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Original Article

A Portable Solar Water Purifier with Reverse Osmosis and Ultra Violet Disinfection System

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Abstract - *Climate change, global warming and water pollution have affected the availability of safe, pure and clean water in large quantities. Due to this, a large number of people around the world do not have easy access to pure water for drinking, cooking or cleaning purposes. The problems are accelerated when floods and other environmental disasters happen that cannot be estimated earlier. Humans may use and drink untreated and unsafe water that may contain a large no. of contaminants consisting of harmful germs and chemicals. In a report by NITI Aayog (2022), it is estimated that by 2030, about 600 million people may be affected by safe, pure and clean drinking water, which is approx.40% of India's projected population by 2030. The only solution for the above scenarios is the purification of water that should be affordable, cost-effective, portable and low maintenance requirement so that it can be implemented in remote and distributed communities where river, lake and brackish water is unsuitable for drinking purposes. A solar powered water purification system may be advantageous rather than conventionally sourced types that are costly and cause environmental pollution. In this research, a portable, fully solar powered water purifier is designed and developed, which is integrated with Reverse Osmosis (RO), Ultra Filtration (UF) and Ultra Violet (UV) disinfecting systems. The system design is very compact, requires small space and can be installed in remote or flood affected areas where potable water is essential to survive. The purifier is economical and requires very little maintenance cost.*

Keywords - *Solar radiation, Solar controller, Reverse osmosis, Ultra violet radiation, Water purification.*

1. Introduction

Every living organism depends on water to survive its life on earth. Our earth's surface is covered with 70% of water, whereas only 2.5% is clean water [1]. Water shortage is now a global issue which is affecting all continents of the world. The unavailability of fresh water may hamper human life as water is the basic need of all living bodies [2]. Water shortage implies that fresh water is not easily available to meet the demand. Approximately 4 billion people in the world are facing tough water shortages every year for at least a month. Of all water content in the earth, 97% of water is salty, 3% of water is tough to access, and only 0.014% of water is fresh and useful for drinking purposes [3]. Earth is technically full of water, but it is not uniformly distributed since some parts are very wet and others are very or less dry. Water shortage should be talked about both nationally as well as globally. Globally, there is a disparity between the supply and demand of clean water [4]. There are many reasons for the rise in demand for clean water, like rapid growth of population, changes in consumption style, changes in life style and rises in irrigation of land. There are many reasons which are responsible for the inadequate supply of water, such as reduction in the area of forest, pollution, climate change, rises in the amount of greenhouse gases and contamination of water [5]. Around the world, most countries are facing both physical and economic water shortages due to improper management of water [6]. There is an inequality in water resources in these countries. Sufficient water is available to satisfy both irrigation and domestic needs in some parts, whereas there is a huge shortage of water in other parts. The only reason behind this is poor management of the supply of water. There are some additional causes for the above situations are excess use, waste of water and degradation of groundwater level [7, 8]. There are two reasons for economic water shortage, which are termed as, lack of infrastructure and problems faced by people to compensate their demand for potable water. Due to this water shortage, nearly 25% of people are affected. In the African continent, people travel very long distances to collect their drinking water due to the unavailability of fresh water in most of the part. United Nations, in the year 2016, framed Sustainable Development Goals, which were earlier named as Millennium Development Goals. All man-made activities like water pollution, deforestation and global warming have very adverse effects on the environment [9]. The reduction of freshwater as well as groundwater is now an alarming situation. Climate change is affecting the ecosystem a lot, like shrinking lake water levels, reducing water flow in rivers and melting of glaciers [10, 11]. The necessity of obtaining safe and clean drinking water was highlighted in target 7B of the United Nation's Millenium Development Goals, which targeted to reduce the population (1990-2015) of availing clean potable water sources by 50% [12]. As per the WHO report (2006), the target was fulfilled [13]. By reducing the deaths by 31% due to consuming contaminated water, the target was successfully achieved [14]. Potable drinking water is now inaccessible to more than 780 million population [15]. Unsafe drinking water causes yearly approx. 1.5 million deaths, out of which more than 90% cases are children. Rapid population growth causes excessive demand for clean drinking water, whereas existing water sources are highly contaminated. In developing nations, both the quality and quantity of drinking water should be improved, and the purification systems should be affordable and user-friendly. In some remote and developing areas, large-scale water purification systems and storage units are not still feasible to implement. In many developing countries drinking water is a challenge to obtain. Though safe drinking water is promised in many areas by the authorities, it is not kept later. Many countries in Southeast Asia are eye witnessing severe natural calamities which is due to climate changes caused by global warming [16]. Due to global warming, the average earth's temperature has increased by nearly 0.8^0C over the last 100 years. Global warming is also causing other natural calamities like floods and droughts due to La Nina and El Nino [17]. Out of all calamities, extreme floods and thunderstorms are most common. Only floods take a greater position of all natural calamities in Asian countries which is approximately forty percent (40%), as shown in Figure 1 [18].

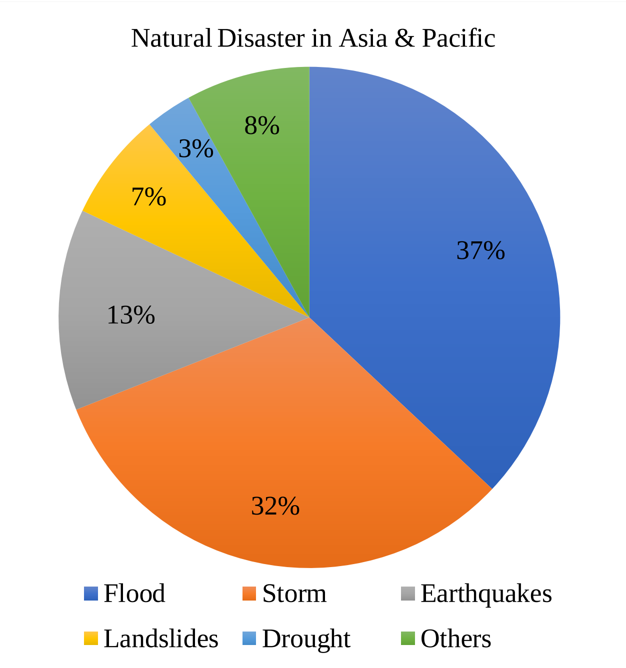

Fig. 1 Types of natural disasters in asia and the pacific

Flood causes severe problems like loss of agricultural production, health issues, and loss of property and life. In the year 2017 alone, in South Asia, 1200 people died and 41 million people were adversely affected due to flood only [18]. During floods, water is highly contaminated with industrial and domestic waste and germs. Drinking such water, as safe water was hard to avail at that time, causing illnesses caused by communicable diseases, which are mainly faecal oral diseases [19]. Major waterborne contaminants are bacteria like campylobacter, shigella, salmonella and Escherichia [20].

When such bacteria contaminate water, several health issues are happened like typhoid fever, cholera and gastroenteritis. They cause repeated vomiting, high fever, heavy loss of body fluids and even death due to shutdown of organs and dehydration. Though these diseases are very common due to the presence of contaminants, they can be easily prevented if water is treated before consumption for drinking or cooking purposes [21]. Table 1 represents several waterborne diseases and their effects if consumed for drinking or cooking purposes.

Table 1. Types of contaminants and associated health issues

Sl No.	Types of Contaminants	Health Issues
1	Organic pollutants	Problems in the nervous system, reproductive system, liver, kidney, anemia and cancer
2	Inorganic pollutants	Problems in the skin, kidney, thyroid and circulatory system
3	Microorganisms	Problems like vomiting, diarrhea, cramps and kidney failure
4	Ionic pollutants	Irritation in eyes and or noses and stomach problems
5	Colloidal pollutants	Problems like stone formation in the kidney, allergies and stomach malfunction

In this situation, a water purifier with modern technology must be developed that should be affordable and user friendly [22, 23]. Solar-powered distillation water purifiers and RO based portable water purifiers are very popular nowadays [24, 25]. The above pieces of literature focus on solar power distillation systems where contaminated water is heated to generally up to 85^0C.After condensation, the treated water is stored.

In this system, disease causing microorganisms are killed, but organic, inorganic and ionic pollutants are not removed. Reverse Osmosis (RO), UV and UF based purification systems can purify all types of contaminants from the polluted water. Solar power RO and UV systems are very economical as they use renewable energy (solar energy) instead of conventional energy sources (coal, oil and gas) to generate electricity.

Compact design and lightweight are a very common phenomenon of a water purifier to use in remote areas and emergencies like drought and flood. Most of the reported studies do not focus on fully renewable energy sourced RO, UF and UV based purification systems. In this paper, a fully solar power RO, UV and UF system is designed and constructed which is portable, affordable and economical for use in remote areas as well during emergencies.

2. Methodology

The purification system consists of a highly efficient solar panel consisting of photovoltaic cells of capacity 60W, 17.7 Volt. The battery unit has a capacity of 14 AH and a voltage of 12 Volt. Two batteries are connected in series to get an output voltage of 24 Volt DC to the RO booster pump. The storage unit is installed to collect a pure water capacity of 5 Liters. The proposed system is portable and fully solar powered. It is designed to have RO and UV units to provide chemicals and germs free water. Solar energy coming from the sun is absorbed by the panel and converted to electrical energy, which is stored in a battery that runs the RO booster pump. Figure 2 shows the filtration unit of the system. The raw and contaminated water is passed through a sedimentary filter that cleans both sand and clay, which is termed sediment particles from the water. After the sedimentary filter, water goes to the pre-carbon membrane, whose function is to remove several unwanted components like chlorine, volatile organic compounds, taste and odour from water [26, 27]. Post-carbon filter is used to filter out even smaller particles. From the pre-carbon filter, water is supplied to the RO membrane using an RO booster pump powered by the battery. Then, the water goes to the UF unit, where both bacteria and microorganisms are killed. The UF unit also destroys the disinfectants. Minerals that are essential for our body, like copper, magnesium, calcium and potassium, are added by passing water through a mineral cartridge. Finally, water is passed through a UV filter where 99.99% of microorganisms which are very harmful are killed without the addition of any unwanted chemicals. Figures 2 and 3 represent the flow diagram of sample water through the different purification units and the supply of power from the solar photovoltaic cell to the RO booster pump, respectively.

2.1. Hardware Components

All the hardware components used for making the purifier are shown in the images below. Figure 4 shows the solar panel unit, which collects solar radiation from the sun and supplies DC current to the battery. The charge controller unit, as shown in Figure 5, controls the charging of the battery during the daytime. It also prevents the backflow of current towards the panel when solar radiation intensity reduces or there is an absence of any radiation like night time or cloudy atmosphere. The battery unit (Figure 6) stores the electrical energy and runs the RO booster pump which is of capacity 28.8W and 24VDC. All the filtering units shown in Figure 7 contain a sedimentary filter, pre-carbon filter, post-carbon filter, RO, UF, UV and mineral cartridge.

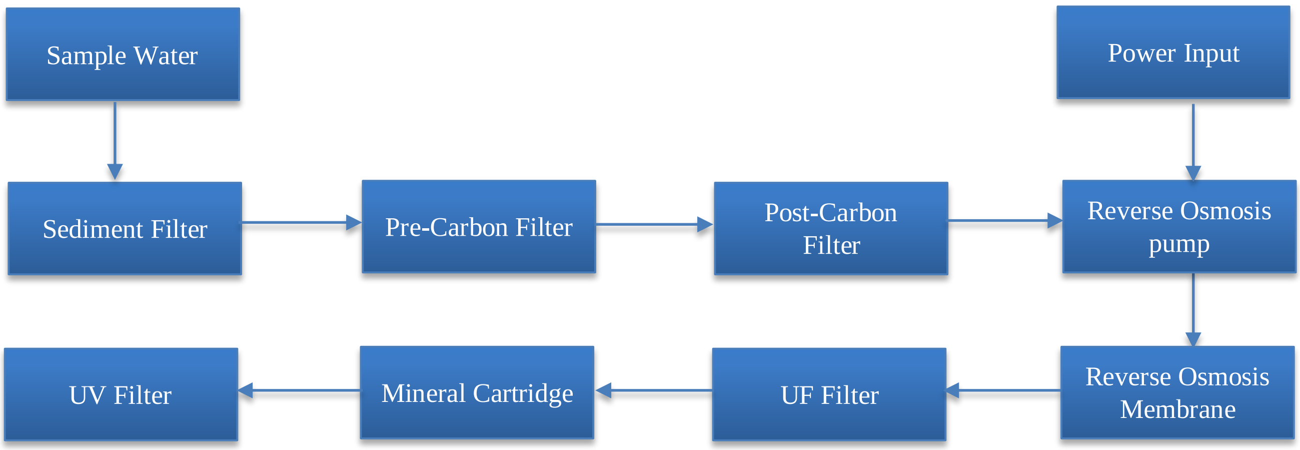

Fig. 2 Flow sequence of contaminated water throughout the system

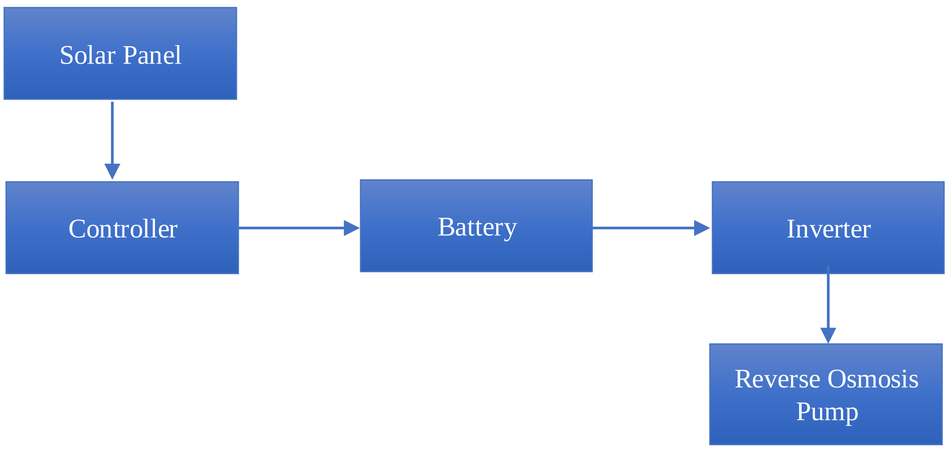

Fig. 3 Sequence of power supply throughout the system

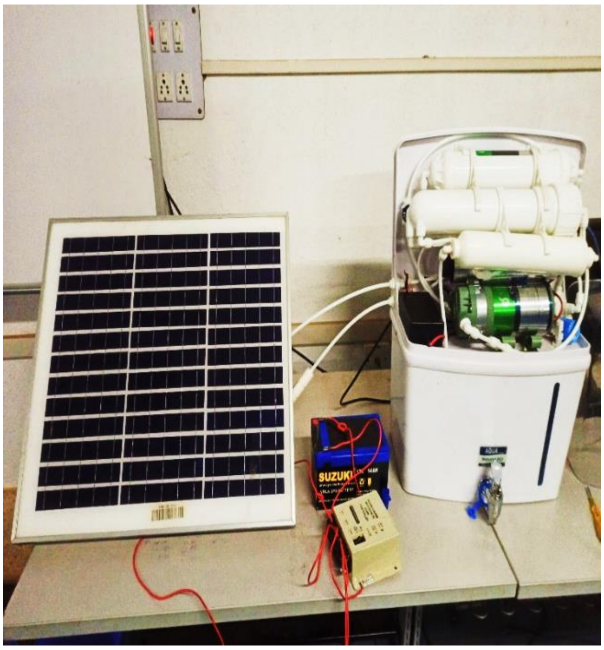

Fig. 4 Solar panel unit

Fig. 6 Power storage (battery) unit

Fig. 5 Charge controller unit

Fig. 7 Water filtration unit (RO booster pump, filters and storage unit)

2.2. Component Specification

The energy producing, storing and consuming units are shown in Table 2.

Table 2. Energy and other components specification with quantity

Name of the Component	Specification	Quantity
Solar Panel	60W,17.7V	1
Battery	14AH,12V	2
RO Pump	28.8W (24VDC, 1.2A)	1

3. Results and Discussions

Different times calculations like full charging of batteries, the total run time of the RO booster pump, which is drawing power from a battery and the total time required to fill up the storage unit are tabulated below:

Table 3. Total time required to fill up the storage unit

Sl No.	Activity	Time Required
1	Full Charging of Batteries	5 Hours 36 Mins
2	Continuous Running of RO Booster Pump	9 Hours 20 Mins
3	Filling of 5L Storage Unit	2 Hours 30 Mins

The tests performed on the input and output water samples and results are shown in Table 4.

Table 4. Underground water sample collected from water pipeline

Test	No. of Samples									
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**
TDS	180	170	324	507	639	359	165	210	364	265
pH	9	10	9	10	9	9	10	6	9.1	10
Hardness	280	260	270	240	230	240	235	245	241	230
DO	8.8	9	8.7	8.6	8.3	8	8.2	7.8	7.2	6.8
E. Cond.	2	1.7	1.6	1.8	1.5	1.25	1.35	1.15	1.1	1
Turbidity	25	22	19	17	20	16	15	12	11	6
Ca-Hardn	160	160	150	140	130	135	140	140	125	140
Arsenic	0	0	0	0	0	0	0	0	0	0

Table 5. A purified water sample collected from the purifier outlet

Test	No. of Samples									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
TDS	98	95	112	119	129	56	63	73	59	67
pH	8	7	7.3	7.2	7.5	7.7	7.4	7.2	7	8
Hardness	220	210	200	160	120	110	130	100	105	100
DO	7.3	7.1	7	6.9	6.7	6.5	6.6	6.1	6	5.8
E. Cond.	1.8	1.6	1.5	1.6	1.25	1.15	1	0.75	0.85	0.65
Turbidity	17	16	11	7	6	8	5	4	2	2
Ca-Hardn	140	140	100	90	80	70	75	60	62	60
Arsenic	0	0	0	0	0	0	0	0	0	0

Table 4 demonstrates the tests conducted on underground water samples that germs, chemicals or both may contaminate. Ten samples are taken and tested for quality checking like TDS, pH, DO, Hardness, Turbidity, Ca-Hardness, Arsenic and Electrical Conductivity.

Table 5 demonstrates the same tests conducted on purified water samples. Ten samples after quality checking prove that TDS, pH, DO, Hardness, Turbidity, Ca-Hardness, 603Arsenic and Electrical Conductivity values are much less than contaminated water. A lower pH value proves that purifier output water is safe for drinking purposes.

Fig. 8 Water sample before and after purification

The test result shows that the water sample which is collected from the water tap is free of any TDS and other impurities.

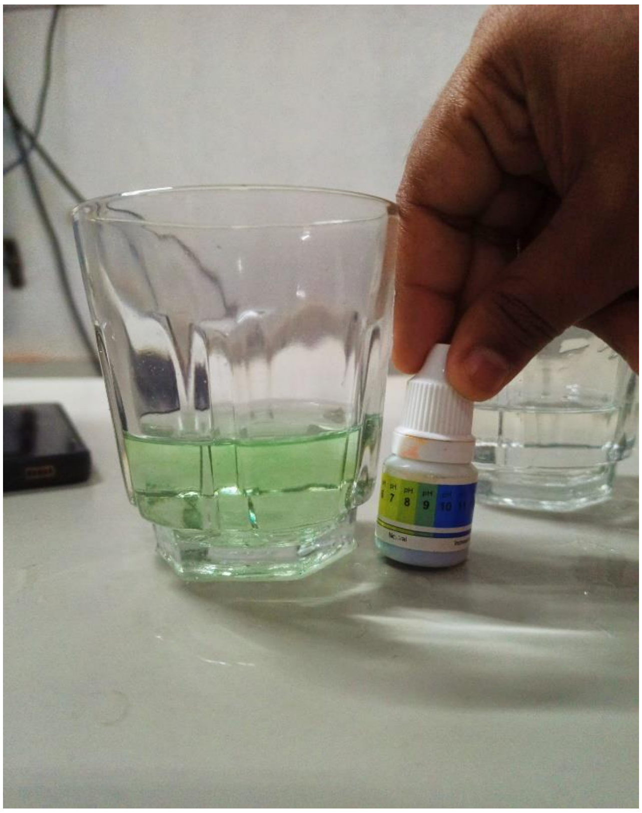

Fig. 9 pH testing of purified water

pH result confirms that water is safe for drinking purposes as water is neither acidic nor alkaline.

Fig. 10 TDS testing of purified water

Table 6. Price (INR) of different components of purifier unit

Name of Components	Price (INR)
Solar Panel (60W)	1000
Solar Controller	300
Charging Battery	1500
RO Booster Pump	1300
RO, UF, UV Unit	2200
Sedimentary Filter, Mineral Cartridge	500
Pre & Post-Carbon Filter	400
Cabinet with Storage Unit	1500
Others	1200
Total Price	9900

The TDS test result of one sample, as shown in Figure 10, is suitable for safe water.

The cost of different items of the purifier unit is shown in Table 6.

Table 6 shows that the total price of the purifier unit is 9900 INR only, which is affordable, and it is capable of providing approximately 80 liters of water in a single charging of the battery by the solar panel.

From Figures 11 to 17, the Turbidity, TDS, pH, Electrical Conductivity, Dissolved Oxygen, Total Hardness and Ca-Hardness values are plotted for ten samples before and after the purification process. All the graphs show that the purified water samples contain much less contaminants than raw water, which makes it safe for drinking and cooking purposes.

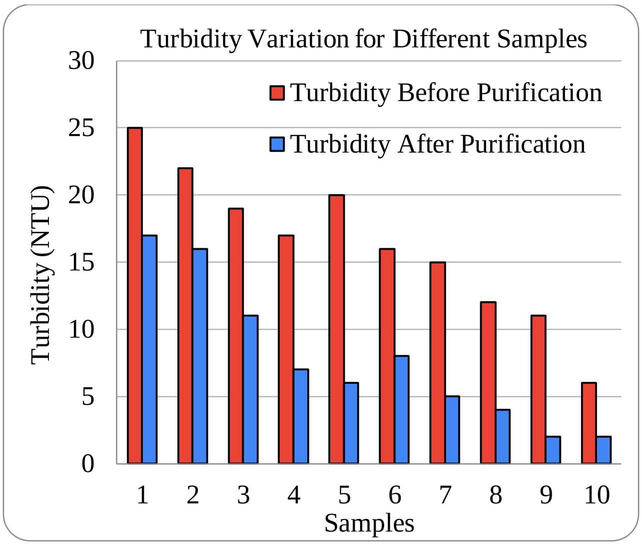

Fig. 11 Turbidity of different test samples before and after purification

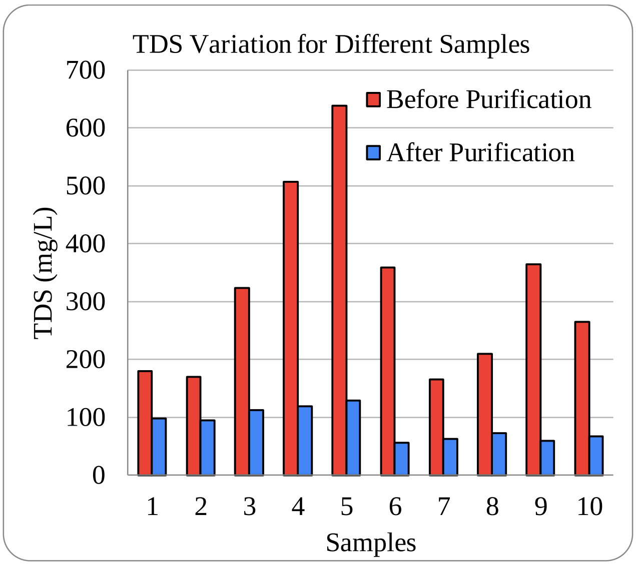

Fig. 12 TDS value of different test samples before and after purification

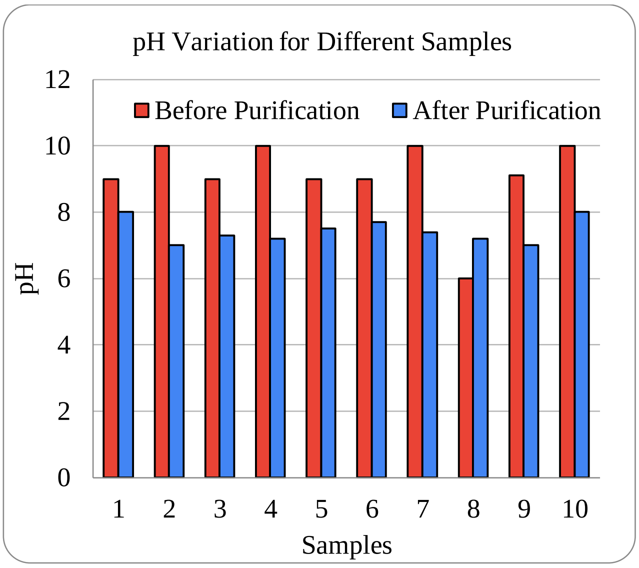

Fig. 13 pH value of different test samples before and after purification

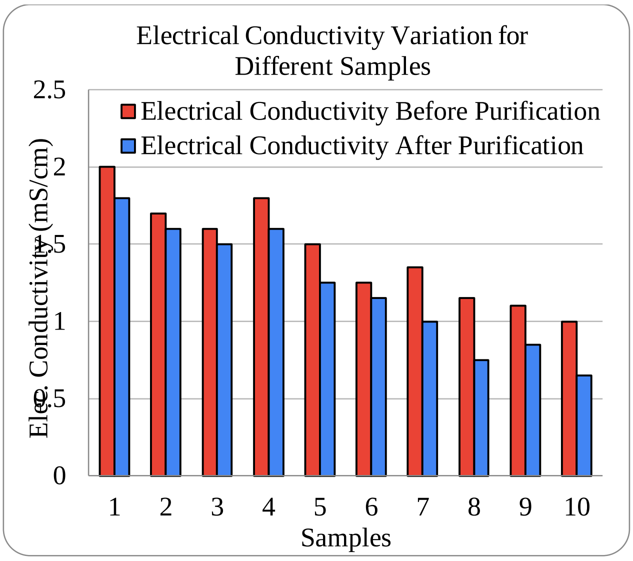

Fig. 14 Electrical conductivity of different test samples before and after purification

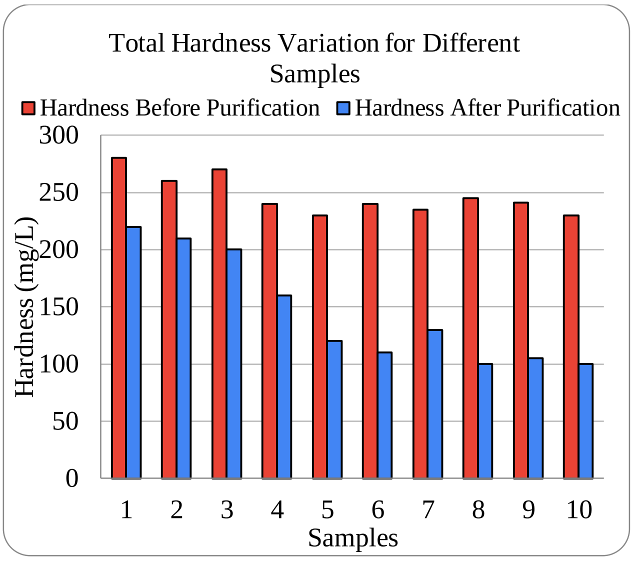

Fig. 16 Total hardness of different test samples before and after purification

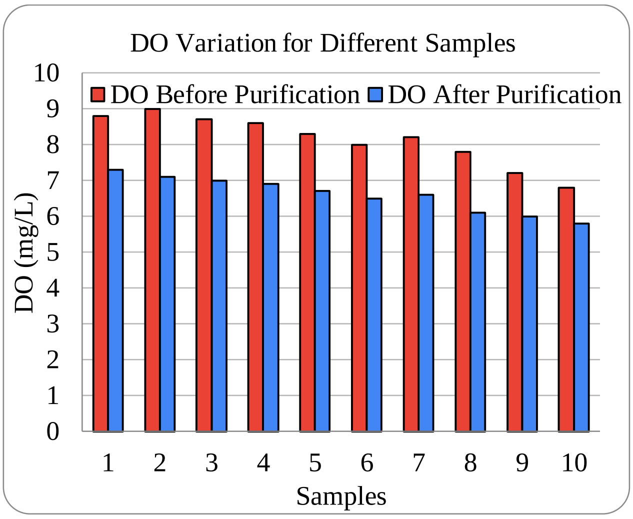

Fig. 15 Dissolved oxygen of different test samples before and after purification

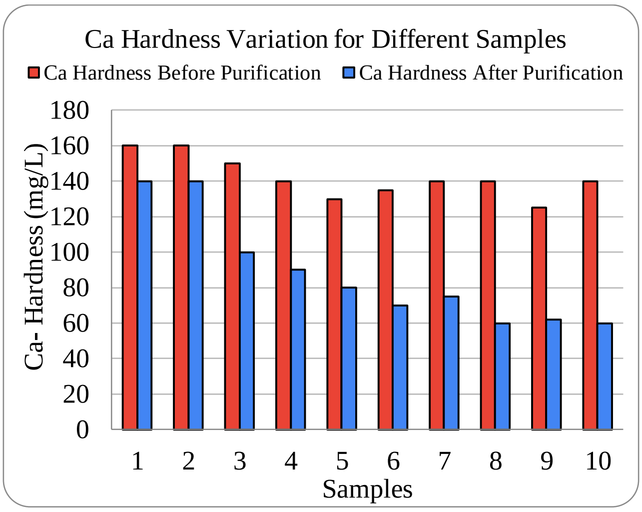

Fig. 17 Calcium hardness of different test samples before and after purification

4. Conclusion

The objective of this research is to design and implement a solar energy-based RO, UF and UV-based water purifier which is portable due to its lightweight, cost effective, simple design, affordable and eco-friendly. The cabinet is made of polymer composite, which is transparent and lightweight. As the pump is powered by solar energy-generated electricity, no carbon dioxide or other poisonous gases are associated and the system does not produce any noise. The compact design helps it to install in places where space is limited. After testing Turbidity, TDS, pH, Electrical Conductivity, Dissolved Oxygen, Hardness and Ca-Hardness, it can be concluded that the quality of the water is enhanced to a greater extent. The pH value of the purified water is the same of drinkable water. The system is ideal to be used in rural areas and flood and drought like emergencies.

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