Research Article

Water harvesting cube

M. Salim Ferwati[1]

Abstract

Water scarcity is at the center of the world's greatest challenges, including famine, disease, and sustainable development. In many countries, there are active researches aimed at improving the supply of fresh water through actions such as seawater desalination and water recycling. Researchers are also working, on a smaller scale, to harvest water from the atmosphere to serve individual households or small communities. Cool surface condensation, fog catchers, and humidity harvesting are three examples of sustainable approaches that relied on affordable and simple equipment. This paper aims to introduce the possibility of using water condensation to generate potable water by using a self-sustainable-energy device. The device is scalable; being able to meet the needs of a single household and up to a residential district. The focus of this research is on the function of a *water-harvesting cube*. It consists of a set of solar panels, an energy converter, a dehumidifier(s), a water treatment component, and a water storage tank. The sum of all parts forms a 1 × 1 × 1 m cube. The premise of the proposal is that one dehumidifier can produce a sufficient amount of pure water for an individual's various daily uses. The researcher conducted two experiments during the summer of 2018, one in London, Ontario, Canada, and the other in Doha, Qatar. The result showed that in an environment of 50–70% relative humidity, a single dehumidifier could produce up to 15 L of pure water per day. The research here proves that the proposed water harvesting cube is efficient, affordable, and requires low maintenance.

Keywords Pure water · Solar panel · Dehumidifier · Harvesting water · Condensation · Self-sustainable-energy device

1 Introduction

In the age of climate crisis, seeking sustainable, liveable, and resilient urban development is a substantial responsibility for researchers and scientists in all fields. Researchers from different disciplines often work in a joint effort to search for optimum solutions for sustainable urban development. This work is not only evident in publications, but also prominent international conferences held annually addressing these subjects such as the International Conference on Urban Climate (ICUC), the International Symposium on Sustainable Solutions in Structural Engineering and Construction (ISEC), and the International Conference on Innovative Applied Energy (IAPE). The significance of these conferences is to highlight human settlement problems and suggest solutions for environmental degradation as a result of unsustainable construction, environmental disaster, and waste energy. The researchers' efforts have led to innovations in the urban development of smart cities and eco-districts. The solutions, however, are often costly at large scale, meaning that they are often implemented in wealthy nations. This includes, for example, the recent development of Lusail City in Qatar. The fundamental question is rather how we can present solutions globally.

The author argues that instead of presenting solutions on a large urban scale (such as the city) to focus instead on small-scale development (the households). Solutions on the household scale collectively constitute sustainable solutions for entire districts or cities. Large-scale sustainable

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urban development requires governmental coordination and significant private investment to implement. On the contrary, small-scale development can be faster and more affordable per individual. The author of this research is seeking a sustainable, eco-friendly, and affordable solution for a self-sustaining household. In 2016, in an initial step towards developing a self-sustaining house, the author leveraged the wind in hot-arid climates to develop a self-cooling wall [1]. In 2017, he took a second step by studying the effects of projected wooden elements above an opening in increasing the crosswind ventilation inside a building [2]. This paper takes the third step towards that goal by offering a method of generating fresh water supply for an individual household.

Regions with different climates and geographical characteristics experience vastly different water accessibility. Some have plenty of rainfall, rivers, springs, and lakes, while for the rapidly growing segment of others, the reality includes continuous droughts and limited water sources. In the latter case, when a community has access to the sea, they may desalinate seawater to meet their daily needs. "There are more than 11 thousand desalination plants all over the world with an overall production of more than 6 billion gallons of desalinated water per day [3]. In some regions such as the Middle East and Western Asia, more than half" of the consumed water comes from desalinated water [3, p. 149]. The absence of natural water resources is, of course, the major reason for sparse inhabitation of drylands, as is the case of The Empty Quarter in Saudi Arabia. Other regions rely on groundwater, but with a shortage of rainfall, groundwater begins to deplete over time. Recently, with the increasing concern for climate change and sustainable society, improving water source management and recycling water have become two other major methods to obtain and maintain fresh water. Water source management and water recycling cannot, however, provide sufficient quantities for society alone. There is thus a contemporary urgency for the creation of efficient, affordable, and scalable methods of harvesting water.

This paper has four main sections. The first section will support the introductory argument by highlighting the case of Qatar as a representative of vast hot, arid regions in the world where there are growing concerns about future water security. The second section briefly introduces recent studies of water air harvesting. The third section goes through a literature survey of small-scale solutions for water shortage. The last section will introduce the water harvesting cube, a solution to provide fresh water by an off-grid operated device.

2 Water resources in hot arid regions, the case of Qatar

Qatar is a country of 11,590 square kilometers on the Arabian Peninsula (Fig. 1). It lies in a hot-arid zone and therefore experiences severe water shortages. Qatar is also experiencing a rapid rate of population growth, increasing from 592,257 people in 2000 to 2,712,525 in 2018, a growth rate of 4.58%. According to the Ministry of Development, Planning, and Statistics, 97% of Qatar's population lives in cities, making it one of the most urbanized countries in the world. [4].

In 2018, the World Bank Group indicated that the average annual rainfall in Qatar from 1901–2015 was 64.68 mm. [5] Precipitation occurs in December, January, February, March, and April while staying very dry the rest of the year. Qatar lacks many natural water resources. The rapid population growth has thus led to an increased demand for water in a place of low supply, leading to a desperate need of new sources. Qatar has three sources of fresh water: desalination of seawater, groundwater, and treated sewage effluent (TSE). Figure 2 shows desalination as the primary source of water, reaching 845 million m^3 in 2014, or 66% of total water production. Obtaining water from the sea leaves an unanswered question of what to do with the resulting sea salt of the desalination process. Groundwater is the second largest source, reaching 350 million m^3 in 2014, or 27% of the total water production. Treated sewage effluent (TSE) is the only source for recycling water. It started in 2003, and as of 2014, its production had reached 87 million m^3 in 2014, or 7% of the total water production. Both Desalination and TSE have high operation costs. [6].

3 Recent studies in the field

The processes of seawater desalination, TSE, and groundwater extraction and management are costly, energy intensive, and may even be considered environmentally unsustainable as a result. The search for a more accessible and affordable method is therefore constant, especially for countries in drastic need of fresh water. "The affordability of water has a significant influence on the use of water and selection of water sources. Households with the lowest levels of access to safe water supply frequently pay more for their water than households connected to a piped water system. The high cost of water may force households to use alternative sources of water of a poorer quality that represent a greater risk to health" [8, p. 85]. This research directs the intention towards the atmosphere that has approximately "13,000 trillion liters

Fig. 1 Qatar location map [7]

of water, equivalent to nearly 10% of all freshwater present in lakes worldwide" [9]. Searching for sustainable solutions to obtain fresh water is still not up to a satisfactory level. The study objective is to propose a solution for water accessibility by looking at the humidity in the air as an alternative water source to sustain daily household needs. The solution should be affordable, operate at net-zero energy, and cause no harm to the environment.

4 Literature survey of small-scale solutions for water shortage

Before discussing the proposed solution, the following is a glance at recent primary studies that target atmospheric water. There are five different methods applied up to date. The differences among these methods are based on seven parameters: 1. the required area size for the equipment, 2. Orientation, 3. Materials and constituent parts, 4. Amount of water produced/day, 5. Cost of the equipment and its operation, 6. Rate of sustainability, 7. The suitability of regions for the application.

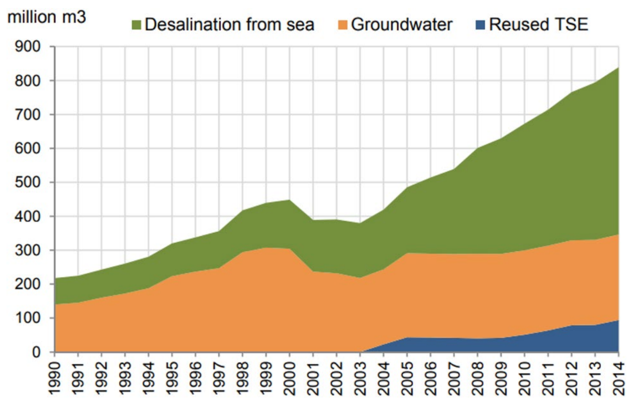


Fig. 2 Total water production and re-use by the source of water in Qatar (million m^3) 1990–2014 [6]

4.1 Yielding of dew water

In Oct 2004, Girja Sharan, a Hydraulic engineer, searched for a way to solve the drinking water crisis with condensation [10]. His study relied on yielding dew water on galvanized iron roofs. The study took place in Kothara, North-West India.

4.2 Fog harvesting

This method relied on erecting a plastic net by the support of two poles, like a volleyball net. Cho [11] said, "Fog collectors can be used in regions and deserts that receive less than one millimeter of rain each year, but to work, they require fog and light winds."

4.3 Harvesting water from dry air

This device was developed at the Device Research Laboratory at the Massachusetts Institute of Technology (MIT), and the University of California, Berkeley. The operation of the device relies on a porous metal-organic framework (MOF). The operation of the device relies on ambient sunlight and no electricity. The device has MOF crystals embedded in the copper sheet sandwiched between the solar absorber and a condenser. [9] The MOF "captures water from the atmosphere at ambient conditions by using low-grade heat from natural sunlight at a flux of less than one sun (1 kW per square meter)." [9] In relative humidity (RH) as low as 20%, the device can produce 2.5 L/day. As it operates in low RH, the device is suitable for desert environments.

4.4 OffGridBox

Emiliano Cecchini developed this device for an Italian company. It is a cube that measures 1.8 × 1.8 × 1.8 m. The off-grid box contains generators that convert and store solar energy, as well as collect and treat clean drinking water [12].

4.5 Solar hydropanels harvest drinking water and energy

Cody Friesen, an associate professor at Arizona State University, School for Engineering of Matter, developed this method in 2016. [13] The device called Source, produces water by using photovoltaic and hydropanels. Diane Pham [13] described the process as follows: "the photovoltaic at the center of the array drives a fan and the system's communication with the hydropanels. The hydropanels themselves consist of two different proprietary materials, one that can generate heat, and another that can absorb moisture from the air. Together they can condense water into an onboard, 30-liter reservoir where it is mineralized with calcium and magnesium."

Table 1 compares the five methods of harvesting water from the atmosphere. Table 1 shows that all five studies have started taking place since 2007. Even though all studies are suitable for regions with water shortage, the first two studies are limited to specific climatic conditions (fog, light wind, and dew) while the last three are suitable everywhere, including hot arid zones. Additionally, the last three studies are relatively costly for poor societies where water is most needed. The following section introduces another solution to solve the shortage of water. This solution is affordable, sustainable, and possible to commercialize.

5 Research focus

The focus of this research is on developing a device that produces enough water to meet the minimum daily requirement of a household. The author calls this device 'Water Harvesting Cube.' The cube consists of a set of nine solar panels, an energy converter, a dehumidifier(s), a water tank, and a water treatment system. All parts included in the cube possess a maximum dimension of 1 m. The solar panels allow the cube to operate off a central electrical grid system. Table 2 illustrates the proposed design of the cube.

To define the significances of the cube three main questions are raised: First, what would be the weight and cost to operate the cube? Second, what will be the needed number of dehumidifiers to harvest enough water for an individual? Moreover, is the obtained water drinkable?

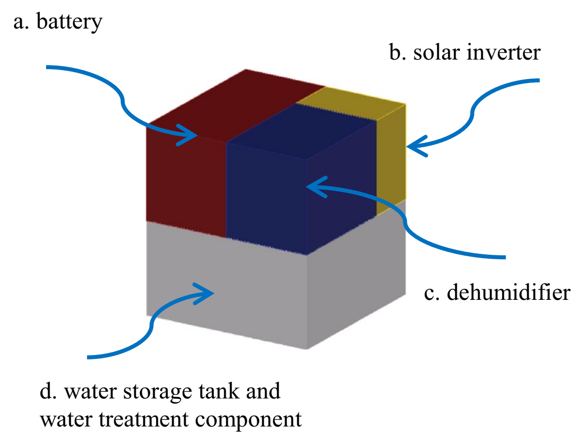
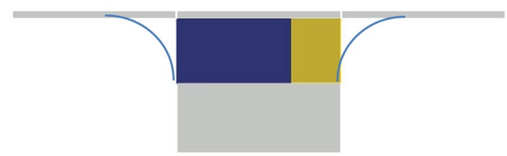
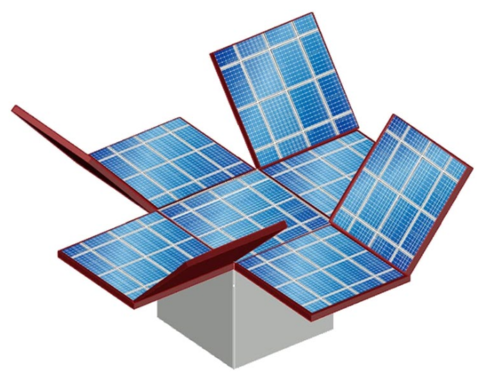
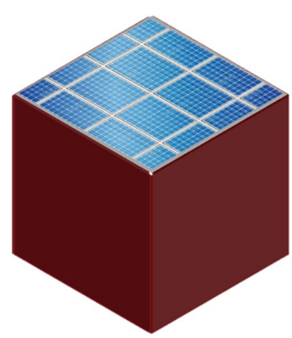
Table 1 A comparison of the five methods used harvesting water out of the atmosphere (Author)

Water extract methods	Area size for the equipment/device	Orientation	Material and constituent parts	Amount of produced water	Cost of equipment and operation	Rate of sustainability	Suitable region for the application	References
1. Yielding of dew water on galvanized iron roofs	18 m^2	Double-sloped (30°)	Galvanized iron	113.5 L (6.3 mm).	Not specified, but the cost of the parts and installation is affordable	Highly sustainable/zero energy/environmentally friendly	Can be found in every place. However, it becomes significantly important in the region that has a poor rate of rainfall such as deserts. Dew is usually formed at night	[10]
2. Fog catcher system	Different area size. Possible 4 m × 8 m	Held vertically by two poles, like a volleyball net. It can be set in any direction	Net of polypropylene or polyethylene mesh and two poles	According to Collyns 2009, during foggy days, one panel of 4 m × 8 m produces 120 L of fresh water	Not specified, but the cost of the parts and installation is affordable	Sustainable/net-zero energy/eco-friendly	Scattered areas in the world, for example: California's Great Central Valley (Nov–Mar); Tampa Bay area of Florida (Dec to Feb); Sydney's fog season (Apr to Oct); Japanese coast of the Pacific Ocean (May to Aug)	[11] [14] [15]
3. Harvesting water from the dry air	Not specified, but it occupies the area of the device only	No required	"Use a metal-organic framework (MOF) material that has a steep increase in water uptake over a narrow RH range to harvest water, using only ambient sunlight to heat the material"	2.8 L of water per kg of metal-organic framework daily at 20% RH	Not specified, but continuous supply for MOFs substance is costly	Eco-friendly	Desert environment, a region with RH as low as 20%	[9]

Table 1 (continued)

Water extract methods	Area size for the equipment/device	Orientation	Material and constituent parts	Amount of produced water	Cost of equipment and operation	Rate of sustainability	Suitable region for the application	References
4. Compact Off Grid Box	At least the required area is 12-m^2	South and west are the best directions. The angle depends on the location. Can be determined by multiply the location latitude by 0.76, plus 3.1 degrees [16]	Equipped with 12 solar panels, an inverter, and battery storage in a 1.8 × 1.8 × 1.8 m container	Does not specify precisely how much water is harvested per day. It has a built-in storage tank that holds up to 396 gallons of water, however	Costly at USD 15,000 per unit	Sustainable/Eco-friendly	Where it is needed most	
5. Solar hydropanels harvest drinking water and energy	Approximately 4-m^2	The device can be set at the top of the building or in an open area. With direction toward the south	It consists of photovoltaics, a fan under the PV panels, and two different proprietary materials of hydropanels, one generates heat, and the other absorbs moisture from the air	Each panel could produce 10 L of water per day	Requires professional installation; each panel costs 2500 USD	Sustainable/Eco-friendly	Anywhere with exposure to the sun; it even works in dry climates of 50% humidity. The harvested water requires mineralization of calcium and magnesium	[13]

Table 2 The Table explains with illustrations the components of the water harvesting cube

<table>
<tr><th>Explanation of the cube</th><th>Illustrative drawings</th></tr>
<tr><td>1. The composition of the Cube:
The box is made of aluminum or fiberglass to produce a lightweight Cube. The dimensions of the water-harvesting cube are 1 × 1 × 1 m. It contains the following internal components:
A solar battery of 1 × 0.5 × 0.5 m. I suggest the use of deep-cycle batteries
An inverter to transform direct current (DC) electricity into alternating current (AC) power. The inverter, photovoltaic array, and a power meter are set in the space of 0.5 × 0.5 × 0.3 m
An active dehumidifier (2 units) is set in the space of 0.5 × 0.5 × 0.7 m. It requires 28 kW/h to run each unit
Storage for collecting water with a size of 1 × 1 × 0.5 m. This includes a water treatment component</td><td>
</td></tr>
<tr><td>2. The Solar Panels:
A set of nine foldable PV solar panels, each at 1 × 1 m, are attached to the side of the cube: 2 folded to each of the four sides and one on top of the cube
When the panels unfold, they form a 3 × 3 m solar panel surface area (9 m^2)
Optional feature: Since the amount of electricity produced by the solar panel is mainly dependent on the position and intensity of the sun, the solar panels can be inclined to face the sun using a sun-tracking sensor linked to a built-in mechanical system
The right figure shows a side view of the Cube when all solar panels are unfolded. In this position, the Cube is set for full operation</td><td></td></tr>
<tr><td>3. A Perspective of the Cube:
The right figure shows a perspective of the nine folded PV solar panels. It illustrates how the two panels of each side connect to the top panel and how they unfold to form the larger PV surface
The corner panels are flipped over the side panels which can then be folded down to the sides of the cube</td><td></td></tr>
<tr><td>4. The Folded Cube:
After folding down the four-sided PV Panels over the side surfaces of the cube, the water harvest cube appears as shown in the right figure
In this position, only the top solar panel is exposed. It charges the batteries when the cube is not fully operating
Handles on all sides can be added to ease the carrying of the cube</td><td></td></tr>
</table>

Regarding the cost of operation, the cube uses PV panels to eliminate dependency on city electrical grids, saving 12 h of electricity consumption costs necessary for operating the dehumidifier. One solar panel produces about 1 kWh per day of electricity. The proposed cube, carrying up to nine PV panels, can, therefore, produce 9 kWh per day (9000 kW). One dehumidifier requires 280 kW per hour. The nine solar panels will thus generate enough power to run two dehumidifiers for 16 continuous hours. The allocated place in the cube of 0.5 × 0.5 × 0.7 m, is sufficient for two units. There is also the possibility to produce a cube with one dehumidifier at a smaller volume of 0.6 × 0.6 × 0.6 m and a reduced PV panel area. One-unit cubes can produce around 15 L per day. Two-unit cubes can, therefore, produce up to 30 L per day, enough for two individuals in a region that experiences drought. An additional number of cubes will help meet the needs of a household.

In responding to the second question regarding the sufficiency of the produced water for an individual, two experiments and a literature review are conducted to define the minimum amount of water needed for an individual to survive. This is summarized in the following paragraphs.

Experimentation 1: In the summer, Ontario, Canada reaches a high humidity of an average of 80%, which often requires the use of a dehumidifier to prevent the growth of fungus. The author used a dehumidifier with a 15-L water tank. It was running 24 h a day, seven days a week for July and August of 2017 and 2018. The result was an average yield of 8–12 L of water per day.

Experimentation 2: In Qatar, we measured the drops of water resulting from running a 1.5-ton split-unit air conditioner. The result was the accumulation of 0.5 to 1 L of pure water per hour, depending on the degree of humidity.

The use of water condensation, like in both experiments, is not a new idea. One can easily find examples around the world where people demonstrate their attempts to make use of the water from dehumidifiers and air conditioners.[1]

Condensate water is often wasted because it is not integrated into the building water system. Water is a precious substance that we cannot afford to waste especially when there are people who do not have the minimum amount of water for their daily needs. Figure 3 shows the average water used per person per day for selected countries in 2006. The findings show for example that the average water use per capita is 575 L in the US, 149 L in the UK, and 15 L in Ethiopia [14]. Generally, the more affluent the country, the greater the consumption of water per capita. In its 2011 report, the World Health Organization (WHO) indicated that in case of emergencies an individual requires 2.5 to 3 L per day (lpd) to survive (drink and food) [18] (Table 3).

This finding takes us to the third question—is the condensed water produced by dehumidifiers drinkable? For human consumption, the distilled water is not advisable

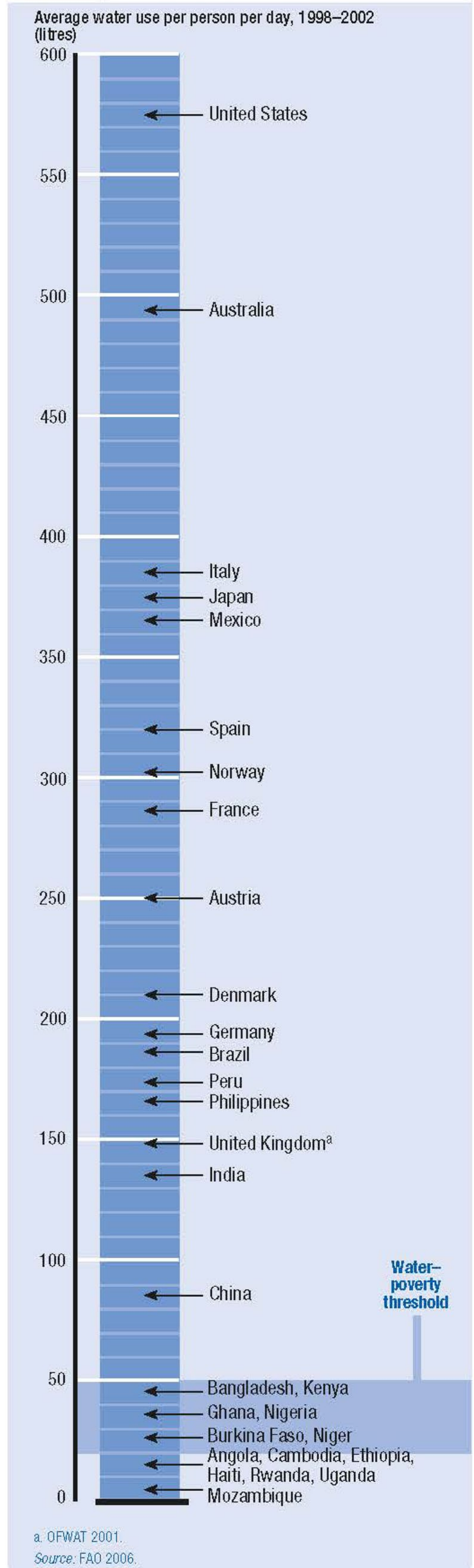


Fig. 3 On the left lists the average water use per person per day [17]

[1] For examples, see the two links: https://alumni.stanford.edu/get/page/magazine/article/?article_id=29155 and http://atlasbutler.com/heating-and-cooling-repair/4-ways-reuse-dehumidifier-water/.

Table 3 Simplified table of water requirements for survival (per person) [19, p. 9.2]. The table suggests that it is not necessary to use drinkable water for different usages. People may use potable water for drinking, recycled or grey water for basic hygiene practice, and lower quality water for growing crops

Type of need	Quantity (lpd)	Comments
Survival (drinking and food)	To 3	Depends on climate and individual physiology
Basic hygiene practices	To 6	Depends on social and cultural norms
Basic cooking needs	To 6	Depends on food type, social and cultural norms
Total	7.5 to 15	lpd: liters per day

to drink. Distilled water is "defined as water almost or completely free of dissolved minerals as a result of distillation, deionization, membrane filtration (reverse osmosis or nanofiltration), electrodialysis or other technology" [18, p. 149]. SPT, a dehumidifier manufacturer, explicitly warns its customers of drinking the distilled water for example [20]. To transform this water into potable water requires simple treatment. The cube will contain a part for this treatment that adds chemicals such as calcium carbonate or limestone to make the water potable; as is the case with desalinated water processing [18, p. 150].

The condensed water can also be used for different daily needs even without this treatment. This includes watering plants, washing, cleaning, flushing toilets, etc.

In addition to the mentioned significances of the water-harvesting cube, there are three others:

1. Lightweight. The cube will be made of light materials. In a rough estimation, the expected weight will be around 30 kg or less.
2. Possibility to commercialize. E-commerce companies such as Amazon, Alibaba Group, and eBay, can market the device as it is an assembly free and compact device.
3. Easy to install. Once the device is set on the roof or in an open space with access to the sun, the user can raise the PV panels and switch on an electrical key to start the operation of the device. The dehumidifier will start operating once the amount of the converted electricity is ample to run the dehumidifier(s).

6 Conclusion

In regions with scarce water recourses, people suffer due to the lack of access to fresh water required for drinking and sanitation. There are therefore many efforts to find innovative and efficient ways to harvest and manage water resources. Obtaining fresh water from the atmosphere (dew, humidity, and fog) is a promising method in its early stages of development. The small-scale approach of this alternative water collection, however, has not yet attracted enough attention from researchers. This paper discusses five existing methods used to harvest water from the atmosphere. It also introduces the *water harvesting cube* as another method of using condensation to generate potable water for a household using the self-sustaining energy of the device. The cube contains all the necessary parts to convert and store solar energy. It also contains a water tank and a dehumidifier(s). The proposed water harvesting cube is a simple device that can continuously produce water. The device operates off-grid, and excess electricity can be stored in the battery for night use. Its measurement is proposed to range from 0.6 to 1 m, depending on whether one or two dehumidifier units are needed. The proposed device can be marketed through e-commerce services such as Amazon, Alibaba Group, and eBay. The cube can then be easily installed on building rooftops or in an open area with access to the sun.

Additionally, the obtained water can be directly connected to the main water storage tank of the household after being treated. The Water Harvest Cube is a solution for water shortage that not only provides individuals and communities with much-needed water but also does so in an efficient, affordable, and low maintenance manner. It is anticipated that this solution for water shortage will not only play a significant role in alleviating household suffering but could also potentially play a socio-political role in alleviating continuous tensions and disputes among societies and individuals over water resources.

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Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

Human and animal rights The research does not involve Human Participants and Animals.

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