Submission for the Stockholm Junior Water Prize (2024)

Bilge Vessel and Scupper Valve
Decentralised Greywater Collection and Recycling System

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Abstract

The whole world is facing an acute water crisis and there is an urgent need to reduce, recycle and reuse potable water in whatever way possible. The present applied research project focuses on the development of an indigenous, sustainable, cost effective, decentralized greywater treatment unit which collects, treats, and reuses greywater generated in a household at the source. This product driven intervention has two units: Scupper Valve and Bilge Vessel which help households save and fight the water crisis without any major modifications in the current home plumbing system and takes up very little space in the bathroom. The preliminary prototype testing demonstrates its effectiveness in collecting and treating greywater to an improved level. A single-family can save around 5,000-6,000 litres of precious potable water per month and can reduce 50% of their water demand. This decentralised approach reduces carbon emissions by 80-85% compared to the traditional centralised sewage treatment setups (water pumping and operational energy), offsetting 18,000 tonnes of CO_2 emissions annually. Additionally, due to lower sewage output, it contributes towards embodied carbon savings linked to the plumbing network infrastructure and construction of sewage treatment plants. This solution, therefore, addresses two main challenges viz-a-viz water scarcity and operational carbon emissions associated with freshwater supply, wastewater treatment and conveyance of treated water.

Keywords

Greywater, Recycling, Reuse, Wastewater Treatment, Decentralized, Embodied

Abbreviations and Acronyms

BV	Bilge Vessel	MLD	Million litres per day
cm	Centimeter	pH	Power of Hydrogen
CO_2	Carbon Dioxide Emission	SV	Scupper Valve
DC	Direct Current	STP	Sewage Treatment Plant
kl	Kilo Litres	NTU	Nephelometric Turbidity unit
lpcd	Litre per capita per day		

Acknowledgements

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Biography

I am Mannat Kaur, a 16-year-old student studying at Delhi Public School RK Puram. I am deeply passionate about STEM, Innovation, Machine Learning and Sustainability, particularly climate change and water conservation. I aspire to apply concepts hedged within science and technology to create solutions that contribute to mitigating climate change and fostering a sustainable society. Additionally, I am a National Level skating player and have been pursuing the same for the past 7 years. Painting, particularly charcoal art, is both a passion and a therapeutic outlet for me.

I strongly believe in the saying, “We cannot direct the wind, but we can adjust the sails” and this belief motivates me to be a better version of myself, create impact and contribute to improving the lives of people around me with my research skills, creative acumen and knowledge of Computer Science.

1. Introduction

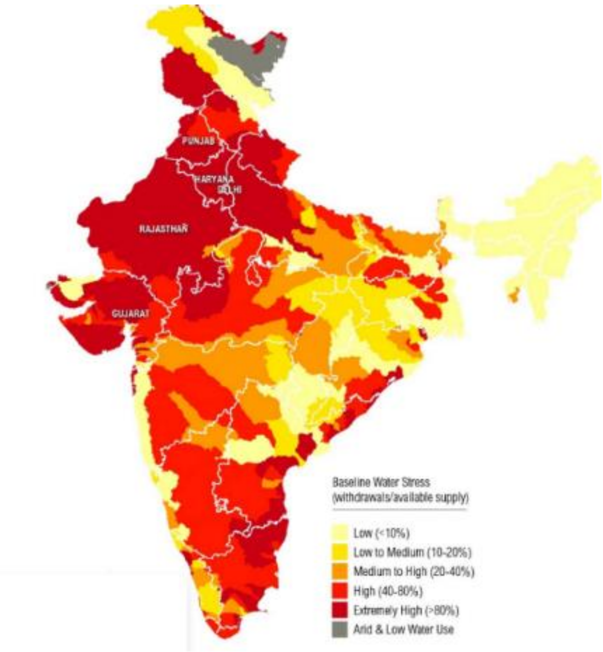


Figure 1 Baseline Water Stress

As a nation we are facing an acute water crisis. According to statistical data, many regions in India can face drought in the forthcoming years. Recently Bengaluru, India's tech hub, was in a serious water shortage turmoil because the Northeast monsoon did not bring enough rain. Similarly, the western suburbs of Mumbai, a metropolitan city of India had no water supplies. Chennai was also seen struggling with water crisis and it became the first Indian city to go dry. In other states of India like Rajasthan, this paucity led to unrest among locals in the form of fights and quarrels. The Salai village in Vellore, Tamil Nadu also suffered water scarcity for many years. *Figure 1* depicts the baseline water stress in various parts of India. As can be seen, many stretches across the country are already water stressed and the situation worsens during peak summer.

Even other parts of the world are facing water crisis. In Cape Town, South Africa, the water table has gone down alarmingly. The citizens are facing severe drought and are struggling to make ends meet because of the increased demand. Additionally, many areas in the USA viz California, New York are experiencing fires, droughts, and water shortages due to dry weather, climate change and global warming. Qatar, Middle East, and North African regions are also at a very high risk. Thus, there is a need to reduce, recycle and reuse water in whichever way possible to alleviate the water stress scenario faced globally.

Water is used for drinking, bathing, flushing, utensil cleaning, clothes washing, mopping/car washing and watering plants in a home. As per Ministry of Housing and Urban Affairs (Ministry of Jal Shakti, 2020) 135 lpcd has been suggested as the benchmark for urban water supply. As per National Building Code 2016 (CGWA, 2016), 45 litre per head per day may be taken for flushing requirements and the remaining quantity for other domestic purposes. The wastewater generated from home can be categorized as *blackwater* and *greywater*. Toilet and kitchen wastewater is categorized as blackwater because of high organic loading relative to the cleaner wastewater from baths, sinks, washing machines, and other kitchen appliances, which is called greywater. Table 1 indicates the approximate demand of domestic water and greywater generated per person per day. It can be seen that greywater from bathing and laundry can fulfill the non-potable water requirements of flushing.

Table 1: Water Demand and Grey Water Generated

End Use	Domestic Water Demand (l/person)	Grey Water Generated (l/person)
Drinking and Cooking	15.0	
Bathing	30.0	27.0
Laundry	20.0	18.0
Flushing	45.0	
Mopping/Car Washing	5.0	
Irrigation	20.0	
Total	**135.0**	**45.0**

Recycling greywater for non-potable end uses can reduce the burden on potable water sources and minimize sewage production. This reduction in water demand and sewage output/wastewater generation can, in turn, reduce the operational carbon emissions associated with the centralized treatment of sewage and the transportation of freshwater and treated wastewater. According to the report (CLASP, 2021) on water efficiency opportunities in India, approximately 0.98 kwh/m^3 of energy is embedded in water desalination, treatment, pumping and wastewater processing. Similarly, another report (Griffiths-Sattenspiel & Wilson, 2009) highlighted that the energy needed to move, treat, and use water in the US produced 290 million metric tonnes of CO_2 annually, equivalent to 5% of the nation's carbon emissions.

Given the acute water scarcity and increasing global carbon emissions from the centralized wastewater treatment, there is a dire need for solutions which facilitate collection, segregation, recycling and reuse of wastewater at the household level.

Many researchers have undertaken projects on water conservation and wastewater reuse and have found innovative solutions. Diana et.al (1996) discussed the examination of greywater quality and its potential health and environmental risks, as well as conducted soil tests to assess any long-term effects on gardens. It provided insights into greywater testing, filtration results and disinfectants. Godfrey et al. (2009) conducted a cost benefit analysis of the constructed greywater treatment system in the residential schools in Madhya Pradesh. They deliberated that the internal and external benefits of grey water reuse are substantially higher than the internal and external costs. Racoviceanu and Karney (2010) investigated the environmental impact of water supply systems in Toronto, comparing two conservation methods—water efficiency and rainwater harvesting—using a life cycle-based hybrid methodology. Both strategies showed significant water savings, with rainwater harvesting demonstrating strengths in hydraulic stress reduction and postponing capital investments. Despite variations in energy use and emissions, both approaches are deemed valuable for enhancing water system sustainability. Muthukumaran et al. (2011) showcased the Sharland Oasis house in regional Victoria, Australia, designed for water and energy efficiency. They demonstrated that utilizing alternative water sources and efficient appliances could save up to 77% of potable water compared to 1990s household usage. Community survey results suggested high receptivity for greywater reuse in certain uses, but education programs were needed to promote broader acceptance across different social groups. Mourad et al. (2011) evaluated the potential for potable water saving by using greywater for toilet flushing in Syria. They conducted interviews to reflect the social acceptance, water consumption, and the percentage of different indoor water uses. They used an artificial wetland and a commercial bio-filter to treat the greywater and performed an economic analysis for the treatment system. Boutilier et al. (2014) aimed to provide safe drinking water to reduce the global burden of waterborne diseases. They showed that plant xylem from the sapwood of coniferous trees could remove bacteria from water by simple pressure-driven filtration. Shin et al. (2017) introduced a novel method for particle separation in water purification, using CO_2 exposure instead of traditional membrane filtration. This membraneless process offered low energy consumption and minimal fouling, making it a promising alternative to conventional methods. Ahmadpari et al. (2022) discussed the role of greywater in sustainable water management. They underscored the importance of proper handling to prevent greywater from becoming a health hazard and emphasized on the benefits of directly introducing it into the soil for biological purification, optimizing water consumption.

Our effort in this applied research project is to develop a decentralized greywater collection and treatment unit. The paper is structured as follows: Section 1 provides an introduction, outlining the historical context and development of the problem. Section 2 presents findings from the survey conducted to identify potential barriers and challenges for greywater reuse at home. Section 3 delves into the design and functionality of the system. In Section 4, we explore the system’s key features and benefits. Section 5 outlines the projected impact and water, energy savings. Section 6 summarizes our results and discussion, while the final section discusses plans for future development of the system.

2. Acceptability, Awareness and Barrier Assessment

A semi-structured questionnaire was developed to collect data on the levels of awareness and the potential barriers surrounding the use of greywater in household settings. The survey consisted of the following sections.

1. Demographic Distribution and Family Size

The first set of questions aimed to gain insights into household demographics and characteristics to better understand our target audience. Participants were asked to provide information on their city of residence and the number of members in their family. The demographic distribution and the family size of the survey respondents is listed in Table 2 and Table 3 respectively.

Table 2: Demographic distribution of respondents.

Country	City Classification	% Respondents
India	Tier I	66.3%
	Tier II	23.8%
	Tier III	5.0%
US	Tier I	2.5%
	Tier II	3.8%
	Tier III	0.0%

Table 3: Family size of Respondents

Family Size	% Respondents
<3	11.90%
3	13.10%
4	28.57%
5	23.81%
6	11.90%
>6	11.90%

2. Awareness, Practices, and Perceptions of Water Recycling and Reuse

The second set of questions aimed to gain insights into the awareness, practices, and perceptions surrounding water recycling and reuse. The first question delved into participants' awareness of the possibility of recycling treated wastewater from everyday activities such as bathing, laundry, and dishwashing for non-potable purposes like flushing, car washing, and gardening (Figure 2).

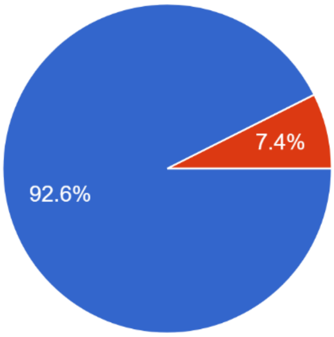


Figure 2: Percentage of survey respondents who were aware that greywater can be used for non-potable uses after treatment (Blue-Yes; Red-No)

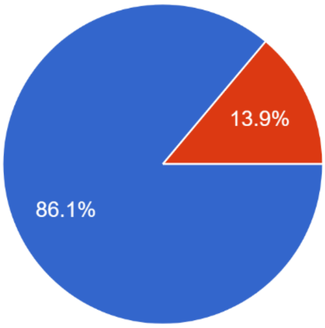


Figure 3: Percentage of survey respondents who are interested in installing wastewater reuse system at home. (Blue-Yes; Red-No)

3. Interest and Challenges in Implementing Wastewater Recycling System

The last set of survey questions was designed to understand the attitudes and perceptions of the respondents regarding the installation of wastewater reuse systems in residential homes (Figure 3). The survey aimed to explore the interest of the participants in adopting such systems and to identify potential challenges and barriers they may perceive in implementing wastewater reuse technology.

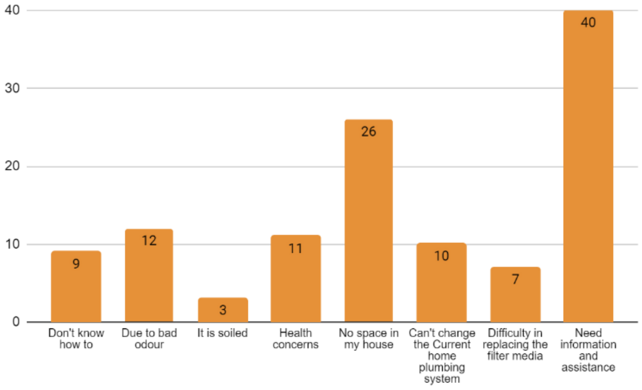


Figure 4: Potential challenges respondents perceive in implementing wastewater reuse technology.

The survey results (Figure 4) provided valuable insights into opportunities for promoting sustainable water management practices and barriers towards the implementation of wastewater reuse systems in residential settings. The results revealed a spectrum of challenges perceived by respondents in implementing wastewater systems in their homes. Notably, space constraints emerged as a significant issue, with individuals reporting inadequate space in their homes for system installation. Additionally, many expressed concerns about the difficulty associated with collecting greywater from various sources, altering their existing home plumbing systems, and replacing filter media from time to time. Lack of knowledge on how to proceed, need for information and assistance in navigating these challenges and health concerns also emerged as a notable challenge, alongside concerns regarding odour and the cleanliness of the system.

3. System Design

This applied research project aims to bridge the gap highlighted by the end user in the survey for adoption of greywater reuse system at the household level. The solution Bilge Vessel and Scupper Valve was meticulously designed to mitigate the identified barriers while optimizing functionality and ease of installation. The solution has two units: Scupper Valve (SV) and Bilge Vessel (BV) (Figure 5). SV helps in collecting the wastewater from sources like the shower, kitchen and pumping it to the BV which in turn filters the wastewater and stores the recycled water for non-potable domestic uses such as flushing, mopping, irrigation and car washing, etc. This project has the potential to conserve water and energy at various levels and has an impact not only at household level but in the whole water supply network/system i.e., desalination, energy in moving water, leakage of freshwater in the supply network, spillage of sewage, treatment of sewage and other running costs.

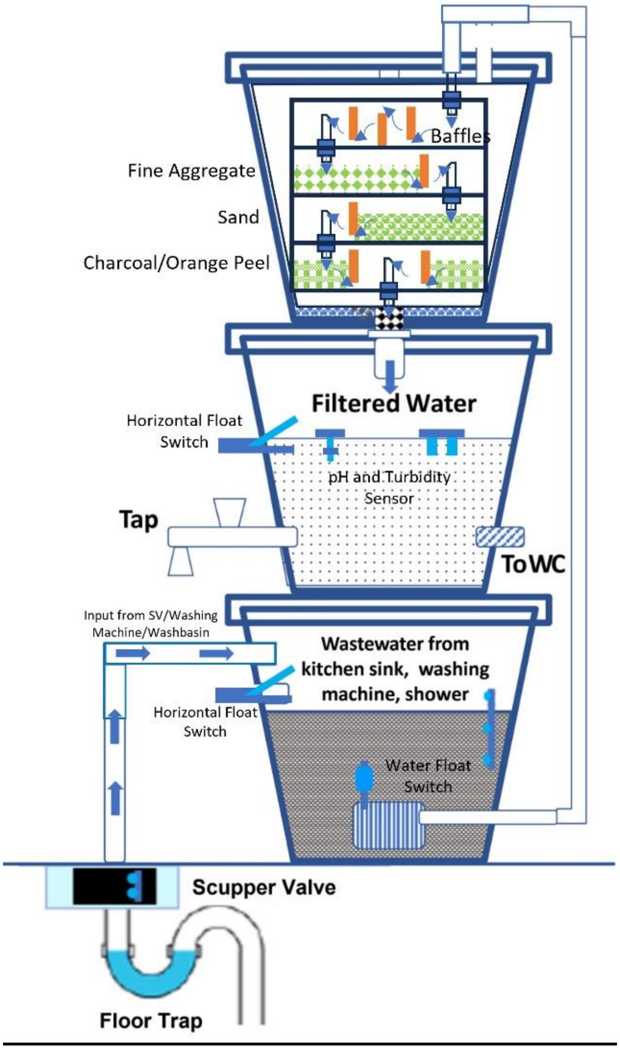


Figure 5: Schematic Section of BV and SV setup

1. Scupper Valve (SV)

Generally, collecting wastewater from the washbasin or washing machine is comparatively simple since the outlet is at a higher level from the floor. However, collecting shower water/kitchen greywater is a challenge which is where the SV comes into the picture. It is a case-like device that consists of a small fountain pump, a water-level float switch and a sink drain stopper housed in an 8-9 cm diameter drain trap (Figure 6 and Figure 7). It is placed in the floor drain trap of the bathroom which pumps the soapy shower water to BV.

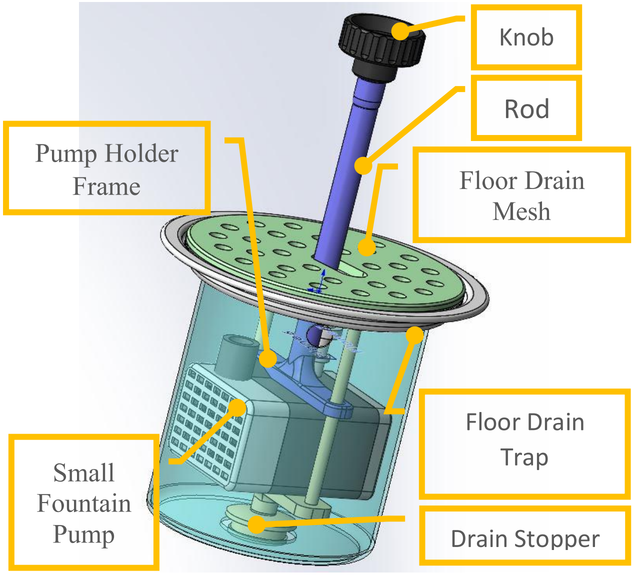


Figure 6: 3D View of Scupper Valve

Figure 7: 3D printed Assembled Scupper Valve

It consists of two components.

1) **Modified Floor Drain Trap:** The drain trap is a circular container with a diameter of 8.5 cm and has an opening of 3.0 cm at the bottom equipped with a push-type drain stopper (Figure 8 and Figure 9). This push type drain stopper gives the flexibility to drain water if it is too dirty or if sufficient wastewater has already been collected in the filtering system, BV. Additionally, the drain trap has a small opening at the top to avoid any flooding of the bathroom floor.

Figure 8: 3D printed components of the floor drain trap

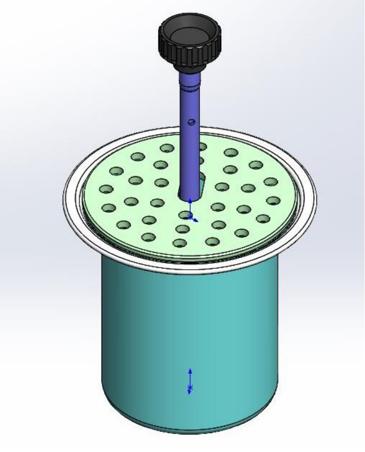


Figure 9: 3D Model of the Floor Drain Trap/Scupper Valve

2) **Pump Holder:** A pump holder is attached to the top of the push type drain and becomes a single unit (Figure 10 and Figure 11). The holder ensures the pump remains stable and securely fixed in its position. This also helps in operating the drain stopper (Figure 12). A water level float switch is integrated to the pump and is housed in the holder. The operation of the pump is controlled by the water float switch (reed switch) based on the water level (Figure 13). As soon as the water level reaches the top of the float switch, it switches the pump on which pumps the water to the BV, allowing the optimization of the operation.

Figure 10: 3D printed components of pump holder

Figure 11: Pump Holder attached to the push-type drain stopper

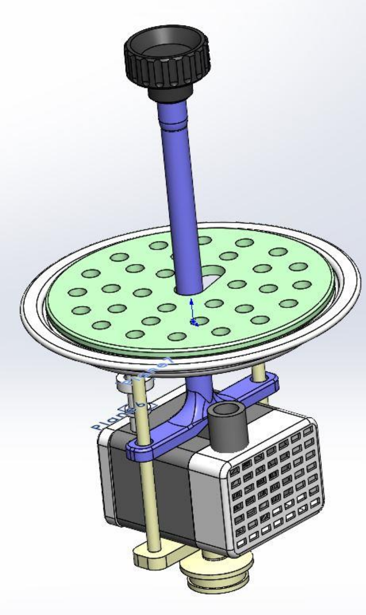


Figure 12: Detailed 3D View of the Pump holder

Figure 13: 3D printed pump holder

2. Bilge Vessel (BV)

BV is a three-bucket filtering system stacked one over the other, inspired by the concept of Khamba Composting which makes it a compact solution. The wastewater from SV is pumped to the lowermost bucket which acts as a retention bucket for wastewater. The wastewater from the lowermost bucket is pumped to the topmost bucket which is the filtration bucket.

1) **Lowermost Bucket:** A small submersible pump with a water float switch, externally attached, pumps the water to the topmost bucket in a regulated manner to ensure that it gets switched off when the water drops down below a certain minimum level preventing it from burning out. Three holes are drilled near the top edge of the bucket at different levels. The topmost hole acts as an inflow and is connected to the outlet of the SV/Washing machine/Washbasin's outlet. The second hole is drilled on the opposite side and at the same level as the first one. A horizontal float switch is attached here to prevent the overflow of water pumped by the SV. The third hole is drilled just below the second hole which acts as the overflow outlet and is connected to the floor drain trap (a precautionary measure). After the setup, the bottommost bucket is closed with the lid (Figure 14).

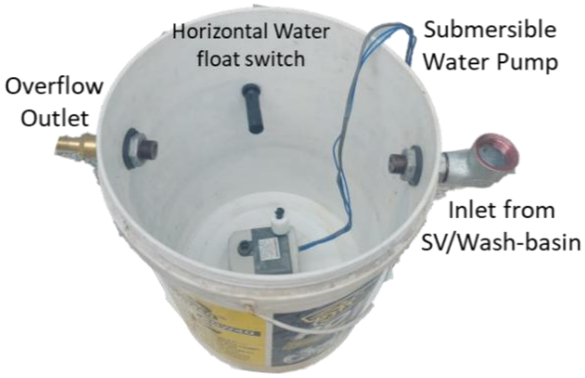


Figure 14: The setup of bottom bucket with submersible water pump, horizontal water float switch, inlet, and outlet components

Figure 15: Water pump with a Vertical Water float switch integrated into it to protect the submersible pump from burning out

2) **Top Bucket:** The top bucket is the filtration bucket with the filtration media. In the earlier design iteration, the topmost bucket had layers of filter media stacked on over the other in layers however, in the past year, upon feedback from a few users, it was found that the replacement of the layers of filter media was a huge problem. To address this issue, the filter media (fine aggregate, sand, activated carbon, and orange peels) was reorganized into separate containers, stacked one above the other, and interconnected to facilitate water flow from the top container to the bottom (Figure 19).

Figure 16 Path of water flow in the container with baffles

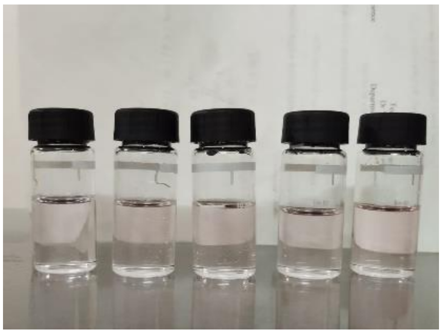


Figure 17 Test samples taken at regular time intervals for the chlorine/chloride tracer study

To improve the efficiency of filtration physical barriers or baffles (Figure 16) were introduced in each container, effectively slowing the water flow, increasing retention time, ensuring maximum contact of water with the filtration media (contact time) and distributing the water evenly across the entire surface area and facilitating sediment settlement.

Baffle Factor was estimated using Chlorine/Chloride Tracer study and the results showed a significant increase in retention time by lengthening the water path and guiding the water flow more effectively.

Table 4 Baffle Factor Calculations

Volume of container (litres)	1.53
Flow Rate of input feed (litres/min)	0.9375
T (system time) (min)	Volume of container / Flow Rate 1.53/0.9375= **1.632**
Time at which the output reaches 10% of the feed concentration T_{10} (min)	0.45
Baffle Factor	T_{10} / T (system Time) 0.45/1.632= **0.28**
The HI93414 high accuracy Turbidity and Chlorine Portable Meter was used for chlorine measurements	

Fine aggregate (Figure 20) and Sand (Figure 21) strain out the suspended matter, solids from the greywater and activated charcoal/peels of orange (Figure 22) remove organics that affect the taste, odour, color of the water.

Figure 18: Top container with baffle filtration setup

Figure 19: Four containers stacked together (housed in the top-most bucket)

Figure 20: Second container with fine aggregate and baffle slabs

Figure 21: Third container with sand. An additional layer of fine aggregate was added in the circular chamber to prevent sand from passing through to the next container

Figure 22: Fourth container with activated charcoal and orange peels

This container-based configuration allows users to simply detach a specific container from the network to clean or replace the media when needed.

The wastewater is treated through these baffles and gets stored in the middle part of the BV.

3) **Middle Bucket:** The middle bucket has a horizontal water float switch which controls when the water from the lowermost bucket should be pumped to the topmost bucket. If sufficient treated water is present in the middle bucket, the water float switch disconnects the connection and the water is not pumped, preventing any overflow.

   The middle bucket also has pH and turbidity sensors installed which continuously monitor the quality of treated water, providing real-time information of the quality of treated water. When the water quality of the treated water begins to deteriorate, it helps ascertain when the replacement of the filter media is required, ensuring cleaning and hygienic surroundings.

   The bucket also has UV Lamps for decontamination of the filtered water, killing bacteria, pathogens (if any) and preventing microbial growth.

   A two-way bib tap is connected to the middle bucket, one outlet is connected to the cistern of the WC and through the other the filtered water can be used for other non-potable end-uses.

   The lid of the middle bucket is joined to the top bucket through a PVC bulkhead fitting. This connection helps water flow from the top bucket to the middle bucket.

Figure 23: Middle bucket with water float switch and outlet

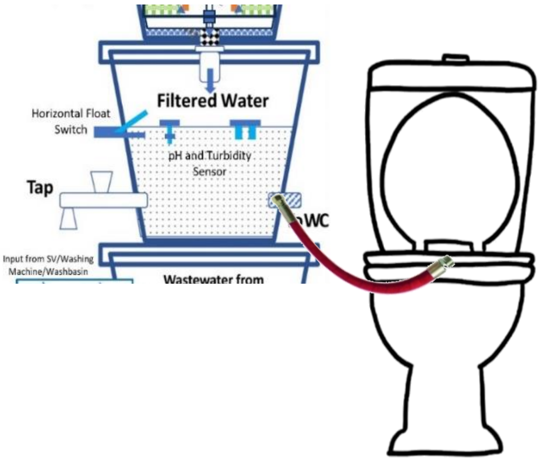


Figure 24: Schematic showing the outlet from middle bucket connected to cistern of WC

4. Key Features and Benefits

This system is compact, environment friendly, low cost, modular and scalable, intelligent, and smart. Various features are detailed out as follows.

1) **Compact:** One of the barriers highlighted by the survey respondents was lack of space for installing a wastewater system. BV has a vertical stack design inspired by the classic stack composter called Khamba which fits into tight spaces. This design takes less floorspace

equivalent to the space taken by a water bucket, about one and a half feet (Figure 26). The SV too fits into any drain like a plugin.

2) **Environment Friendly:** It uses natural materials like Fine aggregate, Activated carbon, Sand which last for a longer period, making this system an environmentally friendly solution.

3) **Economical:** The components used in the project are low-cost materials, easily available in the local market. The whole setup costs about ₹2,000 (Table 5). A family of 4 can recover the money in a year through savings in their water bill.

Table 5: Cost breakdown of whole setup

S.No.	Item Name	Qty	Unit	Cost (₹)
1	Paint Buckets	3	Nos.	450
2	Fine Aggregate	3000	cm^3	10
3	Fine Aggregate	3000	cm^3	10
4	Sand	3000	cm^3	30
5	Activated Charcoal	3000	cm^3	100
6	Connecting Pipes	5	m	30
7	Water Cooler Pump	2	Nos.	300
8	Controllers and Sensors	5	Nos.	1000
	Total			**1930**

4) **Simple to assemble and install**

Figure 25: Modular setup of the BV where additional buckets can be added

Figure 26: A photo of the installed setup demonstrates its ability to fit into a small space through vertical stacking.

5) **Modular and Scalable:** The BV design is expandable and scalable, and more buckets can be added if there is a need to store and recycle additional water to meet the demand (Figure 25). It can be easily scaled at society, city, state, and country level as it requires no changes in the

existing plumbing network of bathrooms or society. The setup can also be designed innovatively to match the bathroom interiors.

6) **Intelligent and Smart:** The system incorporates various sensors, including the water float switch, horizontal water float switch, Arduino Uno, pH sensor, and turbidity sensor to streamline the pumping process, ensuring energy efficient operation and minimizing human intervention.

   The operation of the SV and BV pump involves a series of checks to determine when it should be activated which is done with the help of water float switches strategically attached to serve the purpose. The pumps run periodically and are not pumping water constantly, operating for about 10 seconds in 5 minutes. As a result, the total carbon footprint—including emissions from installation, energy use, and wear-and-tear replacements over time—is minimal. Arduino Uno also logs water usage through an in-line water meter and the user can see the amount of water saved on a daily, monthly, or annual basis (Figure 27).

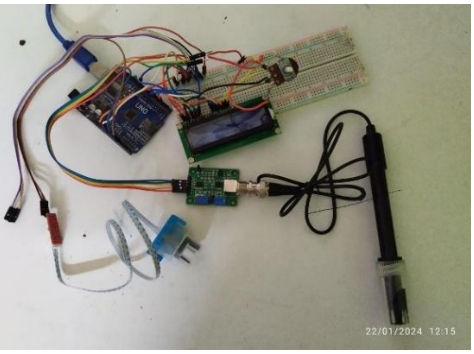


Figure 27: Arduino setup with LCD display, pH sensor and turbidity sensor

Figure 28: The setup can be designed aesthetically to match with bathroom interiors.

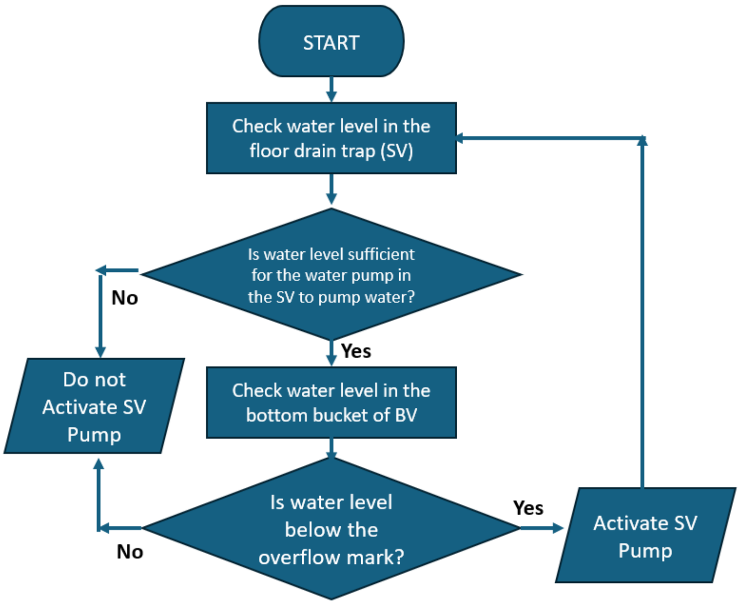


Figure 29 Algorithm for pump operation of SV

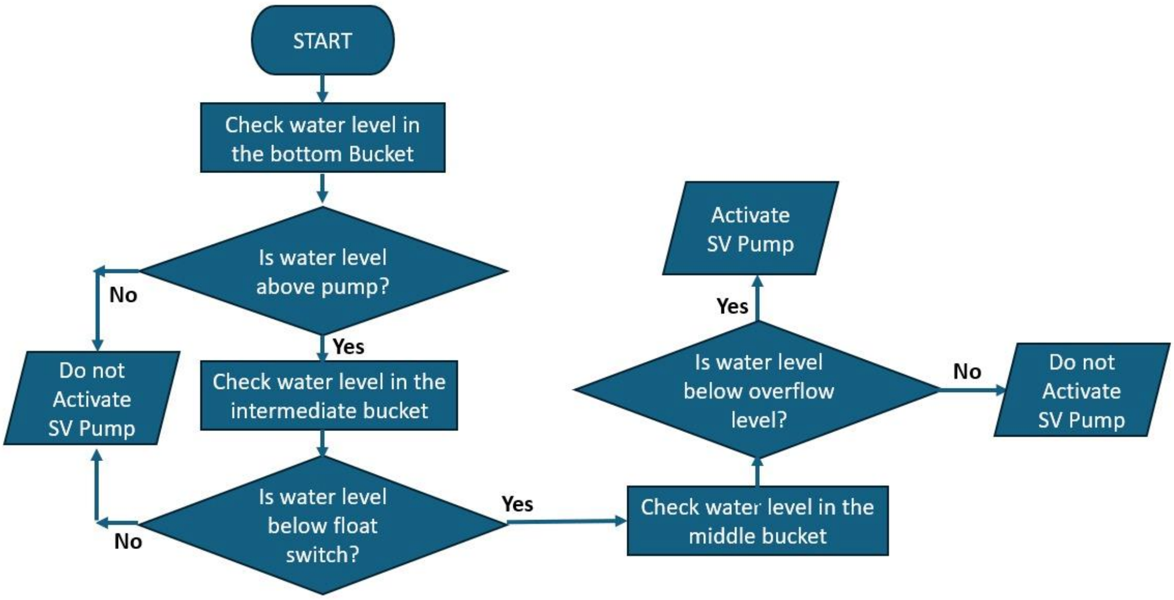


Figure 30 Algorithm for pump operation of BV

5. Impact Assessment: Projected Water, Energy and Cost Savings

The proposed product invention has the potential to conserve water addressing the water shortage issue not only at household level but at community, city and global level.

A single-family home of 4 people with an initial investment of around ₹2,000 can save around 5,000-6,000 litres of precious potable water per month and can recycle and reuse 50% of their water demand through this system. A household can recover the money in a year through savings in their water bill and at the same time save around 50,000 litres of potable water annually.

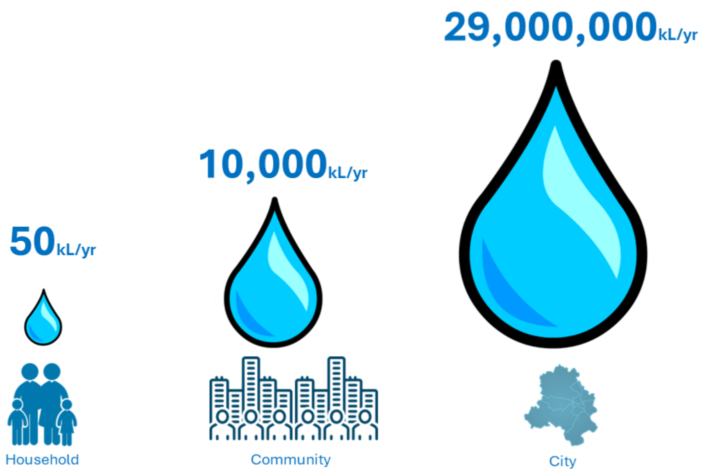


Figure 31 Infographics showing water savings at different levels

As per the 2011 census, 2.9 million households in Delhi have proper bathing facilities within the premises. If 20% of homes in Delhi adopt this solution and considering 100-litre water savings per day, Delhi city can save 58 MLD of fresh water per day. This will also result in saving pumping energy as the municipal corporation will have to pump less water because of lower demand, resulting in lower carbon emissions in water conveyance. The estimated annual savings is 18,000 tCO2e (Table 6).

Table 6 Emission saving calculations

Energy embedded in water treatment; pumping; waste processing (kWh/m3) (CLASP, 2021)	0.98
Quantity of water saved if 20% household adopt the solutions (MLD)	58
Energy saved due to lower water demand (kWh/day)	58,000 (m3) x 0.98 (kWh/m3) = **56,840**
Grid Emission Factor (Central Electricity Authority, 2023) (kgCO2e/kWh)	0.887
Emissions saved per day (kgCO2e)	56,840 (kWh) x 0.887 (kgCO2e/kWh) = **50,417**
Annual Emission savings (tCO2e)	50,417/1000 x 365 = **18,402**

As the solution also minimizes wastewater generation and is decentralized, it alleviates the burden on centralized municipal sewage treatment plants. Specifically, it could reduce sewage production by up to 5,81,39,740 liters per day and would in turn lead to less load on the STPs. Just to put the picture in perspective, the capacity of Pappankalan Sewage treatment plant (CPCB, 2004) is equivalent to the water treated and reused by BV, if 20% of homes in Delhi adopt it. The calculation shows that this decentralised system consumer 80% less electricity compared to city level sewage treatment and pumping energy (Table 7).

Table 7 Centralised v/s Decentralised system energy consumption/emission comparative

No. of Household with proper bathing in Delhi	2,900,000
20% of household implement this system	580,000
Quantity of water saved by a family per day (Liters/day)	100
Total Water saved at city level (Liters)	580,000 x 100 = **58,000,000**
Centralised System-Energy Consumption/Emissions	
Energy embedded in water treatment; pumping; waste processing (kWh/m3) (CLASP, 2021)	0.98
Energy Consumption at centralised level (kWh)	0.98 x 58,000,000/1000= **56,840**
De-Centralised System-Energy Consumption/Emissions	
Bilge Vessel+ Scupper Valve Pump Wattage(W)	36 W (18W + 18W)
Average consolidated operation hours (hr)	0.566
Energy Consumption for one household (kWh)	36 x 0.566 /1000 = 0.0204
Energy Consumption for 20% of Delhi's household	0.0204 x 580,000 = **11,832** **(~80% lower than centralised system)**

With reduced strain on the municipality, there's an opportunity to avoid constructing additional centralized sewage treatment facilities, resulting in one-time infrastructure cost savings of ₹56 million and annual operational cost savings of ₹36 million.

6. Results and Discussion

1. Analysis of Treated Greywater Quality

The results (link) of the treated greywater sample have been analyzed and compared against the wastewater standards for flushing from various countries, including the United States, Japan, India, Abu Dhabi, the United Kingdom, and Jordan. The detailed comparison of each parameter's test results against the standards is presented in Table 8.

Table 8 Comparative Table of Treated Greywater Performance Against Standards from Different Countries

			Standards and criteria/guidelines for water reuse for toilet flushing					
Parameter	**Unit**	**Sample Test Results**	**India (CPEEHO)**	**US (EPA)**	**Japan**	**Abu Dhabi**	**UK (BS8525)**	**Jordan (JSI 767)**
Turbidity (NTU)	*NTU*	18	≤2	≤2	NU	≤5	<10	≤5
TDS	*mg/l*	849	2100	-	-	-	-	-
pH	*unit less*	7.48	6.5 to 8.5	6.0-9.0	5.8-8.6	6-8.5	5-9.5	6.0-9.0
BOD	*mg/l*	21	<6	≤10	≤20	≤10	-	≤10
Residual Chlorine	*mg/l*	Absent	1	1	-	0.5-1	<2	-
Total Phosphorous	*mg/l*	0.01	1	-	-	-	-	-
Nitrate Nitrogen	*mg/l*	11	10	-	-	-	-	50
Oil & Grease	*mg/l*	1.4	10	-	-	-	-	-
Faecal Coliform	*No./ 100 ml*	118	Nil	ND	1000	23	250	<10
Helminthic	*Eggs/litre*	Absent	-	-	-	0	-	-

ND= Not Detectable
NU=Not Unpleasant

🟩 The sample test results show **compliance** with the standards and criteria/guidelines
🟧 The sample test results show **non-compliance** with the standards and criteria/guidelines

The **total dissolved solids (TDS)** are well within the acceptable range specified by India, suggesting that the treated greywater has a low concentration of dissolved substances. The **pH** of the treated greywater is within the acceptable range for all countries, indicating that the water is neither too acidic nor too alkaline and thus safe for various uses. However, the **biochemical oxygen demand (BOD)** exceeds slightly the limits for most countries, except Japan, highlighting potential organic pollution that requires further reduction. The **turbidity** level of the treated greywater exceeds the acceptable limits in all compared countries except Japan, indicating a need for further treatment to reduce particulate matter. The absence of **residual chlorine** in the sample is a positive outcome, reflecting that the water does not contain excessive chlorine, which can be harmful and undesirable in reused water. The **total phosphorus, nitrate nitrogen, oil** and **grease** levels are compliant with the Indian and Jordan standards. The faecal coliform count is significantly higher than the standards for India, the US, Abu Dhabi, and Jordan, suggesting insufficient disinfection, although it meets the standards for Japan and the UK. The absence of **helminthic eggs** in the sample complies with the standards for Japan and Jordan, indicating no parasitic contamination.

To reduce faecal coliform levels, we are considering using additional disinfection methods such as UV treatment, ozonation, or chlorination and also incorporating aeration to reduce the BOD levels. The filtration media significantly reduces turbidity from 382 NTU to 18 NTU. Turbidity levels in the range of 18-25 NTU are generally acceptable, provided that the Total Dissolved Solids (TDS) remain within permissible limits. To further improve turbidity reduction and account for user's specific perceptions and needs, we are experimenting with a wide-angle camera strategically positioned to monitor the floor drain trap in the bathroom. This camera will capture close-up images of the water flowing towards the floor drain trap, enabling the Scupper Valve to intelligently decide when to initiate the pumping process and when to drain the water.

Figure 32 Inlet Grey Water Sample (Right); Treated Greywater Sample (left)

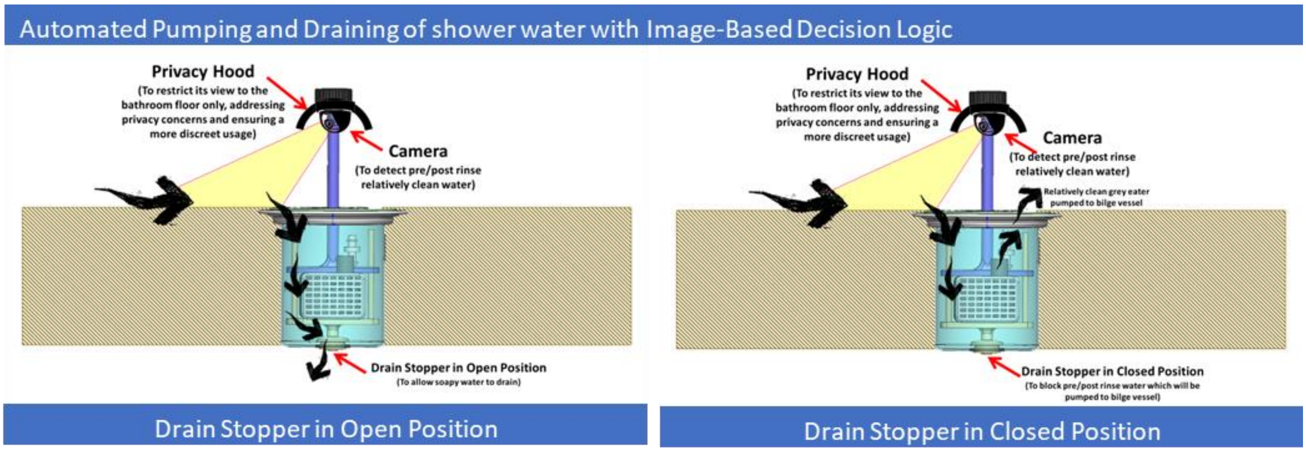


Figure 33 Schematic working of Camera and the floor drain trap to selectively capture pre and post rinse greywater

This ensures the selective pumping of relatively clean water specifically, the pre-cleansing shower water and post-cleansing water (based on personal demands and requirements) with reduced soap content to the BV. This innovative approach aims to enhance the detection and management of particulate matter, ensuring even clearer greywater for reuse. The results show that the image processing component is able to distinguish effectively between the pre-rinse and post-

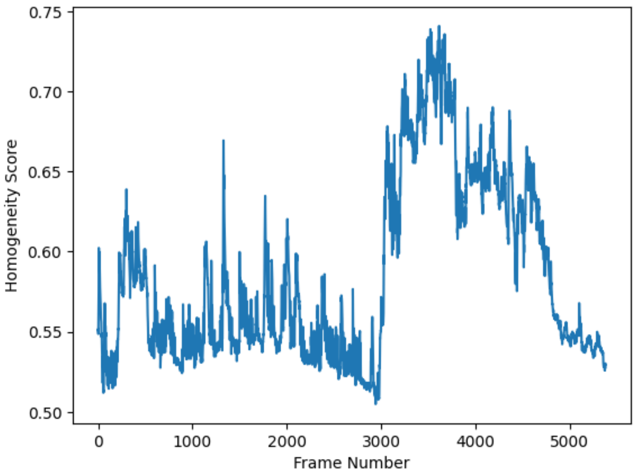
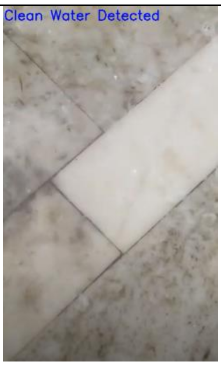
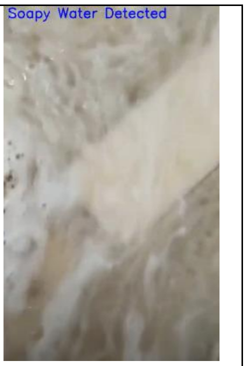
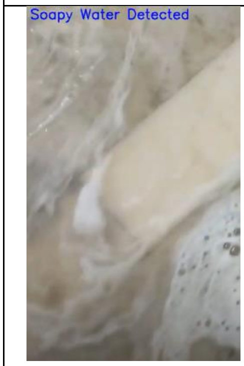
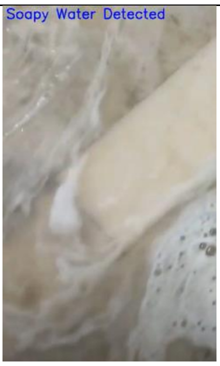


Figure 34 Homogeneity Score over time

rinse water from the heavily soapy flows, enabling effective operation of the device. The identification was carried out by homogeneity score (or homogeneity index) which is a measure used to quantify the similarity or uniformity of pixel values within an image or a region of an image. The figure shows higher homogeneity score around 3,000th frame where soapy water is seen in the video.

Table 9 Frames from Video Demonstrating Identification of Clean Shower Water and Soapy Shower Water

2. Prototype Performance Evaluation

The proposed prototype for greywater collection and treatment effectively collected and treated greywater to an improved level. SV seamlessly integrates with the existing flow drain trap and efficiently pumped greywater to BV. The water float switch intelligently regulates the pump, conserving energy and preventing burnout through automatic activation based on water levels in the drain. The incorporation of baffles in the containers slowed down the water flow, allowing suspended particles to settle. Activated carbon and orange peels in the last container effectively eliminated unwanted odors, enhancing overall water quality. The container-based setup allowed easy cleaning, efficiency and reusability of the filter media. Treated greywater stored in the middle bucket seamlessly integrates with the WC cisterns for flushing and other non-potable end-uses requiring no alterations to the existing home plumbing setup. This filter media has been widely used on a large scale for filtration for a long time. My intervention involves adapting this technology for use in an individual home setup, ensuring it is sleek, compact and efficient in its filtering capacities.

7. Conclusion

In India, only around 20% of the new and upcoming real estate is organised and have their own sewage treatment systems within their localities, while other unorganised real estate, individual homes and older buildings, and apartments lack such facilities. Moreover, in these newer constructions, greywater and sewage are combined after collection and then pumped to the local STPs. However, this process, in itself, requires significant energy as the wastewater must be separated into its different components before undergoing specific treatment processes for each. The proposed decentralised design interventions comprising the Scupper Valve and Bilge Vessel offer households an effective means to combat water scarcity without necessitating major modifications to existing plumbing infrastructure. The projected impact analysis, life cycle assessment and cost-benefit analysis reveal substantial potential for water, energy, and cost savings at both the household and community levels. This decentralized approach not only contributes to infrastructure savings but also plays a vital role in reducing operational costs associated with centralized sewage treatment plants. **In summary, our research and solution is an attempt to bridge the gap between theoretical knowledge and practical application. We integrate various sciences, technologies and design considerations, focussing on not only research but also considering the end-user and the overall impact.**

8. Future Plans

Below are a few areas to be integrated as the second phase of design improvement and additional functionality:

1. Conduct ongoing monitoring and evaluation to assess effectiveness and identify areas for improvement. Analyze the impact by comparing household water bills before and after implementation.
2. Connect the water meter to an online central website for real-time monitoring and quantification of water recycled and saved.
3. Refine the design of the SV and integrate the image processing component to it.

References

Ahmadpari, H., Sedigh, M. M., & Hassanpour, F. (2022). Investigating the use of gray water to achieve sustainable water management and optimizing water consumption. *International Conference on the New Horizons in the Agricultural Sciences, Natural Resources and Environment.* Tehran.

Alina, R., & Bryan, K. (2010). Life-Cycle Perspective on Residential Water Conservation Strategies. *Journal of Infrastructure Systems, 16*, 40-49.

Central Electricity Authority. (2023). *CO2 Baseline Database for the Indian Power Sector.* Ministry of Power, Government of India.

CGWA. (2016). *Estimation of water requirement for drinking and domestic use (Source: NBC 2016, BIS)* . New Delhi: Central Ground Water Authority, Government of India.

CLASP. (2021). *In-depth Assessment of Water Efficiency Opportunities in India.* New Delhi: CLASP.

CPCB. (2004). *Status Of Sewerage And Sewage Treatment Plants In Delhi.* New Delhi: Central Pollution Control Board.

CPEEHO. (2013). *Latest Manual on Sewerage and Sewage Treatment Systems Part A Engineering.* CPEEHO.

Diana, C.-B., Robert E., E., & Scott, M. (1996). An investigation into greywater reuse for urban residential properties. *Desalination, 106*(1), 391-397.

Griffiths-Sattenspiel, B., & Wilson, W. (2009). *The Carbon Footprint of Water.* River Network.

Khaldoon, M., Justyna, B., & R, B. (2011). Potential Fresh Water Saving Using Greywater in Toilet Flushing in Syria. *Journal of environmental management, 92*, 2447-53.

Michael, B., Jongho, L., Valerie, J., Varsha, V., & Rohit, K. (2014). Water Filtration Using Plant Xylem. *PloS one, 9*, 89934.

Ministry of Jal Shakti. (2020, March 02). Retrieved from https://pib.gov.in/PressReleasePage.aspx?PRID=1604871#:~:text=As%20per%20Ministry%20of%20Housing,to%20higher%20level%20by%20states.https://cgwa-noc.gov.in/landingpage/Guidlines/NBC2016WatRequirement.pdf

Sam, G., Pawan, L., & Satish, W. (2009). Greywater reuse in residential schools in Madhya Pradesh, India—A case study of cost–benefit analysis. *Resources, Conservation and Recycling, 53*(5), 287-293.

Sangwoo, S., Orest, S., Patrick, W., & Howard, S. (2017). Membraneless water filtration using CO2. *Nature Communications, 8*, 15181.

Shobha, M., Kanagaratnam, B., & Nicole, S. (2011). Quantification of potable water savings by residential water conservation and reuse – A case study. *Resources, Conservation and Recycling, 55*(11), 945 - 952.