Rainwater Harvesting and Filtration System.

EE399 - Semester 2 Community-Based Project

Final Report

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Abstract

The Average roof in Ireland produces approximately 1,000 litres of water per square meter each year, which for most houses adds up 100’000 litres each. The model that we have designed will allow houses to collect and efficiently make use of the water that would otherwise run off the roof. [1]

Introduction

According to Irelands national water utility, Uisce Éireann, formally known as Irish water, the amount of water the average person uses a day is 133 litres. When compared to the statistics for rainfall in Ireland along with the average roof area, this yields a value of almost 273 litres a day for each household, with an average of 2.75 people per household in Ireland according to the latest CSO results. This all means we can approximate that over 75% of the water each household needs per year could potentially be collected from the rain falling on their roof. [1][2][3]

The aim of this project is to design a system that will collect the water that is already running off a house via the guttering and store it in series of tanks where it is cleaned and filtered to be ready to use indoors for applications such as the toilets, showers and even for washing dishes. Upon embarking on this the project goals are as follows,

- To further investigate the need for enhanced water collection.
- To research the suitable design requirements necessary for such a system.
- To design a multi tank system to store, filter, and clean to water to a safe degree to use inside the house.
- To design a prototype system for demonstration and testing.

Should an efficient rainwater collection system such as this, be implemented in every house in Ireland, the need for mains water could see a reduction as high as 75%, if this statistic were not impressive enough, the remaining 25% would also be used far more efficiently. 99.9% of houses in Ireland had a piped water supply by 2016, 99.6% of which is deemed safe to drink. [2][3]

This does however mean that unless a house already has a water collection system in place, the water being flushed down the toilet in 99.6% of houses, would have been clean enough to drink. Therefore, this highlights the need for a much more efficient use of the resources we have available to us. [2]

Community Engagement

As part of the research that was undertaken for this project, community engagement was an exceptionally large consideration. The degree to which our proposed idea would be able to increase the efficiency of water usage, solely depended on the amount of rainwater currently not being collected and used in the house.

A survey was designed to gauge the number of households that currently implement any sort of water collection system, and building on those that had, the possible uses for the water they had collected along with any concerns for the cleanliness of the water.

These surveys were distributed between a wide range of candidates, such as those that lived in estates, ‘one-off’ houses, and even those that lived in shared house schemes and apartments where water collection may or may not have been implemented by the owner of the property.

Survey 1

1. Do you currently implement a rainwater collection system where you live?

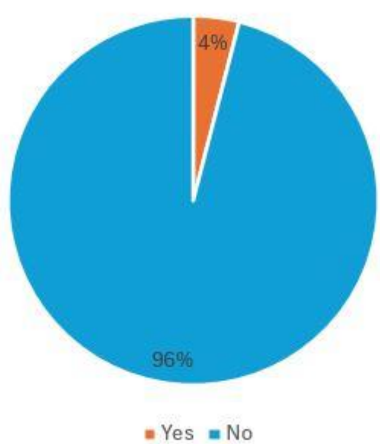


Figure 1: Pie Chart of survey.

2. If yes, what do you use the collected water for?

Response 1: “watering the plants”.

3. If not, is there any particular reason you do not have one?

Response 2: “The return on investment seems longer than solar panels”.

Response 3: “Apart from cost I also have a small roof”

Response 4: “I don’t have a garden so there would not be much use for one”

Response 5: “The water probably wouldn't be very clean”

Response 6: “We have a well instead”

Response 7: “Cost may be expensive”

Response 8: “No Room as I live in an estate

4. Have you got any concerns regarding the cleanliness of the water collected?

Response 1: “I don't use it inside the house just in case it is not clean”.

Response 2: “I don’t think rainwater is safe to use in the house as it is”

Response 3: “Yes, I think the water would need to be filtered”

Response 4: “Yes, sometimes the water smells after long periods”

5. Would you be open to a rainwater collection system that cleans the water as it is collected? do you see any drawbacks with a system like this?

Response 1: “Yes, I usually have a lot of water collected so it would be great to get more use out of it. Would size be an issue?”

Response 2: “I would be open to the idea. Where do I store it?”

Response 3: “Yes, so long as it is affordable”

Response 4: “How much would it cost”

Addressing community

The surveys were collected, and the results analysed to determine whether a rainwater harvesting, and filtration system was a worthwhile investment. While all survey participants were in some way open to the idea of a rainwater collection and filtration system all the participants stated they had no water collection system currently in place with only 1 participating stating they had, which was only used for gardening. While this was a shocking statistic for a country with so much rain, (1000-2000mm per year), it does point towards a large gap in the market for an affordable rainwater collection and filtration system that could be implemented in any house in Ireland. Making use of the filtered rainwater for more than just gardening. [4]

One concern noted in the survey was the size and cost of such a system, our aim would be to produce a solution that is affordable to everyone, and small enough to be implemented in even small tight housing developments were space around the house is limited.

The more you can use the water collected, the less space you need to store it. Another one of the concerns raised in the survey was the safety of water that has been sitting for prolonged periods of time. This is true for simple existing rainwater collection systems where the water is usually only redistributed outside of the house, for applications such as gardening. However, should the water be used for things like flushing toilets and washing clothes, the length of time the water is stored is reduced as it is being used up as fast as it is being collected.

Background Research

For the research for this particular project we started by looking at existing solutions for both small scale rainwater harvesting along with commercial solutions, and noticed a significant gap in the market for anything in-between. We then looked at the levels of bacteria different systems deal with.

Sustainable drainage systems

Sustainable drainage systems, or (SuDS) is a blanket term given to large scale rainwater harvesting solutions aimed to control the flow of run off rainwater focused on a sustainability standpoint. While this includes the idea of reusing rainwater within the house, there are many advantages to having more control over the flow of the runoff water, one of these advantages being a reduced risk of flooding. Large built-up areas where natural soakaways have been removed and replaced with concrete, or other nonporous materials, come with a risk of flooding. Particularly if a standard drainage system was used. By implementing rainwater harvesting for every individual household, suddenly the amount of water running of into soakaways and drains is more manageable and the risk of flooding is reduced. Not to mention the harvested rainwater itself means there would be a much smaller demand for large scale water treatment, which of course is especially important from the perspective of sustainability. [5]

Existing rainwater harvesting systems:

Simple Household solutions

The most common solution to rainwater harvesting that currently exists for personal use is the use of water butts. These water butts are plastic containers, often green in colour and placed at the side or back of a house receiving a water feed directly from the guttering system that is already in place for the house. While the use of a primitive system such as this is still extremely useful and will indeed reduce the amount of clean water used for the household, there is an array of issues associated with this method.

- **Debris is the water:** In most cases the water butt harvests rainwater from an open gutter system meaning that any debris from the roof of the house such as leaves, and dirt get collected in the tank at the bottom.

- **Lack of filtration system:** This type of water butt systems lacks any sort of filtration with the water simply stored in the tank that it has been harvested into directly from the gutter.

- **Lack of integration with the household:** The water that has been collected in the water butt is accessed via a plastic tap at the bottom of the tank which poses several issues. The water at the bottom of the tank is the water containing the highest level of debris as it will have sunk to the bottom. A tap system like this is exceedingly difficult to use for anything other than gardening as it requires the tap to be manually opened and the water collected in a bucket for redistribution. It is impossible to buy a system like this that can be easily integrated into the household for even things such as the toilet flushing.[2][5]

Commercial Solutions

While small scale rainwater harvesting is still a very uncommon practice amongst the average household, there have been some steps taken for commercial implementation of such systems. Instead of using standard plastic water butts placed outside commercial buildings, underground water tanks have been used instead. There are many advantages to this, for one, it is far easier to manage large volumes of rainwater as the underground tanks can be far bigger whilst taking up less otherwise useful space. This would pose a huge advantage even for tightly spaced houses where even a small underground tank would avoid compromising the above-ground space. This would be especially important for new buildings, where the cost of implementing an underground tank would be least severe. [2][6]

A second advantage of the systems seen implemented in commercial settings is the reduced disturbance in the water quality due to environmental impacts. When the water is being stored underground as opposed to sitting in a plastic tank by the side of a house, potentially harmful impacts such as the sunlight heating up the water in tank can be avoided. While heating water to a boiling point will kill bacteria, a small amount of heat can spread bacteria and it more harmful. The tank itself will also receive a faster level of degradation when exposed to the elements. While the upfront cost of them may be higher, they should last far longer, making them the more efficient option where feasible. That being said, collecting rainwater to filter in any capacity will be a major step forward for most households.

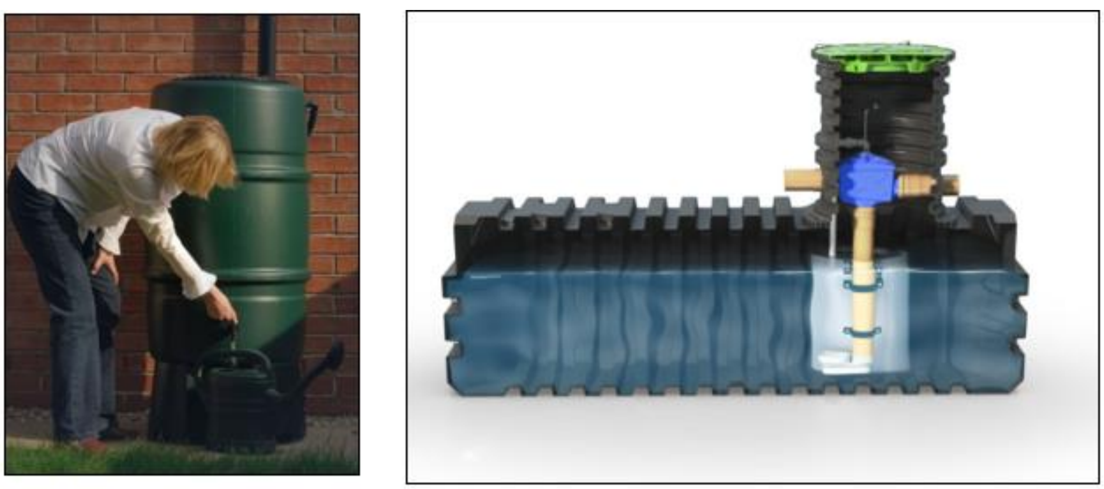


Figure 2: Existing water collection Solutions.

Bacteria in water

Rainwater itself does contain some level of bacteria, however much less compared to ground water, most of the bacteria our system would have to deal with would be picked up as the water is running off the roof and into the first collection tank. While an ultrasonic cleaning component would separate the different particles in the water, a filter would be needed to catch them and stop them getting through the system. For an application such as this, where the water is not going to be used for drinking, charcoal mesh filters would be more than adequate.[7]

Project Management

Gant Chart

Figure 3: Gant Chart

Breakdown of tasks

The project timeline will be split up into various stages focusing on each aspect of the project. The first step will be to research the several types of systems used to clean and filter water. The second will be to design up a compact protype to clean and store rainwater using the different methods researched, after this we will hope to build the protype which we can then test to obtain results at which point we will hopefully made significant progress towards creating a rainwater harvesting system which could be easily implemented in the vast majority of households around the country.

Technical information

After conducting our research, the conclusion was reached to design a 3-tank system whereby the rainwater is collected in the first tank and stored temporarily, a second tank then uses a method of ultrasonic filtration where the solids are separated from the water and sink to the bottom where they can then be extracted by a method to suit the scale of the system. The clean water that has now been separated from the contaminants will be filtered once more into a third tank with a more commonly used method consisting of mesh and charcoal filters. The water in the third tank is as far as this prototype will go, as this demonstrates the full process and the possibility of implementation. From here the water can be stored in either underground tanks, or tanks that are situated inside the house where the standard water supply is stored, where it can be used straight away for flushing toilets and applications such as washing clothes.

Ultrasonic cleaners

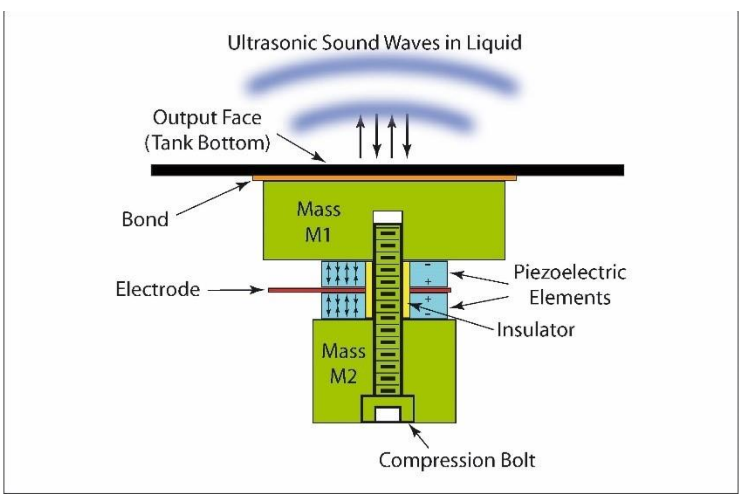
For our system, How an Ultrasonic Cleaner works is pivotal to the understanding of the proposed circuit. An Ultrasonic Cleaner works by producing high-frequency sound waves through a medium, often water to agitate solids and loosen the molecules also known as cavitation, for later allowing for easier filtration later in the system. These operating frequencies produced are around 40 kHz.
Cavitation is where using the sound waves energy creates a cavity. This cavity forms a microscopic bubble in the solution placed in the ultrasonic cleaner. These bubbles implode forcing contaminants to dislodge from the solution and depending on density, the resulting solution will be skimmed from varying heights in the tank. The components used in an ultrasonic cleaner are three components both equally as important as the last. The first component is a tank or reservoir to clean the fluid.

The secondary component is an ultrasonic generator. This power electronic circuit converts ac electrical energy. This energizes the transducer at an ultrasonic frequency. To simplify, the ultrasonic generator sends a high voltage electrical pulse to the transducer.
The ultrasonic generator working principle is to send electrical energy pulses to the transducer, which transforms energy into mechanical (pressure) waves in the cleaning fluid for vibratory ultrasonic washing action. While the ultrasonic frequency of 40 kHz is a good middle ground to balance in force of bubbles to rate of bubbles per second enabling fine cleaning detail. If the frequency is lowered to 20kHz, this allows for larger particles to be cleaned, however this is not useful for cleaning water, so on the other hand, a higher frequency for example 200kHz can clean the water effectively but sacrifices efficiency as the total cleaning time increases substantially.

Figure 4: Ultrasonic Generator

[8]

Lastly, the Ultrasonic transducer converts the ultrasonic electrical energy produced by the power electronic circuit to mechanical energy via the previously mentioned cavitation process. This device generates sound waves well above the average human hearing threshold of 20kHz, known as ultrasonic vibrations.



[9]

Figure 5: Ultrasonic Transducer

The transducer construction is an active element, with this use case a piezoelectric crystal, a backing plate or M2 in fig -, and the radiating plate or M1 in the above figure. The piezoelectric crystal utilizing the piezoelectric effect, changes size and shape when receiving electrical energy. The backing of the transducer absorbs the energy radiating from the back of the piezoelectric crystal, this is done with a thick-walled material. The radiating plate of the ultrasonic transducer acts as a diaphragm converting ultrasonic energy into mechanical pressure waves through the solution in the tank. When the piezoelectric crystal pulses electrical energy, the radiating plate reciprocates ultrasonic vibrations into the tank. [8]

Filtration

Fine Mesh filter

The Fine Mesh Filter (FMF) section goes hand in hand with a GAC filter layer. A FMF has anti-bacterial properties depending on the size of the holes in the cellulose layers. To do this, the holes need to be smaller than the bacteria, however this decreases flow rate. To increase flow rate of the filter paper is needed as electrical pump will cause clogged paper filters, an alternative is to use positively charged filters, this process of positively charged layers is called Layer by layer (LBL) modification. This process is achieved by alternating the adsorption of cationic Polyvinyl amine (PVAm) and anionic Polyacrylic acid (PAA). The paper filters were modified by the LBL method to introduce a positive net surface charge onto the cellulose fibres. To conclude, 3 layers is the best balance of LBL modification. [10]

Figure 6: Combined Fine Mesh Filter and GAC

Granular Activated Carbon (GAC) Filter

Granular activated carbon also known as “charcoal” filters, is made of a raw organic material, in this case the raw material is coconut shells due to the high concentration of carbon. Heat, or the energy generated by high flow of water activates the carbon’s surface area. This activated carbon removes certain dissolved chemicals or solids in water as its going through a GAC section of the filter absorbing a portion of the TDS. This is heavily reliant on the concentration and average contaminates in the water, as well as the total water usage. This is necessary to determine the amount of GAC needed so refill periods are not frequent. GAC is a finite resource, due to the performance reduction as it continues to bind and remove chemicals, replacement is needed periodically. This period is typically several years or higher, replacement will eventually need to take place. However, the benefits outweigh this drawback. [11]

System Design and mathematical equations

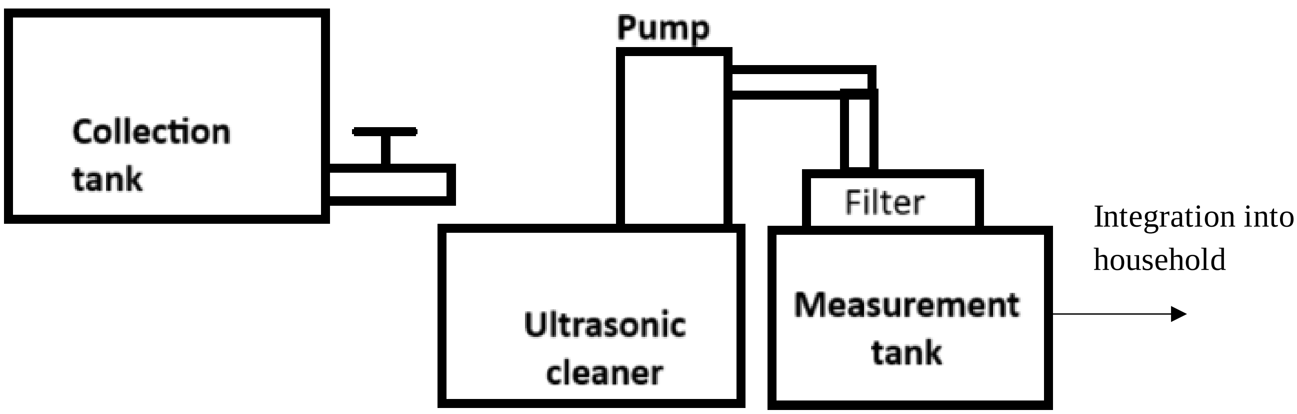


Figure 7: Ultrasonic water collection system.

Single tank 	$\frac{H(s)}{F(s)} = \frac{1}{sA+k}$	Input – flow rate, F Output – height of liquid, H	A – Cross-sectional area of tank (m^2) k – constant*

Figure 8: Transfer function single tank breakdown.

Transfer function of a single tank

$$\frac{H(s)}{F(s)} = \frac{1}{sA + k}$$

Figure 9: Transfer function equation.

F = flow rate

H = height of liquid in tank

A = Cross-sectional- area of tank

k = constant

This transfer function would work for the first tank, with addition with more than one tank in the system, an adjustment for flow rate is needed for the pump.

Finished Model

Figure 10 represents our finished model, the model follows the diagram consisting of an initial collection tank, followed by the ultrasonic cleaner from which the water is then pumped into the filtration system, and lastly into the final storage tank.

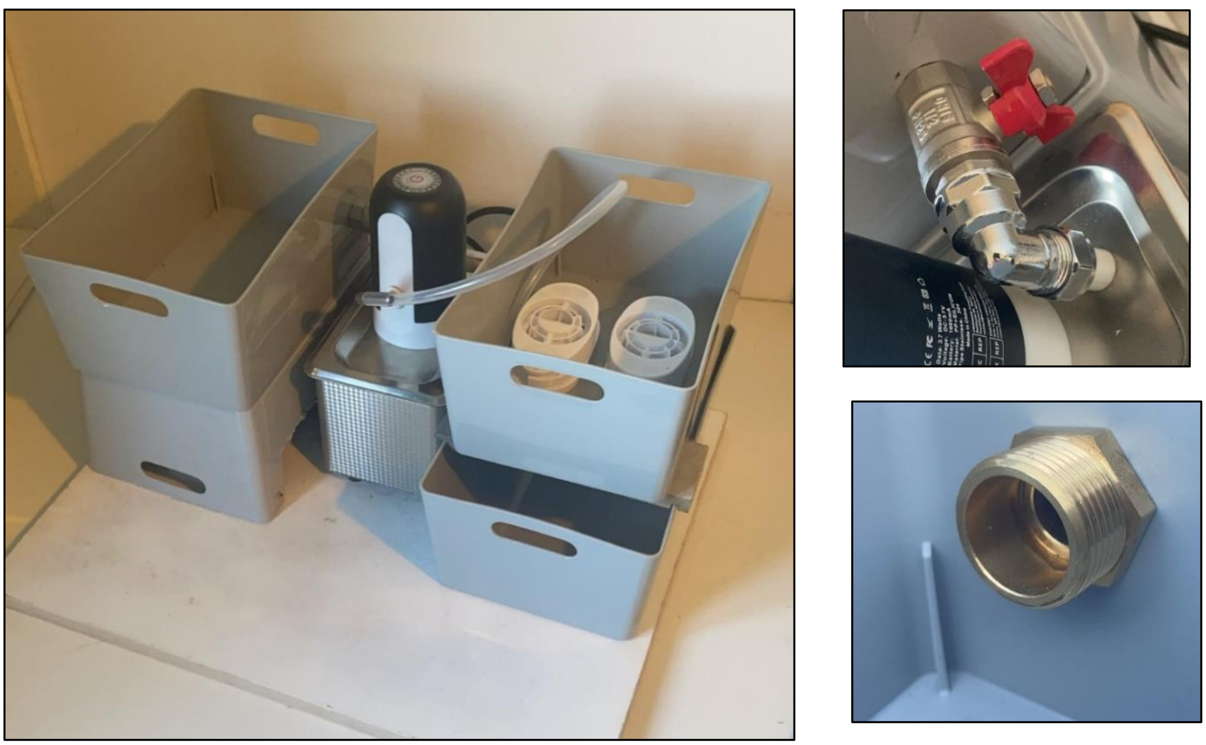


Figure 10: Physical Model

Results

TDS (Total Dissolved Solids) testing

Testing process

All equipment used is rinsed with deionised water pre and post use to ensure non contamination of water samples. Each water sample is collected with a syringe, tip is 5mm to ensure that TDS value is not affected by extraction. Then the sample water is pumped into a glass vial and sealed to further ensure non contamination.

Category	Unchanged	Filtered	Ultrasonic w/o Filter	Ultrasonic w/ Filter	Skimmed
Clean water	175	160	150	145	50
Mcdonalds tea	750	450	300	100	45
River Water	2675	1735	600	170	70
Dirty water	15000	6185	2345	230	90
Sea water	8350	4860	1475	180	75
Rainwater	850	400	250	80	40
Bottled water	350	210	195	150	50

Analysis of System performance

Testing the combined fine mesh and GAC filter on its own, there is a significant reduction in TDS compared to even the ultrasonic cleaner on its own. However, there was a noticeable degradation in the filter after only a few dozen complete cycles of the system. Trying to pinpoint this was pivotal in the final design of our system.

With the control of clean water, there is a clear reduction in TDS after every process in the system, confirming that each independent component work effectively. Outside of the control, as a test, dirty water, taken from puddle near Lyreen river, Maynooth, while the river water was obtained from the same river. Even with the initial worst preforming TDS value, post full system process, the water is within safe thresholds for use. The most favourable is rainwater post ultrasonic cleaner with the filter and skimmed resulting in a TDS reading of 40. This supports our target water source of rainwater being worthwhile to process, as the system is safe for use in businesses and in the home.

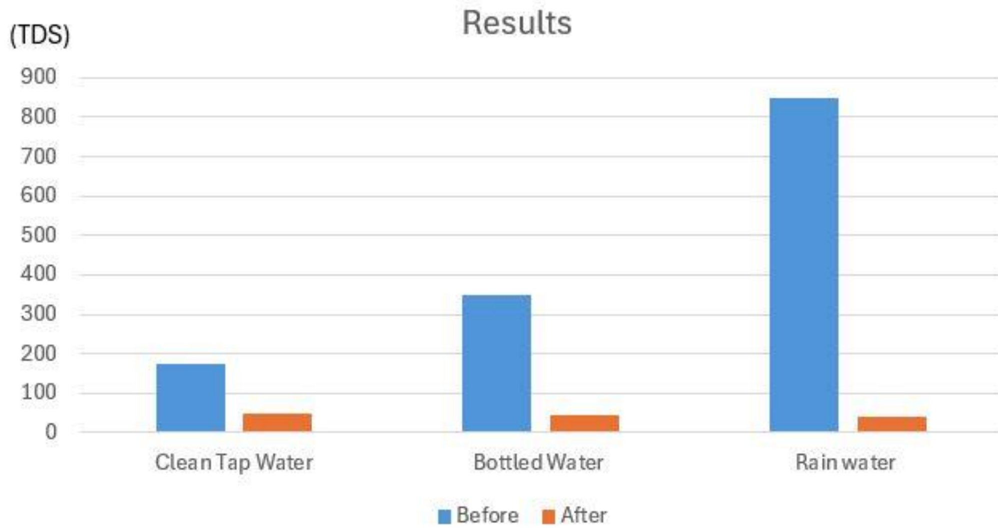


Figure 11: Graph of TDS readings.

As seen in the figure 11, there was a significant reduction in all values of TDS for the different types of water tested, when rainwater was compared to drinking water whether from a tap or a bottle. The finished results were approximately the same. The reduction in the values for the drinking water is due to the added minerals in the water such as fluoride or lime.

These results were gathered for a volume of 1 litre of water with just 1 minute of ultrasonic cleaning.

Ethical considerations

Ethical considerations were a huge factor for a project that revolves around the sustainability of our water supply, to begin, we made sure our project was following the (SuDS design) guidelines as indicated by Dublin City Council, the following objectives are deemed the pillars of these sustainable systems:

Controlling the quantity of runoff water

Our designed system operates by harvesting the runoff rainwater from the roof of a house which would otherwise be directed straight into the waste drain. One if the ethical considerations considered was to carefully control the quantity of water in the system. It would be potentially harmful to if the system was to start overflowing and potentially flood the homes where the system had been installed. While our system is only a prototype, it is still necessary to consider that an overflow feed would be necessary to prevent flooding in the event that a household is using less water than they are harvesting and have the capacity to store.

A simple solution would be to redirect the overflow back into the main drains that would have originally been used before a rainwater harvesting system was put in place. However, it would be even more optimal where space is not restricted, to redirect this water back safely into the ground, following the sustainability directives laid out by Dublin city council. This may be done using filter drains and channel rills to slow the runoff water. Another effective solution where free space is optimal is a controlled reed pond or wetland, directing the water into a contained area to naturally irrigate posing a minimal negative impact to the environment.

Managing the quality of the runoff water

By collecting the rainwater straight from the roof, we are minimising the risk of the runoff water carrying pollution into nearby streams and rivers, especially in areas of high pollution such as farming fields where fertiliser is being used. In this case, the roof space from the sheds may be used to significantly reduce the rainwater running off into the fields and flushing pollution into areas where it may cause harm to humans or other wildlife.

Creating and sustaining a better place for people

Cleaning water to a drinking level quality takes significant resources not to mention a high cost, currently at the expense of the Irish government funding most but not all the clean water supplied to 99.6 of the houses in the country. Regardless of who is paying for it, however, there is no denying significant steps forward must be made to increase the focus on making this practice more sustainable. One of the aims of this project is to provide an opportunity to reduce the amount of clean water that is wasted for functions such as toilet flushing and clothes washing thus reducing the demand for resources required in the process and encouraging a more sustainable practice.

Health and safety

The water used for this particular project was tested throughout to ensure health and safety was the number 1 priority. It is worth noting that additional steps such as UV treatment would be necessary for any guarantee that the water is to a drinking standard. The aim of this project was to produce water that can be used inside the house for applications such as flushing toilets and washing clothes, and thus still reducing the need for clean drinking water.

Conclusion

The development of a rainwater collection and harvesting system is overall a beneficial addition to any Household in Ireland due to the amount of rainfall Ireland sees per annum. The goal was the create an effective, simple and sustainable system that works by collecting, cleaning, and distributing rainwater throughout the house with little to no downtime. The proposed system in this document achieves these goals (testing).

The initial problems with the system were how to remove contaminants in the collected rainwater, by looking at previous industrial and domestic solutions to rainwater cleaning. The result was two extremes on the market, which we believed were not sufficient in either water quality in cheaper systems, and the overall cost of installation or cost of maintenance on more expensive systems. Our solution is an ultrasonic cleaner pre-fine mesh and GAC filter. We observed increased reliability and longevity in the system while achieving consistent water quality.

A clear focus throughout the development is customer feedback, ensuring that the customer requirements are met with valid adjustments. For example, one customer shared concerns over the issue of standing water affecting the quality, to combat this an additional tank was added to the system. The issue of standing water was mitigated while providing an extra layer of cleanliness to the collected rainwater.

To improve this self-sustaining system, many modifications can help either scale up or scale down the product. These include if the user requires more water on demand, a larger pump, the benefit of the addition would be twofold, an overall increase in system flow to the user and an increase in system reliability. Another addition could be to increase layers in number of or thickness of each layer in the fine mesh filter. Finally, an electronically controlled actuator valve, that could either work on direct customer intervention or level/pressure sensor in the initial water collection tank.

Upon the customer's request budget and/or space, the system can be scaled up or down to fit the needs of the user by size of tanks, pump, mechanical or electronically controlled valve, and wattage of ultrasonic cleaner.

Future work

For this system to be scaled up for domestic use, further testing would be required to discover how long the ultra-sonic cleaner would need to run to clean the amount of water harvested by the household, while our model uses very little electricity, it would be essential to only run the system for as long is necessary for it to remain a competitively efficient solution.

While the water harvested and filtered would be mostly clean enough to drink, as stated before, additional steps such as UV treatment would be necessary to ensure any bacteria collected has also been killed. This was not the focus of our model as the reduction of TDS values below a drinking level is more beneficial towards other appliances in the house. While the minerals in drinking water are good for our health, the build-up of these minerals reduces the life of plumbing components and appliances such as washing machines.

References

Date of Access – 20/04/2024

[1] - Irish Independent

[2] - Uisce Éireann

[3] - Central Statistics Office

[4] - Met Éireann

[5] – South Dublin City Council – (SuDs)

[6] - Commercial Rainwater Harvesting

[7] - Rainwater Bacteria

[8] – Ultrasonic Generator

[9] – Ultrasonic Transducer

[10] – LBL Modification

[11] - GAC Filters