Diplomarbeit

Study to find cost effective solution for converting Sewage Treatment Plant (STP) treated water into potable water quality for an apartment complex.

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Study to find a Cost effective Solution for Converting STP treated water into potable water quality for an apartment complex.

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I am profoundly grateful to a few individuals whose guidance, support, and encouragement were indispensable in the completion of this project wok.

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Contents

List of Figures

1 Abbreviations

STP	Sewage Treatment Plant
WTP	Water Treatment Plant
KLD	Kilo Liter per Day
SBR	Sequential Batch Reactor
DNRAOC	DNR Atmosphere Owner's Condominium
MC	Management Committee
UB	Upper Basement
LB	Lower Basement
GF	Ground Floor
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
SS	Suspended Solids
MLSS	Mixed Liquor Suspended Solids
kW	Kilowatt
kL	Kilo liter
BWSSB	Bengaluru Water Supply and Sewage Board
TWT	Treated Water Tank
RAW	Raw Water Tank
RWT	Rainwater Tank
TDS	Total Dissolved Solids
SGMD	Sweeping Gas Membrane Distillation
DCMD	Direct Contact Membrane Distillation
AGMD	Air Gap Membrane Distillation
SPMD	Solar Powered Membrane Distillation
CMD	Conventional Membrane Distillation

2 Introduction

The increasing scarcity of freshwater resources has prompted a global reassessment of water management strategies. As urban populations expand and industrial activities intensify, the demand for potable water continues to rise, often outstripping available supplies. Traditional water sources are becoming insufficient, leading to the exploration of alternative solutions.

Over the last decade, Bengaluru has experienced rapid population growth, with its population increasing from approximately 8.3 million in 2010 to over 13.6 million in 2023. This represents a growth rate of about 64% over the period. Such a significant increase in population has placed considerable pressure on the city's infrastructure and resources, particularly its water supply.

Concurrently, Bengaluru has faced challenges with decreasing groundwater levels, primarily due to over-extraction and insufficient recharge. Studies have shown a drastic reduction in both the number and quality of water bodies in the region. Over the past few decades, the city has seen a 79% decrease in water bodies, contributing to the reduction in groundwater recharge areas and further exacerbating water scarcity.

The combination of rapid urbanization, population growth, and environmental degradation has significantly strained the city's water resources, making the exploration and implementation of sustainable water management strategies, like converting treated wastewater to potable water, increasingly critical for the city's future sustainability.

This master's thesis investigates the feasibility and effectiveness of converting treated wastewater from a sewage treatment plant into potable water. The study focuses on the technical, economic, and environmental aspects of advanced treatment processes required to ensure the water meets stringent drinking water standards. It aims to provide a comprehensive analysis of the entire conversion process, from initial treatment stages to final purification, highlighting the challenges and potential benefits associated with this practice.

The technical aspect of this study involves a detailed examination of various advanced treatment technologies such as microfiltration, ultrafiltration, reverse osmosis, and advanced oxidation processes. These technologies are crucial for removing contaminants that are not eliminated during conventional wastewater treatment. The thesis evaluates the performance of these technologies in achieving high-quality water that meets or exceeds regulatory standards for potable use. Additionally, the integration of these technologies into existing sewage treatment infrastructure is assessed to determine the practical implications of retrofitting and upgrading current facilities.

Economically, the thesis analyzes the cost-effectiveness of converting treated wastewater into potable water compared to traditional water supply methods. This includes a cost-benefit analysis considering capital investment, operational costs, and long-term savings from reduced dependence on external water sources. The economic evaluation also considers the potential for public-private partnerships and funding mechanisms that can support the implementation of advanced water treatment technologies.

From an environmental perspective, the thesis explores the sustainability of water recycling and its impact on local ecosystems. By reducing the extraction of freshwater from natural sources, wastewater reuse can alleviate stress on rivers, lakes, and groundwater reserves. Moreover, this practice contributes to a circular economy by maximizing the utility of water resources and minimizing waste discharge into the environment. The environmental assessment also addresses potential risks, such as the management of concentrated waste streams generated during advanced treatment processes.

3 Sewage Treatment Plant description and water analysis

The section gives a brief description of the sewage treatment plant in an apartment complex containing 270 apartments along with treated water results.

3.1 Apartment description

The name of the apartment complex is DNR Atmosphere, located in the locality called Whitefield in the city of Bengaluru, India. The apartment consists of 4 towers with Upper Basement and Lower basement used for car parks. Ground floor till 15 floors for residence. In total there are 270 apartments. The apartment's day to day maintenance is carried out by the company: Uniservice facility Management private limited.

As per the statute, the apartment complex welfare association has been registered under the name of DNRAOC – DNR Atmosphere Owner's Condominium and the Management Committee (MC) is elected each year and oversee the operations of the

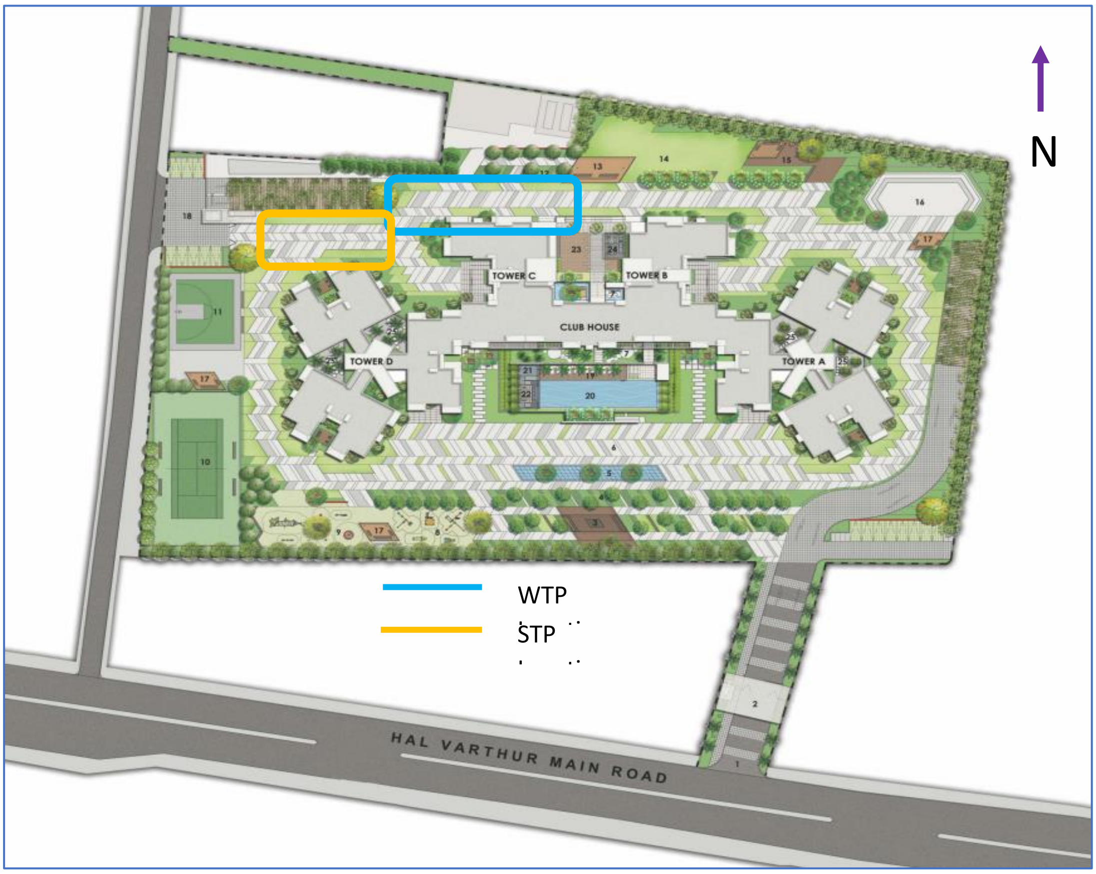

Figure 1: Location description of STP and WTP in DNR Atmosphere

apartment. As part of the MC – one resident would take up the role of Water management and fire system. The major water systems in the apartment complex are:

1. Sewage Treatment plant
2. Water treatment plant
3. Fire Hydrant system.
4. Swimming pool
5. Gardening water system

The Location of the two systems is given in figure 1.

3.2 Sewage Treatment Plant

3.2.1 Basic description

The sewage treatment plant in DNR Atmosphere has an installed capacity of 190,000 litre per day (KLD). The STP is in the Upper and Lower basement (below the ground level) at the Northwest corner of the property. The system was designed by M/s. xxx and constructed by M/s xxx.

Figure 2: Access to STP

The sewage treatment plant received its Certificate for operations in 2015. Figure 2 shows the access to the STP.

The sewage treatment plant is connected with all the 4 towers of the apartment complex via tubing systems. The wastewater flow is based on gravity and is pressure less. All the four tower tubes have been mounted on the roof of UB. The final pipe has been routed through underground below the Tower D and drains into the sewage plant as one single inlet. Figure 3 shows the line diagram and visuals of the STP. The various parts of the STP are:

- List of Civil construction units:
  - BSC – Bar Screen Chamber
  - EQT – Equalization Tank
  - PAT – Pre-Aeration Tank
  - AT – Aeration Tank
  - DT – Decant Tank
  - SHT – Sludge Holding Tank
  - TWT – Treated Water Tank
  - DP – Drain Pit
- List of Mechanical Units:
  - RSP – Raw Sewage Pump
  - CBD – Coarse Dubble Diffuser
  - FBD – Fine Bubble Diffuser
  - AB – Air Blower
  - DV – Decant Valve
  - STPP – Sludge Transfer Pump
  - FFP – Filter Feed Pump
  - PSF – Pressure Sand Filter
  - ACF – Activated Carbon Filter
  - SBF – Sludge Bag Filter
  - CL – Chlorinator
  - BV – Butterfly Valve/Ball Valve
- Characteristics of Raw Sewage water are:
  - Flow – 190 KLD
  - pH – 7 – 10
  - BOD – 250 – 350 mg/L
  - COD – 500 – 600 mg/L
  - SS – 150 mg/L

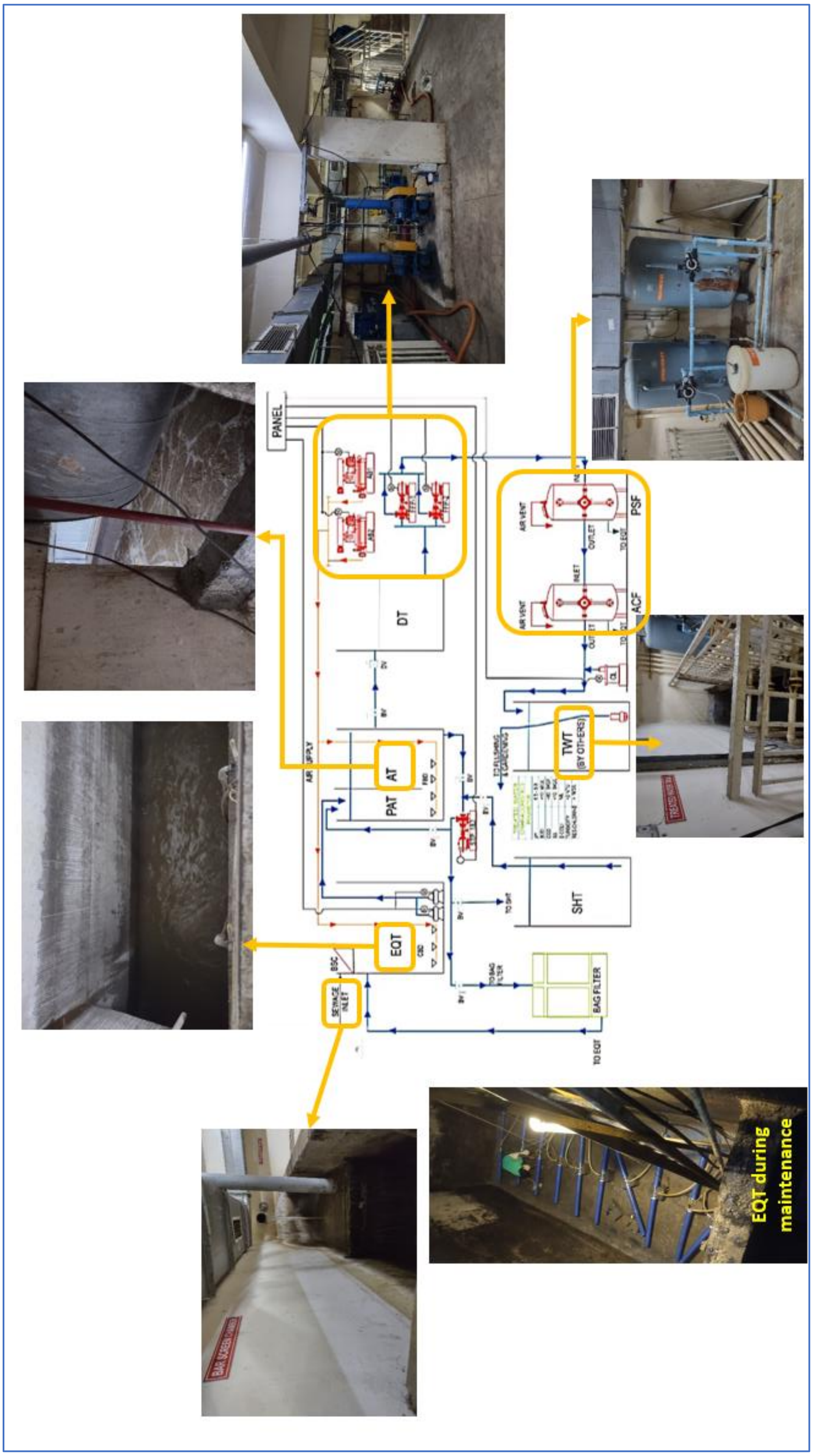

Figure 3: Line diagram and visuals of STP.

3.2.2 Treated water quality – Reference.

The starting point for this thesis is to analysis the treated water from the STP. As per Government regulations the Facility team regularly send samples of the treated water for analysis with certified labs. Nevertheless, only basic parameters are measured.

Figure x in Annexure is a sample monthly report of the test results from the lab for treated water. The results do not provide a full analysis of the water. The governing standard in India for potable water quality is issued by the Bureau of Indian Standards (BIS) – Drinking water specifications → IS: 10500-2012. The requirements are classified into [1]:

1. Organoleptic and physical parameters
2. General parameters concerning substances undesirable in excessive amounts.
3. Parameters concerning toxic substances.
4. Parameters concerning radioactive substances.
5. Pesticide residues limit.
6. Bacteriological quality of drinking water.

The variables to be measured with respect to the above classifications are:

- Total dissolved solids, pH & Turbidity
- Aluminum (as Al)
- Alkalinity & Hardness
- Ammonia (as Total Ammonia-N)
- Barium (as Ba)
- Iron (as Fe)
- Manganese (as Mn)
- Sulfate (as SO4)
- Nitrate (as NO3)
- Chloride (as Cl)
- Fluoride (as F)
- Total Arsenic (as As)
- Total Chromium (as Cr)
- Copper (as Cu)
- Cyanide (as CN)
- Lead (as Pb)
- Mercury (as Hg)
- Zinc (as Zn)
- Total coliform bacteria & E-coliform bacteria
- Calcium

- Magnesium
- Nitrite
- Phosphate
- Cadmium

With this new requirement, raw water and treated water samples were collected for three consecutive days and sent for lab testing. Annexure Figure x & y were the test results based on IS: 10500-2012. Figure x summarizes the test results for a period of three days.

Dates	28.04.2024		29.04.2024		30.04.2024	
Parameters	Raw	Treated	Raw	Treated	Raw	Treated
pH value @ 25 degC	6.77	7.3	6.75	7.35	6.8	8.25
Turbidity	24	1	26	0.9	30	1
TDS (mg/L)	1400	1200	1450	1210	1450	1500
Total Hardness as CaCo3 mg/L	490	450	478	458	509	539
Calcium (mg/L)	129	121	125	128	127	145
Magnesium (mg/L)	40.5	35.7	40	28.5	40.5	42.9
Chloride (mg/L)	362	413	537	447	364	634
Sulphate SO4 (mg/L)	65	68	95	70	65	120
Aluminium (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ammonia (mg/L)	2.5	0.13	2.8	0.14	2.2	<0.1
Copper (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoride (mg/L)	0.42	0.35	0.43	0.36	0.42	0.32
Iron (mg/L)	0.47	0.13	0.45	0.16	0.49	0.12
Manganese (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrate (mg/L)	4	2	4.5	2.5	4.8	2.2
Nitrite (mg/L)	0.36	0.16	0.38	0.13	0.38	0.13
Total Alkalinity CaCO3 (mg/L)	653	326	298	320	485	320
Barium (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium (mg/L)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cyanide (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel (mg/L)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Total Arsenic (mg/L)	<0.02	<0.01	<0.01	<0.01	0.021	<0.01
Total Chromium (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phosphate PO4 (mg/L)	3.5	0.61	3.4	0.58	3.4	0.58
Total Coliform Count (MPN/100ml)	64	34	63	32	68	34
E.Coli (MPN/100ml)	<1600	0	<1600	0	<1600	0

Figure 4: Full water test results.

In the chapter the test results will be analyzed to deduce the various systems that can be utilized to treat the water to reach the potable quality.

4 Water analysis-based treatment system exploration

4.1 Analysis of the water test results.

The STP SBR treatment process effectively neutralizes the pH, bringing it closer to neutral (7.0). The increase towards slightly alkaline conditions (up to 8.25) is typical for treated wastewater.

Significant reduction in turbidity indicates effective removal of suspended particles. Lower turbidity in treated water implies better water clarity and lower microbial contamination risk (Figure 8 shows the daily MLSS check performed by the STP operator to control the batch quality of treated water – this method is used to check the amount of suspended solids), which is crucial for most non-potable applications, which evident by the current usage in the apartment complex already: the treated water is used for toilet flushing, watering the plants in the garden around the apartment complex and floor cleaning.

Figure 4: MLSS method used by STP Operator to check treated water batch quality.

TDS reduction is minimal, with some variability. One of the main reasons for high TDS is the incoming water. The main source is borewells in and around Bengaluru. Bengaluru has a rocky terrain thereby containing many minerals which gets dissolved in the ground water.

The reduction of E.Coli to 0 in some samples indicates effective microbial pathogen removal. For Nutrients like Nitrate and Phosphate: There is a reduction in concentrations, but they are still present at detectable levels in the treated water. Heavy Metals like Lead, Mercury, Arsenic levels are generally low or undetectable in both raw and treated water. Fluoride and Ammonia reductions levels are notable, indicating effective treatment processes that reduce toxicity and odors.

The STP is effective in neutralizing pH, reducing turbidity, and significantly lowering bacterial counts, particularly E.Coli, making the treated water safer for environmental discharge and potentially suitable for gardening reuse. However, the high TDS and hardness could limit other uses without further treatment.

4.2 Available Water Treatment Systems

Considering the water test results analysis, it is evident that a further treatment process is required to further improve the water quality to potable levels. Various purification technologies available commercially are:

- Reverse Osmosis (RO)
- Membrane Distillation (MD)
- Biofiltration
- Ultrafiltration (UF)/ Nanofiltration (NF)
- Advanced Oxidation Processes (AOP)

Plus, disinfection through Ultraviolet (UV).

4.3 Evaluation criteria

Before searching for a system, factors such as:

1. Space available for installation of the system
2. Power consumption
3. Ease of operation and maintenance
4. Initial investment costs

Considered as crucial in selecting a system. Currently there are two locations which can used to install a water treatment system in the apartment complex. One location is at the ground level near the rear gate at North-West corner of the property. This location is suitable as it is close to the STP and near to Urban drainage system. Secondly the roof of the apartment complex – this location is close to the overhead tanks containing the treated water used for flushing and enables a seamless connection to rainwater tanks – to supply the treated water from the proposed system.

5 Selection of System

5.1 Introduction

India is part of the Global solar alliance. This cooperation of countries aims to harness the solar energy. In Bengaluru, the average solar radiation is approximately 5.38 kWh/m^2 per day (data from Indian Meteorological Department), with the city experiencing around 320 sunny days annually – Solar based systems would be researched first. Then the commonly used RO systems would be researched. Based on literature research calculations were performed to kind key parameters and collect price details from vendors.

5.2 Process description for selected water treatment technologies.

5.2.1 Reverse Osmosis (RO)

Reverse osmosis (RO) is a water purification technology that uses a semi-permeable membrane to remove ions, unwanted molecules, and larger particles from drinking water. In RO, pressure is applied to overcome osmotic pressure, a colligative property, driving water through a membrane while blocking most solutes suspended in it.

Pre-Treatment: Water first passes through pre-treatment filters to remove large particles, sediments, and other impurities that might clog the RO membrane.

Pressurization: A high-pressure pump increases water pressure to push water through the RO membrane.

Membrane Filtration: Water is forced through the semi-permeable membrane, which is fine enough to catch dissolved salts, bacteria, and other impurities, allowing only water molecules to pass through.

Post-Treatment: After filtration, water flows through a post-treatment system which can include carbon filters or UV lights to further purify the water of any residual taste, odor, or microorganisms.

Waste Discharge: The concentrated brine, containing the rejected contaminants, is flushed away as waste, while the treated water moves to storage.

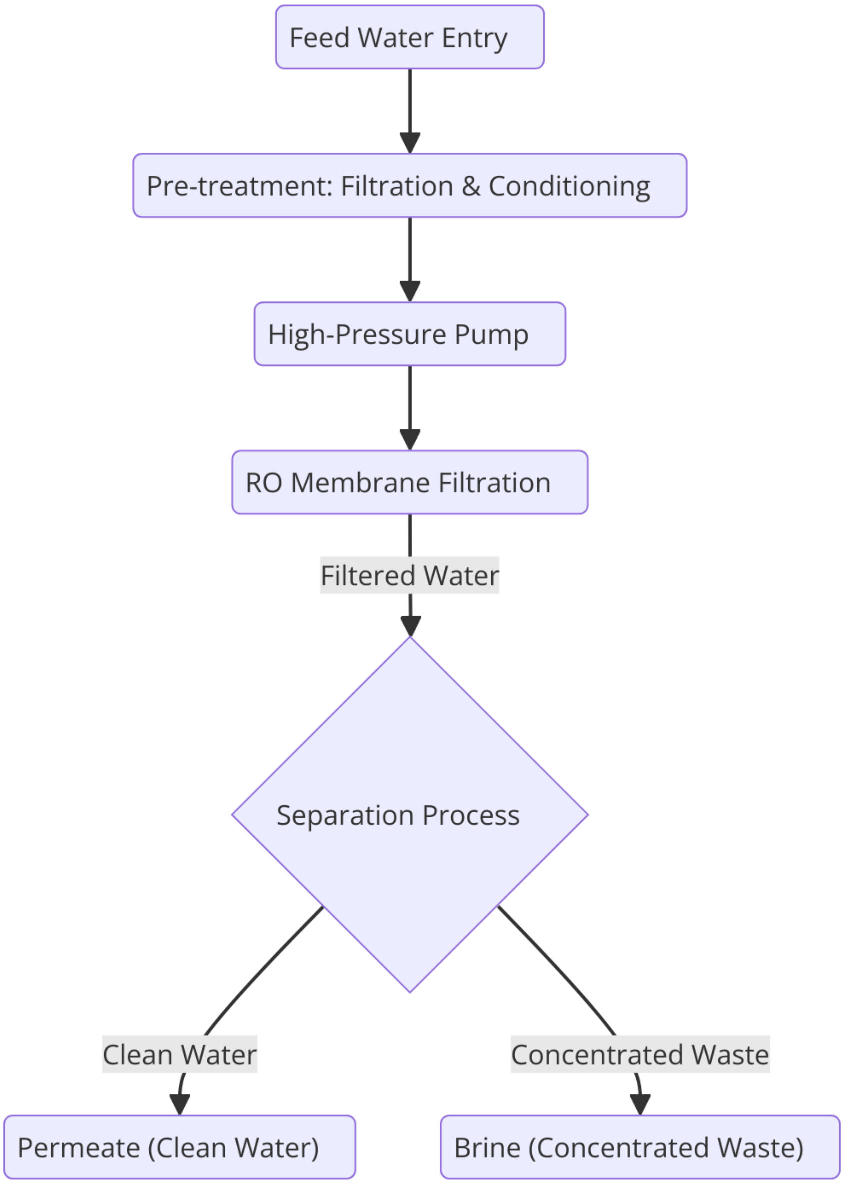

Figure 5: Flow chart - Reverse Osmosis.

5.2.2 Membrane Distillation (MD)

Direct Contact Membrane Distillation (DCMD): DCMD involves a hydrophobic membrane where hot saline water is passed on one side and cold water on the other. The temperature difference causes water vapor to transfer from the hot to the cold side, condensing as pure water.

Solar Membrane Distillation: Solar MD uses solar energy to heat the feed water. This can be achieved by integrating solar collectors in the system, which heat the saline water, utilizing the sun's energy to drive the distillation process.

Process Description for Both Types:

Heating Source: For DCMD, a conventional heater or solar energy heats the saline feed water. In solar MD, solar collectors directly heat the water.

Vapor Transmission: The hot water vaporizes at the membrane surface, and the vapor passes through the membrane due to the temperature gradient.

Condensation: On the colder side of the membrane, the vapor condenses to form distilled water.

Collection: The condensed water is collected as product water, and the remaining brine is either recycled or disposed of.

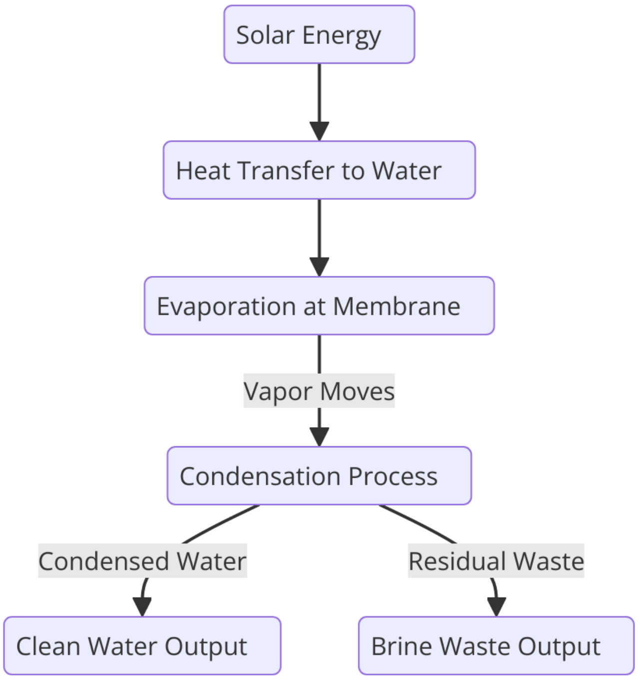

Figure 6: Flow char - Solar Membrane Distillation

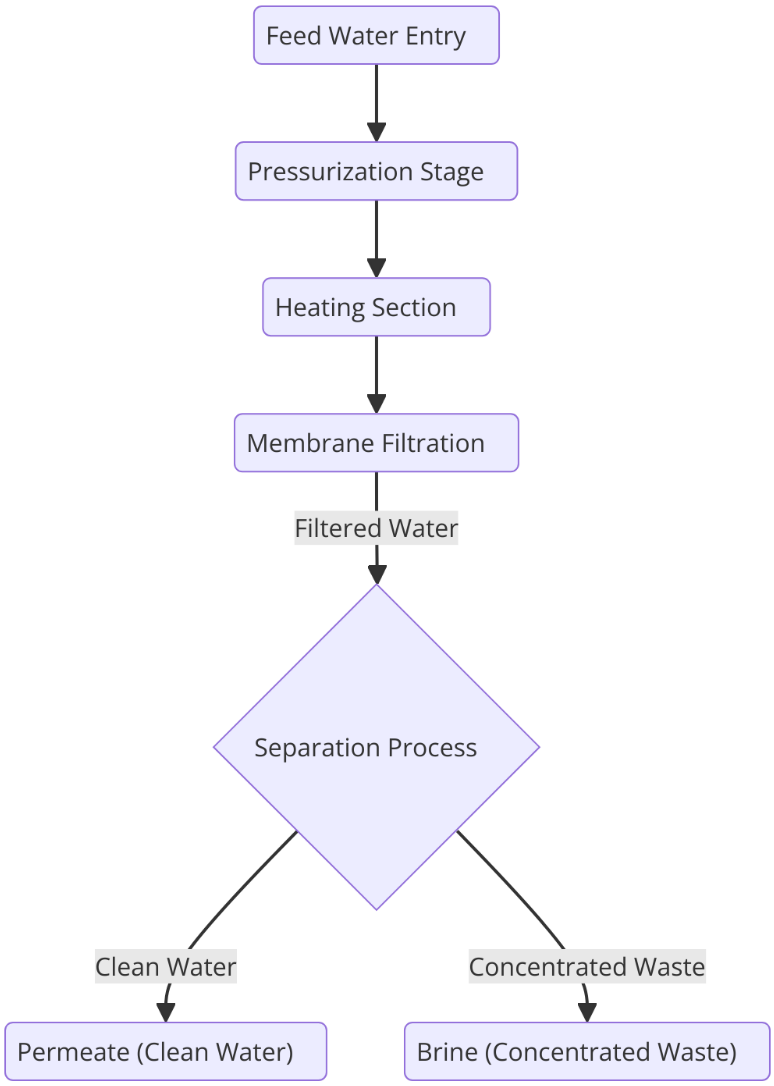

Figure 7: Flow chart - Direct Membrane distillation.

5.2.3 UV Filtration

Process Description: UV filtration is a disinfection method that uses ultraviolet light to kill or inactivate microorganisms by destroying nucleic acids and disrupting their DNA, leaving them unable to perform vital cellular functions.

UV Exposure: Water is exposed to UV light in a treatment chamber where UV rays penetrate harmful pathogens in the water and destroy illness-causing microorganisms.

Flow Control: The flow rate is controlled to ensure that water does not pass through the chamber too quickly, ensuring adequate exposure to UV light.

Post-Treatment Monitoring: Sensors monitor the UV intensity to ensure sufficient light levels are maintained to achieve effective disinfection.

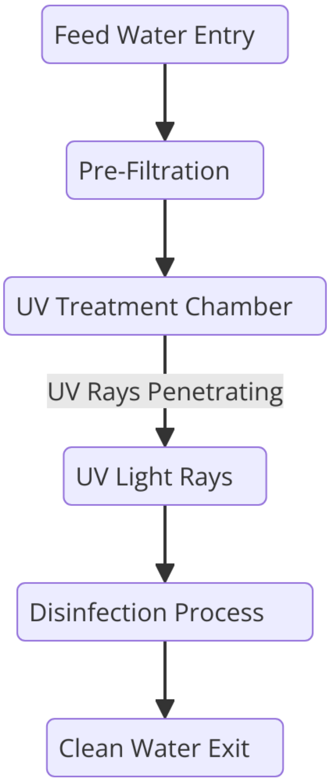

Figure 8: Flow chart - UV water treatment.

5.3 Literature survey

The research paper Performance investigation of a novel solar direct drive sweeping gas membrane distillation system [2] explores an innovative approach to desalination using solar energy. The study introduces and assesses a solar-powered membrane distillation system that incorporates a sweeping gas configuration and a multi-surface solar concentrator. This system is designed particularly for small-scale use. The system integrates a novel multi-surface concentrator with a sweeping gas membrane distillation (SGMD) module. The concentrator enhances the solar radiation absorption, thus increasing the temperature of the feedwater and, consequently, the overall efficiency of the distillation process. The multi-surface concentrator is optimized to collect solar energy effectively, reaching an optical efficiency of over 70% within an incident angle of 20 degrees. The system incorporates SGMD that facilitates reduced energy loss by utilizing a gas to carry vapor through the membrane, which decreases the likelihood of membrane fouling and enhances distillation efficiency. The system demonstrated a water yield of 5.1 kg/m²/day, with a payback period estimated at 3.4 years, indicating good economic viability and efficiency.

The paper has tests conducted under real-world conditions to confirm the theoretical predictions, showing the system's capability to function efficiently in varying environmental conditions.

Impact of Parameters: The study extensively explores the influence of operational parameters like irradiance, inlet air temperature, and feed salinity on the system's performance. This analysis is crucial for optimizing the system to maximize output in different geographical and climatic conditions. The System demonstrated High thermal efficiency due to the effective use of solar energy and reduced heat losses and low operational cost due use of direct solar heat minimizing the need for additional energy sources.

While the payback period is reasonable, the initial setup cost is expected to be high due to the complexity of the multi-surface concentrator and the membrane system. Moreover, the system is not yet commercially available. Another challenge expected would be the maintenance as the system is not yet commercially available.

As the system from [2] was a novel system, the research paper Performance and Economic analysis [3] was reviewed for exploring Direct contact Membrane distillation and Air gap Membrane distillation. The study evaluated a solar membrane distillation (MD) system capable of configurations such as direct contact MD (DCMD) and air gap MD (AGMD). It explored the system's efficacy under various conditions and integrates renewable energy source: solar energy.

DCMD configuration provided a 43% higher water flux compared to AGMD. Implementation of solar energy resulted in a 30% decrease in specific energy consumption (SEC) and a 17% increase in the gained output ratio (GOR) on sunny days. Cost analysis showed that solar integration could make the system cost-effective over its operational life. Another area of interest was explored – if the water treatment could be coupled with solar power generation. With this regard, Solar Powered Membrane distillation and conventional membrane distillation [4] research paper was reviewed. This paper compares solar-powered membrane distillation (SPMD) with conventional membrane distillation (CMD) through a life cycle assessment. The focus is on the environmental impact of these systems using different types of photovoltaic (PV) panels.

Five types of PV panels were assessed for their environmental impacts, with amorphous Silicon (a-Si) panels showing the least environmental impact across most categories. SPMD systems generally had a lower environmental footprint than CMD systems. Other finding from the research wre, SPMD systems, particularly those using a-Si PV panels, offered significant reductions in environmental impacts compared to CMD systems.

As the solar based systems are yet commercially available. RO based systems were also analyzed. The research paper Reverse osmosis integrated with renewable energy as sustainable technology: A review [5] was reviewed, as it uses renewable energy with Reverse Osmosis.

The paper discusses the prevalence of RO in desalination, its efficiency in removing various contaminants, and its advantages over traditional thermal desalination methods, which include lower energy requirements and a reduced carbon footprint. The paper discusses various forms of renewable energy integration with RO systems, primarily focusing on solar, wind, and wave energy. Quantitatively, the integration of solar energy with RO has been highlighted with several pilot projects achieving significant reductions in carbon emissions and energy costs. For instance, a project mentioned in the document achieved up to 70% reduction in energy usage by integrating solar photovoltaic (PV) panels with RO systems. The integration not only supports continuous operation during daylight hours but also contributes to substantial energy savings and operational cost reductions over time.

Technical challenges primarily revolve around the intermittent nature of renewable energy sources and their impact on the consistent operation of RO systems. The paper quantifies this by discussing variability in energy supply, where solar energy can fluctuate between 100 to 800 W/m² throughout a day, influencing the RO system's performance. To address this, advanced energy storage solutions and hybrid systems that combine multiple renewable sources or link with the grid are considered. For example, energy storage advancements have allowed for up to 90% efficiency in retaining generated energy, thereby stabilizing the power supply to RO systems.

Economically, the integration of renewable energy with RO systems is shown to decrease the reliance on fossil fuels and reduce operational costs by 40-60% over the lifecycle of the project, depending on the local cost of electricity and renewable infrastructure setup costs. Environmentally, the shift to renewable energy sources significantly reduces the carbon footprint of desalination plants. The document cites examples where carbon emissions were reduced by over 50% compared to conventional RO systems powered by fossil fuels.

Another aspect of RO system specifically, the fouling of the membrane and its impact on performance was analyzed in the research paper Effect of membrane properties on the performance of batch reverse osmosis (RO): The potential to minimize energy consumption [6]. The paper investigates the impact of varying membrane permeabilities on the energy efficiency and performance of batch RO systems. Four different 8-inch RO membranes were tested using a free-piston setup at a recovery rate of 0.8, assessing specific energy consumption (SEC), permeate quality, and salt rejection. Membranes with higher permeability (4.6 to 5.7 L/m²/h/bar) showed a 25-29% lower SEC compared to the lowest permeability membrane (2.7 L/m²/h/bar). Increasing membrane permeability from 5 to 20 L/m²/h/bar could reduce the hydraulic SEC by an additional 17-28%. Lower permeability membranes demonstrated better salt rejection (>95%) but at the cost of higher SEC. Higher permeability membranes, while reducing SEC, showed reduced salt rejection (82-96%).

To have a better comparison between the systems, only the treatment systems – Membrane distillation with Solar and RO system properties are calculated. With the derived numbers, a Request for Quote (RFQ) was to be submitted to vendor to deduce the final cost of installation and operation. As the treated water is already sent through a Sand and Charcoal filter at the STP, a separate filter system was not considered for the input water to this system. An UV treatment system was considered to make sure that the ecoli were completely removed.

Secondly, the treatment requirements for brine were calculated to provide a viable solution for safe disposal, rather to send the brine back into STP or Underground sewage line.

While evaluating the space requirement and costs involved in plumbing – the North-West corner of the apartment complex was found unsuitable for installing the treatment plant. As the STP treated water was already available in the overhead tanks and gravity could be used to supply the potable quality water down to RWH Tanks through existing water pipes, the terrace of the apartment complex was selected as a suitable location for installation.

5.4 Calculation of System Parameters

A 1000 Liters per day system was decided to perform the calculation. The area of the RO membrane is important for achieving the desired output in this case the target values prescribed in the BIS 10500:2012 to reach potable water quality.

$$A = {}^{Q}/_{J}$$

where, A = Membrane area (m2), Q = Daily production required (1 m3/day), J – Permeate flux (m3/m2/day)

Assuming an average permeate flux of 0.48 m3/m2/day, the membrane area A required is:

$$A = \frac{1}{0{\cdot}48} = 2.08m^2$$

Next the Power (P in kW) consumption is calculated considering a system pressure (ΔP) of 35 bar and recovery rate of 50% - meaning double the flow rate of Q = 2 m3/day. Pump efficiency (η) is considered as 65%.

$$P = \frac{Q \times \Delta P}{\eta} = \frac{2{\cdot}31 \times 10^{-5} \times 3500000}{0.65} = 0 \cdot 25kW$$

5.5 Calculations for Membrane distillation system

As terrace was chosen as the location for installing the plant, solar powered membrane distillation system was explored. From research paper by Yungsheng Zhao et al. [2] was reviewed to plan the system for the apartment complex. The aim of the paper was to develop and investigate the performance of a novel solar direct drive sweeping gas membrane distillation system with a multi-surface concentrator for small scale use. The research involved the designing collectors and a mathematical model to study the effects of various operating parameters. However, since this system is still in development stage and commercial availability of sweeping gas membrane or direct drive membrane distillations – the idea of Conventional solar membrane distillation was explored.

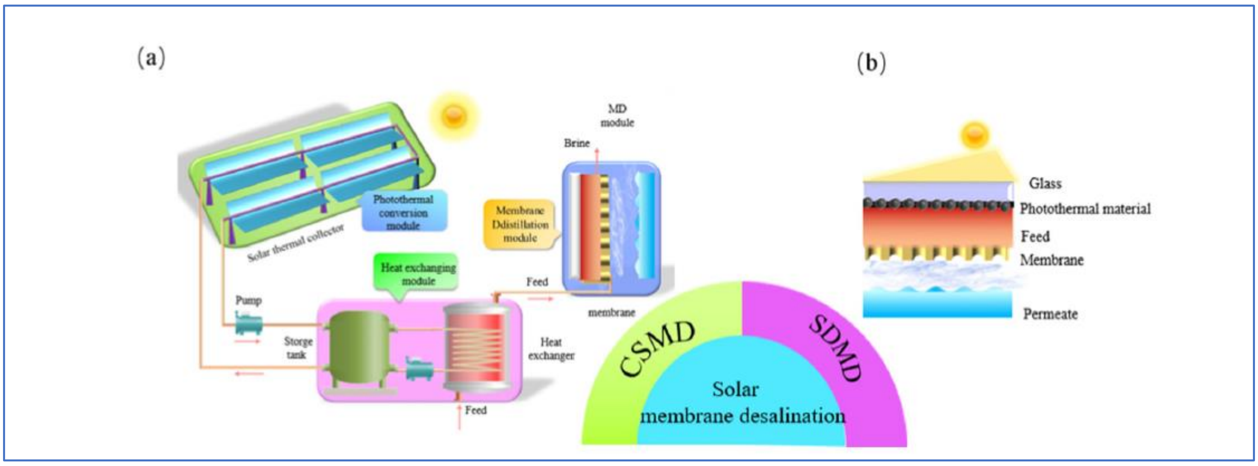

Figure 9: a) Conventional Solar membrane distillation system (b) Solar direct-drive membrane distillation with evacuated solar tube [2].

The research paper used water with pH of 7.2, TDS of 500 mg/L and Turbidity of 1.5 NTU (Nephelometric Turbidity Units). As these values were like the treated water values of the STP plant in the apartment complex – the same membrane size of 0.2 micrometers and material hydrophobic microporous membrane was considered for the calculations. Hence for a requirement of 1000 L/day and permeate flux of 5 L/m2/h

$$A = {}^{Q}/_{J} = \frac{41.67m\,{}^{3}/_{h}}{\frac{5m^3/m^2}{h}} = 8 \cdot 33m^2$$

Energy required for the system was then calculated to deduce the surface area required for the solar panel as well as the heat storage to increase the efficiency of the overall system.

$A = \frac{Q}{I \cdot \eta} = \frac{10kwh}{0.2\ x\ 5^{kw}/_{m^2}}$ = 10m^2

Where, Asp is solar panel surface area, Q is the energy required in kWh = 10 kWh, I is the solar irradiance in kW/m2 = 5 kW/m2 (Average solar irradiance in Bengaluru is 5.38 kW/m2 per day with almost 320 sunny days) and η = 0.2 is the efficiency of the solar panels. And heat storage

$Q = m \cdot c \cdot \Delta T$ = 1000kg x 4.186 kJ/kg°C x 50°C = 58.14 kWh

M = mass of water (1000 litres or 1000 kg assumed for simplification), c = specific heat capacity of water = 4.186 kJ/ kg°C and temperature difference (assuming 20 °C and 70 °C) = 50 °C.

UV Treatment power requirement [2], governing equation is:

$$P = \frac{Q \cdot D}{E}$$

Where, P = Power of the UV lamp in W, Q = flow rate (1000 litres/day = 0.0116 L/s), D = UV dose in mJ/cm2 = 40 mJ/cm2 (assumed) and E = electrical efficiency of the UV system (35% assumed).

Energy per day = P x24 hours = 1.33 W x 24 = 31.92 Wh/day = 0.032 kWh/day.

5.6 Handling of Brine

Assuming 50% as RO reject and a system efficiency of 30% for the Solar membrane distillation systems: the Brine reject for a pilot platn of 1000 Liters per day was calculated:

RO System – 1000 Liters per day, and

Solar Membrane distillation system – 2333 Liters per day.

The brine produced during the desalination treatment from both the discussed topics would handled for futher treatment based on the research papar [8] and [11]. The research [11] was the Bachelor thesis where the Industrial effluent treatment through packed bed solar collector was studied. Combining both the ideas a hybrid packed bed system is proposed for the treatment.

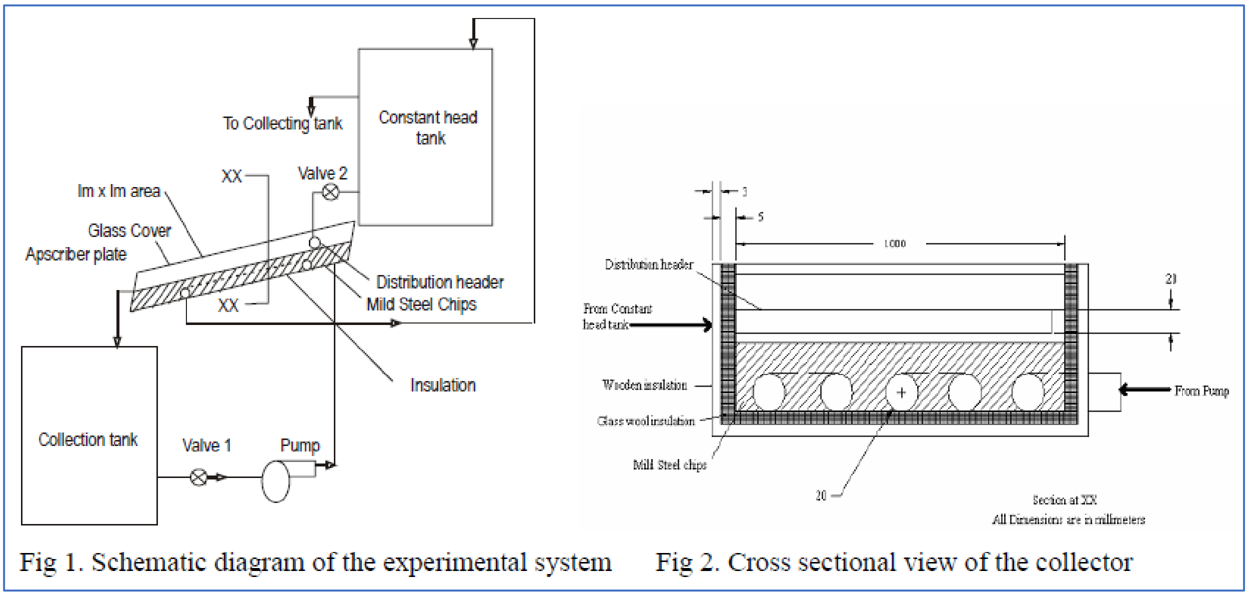

Figure 10:: Schematics for brine treatment [11].

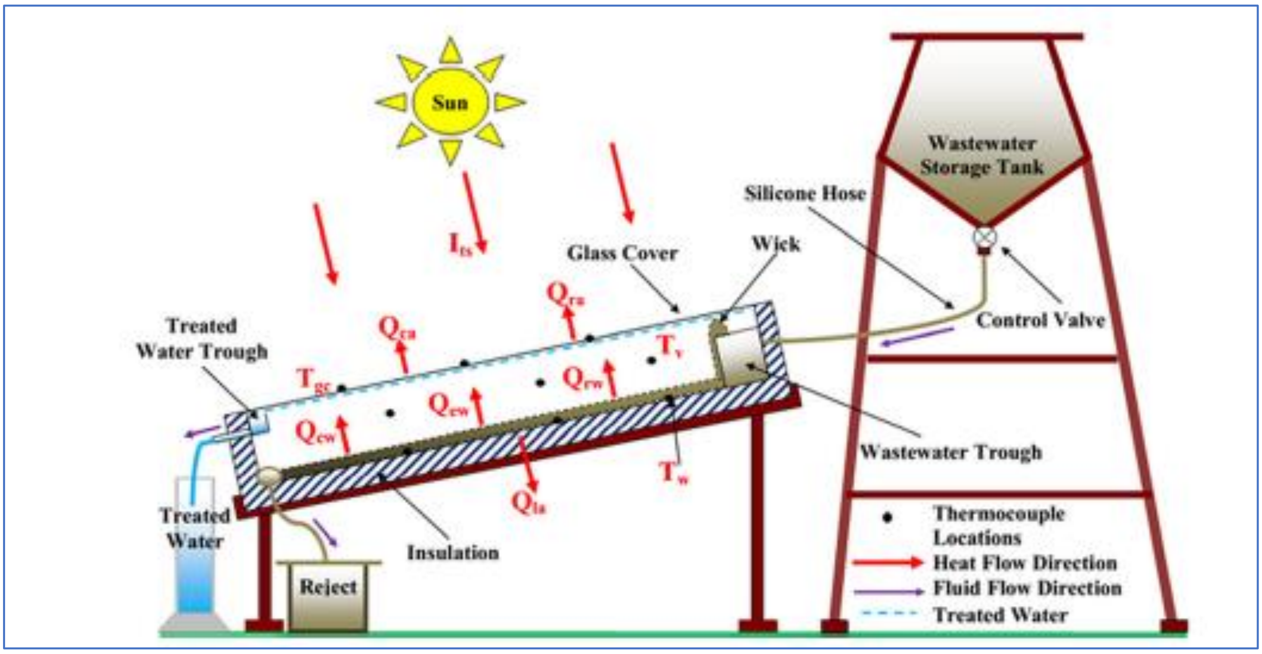

Figure 11: Schematics 2 - for Brine further treatment [8].

5.7 Calculation of UV Treatment requirements

For an effective water treatment and the nature of requirement ie. Potable quality of the treated water – a UV Treatment was proposed [12]. The power requirement of the UV system with 1000 Litres per day would be:

$P = \frac{Q \times D}{E}$, where P= Power of the UV lamp in watts. Q = Flow rate in Liters per second. D = UV dose in mJ/cm^{2}and E = electrical efficiency of the UV system (assumed 35%)

Hence,

P = (0.0000116 m^3/s × 40000 mJ/m^2)/0.35 = 1.33W

Hence the total energy requirement for a day is 1.33W x 24h/1000 = 0.032 kWh/day.

6 Comparison and suggestions

6.1 Recap

This chapter aims to delve into a comprehensive comparison between Reverse Osmosis (RO) and Solar Membrane Distillation (MD) systems for the treatment of sewage water to meet potable standards. The analysis will leverage data from earlier chapters, specifically Chapter 4's water analysis data and Chapter 5's system parameter calculations. Insights will be contextualized within the framework of India's unique environmental, economic, and technological landscape. The goal is to determine which system offers the most practical and sustainable solution for the apartment complex based in.

6.1 Technical Comparison

Reverse Osmosis (RO) System

Efficiency and Performance: RO systems in general effective, achieving removal efficiencies for TDS (Total Dissolved Solids) up to 99%, which is critical for potable water standards (predominantly used in household treatment) [10]. TDS from 2000 ppm to less than 500 ppm, which is within the drinking water standard set by the World Health Organization and BIS 10500:2012. The average pore size on RO membranes is about 0.0001 microns (commercially available in India), allowing the removal of most contaminants including bacteria, viruses, and larger ions. RO can effectively reduce lead content from 100 ppb to below 10 ppb, adhering to EPA standards.

Specific energy consumption for RO ranges from 3 kWh/m³ to 4.5 kWh/m³ depending on feed water salinity and system efficiency. Pressure requirements for RO systems typically range from 15 to 60 bar, influenced by feed water salinity. The energy required to run the system, it is advised to install Solar panels to offset the electricity requirements.

Membrane Distillation (MD) System

MD systems typically achieve salt rejection rates between 95% to 99%, slightly lower than RO in some instances but still sufficient for most potable applications. The thermal efficiency of MD systems can reach up to 80% under optimal conditions, with the potential to utilize low-grade heat sources such as solar energy. MD can operate effectively with input water temperatures ranging from 60°C to 85°C, providing flexibility in heat source utilization. From review [2], by installing a heat storage the system can function on days when the solar energy could be low or during night time.

MD systems primarily use thermal energy, which can be sourced from solar thermal systems. The average energy consumption for solar MD ranges from 250 to 750 kWh/m³, heavily dependent on solar availability and system design. MD systems have been shown to produce potable water at energy costs as low as 2.5 kWh/m³ when integrated with efficient solar thermal setups.

6.2 Economic and Environmental Impact Analysis

Installation and Operational Costs:

The installation cost per cubic meter of capacity for RO systems is approximately $600 to $1,200, with ongoing operational costs primarily driven by energy and membrane replacement [13].

MD systems, especially solar-driven, show higher initial costs ($1,000 to $2,000 per cubic meter) [tentative data received from Suppliers] due to the need for solar thermal equipment, but operational costs shall be offset by solar subsidies and lower energy prices.

Cost-Benefit Analysis:

RO systems generally have a payback period of 2 to 5 years, depending on water pricing, system size, and operational efficiency [input from neighboring apartment using the system].

MD systems, with solar integration, can achieve payback periods of 3 to 7 years, influenced by local solar incentives and energy pricing structures [2].

Environmental Impact

Carbon Footprint and Sustainability:

RO systems, while energy-intensive, can be coupled with green energy solutions to reduce their carbon footprint. Typical CO2 emissions are around 1.6 kg CO2 per cubic meter of water produced, depending on the energy source.

MD systems inherently have a lower carbon footprint when powered by solar energy, with potential emissions as low as 0.5 kg CO2 per cubic meter, promoting a more sustainable operation.

Brine and Waste Management:

RO systems produce brine that requires careful disposal or treatment, which can have significant environmental impacts if not managed properly.

MD systems also produce brine, but typically at lower concentrations, which might be easier to treat or dispose of, especially in solar-driven configurations.

6.2 Quantitative Analysis and Data

Parameter	Reverse Osmosis	Membrane Distillation
Efficiency (Contaminant Removal) [2] [8] [10]	90-99%	85-99%
Energy Consumption (kWh/m3)	3 – 4.5	2.5 (with Solar heating)
Area required	~ 2 sq. m	~8 sq. m
Payback Period	2-5 years	3-7 years
Water Recovery rate	50-75%	50-80%

6.2.1 Operational and Maintenance Requirements

RO systems require regular maintenance, including membrane and filter replacements and system cleaning to prevent fouling and scaling. Solar MD systems also need maintenance, primarily focused on the solar components and the integrity of the thermal systems.

Serviceability and Parts Availability: Given the prevalence of RO technology in India, components and service expertise are readily available. In contrast, Solar MD systems might see delays in service and higher costs for parts, affecting overall system uptime and reliability.

Figure 12:Location proposal of Solar system: Roof.

Figure 13: : Roof coating breakage

Location: the location for RO system would be near the WTP in the Lower basement. Reason for the selection was minimal plumbing for bring STP treated water to the RO system and the treated water could be connected to the WTP in the same level.

For the Solar system, roof would be chosen. However, in the recent months a new challenge has risen. The waterproof coating on the roof has started to degrade. Hence the RWA was skeptical about installing Solar system on the roof as it might further degrade the floor. In addition, if there were to be repair work carried out for the waterproofing the entire solar system must be dismantled and made offline. The roof waterproof coating had become a main challenge to the solar system.

6.3 Case Studies and Practical Examples

Incorporating real-world applications from India where these systems have been implemented will provide practical insights into their operation. For instance, exploring the implementation at a residential complex in Bangalore, where an RO system was retrofitted to work alongside existing water treatment setups, could highlight practical challenges and user satisfaction.

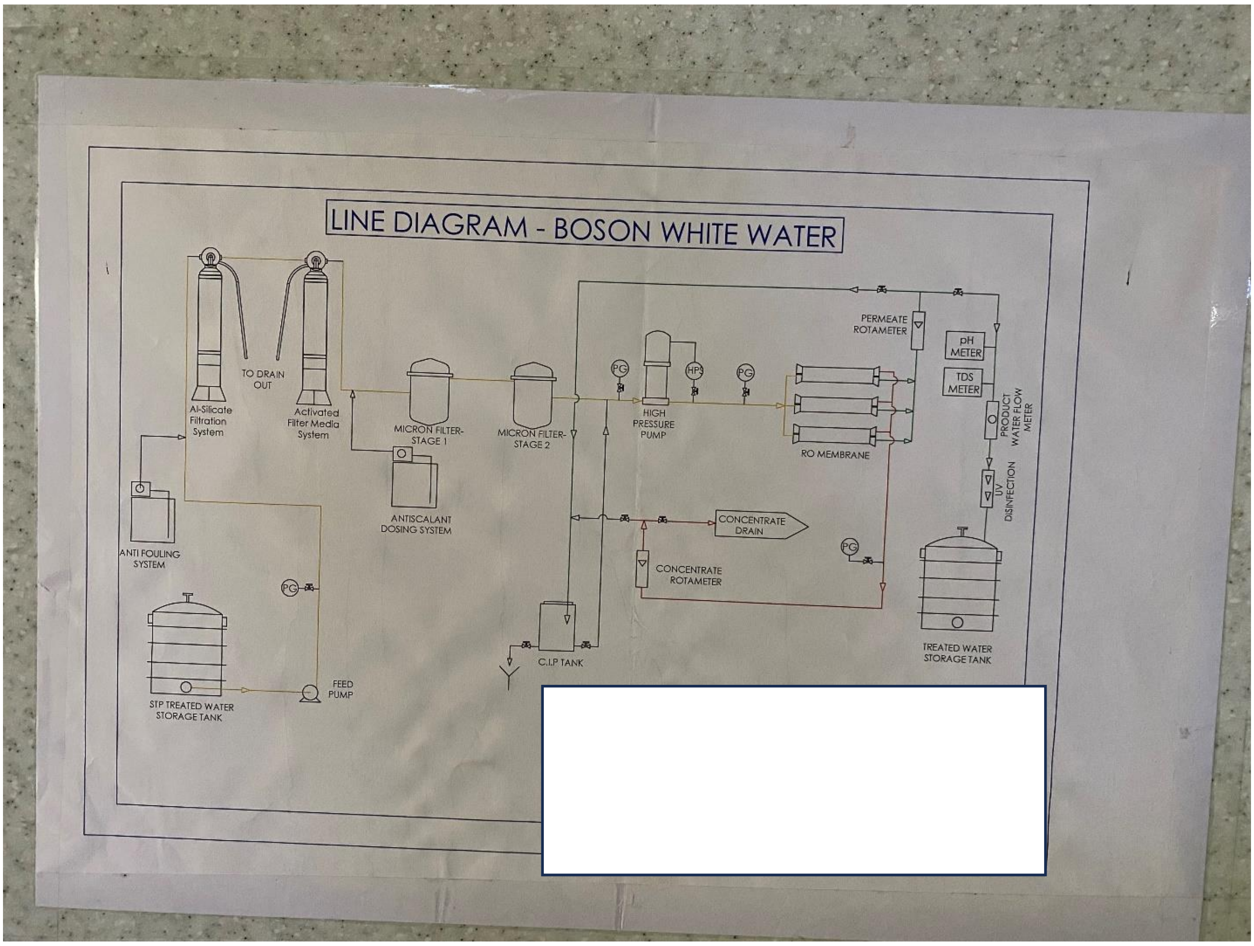

Figure 14 : Boson White water system installed in an commercial establishment housing 10000 people.

Boson white water system [figure 12]is currently commercially available for treating STP treated water to potable quality water. The system has been installed across the country has proven record of treated water quality. However, when the company was contacted for a possible solution to the apartment complex – the commercial agreement and space requirement could not suit the apartment complex.

One apartment nearby has installed a RO system for their water needs. The apartment has 90 families, and all their water needs are taken care by the RO system. The RO system works continuously, and the treated water is stored in a TWT. This system has been operational for the last 7 years without any major break downs. The RWA has not installed an UV treatment system in the output, rather rely on the 5-micron filters.

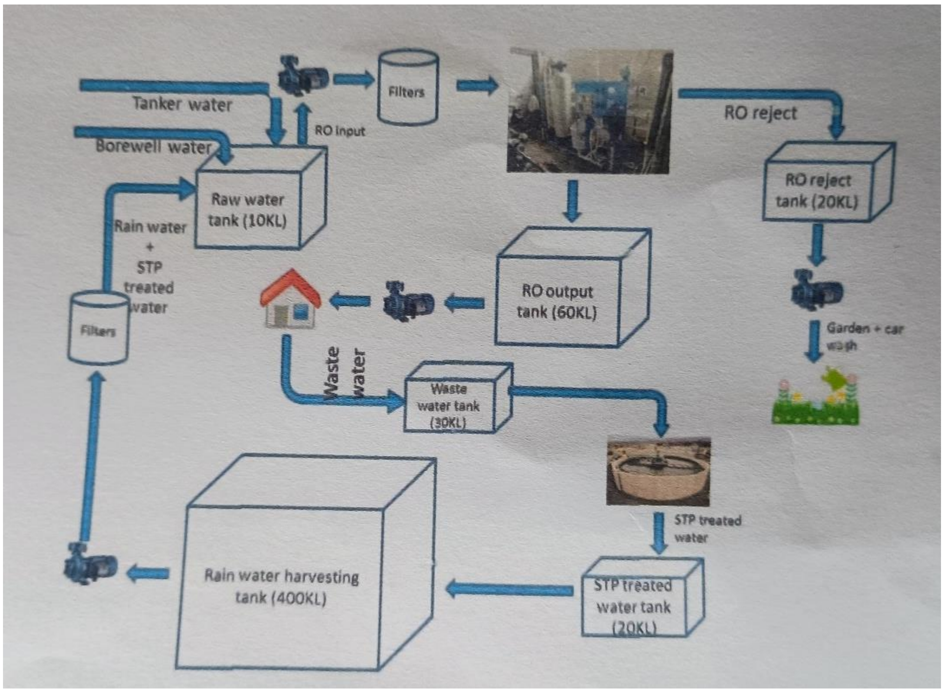

Figure 15 Nearby apartment RO system – circuit diagram.

Figure 16 RO system with WTP.

Figure 17 RO System

The space requirement for the RO system was very compact. Secondly, the membrane requires a change every 3 years and costs an estimated Rs 300,000. The reject water as per the residence is about 30% and the brine is pumped into the recharge pits of borewells.

6.4 Final Recommendation

The study was performed to find a suitable solution. RO system and Solar MD systems were analyzed. The solar systems advantages of less energy demand and use of renewable energy were a major advantage. However, due to the lower efficiency of the system (based on research from chapter 4) and requirement of additional heat sinks to operate the system round the clock possess a disadvantage. The challenges pertaining to the roof of the building and lack of support from suppliers has led to further scrutiny of the solar system.

On the other hand, the RO system – though energy intense, provides couple of advantages like readily available suppliers, compact space and proven record. Considering the technical, economic, and environmental factors, the final recommendation from this study will lean towards the system that offers the best balance of cost, efficiency, sustainability, and practicality for the specific needs of our urban apartment complex. In the current urgency for a viable solution which could be operational before the summer to cater to the water requirements, this study recommends the installation of a RO system.

7 Reference

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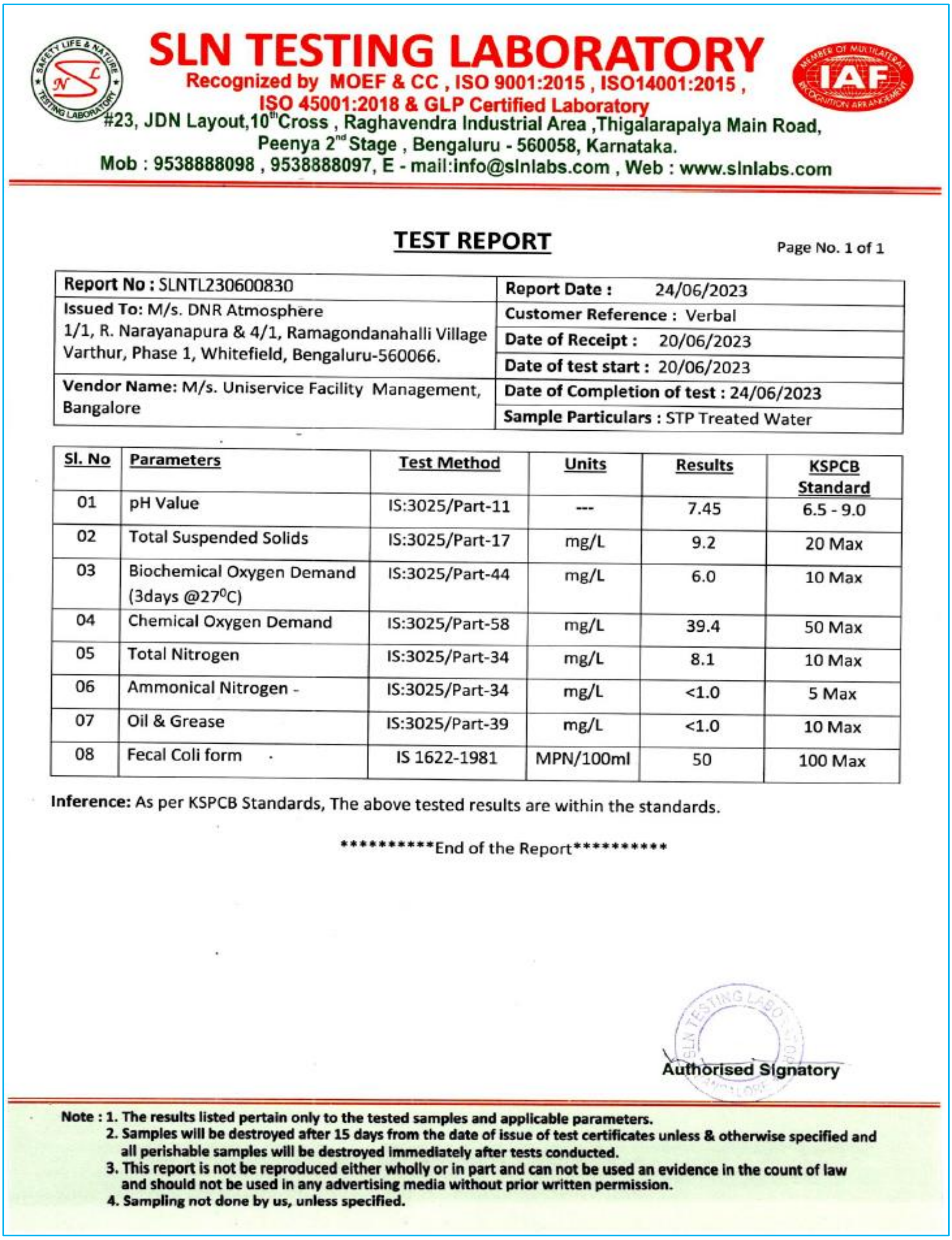
8 Annexure



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TEST REPORT

Page No. 1 of 1

Report No : SLNTL230600830	**Report Date :** 24/06/2023
Issued To: M/s. DNR Atmosphere 1/1, R. Narayanapura & 4/1, Ramagondanahalli Village Varthur, Phase 1, Whitefield, Bengaluru-560066.	**Customer Reference :** Verbal **Date of Receipt :** 20/06/2023 **Date of test start :** 20/06/2023
Vendor Name: M/s. Uniservice Facility Management, Bangalore	**Date of Completion of test :** 24/06/2023 **Sample Particulars :** STP Treated Water

Sl. No	Parameters	Test Method	Units	Results	KSPCB Standard
01	pH Value	IS:3025/Part-11	---	7.45	6.5 - 9.0
02	Total Suspended Solids	IS:3025/Part-17	mg/L	9.2	20 Max
03	Biochemical Oxygen Demand (3days @27°C)	IS:3025/Part-44	mg/L	6.0	10 Max
04	Chemical Oxygen Demand	IS:3025/Part-58	mg/L	39.4	50 Max
05	Total Nitrogen	IS:3025/Part-34	mg/L	8.1	10 Max
06	Ammonical Nitrogen	IS:3025/Part-34	mg/L	<1.0	5 Max
07	Oil & Grease	IS:3025/Part-39	mg/L	<1.0	10 Max
08	Fecal Coli form	IS 1622-1981	MPN/100ml	50	100 Max

Inference: As per KSPCB Standards, The above tested results are within the standards.

**********End of the Report**********

Authorised Signatory

Note : 1. The results listed pertain only to the tested samples and applicable parameters.
2. Samples will be destroyed after 15 days from the date of issue of test certificates unless & otherwise specified and all perishable samples will be destroyed immediately after tests conducted.
3. This report is not be reproduced either wholly or in part and can not be used an evidence in the count of law and should not be used in any advertising media without prior written permission.
4. Sampling not done by us, unless specified.

Figure 18 STP Water Test report from 26. Jun 2023.

Bharat Quality Testing Lab

An ISO 9001-2015 Certified Laboratory

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Email – bqtlab@gmail.com Website-www.bqtlab.com

QRO QUALITY RESEARCH ORGANIZATION

TEST REPORT

Report No. : BQTL/TR/012	**Report Date** : 14.05.2024
M/S.DNR Atmosphere Owner Condominium 236/66 DNR Atmosphere, Varthur Rd Ramagondanahalli, Bangalore Urban-66	**Customer Reference** : Verbal **Date of Receipt** :03.05.2024 **Date of test Start** : 03.05.2024
Sample received by : Customer	**Date of Completion of Test**: 13.05.2024
Sample Nature : STP Raw Water (28.04.2024)	**Sample Job Number** : BQTL/012 **Sample Particulars** : Water

Sample Description : Slightly Colour Turbid Liquid having Objectionable Odor

Test	Result	Protocol
pH Value@ 25^{0}C	6.77	IS 3025/Part-11
Turbidity as NTU	24	IS 3025/Part-10
Total Dissolved Solids, mg/L	1400	IS 3025/Part-16
Total Hardness as $CaCO_3$, mg/L	490	IS 3025/Part-21
Calcium as Ca, mg/L	129	IS 3025/Part-40
Magnesium as Mg, mg/L,	40.5	IS 3025/Part-46
Chloride as Cl, mg/L	362	IS 3025/Part-32
Sulphate as SO_4 mg/L,	65.0	IS 3025/Part-24
Aluminium as Al, mg/L	<0.01	IS 3025/Part-55
Ammonia as Total Ammonia – N, mg/L	2.5	IS 3025/Part-34
Copper as Cu, mg/L	<0.01	IS 3025/Part-42
Fluoride as F, mg/L	0.42	IS 3025/Part-60
Iron as Fe, mg/L	0.47	IS 3025/Part-53
Manganese as Mn, mg/L	<0.01	IS 3025/Part-51
Nitrate as NO_3 mg/L	4.0	IS 3025/Part-34
Nitrite as NO2 mg/L	0.36	IS 3025/Part-34
Total Alkalinity as $CaCO_3$ mg/L,	653	IS 3025/Part-23
Barium as B mg/l	<0.01	IS 3025/Part-61
Cadmium as Cd , mg/L,	<0.002	IS 3025/Part-41
Cyanide as CN, mg/L,	<0.01	IS 3025/Part-27
Lead as Pb, mg/L	<0.01	IS 3025/Part-47
Mercury as Hg, mg/L,	<0.001	IS 3025/Part-48
Nickel as Ni, mg/L,	<0.03	IS 3025/Part-54
Total Arsenic as As, mg/L,	0.02	IS 3025/Part-37
Total Chromium as Cr mg/L,	<0.01	IS 3025/Part-52
Phosphate PO4 mg/l	3.5	IS 3025/Part-31

Tested by

Bharat Quality Testing Lab Bangalore

J.N. Nalini
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Figure 19 Sample test report for variables provided in IS: 10500-2012.

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Email – bqtlab@gmail.com Website-www.bqtlab.com

TEST REPORT

Report No. : BQTL/TR/012	**Report Date** : 14.05.2024
M/S.DNR Atmosphere Owner Condominium 236/66 DNR Atmosphere, Varthur Rd Ramagondanahalli, Bangalore Urban-66	**Customer Reference** : Verbal **Date of Receipt** : 03.05.2024 **Date of test Start** :.03.05.2024
Sample received by : Customer	**Date of Completion of Test**: 13.05.2024
Sample Nature : STP Raw Water (28.04.2024)	**Sample Job Number** : BQTL/012 **Sample Particulars** : Water

Sample Description : Slightly Colour Turbid Liquid having Objectionable Odor

Microbiological Test

Protocol: IS 1622-1981

Tests	Results	Limits as Per IS 10500-2012
E. Coli MPN/ 100ml Sample	64	Not Detectable
Total Coliform Count MPN/ 100ml	<1600	Not Detectable

-------------End of the Report-------------

Tested by

Bharat Quality Testing Lab Bangalore

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Figure 20 Sample test report for Organic variable provided in IS: 10500-2012.