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SCHOOL OF ENGINEERING
Department of Civil Engineering and Architecture

NEW TRENDS IN DRINKING WATER TREATMENT AND DISTRIBUTION

JOOGIVEE TÖÖTLEMISE JA JAOTAMISE UUED SUUNDUMUSED

MASTER THESIS

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(*On the reverse side of title page*)

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2. To compare the available technologies in the water treatment field
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PREFACE

This research paper is written as a part of study curricula for completion of master's in environmental engineering and management at Tallinn University of Technology. The concept for the topic was endorsed by observing the recent trends in drinking water scarcity. During my Erasmus stay in Prague, I got inspired to do my research on this topic.

I would like to acknowledge Prof. Karin Pachel for her supervision for guiding and assisting in the completion of the work. Similarly, I would like to thank the entire team of Environmental Engineering and Management faculty, Tallinn University of Technology, Tallinn for support and providing the platform.

I would like to thank Prof. Pavel Jenicek for assisting me from the beginning of the thesis. I would also like to thank Prof. Ing. Vaclav Janda for all his help and cooperation. I Would like to express my entire gratitude to the entire department of Sustainability and Environmental engineering, University and Chemistry and Technology, VSCHT, Prague.

The entire thesis aims at the new trends in the drinking water field and the possible channel for the distribution of the treated water. The entire research is done based on five of the new trends in the water treatment sector. They are the Membrane Filtration process, Ultraviolet Irradiation, Advanced oxidation Technology, Ion Exchange Technology, and Biological Filtration system. Comparison among the technologies has been done using Analytical Hierarchy Process based on the scholarly articles and studies.

Keywords: DWTP, DWS, Membrane Filtration, UV irradiation, Advanced Oxidation Technology, Ion Exchange Technology, Biological Filtration, AHP, Master thesis

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LIST OF ABBREVIATIONS AND SYMBOLS

AI Artificial Intelligence

DWTP Drinking Water Treatment Plant

DWS Drinking Water Supply

NTU Nephelometric Turbidity Unit

TDS Total dissolved Solids

DO Dissolved Oxygen

BOD Biochemical Oxygen Demand

COD Chemical Oxygen Demand

RO Reverse Osmosis

CNT Carbon Nanotubes

NF Nano Filtration

UF Ultra Filtration

MF Microfiltration

UV Ultraviolet

DNA Deoxyribonucleic acid

HRT Hydraulic Retention Time

AOP Advanced Oxidation Process

AOT Advanced Oxidation Technology

IET Ion Exchange Technology

WDS Water Distribution System

PVC Polyvinyl Chloride

PEX Cross-Linked Polyethylene

DWDS Drinking Water Distribution System

PUB Public Utilities Board

AHP Analytical Hierarchy Process

CI Consistency Index

CR Consistency Ratio

1 INTRODUCTION

Drinking water is the most essential liquid for sustaining human life. Consumption of clean water is the main way to be healthy and drinking the water in the right amount can help reduce lots of illnesses. The term clean water relies on various characteristics of the water. These characteristic includes the physical, chemical and microbial properties of water. These properties solely depend on the substances that are dissolved or present in the water. Drinking water in this means the water that is fit for a human to survive. Safe water or clean water has its definition in various fields as per the requirements. The water that can be fit for drinking purposes may not be fit for cooling the nuclear reactors due to the presence of the minerals salts, which can erode the entire distribution system. Researchers have been concerned about the safest way since water is the medium that can carry the disease-causing agents. Consumption of water with pathogens and toxic materials can impact human health seriously[1]. The greatest threat is the water crisis which will be the global water shortage around all the parts of the world. Everything that used to be newest becomes normal and simple with time. The extreme rise in the population and the global rise in temperature and pollutions had made revolutions to choose a new method for drinking water treatment.

Identifying the new source of drinking water has been challenging. Groundwater which is the main source of drinking water constitutes 97 percent of the world's freshwater. In many developing countries, groundwater is the main source of drinking water. The water is easily available and is better in terms of microbial quality as compared to surface water. However, due to limited campaigns on the monitoring of the water quality, groundwater source has become the most vulnerable source for an outbreak of diseases[2]. On a planetary scale, the earth can never be without water. It is all due to the water cycle. However, the water from all the sources cannot be used for drinking purposes due to the presence of loaded minerals which is unsafe for drinking purposes. Only about 1 percent of water is fresh and this source cannot be relied on. With regards to this situation, recent trends in the treatment of surface water have flourished. Seawater desalination has been the best possible solution to this emerging problem[3]. Similarly, the use of recycled water has been practiced in various regions of the planet. The water through the closets, toilet, and bathroom are retreated and recycled, and matched as per the drinking water guidelines. This method can be used to reduce the shortage of water in the town where the freshwater source is scarce. The conventional system practiced in many countries uses water from the river, lake, or aquifer and is distributed after being treated as per the drinking water standards. However, the water after being used is discharged into the water bodies after being treated as per the guidelines of the effluent. Water reuse concept uses this treated effluent for the DWTP influent which makes water supply system functioning without any scarcity of water.[4]

1.1 Background

The world has made a remarkable development in technologies. The advancement of technology has accelerated the world to reach the country's respective targets within a short time. But if these advanced technologies are confined to the water distribution system could lead to a sustainable solution to the present scarcity and water treatment-related problems. Industrial Revolution and the technologies such as Artificial Intelligence, Blockchain, Drones, and remote sensing with embedded virtual reality versus augmented reality if can be used for supply and distribution of water, we could save more quality and safe water. Artificial Intelligence has been endorsed in several fields because of its ability to solve complex problems with the least effort in numerous fields. The use of this technology in the management and the operation of the treatment plant can effectively reduce human labor and the manual error caused due to the fluctuation caused in the working environment. AI having the capability to diagnose the water quality from its autonomous learning method can optimize the operation process during the treatment process. Drinking water treatment by the conventional method involves a series of processes such as coagulation, flocculation, sedimentation, filtration, and disinfection. These processes can be optimized by practicing the newly invented technology that reduces the managing and monitoring expenses.[3]

1.1.1 Drinking water treatment system

Treatment refers to the procedure of removing the unwanted entities from the given sample. Treatment of water is the method of making the water suitable for the desired activities. The activity related to water can be for Irrigation, drinking, industrial use, or some other water-related recreational works. Treatment related to drinking water involves the removal of unwanted pathogens and reducing the concentration of anthropogenic particles which can be crucial concerning human health.

The overall aim of drinking water treatment is to make the water acceptable as per the guidelines practiced in the specific area. Since the ancient era, various methods of treatment have been practiced improving the quality of the water. General treatment systems include several steps including physical, chemical, and biological methods. The process is based on the drinking water regulations and can vary as per the source of the raw water and the area specified.

1.1.2 Water distribution system

The Water Distribution System(WDS) is a setup technology for the distribution of water from the main treatment plant to the consumer units. The technologies used for the efficient and dynamic distribution of water affects the overall performance of treatment and distribution plant. With a widespread population, the management of distribution networks has become more complicated. Furthermore, the recent development in technologies and the advancement in people's lifestyles have made the system to be futuristic and ideal in the weather and the environmental conditions.

WDS efficiency highly affects the total water loss. The effectiveness of the system depends on various constraints such as the capability of the distribution system to meet the growing population need, monitoring of the loss, and supply of potable water without the introduction of pathogens in the midway. AI has been used by many suppliers to determine the possible prediction of the water demand and forecasting the futuristic scenario of the supply concerning current trends. However, the introduction of AI is not only the solution to the problems. It should be implemented in such a way that it could handle the data, control structures, and formulate the strategies based on the demand. An optimized distribution network can save a huge amount of water which is beneficial both economically and environmentally.

2 THE AIM, OBJECTIVE, AND RESEARCH QUESTION

The main aim of the research is to find the recent trends developed in the drinking water treatment and distribution field. Along with the use of this advanced technology, the study is to carry out the effectiveness of the newly invented models. AI on the one hand can be handy in daily operations. However, the particular model can be outrageous during the outbreak of some pollution and during the seasonal change. So, the main approach is to find out the best-suited technology that can be highly precise and can be operated in a different specific model.

To fulfill the objective, overall efficiency, complexity in different stages of water treatment will be studied. Furthermore, the sustainability and the capacity of the water treatment will also be parameters to choose the best method. Collected data and results will be analyzed and interpreted to find out the main findings and to give recommendations for the technology.

The main research question for the study are

- What are the newly developed methods for drinking water treatment and distribution systems?
- Which of the treatment method is best compared to the alternatives?

3 LITERATURE REVIEW

As stated earlier, a pure and sustainable water supply has been associated with population growth, climate change, and natural calamities. Traditional water treatment technology uses high energy requirements to operate efficiently. High economic costs and the introduction of new pathogens and pollutants make the existing treatment technology unable to match the recent parameters of safe drinking water. They were able to remove pathogens and main pollutants only, which is no match to the modern drinking water needs. Similarly, the concept of reuse of wastewater has brought a new approach in the method and types of anthropogenic pollutants to be treated. Conventional treatment plants are based on the centralization and the distribution from the main hub but the new technologies focus on more decentralized trends in the treatment of water. i.e., household point of use. Advanced technology includes the use of the electronic nature of molecules present in water to process water into the safe category. Electroactive separation and catalytic processes are the newest trends in this field. Furthermore, with the advancement in the biotechnology field, the bacteria and pathogens present in the wastewater itself can be cleansing agents for other viruses only with a small trigger in their reproductive environment[5].

Treatment technologies are often classified into three categories based on the process and their operational criteria. They are:

- Physical Process: This includes the process which is responsible for removing impurities of the water such as particle size, viscosity, and specific gravity[6]. Screening, sedimentation, sand filtration are examples of this process.
- Chemical Process: Coagulation, ion exchange, and precipitation are the example of the chemical process which depends on the chemical properties of the impurities in the water[6].
- Biological process: This process is based on the biochemical process of the dissolved particles and impurities. Biological filtration activated sludge process, anaerobic oxidation method comes under biological treatment process[6].

The literature review of the research is based on the newly developing trends in the DWTP with an overlook to the conventional technologies. Furthermore, the efficiency and suitable environment of the treatment methods and their effectiveness will be discussed.

3.1 Water quality

Water quality is the collective characteristics of water based on its physical, chemical, and microbial properties. These properties are the major indices for determining the quality of water. Based on the nature of the water use, the quality parameters differ from sector to sector. For drinking purposes, water that is clean in appearance and with pleasant taste and odor without having harmful chemicals and pathogens is regarded as safe water. Generally, the water quality is assessed by grouping the similar characteristics of water and the treatment process involved.[7]

The type of substances present in water depends on the source of the water and the environmental conditions. Based on the properties of the organic and inorganics present in water they are further classified as:

Suspended and colloidal substances: The substances that are present on the surface of the water without being themselves dissolved in water are known as the suspended substances. These substances can be removed with simple processes such as filtration, sedimentation, and screening. The relative density of these substances is either lower or higher than that of water and either float or settles at the bottom. Colloidal particles are the ones carrying some electric charge and do not settle down like the suspended particles. Colloidal substances are defined based on the size from 10 nanometers to 1 micrometer. [8]

Dissolved substances are the ones difficult to distinguish by naked eyes. It comprises the dissolved gases such as oxygen, carbon dioxide, nitrogen, ammonia, and many other inorganics and organic substances such as sodium chloride, humic acids, and carbohydrates. These substances are generally removed by an advanced process such as osmosis and ultrafiltration.

Based on the nature and properties of the suspended and the colloidal matters the quality parameters are distinguished into mainly three categories.

3.1.1 Physical parameters

Turbidity is the ability of water to pass the light through the water. High turbid water is unacceptable because this makes water aesthetically unacceptable. Turbid water is difficult to treat and increases the treatment cost of the water. Turbidity is measured using an instrument called nephelometric turbidimeter and thus the unit of turbidity is measured in NTU. Water with more than 5 NTU is considered aesthetically unacceptable because it seems cloudy[9].

Temperature affects many other chemical and physical properties of water. Viscosity, solubility, and chemical reactions undergoing during the treatment process are affected by the variation of the temperature. Water at a temperature between 10-15^{o}C is considered drinkable [10].

Colour is the general appearance of the water. Watercolour is classified as true and apparent colour based on whether the water sample has suspended material or is filtered out. The Colour of water is measured by comparing the sample with the standard sample of some coloured disk and is generalized as the colour equivalent which is the colour generated by 1 mg/L of platinum [10]. Colour is measured on a scale of 0-70. Clean water is colourless i.e., it should not have any organic matter, vegetation, and other debris.

Taste and odour are due to presence of the organic and inorganic matters in water. The odour of water can change due to presence of the dissolved gases in water. The unit of taste of water is calculated in terms of threshold number[9]. The odour of water is calculated by mixing the sample with odour-free water and calculating the odour of the intermediate sample.

Solids are the salts, minerals, and inorganic salt present in water. Based on the characteristics of the solids they are classified into sub-categories i.e., total suspended solids and total dissolved solids. Solids can be removed either by evaporation, filtration, or chemical treatment[11]. The number of solids in water plays a vital role in determining the organic matter present in the water. Freshwater has total dissolved solids (TDS) less than 1500 mg/L TDS and waste or brackish water has solids ranging from 1500-5000 mg/L[9].

Electrical Conductivity is the measure of the ability of water to pass the flow of electricity. This is directly dependent on the concentration of the ion present in the water. The higher the concentration of the ions, the higher is the conductivity of the water. The ion in water is due to the presence of alkalis, chlorides, and sulphides, and other inorganic compounds and dissolved salts. It is used to calculate the salinity and total dissolved solids (TDS) of water. Distilled water has almost zero conductivity whereas saline water has the highest conductivity[12]. Normal drinking water has conductivity around 0.005-0.05 S/m whereas ultra-pure water has a conductivity of 5.5 x 10^{-6} S/m and seawater with 5 S/m[9].

3.1.2 Chemical Parameters

pH is the measurement of the strength of the solution whether it is acidic or basic. The concentration of the hydrogen or hydroxyl ion in a solution measures the pH of the solution. It is a dimensionless parameter and is measured on a scale of 0-14. An acidic solution has less value whereas basic water has a higher value. Generally, water that has a pH of around 7 is pure. However, water varying from 6.5-8.5 pH is drinkable[13].

Acidity is the measure of the acid present in water that can neutralize the base present in water to maintain the pH level of water. Acidity is due to the presence of carbon dioxide, minerals, and salts of ferric and aluminium sulphates [10]. Acidity is measured by titrating the sample with standard sodium hydroxide using phenolphthalein as an indicator[10], [13].

Alkalinity is due to the presence of hydroxide, carbonate, and bicarbonate in water[13]. Alkalinity affects the pH and total hardness of water and is responsible for the toxicity of many substances. It is measured by titrating the sample with dilute HCl or H_2SO_4. A higher level of alkalinity in source water denotes chemical or industrial pollution.

Dissolved Oxygen (DO) is the amount of oxygen that is soluble in water. Dissolved oxygen is dependent on the pressure, temperature, and salinity of the water. The higher the dissolved oxygen, the better is the quality of the water[9]. The amount of DO in water is directly dependent on the temperature, pressure, and salinity of the water. Usually, the DO of water is higher in summer due to the rise in temperature and duration of sunlight[14]. The amount of oxygen consumed by bacteria is calculated by calculating the difference between initial and final DO. This parameter further assists in measuring the biological oxygen demand and chemical oxygen demand of water for treatment.

Biochemical Oxygen Demand (BOD) is the amount of oxygen consumed by bacteria and microorganisms under specific temperature and aerobic conditions to decompose the organic matter. Usually, the BOD of a sample is measured over 5 days [14].

Chemical Oxygen Demand (COD) is the amount of oxygen required for the chemical oxidation of the organic compounds in the water. COD is also a measure of the organic material contamination of water and is expressed as mg/L. Both BOD and COD determine the key quality of the water.

Chloride ions in drinking water are not that harmful directly but can be the causative agent for cancer and kidney diseases. The high amount of chloride can make water salty and unpleasant[13]. Chloride in the water sample is measured by titrating the sample with a standard silver nitrate solution. The indicator used during the titration can be potassium chromate solution of fluorescein solution in alcohol[14]. Standard drinking water should have a chloride level of more than 250 mg/L[10].

Chlorine residual in water is due to the addition of chlorine during the disinfection process. However excessive chlorine in the water is not aesthetic. Sometimes chlorine can react with organics in water resulting in the formation of trihalomethanes which is a carcinogenic agent[13]. Drinking water should not have chlorine more than 0.2 mg/L.[13]

Sulphate ions in water do not have significant harm to the public. However, an excessive amount of sulfate can make water aesthetically unpleasant and change the taste of water. It is measured by the nephelometric method where the concentration of turbidity is compared against synthetically prepared sulfate solution[14].

Nitrogen can be found in four different forms in water. If water is heavily polluted, nitrogen is in form of organic and ammonia which are further converted into nitrates and nitrites by microorganisms. These organic nitrates are the basic source of nutrients for the growth of plants and other organisms in the water. So, excessive nitrogen is unacceptable for drinking. Water having more than 10 mg/L is unacceptable for drinking[13]. This is measured using 425nm radiation spectroscopically with Nessler's agent[14].

Fluoride in water is responsible for good dental health. Excessive of fluoride ion causes the discoloring of the teeth generally called as dental fluorosis. The amount of fluoride in water depends on the temperature of the water. Usually, the allowable amount of fluoride in warmer regions is 1.4 mg/L whereas in colder regions is 2.4 mg/L.[13]

Iron and manganese are not harmful to public health but an excessive amount of these can increase the turbidity of water and makes water bitter even when the concentration is very low. Iron and manganese are present in an aqueous form in groundwater and when they get exposed to air, they transform into ferric and manganic forms which are responsible for watercolor. They are measured by different instruments like atomic absorption spectrometry, flame atomic absorption, electrochemical atomic absorption spectrometry[10].

Hardness is the measure of the mineral content such as calcium and magnesium carbonates, bicarbonates, and sulfates. Generally, groundwater is harder as compared to surface water. Hardness is further classified into two categories. i.e., temporary hardness which is caused due by carbonates and bicarbonates and can be removed by simple boiling whereas the second one is permanent hardness which is due to sulfates and chlorides and cannot be removed by boiling procedure.

Toxic inorganic substances are those which if present in water in a small amount can cause great danger to human health. Toxic substances are further classified into metallic compounds and non-metallic compounds.

- Metallic compounds: They are the group of heavy metals that are toxic like cadmium, chromium, lead, mercury, silver, arsenic, barium, thallium[15]. They may be fatal, and the level of danger varies from metal to metal. This can be determined by atomic absorption photometers, spectrophotometers [12].

- Non-metallic compounds: These are nitrates (NO_3^-) and cyanides (CN^-) compounds. Both are toxic if inhaled and should be removed from the water. Cyanide compounds can cause a chronic effect on the central nervous system and can also cause blue skin syndrome. These compounds are measured using titrimetric, colorimetric, or electrometric processes.[13]

Toxic organic substances are artificial compounds such as insecticides and pesticides. Detergents, solvents, and disinfectants when reaching the source of the water contaminate the water. Generally, they are measured using gas chromatography, mass spectrophotometry instruments.[13]

Radioactive substance is usually found in small amount mixed with soil and rock and can easily dissolve in water. Radioactive radium and uranium are the main radioactive substances found in water. Radon gas which is a type of radioactive gas formed due to the decay of radium usually occurs in groundwater naturally. Furthermore, nuclear activities, effluent from the industry, labs, and medical research centres can be the source of radioactive substances. This radiation when perceived by a human directly can cause genetic and somatic disorders to alive tissues.[12]

3.1.3 Biological parameters

Biological parameters are the most important parameters to determine the quality of water. Concerning human health, biological parameters need to be more precisely controlled as compared to physical and chemical parameters. Usually, various micro-organisms are present in water. Many of them are harmless but if the water is polluted they might have pathogens. Pathogens are disease-causing micro-organisms. It is therefore mandatory to treat those harmful pathogens before consumption. This parameter is further categorized into four subcategories.

Bacteriological aspect: Bacteria are the unicellular organism generally either in rod, spherical or spiral shape. They are the simple and smallest living thing able to multiply in a short period if everything goes efficiently. Bacteriological aspects are commonly indicated as total coliforms to indicate the quality of water. There are mainly two types of bacteria. The first one which reproduces and grows in presence of oxygen is aerobic bacteria whereas the next one is anaerobic which does not require oxygen. Some bacteria can survive and reproduce regardless of the presence or absence of oxygen and are termed facultative bacteria. Bacteria have been the causative agents for various types of water-borne diseases such as typhoid, tularemia, shigellosis, and cholera[13].

Virological aspects: Viruses are the smallest known biological structure that can reproduce. Viruses cannot grow by themselves and are requires a host for their survival. The virus is smaller than bacteria and can pass through the faceal material of the infected person and starts spreading throughout the source of water. Major viral outbreaks are rotavirus, Poliovirus, Hepatitis A, and E.[13]

Parasitological aspects: Drinking water should be free from parasites. Some pathogenic parasites such as *Entamoeba histolytica, Giardia, Balantidium coli* are unwanted and should be treated. Protozoa can be both parasitic and free living. They are unicellular organism that consumes organic particles, bacteria, and algae as food and turns into multicellular animals[13].

Algae: Algae affects the quality of water in many ways. They are responsible for the color, odor, and taste of water. Similarly, they affect the overall lifecycle inside the water by blocking the sunlight and preventing the photosynthesis process. Some of the algal species are responsible for the production of toxic compounds. *Microcystis* algae produce hepatotoxin which is toxic. Similarly, *Anabaena* and *Nostoc* produce neurotoxin. Blue-green algae can kill cattle and domestic animals if they drink water containing those algal species.

Table 3.1.3.1: Parameters of water quality[13]

S. No.	Water quality parameters		
	Physical Paramters	**Chemical Parameters**	**Biological Parameters**
1	Turbidity	pH	Bacteriological aspect
2	Temperature	Acidity	Virological aspect
3	Colour	Alkalinity	Parasitological aspect
4	Taste and odour	Dissolved Oxygen	Algae
5	Solids	Biochemical Oxygen Demand	
6	Electrical Conductivity	Chemical Oxygen Demand	
7		Chloride	
8		Chlorine residual	
9		sulfate	
10		Nitrogen	
11		Fluroide	
12		Iron and Manganese	
13		Hardness	
14		Toxic organic substances	
15		Toxic inorganic substances	
16		Radioactive substance	

3.2 History of drinking water treatment

Looking into history, many of the ancient civilizations were established near water sources. Clean water was categorized based on visual observation. Clarity was a major aspect regardless of the microscopic pathogens present in the water. The only water treatment was to remove the foul smell and make it drinkable and purify to the extent so that it can be drinkable [16]. Water quantity was a major aspect neglecting the quality until major outbreaks and pandemics occurred. The old Sanskrit and Greek writings show the sign of the use of sedimentation and boiling methods used for the treatment of water[17]. Water reservoirs were exposed to sunlight to kill the pathogens and using fine fabrics to strain the water was the earlier practice for treatment. Around 1500 BC, Egyptians used the chemical Alum to settle out the floating debris in the water. The concept of filtration was developed only during the 1700s and the slow sand filter method was evolving in Europe around 1800[5]. Egyptians were the first to use chemicals like alum which are still used as coagulants. i.e., Potassium alum, sodium alum, and ammonium alum[18].

Various plants and herbs were also used for the treatment process. Among them, *Moringa oleifera'*s seed was crushed into powder and added to water as a coagulant and has similar beneficial properties as that of alum[19]. The use of brass containers to store the water was a common practice in ancient Indian civilization. Indian people used charcoal to filter the water around 2000 BC[20].

Mayan civilization shows the development of wells, small dams, and canals for the transportation of water. The features for water distribution were based on the landscape features. From 400 BC to 1000 AD, the advancement of the classic distribution method was gradual based on the population growth inside the civilization. Similarly, the Khmer civilization that was dominant on Combodia practiced the methods of storing water by constructing dams, reservoirs to store water and to utilize this during the period of natural calamities and droughts[21].

Roman Civilization in Europe was the first to supply clean water to cities. They used aqueducts and the pipe system to supply water to the people. The first municipal water filtration plant was build in Scotland in 1832 which sole motive was to supply clean water since the treatment of pathogens was not in practice at that time[22].

Paisley, Scotland is the first city to distribute its inhabitant's filtered water. The filter was named Paisely's filter and is a type of slow sand filter. Slow sand filters were constructed in different parts of Europe and the United Kingdom during the end of the 19th century. In the late 1800s and early 1900s, scientists discovered that turbidity was not only the causing agent for pollution, rather faceal matter and other particulate matter presents were the actual reason for water contamination.[20]

Chlorine was used for the first time as a disinfectant around 1908 in Jersey City, New Jersey. Similarly, different filtration techniques such as reverse osmosis, ozonation gradually developed around the 1970s and 1980s. The introduction of chlorine as a disinfectant played a great role in reducing waterborne diseases.[20]

3.3 Overview of conventional treatment technology

Conventional treatment plants mainly were developed to treat surface water[8]. The main process includes bar screening, grit removal, pre-oxidation followed by coagulation-flocculation, sedimentation, filtration along with the final disinfection unit[23]. Generally, conventional treatment methods are also called centralized treatment systems. Water is treated at the central station and then distribute from the system through distribution channels[24]. A common water treatment plant comprises the physical treatment unit with associated chemical processes. The primary stages consist of the removal of the suspended and the floating particles using different available technologies. Following the primary treatment, the second stage is chemical treatment and the disinfection of the water. Finally, the water is then stabilized chemically to avoid corrosion in the pipes before the distribution process. Before the treatment begins, the water is sent into a settling basin to remove the suspended and larger particles that are present in the water. The process is generalized as the coagulation and flocculation method.

The main process in conventional treatment technology are:

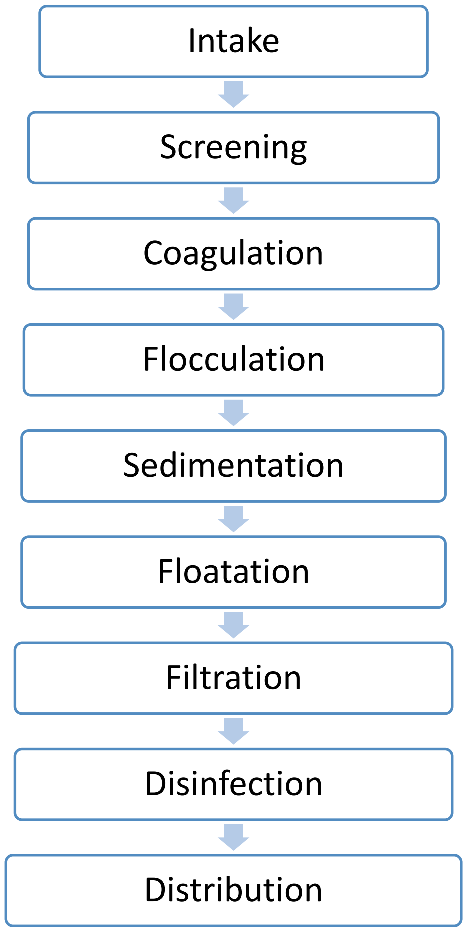

Figure 3.1.3.1: Conventional water treatment Process[25].

3.3.1 Coagulation and flocculation

Coagulation is the method of removing the suspended and colloidal particles present in water with the use of chemicals such as aluminum sulfate, ferric sulfate, ferric chlorides[26]. The chemicals used are called coagulants. This is a neutralization reaction in which the positive charges in the coagulant react with the negative charges present in the water. This tends to combine the particles and the results in the formation of flocs. The process undergoing after coagulation is flocculation. Figure 3.3.1.1 shows the primary process during the coagulation and flocculation process.

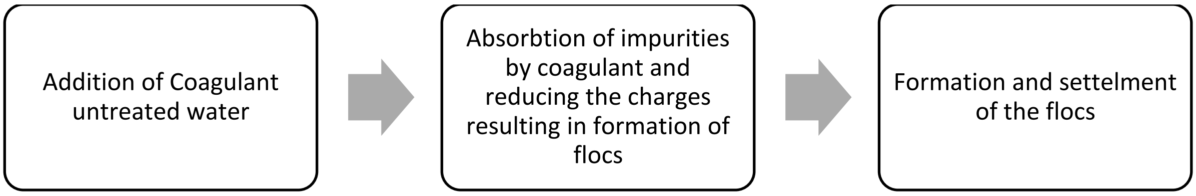

Figure 3.3.1.1: Coagulation and flocculation process[27].

Different types of chemicals have been used to date as coagulant agents. Some of the most common of these coagulants are:

Aluminum Sulphate generally named alum has positive charges that neutralize the negative charges carried by the colloidal particles. As a result of this reaction, Aluminum hydroxide is formed which precipitates as solid and further can be removed using simples sedimentation techniques[28].

Ferric Chloride forms ferric hydroxide when added to water. The colloidal particles present in water combine with the hydroxide ion thus forming a floc which finally settles down.

Hydrated lime is another coagulant that behaves differently as compared to aluminum sulfate and ferric chloride. Lime when added to the water forms carbonate ions increasing the natural alkalinity in the water and increasing the precipitation of the calcium carbonate in water thus making the density of the colloidal particles heavy resulting in settling down and facilitating the easy removal[29].

Flocculation is the second stage of the water treatment process. Here the water to be treated undergoes aggregation and thus forming large clusters of debris. Flocculation itself undergoes two stages. The first stage is called spontaneous flocculation or perikinetic flocculation which occurs due to Brownian movement and the process commences immediately after the reaction starts and ends quickly as the flocs are limited and Brownian movement does not affect [29].

However, flocculation is considered as part of coagulation. Flocculation is carried out in a simple mechanical stirrer or in a basin containing baffles to stir the mixture of water and coagulant. The major principle followed in the flocculation is decreasing the velocity of the water so that agglomerates can form in high quantities.

Sedimentation is defined as the process of settling heavier particles in a fluid. A similar phenomenon occurs in the water treatment process. The debris and the aggregates formed after the process of coagulation and flocculation are allowed to settle for a certain interval of time. After the flocs settle at the bottom, clean water is passed to the filtration chamber.

The traditional sedimentation tanks are rectangular with four zones. The first zone is the inlet zone where water spreads throughout the tank horizontally and vertically. The Outlet zone is the zone where water flows upwards. The sludge zone works as a medium to remove the settled flocs from the tank. Remaining all other parts of the tank is the zone of settling where water is stabilized[30].

Filtration is the process of removing the microbial particles present in the water. Traditional filtration systems were mainly termed sand filtration or rapid sand filtration. The sand acts as porous media which blocks the particulate matter from water. Filtration chambers are made up of sand, gravel, and charcoal. Based on the filter design, they are categorized into two classes. Pressure filters are the ones with closed vessels and water is forced through the layers with pressure whereas in gravity filters water flows downwards due to gravitational force[31].

Disinfection is the process of introducing chemicals to treat the microorganism and pathogens left after the filtration method. Chlorine has been widely used as the disinfection media since history. Chlorine can either be used in gaseous form or liquid for treating the water. However, the use of chemicals for disinfection results in killing all the harmful and harmless microorganisms [32]. Similarly, the use of chlorine enhances the production of trihalomethane which is distinguished as an animal carcinogen and can lead to severe health hazards[32].

3.3.2 Current trends in drinking water treatment

Drinking water treatment has not undergone significant advancement in the 19th and 20th centuries. However, the advancement has outpaced since the beginning of the 21st century. The normal process includes the collection of water from sources such as lakes, rivers, and some other freshwater bodies. With numerous filtration stages followed by the coagulation and flocculation process with some of the advancements in the chemical treatment, stages end up treating with chlorine. Chlorination has been one of the major treating chemicals since the end of the 19th century[16].

Addressing the undeniable demand for pure water, various technologies and methods have been developed during the period. Throughout the world, the most widely used treatment technologies include various methods divided into primary (screening, filtration, centrifugation, separation, sedimentation, coagulation, and flocculation), secondary (aerobic and anaerobic treatments), and tertiary treatment which includes distillation, crystallization, evaporation, solvent extraction, oxidation, precipitation, ion exchange, reverse osmosis, nanofiltration, ultrafiltration, microfiltration, adsorption, electrolysis and many more. With the addition of new anthropogenic pollutants in the source of water, new emerging methods have developed with time. The conventional method consists of series of methods which makes it time-consuming and insufficient to remove the newly introduced pollutants. Some bacteria present in the water when treated may release enzymes and toxins which will even worsen the quality of water.

The majority of the treatment plants in Europe still undergo the same old conventional method with only certain changes in the chemical treatment methods. The procedure begins with the collection of the water from the sources which can be surface water or underground water. Then the water is clarified using the mechanical treatment methods followed by the chemical treatment. The majority of the treatment plants avoid the chlorination method. They rather use advanced methods such as Ozonization, activated carbon, or some layered membrane filtration process[33]. However, a small amount of chlorine is used at the end before the water is being distributed to the consumers[34].

The main water treatment process currently in practice consists of:

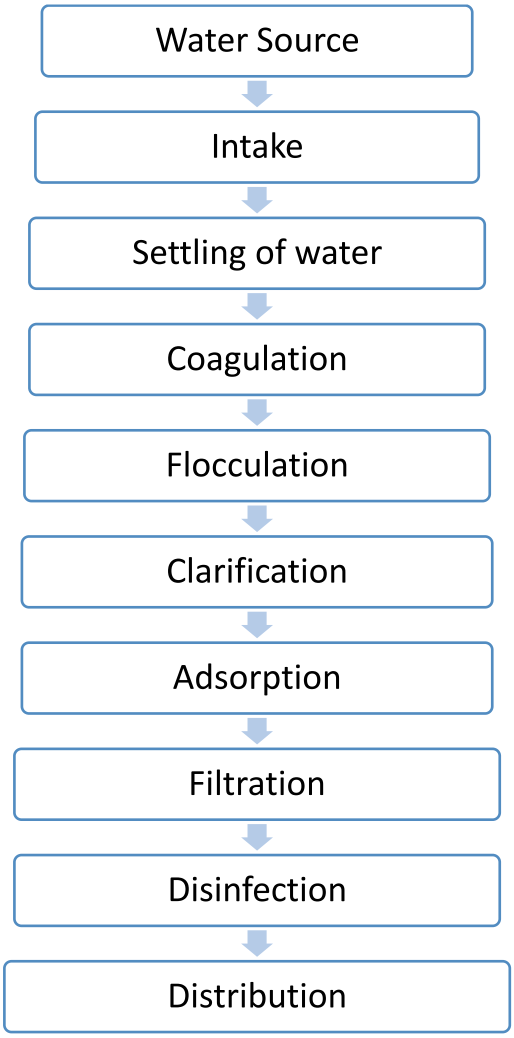

Figure 3.3.2.1: General water treatment process [35]

3.4 Overview of advanced treatment process

Advanced treatment methods are those other than the process in conventional treatment methods. Generally, this method is based on membrane seperation[36]. Ozonation, activated carbon adsorption are some of the advanced processes for the removal of iron and manganese. Depending upon the types of pollutants the process can be more complex. With the change in behavior of the human consumption and modification on the characteristics and water quality parameters, some of the advance processes can work smoothly and gives expected results whereas some other process cannot.

Various water treatment technologies are in the developing phase or have been already developed. Technologies that can be used in the municipal level treatment plants are discussed below. Based on the treatment cost and regulatory requirements, advanced treatment processes are classified into five main classes.

3.4.1 Membrane Filtration

The membrane filtration process is classified based on the force that drives the seperation[37]. They are:

- Pressure driven process: Microfiltration, Ultrafiltration, Nanofiltration, Reverse Osmosis
- Electric potential driven: Electrodialysis, Electro floatation
- Concentration gradient: Forward Osmosis

Treatment technologies based on pressure-driven membrane technologies are classified based on the size of the pore. The table below shows the typical classification of those processes;

Table 3.4.1.1: Classification of the membrane by pore type and species[38]

Type of pores (size nm)	**Type of Membrane** (size nm)[39], [40]	**Species**[41]	**Dimension range**[41]
Macropores (>50)	Microfiltration(50-500)	Yeast and fungi	1000-10000
		Bacteria	300-10000
		Oil emulsion	100-10000
Mesopores (2-50)	Ultrafiltration(2-50)	Colloidal solids	100-1000
		Viruses	30-300
		Proteins	3-10
		Humics	<3
Micropores	Nanofiltration(<=2)	Normal AntibIETics	0.6-1.2
	Reverse osmosis(0.3-0.6)	Organic antibIETics	0.3-0.8
	Forward osmosis(0.3-0.6)	Inorganic ions	0.2-0.4
		water	0.2

Reverse Osmosis: This is based on the phenomenon of purifying the dissolved substances from the stream in a permeable membrane and allowing only clean water to pass through it. It is capable to remove solids, colors, organic compounds, nitrate from the intake water. The feed water is pressure feed into the semi-permeable membrane where water enters and the rest of other impurities remain in the pores. The membrane is made from cellulose acetate, polyamides, and various other polymers.

Comparing with the conventional method of treatment, reverse osmosis can remove dissolved solids, organic and inorganic pollutants.

RO plant comprises a simple technique consisting of feed, permeate the membrane, and a rejected stream. After screening and grit chamber, i.e., removal of inorganic solids and suspended solids, the feed water is passed at high pressure through the permeable membrane. Depending on the composition of the membrane, the post-treated water can require post-treatment to make it drinkable.[42]

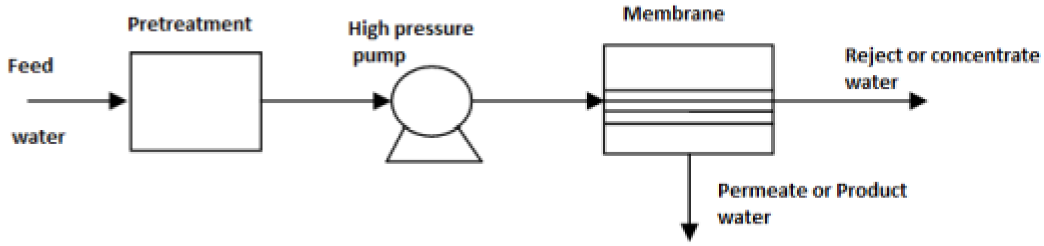

Figure 3.4.1.1: Schematic diagram of reverse osmosis process[43]

Advantages of Reverse osmosis compared to conventional treatment system:

- Easy and simple design and has a low maintenance cost.
- Inorganic and organic compounds can both be removed from the feed water thus not required numerous treatment steps
- Based on the principle of recovery and recycle thus minimizing the waste and making the system more cost-effective.
- Operated at ambient temperature, reducing the chances of corrosion.[44]

Nanofiltration is based on the membrane filtration process which has pores in nanometer smaller than used in microfiltration and ultrafiltration. This method is usually used for surface and groundwater sources where the number of dissolved solids is less compared to other sources. Materials such as Carbon Nanotubes(CNT), Zeolites, and Graphene is used as membrane material for the treatment method. Nano-pores present in CNT makes the membrane efficient to act as a barrier against different ions due to energy imbalance. Nanomaterials present in the membrane allow water to pass without any frictional force and reject salts, ions, and pollutants[45].

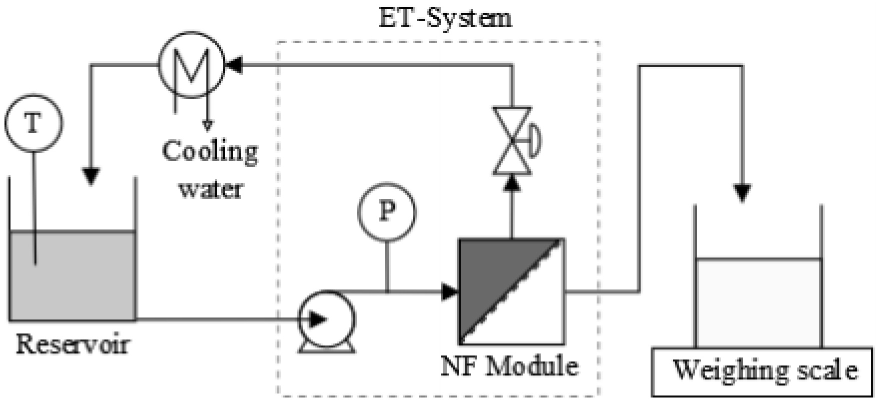

Figure 3.4.1.2: Nanofiltration setup[46]

During the purification process, monovalent ions of sodium and chloride pass through the pores. However, the divalent ions such as Ca2+ and SO42- are blocked. So, this treatment method is effective in removing Ca and Mg ions which causes the hardness of the water. It consumes less energy as compared to the RO process thus more energy efficient[47]. NF if connected with an additional process such as activated carbon has a more effective result[48].

Ultrafiltration(UF) is different from RO and NF in the way that this uses a sieving mechanism instead of a porous membrane. Here, water is fed to a semipermeable membrane with high force. Suspended solids and molecules with high molecular weight remain on one side and water with low molecular weight particles mixed filter through the media[36]. Therefore UF is not effective in removing dissolved ions.

UF membranes require regular cleaning to prevent fouling from microbes and algae. UF is capable of removing around 90-95% of arsenic from the water and does not require any chemical addition. Furthermore, this process can be used for softening hard water. The main advantage of the process is that it requires less space as compared to the conventional water treatment system. This method can be incorporated with activated carbon and RO to treat high silt density index water.[49]

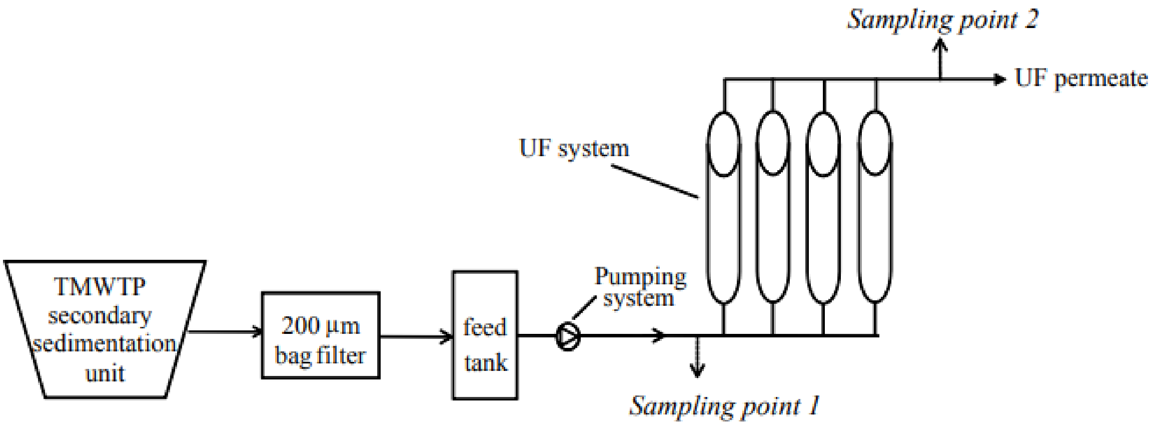

Figure 3.4.1.3: Flow Diagram of UF system[50]

Microfiltration(MF) is similar to that of UF in the working mechanism. The main difference between UF and MF is the size of the pore and the pressure applied during the treatment process. The pore size in MF is larger than 50nm whereas in UF the pore size is 10-50nm. Similarly, the operating pressure is around 200-800 kph in UF and is 100 Kpa in MF. This process is capable of removing particulate matter, bacteria and protozoa.[8]

Electrodialysis(ED) is another type of membrane-based process in which water is passed through the semi-permeable membrane impaired with electric potential. The membrane consists of cation and anion. Cation-based membranes are with a negative charge and reject the negatively charged ions whereas positively charged particles pass through. Similarly, the anion-selective membranes allow passing negatively charged particles. Arranging such membranes in a row with alternative charges prevents the flow of unwanted ions from the water. Neutral particles are not removed in this case. However, pretreatment is necessary if the water contains a huge amount of suspended particles[51]. This method of water treatment can be used for the desalination of high-silica water and industrial water also[52].

3.4.2 Summary of the membrane filtration process

Overall all the above-mentioned technologies use porous membranes to separate the contaminants. The major working principle is based on the separation of the contaminants by passing through the membranes. This technology can be used to treat large volumes of water with excellent efficiency. The operation cost is lower as compared to chemical treatment methods. However, it is required to change the membranes time and again to prevent the membranes from fouling. Furthermore, the unit for treatment is compact and requires less space.[53]

Table 3.4.2.1: Properties of membrane filtration system[54].

Treatment method	**Pressure-bar**	**Contaminants removed**	**Permeation**	**Cost and Efficiency**
Reverse Osmosis	30-70	TDS, pathogens, turbidity, Chemicals(As, Ni, Cu, Cr, Ra, Pb, Cd, Hg, Ni, F)	Water	Very Efficient and cost-effective
Nano Filtration	10-40	Bacteria, protozoa, viruses, divalent cations, and organic matter	Water, Low molecular weight solutes	Efficient but costly
Ultra filtration	0.5-10	Suspended Solids, Bacteria, protozoa, viruses, and chemicals	Water, Low molecular weight solutes, Nano particles	Efficient and costly
Micro-Filtration	0.5-2	Bacteria, Protozoa	Water, Low molecular weight solutes, and colloids	Fair efficient but costly
Electrodialysis	Based on electric potentials	Nitrates, nitrites, fluoride, As, Cd, U.	Water, solutes, low molecular weight solutes	Less Efficient but costly

3.4.3 Ultravoilet Irradiation

Ultraviolet(UV) irradiation is the disinfection process that uses the antibacterial effect of UV light. The wavelength of UV light used for the treatment of the water ranges from 240 to 280nm[55]. This method inactivates or kills the microorganism with the UV wavelength.

UV lights are a part of the light from the sun. The UV spectrum has a higher frequency than normal lights and less than that of X-rays. UV rays penetrate the outer membrane of the microorganism and disrupt its DNA. Since there is no chemical reaction taking place, so this method is a chemically stable process. Only the energy from rays is effective in this process. UV systems use radiation at 254nm for disinfection and are produced from mercury vapor lamps. These lamps are not directly imposed into the water. These are covered with an external glass sleeve and transparent Teflon tubes. UV radiation of 185nm is used in some ultrapure water disinfection systems. These are called low-pressure type UV disinfection systems.[56]

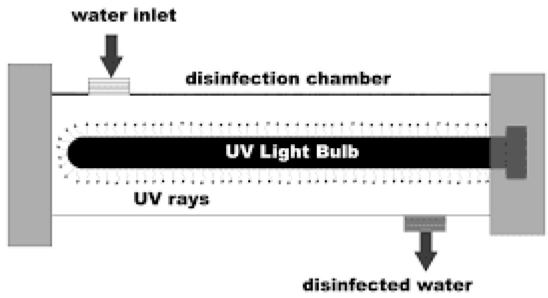

Figure 3.4.3.1: UV tube method [57]

The working mechanism of the UV technology consists of a bulb that is suspended in a large tube. Water to be treated is passed from one end and the UV light emitted by the bulb inactivates the microorganism. The efficiency of the system entirely depends on the intensity of the UV rays and the duration of the ultraviolet radiation. So, the design should be such a way that there is the availability of sufficient exposure time to treat the water and is dependent on the Hydraulic retention time (HRT).

UV treatment systems kill pathogens and stop reproduction. The dead microorganism remains in the water and remains inactive. The operation and maintenance of the UV system are relatively low. The main advantage of the process is that a huge volume of water can be disinfected in a short interval of time and there are no requirements for transportation and handling of the chemicals[58]. The main drawback of this process is the frequent replacement of the UV radiating lamps and this process does not improve the taste odor and clarity of the water. It can be used only for the removal of microbial pollution in the water. The disinfection occurs only inside the unit, so there might be chances of regrowth of organisms after leaving the unit. Therefore, the effectiveness of this process depends on the pretreatment method used. The main advantages and disadvantages of UV technology is presented in table 3.4.3.1;

Table 3.4.3.1: Summary of UV treatment technology[58]

S. No	Advantages	Disadvantages
1	Large volume of water can be treated quickly	The cost of the treatment equipment is relatively high
2	No need for chemicals for disinfection	Frequent replacement of the tube

3	No change in odour and taste of water	It only kills the organism but is unable to filter them out. So, chances of regrowth of microorganism

3.4.4 Advanced Oxidation Technology

Advanced oxidation processes (AOPs) are based on the generation of oxidants to oxidize organic and inorganic impurities in the water. This includes the oxidation of synthetic organic chemicals, color, taste, sulfide, iron, and manganese[59]. Thus AOP technology can be used in the water reuse and reclamation process. This method can be further used as a bridging gap between the traditional treatment process to meet the water quality parameters of the recent decades.

AOPs are capable of generating the strongest oxidants i.e., hydroxyl radicals (OH) which can oxidize relatively all the compounds present in water. Pollutants and organic compounds react quickly with hydroxyl radicals and get converted into small inorganic molecules. AOP technologies are capable of reducing the concentration of pollutants in water from high to significantly lower levels [60]. This treatment method is classified into two classes as non-photochemical method and photochemical methods based on the generation of the hydroxyl ion.

- Non-photochemical methods: In this method, hydroxyl ions are generated without the use of light energy. Ozone and ferric ion are used as a catalyst in the production of hydroxyl ion. These comprise processes such as ozonation at elevated pH(>8.5), the addition of ozone and hydrogen peroxide (O_3/H_2O_2), combining ozone with catalyst (O_3/CAT), and Fenton system (H_2O_2/Fe^{2+})[60].
- Photochemical methods: In this method, UV light is radiated using various lamps or filter technology and chemical synthesis takes place in the presence of the light. Excimer lamps with emission wavelengths around 172-222nm have been a more effective indirect photolysis process producing hydroxyl radicals[61]. Photochemical methods are further classified into Ozone-UV radiation method(O_3/UV), Hydrogen peroxide-UV radiation(H_2O_2/UV), Ozone-hydrogen peroxide- UV radiation (O_3/H_2O_2/UV), and photocatalytic oxidation (UV/TiO_2)[59].

Having the higher cost of operations, this method has not been commercialized on large scale. However, the capability of AOPs to oxidize most recalcitrant organic and inorganic compounds makes it highly effective in the water treatment and water reclamation sector.

3.4.5 Ion Exchange Technology

Ion exchange technology is one of the most powerful technology in water chemistry for water treatment to obtain the required water quality. Due to its flexible operation environment and operational configurations, this method can be employed in a decentralized and centralized system for water treatment[62].

Ion exchange technology is based on the method of removing the ionic contaminants from water by the exchange of undesirable ions with non-toxic ions. This process is a physical-chemical process and the ions interacting with each other should be of similar electrical charge.

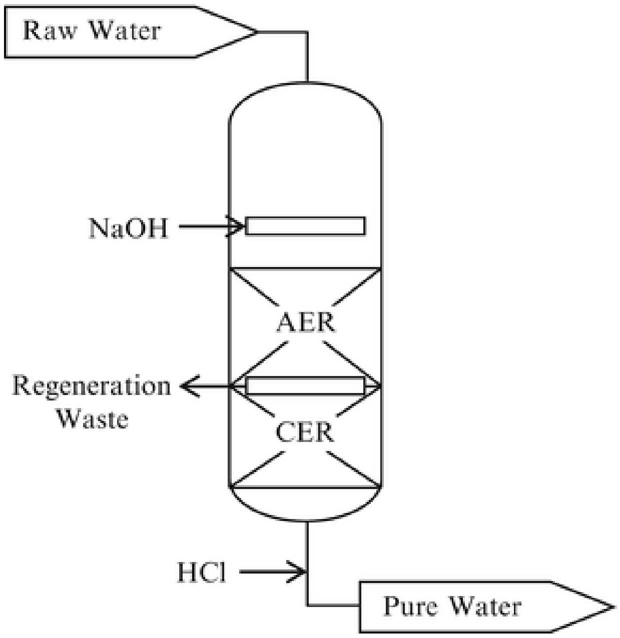

Figure3.4.5.1: Schematic diagram of Mixed bed Ion exchange technology[63]

As shown in the figure, the Mixed bed Ion exchange system consists of packed acidic cation-exchange resin and strongly basic anion exchange. When feed water is passed through the mixed bed, water undergoes recurring treatments with cation and anion and finally leaving the clean water with less than $0.1 mSm^{-1}$ conductivity. During the process, firstly cation and anion are differentiated due to differences in their densities. Then the regenerated materials like HCl and NaOH are separated by continuous cation and anion converters. A decarboxylation tower blows the air upwards when waterfalls and reduces the Co_2 gas to acidic water which is removed by Henry's law.[63]

Ion-exchange technology has shown effectiveness in removing the hardness of the water. Similarly, this method is efficient in the removal of nitrate, chloride, silica, radium and Uranium, arsenic, barium, boron, and many other unwanted ions from the water. However, the efficiency of removing bacteria is not so effective[64]. With minimal maintenance and quick installations procedure, this method has been widely used in the industry to treat wastewater. This method can be used to treat either raw or wastewater. However, the higher operating cost and regeneration of the ion exchange beds that result in the formation of high salt water does not make this process applicable on a small scale.

3.4.6 Biological filtration

Biological filtration is a method that uses the characteristics of microorganisms to remove contaminants from the water. Many of the processes in the water treatment sector rely either on a physical or chemical process to attain quality remarks but the biological filtration system has made a remarkable place by producing efficient and sustainable biologically stable water. This method came into practice due to the formation of biodegradable organic matter(BOM) during the ozonation process. As a result of the introduction of this process, BOM was subsequently reduced.

A biological filtration system is used as a secondary treatment process before distributing the water to consumers to reduce the chances of the growth of microorganisms. This method is divided into two major treatment steps. The first is the suspended growth process where the degradable organic matters are suspended in water and decomposed in the presence of the gases and cells. The second method is the attached growth system. In the attached growth system, a larger surface area and high void ratio play a major role in microbial growth that determines the efficiency of the system.[65]

The biological treatment successfully removes organic matter, color, chloroform, nitrate, bromate, iron, manganese, selenate, and various other contaminants. Chemicals are barely used during the process thus making this an economically viable process.

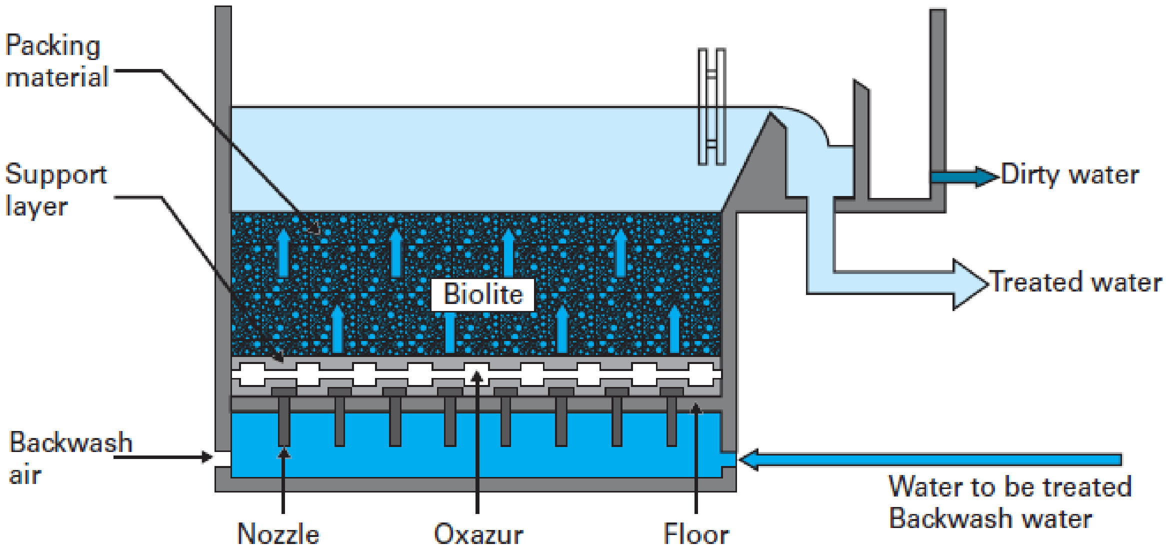

Figure3.4.6.1: Schematic diagram of Bio filters[66]

The system consists of a simple design with three main components. First of all, Water is spread evenly on the surface of the biofilter which is the distribution system of the process. Then the bio-filter having a high surface area acts as a filter media itself. Finally, the treated water is then driven out with aid of gravitational force which is an underdrain system. The filter used is made of biolite material which is a type of clay having a higher density and rough surface. Due to these characteristics, the treatment system is instant despite hydro-pneumatic wash. Oxygenation is necessary for the aerobic reaction which is diffused from the base of the plant[67]. This is further classified into aerated type biofilter and non-aerated biofilter.

3.5 Trends in drinking water distribution system

The water distribution system is an interconnected network of pipelines, pumps, and monitoring systems for supplying the treated water to the consumers. Distribution networks in drinking water are either configured in a loop layout or branched layout[68]. Branched layouts are generally practiced in less populated cities where the water demand is low whereas the loop layout is for big urban cities which experiences several interruptions. However, most of the distribution systems nowadays follow the looped layout due to several disadvantages of the branched network besides its simplicity. The branched network system is unable to supply water continuously if there is any interruption in the midway. Similarly, there is a high risk of accumulation of the salts and minerals in the distribution pipelines resulting in the change of odor and quality of the water for the consumers who are at the end of the network.

The main objective of the Water Distribution System(WDS) is to provide stable, economic, and safest drinking water to consumers. To fulfill this purpose, the entire distribution network should be carefully designed considering the operation and maintenance cost and health hazards on the other hand. This involves selecting the best layout for distribution with considerations to the materials used for the pipelines and monitoring of the supply system. The nature of the material used in pipelines entirely depends on the topography and the environmental conditions prevalent at the place. Table 3.5.1 shows the different types of material used in the pipelines with their advantages and disadvantages.

Table 3.5.1: Comparision of different pipe materials [69].

Type of material used in pipe	**Advantages**	**Disadvantages**
Steel pipes	- Strong and easy to weld - Can withstand high pressure - Lower installation cost due to its longer lengths	- Expensive initial cost - Highly susceptible to corrosion - Possibility of contamination of water due to leaching by lead - Heavy and clogging due to building of minerals inside the pipe
Copper pipes	- Has a high life span as compared to steel pipes. - Bacteria cannot grow in copper material thus is safer - Recyclable material - Can withstand extreme temperature conditions	- The cost of copper is relatively high - Extraction of copper leads to emission of GHG thus not environmental friendly
Polyvinyl Chloride(PVC) pipes	- Safe from Rusting and corrosion thus high life span - Ability to handle high pressure	- unfavorable in hot temperature - bulking of the material can cause problems in limited spaces

	- Extremely light and easy to handle and work with - Lower cost as compared to copper pipes	
Chlorinated Polyvinyl Chloride	- Non-corrosive and unaffected by rust. - Can withstand high pressure - Lightweight and easy to handle - Has high-temperature tolerance as compared to PVC	- Cannot be used outdoors due to its breaking down if exposed to sunlight for a long period - Compared to PVC, the cost is relatively high
Cross-linked Polyethylene (PEX)	- Long life span and resistance to corrosion. - Flexible and can be used everywhere - Extreme temperature tolerance - Cheaper as compared to copper	- Can be used for indoor applications only - Non-recyclable material - Changes the odor and taste of water - Possibility of contaminating the water due to the materials.
Multilayer pipes(PEX, Aluminium, PEX)	- High resistance to UV radiation and can be used in outdoor conditions also - Thermal conductivity of pipe is less resulting in reducing the loss of energy - Flexible and durable	- Non-recyclable - Emits hazardous gas during combustion - Low melting temperature

The efficiency of the distribution system depends on several other factors besides the properties of the materials used in the pipelines. Another important factor influencing the efficiency of the Drinking Water Distribution System(DWDS) is monitoring the leakage and other possible losses in the distribution network. Online monitoring and the smart system have been practiced in different areas proving to be effective against leakage problems. Furthermore, this advanced system can be used to accumulate the current demand for water and predict the trend for the future.

Smart Water Grid system practiced in Singapore assists Public Utilities Board(PUB) to monitor and control the water distribution for the entire time[70]. This system blends information and communication technology into the distribution system. The sensors, meters, and analysis tools automate, monitor, and control the water transmission and distribution ensuring the quality of the water. Digitization and automation help to automate the data collected remotely in the field and transmit it to the central monitoring analysis system. A combination of this technology in the water distribution network can help to plan and schedule the pipe replacement facility when the water demand is low and when required. Leakages can be controlled and also can be used to mitigate the problem of pipe bursting. Similarly, the use of automated valves integrated with the smart grid system can be further used in sensitive areas to shut down the supply of water if any signals of disruption are seen in the supply network. Furthermore, this system can be used to deliver information regarding the energy consumption and amount of water used by the consumers which will make the consumers more realistic in conserving the water.[70]

Some of the major technology used in leak management sectors are presented in table 3.5.2;

Table 3.5.2: Leak management technology based on the different sensors used[70].

Technology	**Working principle**	**Advantages**	**Drawbacks**
Acoustic sensor based on accelerometers	Based on the sound or vibration due to water escaping through the pressurized pipe	To locate the leakage locations depending on the size of pipe and distance and materials	Only applicable for pipes running in full volume. So, not preferable for big sized pipes
Acoustic sensors based on hydrophone sensors	Based on the sound waves passing through the water	Can be applicable in networks with bigger pipe size as compared to sensors based on accelerometers	Expensive in comparison to the accelerometers sensors since these sensors need to be installed at a distance of not more than 750 meters.

High rate Pressure sensors	Based on the change in pressure due to leakage	Have a wide area of detection of about 1.5km and can be used for pipes of various size	Unable to detect the loss when the distance is near
Virtual district metering areas	Based on the mass balance equations to compute the water loss	No need for extra sensors to be installed.	Not so realistic and requires regular examinations and surveys by operators

Similarly, Artificial Intelligence(AI) can be incorporated in the distribution network to find out the random optimization techniques to save energy in network operations. The first way is by defining the most efficient way in operating methods in terms of minimum service levels, pumping systems, energy, and storage rates. Based on this configuration, the decision-makers can decide on profitable investment sectors in a particular system with regards to either replacing pumps or increasing the storage of the reservoirs to save energy. Hydraulic 2.0 is a high-end network analysis tool that uses AI to find out the probabilistic, dynamic performance, and representation of the distribution networks[71].

4 MATERIALS AND METHODS

The overall analysis of the different treatment methods has been done based on the secondary data and materials available. An approach for comprehensive analysis has been done using Analytical Hierarchy Process (AHP). AHP process was developed by Thomas L, Satty in the 1970s. This method is based on mathematical calculation and psychological decision and can be addressed to structure the complex decision[72]. Analysis was carried out on Microsoft excel.

Several drinking water treatment methods have been developed till today but only five types of drinking water treatment methods have been compared based on 6 different criteria. The following set of criteria were analyzed for the evaluation procedure: Removal efficiency, cost, energy consumption, capacity, complexity, space requirements. The compared treatment technologies are Membrane Filtration (MF), Ultraviolet Irradiation (UI), Advanced Oxidation Technology (AOT), Ion Exchange Technology (IET), and Biological Filtration (BF).To determine the weight of the selected criteria, Analytical Hierarchy Process (AHP) is used to determine the best treatment method[73].

To carry out the analysis, a pair-wise comparison for each alternative and the technology was carried out. Then the weighting coefficients for all the criteria are evaluated based on the goal which is the treatment of drinking water. Weighing coefficients for all the criteria are made relating to the literature review and scholars' articles. All the weighing criteria and pairwise comparisons are made based on Satty's theory. A 9 point importance table is prepared.

Table 4.1: Satty's 9-point table [73]

Importance	**Defination**
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very strong Importance
9	Extreme importance
2,4,6,8	Intermediate values
1/3, 1/5, 1/7, 1/9	Inverse value for comparison

For using the AHP method, the following sets of procedures were followed.

- The weights of each criterion were calculated by developing the pair-wise comparison matrix. The comparison matrix is then transformed to normalized matric by multiplying each row together and calculating the nth root. Finally, the weights of all the criteria were evaluated. To check the correctness of the calculation consistency ratio is calculated and the consistency index is determined.

- Second, ratings for each alternative technology were computed using a pair-wise comparison matrix. For each comparison matrix, the decision alternative was the criteria goal and pairwise comparison between the alternative technologies was calculated. Finally, the comparison matrix was also be normalized by multiplying the values in each row with the n^{th} root. To check the accuracy of the data, the consistency ratio was calculated and finally, the consistency index was calculated.

- Consistency Index is used to check the correctness of the comparison matrices. The formula for computing the consistency Index was proposed by Saaty and the equation is[73];

  $$\mathbf{CI} = \frac{\lambda max - n}{n-1} \qquad (1)$$

  In equation (1), CI denotes the Consistency Index, λ_{max} is the Eigen value and n is the number of comparisons.

  λ_{max} is calculated using another equation;

  $$\boldsymbol{\lambda_{max}} = A\ x \qquad (2)$$

  Where: A is the comparison matrix of dimension n x n and X is the Eigen vector.

  Consistency ratio CR_n is then computed using the formula;

  $$\boldsymbol{CRn} = \frac{CIn}{RIn} \qquad (3)$$

- CRn is the consistency ratio and should be less than 10% for the acceptance of the inconsistency. If the consistency ratio is greater than 10%, the computation should be rechecked and all the above-mentioned steps should be revised. In equation 3, RI_n is the random consistency index and n is the number of the comparison.

- RI_n is calaculated from the random index table given by Saaty.

Table 4.3.5.1: Random Index table[74]

n	Random Index (RI)
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45

- Finally, the weight for each criterion is calculated and the one with the highest score is considered as the best alternative.

5 ANALYSIS AND RESULT

Results and analysis from the AHP analysis based on the literature study are presented below. Table 5.1 is the comparison matrix for each criterion. As shown in the table, the cost is the entire cost of the treatment method to install, operate and maintain. Efficiency is the removal efficiency of pathogens and anthropogenic unwanted substances. Energy used is overall energy used during the treatment process. Capacity represents the volume of water that can be treated by the technology at a given period. Complexity explains the need for skilled manpower to install and operate the treatment technology and space in the area occupied by the entire plant. Each of the factors has its importance in its respective field. However, to compute the best technology by the AHP method a comparison table has been made based on the literature review and studies Table 5.2 is the Normalised matrix to calculate the control weights (CW) which further assists in calculating the consistency index to check the compared data.

Table 5.1: AHP pairwise comparison matrix with respect to the goal

Criteria	Cost	Efficiency	Energy used	Capacity	Complexity	Space
Cost	1	0.5	2	3	2	2
Efficiency	2.00	1.00	2.00	5.00	3.03	2.00
Energy used	0.50	0.50	1.00	5.00	2.00	2.00
Capacity	0.33	0.20	0.20	1.00	0.20	0.20
Complexity	0.50	0.33	0.50	5.00	1.00	2.00
Space	0.50	0.50	0.50	5.00	0.50	1.00

Table 5.2: The normalization of pairwise matrix of table 5.1

Criteria	Cost	Efficiency	Energy used	Capacity	Complexity	Space	CW
cost	0.21	0.17	0.32	0.13	0.23	0.22	0.21
rem eff	0.41	0.33	0.32	0.21	0.35	0.22	0.31
energy consu	0.10	0.17	0.16	0.21	0.23	0.22	0.18
capacity	0.07	0.07	0.03	0.04	0.02	0.02	0.04
complexity	0.10	0.11	0.08	0.21	0.11	0.22	0.14
space	0.10	0.17	0.08	0.21	0.06	0.11	0.12

Table 5.2 is the normalized matrix. To calculate the control weight, first of all, the sum of each column in table 5.1 is calculated. Then each value of the column is divided by the sum of the respective column. For calculating the control weight the sum of each

row is calculated and is divided by the number of the criterion used for comparison. In this case, there are 6 criteria. For calculating the consistency Index, each column is multiplied with their respective CW. Finally, the consistency ratio is calculated as per equation (3).

Table 5.3: Calculation of consistency ratio and consistency index

Criteria	Cost	Efficiency	Energy used	Capacity	Complexity	Space	Sum	Sum/CW
cost	0.21	0.15	0.36	0.13	0.28	0.24	1.37	6.50
rem eff	0.42	0.31	0.36	0.21	0.42	0.24	1.96	6.40
energy consu	0.11	0.15	0.18	0.21	0.28	0.24	1.17	6.47
capacity	0.07	0.06	0.04	0.04	0.03	0.02	0.26	6.20
complexity	0.11	0.10	0.09	0.21	0.14	0.24	0.89	6.40
space	0.11	0.15	0.09	0.21	0.07	0.12	0.75	6.22

λ_{max} = (6.50 + 6.40 + 6.47 + 6.20 + 6.40 + 6.22)/6 = 38.20/6 = 6.36

Consistency Index, CI = (λ_{max} -n)/(n-1) = 0.072

Consistency Ratio, CR = CI/ RI; RI= 1.24 for n=6 from table 5

= 0.072/1.24 = **0.058** < 0.10; so Pairwise matrix is ok.

5.1 Ratings for alternative decision

Pairwise comparison is done for all the alternatives to get the best score.

5.1.1 For removal efficiency

Table 5.1.1.1: Comparision pairwise matrix for removal efficiency

	MF	UI	AOT	IOT	BF	CW
MF	1.00	5.00	3.00	3.00	7.00	0.46
UI	0.20	1.00	0.20	0.33	0.50	0.06
AOT	0.33	5.00	1.00	5.00	3.00	0.28
IOT	0.33	3.00	0.20	1.00	0.50	0.11
BF	0.14	2.00	0.33	2.00	1.00	0.11
Sum	2.01	16.00	4.73	11.33	12.00	1.00

Table 5.1.1.2: Normalisation of table 5.1.1.1 for CI and CR

	MF	UI	AOT	IOT	BF	Sum	Sum/CW
MF	0.46	0.28	0.83	0.32	0.74	2.61	5.70
UI	0.09	0.06	0.06	0.04	0.05	0.29	5.26
AOT	0.15	0.28	0.28	0.53	0.32	1.55	5.60
IOT	0.15	0.17	0.06	0.11	0.05	0.53	5.05
BF	0.07	0.11	0.09	0.21	0.11	0.58	5.54
Sum							27.15

So, For λ_{max} = 27.15/5 = 5.43

CI = (5.43-5)/4 = 0.1075

CR = 0.1075/1.12 = 0.096 < 0.10; ok

5.1.2 For cost

Table 5.1.2.1: Ratings for cost

	MF	UI	AOT	IOT	BF	CW
MF	1.00	7.00	5.00	6.00	2.00	0.48
UI	0.14	1.00	0.33	1.00	0.50	0.07
AOT	0.20	3.00	1.00	7.00	2.00	0.24
IOT	0.17	1.00	0.14	1.00	0.33	0.06
BF	0.50	2.00	0.50	3.00	1.00	0.16
	2.01	14.00	6.98	18.00	5.83	1.00

Table 5.1.2.2: Normalisation of table 5.1.2.1 to check CI and CR

	MF	UI	AOT	IET	BF	CW	Sum/CW
MF	0.48	0.46	1.19	0.35	0.32	2.80	5.85
UI	0.07	0.07	0.08	0.06	0.08	0.35	5.30
AOT	0.10	0.20	0.24	0.40	0.32	1.26	5.28
IET	0.08	0.07	0.03	0.06	0.05	0.29	5.06
BF	0.24	0.13	0.12	0.17	0.16	0.82	5.14
Sum							26.63

So, λ_{max} = 26.63/5 = 5.32

CI= (5.32-5)/4 = 0.08

CR = 0.07 < 0.1; ok.

5.1.3 For Energy efficiency

Table 5.1.3.1: Ratings for energy efficiency

	MF	UI	AOT	IOT	BF	CW
MF	1.00	3.00	2.00	2.00	1.00	0.32
UI	0.33	1.00	1.00	1.00	0.50	0.13
AOT	0.50	1.00	1.00	2.00	1.00	0.19
IOT	0.50	1.00	0.50	1.00	3.03	0.20
BF	1.00	0.50	1.00	0.33	1.00	0.15
Sum	3.33	6.50	5.50	6.33	6.53	1.00

Table 5.1.3.2: Normalisation of table 15 for CI and CR

	MF	UI	AOT	IOT	BF	CW	Sum/CW
MF	0.32	0.40	0.38	0.41	0.15	1.66	5.21
UI	0.11	0.13	0.19	0.20	0.08	0.71	5.30
AOT	0.16	0.13	0.19	0.41	0.15	1.04	5.47
IOT	0.16	0.13	0.10	0.20	0.46	1.06	5.19
BF	0.32	0.07	0.19	0.07	0.15	0.80	5.21
Sum							26.39

So, λ_{max} = 26.389/5 = 5.277

CI= (5.227-5)/4 = 0.056

CR = 0.05 < 0.1; ok.

5.1.4 For Capacity

Table 5.1.4.1: Ratings for treatment capacity

	MF	UI	AOT	IOT	BF	CW
MF	1.00	0.33	0.50	0.50	0.33	0.08
UI	3.00	1.00	0.50	0.50	1.00	0.19
AOT	2.00	2.00	1.00	1.00	0.33	0.19
IOT	2.00	2.00	1.00	1.00	0.33	0.19
BF	3.03	1.00	3.03	3.00	1.00	0.35
Sum	11.03	6.33	6.03	6.00	2.99	1.00

Table 5.1.4.2: Normalisation of table 5.1.4.1 for CI and CR

	MF	UI	AOT	IOT	BF	Sum	Sum/ CW
MF	0.08	0.06	0.09	0.09	0.12	0.45	5.37
UI	0.25	0.19	0.09	0.09	0.35	0.98	5.27
AOT	0.17	0.37	0.19	0.19	0.12	1.03	5.50
IOT	0.17	0.37	0.19	0.19	0.12	1.03	5.49
BF	0.25	0.19	0.57	0.56	0.35	1.93	5.45
Sum							27.08

So, λ_{max} = 27.076/5 = 5.41

CI= (5.41-5)/4 = 0.1025; CR = 0.09 < 0.1; ok.

5.1.5 For complexity

Table 5.1.5.1: Ratings for complexity

	MF	UI	AOT	IOT	BF	CW
MF	1.00	5.00	3.00	3.00	1.00	0.37
UI	0.20	1.00	0.50	0.50	0.33	0.07
AOT	0.33	2.00	1.00	2.00	1.00	0.18
IOT	0.33	2.00	0.50	1.00	2.00	0.17
BF	1.00	3.00	1.00	0.50	1.00	0.20
Sum	2.87	13.00	6.00	7.00	5.33	1.00

Table 5.1.5.2: Normalisation of table 5.1.5.1 for CI and CR

	MF	UI	AOT	IOT	BF	Sum	Sum/ CW
MF	0.37	0.36	0.55	0.52	0.20	2.00	5.42
UI	0.07	0.07	0.09	0.09	0.07	0.39	5.38
AOT	0.12	0.15	0.18	0.35	0.20	1.00	5.50
IOT	0.12	0.15	0.09	0.17	0.40	0.94	5.37
BF	0.37	0.22	0.18	0.09	0.20	1.06	5.26
Sum							26.94

So, λ_{max} = 26.94/5 = 5.387

CI= (5.387-5)/4 = 0.09675

CR = 0.086 < 0.1; ok.

5.1.6 For Space

Table 5.1.6.1: Ratings for complexity

	MF	UI	AOT	IOT	BF	CW
MF	1.00	0.50	1.00	0.33	1.00	0.15
UI	2.00	1.00	0.33	0.50	0.50	0.13
AOT	1.00	3.00	1.00	2.00	2.00	0.31
IOT	3.03	2.00	0.50	1.00	1.00	0.23
BF	1.00	2.00	0.50	1.00	1.00	0.18
Sum	8.03	8.50	3.33	4.83	5.50	1.00

Table 5.1.6.2: Normalisation of table 5.1.6.1 for CI and CR

	MF	UI	AOT	IOT	BF	CW	Sum/CW
MF	0.1	0.1	0.3	0.1	0.2	0.8	5.3
UI	0.3	0.1	0.1	0.1	0.1	0.7	5.6
AOT	0.1	0.4	0.3	0.5	0.4	1.7	5.4
IOT	0.4	0.3	0.2	0.2	0.2	1.3	5.5
BF	0.1	0.3	0.2	0.2	0.2	1.0	5.4
Sum							27.2

So, λ_{max} = 27.22/5 = 5.4439

CI= (5.4439-5)/4 = 0.11

CR = 0.099< 0.1; ok.

5.2 Weighted average result

The weighted result is calculated by summing up all the control weights for each criterion for the respective treatment method. The respective weights for each criterion are presented in the first row.

Table 5.2.1: Weighted average

	Cost	Removal efficiency	Energy	Capacity	Complexity	Space	SUM	Score
	0.21	0.31	0.18	0.04	0.14	0.12	1.00	
MF	0.48	0.46	0.32	0.08	0.37	0.15	1.86	0.31
UI	0.07	0.06	0.13	0.19	0.07	0.13	0.65	0.11
AOT	0.24	0.28	0.19	0.19	0.18	0.31	1.39	0.23
IET	0.06	0.11	0.20	0.19	0.17	0.23	0.96	0.16
BF	0.16	0.11	0.15	0.35	0.20	0.18	1.15	0.19

From table 5.2.1, the score of Membrane filtration technology is higher. Based on all the criteria used for the study, MF seems to be the best treatment method. Similarly, the UI method having the least score in the table becomes the least appropriate among other methods. The reason can be due to its cost and removal efficiency.

6 CONCLUSION

The study aimed to find out the new technologies in the drinking water treatment based on different criteria. AHP method has been an important tool to find out the decision for the complex problem. AHP method works based on the problem and its goal. Decision criteria were calculated for each alternative and evaluation was done. However, the result of the analysis cannot be relied on because of some inconsistency of the AHP system. Due to this, there was a need to reconsider the response and reevaluate the dependencies to fulfill the inconsistency limit.

Based on the six different criteria which include cost, pathogen removal efficiency, energy consumption, the complexity of the process, and space required, the AHP method suggests the membrane filtration process as the best one. Similarly, the AOT method has been the second most preferred method. For further research, Preference Ranking Organization Method for Enrichment of Evaluations(PROMETHEE) I and II ranking methods can be employed by using more criteria to get a better result.

7 SUMMARY

The demand for drinking water can never get down. Considering the number of new emerging pollutants in water, the treatment techniques should be modified. To fulfill the paradox between demand and supply, water reuse and effective water treatment should be recognized and taken into practice. Furthermore, preventing water loss because of the use of conventional techniques is unacceptable. But, on the next side sustainability and eco-efficiency should also be considered. Taking all these problems into account, the best treatment technique would be a combination of different advanced technologies.

Current treatment technologies include numerous steps including chemical treatment. The use of chemicals for disinfection can be minimized if UV technology is incorporated. However, this technology alone is not effective to remove pathogens. So, if this method is incorporated with an Activated carbon filter or any membrane filtration process can give the best result. However, the overall cost of operation can be high and cannot be feasible in all the locations. Moreover, looking at the condition of the developing countries, high-end technologies will be harder to implement because the overall cost of the water might rise which can be unaffordable. But if the loss of water in the distribution network be reduced, the overall cost of water can be reduced. Biological filtration can be adapted in many places which follows the principle of sustainability. Comparison of these advanced technologies with relation to different aspects can give the better number to scale up the most convenient and efficient technology.

All the above-discussed options involve additional energy consumption or have a higher cost, so the LCA evaluation tools can assess the actual durability and specific eco-efficiency of these methods. Major treatment technologies still use electricity as a major source, but a treatment plant depending on the renewable energy sources can be more eco-friendly.

Considering the distribution network, AI-based technology based on blockchain concept can reduce the overall human labor on one hand and can enhance security on other hand. Smart water systems can lead to a smart monitoring system, better revenue of the entire treatment plant, and smart analysis of the data for future water load prediction. However, the effectiveness of this system depends on several criteria and is difficult to predict until it is practiced in the real field.

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