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"Design of Water Treatment Plant for a Residential Building"

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Abstract: This research presents the planning and design of a small-scale Water Treatment Plant (WTP) for a residential apartment located in Udaipur, Rajasthan, India. The selected raw water source is Goverdhan Sagar Lake, a local surface water body that, while abundant, contains chemical and microbial impurities rendering it unfit for direct consumption. A series of physico-chemical tests conducted on lake water and existing bore well supply confirmed that essential water quality parameters exceeded the permissible limits set by standards. Based on the analysis, a compact and modular WTP was designed consisting of a submerged intake structure, screening chamber, pressure filtration system, zeolite-based softening unit, and a chlorine disinfection tank. Calculations for domestic and fire water demand were also done, ensuring the treatment plant meets peak and emergency scenarios. Along with that, recommendations for sustainable practices through energy-efficient pumping, sludge management, and future adaptability for zero liquid discharge (ZLD) or reuse. This provides a base model for small-scale water treatment and leaves scope for future scholars or engineers to improve and expand on the design.
Index Terms: Water Demand, Coincident Draft, Indian Standards, Water Parameter, Hardness, Submerged Intake, Pressure Filters, Zeolite Bed, Sustainability.

I. INTRODUCTION

Clean water is a fundamental necessity for life, yet millions in India still struggle with access to safe and potable water. The reliance on groundwater has led to issues like over-extraction and contamination, while surface water bodies, though plentiful, often contain pollutants that exceed safe limits. In this backdrop, designing localized water treatment systems tailored to specific user groups such as housing colonies or apartment blocks offers a promising solution. This study addresses the water supply needs of Satyam Tower, a mid-rise residential apartment complex located in Goverdhan Villas, Sector 14, Udaipur. With seven floors and 56 residential units, the building currently relies on Groundwater, which recent tests have shown to exceed permissible limits for hardness, nitrate, and fluoride. An alternative source, Goverdhan Sagar Lake, was evaluated and found to be comparatively better in quality but still required systematic treatment before domestic use.

The primary aim of this research is to design a Water Treatment Plant (WTP) that is both effective and economically viable for a fixed-population residential building. Unlike municipal-level treatment plants, the design constraints here include space limitations, lower daily water demand, and the need for user-friendly operation. The WTP incorporates standard treatment stages—screening, filtration, softening, disinfection - optimized for scale and cost.

Key objectives of the study include:

- Evaluating water quality of the raw and current sources.
- Designing treatment units to comply with IS 10500:2012 standards.
- Ensuring the plant is capable of meeting both daily domestic and fire demand.
- Integrating sustainability features such as sludge reuse and energy-efficient pumping.

By providing a modular and reproducible model, this work contributes to decentralized water management strategies and highlights the importance of sustainable engineering in residential infrastructure development.

II. WATER SOURCE

The primary raw water source for this project is Goverdhan Sagar Lake, located southwest of Udaipur with a catchment area of 2.56 square km and a water spread of 30.81 hectares, serves as a crucial water body in the region. It is rain-fed and receives additional inflows from Pichhola Lake via a connecting canal, ensuring a steady water supply even during dry periods. The lake has a maximum storage capacity of 9 million cubic meters, with its deepest section reaching 25 feet, making it a reliable source for water extraction.

Table 1 Geographic Coordinates of Lake and Building

Location	Latitude (°N)	Longitude (°E)	Altitude (m MSL)
Satyam Tower (Apartment)	24.5333	73.6852	625.3
Goverdhan Sagar Lake	24.5386	73.6838	606.3

III. METHODOLOGY AND PROCEDURE:

The methodology for designing the water treatment plant involves multiple stages, ensuring efficient treatment and supply of potable water to the residential building. In this paper, firstly, data collected and various study perform to understand the working of a plant.

A. Data Collection

Literature Review **-** Reference IS codes, research articles, journals, and textbooks related to water treatment processes.
Demand Calculation **-** Determine daily and peak water demand based on population and usage patterns of the apartment.

B. Water Quality Analysis

To assess the raw water quality, essential parameters will be tested, including:

- pH
- Total Dissolved Solids (TDS)
- Hardness
- Nitrate
- Fluoride
- Chloride

C. Design of Water Treatment System

The treatment process will follow these key steps:

- Screening: Removal of large debris and suspended particles.
- Filtration: Use of a pressure filter to remove fine impurities and improve water clarity.
- Disinfection: Application of chlorine to eliminate harmful microorganisms.
- Hardness Adjustment: Bringing water within acceptable drinking standards.

D. Storage and Distribution

Treated water will be stored in before distribution to the apartment units.

IV. DOMESTIC WATER DEMAND

Domestic water demand refers to the quantity of water required in households for activities such as drinking, cooking, bathing, washing, and sanitation. It depends on several factors, including habits, social status, climatic conditions, and local customs. As per IS 1172:1963, under normal conditions, the domestic water demand in India is taken as 135 litres per capita per day (LPCD).

A. Calculations of Water Demand

The calculation of water demand for given population is follows as:
Expected Population = 526
Average per capita daily demand = 135 LPCD
Average Daily Demand = 526*135 = 71,010.00 litres/day
Maximum daily demand = 1.8*71010 = 1,27,818.00 litres/day
Maximum hourly demand = 2.7*71010 = 1,91,727.00 litres/hr
Peak Demand = 3*71010 = 2,13,030.00 litres/day
As per standard, 10% of peak demand is carried in the losses in system.
Losses = 213030*1.1 = 234333 litres/day

B. Fire Demand

Fire-fighting personnel require a sufficient and readily available water supply to effectively combat fires. Water used for fire protection must be stored in reservoirs and should be maintained at an adequate level, ensuring continuous availability for at least 4 to 5 hours of sustained fire-fighting operations.
The fire demand is calculated by using Kuichling's formula

$$Q = 3182\sqrt{P}$$

Where, Q = amount of water in litres/minute
P = population in thousands.
So, $Q = 3182\sqrt{0.526}$
Q = **2307.77 litres/min**
This calculated demand is for Fire-fighting provisions.

C. Coincident Draft

It is extremely improbable that a fire may break out when water is being drawn by the consumers at maximum hourly draft. For general community purposes, the total draft is not taken as the sum of maximum daily demand and fire demand, but is taken as sum of maximum daily demand and fire demand or maximum hourly demand, whichever is more.
When the maximum daily demand when added to fire draft for working out total draft, is known as *Coincident draft*.
Now, in this case let's examine the drafts,
Maximum daily draft = 1,27,818 litres/day
Fire draft = 2307.77 litres/min = 33,23,188.8 litres/day
Coincident draft = max (max. daily demand + fire demand, max. hourly demand)
= max (3451006.8, 1,91,727)
Coincident draft = 34,51,006.8 litres/day
It shows that the distribution system has to be designed for coincident draft instead of maximum hourly draft.

V. SAMPLE TESTING RESULTS

To evaluate the suitability of the water sources, the test results of Sample-I (Lake Water) and Sample-II (Apartment Tap Water) are compared against the BIS IS 10500:2012 drinking water standards. This comparison helps identify potential concerns and determine whether treatment is necessary. The following table presents the comparison of test results with regulatory limits:

Table 2 Comparison of test results with standard parameter

Quality Parameter	Sample – I	Sample – II	Acceptable limit
TDS	426 mg/l	525 mg/l	500 mg/L
pH	8	7.5	6.5–8.5
Temperature	29.3	29.5	4°C to 25°C
D.O.	10 mg/l	4 mg/l	≥5 mg/L
Hardness	340 mg/l	440 mg/l	200 mg/L
Chloride	198.52 mg/l	177.25 mg/l	250 mg/L
Nitrate	25 mg/l	75 mg/l	45 mg/L
Fluoride	1.5 mg/l	2.0 mg/l	1.0 mg/L

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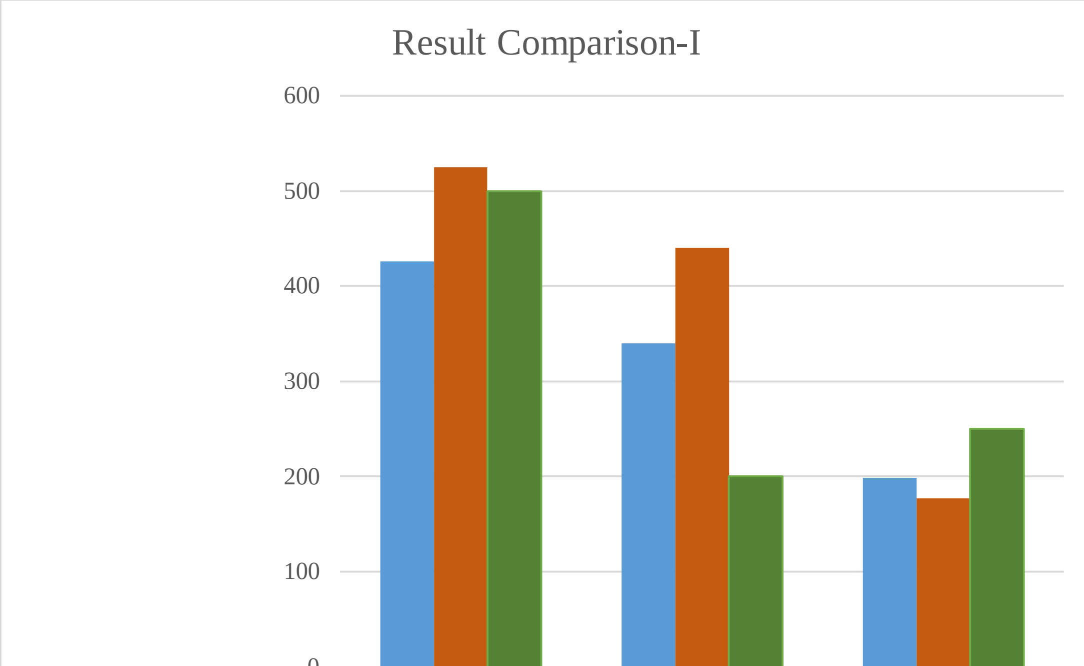
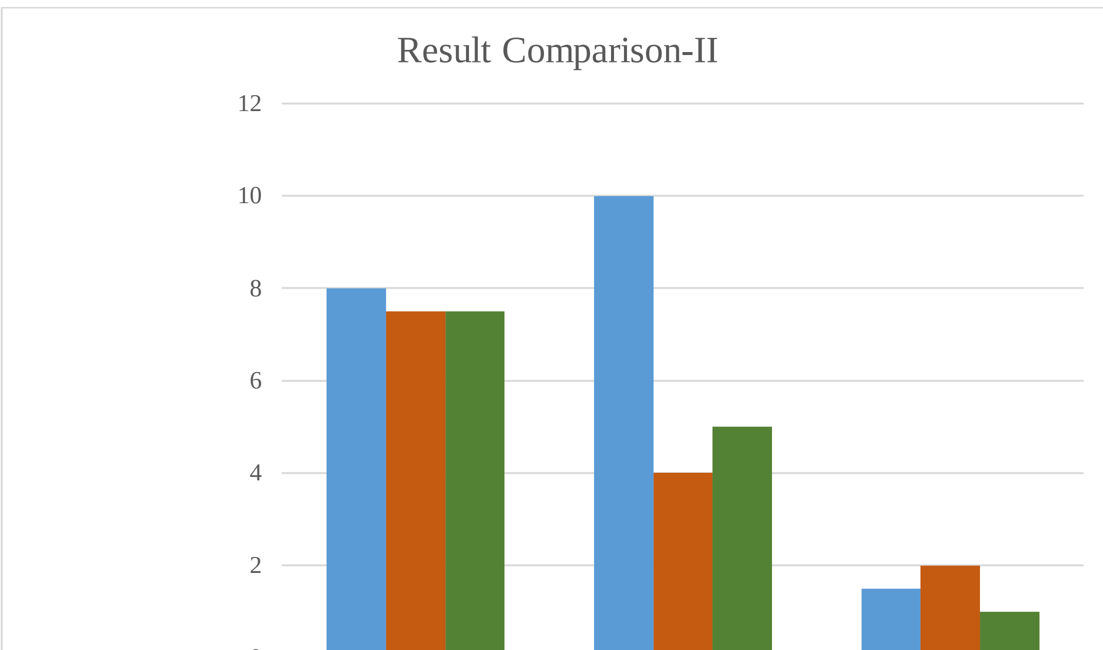


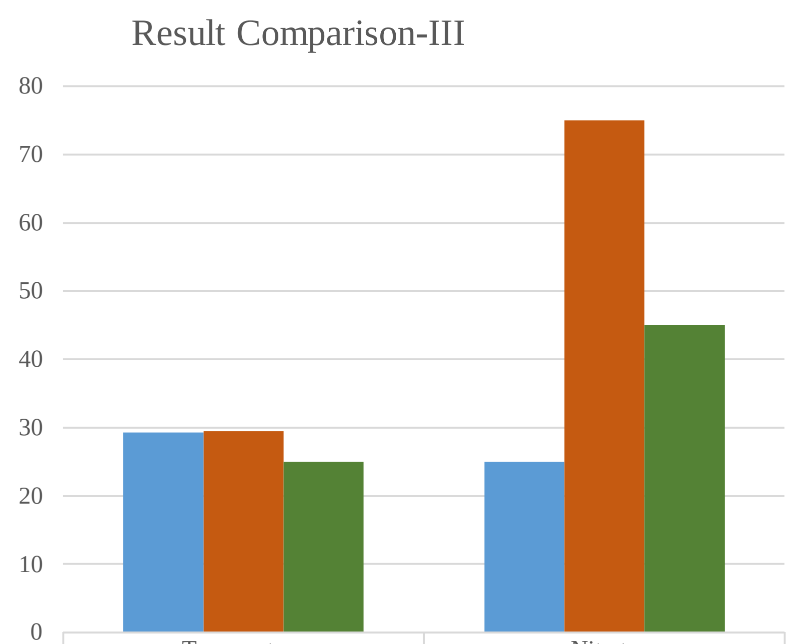
	TDS	Hardness	Chloride
Govardhan Lake	426	340	198.52
Satyam Tower	525	440	177.25
Standard Permissible Limit	500	200	250

Figure 1 Graph –I showing the comparison of samples



	pH	D.O.	Fluoride
Goverdhan Lake	8	10	1.5
Satyam Tower	7.5	4	2
Standard Permissible	7.5	5	1

Figure 2 Graph –II showing the comparison of samples



	Temperature	Nitrate
Goverdhan Lake	29.3	25
Satyam Tower	29.5	75
Standard Permissible	25	45

Figure 3 Graph –III showing the comparison of samples

VI. DESIGN OF TREATMENTS UNITS

The effectiveness of any water treatment plant depends significantly on the proper sequencing and design of its individual treatment units.

Water first enters the system through an intake structure, which is typically equipped with screens to prevent the entry of large debris. From there, it is pumped to the treatment plant, where it passes through various treatment stages.

The typical flow of water through a treatment plant is as follows:

- Screening: Removes large floating matter such as leaves, plastics, and other solid debris.
- Filtration: Eliminates finer suspended particles and reduces turbidity using sand or pressure filters.
- Softening: Helps reduce water hardness by removing calcium and magnesium ions.
- Disinfection: The final stage involves destroying pathogenic microorganisms. This is typically achieved by adding chlorine or other disinfectants in a disinfection tank, ensuring long-lasting protection against microbial contamination.

A. Intake Structure

For small-scale water treatment projects such as this one using lake water, a simple submerged intake is often suitable. It typically consists of a concrete support block to fix the intake pipe.

The intake pipe carries raw water to a jack well, from where it is lifted by pumps for further treatment.

In lakes where silt tends to accumulate at the bottom, the intake opening is usually positioned at a height of 2 to 2.5 meters above the lakebed.

Submerged intakes are generally cost-effective, do not obstruct navigation, and are ideal for sources like lakes where the water level remains relatively constant throughout the year.

Jack Well and Intake Pipe Design:

The jack well, located just below the intake pipe, acts as a settling chamber for silt and sediments. A depth of 2 to 3 meters is typically provided to allow accumulation without clogging the intake pipe.

The intake pipe connecting the source to the jack well is usually of the non-pressure type and is laid at a gentle **slope of 1 in 200** toward the jack well to maintain gravity flow.

To ensure smooth flow and minimize head losses. The flow velocity inside the pipe should not exceed 1.2 m/s. The diameter of the intake pipe should be not less than **45 cm**.

The jack well diameter is generally kept around **5 meters**, which provides adequate space for installation of suction pipes or strainers and also access for regular cleaning and maintenance

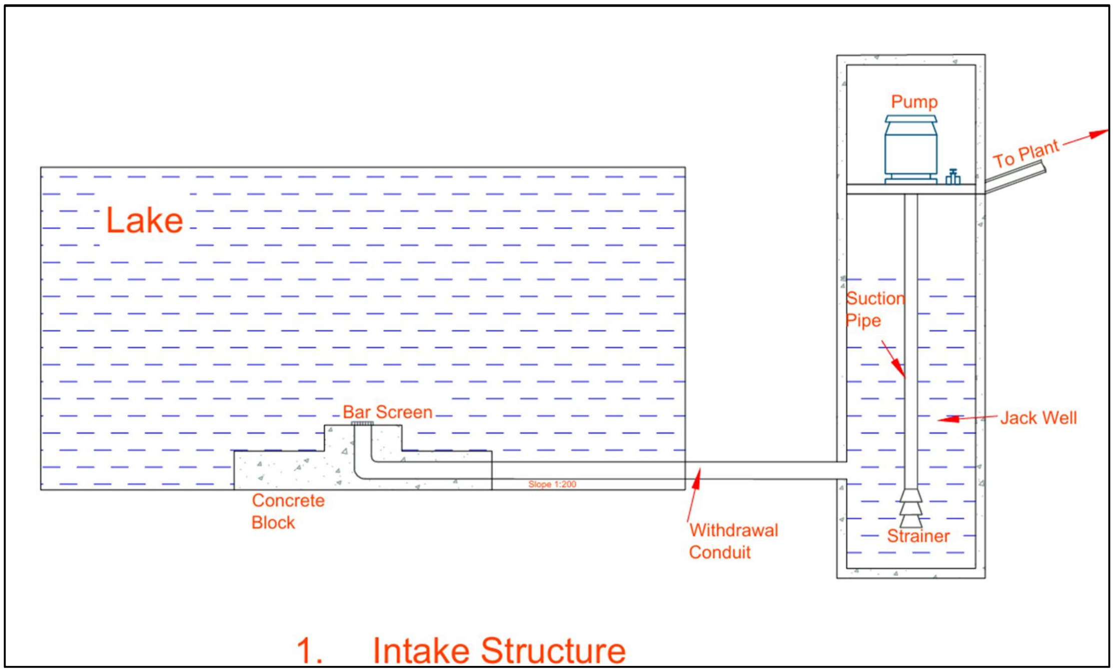


Figure 4 Diagram show the Intake Structure

B. Screening Process

These screens typically consist of parallel iron bars, placed at an **inclination of 50°**, which facilitates easier removal of collected debris. The bars are spaced approximately **3 cm apart**, which is effective in capturing large objects while allowing water to pass through. To prevent pressure build-up and ensure efficient screening, the velocity through the screen openings is kept between 0.8 to 1.0 m/s.

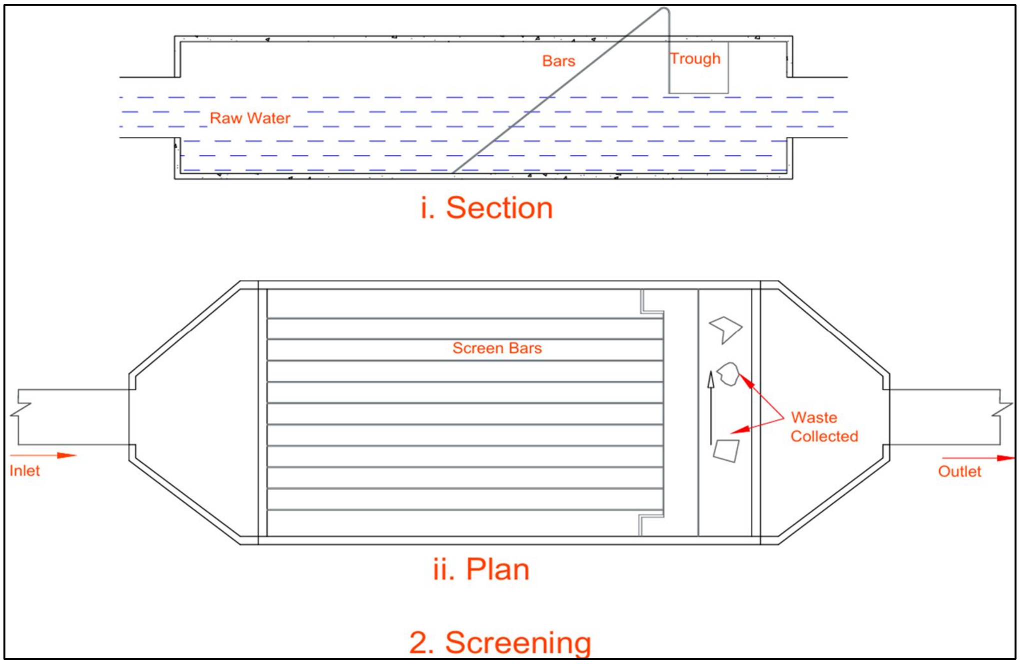


Figure 5 Drawing show the Screening Process

C. Pressure Filter

Pressure Filter is a type of rapid sand filter enclosed within a cylindrical pressure vessel. This system operates under pressure and eliminates the need for a separate sedimentation tank.

Raw water is pumped into a closed pressure vessel at pressures ranging from 300 to 700 kN/m². Coagulant (commonly Alum) is added to the incoming water through a dosing container connected to the inlet line. By which flocculation occurs inside the vessel itself. As water passes through the sand bed, impurities are removed and the clean water exits through the outlet valve.

For maintenance, backwashing is carried out using compressed air, with the inlet and outlet valves closed, and the wash water and drain valves open.

Design of Filter –

Taking maximum daily demand = 0.234 MLD

Rate of Filtration = 7,000 litres/hr/m^2.

Back Wash Time = 30 min.

So, Q = 4,68,668 litres/day

Filter operates = 8 hrs

Effective flow rate = 4,68,668/10 = 46866.8 litres/hr

Let 4% of maximum demand used for backwash.

Total design flow = 468668.8 x 1.04 = 48741.47 litres/hr

Now, Area = Total flow / rate of filtration

A = 48741.47/7000 = 6.96 m^2

As, the surface area of filtration tank is circular

So , $A = \pi r^2$

$6.96 / \pi = r^2$

r = 1.48 m

D = 2.97 ≈ 3 m

Taking Overall height of tank as 4 m.

Freeboard (extra space)	0.9 m
Raw Water Depth	1 m
Sand Layer	0.9 m
Gravel Layer	0.7 m
Underdrain / Concrete Base	0.5 m

Hence, dimension of tank is 3 m (diameter) x 4 m (height).

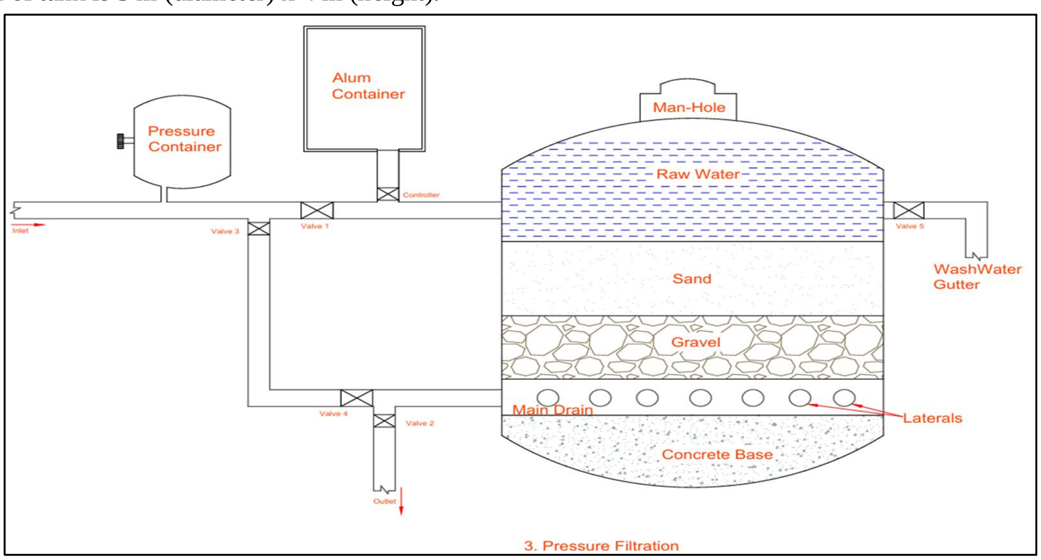


Figure 6 Drawing shows the Pressure Filtration of raw water

Alum Dose –
As we don't have values of alkalinity and turbidity, assuming medium turbidity water (10-50 NTU).
A mid-range of alum dose of 20 mg/l.
Alum dose (kg/day) = (20 x 0.468668)/1000 = 9.37 kg/day.
So, approximately 9.4 kg/day alum dose is required.

D. Softening Process

The Zeolite Process is used for softening the water. Zeolites are hydrated silicates of sodium and aluminium, which possess excellent ion-exchange properties. During the process, the sodium ions (Na^+) present in the zeolite are exchanged with the calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in hard water.
The saturated zeolite can be regenerated by treating it with a 10% sodium chloride (brine) solution, which replaces the Ca^{2+} and Mg^{2+} ions with Na^+ ions, making the zeolite active again for reuse.
Quantity of water to be treated = 4,68,668 liters/day
Quantity of water per hour = 19,527.83 liters
Hardness in raw water as $CaCO_3$ = 340 mg/l
Hardness to be obtained as $CaCO_3$ = 70 mg/l (<200 mg/l as per IS 10500:2012)
Let ion exchange capacity of zeolite = 10 kg of hardness per m^3 of zeolite
Salt required for regeneration = 50 kg/m^3 Zeolite
Let shift of 10 hrs. assumed,
Quantity of soft water required = 19,527.83 x 10= 1,95,278.3 liters
Now the hardness required to be removed is up to 70 mg/l out of a total hardness 340 mg/l,
= [(340-70)/340] x 100 = 79.42 %

Now only 79.42 % the raw water need to softened to zero-degree hardness, and for balance 20.58 % added as raw water to obtain 70 mg/l of hardness.
Quantity of water to be treated = 1,95,278.3 x 0.80 = 1,56,222.64 liters
Now the hardness to be removed = 1,56,222.64 x 340 = 53.12 kg
The amount of zeolite required = Hardness (in Kg) / ion exchange capacity
= 53.12 (kg)/ 10 (kg/m^3)
= 5.32 m^3.

Provide 3 unit of 1.8 m^3 each, with one unit as stand by. Units may have 1.20 m^2 plan area and 1.5 m depth and diameter of 1.23 m.
Zeolite beds will be regenerated by passing 10 % solution of sodium chloride through it.
Quantity of salt required for regeneration = 50 x 5.32 = 266 kg
Using 10 % brine solution, means that 10 kg salt will be dissolved in water to make up 100 kg of solution.
= (266 x 100) / 10
= 2,660 kg of water solution
= 2660 (kg) / 1000 (kg/m^3)
= 2.66 m^3.

Hence, tank of 2.7 m^3 capacity can be provided.
If 1.5 m is the diameter of tank,
Height = $2.66 / [(\pi \times (1.5)^2)/4]$
H = 1.53 m.
Using 0.15 m free board,
The overall tank size will be 1.5 m (diameter) x 1.68 m (height).

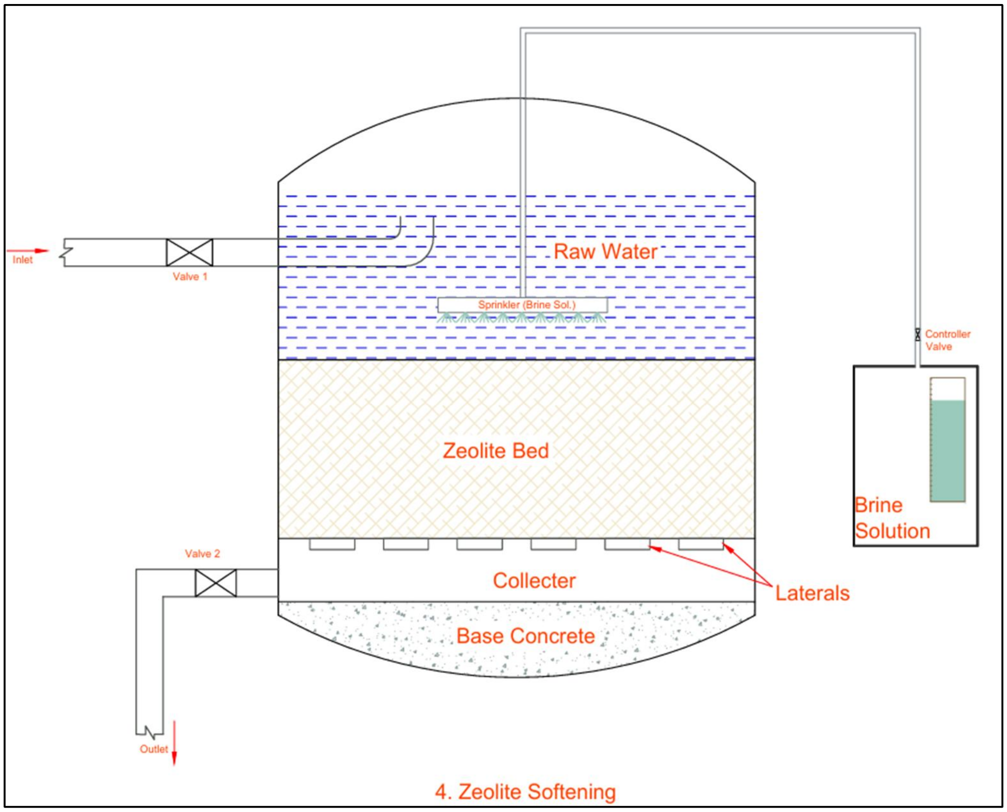


Figure 7 Drawing shows the Softening of water through Zeolite Process

E. Disinfection Tank

To make the water safe for human consumption, especially for drinking, it is essential to eliminate the harmful pathogens through a process called "Disinfection". Among various disinfection methods, chlorination is the most widely used and effective technique. Chlorine acts as a strong oxidizing agent and disinfectant, capable of destroying most bacteria, viruses, and other microorganisms. One of its key advantages is that it provides residual protection, preventing bacterial growth even during distribution.

However, care must be taken in dosing. Excessive chlorine may result in a bitter taste and user complaints due to the presence of free residual chlorine.

The residual chlorine in the water should be maintained at around 0.2 mg/L after a specified contact period, usually around 30 minutes.

Design of Disinfection:

To kill the harmful bacteria's, chlorine dose used.

For general disinfection,

Assume chlorine dose = 3 mg/l

Chlorine required = (Dose X Quantity) / 10^6

= 3 x 468668 / 10^6 = 1.4 kg/day.

Have to maintain 0.2-0.5 mg/l at outlet.

Volume of tank = Flow rate X contact time

= [234334/ (10^3 x 24 x 60)] x 30 = 9.76 m^3.

Let depth of tank be 2.5 m,

V= L x B x D

L x B = 9.76 / 3.5 = 2.78

Let, L = 2B

B = 1.17 ≈ 1.2 m

So, L = 2.4 m

Hence, the dimension of tank area 2.4 m (length) x 1.2 m (width) x 3.5 m (height).

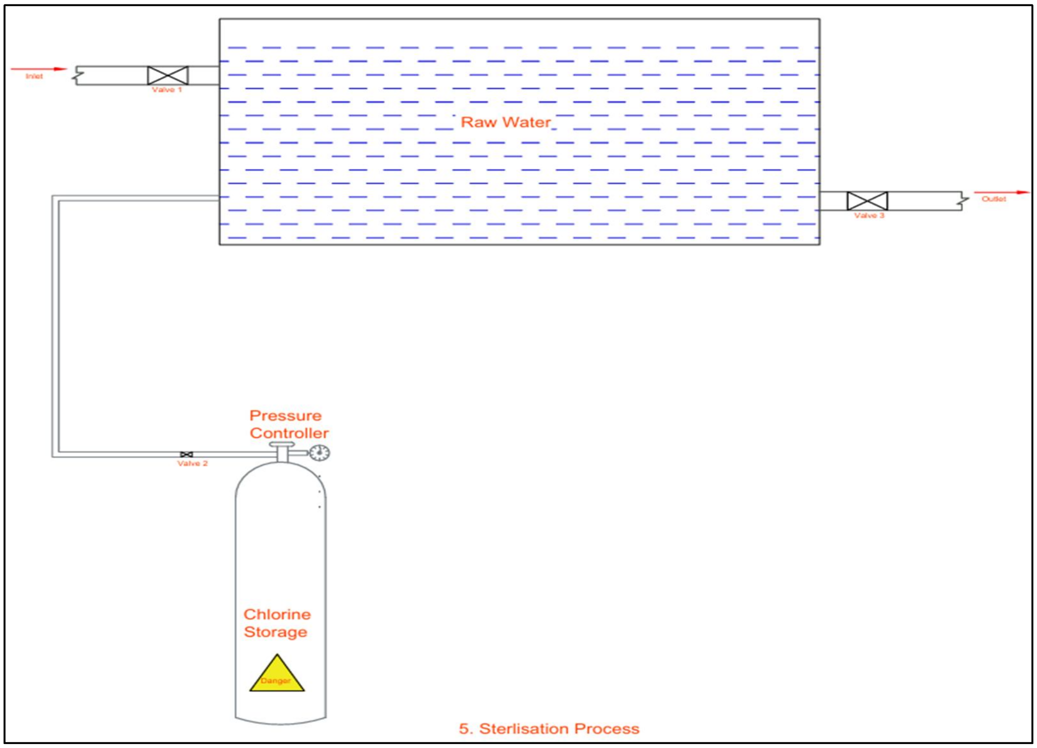


Figure 8 Drawing shows the Disinfection Process with Chlorine dose

F. Distribution System

After the treatment process of raw water, it is distributed to the users. The process of distributing the treated water to the consumer through the pipelines is known as "Distribution System".

In an overhead tank water distribution system, water is first collected in an underground reservoir, which is used to store the incoming supply form the treatment plant. A pumping method is used to pumped to an overhead tank located on the terrace of a building. From there, gravity helps distribute the water to various floors and fixtures within the building. This method ensures a consistent water supply with adequate pressure.

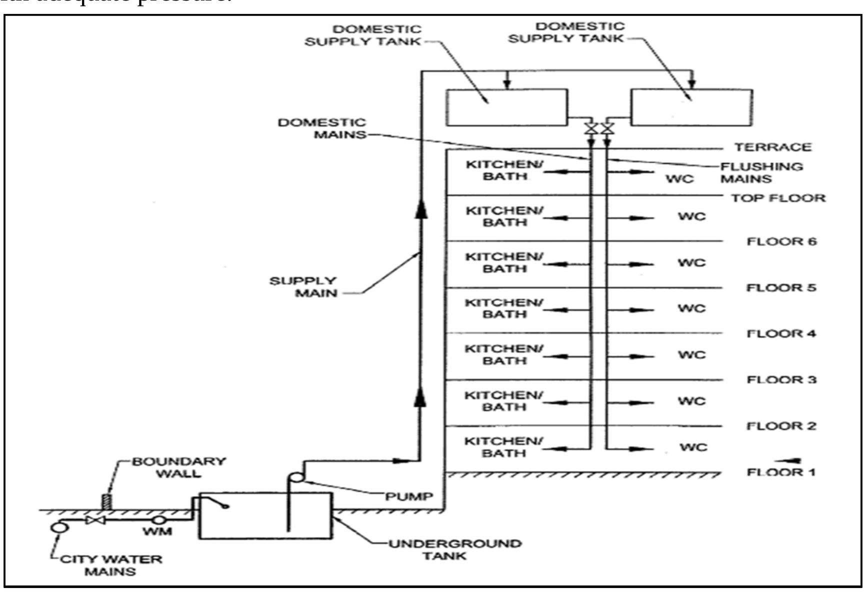


Figure 9 Figure showing the Distribution System
Image Credit: Water Supply Engineering Book, SISTU.

VII. SUSTAINABILITY FACTORS

The sustainable practices in the design and operation of water treatment plants is becoming crucial where water consumption and environmental impact are in considerations.

A. Sludge Management

The process of dewatering the sludge makes it easier to handle and transport, minimizing the potential for spills or leaks during these operations. This might include using the sludge as a soil amendment or in the production of other materials, depending on its composition and local regulations. If sludge is not managed properly, it can lead to the generation of unpleasant odours and pose a risk of environmental contamination to both soil and water resources.

B. Energy Efficiency

It is also important to note that water treatment processes in general require energy for pumping, heating, separation, as well as the operation of sensors and control systems. The application of Hydro solar technology would likely involve the utilization of solar photovoltaic (PV) panels to generate electricity needed for the WTP's operations.

C. ZLD System

Zero Liquid Discharge (ZLD) is an advanced and ambitious wastewater management strategy with the fundamental goal of eliminating any discharge of liquid waste into the environment. By treating and reusing water within a closed loop, a ZLD system dramatically reduces the apartment complex's dependence on external freshwater sources.

D. Scalability

Designing for scalability from the initial stages of a water treatment plant project is a proactive and forward-thinking approach that can yield significant long-term benefits by avoiding substantial costs and operational disruptions associated with major future upgrades.

VIII. SCOPE FOR FUTURE WORK

The practicality and efficiency of the designed water treatment system, several improvements and additional considerations can be taken up by future batches those who are interesting in this course study.

- Pipe and distributions system – The pipe sizing needs further refinement to align with practical implementation.
- Pump Selection and Design – Energy efficient pumps can be used to optimize power consumption.
- Sludge Management – As explain earlier, there are different methods for proper sludge management.
- Sewage Treatment – To reduce the dependency on lake water, implementation of Sewage Treatment Plant is recommended.

IX. CONCLUSION

The design of a water treatment plant for residential building is crucial for providing clean and safe potable water. This project systematically analysed the population, water demand and water parameters for treatment processes, including filtration, softening and disinfection, to produce water that meets standard parameters. The design decisions were taken keeping in mind for small-scale implementation. Moreover, this paper also explores on the topics related to sustainable practices which can carry in plant like use of renewable energy sources, sludge management, reusing of water, etc.

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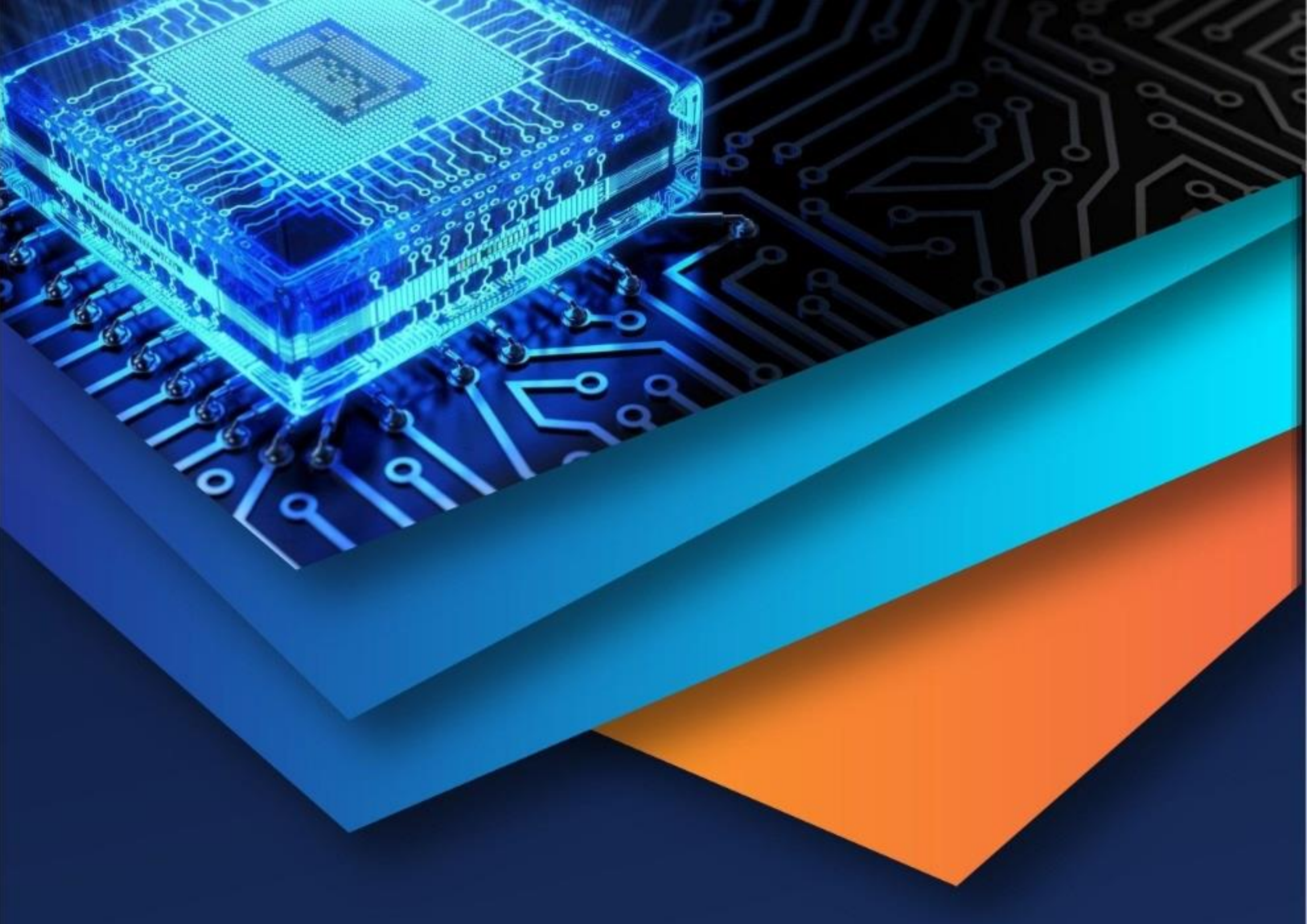

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