0.91 NTU after passing through the filter. The slow sand filter in this study reduced E-Coli count by 69%.

Azat et al. 2019 Discussed in this article is to critically summarize and synthesize features and advantages of slow sand filtration methods to improve the quality of drinking water with special focus on less-developed countries. Filters are easy to manufacture from local materialand do not require expensive additional chemicals or complicated operation and maintenance. Surprisingly few people in less-developed countries still have not access to SSFto obtain safe drinking water. This is noteworthy in view of the SSF simplicity and efficiency in preventing WASH diseases. Obviously, SSF has a much larger role to play in helping to reach the UN Developing Goals. In view of this, the objective of this review article is to critically summarize and synthesize features and advantages of SSF methods for less-developed countries to improve the quality of drinking water.

Benner et al. 2022, discussed the micro pollutant problem in context by providing a comprehensive summary of the reported occurrence of micro pollutants in raw water used directly for drinking water production and in finished drinking water finally, proposed biological treatment and bio augmentation as a potential targeted, cost-effective, and sustainable alternative to existing processes while critically examining the technical limitations and scientific challenges that need to be addressed prior to implementation. This review will serve as a valuable source of data and literature for water utilities, water researchers, policy makers, and environmental consultants. occurrence of a variety of organicmicro pollutants in finished drinking water resources around the world. Many traditional drinking water treatment processes have been shown.

Jessica et al. 2023, discussed particle matter in slow sand filter process was removed by 99%regardless of season (temperature). The removal efficiency of dissolved organic carbon (DOC) and UV254 was higher in summer than in winter by 15% and 21%, respectively. the active bacteria was removed up to 93 and 92% in summer and winter, respectively. These stable operations ensure that slow filtration process iseffective in controlling of water quality.

Set al. 2021 aims to provide a comprehensive overview from the earliest to the most recent publications on the HSSF design, operational parameters, removal mechanisms, efficiency.Filter operation has multifactorial conditions, as well as for the physicochemical water quality parameters, there are wide values for the average removal of microbiological parameters. This paper will contribute to expanding the knowledge of HSSF in the peer- reviewed literature**.**

Cescon et al. 2020 deals with the performance of alternative media which is compared withtraditional sand or anthracite for eater treatment. Mainly this paper deals with review of filtration processes and operating configurations. In this study the sand replaced with glass media and dual media configuration with sand and GAC can be remove of organic contaminant in waste water treatment.

fitrianaet al. 2023 aims in the study, to show that the design method and variation of the slow sand filter remove TDS, TSS and iron. The research which was conducted out from December 2022 in the area of Kali jagir which was in Indonesia. As per the author the water from Kali jagir food a via was used in the study because of the water quality of the river in disaster areas Kali jagir surabaya is one of the tributaries of Kali surabaya of the brantas river.On the basis of the study results of the water quality characteristics of Kali jagir suravaya the turbidity concentration was 32 NTU and iron was 1.31 mg per litre. The result should that theactual values of turbidity TSS and iron where 79.61% 89.3% and 50% close to predicted value of 82.07% 89.5% and 50.14% and author concluded that sampling and analysis of water from filter processing for each parameter being tested should be carried out more than once so the result will be more accurate.

Liuet al. 2018 deals with bio filtration method which is helps to remove microbiological contaminants bacteria, heavy metals organic matter ability etc. Due to the shortest water resources in China the state has implemented a project about rainwater harvesting. The removal efficiency of flues and filter was approximately 22-30% on particular organic carbonIn this project the bio slow sand filter after running 150 days a brown layer formed on the surface which is approximately 2 cm. The ultimate result indicates the filtration method couldachieve water quality result better. the effluent quality meets the requirements of “standards for drinking water quality” of China.

Ochieng et al. 2004 aimed at introducing multistage filtration (MSF) (a combination of slow-sand filtration (SSF) and pretreatment system - horizontal flow roughing filter (HRF)) as an alternative water treatment technology to the conventional one. A pilot-plant study was undertaken to achieve this goal. Evaluating the MSF performance vs. the existing conventional system in removing selected physical and chemical drinking water quality parameters together with the biological water quality improvement by the MSF without chemical use was done. Evaluation of the effectiveness of the MSF system utilizing locally available material, i.e. gravel, improved agricultural waste (charcoal maize cobs) and broken burnt bricks as pretreatment filter material was also done. The benchmark was the Kenya Bureau of Standards (KEBS) values for the selected parameters. Results showed that with proper design specifications, MSF systems perform better than conventional systems undersimilar conditions of raw water quality and environmental conditions.

Bagundolet al. 2013 aimed to investigate the efficiency of slow sand filter in purifying well water using labo rivers and as the filter media. The studies and turbidity tests where done on water sample from deep and shallow well before and after filtration at 0.30 m 0.60 m and 0.9km filter depths side at 200 L per hr. m²300 L per hr. M² and 400 L per hr. m² flow through rates. the bacteria's and turbidity removed by which filter in the study is was made by find sent Loam and organic matter contains from Labo River in Misamis Occidental Philippines.In which the sand particles 0.16 mm to 0.30 mm and passing SIM number is 50 and remaining sieve number 100, which is used on the basis on US standard sieve size.by the study the author concluded that isolating bacteria in dash -schmutzdecke– may provide further knowledge on the efficiency of slow sand filter in water purification.

Boller et al. 2022 Tried to achieve this goal is a challenge in rural areas. A strong partnershipbetween users of a water treatment system was critical to the success of community-scale technological change. In this study, the efficiency of a water treatment system was evaluated after the implementation of a technological change in a rural area. The slow filters were not removed but remained out of commission and separate to the new system. the slow filter.

There was a removal of fecal coliforms of 98.91% in the rapid filtration system (conventionaltreatment) and 99.09% in the slow filtration system. The results indicate that total coliforms and fecal coliforms were removed in a high proportion after the raw water was subjected to coagulation, flocculation, sedimentation and filtration. After disinfection with calcium hypochlorite solution, these microbiological parameters were not present. This document presents evidence that the modernization of a treatment plant improves the quality of drinkingwater, thus, in this study, when replacing a slow filtration system with a conventional treatment system that includes rapid filtration, the quality of the treated water improved markedly. A conventional treatment allows treating raw water with high levels of turbidity and color, something that cannot be easily removed using slow filters. From the results of the analysis of the physicochemical parameters, it was observed that nine of the eleven parameters did show a significant difference, therefore it can be said that there is a difference in the quality of the water after the improvements implemented in the treatment plant

therefore the modernization was effective

Charron et al. 2015 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). Nutrient limited conditions exhibited lower DOC removals than nutrient rich conditions when ozone was present (9.3% vs 26% DOC removal, respectively). However, there was no difference in removal when no ozone was present (5.6% vs 6.4% DOC removal, respectively). Multi-stage filtration showed an effective treatment of source water when pre-ozonation was applied and at nutrient rich conditions; however, the turbidity and aesthetic objectives outlined by Health Canada were not fully met. Nutrient limited conditions coupled with insufficient pre-ozonation were majorlimiting factors in terms of the overall performance of both a slow sand filter and a biofilter operated within a pilot trailer. Therefore, when choosing to use multi-stage filtration at a specific site, it is important to determine the nutrient availability of the source water.

Additional nutrients can be added ahead of the filters if it is found that the source water is nutrient limited. In addition, bench scale ozone tests can be performed to determine the minimum ozone dose required, so as not to increase the amount of ozonation by-products in the treated water.

Rao et, al 2019 discussed this experiment Experiments were performed by permeating groundwater contaminated with pathogens (total coliform and *E. Coli*) and inorganic contaminants through the bentonite amended slow sand filter (BASSF). Surprisingly, the BASSF retained inorganic contaminants besides pathogens. Water-leach tests (pH of water leachate ranged from 2 to 9) with spent BASSF specimen indicated that the inorganic contaminants are irreversibly adsorbed to a large extent.

Yassir et al. 2019 study the removal efficiency of SSF, a continuous fixed-bed adsorptionstudy was achieved by using sand as an adsorbent of metallic trace elements (Cd, Cu, Pb and Zn) from contaminated water of Tensift River. This river received wastewater directly from industrial unit of Zn and Pb extraction of Draa Lasfar mine located at 13 km in northwest of Marrakech City in Morocco. Results showed that SSF can remove 100% of metallic pollutants and the removal efficiency of this process to decontaminate water depends greatly on the sand bed height (filter). Thus, the long filter eliminates more pollutants than the smaller ones. This result can be attributed to the exposition of new fixationsites of metallic pollutants on the sand surface that facilitates their adsorption process.

Fitriani et al. 2022 study investigated the utilization of blood clam shells as a potential substitute for conventional media, as well as the influence of the acclimation time on the efficacy of an intermittent slow sand filter (ISSF) in the treatment of real domestic wastewater. ISSF was operated with 16 h on and 8 h off, focusing on the parameters of turbidity, ammonia, and phosphate. Two media combinations (only blood clam shells [CC] and sand + blood clam shells [SC]) were operated under two different acclimatization periods(14 and 28 d). Results showed that SC medium exhibited significantly higher removal of turbidity ($p < 0.05$) as compared to CC medium (45.99 ± 26.84 % vs. 3.79 ± 9.35 %), while CC exhibited slightly higher ($p > 0.05$) removal of ammonia (23.12 ± 20.2 % vs. 16.77 ± 16.8
%) and phosphate (18.03 ± 11.96 % vs 13.48 ± 12 %). Comparing the acclimatization periods, the 28 d of acclimatization period showed higher overall performances than the 14 d.

Fava et al. 2013 aimed to evaluate the efficiency of four household slow sand filter (HSSF) models for the removal of microorganisms from river water throughout the development of their biological layers (schmutzdecke). Two models were designed to be operated continuously (HSSF-CC and HSSF-CT) and two intermittently (HSSF-ID and HSSF-IF).
Filters were fed daily with 48 L pre-treated river water (24 h sedimentation followed by filtration through a non-woven synthetic blanket). Water samples were quantified by coliform group bacteria and analysed by bright field microscopy to visualize the microorganisms.
Total coliform reduction was between 1.42 ± 0.59 log and 2.96 ± 0.58 log, with continuous models showing a better performance (p-values < 0.004). Escherichia coli reduction varied from 1.49 ± 0.58 log to 2.09 ± 0.66 log and HSSF-IF, HSSF-CC and HSSF-CT presented a similar performance (p-values > 0.06), slightly better than the one presented by HSSF-ID (p-value=0.04). Microorganisms, such as algae, protozoa and helminths were detected by micro0scopy in raw water and pre-treated water.

Mian et al. 2016 aimed to remove iron andhexavalent chromium from water using slow sand filters inoculated with iron-oxidizing bacteria Acid othiobacillus ferrooxidans. An experiment was performed for 37 days under controlled conditions, a water sample was prepared synthetically and another sample was collected from water filtration platform Abbottabad city in KP Province- Pakistan and influents and effluents were tested for different parameters like pH, turbidity, hardness, total plate count, total dissolved solids, electrical conductivity analysis of iron and hexavalent chromium in water. Acidothiobacillus ferrooxidans culture was isolated from soil using the differential iron media i.e. 9K medium and was inoculated into sand filters. At the end of the experiment, the removal efficiency of ferrous iron was about 52% and that of hexavalent chromium was 60.2%. In simultaneous treatment, it was observed that removal efficiency of iron was about 68%while that of hexavalent chromium was about 93% suggesting that slow sand filters were more effective for the removal of hexavalent chromium than iron.

Mahvi et al. 2004 Explain there that vertical or horizontal flow gravel beads can be used in water treatment as roughing filter. In this study was used for investigation d h r f performance, and its results systematically ill date good effluent quality. With raw water quality of 200 to 400 NTU. the effluent turbidity of the filter run with. influent turbidity wearing over time was compared with that of two filter dance the first with 200 to 250 NTUand second wait 350 to 400 NTU. And author suggested that simple dhf operation could be an appropriate pre treatment technology for towns and small circles in developing countries.The filter runtime generally decreased with the increasing coagulation doors Hitler scene allcases development linearly and worse within a reasonable remit for 20 cm.the length of the filter was 6.5 m initial turbidity was 250 to 300 and pH was 7.2 and filtration rate was 5 m per hour.

Maiyo et al. 2023 aimed in this topic about slows and filter for rural populations in developing countries. Author mainly discussed and reviews the recent reports and adoptions on contaminant removal. This paper is mainly review of slow sand filter for the 21 st century. Author explain that ssf have been reported to remove several microbial physical and chemical contaminants several design and operation and parameters affect ssf performance among these the HRD and filter maturity a key however extended period of time or generally not required for filters to be effective reducing contamination show the maturity period can be several days as the hit is vital to filter performance. Some studies have reported that some source water quality parameters filter performance was not affected by specific changes in this parameters who will it all reported that influent turbidity total coliform and physical coliform did not affect the removal efficiency of protozoa similarly India at all reported that effluent microbial water quality was not impacted by variations in influence turbidity over therange of 10 to 50 NTU.

Lundqvist et al 2019 have performed an integrated chemical and bio analytical profiling of surface water samples from Swedish agricultural areas. A total of 51 pesticides and transformation products were detected in the water samples. Most of the compounds were herbicides, followed by fungicides, insecticides and transformation products. The highest total pesticide concentration in an individual sample was 39 µg/L, and the highest median total concentration at a sample site was 1.1 µg/L. The largest number of pesticides was 31 in a single sample. This study demonstrated that integrated chemical analysis and bioanalysis

can be performed in water samples following liquid/liquid extraction with a final enrichment factor of 5. AhR and ER activities were induced in water samples from agricultural areas. The activities were presumably not caused by the occurrence of pesticides but induced by other anthropogenic and natural chemicals.

Freitas et. al 2021 studied the effects of a 50% reduction in the depth of the filter medium in household slow sand filters (HSSFs) were assessed. Physicochemical and microbiological properties from river water in a continuous flow. Simple pre-treatment and disinfection procedures were also considered as extra treatments. Using two filter models conventional filtration layer with a media depth of 50 cm (T-HSSF) and a compact filtration layer (C- HSSF) with a media depth of 25 cm were both assessed. HSSFs were supplied with pre- treated river water for 436 days at a constant filtration rate of 0.90 m^3/m^2/day with a daily production of 48 l/d. The pre-treatment process involved 24-hour water sedimentation followed by synthetic fabric filtration. The water was cleaned with sodium hypochlorite (2.0 mg L1 of NaOCl 2.5% for 30 min). Weekly analyses of water samples were conducted for elements including turbidity, organic matter, Colour, and E. coli, among others. The HSSFs' ability to remove protozoan cysts and oocysts was also assessed. Following pretreatment, theHSSF river water's turbidity was decreased to 13.2 to 14.6 NTU, enabling the filters to function. The results of statistical analysis showed that there was no significant difference ($p > 0.05$) between the T-HSSF and C-HSSF efficiency throughout the whole operation period. Therefore, for virtually all of the studied parameters, medium depth decrease did not impair continuous HSSF performance. On one evaluation day, Giardia cysts did pass through the thinner medium, thus it's possible that this had an impact on their retention. The residual bacteria in the filtered water could be reduced by disinfection, but protozoa could not be destroyed. The total filtered water quality and quantity were unaffected by the filtration layer decrease, demonstrating that a small HSSF model can be a practical choice for water treatment.

National Review

Velan et al. 2013 Discussed in this study about etailed studies were carried out on Horizontal vacuum belt filtration of beach sand minerals such as Illmenite, Rutile and Garnet by varying solids contents in feed slurry, cake thickness and filtration cycle time and keeping the variables pH and temperature at constant, by using different filter clothes.Delkor bench scale vacuum filtration equipment was used to conduct these tests. The particle size distribution was between -50 + 120. Based on the laboratory results followed by scale up studies, the industrial scale belt filters were designed and commissioned at site. The industrial scale filters are delivering the results better or as achieved in the laboratory experiments. Detailed studies on belt filter for heavy minerals were carried out using different wash ratios, cake thickness, and various types of filter cloth using Delkor laboratory Buchner funnel test kit. The parameters were optimized and based on the results plant scale horizontal filters were sized, manufactured and commissioned for cake moisturecontent of 6 %.

Sabogal-Paz et. al 2020 examined the household slow sand filter (HSSF) has been employed as a drinking water treatment alternative in rural areas all over the world, but more research is still needed to determine how well it can treat influent water to a level of purity comparable to rainwater. Low pH and low mineral ion concentrations in rainwater can affect the filter medium and, in turn, the effectiveness of the HSSF. Furthermore, plastic can be utilized to construct the roofs of houses that collect rainwater. As a result, itmight introduce contaminants like Bisphenol A (BPA) into the water. In this context, the performance of two pilot-scale HSSFs was examined to treat water containing BPA and low mineral ion concentrations in both continuous and intermittent flows. In order to reduce the likelihood of contaminants showing up in drinking water, filter media and construction materials must be carefully chosen. Leaching of the filter media was seen during the trials. The HSSF efficiency for BPA and DOC removals was influenced by operational variations between continuous and intermittent flows; however, the filters' performance was low, likely as a result of the sluggish schmutzdecke formation. The HSSF may be categorized as a plug flow reactor based on the findings of the tracer tests, hence there is no need to develop any methods to enhance its hydraulic performance.

Mondal et al 2023 Study on the Impact of Agrochemicals on Environment and Human Health in North 24 Parganas District of West Bengal. In this study, it has been found that 54% of farmers use crop-wise fertilizer more than the recommended amount; only 10% of farmers abstain from chemical fertilizer use. There is a significant relationship between crop-wise fertilizer use and the application of weedicides and pesticides to the environment. The farmers who are using this kind of chemical pesticides reported severe environmental hazards62% of farmers observe any bird extinction surrounding their agricultural field, 36% responded that the water quality of the pond nearest to the agricultural field deteriorates and 28% reported the occurrence of fish death and 36% farmer reported that on monsoon season their field water goes to low water region (Bil) and contaminate water.

kar et al 2017 evaluation the impact of mass bathing on water quality of Ganga River during the festival Mahalaya, 2016. For Hindus, the festival Mahalaya was considered to honour the soul of departed ancestors by taking a dip in Holy River. An examination of river water from

river Hooghly, West Bengal, India was carried out at Mahalaya Festival to estimate the impact of mass bathing during new moon day (called as Amavasya in India) in terms of the Water Quality Index (WQI). WQI provides a single number that helps to express overall water quality based on water quality parameters. The sampling was done from the three selected popular ghats in Howrah and North 24 Parganas District, West Bengal during the event of mass bathing, pre-mass bathing and post-mass bathing. The value of WQI was foundin between 56.87-78.24 for each case in all three ghats. WQI value showed very poor water quality in the most popular Dakhinewswar ghat during mass bathing. Keywords: Ganga, Mahalaya, Mass bathing, Water quality, WQI.

Gupta et al 2013 have explained the water quality evaluation of the Ganga River from up to the downstream area at Kanpur City. The objective of the present study is a water quality evaluation of the Ganga River in Kanpur City where industrial water mainly from tannery industries is removed. The deteriorating water quality of streams is due to anthropogenic activities and reduced freshwater availability. The industrial wastewater (effluent) entering in Ganga River directly Increases River water pollution. The tanning industry is a major source of Ganga pollution in Kanpur city. It is deteriorating the quality of water and aquatic flora. A total of fifty water samples were collected from January 2012 to May 2012 to analyze the twelve physicochemical parameters. The industrial effluents in the Ganga River are identified by their abnormality in different physiochemical parameters.

Sharma et al 2021 evaluate in this study, SSF has been used for removing fine suspended particles, microbes, minerals and flocs present in water. The aim of this research article is to invent and install an economic and non-conventional slow sand filter for treating water to resolve the issues related with impure water. Deigned SSF has been operated under the hydraulic loading of 4.6296 L/sec/m^2 and an operational period of one hour. Cross sectional area of bed has been taken as 0.0576 m^2. This technique is a small-scale scheme and easily employed for intermittent use that made it suitable for household purpose. Four processes namely Mechanical trappings, Predation, Adsorption and Natural death that has been taken place during the filtration process has been widely discussed in this paper. Various chemical and physical characteristics of water has been tested. Major parameters like pH, TDS, turbidity, Salinity, conductivity and salinity of filtered water have been tested for raw water and test results has been compared with Indian standard parameters.

Singh et al. 2023 deals with the global occurrences of pesticides in potable water and discussed the conventional and advanced technologies for the removal of pesticides. Micro remediation technology has the potential for up to 90% pesticide removal from water resources. Physical methods along with oxidation methods can be employed for complete removal of pesticides from drinking water. Pesticide can be removed by ozonation nano filtration also shown.

Vilas et al. 2013 evaluate in this study Here we use a motorized shaft that is mounted horizontally using stepped pulley. The shaft is connected to a filter frame with mesh below and this frame enclosed on the sides. We use a rod connected from the shaft to the filter framein a way such as to achieve the rotary motion to reciprocating motion. We will used this reciprocating motion to vibrate a separator. The separator is vibrate then sand fall down with proper size of separator and we will gate the different sizes of sand in separate compartment of frame.

Agrawal et al. 2010 Have explain One of the most terrifying effects of pesticide contamination of groundwater came to light when pesticide residues were found in bottled water. Between July and December 2002, the Pollution Monitoring Laboratory of the New Delhi-Based Centre for Science and Environment (CSE) analyzed 17 brands of bottled water; both packaged drinking water and packaged natural mineral water, commonly sold in areas that fall within the national capital region of Delhi. Pesticide residues of organochlorine and organophosphorus pesticides, which are most commonly used in India, were found in all the samples. Among the organochlorines, gamma-hexachlorocyclohexane (lindane) and DDT were prevalent, while among organophosphorus pesticides, Malathion and Chlorpyrifos were the most common. All these were present above the permissible limits specified by the European Economic Community (EEC), which is the norm, used all over Europe.

CHAPTER: 3

THEORY OF
MULTI STAGE FILTER

CHAPTER: 3

THEORY

3.1 THE BENEFITS OF MULTISTAGE FILTRATION

Slow sand filtration is a proven, sustainable, and reliable drinking water treatment alternative for small communities, which can be beneficial for addressing the small systems challenges described above. The process provides treatment through physical filtration of particles and biological removal of pathogens and organics in the upper biologically active layer of the sand bed, known as the schmutzdecke. It is a simple technology that is relatively easy to operate and understand, requires little maintenance, and is capable of achieving high standards of treatment without the use of coagulant chemicals, of which the purchase (material) and transport costs alone can be debilitating for a remote community. Furthermore, the performance of chemically assisted filtration is highly dependent on source water chemistry, and can be operationally intensive for surface water of variable water quality, in terms of maintaining optimal coagulant dosage and pH levels.

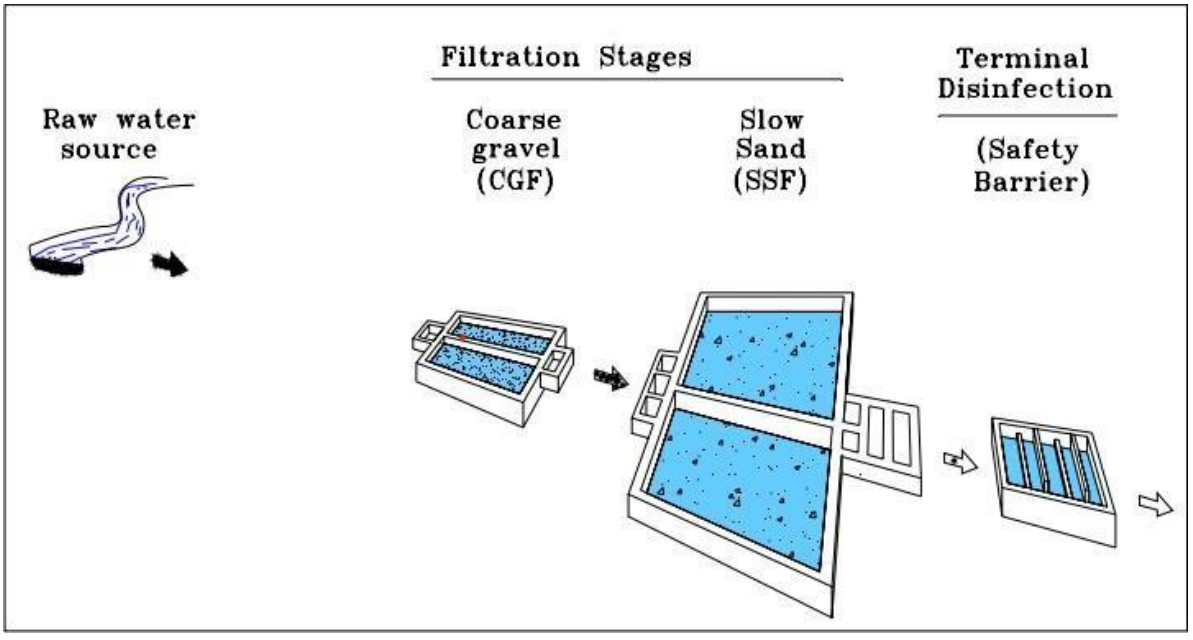


Fig 3.1 General layout of a multi-stage filtration water treatment plant (Galvis et al. 2000)

A general layout of Multi stage filter already shown in **Fig:3.1**. Slow sand filtration, on the other hand, can operate under a wide range of operational and source water quality conditions, with little or no process adjustment, which is a testament to the robustness of the process. It also requires less maintenance in terms of cleaning, as typical filter run lengths of one or more months can be expected between cleanings. In addition to the cost savings from reduced maintenance, its operational energy costs are minimal, as water can flow through the filter under gravity conditions, without the use of pumping, and energy intensive backwashing of the filter is not required in the cleaning process (for more details of the cleaning process, refer to Section 2.3.4). Finally, another advantage of slow sand filtration for a remote community is that it does not require the use of specialized equipment and can potentially be

constructed with locally available materials, mainly from properly graded sand/gravel, concrete, and standard piping.

However, while slow sand filtration presents a number of attractive advantages over other conventional technologies, it does have a few significant limitations, which may be of concern for some source waters. First of all, the process is sensitive to raw water turbidity where consistently high levels of turbidity (20 to 30 NTU) can lead to premature clogging of the filter, decreased filter run length, and frequent cleaning requirements. Besides increased maintenance requirements, frequent cleaning also results in an increased opportunity for pathogen breakthrough by disturbing the biological equilibrium of the filter bed. Secondly, treatment is less efficient at low water temperatures (<5o C), which hinder biological activity in the filter bed. This poses a particular concern for communities in northern climates.

Finally, it is less efficient than chemically assisted filtration at removing negatively charged stable suspensions of colloidal matter (most colloidal material in natural water is negatively charged).

Multistage filtration, consisting of a slow sand filter preceded by a roughing filter, can overcome these treatment limitations and provide a reliable treatment alternative for surface water sources of variable turbidity and cold temperatures. It is a robust multi-barrier treatment process, in which waterborne particulate matter and pathogens face a series of treatment barriers, which may produce an effluent water quality that is better than that of slow sand filtration alone. The roughing filter, consisting typically of three layers of gravel media 3 (coarse to fine), is used to attenuate turbidity peaks, especially during runoff events, and reduce the solids loading on the slow sand filter, hence increasing its run length, and improving effluent quality. The roughing filter may also allow the slow sand filter to operate at higher than typical hydraulic loading rates. Furthermore, it provides a large surface area for the sedimentation of colloidal matter, and provides additional biological treatment and hydraulic retention time, which may be important during colder water temperatures and runoff events of highly contaminated source water. Thus, roughing filters may not only be important for protecting the operational integrity of the slow sand filter, but may also be a significant treatment barrier in the overall process of pathogen removal. But most importantly, the roughing filter does not require energy for backwashing, thus it is consistent with the costsustainable paradigm that traditional slow sand filtration is reputed for.

The success of multistage filtration has been documented in several jurisdictions throughout the world, mainly in tropical regions using extremely contaminated surface water with high solids loadings. In North America, where single stage slow sand filtration has been largely replaced by chemically assisted rapid sand filtration, there has been a recent increase of interest in the use of multistage filtration for surface water treatment. LeCraw et al. (2004) document the performance of multistage filtration in a number of pilot and full-scale installations in cold climate locations throughout North America. The results are promising for small communities in northern climates that are seeking a safe and cost-effective treatment alternative.

However, multistage filtration has yet to be systematically challenged in colder climates. There are still a number of key issues that need to be investigated to define the envelope in which it can perform satisfactorily for small systems in North America. Such issues include its performance under increased hydraulic loadings and elevated influent turbidity together with cold water conditions. Recent literature reveals the impact of additional stages of preozonation and post-granular activated carbon filtration for removal of

organics, colour, and disinfection by-product precursor material; however, further exploration under the above operating conditions is warranted. Furthermore, the impact of an additional slow sand filter in series for increased robustness and protection against pathogen breakthrough, particularly 4 during runoff events, cleaning, decreased temperatures, and increased hydraulic loadings remains to be determined. An investigation into increasing the filtration efficiency of roughing filtration, without compromising its operational benefits, may also be important for branding the roughing filter as a significant treatment barrier in the overall process of pathogen removal, beyond just its role of increasing the filter run length of the slow sand filter.

Most importantly, if this technology is to be legitimately accepted as a small system treatment alternative, it is important to define the range of operating conditions under which it could comply with the requirements of regulations such as the Ontario Safe Drinking Water Act, specifically with respect to the removal of turbidity, Giardia lamblia, and Cryptosporidium parvum. (Given that systems in Ontario would also include disinfection, bacterial removals by multistage filtration, while important, are not critical from a regulatory perspective). By investigating its performance under a range of raw water turbidity, temperatures, and hydraulic loadings, a range of small system conditions could be established, for which multistage filtration is a viable drinking water treatment option. This kind of research would further elucidate the potential of multistage filtration as a reliable, cost-effective, and robust drinking water treatment technology for small communities throughout the world, especially in northern climates.

3.2 THE PROBLEM OF SURFACE WATER SUPPLY IN RURAL AREAS

It is estimated that 70% of the world's population live in rural areas. In rural areas of both developed and developing countries, many communities rely on surface water (rivers, lakes, etc.) as a source for drinking water. Groundwater resources may be scarce due to the natural geology of the area, lack of rainwater infiltration in overdeveloped areas, and overuse or contamination of groundwater resources. Often, small communities "do not have the power or the resources to protect watersheds and frequently rely on poor water sources". Yet, often the surface water source represents a threat to human health due to natural and/or anthropogenic contamination. Naturally occurring influences, such as seasonal precipitation patterns and runoff events, results in fluctuations of turbidity, nutrients, and suspended solids. Anthropogenic influences include industrial pollution, municipal wastewater treatment discharge, improperly designed septic systems and latrines, improper management of agricultural drainage, excessive or improper application of excreta-based agricultural fertilizer, and the culture of livestock in direct vicinity of the surface water.

However, it is the combination of both naturally occurring influences with anthropogenic influences, which compound to have the largest impact on surface water quality.

This impact has been experienced globally and throughout North America, where widespread contamination of surface water has led to an emergence of parasitic Giardia and Cryptosporidium as a major cause of waterborne disease in humans. In fact, Giardia is the most commonly reported intestinal protozoan infection worldwide (USEPA, 1999). The World Health Organization has estimated that 200 million people are infected with Giardia every year. In the U.S., it is one of the leading causes of disease outbreaks, and the most frequently identified etiological cause of waterborne outbreaks in public water systems (USEPA, 1999). Furthermore, it is estimated that on average, 1 to 6% of the North American population is inflected with G. lamblia. In 1984, Cryptosporidium became widely recognized as a harmful waterborne pathogen during an outbreak of more than 2000 infected individuals in Texas (D'Antonio et al., 1985). Since its recognition, it is estimated to have affected more than one million individuals in Europe and North America. The largest reported outbreak occurred in Milwaukee in 1993 when 400,000 people became infected from the local water supply.

Most importantly, it is the small communities that are at the highest risk of water-related outbreaks. In fact, water supply surveys have shown that the "rate of non-compliance with drinking water standards increases in proportion to decreases in the size of the population served" (Lippy and Waltrip, 1984). This is because small water systems often lack economies of scale and simply scaling down existing conventional technologies may not be operationally or economically feasible. This is clearly a growing concern for many communities in North America where 92% of all water systems in the United States serve a population of fewer than 5,000 people.

3.3 THE GLOBAL NEED FOR CLEAN WATER

A common definition of clean water is water that is free of pathogenic organisms, toxic substances, colour, turbidity, taste, and odour, and an acceptable level of minerals and organic material (Thanh and Hettiaratchi, 1982). Every human on our planet has a fundamental right to a reliable supply of clean water. Yet, according to the World Health Organization, there are still 1.1 billion people in the world without access to an improved water supply (WHO and UNICEF, 2000). This translates to 6% of the global population lacking access in urban areas, and 29% lacking access in rural areas. This is not only a critical problem in developing countries, but also a challenge faced by many municipalities in both rural and remote areas of the developed world.

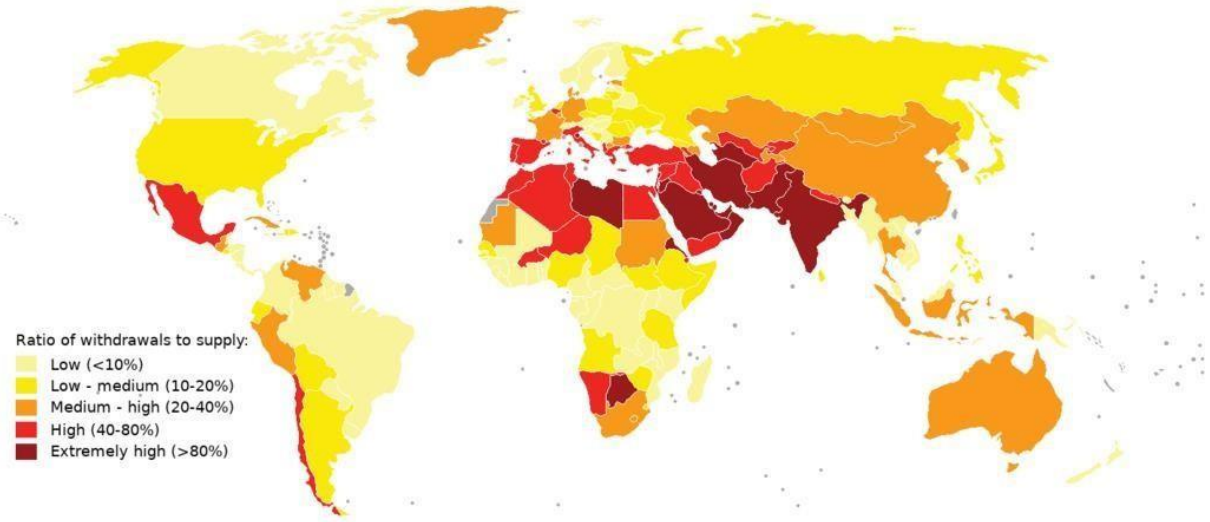


Fig 3.2 Map of global water stress in 2019 (World Resources Institute)

The results of inadequate water supply are catastrophic, as 2.2 million deaths related to diarrhoeal disease occur every year, which equates to one water-related death every 15 seconds (WHO and UNICEF, 2000). Thus, there is a global need for clean water and every man, woman, and child has a fundamental right to a reliable supply.

3.4 THE PROBLEM WITH SURFACE WATER SUPPLY IN RURAL AREAS

It is estimated that 70% of the world's population live in rural areas. In rural areas of both developed and developing countries, many communities rely on surface water (rivers, lakes, etc.) as a source for drinking water. Groundwater resources may be scarce due to the natural geology of the area, lack of rainwater infiltration in overdeveloped areas, and overuse or contamination of groundwater resources. Often, small communities "do not have the power or the resources to protect watersheds and frequently rely on poor water sources".

Yet, often the surface water source represents a threat to human health due to natural and/or anthropogenic contamination. Naturally occurring influences, such as seasonal precipitation patterns and runoff events, results in fluctuations of turbidity, nutrients, and suspended solids. Anthropogenic influences include industrial pollution, municipal wastewater treatment discharge, improperly designed septic systems and latrines, improper management of agricultural drainage, excessive or improper application of excreta-based agricultural fertilizer, and the culture of livestock in direct vicinity of the surface water. However, it is the combination of both naturally occurring influences with anthropogenic influences, which compound to have the largest impact on surface water quality.

This impact has been experienced globally and throughout North America, where widespread contamination of surface water has led to an emergence of parasitic Giardia and Cryptosporidium as a major cause of waterborne disease in humans. In fact, Giardia is the most commonly reported intestinal protozoan infection worldwide (USEPA, 1999). The

World Health Organization has estimated that 200 million people are infected with Giardia every year. In the U.S., it is one of the leading causes of disease outbreaks, and the most frequently identified etiological cause of waterborne outbreaks in public water systems (USEPA, 1999). Furthermore, it is estimated that on average, 1 to 6% of the North American population is inflected with G. lamblia. In 1984, Cryptosporidium became widely recognized as a harmful waterborne pathogen during an outbreak of more than 2000 infected individuals in Texas (D'Antonio et al., 1985). Since its recognition, it is estimated to have affected more than one million individuals in Europe and North America. The largest reported outbreak occurred in Milwaukee in 1993 when 400,000 people became infected from the local water supply.

Most importantly, it is the small communities that are at the highest risk of water-related outbreaks. In fact, water supply surveys have shown that the "rate of non-compliance with drinking water standards increases in proportion to decreases in the size of the population served" (Lippy and Waltrip, 1984). This is because small water systems often lack economies of scale and simply scaling down existing conventional technologies may not be operationally or economically feasible. This is clearly a growing concern for many communities in North America where 92% of all water systems in the United States serve a population of fewer than 5,000 people.

3.5 THE IMPORTANCE OF FILTRATION

The importance of filtration in meeting the requirements of the SWTR has not been learned without incurring tragic costs to community health. In fact, 52 of the 108 reported outbreaks 11 between 1965 and 1996 were caused by inadequate treatment of surface water, where chlorination was used, but not filtration (USEPA, 1999). This is because cysts and oocysts are highly resistant to chemical disinfectants such as chlorine. Furthermore, Craun et al. (1994) found that the incidence of water related disease (mostly Giardia related) was 8 times lower for communities using filtration, compared to those using only chlorination. In response, the USEPA recommends that a multi-barrier treatment approach, including filtration and disinfection under optimal operating conditions, can protect against waterborne transmission of Giardia and Cryptosporidium (USEPA, 1999; USEPA, 2001).

3.6 HORIZONTAL ROUGHING FILTER

A horizontal roughing filter is a type of pre-treatment filter used in water treatment systems to remove large particles and sediments from raw water. It operates by directing water horizontally through a bed of filter media, which captures and retains particulates. The horizontal design allows water to flow horizontally through A filter bed, typically composed of coarser materials. The filter media provides physical barriers that trap and retain particles asthe water flows through. This roughing stage reduces the load on subsequent filtration or treatment processes, making it an effective preliminary treatment step.

For the purpose of comparative study and research, three filters have been provided. Each filter consists of four chambers, each configured with a unique arrangement of media that decreases in size, aligning with the flow direction. Specifically, in Chamber 1, the media size is 10mm, in Chamber 2, it reduces to 5mm, in Chamber 3, it further decreases to 3mm, and in Chamber

4, it is 2mm. To facilitate the convenient collection of water samples for testing water quality parameters, inspection pits have been strategically placed within each chamber of the HRFs. The filter media within each chamber is characterized by a height and width of 0.15m, accompanied by a freeboard height of 0.02m. These dimensions result in a cross-sectional area for the filter(s) of 0.025m^2. This design denotes a designated flow rate of 0.18m^3/day, achieved at a filtration rate of 0.3 m/hr. The individual lengths of Chamber 1, 2, 3, and 4 are 350mm,

350mm, 250mm, and 250mm (centre to centre), respectively. Furthermore, both the inlet chamber and outlet chamber share a length of 105mm each. Collectively, the total length of travel for each of the HRFs spans 1230mm

3.6.1 Types of Roughing Filters

A horizontal roughing filter (HRF) consists of a horizontal filter box with 3 or 4 compartments of same 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 last compartment. The advantage of HRF are its extended bed lengths and solids storage capacity, resulting in less cleaning frequency than upflow roughing filters. It is also more suitable for treating very high suspended solids concentrations. The disadvantage of the HRF is its large space requirements. A diagram of a HRF and its typical design parameters.

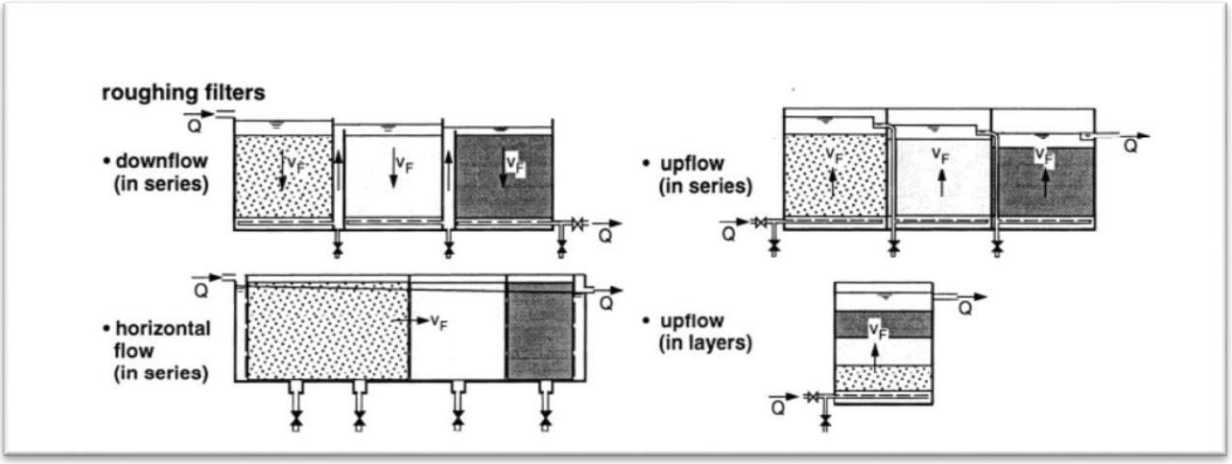


Fig: 3.3 Types of Roughing Filters (Surface water Treatment by Raghing filter, SKAT 1996,180)

A downflow roughing filter in series (DRFS) consists of 3 or 4 individual filter boxes, each filled with gravel, with the coarsest media in the first compartment and the finest media in the last compartment. Water flows downward through each media compartment.

An upflow roughing filter in series (URFS) is similar to the DRFS except that water flows upward through each media compartment. As most of the solids accumulation occurs in the 51 bottom of the filter near the drainage pipes, cleaning is much more efficient in upflow roughing filters. Thus, although upflow and downflow roughing filters perform similarly, upflow roughing filters are recommended for ease of cleaning.

An upflow roughing filter in layers (URFL) consists of one filter box, with multiple layers of media, ranging from coarse media in the bottom to fine media in the top. The advantage of the URFL is that it has much lower space requirements and capital cost than the HRF or URFS. However, the URFL appears to only be efficient with water sources of low to medium suspended solids concentrations (<150 mg/L) (Galvis et al., 1993). This is due to its smaller solids storage capacity and smaller bed depth than the HRF or URFS. A diagram of the URFL and its design parameters

In general, optimal treatment in roughing filters is achieved by using a higher number of individual compartments (ie. reactors) in series, thus resembling the hydraulic behaviour of a plug flow system (Galvis et al, 1996). Thus, a 3 stage roughing filter is expected to perform better than a 2 stage roughing filter. Overall, field tests revealed that upflow roughing filters are more efficient in solids removal, as it has a reduced filter depth (in the direction of flow), and smaller space requirements (Wegelin and Schertenleib, 1993). However, since vertical flow (upflow or downflow) roughing filters have a smaller filter depth compared to horizontal roughing filters, it is recommended that vertical flow filters should be limited to pre-treating raw water turbidities less than 150 NTU (Wegelin, 1996).

3.6.2 Benefits of Roughing Filtration

Gravel filtration has been used in water treatment since the early 1800s, when it was first used in Scotland to pre-treat water prior to 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 prior to slow sand filtration. As roughing filters do not require sophisticated mechanical equipment or the use of coagulants, 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, 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 (upflow, downflow, or horizontal flow) and the depth of media layers in the direction of flow. Selection of the roughing filters depends on the raw water characteristics and the operation and maintenance requirements. Further description of the different roughing filter types and selection criteria.

Traditionally, the main function of roughing filtration is to reduce influent turbidity and suspended solids to levels that are suitable for effective operation of slow sand filters. It can also reduce filter-clogging algae, stable suspensions of colloidal matter, and pathogens without the addition of coagulants. Generally, pre-treatment is recommended for raw water turbidity greater than 10 NTU.

Essentially, the roughing filter protects the slow sand filter from getting overloaded with particulate matter, thus limiting headloss development, and enabling longer filter runs. Actually, it has been found that with pre-roughing filtration, slow sand filters can achieve filter runs that are 5 times longer than without pre-roughing filtration. Roughing filters can have filter runs up to a year with raw water that is periodically high in solids loads.

This is because they are designed to allow deep penetration of solids, resulting in a large capacity for solids storage. They also have low head loss due to their large pores, which are described by Rajapakse and Ives (1990) as lens like cavities underneath the media grains.

The roughing filter can also attenuate sharp and sudden peaks in turbidity and fluctuations in water quality, thus protecting against the disruption of the biological community in slow sand filter. In addition, it provides increased retention times and additional surface area for biological treatment, which becomes increasingly important during low water temperatures.

Finally, from an engineering perspective, pre-treatment with roughing filtration can potentially allow the slow sand filter to be operated at higher hydraulic loadings, thus reducing the filtration area and lowering construction costs. Past experience in Zurich and London has shown that, with adequate pre-treatment, slow sand filtration can operate effectively at filtrationrates as high as 0.4 to 0.8 m/h.

Overall, multistage filtration, which involves pre-treatment with roughing filtration prior to slow sand filtration, is not only important for successful operation of the slow sand filter, but is also a robust approach to improving water quality to consistently safe levels for human consumption.

3.6.3 Cleaning of Roughing Filters

Roughing filters need to be periodically cleaned to remove accumulated particulate matter and replenish the solids storage capacity of the filter. Roughing filters are cleaned by opening a drain valve at the bottom of the filter and allowing the filter to drain freely under gravity, 53 thereby flushing solids from the media. The height of roughing filters should be limited to 1.5 m to facilitate easy cleaning (Collins et al., 1994b).

A drainage velocity of 30 m/h (preferably 60-90 m/h) (Wegelin, 1996) is recommended to induce turbulent flow conditions in the media pores, thus dislodging solid deposits from the media. To achieve this drainage velocity, the difference in head between the initial water level in the roughing filter and the drain should be approximately 2.5 m (Galvis et al., 1998). In addition, the drainage pipes should be sized to allow the filter to drain at the recommended velocity. During draining, agitation and dislodgement of the solids can be aided by repeatedly opening and closing the drain valve to send pressure waves through the sand bed.

This method of cleaning has been proven effective, as recovery of initial filter headloss values is very good. In fact, Galvis and Visscher (1989) found that cleaning of a roughing filter with a final headloss of 30 cm returned the headloss to 5 to 7 cm. Wegelin et al. (1986) found that filter drainage restores the filter efficiency to near the original value. Furthermore, Rajapakse and Ives (1990) found that draining the roughing filters twice resulted in the removal of greater than 70% of the deposited solids from the filter. Cleaning efficiency, however, can be hindered in filters that treat raw waters that are high in NOM (Collins et al., 1994b). This is most likely due to higher growth of sticky biomass and/or algae, which assist in the attachment and retention of solids on the media grains.

The suspended solids concentration of the drainage water during filter cleaning. A large initial peak of suspended solids from accumulations in the bottom of the filter was followed by a second smaller peak due to flushing of the solids throughout the depth of the filter. Also, solids were more efficiently flushed from the finer gravel sizes, probably due to higher pore velocities.

The frequency of cleaning is dependent on the loading of particulate matter and biological activity in the filter, and there are no general recommendations available as water quality conditions are site specific. However, field experience shows that roughing filters are usually cleaned on a weekly to monthly basis. For example, cleaning should occur once every one or

two weeks during months of high precipitation and runoff, and once every one or two months during dry seasons. Generally, cleaning of roughing filters is not labour intensive. In fact, it is estimated that cleaning can take only 2.4 to 4.6 hours per m2 of filter area per month.

Another method of cleaning is the "upflow method" where an increased upward flow of water induces turbulent conditions in the interstitial pore space and dislodges deposited particles, flushing them from the media. This method is effective in removing solids from the filter, however it is more energy intensive due to pumping requirements. Thus, it may not be suitable for some rural areas where energy supply is limited.

3.6.4 Mechanisms of Removal in Roughing Filtration

The most influential mechanisms of removal in roughing filters are gravitational sedimentation, interception, and diffusion. The principle 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. 55 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 56 and Wegelin (1989) who found that the shape and surface texture of roughing filter media has a negligible influence on filtration coefficient.

3.7 CASCADE AERATOR

A cascade aerator is a device used to increase the oxygen content in water through a simple yet effective design. It consists of a series of stepped or tiered platforms over which water flows, creating a cascade effect. As water descends from one step to the next, it breaks into smaller droplets and spreads out, significantly increasing the surface area in contact with the air. This process enhances the transfer of oxygen from the air into the water.

3.7.1. Key Features:

- **Design:** Stepped or tiered platforms that facilitate cascading water flow.
- **Function:** Increases oxygen levels in water through enhanced air-water contact and turbulence.
- **Applications:** Commonly used in wastewater treatment plants and natural water bodies to improve water quality and promote biological treatment processes.

3.7.2. Advantages:

- **Efficiency:** Effective in oxygen transfer with a straightforward design.
- **Maintenance:** Low maintenance due to the lack of complex moving parts.
- **Simplicity:** Easy to construct and operate, making it a cost-effective solution for aeration.

Cascade aerators are valued for their efficiency in promoting aeration and improving water quality with minimal mechanical complexity.

3.7.3. Maximum Dissolved Oxygen Concentration Saturation

The concentration of dissolved oxygen (DO) in water is influenced by a number of factors, including water temperature, salinity and atmospheric pressure. The relationship between water temperature and DO is inverse: Cold water is able to "hold" more DO than warm water.

The following table 3.1 is based on zero salinity (for lakes), and 760 millimeters of mercury (1 Standard Atmosphere) Actual atmospheric pressure can be compensated for when calibrating dissolved oxygen meters by entering feet above sea level, or in some meters, an internal barometer compensates for changes in pressure automatically provided that the barometer is properly calibrated.

Dissolved oxygen values shown in the table 3.1 represent "saturation" for the corresponding temperature. This value is generally used during DO meter calibration, based on the assumption that saturated conditions exist in the calibration chamber, there are no air bubbles under the membrane and that no water droplets are present on the actual probe. Older analog meters require the user to manually adjust the DO value according to the temperature; newer meters perform a self-calibration at the touch of a button and this chart is used to verify the accuracy of the calibration.

3.7.4. Maintenance Guidelines Of Cascade Aerator

Maintaining a cascade aerator is crucial for ensuring its efficient operation and longevity. Cascade aerators are commonly used in ground water and surface water treatment to increase oxygen levels in the water through cascading flows. Here are some general maintenance guidelines:

- Regularly clean the cascade aeration system with a brush if it becomes covered with algae and other biological substances, performing this cleaning at intervals of 10-12 days.
- Inspect the cascade aeration system for any signs of leakage or broken steps. If any issues are identified, promptly address them by applying a waterproof course and cement mortar as needed.
- Monitor flow rates and aeration performance regularly, at least monthly.
- Maintain records of inspections, maintenance, and any repairs.

By following these guidelines, you can help ensure that your cascade aerator operates efficiently and has a long service life. Always adapt these recommendations to the specific requirements of your equipment and local operating conditions.

3.8. BACKGROUND ON SLOW SAND FILTRATION

3.8.1. The Promise of Slow Sand Filtration for Rural Areas

Slow sand filtration has been recognized as an appropriate technology for drinking water treatment in rural areas, and is recognized as a suitable filtration technology for removing waterborne pathogens. It is capable of improving the physical, chemical, and microbiological quality of water in a single treatment process without the addition of chemicals, and can produce an effluent low in turbidity and free of bacteria and viruses. In fact, Wegelin (1988) states, "no other single water treatment process can improve the physical, chemical, and bacteriological water quality of surface water better than slow sand filtration". In addition, the USEPA (1997) states, "when used with a source water of appropriate quality, slow sand filtration may be the most suitable filtration technology for small systems". These two statements elucidate the important role of slow sand filtration for treating surface water in small systems.

Slow sand filtration is a sustainable technology for rural water treatment because it is low cost and simple to operate. In addition, it is able to produce excellent effluent quality without the use of treatment chemicals. In fact, under good source water conditions, Cleasby et al. (1984a) found that slow sand filtration achieved better treatment than coagulation followed by direct filtration. In addition to the potential health hazard of long-term chemical exposure, treatment chemicals are also costly to manage in rural water systems. Due to lack of availability in rural areas, the transportation costs of importing chemicals can be a major 12 concern for small systems. In addition, the use of chemicals requires more maintenance and monitoring from skilled personnel, as the chemical dosing process is highly sensitive to fluctuations in raw water quality such as pH. Thus, the on-going operational costs of a conventional treatment system that uses chemicals can be overwhelming for a small community.

Slow sand filters can be constructed from local materials, can operate without the use of specialized equipment, and is much less labour intensive than rapid filters. Also, as slow sand filters operate under gravity flow conditions and energy intensive backwashing is not required, its on-going energy demand is minimal. It is important to understand that "while construction and capital costs are often paid for or subsidized by senior levels of government, it is the local community that must pay operations costs". Thus, slow sand filtration is an attractive treatment alternative for local communities.

Finally, there is very little water wastage during cleaning of the filters and the production of sludge is much less than rapid sand filters. The sludge can subsequently be handled in its dry state, preventing recontamination of surface water; and used as an amendment to agricultural fertilizer.

The slow sand filter media comprises of silica sand. In this setup, the chosen effective size (ES) falls within the range of 0.3 to 0.35 mm, while the uniformity coefficient (UC) of 2.5 is considered. The design is based on a flow rate of 0.1m/h although different flow rates might be experimented.

3.8.2. Brief History of Slow Sand Filtration

Slow sand filtration dates back to 1804 in Paisley, Scotland, where John Gibb supplied water to the city from the slow sand filter at his bleachery (Baker, 1948). However, the current model for slow sand filtration originated from a one-acre slow sand filter designed by James Simpson for the Chelsea Water Company in London in 1829, which treated surface water from the Thames River (Barrett et al., 1991). Shortly after, filtration became a legal requirement in London for all surface waters (Baker, 1948). But it was not until 1892, during the advent of the germ theory of disease, that the effectiveness of slow sand filtration in preventing waterborne disease was discovered. At this time, there was a cholera epidemic in the city of Hamburg, Germany, where more than 7,500 people died. However, the 13 neighbouring city of Altona, which treated its water with slow sand filtration, had only a few deaths resulting from the epidemic.

The first slow sand filter in the United States was designed by James Kirkwood and completed in 1872 (Baker, 1948). This was followed by many more installations. However, due to dramatically reduced filter run times when treating high turbidity surface water, slow sand filtration has since been largely replaced by rapid filtration. However, there has been a recent re-emergence of slow sand filtration in small communities due to its effectiveness in removing natural organic matter and pathogens such as Giardia (Brink and Parks, 1996). In the state of New England alone, there have been over 25 new facilities either piloted or constructed since 1988. Currently, the USEPA recognizes slow sand filtration as an acceptable water treatment technology, which provides safe water for human consumption.

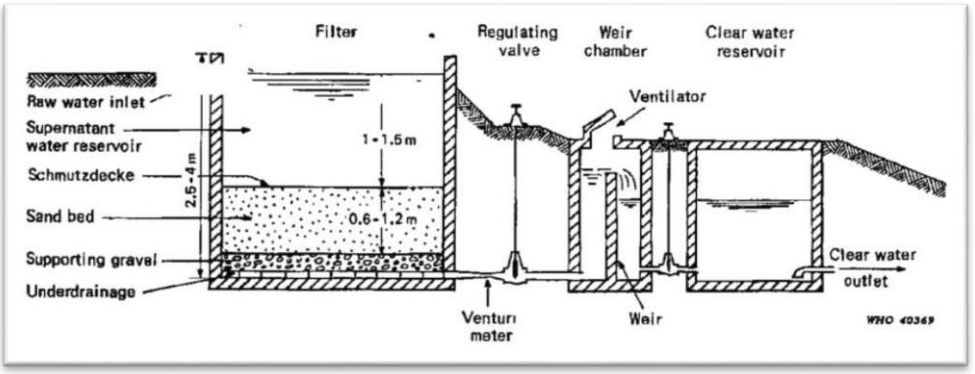


Fig: 3.4 Slow Sand Filter (E Khoury et al. 2018)

3.8.3. Impact of Water Temperature

Water temperature has been shown to affect general filtration performance, with colder temperatures influencing the rate of reactions and the settling velocity of water (Jasim et.al., 2008). Therefore, water temperature can be considered a restricting factor when assessing the best biofiltration treatment methods for a particular source water.

A study by Fonseca et. al. (2001) examined the effect of water temperature and determined that temperature did not affect levels of biomass on top of filter beds, but didaffect the fraction of DOC removal (Fonseca et. al., 2001). Viable biomass is used as a parameter for modelling that predicts organics removal. The results from this study showed that biological activity was a better parameter to use when determining the impact of temperature on removal of DOC.

Another study by Chen & Wang (2012) found that treated water quality improved with increasing ozone and catalyst dosages, but was independent of water temperature at temperatures between 10 ºC and 30 ºC (Chen & Wang, 2012). The use of coagulation and flocculation aides, such as polymers, or of oxidation processes, such as ozonation, has been suggested for Canada and parts of the United States that are subject totemperatures below 5 ºC (Jasim et. al, 2008). Depending on the source water, temperatureshould be considered a factor when developing an appropriate treatment.

3.8.4. Cleaning of Slow Sand Filters

Cleaning must be performed at the end of a filter run, when the headloss across the filter bed has reached its maximum. This occurs when the water level above the sand bed reaches the overflow and begins to flow to waste, thus reducing the actual flow rate through the sand bed. Typically, filter run times range from 30 to 60 days, but could reach more than 100 days

The rate of headloss development is dependent on the filtration rate, the size and uniformity coefficient of the media, and the water quality conditions (Ellis, 1985). For example, a higher filtration rate delivers a higher solids loading to the filter and deposition of particulate matter occurs at a faster rate. In addition, headloss is proportional to the velocity through the sand bed, thus as filtration rate increases, headloss increases.

The traditional method of cleaning slow sand filters involves draining the water level down to just below the sand surface and scraping off the top 1 or 2 cm of schmutzdecke. The schmutzdecke is where the highest concentration of biomass exists, hence the region where most biological treatment is achieved. Thus, pathogen removal may be compromised for a couple days after cleaning until biofilm maturity is re-established. In some cases, however, cleaning may have no effect on treatment efficiency. For example, Fox et al. (1984) found that bacteria removal was unaffected by scraping, and Poynter and Slade (1977) found that scraping had little effect of the removal efficiency of viruses.

After cleaning, the filters are refilled with water from the bottom of the filter. This is done to

avoid entrapment of air bubbles and prevent the scouring of the sand bed if the filter were filled from the top. Using an alternative method of cleaning known as “harrowing” where the sand is raked by a comb harrow, which penetrates 30 cm into the sand bed and detaches particulate debris. The debris is then washed away by a continuous flow of water across the top of the sand bed.

Generally, cleaning times are significantly lower with the harrowing method than the scraping method, and filters could be put back online within days instead of weeks. Also, this method results in minimal or no sand loss, thus re-sanding of the filter after many years of operation is not an issue. But most importantly, Eighmy and Collins (1988) found that very little biomass was lost during cleaning and biomass populations penetrated deeper into the sand bed, providing more biological contact time and improving removals of non-purgeable dissolved organic carbon (NPDOC), ultraviolet (UV) absorbance, and trihalomethane formation potential (THMFP). A description of these parameters is provided.

An additional advantage of harrowing is that it is an in situ cleaning method, and it is not necessary to drain the water level down to expose the sand. Lloyd (1996) found that some protozoa such as spirotichs, which graze on incoming bacteria, are particularly susceptible to desiccation when the sand is exposed. Thus, in situ methods of cleaning are preferred to maintain the viability of the biomass ecosystem in the sand bed.

3.8.5. Physical-Chemical Mechanisms of Removal in Slow Sand Filtration

Physical-chemical mechanisms of filtration are divided into two categories: transport mechanisms and attachment mechanisms. Transport mechanisms govern the transport of particulate matter to the filter media (otherwise referred to as collectors) and attachment mechanisms govern the attachment of particles to the media.

One of the major types of transport mechanisms in slow sand filtration is straining or screening, where particles that are larger than the pore size of the media are physically removed. Huisman and Wood (1974) approximated the pore size of a given media to be about 15% of the media diameter. Thus, it is feasible that a 0.2 mm diameter media could strain out particles larger than 30 µm in size (Haarhoff and Cleasby, 1991). However, as the pore size of the media progressively decreases due to particle deposition and biofilm growth, straining will become more efficient in capturing particles that are even smaller in size

There are particles in surface water that are much smaller than the pore size of the media, such as bacteria (0.1 to 10 µm), viruses (0.01 to 0.1 µm), and colloidal particles (0.001 to 1 µm) (Montgomery, 1985). These particles penetrate deeper into the sand bed, where other mechanisms of transport become important. Impaction occurs when the inertia of the particle approaching the collector is greater than the hydrodynamic force that is carrying the water past the collector (Montgomery, 1985). The particle will deviate from the flow path and impact the collector. Hydrodynamic forces that result from non-laminar regions of flow, changes in flow velocity, and change of pore size may also transport particles to the surface of the collector (Montgomery, 1985).

Sedimentation occurs when the mass density of a particle is much greater than that of water and its settling velocity causes the particle to deviate from the flow path and settle onto the

media surface. Ellis (1985) reports that sedimentation is probably more important with suspended particulates between 4 and 20 µm in size.

Interception occurs when deposited particles accumulate on the media surface, gradually reduce the pore size, and act as additional collectors for subsequently passing particles. It is generally known that as the ratio of the particle size to media size increases, interception also increases (Montgomery, 1985).

Particles in the colloidal range (less than 1 µm in diameter) are influenced by Brownian motion or diffusion and will deviate from flow paths toward the filter media, depending on the electrostatic interaction between the particles and the media (Montgomery, 1985).

As particles are transported to the filter media, attachment mechanisms will act to capture the particle resulting in a successful collision. Such attachment mechanisms include mass attraction (Van der Waals force) and electrostatic attraction between oppositely charged particles (Montgomery, 1985). The effects of Van der Waals forces, however, are onlysignificant if the particle can overcome any electrostatic repulsion barrier and reach the surfaceof the media (Haarhoff and Cleasby, 1991). Interestingly, McConnell (1984) suggests the possibility of multivalent cations acting as a bridge between negatively charged surfaces 18 and negatively charged particles. This theory was confirmed by the finding that "virusadsorption on sand is enhanced with increasing ionic strength and with higher concentrations of higher valence cations in solution" (Galvis et al., 1998).

Adsorption of particles to the media is another important attachment mechanism. Microorganisms such as algae and bacteria will colonize the filter bed and form a sticky zoogleal biofilm on the sand grains to which particles can become attached to. Ellis (1985) suggests that adsorption is more important for smaller particles.

Detachment of particles is another important phenomenon of filters. As particle deposits and growth of biofilm reduce the pore size of the media, the interstitial velocity in the pores increases. This causes an increase in the hydrodynamic shear force on particle deposits and may cause particles to become detached. Shearing forces are expected to be highest in the schmutzdecke (Weber-Shirk and Dick, 1997b). Increased detachment may also occur with sudden increases in the flow rate or influent solids concentrations.

Detached particles can then penetrate deeper into the filter bed and may ultimately breakthrough the filter. For example, Ellis and Aydin (1995) found that particulate deposits decreased rapidly with depth, however were still present at a depth of 400 mm. This highlights the importance of maintaining consistent operational conditions, and avoiding sudden fluctuation in flow or influent water quality.

3.8.6. Biological Mechanisms of Removal in Slow Sand Filtration

The main function of biomass in the slow sand filter is to remove and destroy pathogenic microorganisms and viruses, and to facilitate the breakdown of organic matter. Biological treatment mechanisms are most important for particles less than 2 µm in size.

A summary of the biological treatment mechanisms is given by Haarhoff and Cleasby. These include predation of algae and bacteria, scavenging of detritus by aquatic worms found 19 mainly in the deeper regions of the bed, natural death, inactivation, metabolic breakdown (I e. reduction of organic carbon), and adsorption to the sticky zoogleal surface of the sand. Weber-Shirk and Dick (1997a) suggest that bacterivory or predation of bacteria is the most important of all these mechanisms, and adsorption is the least significant. However, at lower water temperatures, it is suggested that adsorption to biomass is the dominating mechanism, due to reduced biological activity.

Generally, organisms that inhabit biological processes can either be carnivores, herbivores, bacterivores, detritivores, or omnivores. Duncan (1988) provides a survey of the common organisms that can be found in the sand bed. These include aerobic bacteria, flagellates, ciliates, rotifers, flatworms (microturbellaria), gastrotrichs, nematoda (round worms), anellida (segmented worms), and arthropoda (harpacticoids).

Of all these, the predominant organisms are gram-negative pigmented bacteria such as Pseudomonas and Aeromonas, as well as algae, protozoa, and higher order eucaryotes (Eighmy et al., 1993). Bacteria that are typically present in biological processes are generally classified as oligotrophs (Rittman and Huck, 1989). Oligotrophs are "characterized by their ability to simultaneously and efficiently utilize a wide array of substrates present at low concentrations".

The larger microorganisms such as protozoa either feed on suspended particles or bacteria, or are predators of other inhabitants of the sand bed. This is confirmed by Weber-Shirk and Dick (1999) who state, "predators that graze on attached bacteria potentially free up sites for future bacteria attachment while suspension feeding predators directly remove particles from the mobile phase". A proven species to be implicated as a bacterial predator is Chrysophyte (Weber-Shirk, 2002). Other predacious fauna include meiofaunal species (0.1 to 1 mm in size), which feed on individual bacterial or algal cells, suspended particles, or other species (Duncan, 1988). Some eucaryotes are known to be predators to bacteria, while some microorganisms simply produce substances that are toxic to enteric bacteria (Lloyd, 1973; Huisman and Wood, 1974).

Aerobic oligotrophic bacteria grow on the sand media to form a dense biofilm. This sticky biofilm, sometimes referred to as zoogloea, is known to adsorb colloidal material. Some researchers have postulated that filtration efficiency is partially a function of particle adsorption to the sticky biofilm. Bacteria such as Pseudomonas aeruginosa are known to produce extra-cellular polymeric substances (EPS), polysaccharides and proteins, which serve to anchor bacteria to surfaces (Dai et al., 2002). Bellamy et al. (1985b) suggest that these polymers act to flocculate organisms and destabilize clay and bacteria to facilitate attachment (Galvis et al., 1998). Wheeler et al. (1988) suggests that these extracellular polymers can also provide binding sites for viruses.

Removal of viruses is achieved through microbial predation and adsorption to biomass (Wheeler et al., 1988). Due to the relatively small size of viruses, physical mechanisms of removal are of less importance. Wheeler at al. (1988) found that biomass concentration is just as important for the removal of viruses (eg. rotavirus) as it is for the removal of pathogenic bacteria. In fact, they found similar patterns of removal between viruses and bacteria with respect to depth in the filter.

The term ‘bioantagonism’ has been used by a few authors to explain a mechanism of removal whereby incoming pathogenic bacteria are either ‘out-competed’ or ‘inactivated’ by autochthonous (naturally occurring) bacteria in the sand bed. For example, in the natural environment, Sattar et al. (1999) found that survival of Cryptosporidium declined in the presence of autochthonous microorganisms, and this phenomenon was referred to as bioantagonism. Although no specific microorganism was determined responsible for oocyst decay and the actual mechanisms of bioantagonism were unclear, autochthonous bacteria could similarly be responsible for oocyst decay in slow sand filters. This assumption is supported by the research of Uhl (2000), which indicates that the number of pathogens in biofilters decreases rapidly in the presence of autochthonous bacteria. The reasoning is that pathogenic bacteria, or allochthonous bacteria, are accustomed to high concentrations of organic matter where they thrive and experience a high growth rate. However, at low concentrations of organic matter, their growth rate is low. In contrast, the growth rate of autochthonous bacteria is still high even at low concentrations of organic matter (less than 1 mg/L of carbon), thus out-competing pathogens.

The term, ‘inactivation’, is used to describe the removal of enteric microorganisms due to predation or bioantagonism. Each layer of the sand bed has its own inactivation potential, depending on the vertical distribution of biomass. For example, procaryotes and eucaryotes were active throughout the filter bed in inactivating enteric microorganisms (E. coli), however inactivation potential was highest near the surface of filter bed.

3.8.7. 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.
Enteron bacteria	90 to 99.9%	Treatment efficiency affected by temperature, filtration rate, media size, bed depth, and cleaning practices.
Enteron 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%
Biodegradable 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.

Table 3.1 Typical Removal Efficiencies for Slow Sand Filtration (Galvis et al. 2002)

3.8.8. 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 headloss 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 parts of the United States and led to the development of rapid filtration techniques" Most surface waters may reach a turbidity of 30-50 NTU, will occasional peaks of 200 NTU after heavy runoff events (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 headloss. 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, leading to increased risk of pathogen breakthrough.

- The physical process of clogging in 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 subsequent increase in interstitial water velocity. As the interstitial velocity increases, 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.

- Excessive algal matter in the influent (chlorophyll a > 0.05 µg/L,) 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, 25 resulting in an increase in interstitial velocity and decrease in filter efficiency.

- 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. 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. Colloidal matter is much too fine, stable, and numerous to be completely removed by slow sand filtration alone. Colloidal 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 a 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 absorb 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 26 (Tipping et al., 1982; Jekel, 1986). Conversely, the presence of Ca^{2+} or Na^{+} in the water can adsorb to the surface of the particle and destabilize a suspension.

- 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.

- 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 20o C to 2o 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 5o 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, however it should ideally not drop below 3 mg/L.

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.

3.8.9. 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) advocates 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.

3.9. POST-TREATMENT WISH 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 odour 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 producers of bacteria (Uhl and Gimbel, 1996).

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

For example, GAC filters operated at slow filtration rates have been reported to remove greaterthan 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 slowsand filter with a GAC depth of only 7.6 cm above the sand bed.

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 removalof 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. 46 Thus, post- treatment with GAC filtration can provide a significant amount of additional treatment, beyondthat which is capable by slow sand filtration alone. Furthermore, it is an important treatment barrier in the multi-barrier approach to water treatment.

3.9.1. Maintenance Guidelines of Activated Carbon Filter

- When the Activated Carbon Filter (ACF) media becomes exhausted and can nolonger effectively remove odors and colors from the filtered water, it needs to be refilled
- The exhaustion of the media requires either the exchange or regeneration of the activated carbon. When opting for media replacement, a specific process should beconsidered
- Extract all activated carbon media and place in a safe disposal zone
- Bring new media from the store room. Wash it 4-5 times properly
- Place the media up to designated height
- Fill the chamber with water for further filtration

3.9.2. Activated Carbon Process

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

Table 3.2: Typical Properties of Granular Activated Carbon

properties	Bituminous	Sub-bituminous	Lignite	Nut Shell
Bulk Density as packed LB/CF	26-28	25-26	23	29-30
Volume Activity	26,000	25,000	13,800	0

Table: 3.2 Properties of GAC (V. Mishko et al. 2015)

3.10. 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 col our,5 % removal of total organic content.	With raw water, a filtrate quality impossible that has less than 1 NTU turbidity, 95 % removal of coliforms,99 % removal of cryptosporidium and Giardia cysts, 75 % removal of cColour10 % 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	Micro bacterial
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.

Table:3.3 Difference between RSF & SSF (I. Abubakar et al. 2022)

3.11. Parameters Affected by Multi-Stage Filtration

Depending on the country of origin and the regulating body, there are several drinking water standards to which adherence is required. Parameters monitored in Canada include bacterial waterborne pathogens, turbidity, metals, inorganic compounds, organic compounds, hardness,pH, odour, taste, colour, and by-product formation potential (Health Canada, 2014). Below

are concise descriptions of the most common parameters considered for safe drinking waterin remote communities. The majority of these parameters were investigated in this thesis.

3.11.1. Turbidity

Turbidity is one of the most common parameters tested in drinking water systems. It is an indicator of the effectiveness of the treatment in removing potential microbial pathogens. It is a measure of the scattering and absorbing effect suspended particles have on light. In Canada, the relevant guidelines specify a turbidity of less than or equal to 0.3 NTU for conventional filters; less than or equal to 1.0 NTU for slow sand filters; and less than or equal to 0.1 NTU for membrane filtration (Health Canada, 2014). These results must be achieved in at least 95%of measurements either per filter cycle or per month.

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3.11.2. Colour

The appearance of colour in drinking water is due to the presence of coloured organic substances that occur from decay of natural vegetation and the presence of one or more ofmetals, highly coloured industrial wastes, human-made organic substances and coloured suspended solids. In Canada, the relevant guidelines specify a true colour of less than 15 TCU (Health Canada, 2014).

3.11.3. Organic Matter

The removal of NOM is widely used in research as an indicator of the performance of the treatment process studied. NOM is a heterogeneous mixture of organic compounds and their degradation products. These compounds and products can cause harmful contaminants to be present during drinking water production (Metsamuuronen et. al., 2014). The concentration of NOM in drinking water has increased since 1990, due to climate change, changes in soil acidifications, severe drought seasons and intense rain events (Metsamuuronen et. al., 2014). The high variability in the composition of NOM makes it difficult to remove NOM completely from drinking waters. In addition to colour, NOM can also be identified through the presence (or absence) of taste and odour. The relevant Canadian guidelines identify several organic parameters that can cause harm to human health or cause unpleasant aestheticconditions in drinking water.

3.11.4. Inorganic Matter

Inorganic matter in surface water consists of naturally occurring and anthropogenic metals, such as iron, manganese, mercury and nitrogen-based compounds. The Canadian guidelines identify several parameters that cause harm to human health or unpleasant aesthetic conditionsin drinking water. One important parameter is mercury, which has a maximum acceptable concentration of 0.001 mg/L. Mercury in excess of that amount has been proven to cause neurological symptoms (Health Canada, 2014).

3.11.5. Disinfection By-Products

Chlorine is a common disinfectant used in drinking water treatment for the inactivation of pathogens. Chlorine is added to stabilize water in the distribution system. However, it can react with NOM present in the surface water to form common DBPs, such as THMs and haloacetic acids (HAAs). It should be noted that the risks from THMs or other DBPs in drinking water are less than risks posed from consuming water that has not been disinfectedat all (Irabelli et. al., 2008). Therefore, the presence of DBPs is expected in drinking water treatment; however it is important to employ proper controls to minimize the risk. The utilization of a biofilter or slow sand filter to help remove organics that can contribute to theDBP formation potential is one example. In Canada, the maximum contaminant limit for THMs is 0.1mg/L in drinking water (Health Canada, 2014).

3.11.6. Microbiological Parameters

In drinking water treatment, the highest priority parameters are those that deal with microbiological contaminants. Harmful microorganisms in poorly treated drinking water posea great threat to any population. These microorganisms cause gastrointestinal problems in humans. Two indicators are E.coli and total coliforms. In Canada, no E.coli should be detectable per 100mL of drinking water (Health Canada, 2014). The presence of E.coli indicates that: 1) a faecal contamination has occurred; and 2) microorganisms that can cause gastronomic illness may be present in the drinking water (Health Canada, 2014). Total coliforms indicate potential health effects from pathogenic microorganisms. Detection of coliforms in excess of 10% in samples collected during a sampling period should lead to investigation of the causes of the excess levels (Health Canada, 2014).

3.12. PERFORMANCE OF MULTISTAGE FILTRATION

3.12.1. 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 (Galvis64 and Visscher, 1999). In most of these systems, the local consumers of the water supply coverthe low operational and maintenance costs.

The performance of two different MSF systems in Columbia, one of them treating water froma heavily polluted river and the other treating a less polluted surface water. Both MSF systemsprovided 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 usingraw water sources that are more polluted.

One of the main limitations of slow sand filtration is its inability to effectively treat high levelsof 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 between63 and 93 TCU. Due to the high raw water colour, removal efficiencies were high (between 86and 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 to178 days, which far exceed slow sand filter run times of one to four weeks.

3.12.2. 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 to10 NTU (with spikes greater than 30 NTU) and <5 to 60 TCU, respectively. Typical effluent turbidities and colour ranged from <0.1 to 0.2 NTU and <5 TCU, respectively.

3.13. THE BENEFITS OF MULTISTAGE FILTRATION

Slow sand filtration is a proven, sustainable, and reliable drinking water treatment alternative for small communities, which can be beneficial for addressing the small systems challenges described above. The process provides treatment through physical filtration of particles and biological removal of pathogens and organics in the upper biologically active layer of the sandbed, known as the schmutzdecke. It is a simple technology that is relatively easy to operate andunderstand, requires little maintenance, and is capable of achieving high standards of treatmentwithout the use of coagulant chemicals, of which the purchase (material) and transport costs alone can be debilitating for a remote community. Furthermore, the performance of chemicallyassisted filtration is highly dependent on source water chemistry, and can be operationally intensive for surface water of variable water quality, in terms of maintaining optimal coagulantdosage and pH levels.

Slow sand filtration, on the other hand, can operate under a wide range of operational and source water quality conditions, with little or no process adjustment, which is a testament to the robustness of the process. It also requires less maintenance in terms of cleaning, as typicalfilter run lengths of one or more months can be expected between cleanings. In addition to thecost savings from reduced maintenance, its operational energy costs are minimal, as water canflow through the filter under gravity conditions, without the use of pumping, and energy intensive backwashing of the filter is not required in the cleaning process (for more details of the cleaning process, refer to Section 2.3.4). Finally, another advantage of slow sand filtrationfor a remote community is that it does not require the use of specialized equipment and can potentially be constructed with locally available materials, mainly from properly graded sand/gravel, concrete, and standard piping.

However, while slow sand filtration presents a number of attractive advantages over other conventional technologies, it does have a few significant limitations, which may be of concernfor some source waters. First of all, the process is sensitive to raw water turbidity where consistently high levels of turbidity (20 to 30 NTU) can lead to premature clogging of the filter,decreased filter run length, and frequent cleaning requirements. Besides increased maintenancerequirements, frequent cleaning also results in an increased opportunity for pathogen breakthrough by disturbing the biological equilibrium of the filter bed. Secondly, treatment is less efficient at low water temperatures (<5o C), which hinder biological activity in the filter bed. This poses a particular concern for communities in northern climates. Finally, it is less efficient than chemically assisted filtration at removing negatively charged stable suspensionsof colloidal matter (most colloidal material in natural water is negatively charged).

Multistage filtration, consisting of a slow sand filter preceded by a roughing filter, can overcome these treatment limitations and provide a reliable treatment alternative for surface water sources of variable turbidity and cold temperatures. It is a robust multi-barrier treatment process, in which waterborne particulate matter and pathogens face a series of treatment barriers, which may produce an effluent water quality that is better than that of slow sand filtration alone. The roughing filter, consisting typically of three layers of gravel media 3 (coarse to fine), is used to attenuate turbidity peaks, especially during runoff events, and reducethe solids loading on the slow sand filter, hence increasing its run length, and improving effluent quality. The roughing filter may also allow the slow sand filter to operate at higher than typical hydraulic loading rates. Furthermore, it provides a large surface area for the sedimentation of colloidal matter, and provides additional biological treatment and hydraulic retention time, which may be important during colder water temperatures and runoff events ofhighly contaminated source water. Thus, roughing filters may not only be important for protecting the operational integrity of the slow sand filter, but may also be a significant treatment barrier in the overall process of pathogen removal. But most importantly, the roughing filter does not require energy for backwashing, thus it is consistent with the cost sustainable paradigm that traditional slow sand filtration is reputed for.

The success of multistage filtration has been documented in several jurisdictions throughout the world, mainly in tropical regions using extremely contaminated surface water with high solids loadings. In North America, where single stage slow sand filtration has been largely replaced by chemically assisted rapid sand filtration, there has been a recent increase of interestin the use of multistage filtration for surface water treatment. LeCraw et al. (2004) document the performance of multistage filtration in a number of pilot and full-scale installations in coldclimate locations throughout North America. The results are promising for small communitiesin northern climates that are seeking a safe and cost-effective treatment alternative.

However, multistage filtration has yet to be systematically challenged in colder climates. Thereare still a number of key issues that need to be investigated to define the envelope in which it can perform satisfactorily for small systems in North America. Such issues include its performance under increased hydraulic loadings and elevated influent turbidity together with cold water conditions. Recent literature reveals the impact of additional stages of preozonationand post-granular activated carbon filtration for removal of organics, colour, and disinfection by-product precursor material; however, further exploration under the above operating conditions is warranted. Furthermore, the impact of an additional slow sand filter in series forincreased robustness and protection against pathogen breakthrough, particularly 4 during runoff events, cleaning, decreased temperatures, and increased hydraulic loadings remains to be determined.

operational benefits, may also be important for branding the roughing filter as a significant treatment barrier in the overall process of pathogen removal, beyond just its role of increasing the filter run length of the slow sand filter.

Most importantly, if this technology is to be legitimately accepted as a small system treatmentalternative, it is important to define the range of operating conditions under which it could comply with the requirements of regulations such as the Ontario Safe Drinking Water Act, specifically with respect to the removal of turbidity, Giardia lamblia, and Cryptosporidium parvum. (Given that systems in Ontario would also include disinfection, bacterial removals bymultistage filtration, while important, are not critical from a regulatory perspective). By investigating its performance under a range of raw water turbidity, temperatures, and hydraulicloadings, a range of small system conditions could be established, for which multistage filtration is a viable drinking water treatment option.

This kind of research would further elucidate the potential of multistage filtration as a reliable, cost-effective, and robust drinking water treatment technology for small communities throughout the world, especially in northernclimates.

CHAPTER: 4

METHODOLOGY

CHAPTER: 4

METHODOLOGY

4.1 FLOW CHART:

In this chapter, various activities of the study objectives are discussed. The various activities carried out in the study are shown through the flowchart.

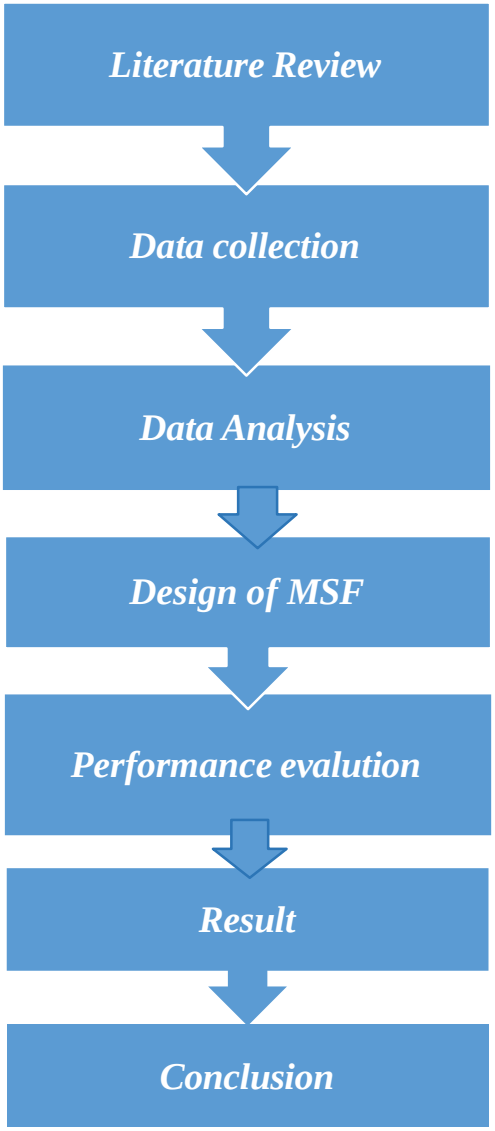


Figure 4.1 Flow chart of Methodology

4.2 LITERATURE REVIEW

The literature review revealed that when conducting a literature review on multi-storage filters, it depends on several key aspects of their methodology. Begin by defining what multi-storage filters are and their primary objectives. Typically, they are used to manage and process large amounts of data efficiently by applying various filtering techniques across multiple storage systems. Discuss the fields and scenarios where multi-storage filters are commonly employed, such as in database management, information retrieval systems, or distributed computing environment.

4.3 MODEL SET-UP

A Multi Storage Filter was developed at the Department of Water Resources Engineering at Jadavpur University, Kolkata, India to examine the aim of the study as shown in figure. The overall framework of MSF is in 3 parts one SSF, One HRF & One ACF. The SSF comprised of in this setup, the chosen effective size (ES) falls within the range of 0.3 to 0.35 mm, while the uniformity coefficient (UC) of 2.5 is considered. The design is based on a flow rate of 0.1m/h although different flow rates might be experimented. The slow sand filter media comprises of silica sand. In this setup, Same as HRF framework was provided by three filters in which Each filter consists of four chambers, each configured with a unique arrangement of media that decreases in size, aligning with the flow direction. Specifically, in Chamber 1, the media size is 10mm, in Chamber 2, it reduces to 5mm, in Chamber 3, it further decreases to 3mm, and in Chamber 4, it is 2mm. To facilitate the convenient collection of water samples for testing water quality parameters, inspection pits have been strategically placed within each chamber of the HRFs. The filter media within each chamber is characterized by a height and width of 0.15m, accompanied by a freeboard height of 0.02m. These dimensions result in a cross-sectional area for the filter(s) of 0.025 m^2. Cascade aeration is employed within the system to ensure an adequate supply of Dissolved Oxygen (DO) in the Slow Sand Filter, facilitating the active growth of microorganisms. Specific measures have been implemented to guarantee a minimum dissolved oxygen level of 5 mg/l is achieved before the water enters the SSF chamber. Last Included activated carbon filter to improve water taste and odour, the removal of potentially harmful organic compounds, and the provision of cleaner and safer drinking water. The ACF 1 and ACF 2 uses carbon media of 1000 IV, while the middle ACF i.e. in ACF 2 800 IV media is used. This can be change on future research requirements. The ACF 1 and ACF 2 provided. Which used carbon media of 1000 IV, while the middle ACF i.e. in ACF 2 800 IV media is used. Which can be change by future requirement.

The design of this model was done based on the water quality analysis of surface water sources in geogenic contaminated rural areas. This multistage filter system, comprises of a combination of distinct treatment processes, for water purification and to ensure the delivery of safe drinking water (conforming to IS 10500:2012). The Multistage Filter (MSF) is a robust and efficient water treatment system that employs a combination of distinct stages to ensure the production of safe and high-quality drinking water. Each stage in this multistage filtration process plays a crucial role in purifying the raw water before it reaches consumers. This integrated approach involves several key components as shown in figure 4.2

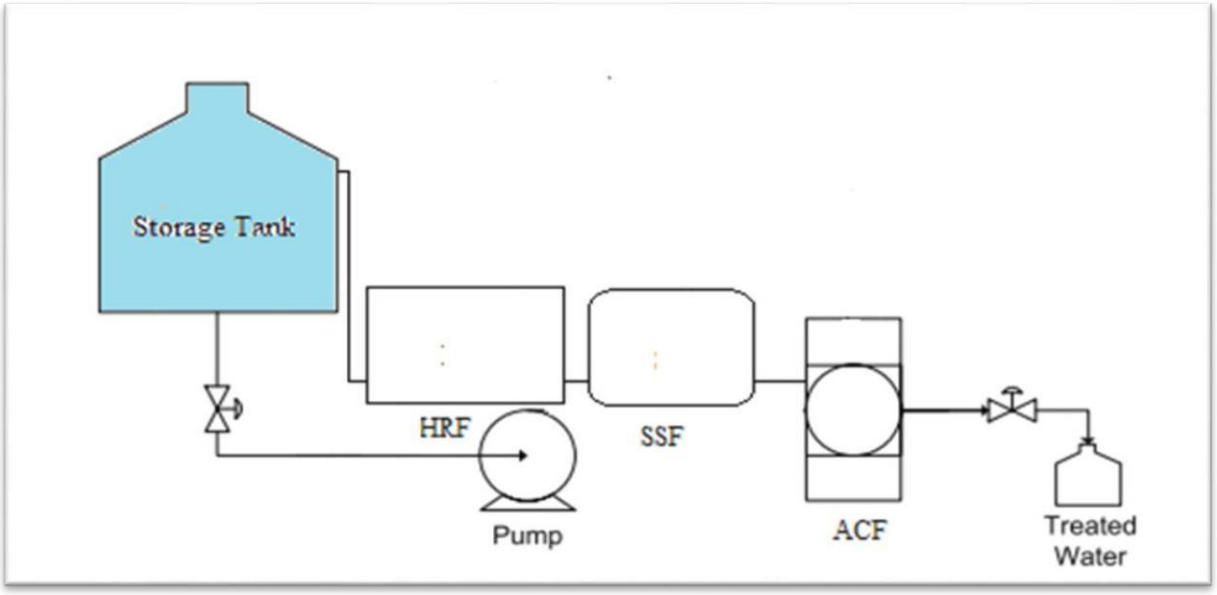


Figure 4.2 Overview of treatment process

4.4.1. Storage Tank

To run the Multi-Stage Filter model a continuous water supply is necessary. A 300 liter water tank is placed and connected to 1 HP pump. Level sensors are installed to make this system automation. When the tank water level below a certain limit then the pump is automatic “power ON” and after filling at certain limit, automatically “switch OFF” the pump. Also manual system is there.



Figure 4.3 Water level sensors setup



Figure 4.4 Pump setup

4.4.2. Horizontal Roughing Filter:

For the purpose of comparative study and research, three filters have been provided. Each filter consists of four chambers, each configured with a unique arrangement of media that decreases in size, aligning with the flow direction. Specifically, in Chamber 1, the media sizeis 10mm, in Chamber 2, it reduces to 5mm, in Chamber 3, it further decreases to 3mm, and inChamber 4, it is 2mm. To facilitate the convenient collection of water samples for testing water quality parameters, inspection pits have been strategically placed within each chamber of the HRFs. The filter media within each chamber is characterized by a height and width of 0.15m, accompanied by a freeboard height of 0.02m. These dimensions result in a cross- sectional area for the filter(s) of 0.025m^2. This design denotes a designated flow rate of 0.18m3/day, achieved at a filtration rate of 0.3 m/hr. The individual lengths of Chamber 1, 2, 3, and 4 are 350mm, 350mm, 250mm, and 250mm (centre to centre), respectively.
Furthermore, both the inlet chamber and outlet chamber share a length of 105mm each. Collectively, the total length of travel for each of the HRFs spans 1230mm.



Figure 4.5 Sieve



Figure 4.6 Sieve analysis

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.

4.4.3. Design of 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 GravelL4 = 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})= $V_{hd} \times (L_h \times W_h)$

= 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

requiredNow, 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

4.4.5. Step Aerator:

Cascade aeration is employed within the system to ensure an adequate supply of Dissolved Oxygen (DO) in the Slow Sand Filter, facilitating the active growth of microorganisms. Specific measures have been implemented to guarantee a minimum dissolved oxygen levelof 5 mg/l is achieved before the water enters the SSF chamber as shown figure

4.4.6. Slow Sand Filter:

Sand used in SSF has 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.



Figure 4.7 Sand for SSF



Figure 4.8 Filling of SSF

4.4.6.1. 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

4.4.7. Activated Carbon Filter:

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.

4.4.7.1. Design of Activated carbon Filter

Minimum column diameter (D_{AC}) to avoid channel 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

$= 0.00458/0.3 \text{ m}^2$

$=0.01527 \text{ m}^2$

*(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}) = $H_{AC} \times A_{AC}$

= 0.7 ×0.0227

= 0.01589 m^3

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

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

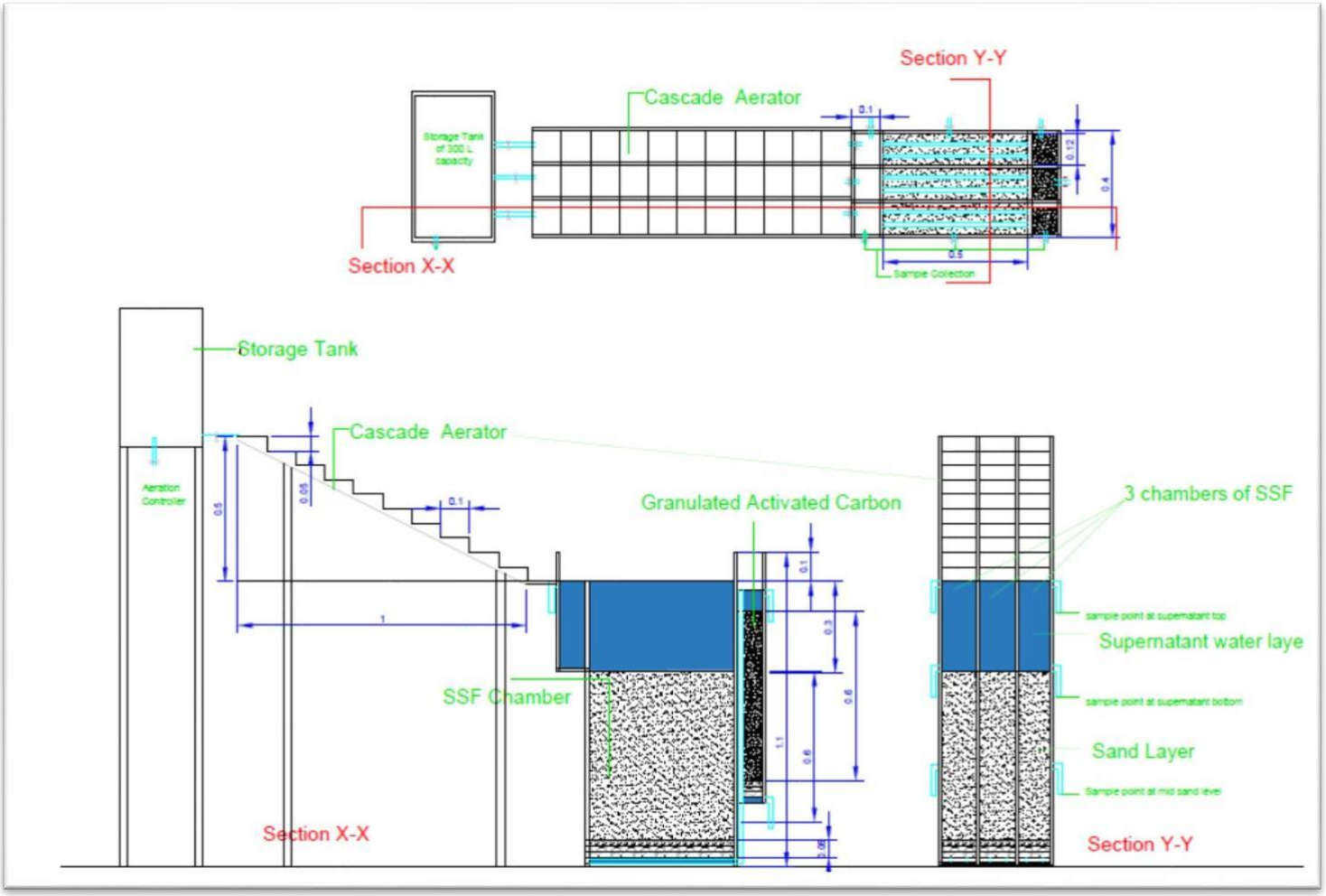


Figure 4.9 Model Diagram with dimensions (working manual for MSF by School of WRE 2021)



Figure 4.10 Horizontal Roughing Filter



Figure 4.11 Cascade Aerator



Figure 4.12 Slow Sand Filter



Figure 4.13 Activated Carbon Filter

The filter unit has five steps targeting the removal different pollutants from the raw inlet water. Horizontal Roughing Filters (HRF) primarily operate through mechanical means to eliminate suspended particles and various chemical pollutants from water. In contrast, Slow Sand Filters (SSF) employ a biological process to eliminate approximately 99% of bacteria while also mechanically removing small suspended solids and chemical contaminants. Additionally, the Activated Carbon Filter (ACF) is effective in adsorbing and eliminating odors, colors, and emerging pollutants. The efficiency of each treatment unit hinges on the successful operation and diligent performance monitoring of the entire plant.

4.5. Sample Collection

In MSF model there are several components, from each every components of model I collect samples. At first taking raw water sample and determine the water quality parameter. Then take the sample from HRF, Step Aerator, SSF and GAC.

- HRF has 3 chambers and each chamber divided into 4 sub parts. Take sample from each parts with various flow rate.
- After aeration take the sample in 3 aerator.
- SSF has 3 components, take sample from each parts.
- Same as SSF ACF has also 3 chamber.

Everyday two times samples are collected from each chamber of MSF and test is carried out. Then made a data sheet of everyday test results and analyze the data in next chapter.



Figure 4.14 Sample Collection from HRF

4.6 PHYSICAL PARAMETERS

4.4.1 Turbidity:

Turbidity is a measure of how clear water is. It is caused by the presence of suspended particles that scatter and absorb light. Typically measured in Nephelometric Turbidity Units (NTU) or Formazin Nephelometric Units (FNU). Turbidity Can reduce light penetration, affecting aquatic plant growth and disrupting ecosystems. High turbidity can harm fish gills and reduce feeding efficiency. High turbidity can indicate the presence of harmful microorganisms and contaminants, posing risks to drinking water quality. Turbidity can Increased turbidity can complicate water treatment processes, requiring more intensive filtration and disinfection.

The turbidity is expressed in terms of parts of suspended matter per million parts of water or shortly written as ppm. It is to be noted that the expression ppm is equivalent to mg per litre. The standard unit of turbidity is the form of finely divided silica in a million parts of distilled water. As per IS10500:2012 refer that the turbidity of drinking water should not be more than 5 NTU, and should ideally be below 1 NTU. Turbidity of the water is conducted by HACH 2100Q instrument is use which is shown in figure.



Fig: 4.15 Turbidity meter

4.7 CHEMICAL PARAMETERS

4.7.1 Dissolved Oxygen

The water contains various gases from its contact with the atmosphere and ground surfaces. The usual gases are nitrogen, methane, hydrogen sulphide, carbon dioxide and oxygen. The contents of these dissolved gases in a sample of water are suitably worked out. Oxygen in the dissolved state is obtained from atmosphere and pure natural surface water is usually saturated with it. The simple test to determine the amount of dissolved oxygen present in a sample of water is to expose water for 4 hours at a temperature of 27°C with 10% acid solution of potassium permanganate. The quantity of oxygen absorbed can then be calculated. This amount, for potable water, should be about 5 to 10 ppm. Dissolved Oxygen is measured by DO meter shown in figure. The test is conducted by HACH HQ40d instrument.



Fig:4.16 DO Testing



Fig:4.17 HACH HQ40d

4.7.2 PH

pH is a measure of the acidity or alkalinity of a water solution. The acidity or alkalinity of a water solution is determined by the relative number of hydrogen ions (H+) or hydroxyl ions (OH-) present. Acidic solutions have a higher relative number of hydrogen ions, while alkaline (also called basic) solutions have a higher relative number of hydroxyl ions. Acids are substances which either dissociate (split apart) to release hydrogen ions or react with water to form hydrogen ions. Bases are substances that dissociate to release hydroxyl ions orreact with water to form hydroxyl ions.

$$pH = -\log10\ [H^+]$$

pH measurement is based on the use of a pH sensitive electrode (usually glass), a reference electrode, and a temperature element to provide a temperature signal to the pH analyzer.

The pH electrode uses a specially formulated, pH sensitive glass in contact with the solution, which develops a potential (voltage) proportional to the pH of the solution. The reference electrode is designed to maintain a constant potential at any given temperature, and serves to complete the pH measuring circuit within the solution. It provides a known reference.

potential for the pH electrode. The difference in the potentials of the pH and reference electrodes provides a millivolt signal proportional to ph. For potable water, the pH value should be between 7 and 8.50 Following are the two methods which are employed to measure the pH value of water. Electrometric method: In this method, potentiometer is used to measure the electrical pressure exerted by positivelycharged H-ions. The pH value is then correspondingly expressed. Instrument use for this test is HM-200.



Fig:4.18 PH meter

4.7.3 Total Dissolved Solid

TDS (total dissolved solids) is the measure of the mass of solid material dissolved in a given volume of water, and is measured in grams per litre. The TDS value is calculated based on the specific conductance reading and a user-defined conversion factor. The highest desirable level of total solids is 500 mg/l and its maximum permissible level is 2000 mg/l.



Fig: 4.19 HM-200

TDS levels show a considerable range, from 126 mg/l to 900 mg/l. The highest TDS concentration is observed at R5, which might be attributed to the accumulation of various dissolved salts, minerals, and pollutants in the water.

CHAPTER 5

RESULTS & DISCUSSION

CHAPTER: 5
RESULTS & DISCUSSION

5.1 TURBIDITY MEASUREMENTS

5.1.1 Initial Turbidity Levels: The turbidity of the water samples entering the Slow Sand Filter filter ranged from 5.89 NTU to 1.1 NTU.

5.1.2 Final Turbidity Levels: After filtration, the turbidity of the treated water was measured between 1.8 NTU and 0.11 NTU.

INTERPOLATION :	Y1+(Y2-Y1)/(X2-X1 (X-X1)

5.2 MISSING DATA CALCULATION BY INTERPOLATION METHOD

5.2.1 Raw Water Interpolation

The table & chart below shows the difference between original raw value of turbidity & Interpolation calculation for the filter throughout the experiment. Interpolation technique estimates the values of unknown data points that fall between existing, known data points. It's often used to predict unknown values for geographical data points.

The turbidity of raw water varies from 5.89 to 2.83 NTU and that of interpolated values varies from 5.89 to 1.28 NTU. The mean value of Raw & Interpolation data 2.79 and 2.82 NTU, which is denotes that percentage error is 2%.

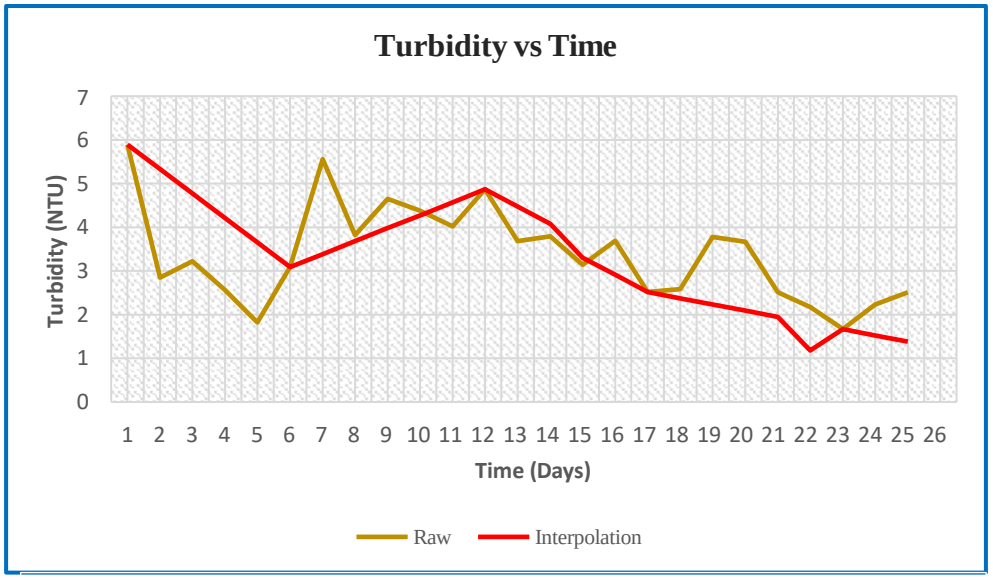


Fig: 5.1 variation of turbidity for actual & Interpolated value

5.2.2 Turbidity at depth 2(D2)

The turbidity of raw water varies from 3.6 to 0.26 NTU and that of interpolated values varies from 3.6 to 0.22 NTU. The mean and standard deviation of interpolation value of Raw & Interpolation data 0.96 and 1.11 NTU and 0.74 & 0.70, which is denotes that percentage error is 6%.

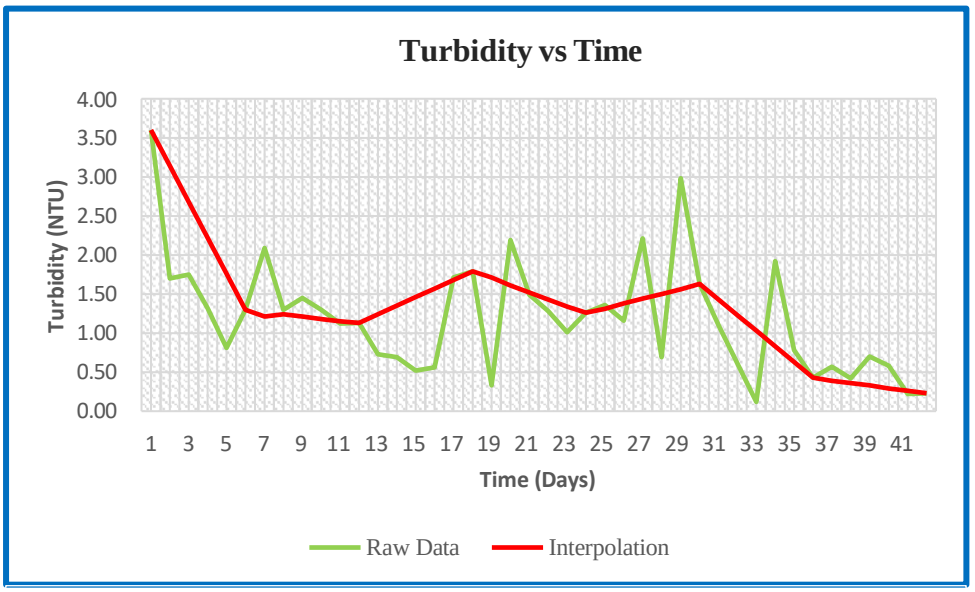


Fig: 5.2 variation of turbidity for actual & Interpolated value (D2)

5.2.3 Turbidity at depth 3(D3)

The turbidity of raw water varies from 2.5 to 0.15 NTU and that of interpolated values varies from 3.6 to 0.21 NTU. The mean standard deviation of interpolation value of Raw & Interpolation data 0.68 & 0.65 NTU and 0.56 &0.51, which is denotes that percentage error is 8%.

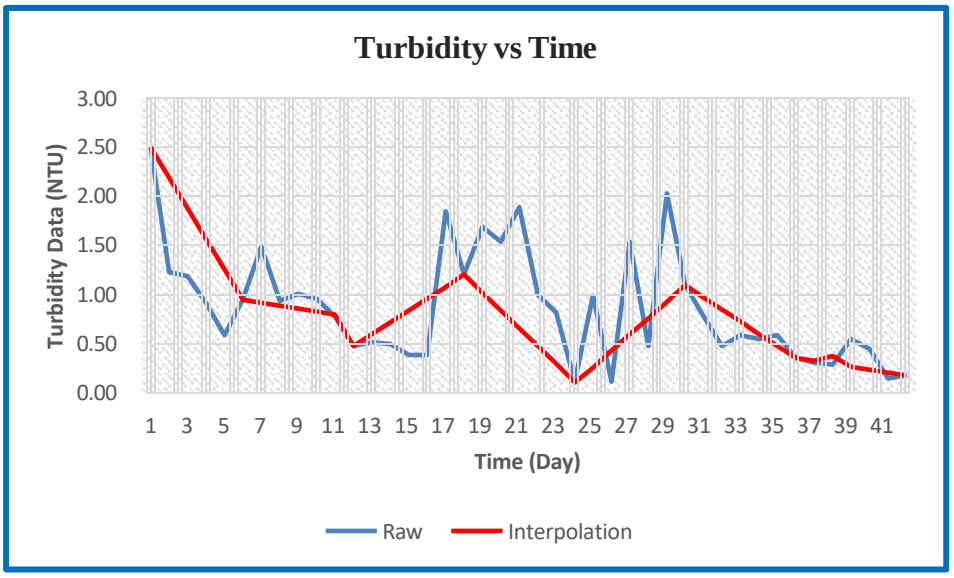


Fig: 5.3 variation of turbidity for actual & Interpolated value (D3)

5.2.4 Turbidity at output

The turbidity of output filter water varies from 1.95 to 0.12 NTU and that of interpolated values varies from 1.95 to 0.10 NTU. The mean and standard deviation of interpolation value of output & Interpolation data 0.68 & 0.65 NTU and 0.36 & 0.38, which is denotes that percentage error is 2 %.

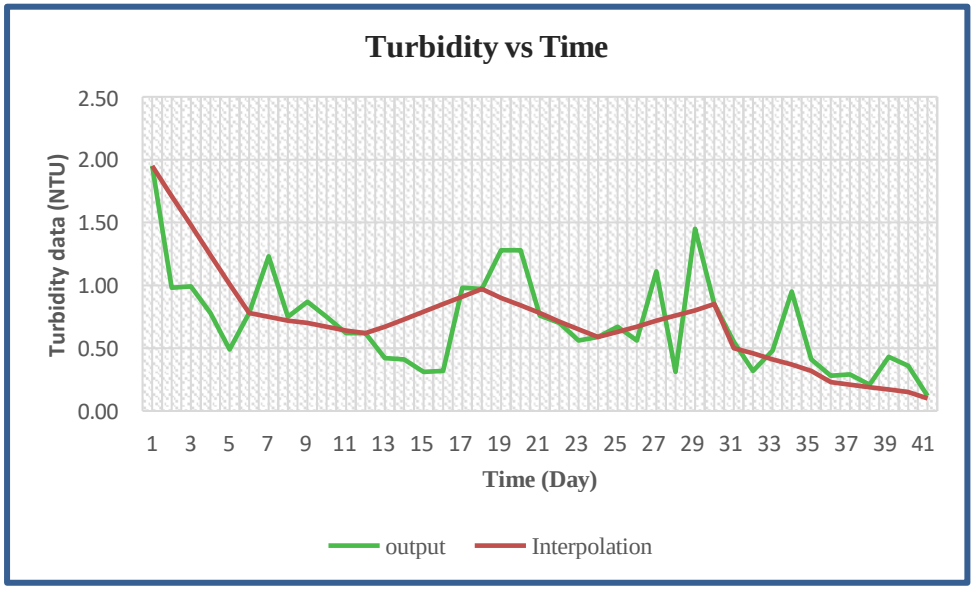


Fig: 5.4 variation of turbidity for actual & Interpolated value (Output)

Turbidity is one of the most important parameters for monitoring the performance of a filter. It is believed that turbidity serves as a carrier for nutrients that can result in biological activity. Turbidity analysis was conducted daily throughout the study. Turbidity levels in the influent

ranged from 1.32-5.89 NTU, whereas the effluent turbidity levels ranged from 0.11 to 1.98 NTU. The wide range of turbidity values resulted from the quality of the influent feed, i.e., direct from the operational line or from the reservoir. The average percent removal ranged from 66% to 91% through 0.35 mm sizes and 50 cm, 55 cm and 60 cm depths of sand from three different chambers of SSF model. This high degree of clarity of the filtered secondary effluent achieved is superior to the quality required of drinking water, which is 1.0 NTU. The low turbidity of the filtrate could also be attributed in part to the high quality of the biologically treated raw water used. The average percent removal of turbidity, i.e., 90%.

DAY	ACTUAL	IHTRRPOLATIO1"t	DIFFERENCE	% ERROR IN
1	5.89	5.89	0.00	0.00
2	2.85	5.33	2.48	57M
3	3.22	4.77	1.55	48.14
4	2.56	4.31	1.65	64.45
5	1.82	3.65	W.83	100.55
6	3.09	R9	0.00	0.00
	5.56	3.38	3.18	3911
8	3.82	J.6B	0.14	J.d6
9	4.65	3.98	0.67	14.41
10	4.38	4.27	0.11	2.51
11	4.02	4.37	0.35	13.68
12	4.87	•k'f	0.00	0.00
13	3.68	4.47	0.79	21.47
14	3.79	4.08	039	7.dS
16	3.14	3.}D	0.16	5.19
17	3.69	iw	077	21.1t
18	2.52	Z.gZ	0.00	0.00
19	2.58	i37	0.31	&14
20	›.n	zr	1.55	41.01
21	›W	ix	1.55	42.92
22	2.51	1.95	0.36	22.31
23	2.17	1.1B	0.99	45.62
24	1.67	1.67	0.00	0.00
25	2.23	1. 2	0.71	31.84
26	2.51	1.38	W.13	45.02
:T7	Lll	i4l	0.90	14.22
28	4.11	J.16	0.95	2ü.lt
29	lxl	3.9D	369	222.31
30	4.65	4.65	0.00	0.00
31	3.66	4.23	0.37	15.57
52	2.26	3.8]	1.56	69.03
33	lel	3.41	2.10	160.31
« 34	1.97	zm	1.02	‹›.n
	6.09	isz	3.51	57M
36	2.17	iIz	0.00	0.00
57	1.81	1.99	0.18	9.94
38	1.97	1.81	0.16	8.12
59	1.26	1.ó4	0.98	30.ld
40	3.26	1.4ó	W.80	55.21
41	2.83	1.2B	1.55	54.77

DAY	ACTUAL TURBIDITY (NTU)	INTERPOLATION	DIFFERENCE BETWEEN ACTUAL TURBIDITY & INTERPOLATION VALUE	% ERROR IN INTERPOLATION VALUE
1.00	2.50	2.50	0.00	0.00
2.00	1.23	2.19	0.96	78.05
3.00	1.19	1.88	0.69	57.98
4.00	0.92	1.57	0.65	70.65
5.00	0.59	1.26	0.67	113.56
6.00	0.95	0.95	0.00	0.00
7.00	1.49	0.92	0.57	38.26
8.00	0.94	0.89	0.05	5.32
9.00	1.01	0.86	0.15	14.85
10.00	0.96	0.83	0.13	13.54
11.00	0.78	0.80	0.02	2.56
12.00	0.48	0.48	0.00	0.00
13.00	0.52	0.60	0.08	15.38
14.00	0.50	0.72	0.22	44.00
15.00	0.39	0.84	0.45	115.38
16.00	0.39	0.96	0.57	146.15
17.00	1.85	1.08	0.77	41.62
18.00	1.21	1.21	0.00	0.00
19.00	1.69	1.02	0.67	39.64
20.00	1.54	0.84	0.70	45.45
21.00	1.89	0.66	1.23	65.08
22.00	1.00	0.48	0.52	52.00
23.00	0.82	0.30	0.52	63.41
24.00	0.12	0.11	0.01	8.40
25.00	0.99	0.26	0.73	73.74
26.00	0.12	0.43	0.31	263.87
27.00	1.54	0.60	0.94	61.04
28.00	0.48	0.76	0.28	58.33
29.00	2.03	0.93	1.10	54.19
30.00	1.10	1.10	0.00	0.00
31.00	0.78	0.97	0.19	24.36
32.00	0.48	0.85	0.37	77.08
33.00	0.59	0.73	0.14	23.73
34.00	0.55	0.60	0.05	9.09
35.00	0.59	0.48	0.11	18.64
36.00	0.36	0.36	0.00	0.00
37.00	0.31	0.33	0.02	6.45
38.00	0.29	0.38	0.09	31.03
39.00	0.55	0.27	0.28	50.91
40.00	0.45	0.24	0.21	46.67
41.00	0.15	0.21	0.06	40.00

Table: 5.2 Percentage error calculation at depth 2 (D2)

DAY	ACTUAL TURBIDITY (NTU)	INTERPOLATION	DIFFERENCE BETWEEN ACTUAL TURBIDITY & INTERPOLATION VALUE	% ERROR IN INTERPOLATION VALUE
1.00	3.60	3.60	0.00	0.00
2.00	1.70	3.14	1.44	84.71
3.00	1.75	2.68	0.93	53.14
4.00	1.32	2.22	0.90	68.18
5.00	0.81	1.76	0.95	117.28
6.00	1.30	1.30	0.00	0.00
7.00	2.09	1.21	0.88	42.11
8.00	1.30	1.24	0.06	4.62
9.00	1.45	1.21	0.24	16.55
10.00	1.30	1.18	0.12	9.23
11.00	1.12	1.15	0.03	2.68
12.00	1.13	1.13	0.00	0.00
13.00	0.73	1.24	0.51	69.86
14.00	0.69	1.35	0.66	95.65
15.00	0.52	1.46	0.94	180.77
16.00	0.56	1.57	1.01	180.36
17.00	1.71	1.68	0.03	1.75
18.00	1.79	1.79	0.00	0.00
19.00	0.33	1.71	1.38	418.18
20.00	2.19	1.61	0.58	26.48
21.00	1.49	1.52	0.03	2.01
22.00	1.28	1.43	0.15	11.72
23.00	1.01	1.34	0.33	32.67
24.00	1.26	1.26	0.00	0.00
25.00	1.36	1.31	0.05	3.68
26.00	1.16	1.38	0.22	18.97
27.00	2.21	1.44	0.77	34.84
28.00	0.69	1.50	0.81	117.39
29.00	2.98	1.56	1.42	47.65
30.00	1.63	1.63	0.00	0.00
31.00	1.10	1.43	0.33	30.00
32.00	0.61	1.23	0.62	101.64
33.00	0.12	1.03	0.91	765.55
34.00	1.92	0.83	1.09	56.77
35.00	0.78	0.63	0.15	19.23
36.00	0.43	0.43	0.00	0.00
37.00	0.57	0.39	0.18	31.58
38.00	0.42	0.36	0.06	14.29
39.00	0.70	0.33	0.37	52.86
40.00	0.58	0.29	0.29	50.00
41.00	0.22	0.26	0.04	18.18

Table: 5.3 Percentage error calculation at depth 3 (D3)

DAY	ACTUAL TURBIDITY (NTU)	INTERPOLATION	DIFFERENCE BETWEEN ACTUAL TURBIDITY & INTERPOLATION VALUE	% ERROR IN INTERPOLATION VALUE
1.00	1.95	1.95	0.00	0.00
2.00	0.98	1.71	0.73	74.49
3.00	0.99	1.48	0.49	49.49
4.00	0.78	1.24	0.46	58.97
5.00	0.49	1.01	0.52	106.12
6.00	0.78	0.78	0.00	0.00
7.00	1.23	0.75	0.48	39.02
8.00	0.75	0.72	0.03	4.00
9.00	0.87	0.70	0.17	19.54
10.00	0.75	0.67	0.08	10.67
11.00	0.62	0.64	0.02	3.23
12.00	0.62	0.62	0.00	0.00
13.00	0.42	0.67	0.25	59.52
14.00	0.41	0.73	0.32	78.05
15.00	0.31	0.79	0.48	154.84
16.00	0.32	0.85	0.53	165.63
17.00	0.98	0.91	0.07	7.14
18.00	0.97	0.97	0.00	0.00
19.00	1.28	0.90	0.38	29.69
20.00	1.28	0.84	0.44	34.38
21.00	0.76	0.78	0.02	2.63
22.00	0.70	0.71	0.01	1.43
23.00	0.56	0.65	0.09	16.07
24.00	0.59	0.59	0.00	0.00
25.00	0.67	0.63	0.04	5.97
26.00	0.56	0.67	0.11	19.64
27.00	1.11	0.72	0.39	35.14
28.00	0.31	0.76	0.45	145.16
29.00	1.45	0.80	0.65	44.83
30.00	0.85	0.85	0.00	0.00
31.00	0.55	0.50	0.50	90.91
32.00	0.32	0.46	0.14	43.75
33.00	0.48	0.41	0.07	14.58
34.00	0.95	0.37	0.58	61.05
35.00	0.41	0.32	0.09	21.95
36.00	0.28	0.23	0.05	17.86
37.00	0.29	0.21	0.08	27.59
38.00	0.21	0.19	0.02	9.52
39.00	0.43	0.17	0.26	60.47
40.00	0.36	0.15	0.21	58.33
41.00	0.12	0.10	0.02	16.67

Table: 5.4 Percentage error calculation at outlet

5.3 TURBIDITY REMOVAL EFFICIENCY

According to experimental set up the result shows that Turbidity is decreasing with days in all three chambers with different depth. Here we discussed only about chamber one, It shows that the Turbidity is removed with the increased depth. Percentage removal of Turbidity is increasing due to formation of bio layer with days. Removal efficiency of formation of bio layer is high so change in removal efficiency is cause by formation of bio layer. Cumulative percentage removal (Raw water to Outlet at SSF) and percentage removal from Raw water to depth 2(D2) is in increasing trend for every chamber up to the scraping cycle, while percentage removal from depth 2(D2) to depth 3(D3) and to outlet is in almost content.

5.4 ACCURACY OF LINEAR INTERPOLATION

Linear interpolation was utilized to estimate turbidity levels where data points were missing. The average percentage error of 4.5% indicates that the interpolation method provided accurate estimations, with minor discrepancies. The relatively low errors suggest that linear interpolation is a reliable method for estimating turbidity in cases where direct measurements are not available. However, it's important to recognize that linear interpolation assumes a constant rate of change between data points, which may not always capture more complex variations in turbidity removal.

5.5 PRACTICAL IMPLICATIONS

The observed turbidity removal efficiency underscores the effectiveness of multi-stage filtration in improving water quality. Accurate interpolation of missing data ensures that performance evaluations and operational adjustments are based on reliable estimates. This is crucial for assessing filter performance over time and making informed decisions regarding maintenance and optimization.

CHAPTER 6

CONCLUSION

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CONCLUSION

This study addresses the monitoring & filtration of residues in surface water of Jadavpur University jheel. Over a period of 41 days, our study on Multistage Filter model has identified that the output turbidity values in the Slow Sand Filter ranged from a minimum of 0.11 NTU to a maximum of 1.95 NTU where The turbidity value of raw(input) water in the slow sand filter is 5.89 NTU. This demonstrates the filter's effectiveness in significantly reducing turbidity compared to the raw water. The research employed that the raw water from jheel entering the system had a maximum turbidity of 57 NTU, which is notably high and indicative of substantial particulate matter. After passing through the Horizontal Roughing Filter, the turbidity was reduced to maximum 5.89 NTU. This preliminary filtration step shows substantial improvement in water quality, but it is the Slow Sand Filter that further enhances this reduction. The Slow Sand Filter's ability to lower turbidity to as low as 0.11 NTU underscores its critical role in achieving high-quality water treatment. This experiment explored the application of interpolation methods to estimate missing or disrupted data, with a specific focus on the turbidity measurements of a Slow Sand Filter over a 41-day period. The analysis involved calculating interpolated values for turbidity data on the 1st and 6th days, revealing a discrepancy of approximately 3 to 4 percent between the estimated and actual values. During inflow The turbidity of raw water varies from 5.89 to 2.83 NTU and that of interpolated values of raw data varies from 5.89 to 1.28 NTU. The mean value of Raw & Interpolation data 2.79 and 2.82 NTU, which is denotes that percentage error is 2%. Similarly the turbidity of output filtrated water varies from 1.95 to 0.12 NTU and that of interpolated values varies from 1.95 to 0.10 NTU. The mean and standard deviation of output & Interpolation data 0.68 & 0.65 NTU and 0.36 & 0.38, which is denotes that percentage error is 2 %.

- **Limitations**

1. the study’s duration was limited 41 day’s testing period, and longer performance may vary.
2. while locally available materials were used, variations in material may exist in different regions
3. The study primarily focused on physical and chemical parameters.
4. The study did not explore the specific socioeconomic and behavioral aspects of filter adoption in communities.

- **Future Scope**

The work here has demonstrated that interpolation methods, particularly linear interpolation, can effectively estimate missing values and enhance water quality monitoring and filtration system performance. However, there are several areas where further exploration could yield valuable advancements:

1. **Enhanced Interpolation Techniques**: Future research could investigate more advanced interpolation techniques, such as machine learning-based methods or hybrid models that combine multiple interpolation approaches. Techniques like kriging, neural networks, or deep learning could offer improved accuracy and adaptability for different types of missing data scenarios.
2. **Real-Time Data Processing**: Exploring the application of interpolation methods in real-time data processing and forecasting could significantly benefit water quality management. Implementing adaptive algorithms that dynamically adjust to changing data patterns and environmental conditions could further refine the accuracy of missing data estimation.
3. **Integration with Other Monitoring Parameters**: Expanding the scope of interpolation to include other water quality parameters alongside turbidity could provide a more comprehensive understanding of water quality dynamics. This could involve developing multi-parameter interpolation models that account for the interdependencies between different variables.
4. **Field-Based Validation**: Conducting extensive field-based validation studies to test interpolation methods under various environmental conditions and across different types of water bodies would provide insights into their practical effectiveness and limitations. Such studies could also explore the impact of data quality and sensor reliability on interpolation performance.
5. **Optimization of Filtration Models**: Further research could focus on optimizing filtration models by incorporating interpolated data, exploring how improved data estimates affect system design, operational strategies, and efficiency. This could include case studies and simulations to validate the benefits of accurate data interpolation in real-world filtration scenarios.
6. **User-Friendly Tools and Software**: Developing user-friendly tools and software for practitioners that integrate advanced interpolation techniques and real-time data processing capabilities could facilitate the practical application of these methods in water quality monitoring and management.

In conclusion, the Interpolation method presents a promising solution for improving water quality parameters in resource-constrained settings, further research and optimization can enhance its effectiveness & applicability.

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