JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

IoT Based Smart Rainwater Harvesting and Classifying System

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Abstract: **Groundwater is a significant source of safe drinking water. As the world's population grows, the need for concrete houses grows as well. As a result, the water table is not recharging naturally by the rainwater, and so it is decreasing. Climate change, population increase, industrialization, and high-water demands—are all causing drastic changes in water resources. Now, we are confronting water scarcity because of these reasons. In this type of situation, rainwater harvesting and efficiently utilizing harvested rainwater can be a live server solution for all of us. One of the common methods for collecting rainwater from the rooftops of buildings. But ensuring rainwater purity is a big challenge while collecting rainwater for drinking. In this paper, we have proposed an Internet of Things (IoT) based innovative solution for rainwater harvesting. Harvested rainwater is often contaminated with many things. That's why we need to purify them before drinking and cooking. But the filtration process of harvested rainwater can increase water expenses. That's why we classify rainwater while harvesting, and for this, we do not need to use any extra expensive filtration. Thus, we can get potable rainwater at a very lower cost. Moreover, we can use less pure water for other household tasks. Along with our designed smart first flush diverter, some sensors and ESP32 SoCs have been used to run the whole system. As a result, the proposed system can be a practical and useful solution for harvesting rainwater in households with ensuring water quality.**

Keywords: Rainwater harvesting, IoT, ESP32, Smart First Flush Diverter, pH, Turbidity.

1. INTRODUCTION

Groundwater has always been essential to the existence of animals and plants, and it is one of the most important sources of water still now. Humans have been using this water by digging wells since ancient times. Because of the diverse demands of the population, the demand for water has expanded several times in recent years. Water is used to save lives and is extensively used in households' day-to-day activities such as laundry, cleaning, gardening, car washing, and so on. As a large amount of water is used for household tasks, so rainfall that isn't suitable for drinking can be used for these day-to-day activities. In addition, the supply of water in certain families is still erratic; therefore, a rainwater gathering system would be beneficial in these locations. Concrete constructions are being built everywhere in metropolitan areas, making it very harder to recharge the underground water table through natural rain [1]. Rainwater, which is one of the important freshwater sources, is completely wasted by going through the drains. This results in a decrease in groundwater levels, which could prove fatal in the future. As almost all people in urban areas rely on groundwater, so it is necessary to find a way to prevent natural water from wasting throughout the drains. Moreover, governments need to monitor people's groundwater usage to reduce its misuse. As prevention is preferable to cure, now is the right time to test and deploy rainwater harvesting systems as much as possible. By installing rainwater collecting systems in residences, the underground water table can be refilled while also meeting water needs for daily use. After dealing with droughts and decreased groundwater levels, many states and local corporations of many countries have made rainwater collection systems mandatory for newly constructed structures.

To harvest rainwater, we need efficient rainwater harvesting systems. Many rainwater harvesting systems already exist in our present times. But most of them have various limitations such as heavy energy-consuming for filtration, costly, difficult to install and maintain etc. That's why we have developed a solution with modern technology to harvest rainwater automatically. The Internet of Things (IoT) technology is used for module-to-module communication in the whole system, and ESP32 SoCs control them all. As the system runs on low power, so 12V DC power supply from a solar panel is enough to run this system. Anyone will be able to use our proposed rainwater harvesting system on their rooftop. Our idea is to classify rainwater into 3 categories. The first category is the initial dirty rainwater, which our system will not store and release through the drainage pipe. The second one is less pure rainwater, which will store in a tank for household work like watering in the garden, toilet flush, washing clothes, house cleaning, vehicle washing etc. Lastly, pure potable rainwater will be stored in another storage tank after a certain period of rainfall. The quality of roof runoff rainwater is influenced by the roof and/or building elements (e.g., length, material, location). Rainwater pollution can be caused by industrial pollutants in metropolitan areas, fossil fuels from automobiles, and agricultural activities (such as pesticide emissions) in nearby rural areas [2]. Furthermore, dust, sediments, and feces from birds and rodents built on rooftops during dry seasons may impact the quality of collected rainwater [3]. As a result, contaminants may be present in higher concentrations in the first flush of roof runoff water, i.e., the first water volume of a rainy event. For these reasons installing a device (or, in this example, a valve) we have separated the first-flush water from the remainder water collection can increase the quality of the harvested water [4]. Sometimes rainwater might be acidic. That's why our system also measures the acidity of the rainwater before storing it in the storage. To ensure storing the cleanest rainwater, it also measures the turbidity of incoming rainwater through the water collection pipe. This paper describes the whole system with some results data obtained from this system.

The paper has discussed in the sequence as follows: literature review in section 2 with existing approaches. The methodology of the proposed system is discussed in section 3 with some diagrams and flowcharts. In section 4, the results have shown with some relevant graphs and tables. Section 5 is all about a discussion on future works.

2. LITERATURE REVIEW

This section summarizes previous research relating to our proposed technique. Many great contributors have made important contributions to rainwater harvesting using modern technologies such as IoT. The authors of the paper [5] proposed a model with a developed prototype for the rainwater harvesting system using the filtration method and sending the information through IoT. Micro-controller, pH sensor, conductivity sensor, and turbidity sensor were used in that system to measure the quality of the collected rainwater. Moreover, they used the single-stage Reverse Osmosis (RO) filtration technique to filter harvested rainwater. In the paper [6], the authors proposed a framework for automated rainwater harvesting. Their proposed solution was simple. They used Arduino controlled servo motor to turn on/off the water inlet depending on the rainfall and storage tank status. While the storage tank was full or rainfall stopped, they closed the inlet and opened it only while the rainfall and water tank were not filled. A basic filtration technique was used to eliminate the visible particle from the collected rainwater while filling the tank. Authors of the paper [7] designed a rainwater harvesting system that is adaptively managed. The main goal of this study was to show that a Continuous Monitoring and Adaptive Control (CMAC) strategy may be used in a traditional rainwater collecting system in New York City to increase performance by decreasing the discharge of rainwater to the combined sewer and also reducing the use of water for local vegetation irrigation. The CMAC system is predicted to absorb and retain 76.6% of roof runoff per year on average, compared to 14.8% and 41.3% for conventional moisture and timer-based systems, respectively. This study [8] described a rainwater harvesting (RWH) system which is adaptive and based on a rainfall-collecting device that used turbidity and pH measuring sensors to determine baseline water quality in collected rainwater before redistributing it to selected toilets tanks and/or irrigation locations. When two or more devices conform to the system, each unit is equipped with an S2B antenna of XBee, allowing both energy-efficient and cost- effective mesh communication. In the study of this paper [9], the authors described a roof rainwater collecting system that employs fuzzy logic control to divert runoff water between two tanks that collect, filter, and then forward the water for reuse. The goal was to separate the initial flush rainfall from the rest of the rainwater, i.e., the greywater from the clear water. Their proposed system was a part of an extensive open-source automated water-waste management system implemented on a building in a Crete city in southern Greece. In this paper [10], the authors proposed a rainwater harvesting system along with autonomous irrigation. Their system store rainwater and use them for irrigation while needed. For the autonomous irrigation, they used soil moisture sensors, and to detect rainfall, a rain sensor was used there, and an Arduino board powered the whole system. In the article [11], the authors proposed an efficient way of rainwater harvesting for households. They simply stored the rainwater based on the clarity of the water. For this, they used turbidity and LDR sensors along with a NodeMCU. To eliminate the filtration cost, they checked water clarity before storing it in the reserve tank. In the study of the paper [12], the authors developed a prototype of a low-cost smart rainwater harvesting system that could detect dirty rainwater and clean rainwater to store them in separate storage. Here they used IoT technology, turbidity, and LDR sensor. The authors of the paper [13] had proposed an IoT-based rainwater harvesting system that could classify the rainwater by measuring its pH level in two separate tanks. However, harvesting pure rainwater only based on its pH level is not a wise and practical idea.

3. METHODOLOGY

Our proposed smart, automated rainwater harvesting system consists of several modules/units. The water collection unit is responsible for collecting water from the roof. It consists of one or multiple rainwater gutters and a microcontroller-controlled smart first flush diverter. The rain monitoring module consists of a digital rain gauge sensor, a pH level measurement sensor, and a rain sensor, and all these are connected to ESP32 SoC by wires. There is also another ESP32 in the main module, which controls the reserve water tank's valves, measures the pH level of the storage tank's water, and activates and deactivates the first flush diverter. A rain monitoring module connects to the main module via their built-in Wi-Fi network. The main module also sends data to the cloud so that the user can monitor the storage of water-related data on his/her smartphone app. Figure 1 represents the overall diagram of the proposed rainwater harvesting system.

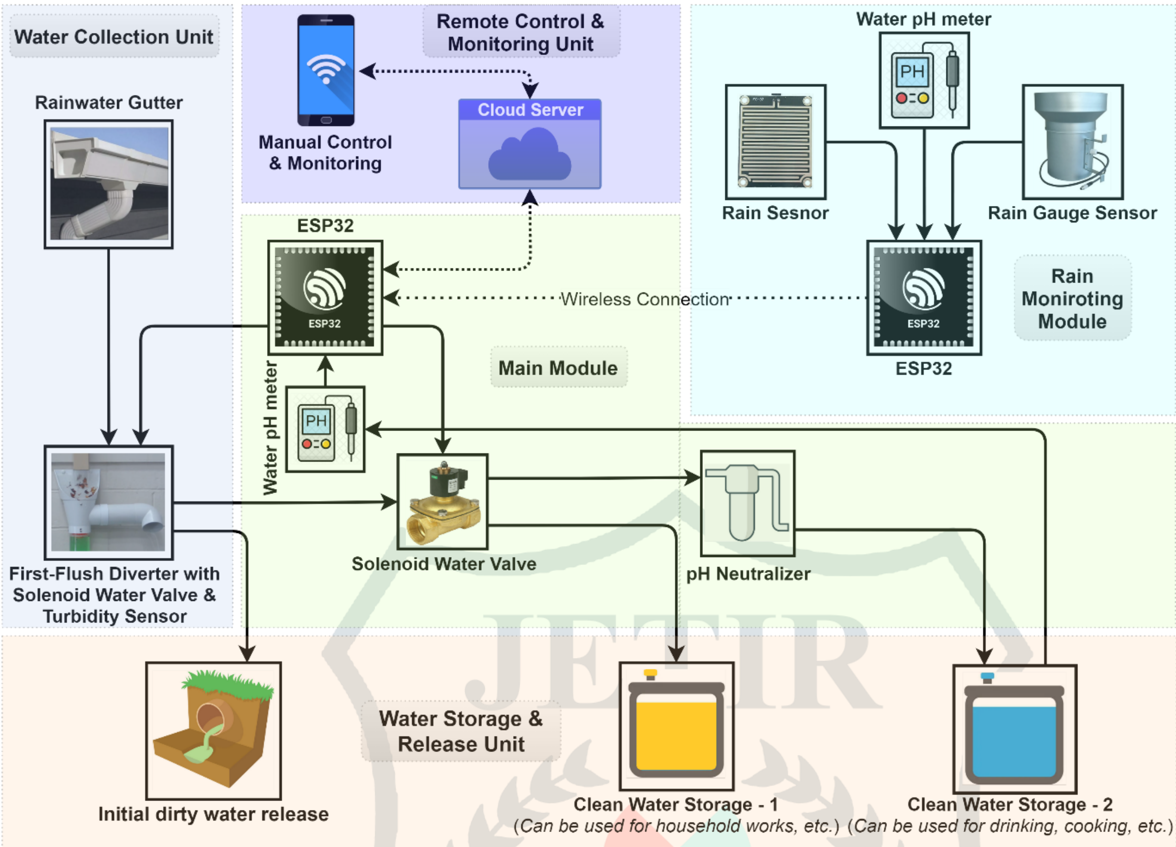


Figure 1: Overall diagram of the proposed system

It activates the rain monitoring module's rain sensor when the rain starts. The pH sensor of the rain-sensing module keeps measuring the rainwater's pH value and amount of rainfall. Rain- sensing module's ESP32 cautiously keeps sending data to the main modules ESP32.

As we know, initial rainwater is often contaminated with many harmful particles and gases. Moreover, the first runoff rainwater can also be contaminated with the roof's material, and the roof always is not cleaned enough. So, to pass the first runoff via dirty water releasing pipe by default, the first flush diverter is turned on (opened). While initial dirty water keeps releasing, the turbidity and pH sensors measure the quality of the releasing rainwater. If currently releasing water quality meets the required threshold value for the tank-1 category water (for household use), then ESP32 turn off the valve of the first flush diverter and keeps filling the tank-1 (which tank is for less pure water).

Table 1: Threshold values of the pH and turbidity sensor for the tank-1 (less pure water tank) and tank-2 (tank for more pure potable water)

Water storage	pH	Turbidity
Tank-1	≥ 5	$\leq$ 15 NTU
Tank-2	> 5.5	$\leq$ 2 NTU

While it reaches the threshold limits for the tank-2 category water, the supply valve of the tank- 1 will be shut off, and the tank-2 will be opened. As rainwater is slightly acidic and contains fewer minerals than the underground water, this water will be passed through a pH neutralizer with mineral cartage as we are storing water for drinking and cooking. After passing water through the pH neutralizer with a mineral filter, the pH level increases up to 6.5 ~ 7.0, which is suitable for drinking. Figure 2 represents the flowchart of the working procedure of this system.

Since we store potable drinking water in the storage Tank-2, we also take some additional safety measures to ensure we are storing contaminated-free, safe drinking water. That's why we analyze the previous rain history (for example: when did the last rain occur, how much rainfall occurred in the last rainfall) using algorithms running on ESP32. We also need some input data to feed algorithms, such as how long after the onset of rains we usually get pure drinking water. As it depends on the roof materials and air pollution rates of this area, so it is better to perform a lab test before setting up our systems in an area. This is for safety reasons and to ensure more pure drinking water.

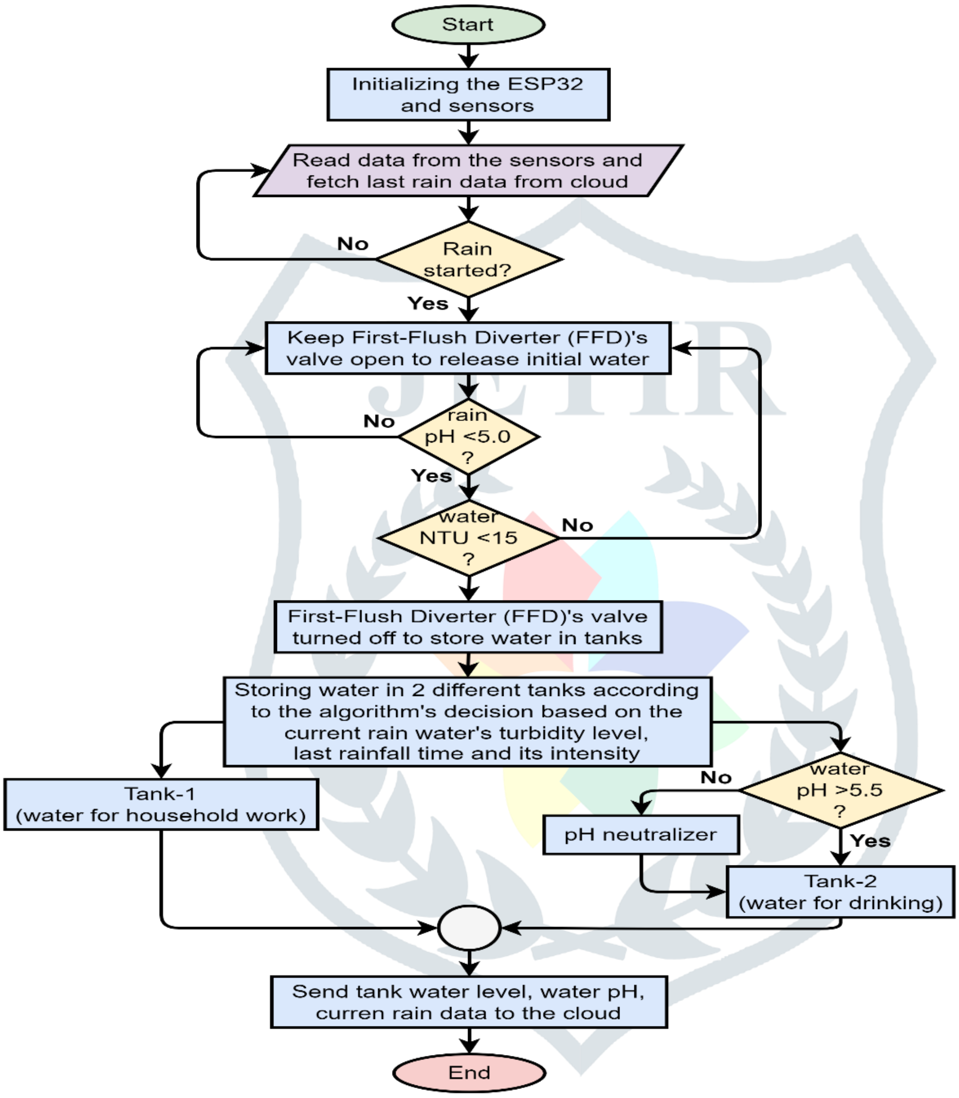


Figure 2: Flowchart of the proposed methodology's working procedures

4. RESULTS AND DISCUSSIONS

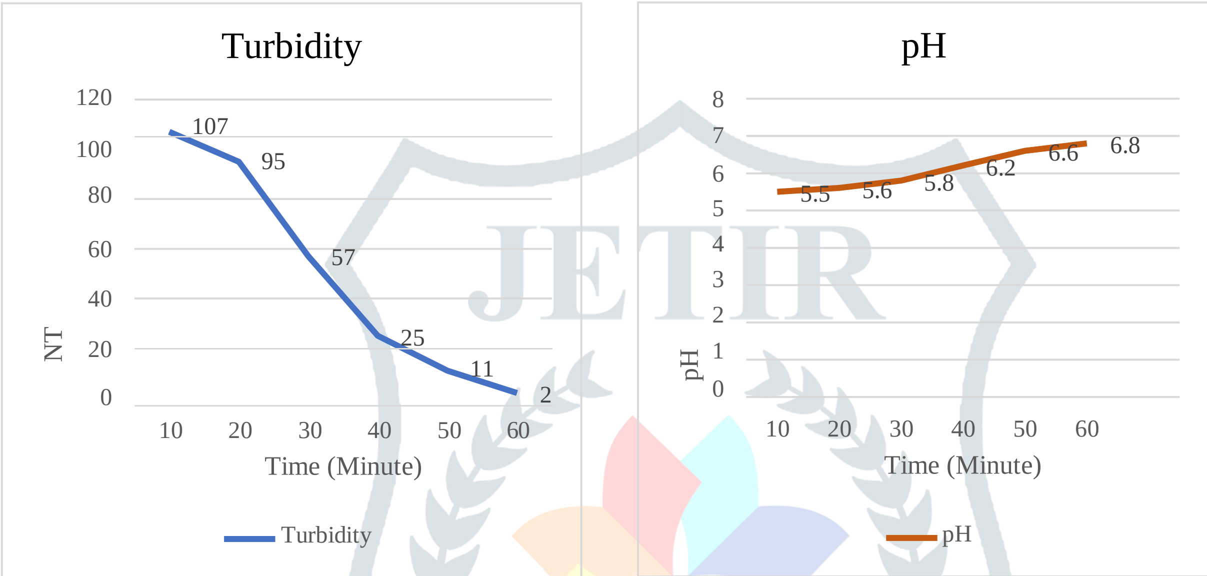
This section represents some results data obtained from the developed prototype of the proposed system.
Many microorganisms might stay on a dirty roof. Moreover, some metals on rooftops can be mixed with rainwater. Besides rooftops metals, many substances contained in the air can also be mixed with the rainwater. That's why initial rainwater may not always be safe to use. But after a certain amount of rainfall, the water quality gradually becomes safer to use. Table 2 shows the lab test results obtained from multiple samples taken at some different amounts of rainfall during a rain session.

Table 2: Status of rainwater samples taken from the gutter at different amounts of rainfall intensity

Parameter	Unit	Rain Depth (mm)							
		<0.5	0.5-1	1-2	2-3	3-4	4-6	>6	Guideline
Fecal Coliform	CFU/ 100 ml	51	39	22	10	0	0	0	0
Total Coliform	CFU/ 100 ml	278	220	149	104	81	22	7	0
Heterotrophic Plate Count	CFU/ ml	106	85	69	48	33	19	11	N/A
Pseudomonas Spp.	CFU/ 100 ml	330	301	283	226	152	85	53	N/A
Suspended Solids	mg/L	6.99	5.40	1.60	12.60	14.5	4.76	0.75	500
Dissolved Solids	mg/L	96.08	86.33	132	97.50	102	93.60	78.09	500
pH	mg/L	5.72	5.62	5.77	5.85	5.92	5.97	6.00	6.5-8.5
Chlorine	mg/L	14	11.43	17.10	11.15	11.13	15.48	4.70	250
Nitrate	mg/L	0.87	0.11	0.13	0.15	0.10	0.14	0.11	3
Nitrite	mg/L	1.75	1.60	0.83	0.55	0.70	2.26	0.34	50
Sulphate	mg/L	9.54	5.32	5.83	4.30	14.50	6.26	1.79	250
Calcium	mg/L	4.48	0.16	2.35	1.75	4.96	2.74	0.75	200
Sodium	mg/L	10.40	7.37	13.90	7.65	5.70	10.44	4.40	180
Ammonia	mg/L	0.22	0.15	0.21	0.11	0.12	0.32	0.20	0.5

Lead	mg/L	0.02	0.01	0.02	0.01	0.02	0.01	0.01	0.01
Iron	mg/L	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.3
Cadmium	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002

Usually, rainwater is more acidic than groundwater. Sometimes it becomes more acidic because of the nearby extensive air pollution. But with the increment of the rainfall duration, we found that the pH value of rainwater increases. The transparency of the gutter's rainwater also increases with rainfall duration. Figure 3 shows the relationship between the pH value and the increment in water clarity concerning the precipitation period.



(a) (b)

Figure 3: Changes in turbidity and pH with the changes in rainfall duration

Sometimes the pH value of rainwater remains 5.5 to 6.5, which is slightly acidic and not dangerous to drink. But it might not be suitable for long-term consumption. Moreover, rainwater contains a very few amounts of minerals like distilled water. That's why its TDS value is too low, about 7-10 ppm. For these reasons, we used a pH neutralizer and mineral cartridge in our system to improve the pH and TDS quality for making rainwater to suitable drinking water. Table 3 shows the values of pH and TDS before and after passing the pH neutralizer and mineral cartridge devices.

Table 3: The values of pH and TDS before and after passing the pH neutralizer and mineral cartridge devices

	Rainwater before entering the pH neutralizer with mineral cartridge		Rainwater after passing through the pH neutralizer with mineral cartridge	
pH	1.	5.6	1.	7.2
	2.	6.3	2.	7.4
	3.	6.8	3.	7.9
TDS	1.	7	1.	86
	2.	12	2.	98
	3.	9	3.	90

We have also developed a prototype of our proposed system with the required hardware like ESP32, rain sensor, water sensor, pH monitor, valve, etc., components. We implemented the system's program on ESP32, written in C++ programming language. Figure 4 represents the prototype that we have made to evaluate our proposed idea.

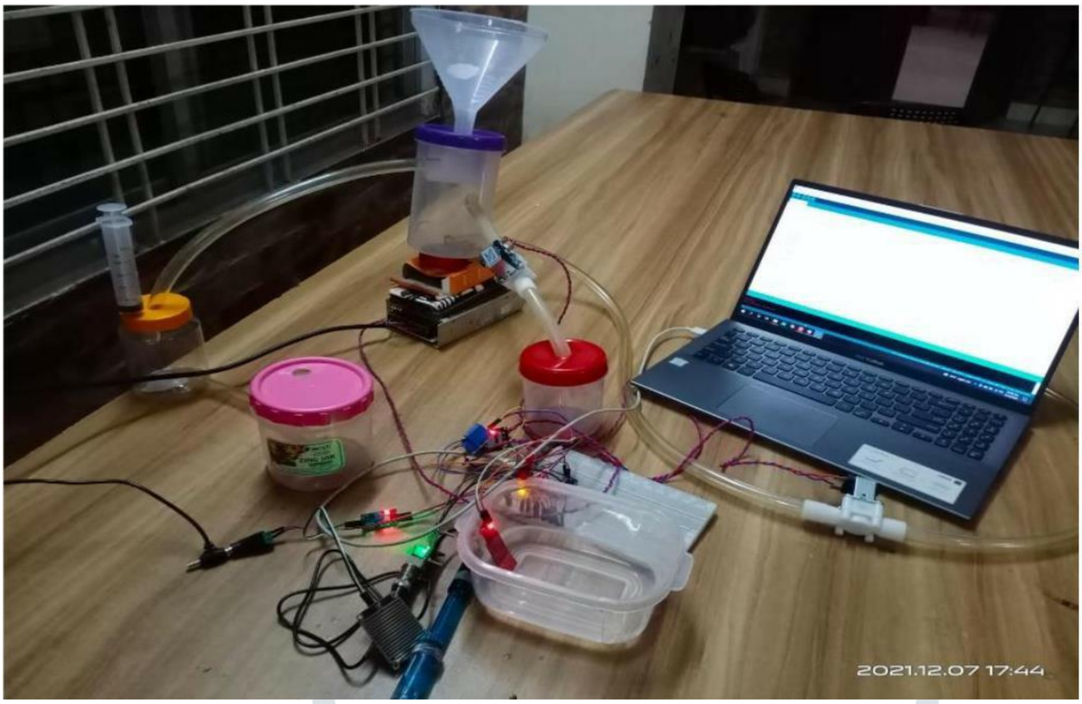


Figure 4: Developed prototype of the proposed system

5. FUTURE WORKS

It is very important to ensure the water purity while we will collect rainwater for drinking. After a certain period of rainfall, we saw that the gutter's rainwater became clearer and purer than the initial rainwater. So, it is very important to efficiently find the time when we should start collecting rainwater for drinking after starting the rain. This time may vary from time to time based on many reasons. That's why we need another effective solution here to ensure purer water and maximize the harvesting amount of drinkable rainwater during a rain period.

At this moment, to know that after how mm of rainfall we can get safe rainwater for drinking from an area, we need to perform some lab tests of sample rainwater collected from that area. This test might need to perform one time or more in a year, depending on the pollution rate of that area. In the future, by combining Machine Learning techniques with the existing method, we can reduce the number of tests because that time, based on the present data, we will be able to predict the future's possible conditions.

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