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Research Article

Save, Generate and Clean Water for Personal Family Use

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Abstract

Being an environmentalist, the water wastage, generate some free and better-quality water for personal house uses. Sources are rainwater from roof, backyard, from humid air and water reduction of drainage and then also inform cleaning water with solar distillation, solar oven, ultraviolet radiation, during many years. Results and analysis, like quality and quantity of water are also mentioned. It's a review of my previous published work on water as well as some new recently measured data.

Keywords: Solar Energy; Rainwater; Water Pasteurization; Water Disinfection; Solar Still; Water from Humid Air

Introduction

After working for 35 years as a researcher and promotor of Solar Energy, I retired 12 years ago. During this period, in addition to doing my official research/teaching job, I could install also some personally designed solar devices, like water heaters, dryers, cookers, pasteurizers, and some PV systems for personal uses in our Sunny house. In addition, I bought some instruments to measure air and water, temperature, solar radiation and air humidity etc.

In general, the quantity of water in Costa Rica is available most of the time and is almost potable. However, to be sure to have some free extra water of reasonably good quality, from chemical and biological point of view, I preferred to do some experiments for analysis and promoting the results.

Fortunately, we have a Sunny house with garden, plants, free roof, backyard, dehumidifier and various solar devices, like solar oven, water house heater, dryer, PV panel, etc. (Photo 1).

In the present manuscript, I will mention different means to generate natural and clean water for drinking, making tea coffee, toilet, garden etc. at lower cost and cleaning water using solar energy and reducing the drainage of rainwater. In other words, this is a review/ summary of part of my work done published partially during 35 years of working at university (obligation) and then 12 years at home during retirement (passion).

Photo 1: Our house with Garden, plants, sunny roof, backyard and many solar devices.

First, I will mention generating/collecting water and then cleaning water. These processes are:

- 1A. Collection of Rainwater from Roof,
- 1B. Collection of Rainwater in backyard,
- 1C. Reduction of rainwater from drainage
- 2. Getting water from humid air,
- 3. Solar Distillation for removing minerals,
- 4A. Solar Pasteurization for inactivating microbes using heat with Solar Oven.
- 4B. Solar Pasteurization for inactivating microbes, using Heat and UV radiation.

In addition to the quality and quantity of water collected, the energy required to extract water from ambient air will also be informed.

Collection of rainwater

Costa Rica, in addition to be blessed with solar radiation, it is also blessed with rain in a year, almost 5-6 months, however mostly after noon. Rainwater can be collected either from the roof and/or from the pots kept in backyard. Fortunately, in our house, we got both Sunny and Rainy Roof and backyard (Photo 1).

Rainwater from roof

As shown in Photo 2 (left), for rainwater collection some of the components are:

- Roof- rainwater is collected from the roof of a house,
- Gutter- The rainwater is channeled into a gutter system,
- Piping- The collected rainwater is then directed through pipes into a storage tank,
- Water treatment/filter- In case required, the rainwater is filtered to remove debris and impurities,
- Water storage - The filtered rainwater is stored in a tank and is used for various uses, like drinking, flushing toilets, watering plants and gardens, washing cars and even for batteries which need maintenance etc.

Photo 2: Concept of Rainwater from the Roof (left) and installed at personal house (right).

Photo 2(right) shows roof water collection installed at our house in Heredia. Normally in Costa Rica, during rainy season (May-Nov.), depending on city rain is about 2.5-4.5m per year. In my city, Heredia, it is about 3m (3000 mm) per year. It is assumed that the rainwater is distilled/clean water if the roof is kept cleaned.

Regarding amount of water collected, if the average rainfall at a place is Z (m) per year and the collecting surface has a total area of about A (m^2) then the quantity of rainwater falling (Q) over the year will be

$Q = Z(m)*A(m^2) = ZA(m^3) = 1000ZA$ litres. (1)

In our case area of our one free roof is 7.5m X 6.4m= 48 m^2, thus the quantity of free rainwater on roof will be 3m X48m^2 = 144 m^3 (or 144000 liters) per year. Water cost in my city is US$2.3/ m^3, including aqueduct and sewer/drainage system.

Quality of rainwater collected will be informed in section C2.

Reducing drainage of rainwater

In general rainwater, if not used properly will go the drainage/sewer and rivers and finally to sea. To reduce this is to filter the rainwater into the soil. For this we have installed one of this system, sold in Costa Rica, under the name BERA (Holland product). According to their website [1] these materials provide solutions that are both sustainable in their manufacture (using solar Energy) and applications. One of their products, Gravel Fix is an advanced 100% recyclable stabilization system with its hexagonal honeycomb structure of high-quality Polypropylene cells and professional Geotextile backing (Photo 3 left). These are installed for gardens, landscapes and urban spaces. ensuring that valuable rainwater is absorbed back into the soil, thereby improving the ecology of the Planet. Photo 3 right shows different pavements (grass, concrete, BERA).

Photo 3: BERA product installed (Left) and Some of paving materials in our backyard, Concrete, grass and Bera (right).

Bera gravel fix is a - green solution for sustainable drainage. The main objective of this product is to manage and preserve rainwater as much as possible.

In one of the experiments realized, we have observed about 90% of the water is filtered through the BERA and membrane in the soil in 1 or 2 minutes.

Assuming the patio/garden/parking area covered with BERA is 100 m^2, thus rainwater avoided (going into drainage) will be 100 m^2 x 3 m = 300 m^3/year (Equation 1). In another city of Costa Rica, the rain fall is about 4.5m/year. Thus, rainwater avoided in this region will be 4.5mX100m^2 = 450 m^3/year).

In our house, we have put about 5 m^2 of BERA (Fig. 3 left), thus the avoided extra rainwater will be 5m^2 x 3 m = 15 m^3 or 15,000 l/year.

Rainwater in backyard

Rainwater after using in the backyard for garden/plants, BERA to avoid drainage, the rest can be collected for different uses.

In case you live in multistory apartments with no personal roof, but have some backyard etc. you can keep some clean containers to collect and store rainwater and can use for drinking, making tea/coffee etc.

Photo 4: Some pots for collection of rainwater in the open backyard.

During rainy season some clean pots are kept at the table in the back yard, where rainwater is collected on different days (Photo 4). Different amounts of water are collected, depending on rain, size of pots and the duration of rain etc.

Our total area of free backyard is about 14.3mX7m = 100 m^2. It includes many lemon trees, some herbs trees, garden for flowers, for capturing Carbon Dioxide, table/chairs for family/friends get together, and various solar devices. About 80 m^2 is covered by plants and receives rain for their growth and for our health. On the other hand, 15 m^2 of concrete pavement is used for walking and 5 m^2 for BERA for avoiding drainage.

Finally, I use only an area of 1.6 m X 0.9 m = 1.44 m^2 for collecting water in pots kept on the Table (Photo 4). Thus, water collecting in pots will be 3mX1.44m^2 = 4.32 m^3 (4320 liters) of water per year, in addition to 144 m^3 on the roof.

Analysis of rainwater

It was done at Chemistry Lab. of my university on Oct. 12, 2024, and the results are shown in Table 1. It also indicates the acceptable limit in some cases for potability of water.

Practically rainwater is like distilled water as its evaporated and condensed without solid particles and thus can be drunk, if the pots are clean.

Water from air

Costa Rica is very humid with relative humidity in the range 70-80%, probably due to two oceans, one on East (Atlantic) and other on West (Pacific) side and good solar radiation and wind.

For comfortable environment the recommended relative humidity is typically between 30 and 50%. This range helps ensure comfort, reduces mold, dust mites and respiratory issues etc.

Below 30%, dry air can cause dry skin, irritates eyes, electricity and respiratory discomfort, whereas above 50-60%, one feels muggy, it promotes mold growth and worsens allergies. Thus, we

Parameters	Tap Water	Rainwater	Acceptable limit for potability
pH	7.96 (*)	5.21-5.75 (**)	6.5-8.5
Elect. Conductivity (µs/cm)	108.5	5.01	400
Hardness Total (mg/L$CaCO_3$)	22.85	11.6	-----
Lead (mg/L Pb)	ND	ND	≤0.01 mg/L
Copper (mg/L Cu)	ND	ND	≤2.0 mg/L
Chlorine (mg/L Cl)	2.33	0.63	≤ 250 mg/L
Sulfate (mg/L)	4.60	2.24	≤ 250 mg/L

Table 1: Chemical Analysis of Tap and Rainwater.

ND: Not Detected (*) Alkaline (**) Acidic.

need dehumidifier to control humidity of air inside the room. In addition to the above advantages, with dehumidifier, one can also extract free water from humid air of the room. This free source of water can be served for some uses [2].

Although there are many types of dehumidifiers, chemical and electrical, I studied in detail and even use electric dehumidifier (AIRPRO) available in Cost Rica, the one showed in Photo 5 (right).

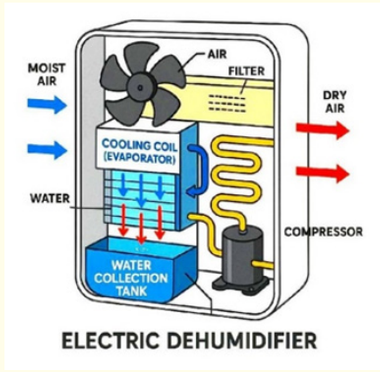


Photo 5: Electric dehumidifier concept and the model used

In brief the Electrical Dehumidifier has following main components (Photo 5 left), Fan, Cooling Coils (evaporator), compressor, condenser Coil, collection tank and humidity sensor and control unit to maintain desired humidity levels.

It has power of about 350W and tank capacity of 3l. The device indicates the humidity of air with time and also indicates P2, when the water tank is full, so that water can be taken out and the tank is kept again. For the study I added also additional external digital thermometer, humidity indicator and portable energy meter (Photo 5 right) to know the energy consumed.

In principal water collected from humid air is not potable and not recommended for drinking unless it's purified by some means. Some of the reasons are [3]:

- **Contaminants from Air:** The dehumidifier pulls in airborne particles like dust, mold spores, and pollutants etc.
- **Non-Food -Safe Surfaces:** The internal parts like coils and reservoir are not designed with food grade materials. They may leach metals, like iron or copper or bacteria etc.

However, it can be used for watering non- edible plants, and cleaning floors or tools, etc.

For urgent needs or survival needs, dehumidifier water can be made potable by chlorination, boiling or UV sterilization etc. as will be explained shortly.

Experimental study

The dehumidifier Air Pro is kept in our house (meeting room). Room size is 6m X 4.5m X 2.4 m = 64.8 m^3.

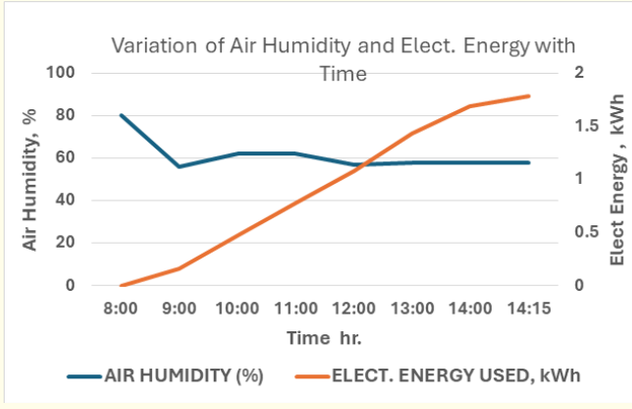
While dehumidifier is simple to operate, this study focuses on electricity used, water collection, and reduction in air humidity etc. The experiment has been done to note time and energy required to extract 3l of water from room for many days, however we will report the results for 2 days. The performance of Dehumidifier on June 20, 2024, is shown in graph 1.

Expt. 1. Thursday, 20/6/2024, Variation of Air humidity and Elect. Energy Used.

Time	H (%)	Energy (kWh)
8:00	80	0
9:00	56	0.16
10:00	62	0.47
11:00	62	0.78
12:00	57	1.08
13:00	58	1.43
14:00	58	1.69
14:15	P2	1.78 Stopped

Table a

The Ambient temp. during this period was 22-25 °C. Water collected was 3 liters in 6 hrs. 15 min. Energy Consumed was 1.78 kWh.

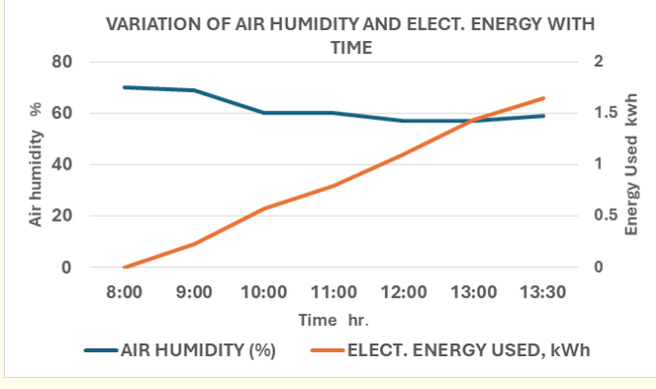


Graph 1: Energy performance of Dehumidifier on June 20, 2024.

Expt. 2. Thursday, 27/6/2024. Variation of Air humidity and Elect. Energy Used.

Time	Power W	H (%)
7:50	278	70
8:00	307	69
09:00	304	60
10:00	303	60
11:00	297	57
12:00	294	57
13:00	311	59
13:30	P2	59 Stopped

Table b



Graph 2: Energy performance of Dehumidifier on June 27, 2024.

The average working power of AIRPRO during 5:5 hrs. was about 300 W. Thus, energy consumed will be 300W X5.5 hr. = 1.65 kWh. The Ambient temp. during this period was 24-27 °C. According to both our studies, it looks like it requires about 0.55 to 0.59 kWh of electrical energy to capture 1 liter of water from the air. On the other hand, according to literature the energy required to extract 1 liter of water from humid air using an electric dehumidifier depends on several factors like ambient humidity, air temperature (warmer air holds more moisture), Dehumidifier efficiency etc. but approximately it consumes 0.5 to 0.8 kWh per liter of water extracted [3], very similar to our data.

Chemical analysis of water

Although as explained earlier, this water is not recommended to drink directly, still I preferred to get the chemical analysis done by Department of Chemistry, on June 27, 2024 as shown in Table 2. It also gives recommended values of potable water.

However, Iron, copper, Zinc, Manganese and Chlorine were not detected, as reported officially by Analysis Lab.

There are many commercial models available in the market. One of these is Ecolo Blue 28 (power 500 Watts), which is not only dehumidifier, but it is an Atmospheric Water Generator which means it pulls moisture from air and turns it into clean drinking water. It produces over 7 gallons (about 28 liters) of fresh water every 24 hours [3].

Now I will share about the study related to the purification of water.

Distillation of water

Once you collect water, then it should be cleaned (depending on minerals or microbes) if required. Any water (including tap) has pure water mixed with some solid particles, mainly some salts. Solar Still is a simple device to distill water to separate solid (salts) and liquid (water).

Concept of solar destillation is not new. There are many desalination plants in many countries. Even a 4800 m^2 plant was built in Chile as early as 1872.

Although lot have been published in literature. I will mention in brief the one studied and published by me and my colleague [4,5]. As shown in Photo 6, it has a metallic basin (tray), kept in a metallic box and has an ordinary transparent but inclined glass, over the box. The metallic tray has a plastic black lining as an absorber of solar radiation.

Parameters	Water from Humid Air	Acceptable limit for potability
pH	7.41 (*)	6.5-8.5 (**)
Elect. Conductivity (µs/cm)	18.7	400
Turbidity (NTU)	0.90	1
Soluble Salts Total (mg/L)	4.0	1000 ($)
Alkalinity Total (mg/L $CaCO_3$)	9.9	-----
Hardness Total (mg/L$CaCO_3$)	≤ 0.20	400
Calcium (mg/ LCa)	1.471	100
Magnesium (mg/LMg)	0.451	30
Sodium (mg/LNa)	0.464	25

Table 2: Chemical Analysis of Water from Humid Air.

(*) Alkaline (**) Acidic. ($) Maximum admissible value.

Photo 6: Photo of a common Solar still designed and studied by author.

The water to be cleaned is kept in the metallic tray. Due to solar radiation, water is heated and only pure water gets evaporated, but the minerals (solid) are retained in the metallic tray.

To collect this distilled (or pure) water, a small steel or aluminum long container is fixed at the bottom/lower side of glass. At one end of this metallic long tray, there is one clean rubber tube connected to a glass/plastic bottle kept outside the box. Pure water is collected in this bottle.

Depending on the solar radiation, the water in tray can attain temperature around 40-70 ℃. The solar still can distill about 3-5 liters of water per day and per sq. meter of absorbing tray with an average efficiency of the order of 40-50%.

Analysis of distilled water

In one of the studies the quality of tap and distilled water was analyzed at chemistry department, and the results are shown in Table 3. This also shows the approximate acceptable values as suggested by different organizations, specifically World Health (WHO) and Environmental Protection Agency (EPA).

Analysis shows that lots of minerals are removed. The process can be repeated with distilled water in case more salts need to be removed.

Pasteurization of water

Water like milk once pasteurize can inactivate pathogens like bacteria, viruses and parasites, while preserving the water's taste and quality. At least there are two common ways to pasteurize water, by heating and/or by Ultraviolet exposure.

Heating water

Water when heated to 70-65°C (instead of boiling) for around 1-3 minutes, can inactivate pathogens while preserving the water's taste and quality [6]. Pasteurization is more energy-efficient and is often sufficient to make water safe for drinking. Instead of using electricity, gas or firewood, one can use also Solar energy/Solar. Solar oven, in addition to cooking/heating lunch meal, at home and at educational centers. can be used also for pasteurization of water [7].

Parameter	Tap water	Distilled water	Acceptable Limit
Hardness (mg/l of $CaCO_3$)	36	4	
pH	7.15 (alkaline)	5.0 (acidic)	6.5- 8.5
Chloride (mg/l)	180	10	≤ 250 mg/l
Sulphate (mg/l)	100	10	≤ 250 mg/l
Copper	ND	ND	≤ 2.0 mg/l
Lead	ND	ND	≤ 0.01 mg/l
Electrical Conductivity (mhos/cm)	80	13.0	

Table 3: [4].

ND; Not detectable.

Although the detail of Solar Oven is described in my earlier papers and book [8-10], as shown in Photos 7, it is a wooden or metal box with thermal insulation on four sides and at the bottom under the metal plate. The metal iron plate is painted black on the top to absorb solar radiation. On the top of the box there are two transparent glasses (about 3 mm thick) separated by about 2-3 cm to allow entrance of low wavelength solar radiation coming from sun but impedes the transmittance of high wavelength emitted by metal plate. Thus, the air inside the box is heated, about 50-150 °C, depending on Solar intensity. At present hybrid model (7 Right) is my favorite one.

Photo 7: Conventional Solar Oven (Left) and Hybrid Solar Oven (Right).

In another recent study done at our house on Dec.18, 2024 I put a transparent glass jar with 500 ml of water at 10;30 am in Solar Oven at our house and digital thermometer to know the water temperature. Water attained temperature of 70 °C at and was pasteurized. was pasteurized at 12md. The day was sunny.

Solar disinfection, ultraviolet radiation

Another way of cleaning water is through Ultraviolet radiation [12]. This is an effective and inexpensive method for producing safe drinking water that can be done at home. It is called the solar water disinfection technique (SODIS). Sunlight and transparent plastic/glass containers are used to kill pathogens contaminating domestic water (Photos 8A and 8B).

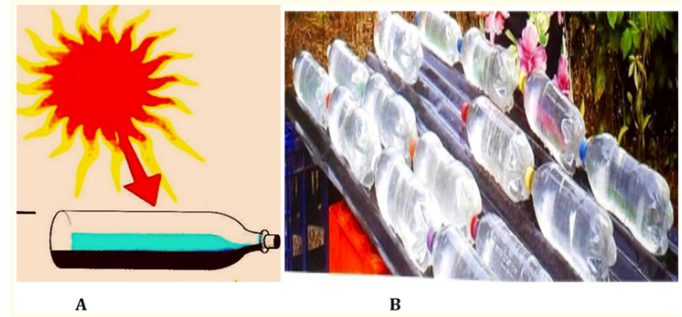
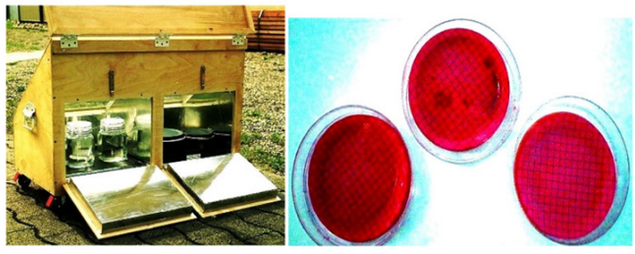


Photo 8: A (Left, concept) and B (right, in working). Inactivation of microorganisms by visible and UV radiation.

Solar disinfection, ultraviolet radiation and thermal radiation

Here in addition to Natural Ultraviolet radiation, also heat is provided.

In another study made in Germany, by this and other colleagues in May 1996 Shyam., et al. [13], with multicompartment Solar Oven. It was designed, constructed and studied at Fraunhoffer Solar Energy Institute. Water was heated in glass jar and also in metallic container (Photo 9A). The water in glass jar was receiving thermal and ultraviolet radiation, whereas metallic jar was receiving only thermal radiation. In addition to water temperature measurements in both jars, coliforms were also measured for tap water and water heated in both jars. It was confirmed [13] that 1 liter of water in glass jar (although at a lower temperature (60 °C) had less coliform than 1 liter of water heated in metallic container (66 °C). Photo 9B shows coliforms in untreated tap water (B, upper), water heated in metallic container 66 °C (B, lower left). Water heated in trans-



A B

Photo 9: Pasteurization of water with heat and ultraviolet radiation (A) and Coliforms study (B).

parent glass jar, 60°C (B, lower right). The day was not very sunny. One can attribute this to the presence of direct light (visible and/or ultraviolet light) plus heat.

Conclusions

In the present study we have informed of different simple means to get free water and make it potable for personal family use for different purposes, like drinking, bathing, making tea, coffee, toilet, garden and plants etc. Some of the ways mentioned are Solar distillation, Solar Pasteurization, Natural Ultraviolet radiation, Rainwater from roof and direct collection and extracting water from humid air. During last 40 years, I have been using one or other use, depending on climate, Sunny and or Rainy season. The solar devices at our house are now as another electro domestic devices and are used frequently. I plan to continue using at the house and hopefully some readers will like copy and follow me.

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