Design of Greywater and Blackwater treatment plant for a multistorey building in Ropar

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Abstract

Wastewater contains dissolved and suspended organic particles that are biologically decomposable or putrescible. Domestic and industrial wastewaters are two general groups of wastewaters that are not entirely distinct. Wastewater treatment partially removes and partially changes the solids in wastewater from highly complex, putrescible organic solids to mineral or reasonably stable organic solids through decomposition. The bulk of BOD and suspended particles in wastewaters are removed during primary and secondary treatment. However, this level of treatment is increasingly becoming insufficient to safeguard receiving waterways or offer reusable water for industrial and domestic recycling. As a result, additional treatment processes have been added to wastewater treatment plants to allow for the removal of more organic solids and nutrients and hazardous compounds. There have been several innovative breakthroughs in water treatment in the past few years. In combination with wastewater reduction and water recycling activities, advanced wastewater treatment technology offers hope for decreasing, if not halting, the loss of useful water. Wastewater recycling and reuse are ideal applications for membrane technologies. The fundamental advantage of membrane technology is that it operates without chemicals, uses relatively little energy, and has a well-organised and straightforward process flow. This paper covers a comprehensively designed approach to treating wastewater.

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List of Abbreviations

LECA = Lightweight expanded clay aggregate

COD = Chemical Oxygen Demand

TSS = Total suspended solids

BOD_5 = five-day biochemical oxygen demand

MBBR = moving bed biofilm reactor

CCT = Chlorine contact tank

UV = Ultraviolet

GI = Galvanised iron

SOTE = Standard oxygen transfer efficiency

AOTE = Actual oxygen transfer efficiency

BODo = Influent biochemical oxygen demand

BODe = effluent biochemical oxygen demand

CODo = Influent chemical oxygen demand

CODe = effluent chemical oxygen demand

MLSS = Mixed liquor suspended solids

MLVSS = mixed liquor volatile suspended solids

TSS = Total suspended solids

SAD = specific aeration demand

TKN = Total Kjeldahl Nitrogen

1. Introduction,

The generation of wastewater due to human activity is inevitable. A large portion of this waste will be disposed of as wastewater. Many factors influence the quantity and quality of sewage. Humans and industries produce different amounts of garbage. The volume and kind of trash generated in households are impacted by the residents' behaviour, lifestyle, the standard of living, and the technical and legal environment in which they live. The majority of trash generated in households will be solid and liquid waste, and there are huge opportunities to change the volumes and content of these two waste streams. Similar issues apply to the industry. However, the problem here isn't the generation but wastewater treatment.

The growth of urbanisation has resulted in an alarming decline in the quality of life in India's cities, causing a shortage of water supply and demanding water usage. Infrastructure flaws, poor sanitation, water shortages, and contaminated natural watercourses plague Indian cities. In this atmosphere, the cumulative impact of the distress is burdensome in terms of managing daily activities and chores. Almost all surface water sources are contaminated by bacteria belonging to the Coliform Group, rendering it unsafe for human consumption unless treated. According to the Department of Drinking Water's estimations, approximately 67 per cent [1] of the population does not have access to sanitary facilities.

2. Literature Survey

2.1 The constituents in wastewater can be divided into categories, as shown in Table 2[2].

Table 1: Wastewater types

Wastewater from society	Wastewater generated internally in treatment plants
Domestic wastewater	Thickener supernatant
Wastewater from institutions	Digester supernatant
Industrial wastewater	Reject water from sludge dewatering
Infiltration into sewers	Drainage water from sludge drying beds
Stormwater	Filter wash water
Leachate	Equipment cleaning water
Septic tank wastewater	

By origin and chemical composition, wastewater is divided into

- **Domestic wastewater** – It is generated from waters used in households – to maintain personal hygiene, flush sanitary facilities, prepare meals, etc. They are very cloudy, have a grey-yellow colouration, a characteristic smell and a slightly alkaline reaction. They contain 40% inorganic impurities and 60% organic in soluble form and suspensions. BoD_5 of these wastewaters ranges from **200 to 600 mg of oxygen/litre**, of which 1/3 is in the form of organic suspensions.

Table 2: Wastewater Constituents

Wastewater constituents		
Microorganisms	Pathogenic bacteria, virus and worms eggs	Risk when bathing and eating shellfish
Biodegradable organic materials	Oxygen depletion in rivers, lakes and fjords	Fish death, odours
Other organic materials	Detergents, pesticides, fat, oil and grease, colouring, solvents, phenols, cyanide	Toxic effect, aesthetic inconveniences, bio accumulation in the food chain
Nutrients	Nitrogen, phosphorus, ammonium	Eutrophication, oxygen depletion, toxic effect
Metals	Hg, Pb, Cd, Cr, Cu, Ni	Toxic effect, bioaccumulation
Other inorganic materials	Acids, for example hydrogen sulphide, bases	Corrosion, toxic effect
Thermal effects	Hot water	Changing living conditions for flora and fauna
Odour (and taste)	Hydrogen sulphide	Aesthetic inconveniences, toxic effect
Radioactivity		Toxic effect, accumulation

- **Industrial wastewater** – It usually contains a variety of chemical substances that are a by-product of industrial plant technological procedures. Coking plants, petrochemical facilities, tanneries, pulp mills, dairies, and sugar industries have wastewater problems. Natural receivers are at risk from untreated wastewater because they do not contain harmful bacteria; they do not constitute a sanitary or epidemiological threat.

- **Agricultural wastewater** – formed from water flowing from fields and farms – usually contains artificial fertilisers, pesticides and microbial pollution. Particularly dangerous is slurry, which can have thousands of times more organic and inorganic pollutants than domestic and household wastewater.

Fig 1: Agricultural wastewater

- **Rainwater** – is sewage arising from atmospheric precipitation, washing away built-up areas. They contain large amounts of organic and inorganic impurities, many in the form of suspensions; similarly to some social and household sewage, they can be treated as greywater and recovered for the aforementioned needs.

- **Municipal wastewater** – sewage is located in municipal sewage regardless of the source of origin (domestic, industrial, precipitation, meltwater or a mixture of this sewage). The definition of urban wastewater is aimed at distinguishing the responsibility of the owner of the sewage system (local government) for their disposal and the consequences of the failure. [3]

2.2 Wastewater comes in three main types:

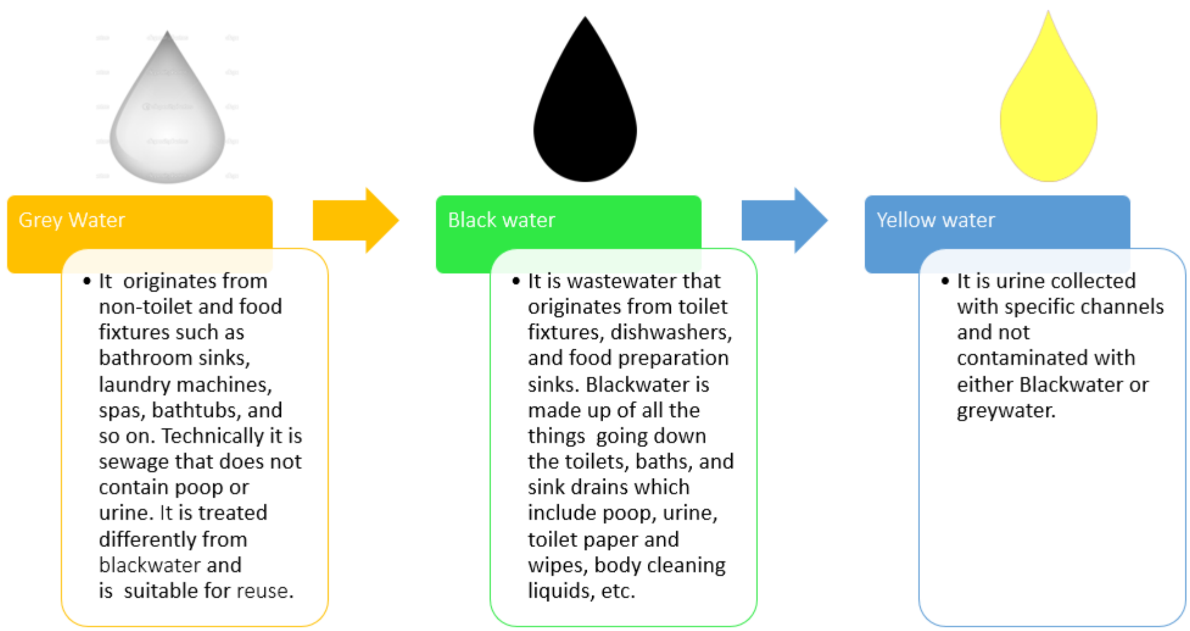


Fig 2: Types of Wastewater

2.3 BOD &COD

In wastewater, organic matter is the most common pollutant. BOD and COD have traditionally been used to measure organic materials. Due to the necessity for dilution series, BOD is slow and inconvenient. The majority of the organic matter in the sample is measured through chemical oxidation by dichromate in the COD analysis. For mass balances in wastewater treatment, COD values are required. The COD content can be separated into fractions that can be considered when designing treatment methods.

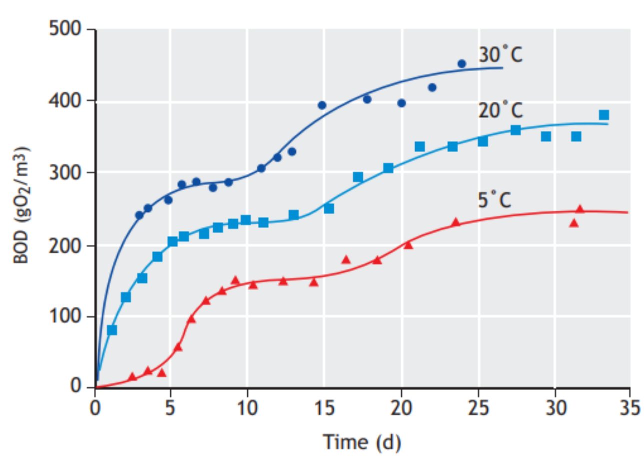


Fig 3: Dependency of time and temperature for the BOD analysis.

2.4 Rainwater Harvesting:

Rainwater harvesting systems capture, redirect, store, and release rainwater to be used later. Rainwater falling on impervious surfaces is collected and transferred into an above or below-ground storage tank (also known as a cistern or rain tank), where it can be utilised for non-potable water and on-site stormwater disposal/infiltration.

Landscape irrigation, external cleaning (e.g. car washes, building facades, sidewalks, street sweepers, fire trucks, and so on), flushing of toilets and urinals, fire suppression (sprinkler) systems, and so on are examples of non-potable usage.

Rainwater harvesting can be classified into two broad categories: surface runoff harvesting and rooftop rainwater collection.

1. **Surface Runoff Harvesting**

   Surface runoff rainwater harvesting collects rainwater flowing down the ground during rainstorms and stores it in a tank beneath the ground surface for irrigation and other uses. It is critical to employ efficient and effective water conservation strategies, such as limiting evaporation, while storing rainwater. It is a simple-to-learn technology that may be pretty profitable if applied correctly. The primary goal of surface runoff rainwater harvesting is to meet the ever-increasing demand for water while reducing pollution, soil erosion, and road flooding.

2. **Rooftop Rainwater Harvesting**

   Rooftop Rain Water Harvesting is a method of collecting rainwater from roof catchments and storing it in reservoirs. Rainwater can be collected and stored in sub-surface groundwater reservoirs using artificial recharge techniques to suit residential demands in tanks.
   The primary goal of rooftop rainwater collection is to save water for later use. Capturing and storing rainwater is crucial in dryland, hilly, urban, and coastal environments. In this report, our primary focus will be on **Rooftop Rainwater Harvesting.**

Components of Rooftop Rainwater Harvesting [4]

1. **Catchment,**
   The catchment of a rainwater collecting system, is the surface that collects rainfall directly. It could be a terrace, a courtyard, or open ground, paved or unpaved. A flat RCC/stone roof or a sloping roof might be used for the terrace. As a result, the catchment is defined as the area that contributes rainwater to the rainwater harvesting system.

2. **Transportation**
   Rainwater from the roof should be brought down to the storage/harvesting system via water pipes or drains. UV-resistant water pipes (ISI HDPE/PVC pipes) with the requisite capacity should be used.

The wire mesh should be installed at the mouth of each drain on terraces to prevent floating material.

3. **First Flush**

The first flush is a mechanism that removes the water from the first shower. To avoid contaminating storable/rechargeable water with impurities from the atmosphere and the catchment roof.

During dry seasons, it will also aid in the removal of silt and other debris from the roof. At the exit of each drainpipe, initial rain separators should be installed.

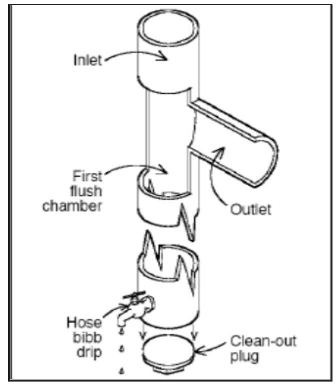
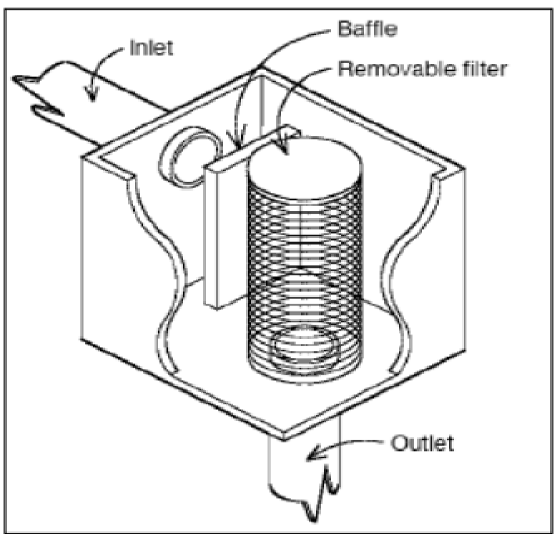


Fig 4: First Flush

4. **Roof Washer**



Roof washers filter tiny material from rainwater collected from roof surfaces and are situated just before storage tanks. Roof washers have a tank with leaf strainers and a filter with apertures as fine as 30 microns, usually between 25 and 50 gallons in size.

The filter works to filter out very minute particles from rainwater collected. Roof washers need to be cleaned regularly.

Fig 5: Roof Washer

2.5 Blackwater and Greywater treatment with Membrane Bioreactor:

A membrane bioreactor (MBR) is a wastewater treatment system that combines a membrane process such as ultrafiltration with a biological wastewater treatment process.[5]

The Membrane Bioreactor works in the same way as a traditional activated sludge process but without the secondary clarifying and tertiary treatment that sand filtering requires.

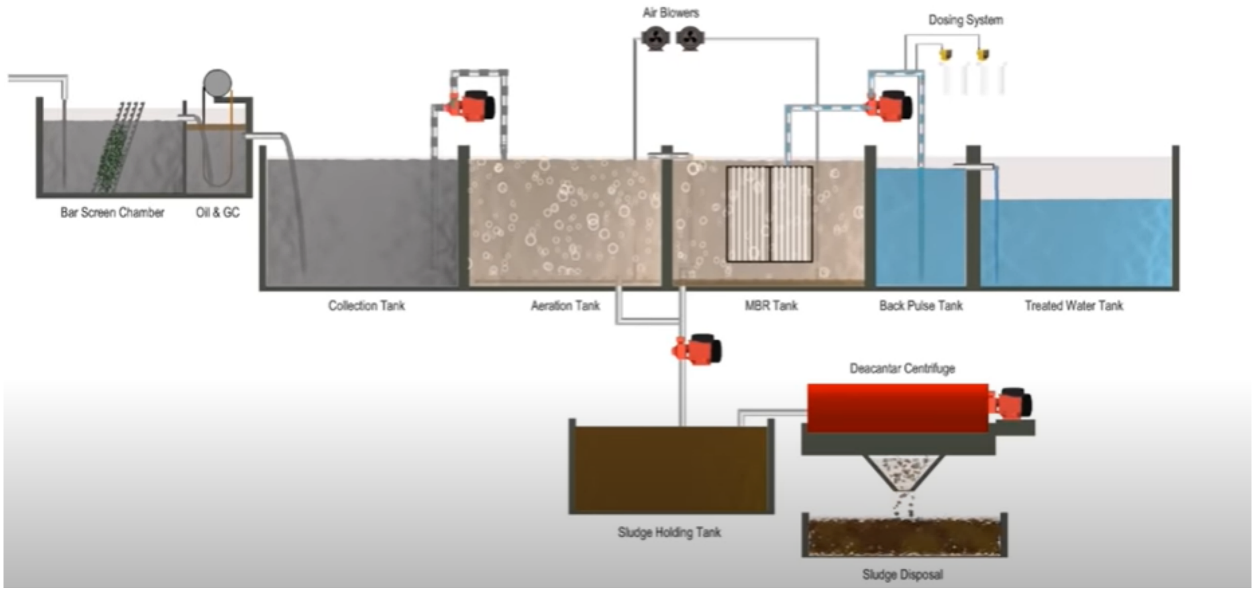


Fig 6: Membrane bioreactor technology

- Membrane bioreactors combine physical membrane barriers with biological treatment to replace clarifiers and media filters while reducing reactor size.
- Aeration brings water and air into close contact to remove dissolved gases and oxidise dissolved metals such as iron, hydrogen sulphide, & volatile organic compound (VOC's).
- MBR can also be used to expand the capacity and treatment efficiency of a wastewater treatment plant with limited land use in densely populated areas, as well as to build underground wastewater treatment facilities.

2.6 Solar Tracker

Even when put at an optimal angle, a solar panel mounted on a building's roof may only absorb 30 to 40% of all falling radiation. The angle at which your solar panels are set impacts the amount of solar electricity you generate. By altering the position of solar panels, production can be significantly boosted. The solar panel must be angled at 90 degrees to the falling sunlight for optimal production.

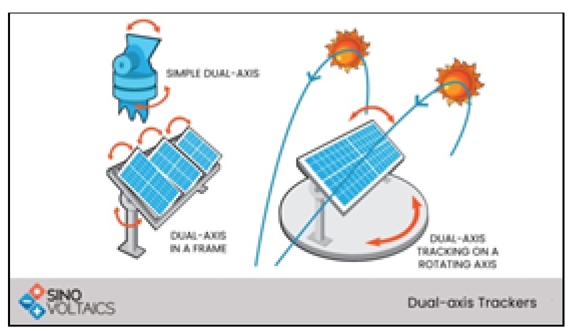


Fig 7: Double axis tracker

A ground-mount system with axis-tracking solar panels is the only way to easily reposition solar panels.[6]

We will install a dual-axis solar tracker to overcome this problem and enhance production. Dual-axis trackers feature two degrees of freedom that serve as rotational axes. In general, these axes are parallel to one another. Dual-axis trackers are used in a variety of situations. Tip-tilt dual-axis trackers (TTDAT) and azimuth-altitude dual-axis trackers are two typical applications (AADAT).

Methodology

Our goal is to optimise the amount of sunshine that reaches the solar panels throughout the day, as standard solar panels only face one direction and receive the most sunlight at certain times. We'll need three essential components to turn a regular solar panel into a sunlight tracker that will orient itself according to the sun's position:-

1. We need a resistor that responds to the intensity of sunlight, so we conducted significant research and discovered that the LDR (Light Dependent Resistor or Photoresistor) could be used in the sunlight detection procedure.

2. In conjunction with the LDR indicated above, we must utilise a motor to aid the orientation of solar panels to receive maximum sunlight. We chose Servo Motors because they may move in any direction and do not have standard clockwise and anticlockwise movements.

3. Finally, we need an Arduino to connect the LDR to a servo motor so that the servo motor moves in response to the LDR's input.

A breakdown of how we will be using the Components mentioned above in our project model is as follows:

- The primary light sensors will be LDRs. The structure that holds the solar panel is equipped with two servo motors.

- The amount of sunlight falling on LDRs is detected. There are four LDRs: top, bottom, left, and right.

- The analogue readings from two top LDRs and two bottom LDRs are compared for east-west tracking, and the vertical servo will move in that direction if the top set of LDRs receives more light. The servo travels in that direction if the bottom LDRs receive more light.

- The analogue results from two left LDRs and two right LDRs are compared for angular deflection of the solar panel. The horizontal servo will begin to move in that direction when the left end of LDRs receives more light than the right set. The servo travels in the direction where the right set of LDRs gets more light.

On Compiling the above-mentioned details in conjunction with the Arduino, the Circuit Diagram proposed by us is as follows:

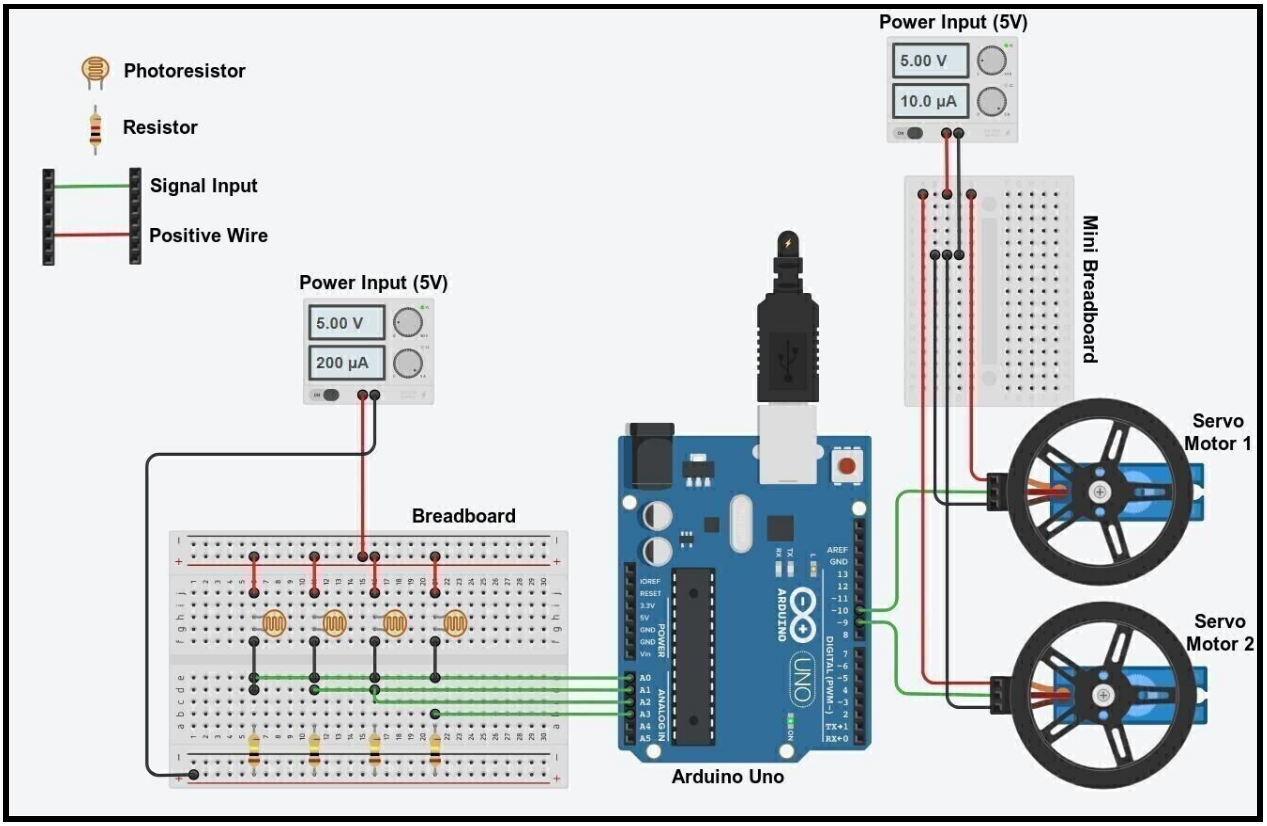
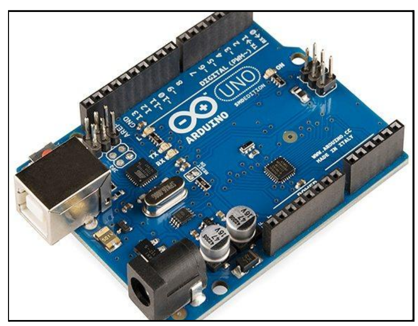


Fig 8: Circuit Diagram

2.7 Organization of work elements

Major Components are-

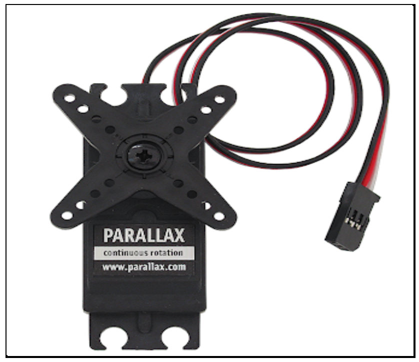
1. Arduino Uno



The Arduino Uno is a microcontroller board with I/O pins that is open-source. The Arduino Uno can be programmed to carry out certain tasks. In our scenario, Arduino is utilised to collect data from photoresistors and send it to servo motors.[7]

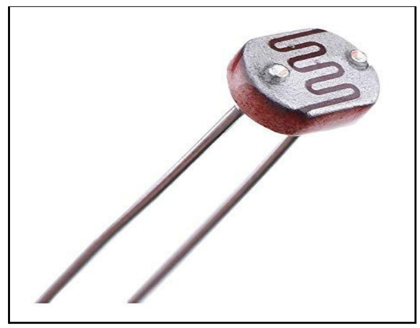
2. Servo motors

A servo motor is also known as a rotary/linear actuator. It permits continuous exact control of rotational/linear motion. To set a precise angle, they are usually operated with a control signal. Here, photoresistors will be used to set the angle of servo motors in the direction of sunlight.[8]



3. Photoresistors / LDR (Light-Dependent Resistors)

Photoresistors are resistors that decrease resistance in response to the amount of light caught on the sensitive surface of the component. Photoresistors will be used to detect the location of the sun based on the intensity of sunlight and send signals to servo motors to rotate accordingly.[9]



4. Solar Panels

Photovoltaic modules (also known as solar panels) are a collection of photovoltaic cells arranged on a framework. It turns sunlight into electricity and uses it as a renewable energy source. We'll put solar panels on the servo motors and position them so that they always face the sun.[10]

Fig: 9-12 Depicting Arduino Uno Servo motors, Photoresistors, Solar Panel respectively

2.8 Code for Solar Tracker:

```
#include <Servo.h>
//Assigning Servos
Servo servohori;    //Horizontal Servo
int servoh = 0;     //Input of Horizontal Servo

Servo servoverti;   //Vertical Servo
int servov = 0;     //Input of Vertical Servo

int servoLimitHigh = 160;   //Limiting rotation from 20 to 160 degrees because of Servo Motor Limit
int servoLimitLow = 20;     //Some servo motors limit to 170 degrees

//Assigning LDRs
int ldrtl = 2;  //top left LDR
int ldrtr = 1;  //top right LDR
int ldrbl = 3;  // bottom left LDR
int ldrbr = 0;  // bottom right LDR
//0,1,2,3 are port numbers A0, A1, A2, A3
//we can connect in any order but then we will have to change port numbers here

 void setup ()
 {
  servohori.attach(10); //attaching to port 10
  servohori.write(0);   //initial write 0
  servoverti.attach(9); //attaching to port 9
  servoverti.write(0);  //initial write 0
  delay(500);
 }

```

<u>Fig 13: Loop() initialisation (of variables)</u>

```

void loop()
{
  servoh = servohori.read();    //reading horizontal servo value
  servov = servoverti.read();   //reading vertical servo value

  //reading values of each LDR
  int topl = analogRead(ldrtl);
  int topr = analogRead(ldrtr);
  int botl = analogRead(ldrbl);
  int botr = analogRead(ldrbr);
  // calculating average
  int avgt = (topl + topr) / 2; //average of top LDRs
  int avgb = (botl + botr) / 2; //average of bottom LDRs
  int avgl = (topl + botl) / 2; //average of left LDRs
  int avgr = (topr + botr) / 2; //average of right LDRs

```

<u>Fig14: Vertical Movement</u>

```
//VERTICAL MOVEMENT
if (avgt < avgb)  //if avgOfTop < avgOfBottom
{
  servoverti.write(servov +1);    //increasing degree of servo (+1=anticlockwise -1=clockwise)
  if (servov > servoLimitHigh)    //checking if rotation is greater than max limit
   {
   servov = servoLimitHigh;       //limiting degree of rotation to max limit
   }
  delay(10);
}
else if (avgb < avgt) //if avgOfTop > avgOfBottom
{
  servoverti.write(servov -1);    //decreasing degree of servo (+1=anticlockwise -1=clockwise)
  if (servov < servoLimitLow)     //checking if rotation is less than min limit
{
  servov = servoLimitLow;         //limiting degree of rotation to min limit
}
  delay(10);
}
else
{
  servoverti.write(servov);   //means avgOfTop=avgOfBottom, no rotation
}

```

<u>Fig 15: Horizontal Movement</u>

```

  //HORIZONTAL MOVEMENT
  if (avgl > avgr) //exactly same as Vertical Movement
  {
    servohori.write(servoh +1);
    if (servoh > servoLimitHigh)
    {
    servoh = servoLimitHigh;
    }
    delay(10);
  }
  else if (avgr > avgl)
  {
    servohori.write(servoh -1);
    if (servoh < servoLimitLow)
     {
     servoh = servoLimitLow;
     }
    delay(10);
  }
  else
  {
    servohori.write(servoh);
  }
  delay(50);
}
```

<u>Fig16: Integrating movement commands</u>

3. Problem Statement

There is a shortage of sanitary infrastructure in India's cities, and the wastewater generated is not appropriately controlled. The water quality of aquatic resources has degraded due to insufficient sewage treatment systems. Deterioration of water quality causes health issues for the general people. Suppose wastewater created in metropolitan areas is not cleaned thoroughly. In that case, the fast-expanding population and resulting wastewater generation may render all permanent aquatic resources unfit for their intended purposes in the future.

Our very own campus goes hand in hand with the problem. The current treatment plant was built 8 years ago to cater to the need of 1000 people, and since then, it has undergone hardly any up-gradation. Below are some of the pics of the treatment facility, which gives the feeling of unpropitious treatment of water.

Fig17: Substandard conditions of Wastewater treatment facility of IIT Ropar.

Moreover, the plant gets off the track several times due to clogging of waste materials and outdated machinery. So to address this problem our team has designed a fully self-sustainable treatment plant that runs completely on solar energy by integrating various advancements made in the field of wastewater treatment.

4. Results and Discussion

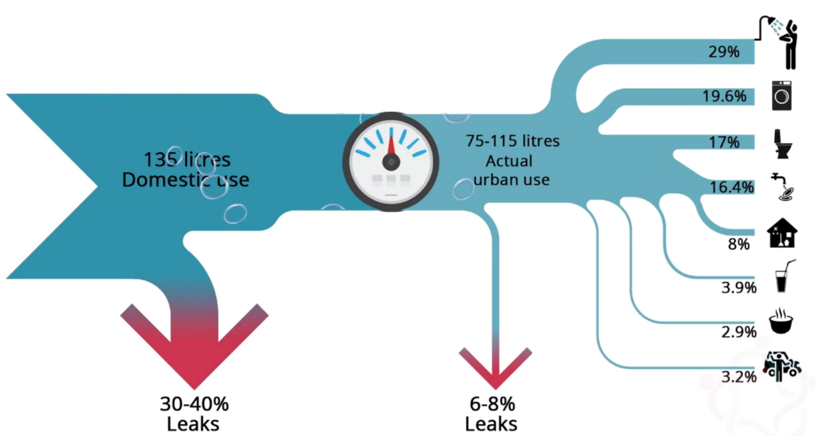
4.1 Estimation of annual generation of grey and blackwater.

Prudent use of onsite water resources and available site area.

1. **Total occupancy:** 800
2. **Peak occupancy at a time -** 500
3. **BUILT-UP AREA:** 2600 sq. metre
4. **BUILT-UP AREA:** 2483.9 sq.metre
5. **ROOF AREA:** 800 sq. metre
6. **IRRIGATION AREA:** 538 sq. metre

Fig18: Design of Building

As per the Ministry of Housing and Urban Affairs the Per capita per day water use in a residential building for the base case is **135L**[11].



Occupant's Activity	Percent usage
Bathing	29.0%
Washing	19.6%
Drinking	4%
Cooking	3%
Toilet	17.0%
Cleaning house	8.0%
Washing Utensils	16.4%
Others	3.20%

Fig19: Water consumption breakdown of various daily life activities [12]

Table3: Annual rainfall of Rupnagar (in mm)[13]

Month	Days in month	Rainfall (mm)	Effective rain (mm)
July	31	460	455
August	31	519	514
September	30	214	209
October	31	15	10
November	30	11	6
December	31	20	15
January	31	48	43
February	28	68	63
March	31	61	56
April	30	50	45
May	31	69	64
June	30	126	121

We assume that 500 people will use the facility daily, and 36% of the total use can be taken care of by non-potable water. The irrigation area is 583m^2 and the water requirement is 1L/m^2 which too can be taken care of by non-potable water. The efficiency of the greywater treatment system is 75% and that of the blackwater treatment system is 40% (underestimated assumption due to high impurity levels). The roof and hardscape areas have a runoff coefficient of **0.85**, and their areas are **952m^2** and **2483.9m**^{2} respectively. Using these, monthly water cycle calculations for the entire year are shown below.

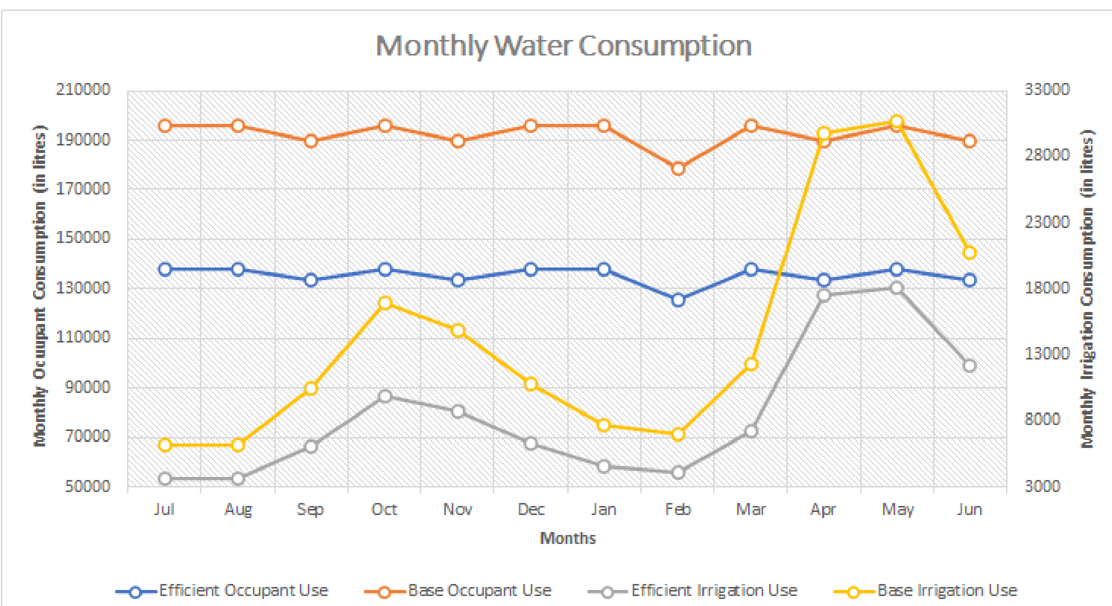


Fig20: Monthly Water Consumption

Using calculation data for both cases, we see that by using low flow fixtures and efficient irrigation practices, occupant use and irrigation use reduced from 2,31,1347.6563 litres annually to 1626503.9063 annually (reduction of 29.63%) and 1,73,454.8888 litres annually to 1,02,032.2875 litres annually (reduction of 41.18%) respectively.

- **Annual Consumption**- 17,28,536.2 L
- **Annual Rooftop Rainwater Harvesting**- 5,75,503.0 L
- **Annual Hardscape Rainwater harvesting**- 15,01,567.2 L
- **Underground Tank Capacity (with partitions)**- 9,589 L (rooftop rainwater) + 25,019.1 L (hardscape rainwater) + 4275 L (municipal water)
- **Overhead Tank Capacity (with partitions)**- 9,589 L (rooftop rainwater) + 27,523.9 L (recycled greywater + hardscape rainwater) + 4275 L (municipal water)

- **Blackwater = 5,53,011 Litres**
- **Greywater = 7,80,321.875 Litres**

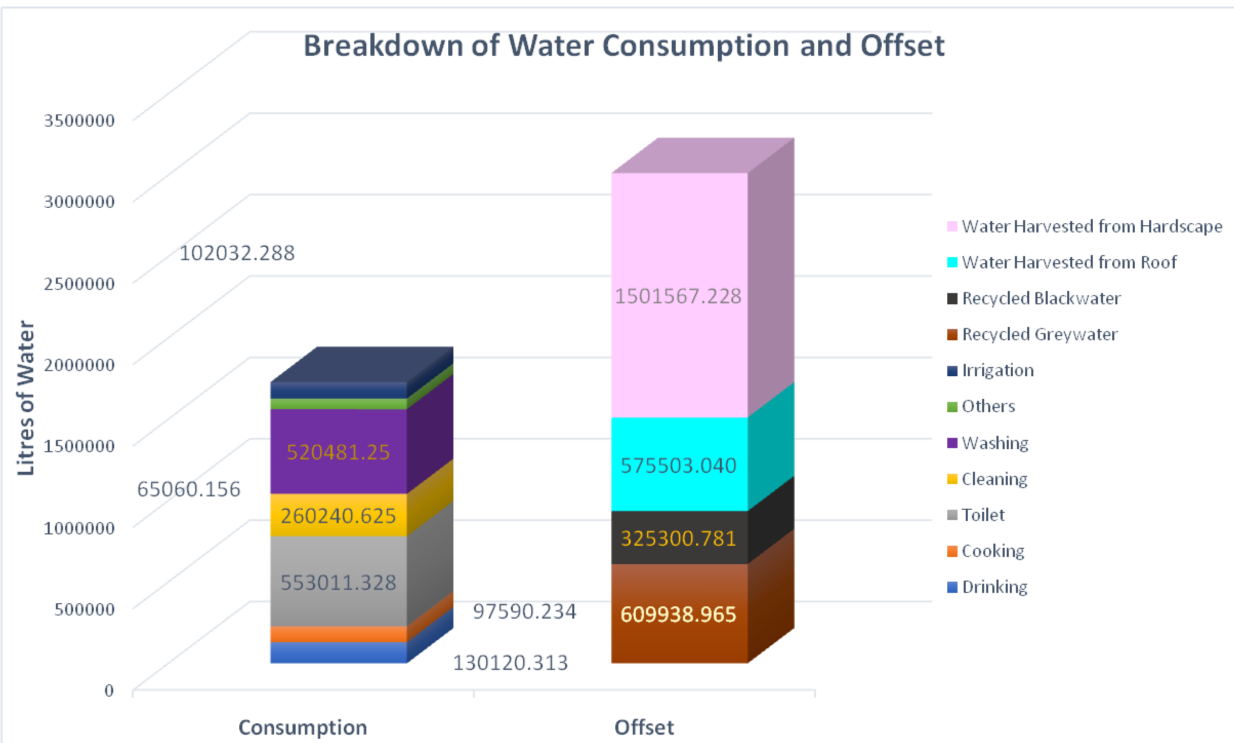


Fig 21: Breakdown of Water Consumption and offset

4.2 Rainwater Storage & Filtration:

Now to store and transport the rainwater, we need to have a proper design and water filters of required efficiency. So let's have a look at the filters that are used for the treatment of water to effectively remove turbidity, colour, and microorganisms. After the first flushing of rainfall, water should pass through filters.

Types of Filter to be used: -

- **Sand Gravel Filter**
  Coarse sand which is of the range **1.5 to 2 mm** in size, is preferred at the top, followed by gravel, **5 to 10 mm** in size, and boulders, **5 to 20 cm** in size, at the bottom. Each layer should have a thickness of roughly **0.5 m**. The coarse sand/pea gravel should be placed on top of the coarse sand/pea gravel so that the silt content from runoff is deposited on top of the coarse sand/pea gravel and can be readily removed. The pit can be filled with overburned broken bricks/cobbles for smaller roof sections[14].

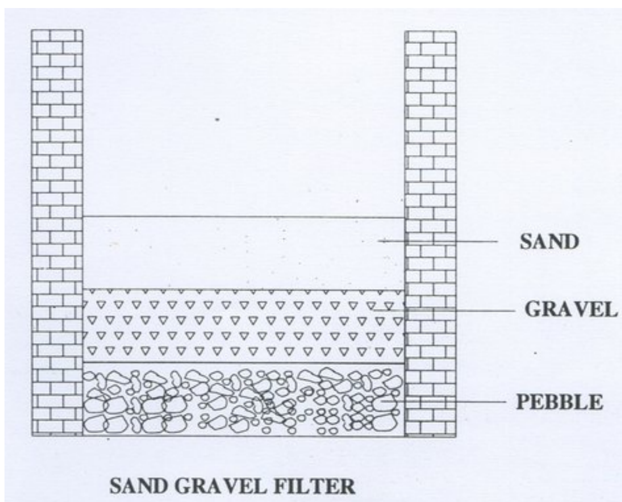


Fig 22: Representation of Sand and Gravel filter

- **Charcoal Filter**
  In situ or in a drum, charcoal filters can be manufactured. The drum or chamber should be filled with pebbles, gravel, sand, and charcoal. The wire mesh should be used to separate each layer. If there is any scent, a thin layer of charcoal is utilized to absorb it.

- **1 micron and 20-micron filters**
  Particulate filters allow for considerably finer filtration. These days, such filters are usually in the form of a sealed housing with a cartridge or bag that catches every minute particle to offer even clearer water. Although some of the coarser grades can be washed and reused, most of these require the cartridge or bag to be changed occasionally when they begin to clog. More advanced versions have a stainless steel element with a

‘backwash’ function – to enable easy cleaning; this can either be done manually or automatically using a timer control. These are extremely effective and reduce maintenance, but are expensive items so are generally only used on larger systems[15].

Fig 23: 1 and 20-micron filters

- **Disinfectant**
  After microfiltration, the water is disinfection near its point of use, making it potable. Disinfectants to be used are

  Chlorine:
  The technique of adding chlorine to drinking water to kill parasites, germs, and viruses is known as chlorination. To achieve safe chlorine levels in drinking water, a variety of techniques can be used. Using or drinking water with tiny amounts of chlorine has no negative health effects and protects against epidemics of waterborne diseases.

  Chloramine:
  Chloramination is the technique of disinfecting and killing bacteria in drinking water by adding chloramine. It is occasionally used as a substitute for chlorination. Chloramines are a group of chlorine and ammonia-based chemical compounds. Monochloramine, a kind of chloramine used in drinking water disinfection, is added into the water at levels that kill bacteria while remaining safe to consume.

Preventing Overflow:
In order to handle a single storm event or numerous storms in a row that surpass the tank's capacity, an overflow mechanism must be included in the Rainwater Harvesting system design. Overflow pipes should possess a capacity equal to or more than the inflow pipe(s), as well as a diameter and slope large enough to empty the cistern while retaining a proper freeboard height. Mechanisms like balloon systems and valves can be employed to avoid overflow[16].

Proposed Design for Rooftop Rainwater Harvesting system:

This is the rooftop rainwater harvesting system. The rainwater falling on the roof flows down through a pipe and undergoes some primary filtration on its way to the tank.
The water is allowed to settle in the tank and then pumped to an overhead tank from which it is drawn for use. It undergoes further treatment like microfiltration and disinfection near its point of

use, making it potable.
Overflow mechanisms like balloon systems and valves and a first flush diverter have also been provided.

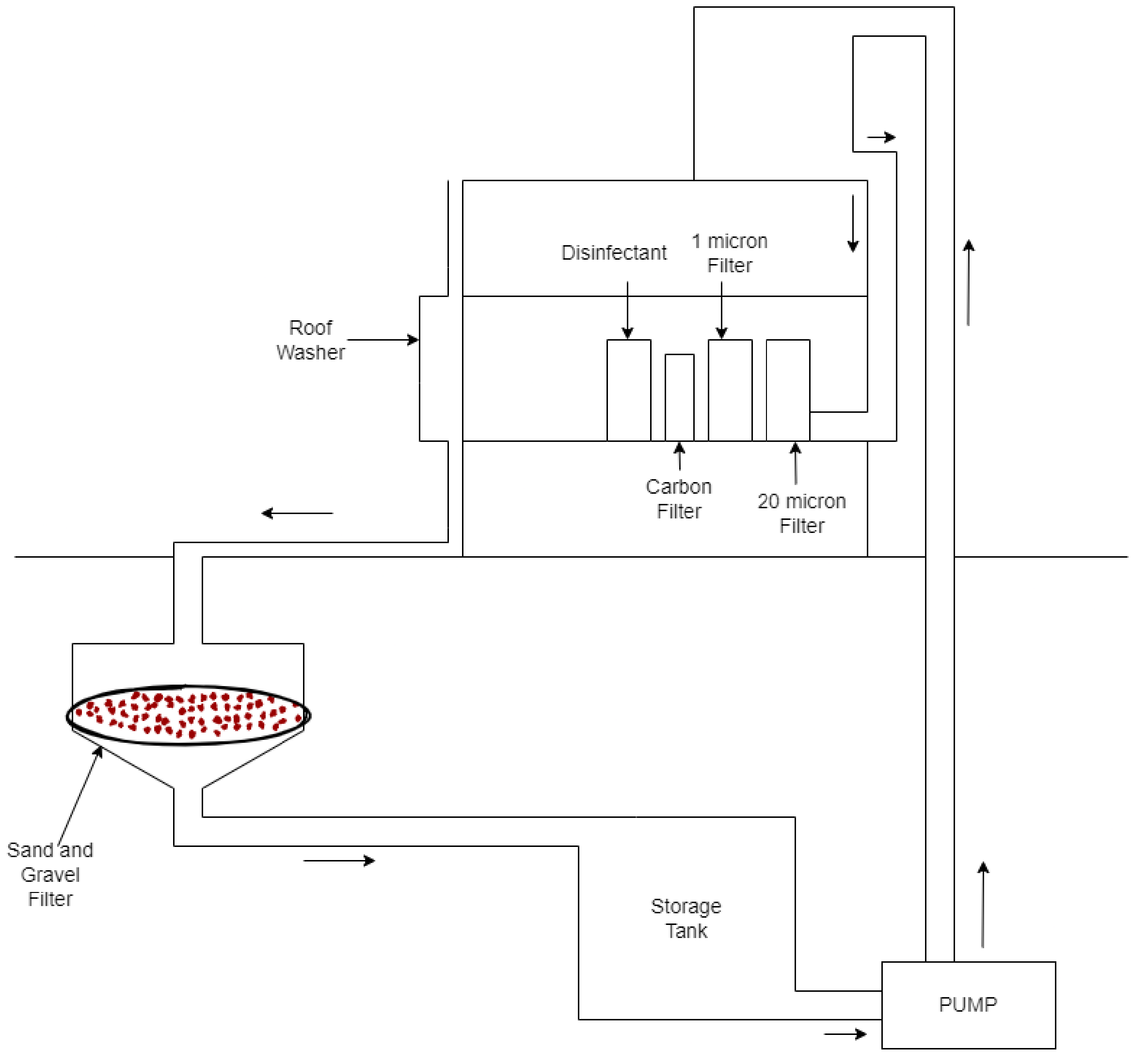


Fig 24: Proposed Design for Rooftop Rainwater Harvesting

4.3 Greywater treatment

Greywater emerges from plumbing systems other than toilets, such as hand basins, washing machines, showers, and bathtubs. Greywater can be safely reused in the garden if managed appropriately. The adaptation of popular green walls (also known as living walls, green façades Green walls can be designed in a variety of ways (e.g., vegetated mat walls, vertical gardens with horizontal pots, etc.), but only modular, container-based designs will be used for greywater treatment due to their lightweight nature and a large amount of growing media volume available for pollutant removal.
A vertical support framework holds specially constructed boxes containing lightweight filter media (a mix of coco coir and perlite) and plants in these green walls. This makes container-based green walls ideal for greywater treatment because all pollution is confined within the pots, and the risk of cross-contamination is significantly reduced compared to vegetated mat wall systems (which only use a water-saturated layer of felt for water distribution). Greywater would be injected directly into the green wall system (at various levels), where it would be treated by a variety of mediums and plants as it flowed down by gravity, with effluent collected at the bottom for reuse functions like toilet flushing and irrigation..[17] We will consider this method to treat greywater in a compact space.

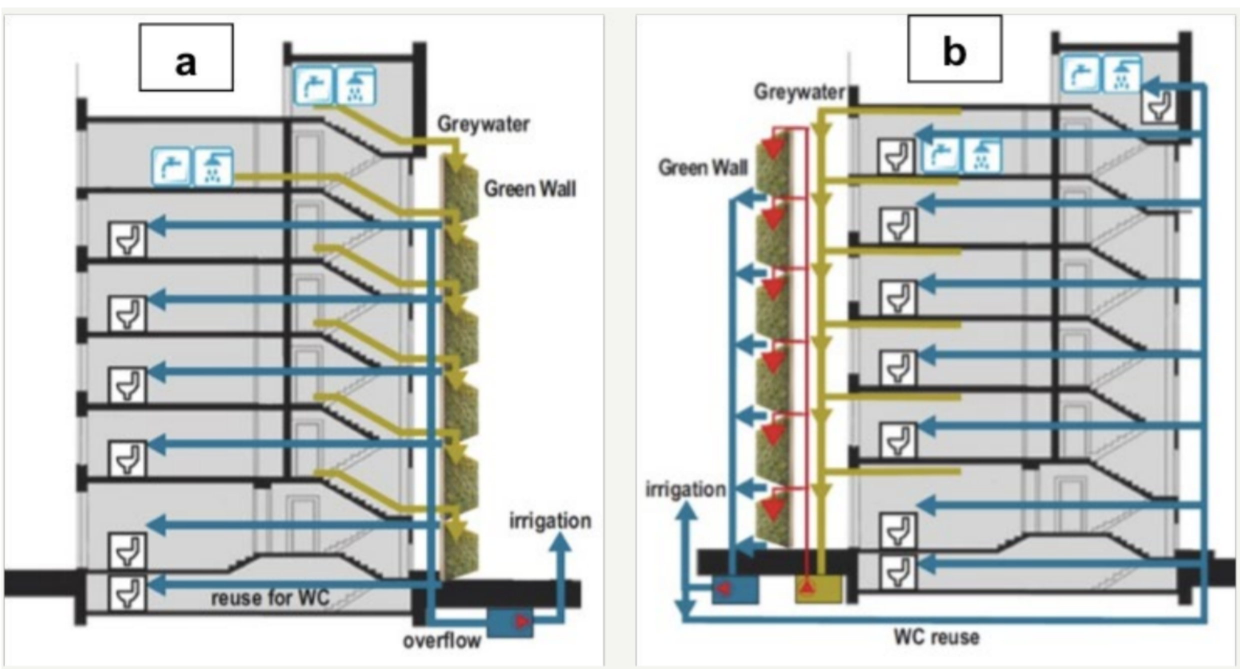


Fig25: Possible implementation schemes for greywater collection, treatment, and reuse in the same building with green walls: a) floor-by-floor and b) unified.

Constructed green walls offer the following benefits:

➔ Thermal insulation for the buildings on which they are installed, cooling of the surrounding microclimate, acoustic buffering, improved air quality, and increased property value.

- ➔ Green walls can considerably minimize a building's environmental effect.
- ➔ Green walls can also help with noise reduction and better liveability.[18]

Pebbles or small rocks cannot be used in green walls, unlike in constructed wetlands. Green walls require lightweight media due to their vertical location on the wall, which reduces the strain on their supporting structures

Physical and chemical qualities such as specific weight, water, nutrient retention capacity, porosity, capacity to distribute water and encourage plant growth, sustainability, and local availability are used to choose these materials. Through research we found that perlite and coconut coir are the two best-performing media among the hydraulically fast and slow media indicated as appropriate media, implying that their combined use is the optimum alternative.[19]

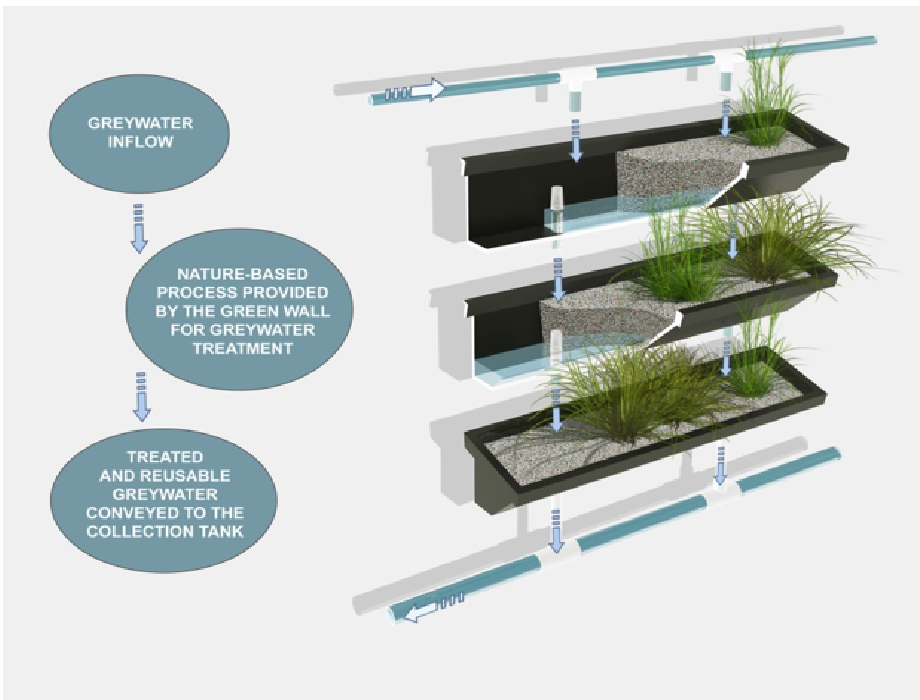


Fig26: Demonstration of how the green wall treats greywater.

Design Parameters

The green walls will comprise 12×6 pot matrices (6 pots in a column and 12 pots in a row). Each pot has a 0.01 m^2 top surface. Plants for both aesthetic and treatment uses will be put in the pots. The first row of pots is loaded using a perforated pipe. The water flow is then divided along with the columns of the matrix design, and a drain pipe collects the water at the bottom.[20]

Materials Used in the pots

➔ Coco coir - price ₹ 17.50-25/ Kg [21]

Coco coir provides water retention which gives enough time for denitrification processes hence removing the pollutants from the greywater. Uses a biological process for removal. The drawback of using coco coir is that it leads to clogging of the pipes. Thus it cannot be solely used and is mixed with perlite to reduce clogging.

Fig27: Coconut coir

➔ Perlite - price ₹ 70-80/ Kg [22]

An amorphous volcanic glass that has relatively high water content. It is 100% natural and is produced without harmful chemicals. Apart from this it promotes plant growth and reduces irrigation demand.
It is excellent for creating a free-draining potting compost. Perlite provides lower retention times or fast hydraulics. Pollutant removal is through physicochemical processes.

Fig28: Perlite

➔ LECA - price ₹ 85/ Kg [23]

LECA is a growing medium, like soil, in which you can grow your plants. LECA is basically baked clay balls that absorb a small amount of water and then expand somewhat. Plants can be watered using the water that has been absorbed by the clay balls. They are light in weight and are perfect for growing plants on green walls.

Fig29: LECA

- ➢ Along with LECA, a blend of perlite and coconut coir will be employed. Combining these two materials with distinct hydraulic properties reduces clogging while also increasing treatment efficiency and allowing biological processes to take place. To treat greywater effectively, a mixture of coco coir and perlite will be utilized, with a ratio of 25% perlite to 75% coco coir or perlite to coco coir ratio of 1:2, as well as light expanded clay aggregates (LECA) and a small amount of sand.[24]

- ➢ Plants will be chosen such that they fulfil both aesthetic and treatment requirements. As these plants are to be grown in pots, they must be small in size i.e. shrubs must be chosen.

The plants used in the model of the green wall proposed by us are - Abelia, Wedelia Portulaca, Alternanthera, Duranta, and Hemigraphis.[25]

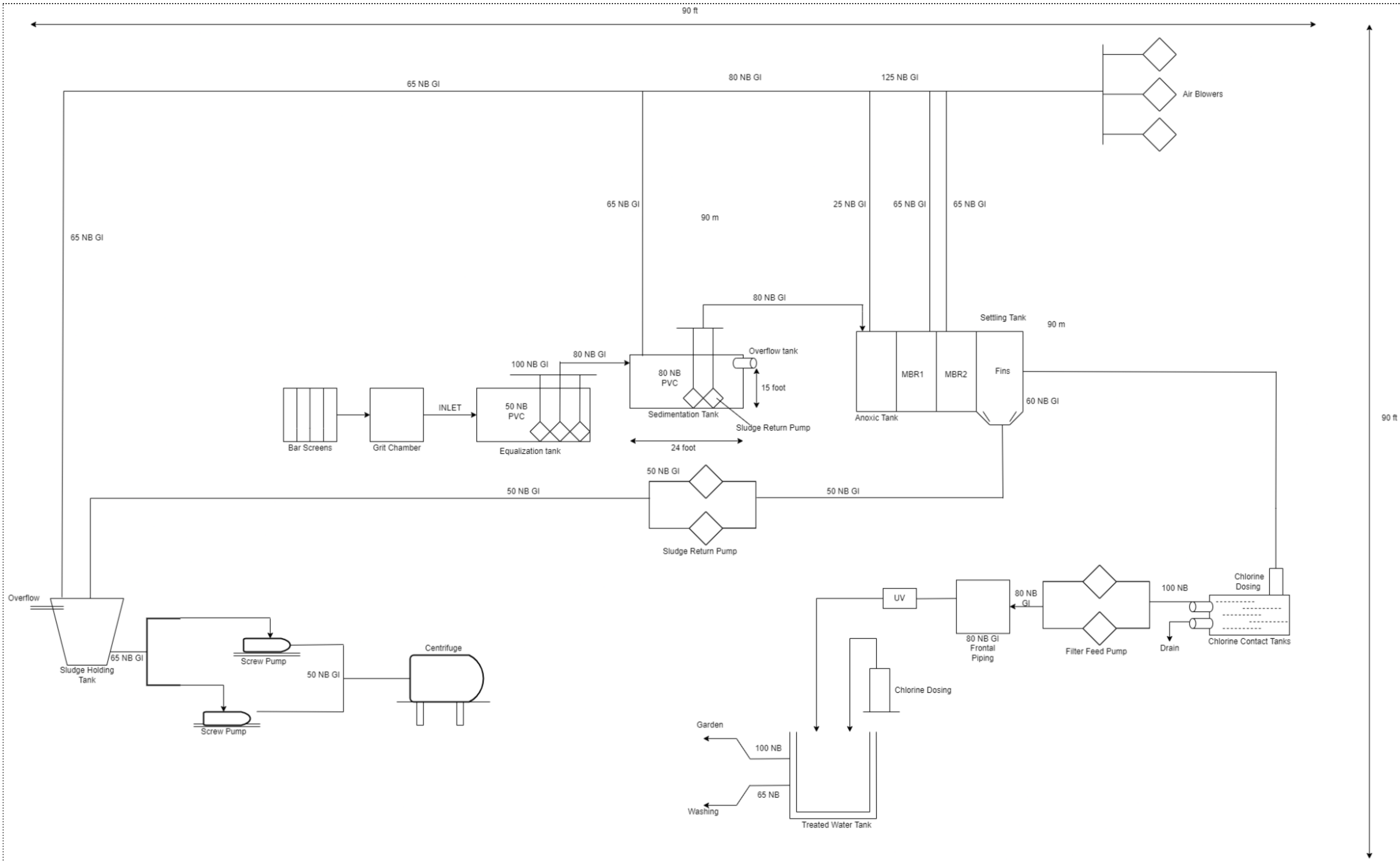
Fig 30: Wedelia Portulaca

Fig 31: Abelia

Table-4:Average impurity removal

Impurities	**Removal rates in %**
Total nitrogen	**70**
Total phosphorus	**23**
E.coli	**60**
TSS	**90**
BOD_5	**54**
COD	**55**

4.4. Blackwater Treatment Plant Layout


90 ft
65 NB GI
80 NB GI
125 NB GI
Air Blowers
65 NB GI
90 m
25 NB GI
65 NB GI
65 NB GI
65 NB GI
80 NB GI
Settling Tank
90 m
Overflow tank
100 NB GI
80 NB GI
80 NB PVC
15 foot
MBR1
MBR2
Fins
INLET
50 NB PVC
Sedimentation Tank
Sludge Return Pump
Anoxic Tank
60 NB GI
90 ft
Bar Screens
Grit Chamber
Equalization tank
24 foot
50 NB GI
50 NB GI
50 NB GI
Sludge Return Pump
Chlorine Dosing
Overflow
UV
80 NB GI
100 NB
Centrifuge
Screw Pump
65 NB GI
Sludge Holding Tank
50 NB GI
80 NB GI Frontal Piping
Filter Feed Pump
Drain
Chlorine Contact Tanks
Chlorine Dosing
Screw Pump
Garden
100 NB
65 NB
Washing
Treated Water Tank

4.5 Blackwater Treatment:

Components used in plant black water treatment plant:

- Bar screens
- Grit chamber
- Equalisation tank
- Anoxic tank
- Settling tank
- Disinfectant tank
- Sludge holding tank
- Centrifuge tank
- Treated water tank

Bar screens:

A bar screen is a mechanical filter that removes big items from wastewater, such as rags and plastics. It is a part of the primary filtration flow and is often installed at the influent to a wastewater treatment plant as the first, or preliminary, degree of filtration.

Grit chamber:

Grit chambers are long, narrow tanks that restrict the flow of water to allow particles like sand, coffee grinds, and eggshells to settle out of it. Pumps and other plant equipment suffer from increased wear and tear due to grit. Its removal is especially critical in places with combined sewer systems, which carry a significant amount of silt, sand, and gravel washed off roadways or land during a storm.

Equalisation Tank:

The equalisation tank's primary duty is to act as a buffer, collecting raw incoming sewage at widely variable rates and delivering it to the rest of the sewage treatment plant at a constant flow rate.

Anoxic tank:

In wastewater treatment plants, anoxic mixers are employed in de-nitrification basins. The method entails the de-nitrification of waste streams using bacteria that break down the nitrate in the waste and convert it to oxygen (energy source).

Settling tank:

A sedimentation tank, also known as a settling tank or clarifier, is a component of modern water or wastewater treatment system. A sedimentation tank allows suspended particles in water or wastewater to settle out as it passes slowly through the tank, giving some filtration.

Disinfectant tank:

To kill disease-causing germs, disinfectants are added to water. The "Water Treatment Rule," which mandates disinfection of public water systems, can sterilise groundwater sources. Primary disinfection methods include chlorine, ozone, ultraviolet light, and chloramines.

UV Treatment:

Ultraviolet light is used in UV wastewater disinfection technology for the disinfection of bacteria, viruses, moulds, algae, and other microorganisms. UV light disinfects by penetrating microorganisms and destroying their DNA.

Sludge holding tank:

Sludge holding tanks are used to store biosolids and can also be used to thicken them before processing or disposal. Sludge holding tanks are mixed to provide uniform sludge concentration, prevent sludge stratification, and provide a homogeneous feed to dewatering machinery.

Centrifuge tank:

Sludge holding tanks are used to store biosolids and can also be used to thicken them before processing or disposal. Sludge holding tanks are mixed to provide uniform sludge concentration, prevent sludge stratification, and provide a homogeneous feed to dewatering machinery

4.6 Treatment Process

Primary:

Material that will float or settle out by gravity is removed during the primary treatment. Screening, grit removal, and sedimentation are all examples of physical processes. Long, narrow metal bars are used to construct screens. They prevent floating waste like wood, rags, and other bulky things from clogging pipes and pumps. The screens in modern plants are cleaned mechanically, and the waste is disposed of on the plant grounds as soon as possible. Sedimentation methods are used to remove the shredded debris. Sedimentation tanks filter the sewage for suspended solids that pass via screens and grit chambers. Also known as primary clarifiers, these tanks are used to clarify water.[26]

Secondary:

The soluble organic matter that escapes basic treatment is removed in secondary treatment. It also eliminates a higher percentage of suspended solids. Biological procedures are typically used to remove organic pollutants, with bacteria consuming them as food and converting them to carbon dioxide, water, and energy for their own growth and reproduction.

The extracted sludge from the settling tank is then passed to the centrifuge process and we use it as a fertilizer

Tertiary:

Effluent from secondary treatment is further treated through the tertiary treatment which includes disinfectant (chlorination) in the CCT tank then effluent further goes through the filters and then finally treated using UV. Then the treated water gets collected into the treated water tank and gets chlorinated again then the water is clean enough to be used for gardening purposes.

4.7 Piping:

We use GI or galvanized iron (GI) pipe for our plant. Galvanization is basically the process of coating a metal with zinc. Due to the fact that they are coated with zinc, modified piping provides a variety of advantages over other methods that are used to strengthen the steel or iron.

4.8 Membrane Bio-Reactor Calculations

Table 5: Wastewater parameters /Characteristics:

Influent BOD, BODo	250	mg/L
sBOD, $sBOD_o$	125	mg/L
Influent COD, COD_o	500	mg/L
sCOD, $sCOD_o$	250	mg/L
rbCOD, $rbCOD_o$	135	mg/L
Influent TSS, TSS_o	250	mg/L
Influent VSS, VSS_o	60	mg/L
Influent TKN, TKN_o	40	mg/L
TKN peak/ave factor , FS	1.5	
Influent NH4-N, NH4-N_o	25.0	mg/L
Aeration WW Temp., Tww	77	^oF
Influent Alkalinity, Alk_o	100	mg/L

Biological kinetic coefficient :

1. **For BOD Removal**

Table 6: Biological kinetic coefficient for BOD removal

Synth. Yield Coeff, Y	0.45 lb VSS/lb bCOD
Temp coeff. θ, for mm	1.07
Temp coeff. θ, for kd	1.04

Resid. biomass fract. fd	0.15
Half Veloc. Coeff., Ks	8 mg/L
Max spec. growth rate at 20 ºC, µmm20	6 lb VSS/d/lb VSS
Endog. decay coeff. at 20 ºC, kd20	0.12 lb VSS/d/lb VSS

2. **For Nitrification:**

Table 7: Biological kinetic coefficient for nitrification

Synth. Yield Coeff, Yn	0.15 lb VSS/lb NOx
Temp coeff, Ө, for mmn	1.072
Temp coeff, Θ, for kdn	1.029
Temp coeff, Θ, for Ksn	1
Max spec. growth rate at 20 ºC, µmmn20	0.9 lb VSS/d/lb VSS
Endog. decay coeff. at 20 ºC, kdn20	0.17 lb VSS/d/lbVSS
Half Veloc. Coeff. At 20 ºC, Ksn	0.5 mg/L
Half Veloc. Coeff. At 20 ºC, Kso	0.5 mg/L

Membrane Characteristics

- Membrane Material:

  The fouling tendency of a membrane in an MBR is influenced by the material it is constructed of. Membranes are categorised as ceramic membranes, polymeric membranes, or composite membranes based on their material.
  Polymeric membranes are usually hydrophobic and have strong physical and chemical resistance. Polymeric membranes foul quickly due to their hydrophobic nature, although they are increasingly commonly employed due to the ease with which pore sizes may be manufactured. This necessitates the surface modification of naturally hydrophobic polymeric materials with a hydrophilic functional group. Compared to the original membrane, the modified membrane has a 25% increase in hydrophilicity, a 49% decrease in biofouling, and a 4% increase in albumin retention.

- Membrane Surface Roughness: Membranes with a higher surface roughness foul more quickly because the rough membrane surface creates a valley for colloidal particles in the wastewater, resulting in valley blockage and increased fouling severity for more uneven membrane surfaces.

- Membrane Pore Size:

  Fine particles (those more minor than the membrane pore size) have an easier time entering and becoming caught in the membrane pores, resulting in pore blocking. Large particles quickly form a top layer on the membrane with smaller pores and capture the smaller particles. The layer that includes the membrane surface can then be easily removed.

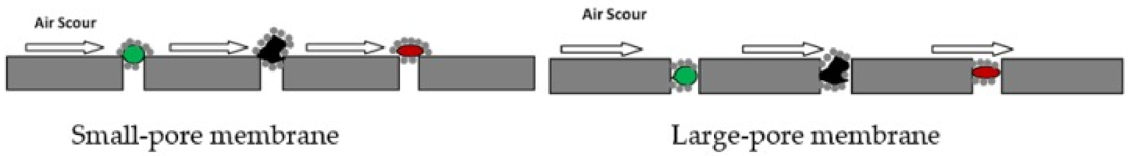


Fig 33: Membrane Pore Size Representation

0.05±0.2 mm pore sized membranes produced the maximum flux among membranes ranging from 0.01±1.6 mm in pore size.

- Process design calculations:

Design Membrane Flux:

$$J = 0.4056T_{ww} - 5.7278$$
$$= 25.5 \text{ L/hr/m}^2$$

Spec. Aer. Demand, SAD = 0.3 m3 air/hr/m2 membrane

Membrane Area Am = Q_o/J = 100 ft^2

Membrane Module Vol. Vm = Am/density= 3 ft^3

Scouring Air Flow Required: Am*SAD = 2 ft^3/min

BOD And COD Removal:

The elimination of COD and BOD_5 in traditional wastewater treatment procedures like activated sludge varies from 80-95 %, but the MBR method can achieve up to 96-99 % depending on the quality and pore size of membranes. Because of the large number of microorganisms in the reactor tanks, the pollutant uptake rate of MBR is higher than that of conventional procedures.

Target effluent concentrations:

Table 8: Target effluent concentration

BOD_e	10 mg/L
TSS_e	10 mg/L
NH_4-N_e	0.5 mg/L
DO in Aer. Tank, DO_O	2 mg/L
Influent TKN, TKN_o	40 mg/L
MLSS in Aer. Tank, XO	10000 mg/L
Initial Estimate of NOx	28.9 mg/L
MLSS in Waste Sludge, XW	10000 mg/L

1. **Calculate the Biomass Production Rate :**

   µm at Tww =µm,20*Θ^{Tww-20}= 8.4 lb VSS/d/lb VSS

   $bCOD_o$ = 1.6*BOD_o = 400 mg/L
   kd at Tww = kd,20*Θ^{Tww-20}= 0.146 lb VSS/d/lb VSS
   S = Ks[1+(kd)SRT] / [SRT(µm - kd) -1] = 0.34 mg bCOD/L

   Biomass Production Rate=
   $$Px,bio = QY(\frac{(So-S)}{(1+kd*SRT)}) + fd*kd*QY*\frac{(So-S)SRT}{(1+kd*SRT)} + QYn\frac{(NOx)}{(1+kd*SRT)}$$
   = 1 lb VSS/day

2. **Determine the Amount of Nitrogen Oxidized to Nitrate:**

   Calculated amount of nitrogen oxidized to nitrate, NOx =
   NOx = TKN - N_e - 0.12*Px,bio/Q
   = 25.4 mg/L

3. **Determine the Production Rate and Mass of VSS and TSS in the Aeration Basin:**

   bpCOD/pCOD = (BOD_o - $sBOD_o$)/(COD_o - $sCOD_o$)
   = 0.8
   nbVSS = [1-(bpCOD/pCOD)VSSo]
   = 12 mg/L

Aeration Tank VSS Production Rate = Px,vss = Px,bio + Q(nbVSS)
= 2 lb VSS/day

Aeration Tank TSS Production Rate, P_x,TSS = Px,vss + Q(TSS_o - VSS_o)
= 4 lb VSS/day

Mass of MLVSS = Aeration Tank VSS Production Rate*SRT
= 8 lb VSS

Mass of MLSS = Aeration Tank TSS Production Rate*SRT
= 20 lb TSS

4. **Calculate Aeration Tank Volume and dimensions:**

   Flow rate =0.033 m^3/s

   Over flow rate = 800L/day-ft2

   Area = 780321.87/800 = 90.67m2

   Volume V = Q*t = 0.033*2*60*60 = 237.6m3

   Depth(d) =V/A = 2.6m

   Width (w) = 4.77 m

   Length(l) = 19m

5. **Calculate Sludge Wasting Rate**

   Waste A.S. Rate, Qw = (V*MLSS)/(SRT*TSS_W)

   = 11,616 gal/day

6. **Oxygen/Air Requirement and Blower Calculations (for the Aeration Tank):**

Table 9: Air requirement and blower calculations

O_2 needed per kg BOD	1.00 lb O_2/lb BOD
O_2 needed per kg NH4-N	4.40 lb O_2/lb NH4-N
SOTE as Function of Depth	2.00% % per ft depth
AOTE/SOTE	0.33
Press. Drop across Diffuser	12.0 in W.C.
Depth of Diffusers	14.5 ft

Standard Temperature	68 ºF
Standard Pressure	14.7 psi
Atmospheric Pressure	14.7 psi
Air Density at STP	0.075 lbm/SCF
O2 Content in Air	0.0173 lbm/SCF

Press. at mid depth, PD = P_a + γ(Diffuser Depth/2) = 17.8 psi
BOD Removal Rate = (Q_o*(BOD_o - BOD_e)) = 0.125 lb/hr
NH_3N Removal Rate = (Q_o*($NH3N_o$ - $NH3N_e$))

Oxygen Requirement = (BOD removal rate)(lb O2/lb BOD)+(NH_3N removal rate)(lb O_2 /lb NH_3N) = 0.2 lb/hr

SOTE = (SOTE %/m depth)(Diffuser depth) = 29%
AOTE = SOTE(AOTE/SOTE) = 9.6%

Air requirement = (O_2 requirement/AOTE)/(O2 content in air)
= 2 SCFM
Blower Outlet Pressure = P_a + Pressure drop across diffuser + γ(Diffuser Depth
= 21.4 psia

4.9 Pump system:

<u>Number of pumps - 15</u>

- ➔ 2 air blower - 12.5hp each
- ➔ **2 Sludge loading and 2 sludge return - 4hp each**
- ➔ 3 drainage - 2hp each
- ➔ 1 chlorine dosing - 2hp
- ➔ 1 backwash - 5hp
- ➔ 2 gardening and 2 flushing - 5hp each
- ➔ 2 filter feed and 3 raw sewage relift - 5hp each

Sample Calculation of Sludge Loading Pump having following Details

- Static Suction Head (h_2) =15 m
- Static Discharge Head (h_1)=30 m
- Required Amount of Water (Q_1)=2.2 Liter/min.
- Density of Liquid (D) =1000 kg/m^{3*}
- Pump Efficiency (pe) =80% *
- Motor Efficiency(me) = 90% *
- Friction Losses in Pipes (f)=30% *

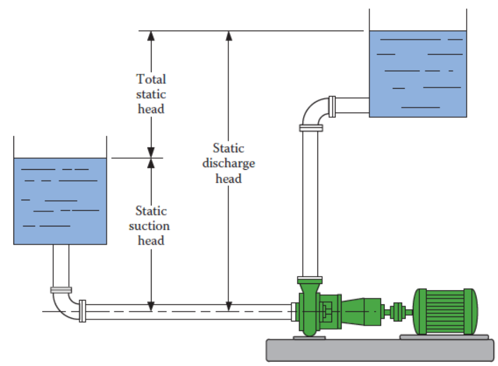


Fig 34 : Static Suction and Discharge Head

(* - Since we couldn't get the precise values we have followed the most commonly taken values in standard texts like Metcalf and Eddy)

- Flow Rate (Q) =2.2x1.66/1000 = 0.003652 m^3/sec
- Actual Total Head (After Friction Losses) (H) = (h1+h2)+((h1+h2)xf)
- Actual Total Head (After Friction Losses) (H) =45 +(45×30%)= 58.5 m.
- **Pump Hydraulic Power (ph) = (D x Q x H x 9.87)/1000**
- Pump Hydraulic Power (ph) = (1000 x 0.003652 x 58.5 x 10)/1000 = **2.13 KW**
- Motor/ Pump Shaft Power (ps)= ph / pe = 2.13 / 80% = **2.67 KW**
- Required Motor Size: ps / me = 3.87/ 90% = **2.96 KW ≈ 4 HP**

4.10 Estimating energy consumption of pumps:

Total energy = 95hp

1 hp = 0.746kW

95hp = 70.84kW

4.11 Estimating operating duration for each pump per day -

Air blowers - 24hrs

2 Sludge loading and 2 sludge return - 3hrs

3 drainage - 3hrs

1 chlorine dosing - 3hrs

1 backwash - 3hrs

2 gardening and 2 flushing - 3hrs each

2 filter feed and 3 raw sewage relift - 3hrs each

4.12 Estimating number of solar panels

Estimated average operating time of pumps - 5.1 hrs/day

Energy required per day - 70.84kW ✖ 5.1 ✖ 3600 = 1.3 ✖ 10^9 Joules or 361.11 kWh

Estimating number of solar panels required -

Energy produced by single solar panel = 3kWh/day

After adding solar trackers, the energy produced = 4.05kWh/day

No. of solar panels required = 361.11/4.05 = about 80-90 solar panels.

4.13 Estimating area required:

Area required to to set up 1kWh solar panel = 5.25 m^2

Per day energy consumption of our plant = 361.11 kWh

Area required = 361.11 ✖ (5.25*0.65) m^2 = 1232 m^2

Approximate area of plant (obtained from on-site visit) = 8100 ft^2 or 752.5 m^2 approx.

The point to be noted here is that the roof area is 800 m^2 and the total area required to mount the panels is 752.5 m^2 which means all the solar panels can be easily installed on the roof itself. The solar panels thus can easily provide the necessary power to make the waste treatment plant self-sustainable.

Expected Output

Statistical analysis:

- It is found that static solar panels provide about 300 Watts/hour on a normal day. With 10 hours of sunlight, it can produce 3KWh/day.
- It is estimated that a solar tracking system will increase the output of solar panels by **35%.**

- Therefore will provide about **405 Watts/hour** on a normal day and with 10 hr of sunlight now it can produce 4.05KWh/day.
- It takes approximately **800 kWh** of energy to treat 300,000 gallons of wastewater. We have 500000 litres of wastewater. It would take around 352.22KWh in the treatment.
- It would take around 8-9 solar panels to produce this amount of energy.[27]

Cost analysis:

- Normal solar panel system integration requires about 1000$ per solar panel.
- A single tracking system (solar panel movement in a single direction) will require an additional 500-700 per solar panel. Adding up additional expenses will drive the cost up to about 1700$.
- It would cost $136,000 - $153,000 to install 80-90 solar panels.

5. Conclusion

We have developed a comprehensive Blackwater treatment plant design incorporating MBRs, UV Filtration, Grit chamber, etc. It is easy to integrate as it contains even the minute details of process flow and pump/pipe specifications at each step. To start with the water part, we achieved a net positive water performance cycle without depending on offsite consumption. We then prepared a diversified flow diagram of rooftop rainwater harvesting to capture 5,75,503 litres of water annually. Next, we successfully calculated the annual generation of Black and Greywater.

To begin with the treatment, we first discussed the treatment of Greywater using effective natural remedies such as Coco hair, Perlite, LECA, Abelia, etc. which gave an average removal of 60% and 90% from Ecoli & TSS respectively. Next, we calculated the biomass generation rate in MBR, followed by its dimensions (19m x 4.77 x 2.6m) and the oxygen air requirement for the aeration tank. Calculating the capacity of 15 pumps proved to be a real challenge. We then integrated the plant with Arduino Powered Solar trackers to make it self-sustainable. To produce an equivalent power, the number of solar panels came out to be 80-90, occupying a 752.5 m2 area. It proved to be a perfect fit for our building, with a rooftop area of 800m2, hence validating all of our calculations.

6. Future Scope of Work:

➔ In the near future, emerging technology such as online sensors with real-time feedback will undoubtedly play a significant part in water reuse.

➔ Membrane technology advancements will also be crucial in reducing energy use and increasing water recovery rates.

➔ These technological advancements should be prioritised across the board in order to achieve the best water quality for the application. As a result, the future will be defined by fit-for-purpose therapy and increasingly distributed systems that can be interconnected and controlled autonomously.

➔ Because of their environmental friendliness and cost-effectiveness, anaerobic and aerobic methods have recently become popular and we will try to incorporate them in future in the treatment of organic wastes.

➔ We can also work on integrating MBBR Tank in the plant. It has grown in popularity as a method of biological wastewater treatment. To break down garbage, MBBR uses plastic carriers covered in biofilm. MBBR is a new method for nitrification and denitrification, in addition to being an excellent way of eliminating organic contaminants.[28]

➔ We can further invest in modern ventilation technology as they pay off very quickly and improve plant efficiency without undue expense.

➔ For ensuring energy-efficient water treatment in the future we can incorporate the use of hydroelectric power in the inlets and outlets of the wastewater treatment plant. To further boost energy efficiency, it is recommended to employ bar screen debris as a supplementary fuel source, particularly in the case of bigger plants with sludge incineration.

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