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Research Article

Towards the Adoption of Non-conventional Water Resources (Green and Grey Condensation): The Case of Egypt

Amr Gomaa Gnedy, **Ahmed Osama Daoud***, **Yahya Elmansy**

Civil Engineering Department, Faculty of Engineering, The British University in Egypt (BUE), Cairo, Egypt
E-mail: Ahmed.Daoud@bue.edu.eg

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Abstract: This research evaluates the dependency between air conditioner water and rainwater as a solution to water scarcity in Egypt. A sample from rain and air conditioner water has been collected in Cairo for lab testing. Also, an experiment involving a 1-tonne air conditioner has been conducted to estimate the volume of output water from the air conditioner. Moreover, a study of the meteorological data of El Shorouk City and the potential for water capture and reuse have been estimated. The British University in Egypt (BUE) has been taken as a case study to evaluate the amount of water per year that can be generated if the aforementioned two water sources are used. The lab testing results of rain and air conditioner water indicated that both had a slightly acidic nature with low mineral content. However, both samples meet standards for irrigation of crops and non-potable uses set by the Egyptian Decree of Health Ministry (No. 458) (2007). As for BUE, the amount of water that may be collected from air conditioners and rainfall was estimated at 1523.45 m³ and 8065 m³ per year, respectively. This water may be used for irrigation of green areas, distilled water for soil and concrete labs, or cleaning purposes.

Keywords: non-conventional water resources, green and grey condensation, water shortage, Egypt

1. Introduction

Today, before the problem of the Grand Ethiopian Renaissance Dam escalates even further, Egypt is already suffering from water scarcity. The exponential rise in population without an increase in water resources or the development of better water management systems is to blame for this. In the year 1947, when the Egyptian population was about 19 million per capita [1], the water consumption was 2,604 m^3 per capita per year [2], enough to put Egypt clear of the United Nations' threshold for water scarcity at 1000 m^3 per capita per year. Since then, the population has exploded in numbers until the current water consumption dropped to 560 m^3 per capita per year [3], only 60 m^3 away from being classified as absolute scarcity. It is important to mention that, according to WorldOmeter, the Egyptian population as of December 11, 2021, stood at an average of 105 million per capita [4]. No surprises there, as it explains the water scarcity issue, but the same website predicts Egypt's population to grow to about 160 million per capita by 2050. This should cause the water availability to drop below 350 m^3 per capita per year, all without considering the drop-in water availability that might be caused by the Ethiopian Dam [4].

Water is without question the most important resource on Earth. Its absence has great effects, from health to irrigation, but most importantly economic effects. It is expected that the Middle East and North Africa (MENA) region

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will suffer a 6% to 14% drop in gross domestic product (GDP) because of the effects of water scarcity [5]. This research, inspired by the Egyptian water scarcity problem, will focus on some sources of Egypt's wasted water and whether they can be the answer to this problem. It will contain a study of these two resources' history, the volume of water that can be recycled, the quality of water, and whether it can be recycled at all, as well as recommendations for the management of these resources and further study.

2. Research aims and contributions

The research aims to achieve the following:

a) Assessment of rainwater and air conditioner water quality and identification of their possible uses.

b) Performing runoff calculations for the possible volume of rainwater to be collected at the British University in Egypt (BUE) as a case study.

c) Providing a formula to estimate the volume of air conditioner water based on time of operation, thus estimating the total generated water per year.

The aforementioned aims are achieved through the collection of meteorological data, the collection of water samples, and an experiment involving a 1-tonne air conditioner.

The main contributions of this research are the following:

a) The study of BUE's air conditioners and their capacity.

b) The use of numerical methods to deduce a formula for the estimation of the water volume.

3. Literature review

Water on earth follows the hydrologic cycle, nature's way to keep its water clean and fresh (which will be called green condensation for the remainder of this research). While this may be the natural order, there is a small-scale hydrologic cycle (we will call it grey condensation for the remainder of this research) that occurs inside our houses almost every day of the summer.

Grey condensation starts at the water's surface as it evaporates, continues in the air inside our home, and ends when air conditioners are turned on as the water drops out through the air conditioner's internal drainage system. Inside the air conditioner, the air is cooled by passing over a cooling coil. The cooling coil is cold enough to cool the air to the desired degree and also to condensate the humidity in the air. Grey water then flows out of the air conditioner, the same way rain pours from the sky.

The difference between green and grey condensation is that the passage through the atmosphere and contact with soil during rainfall (which does not happen in grey condensation) provides water with various minerals [6]. Since green condensation is responsible for the freshwater courses on earth, rainwater should be clean and fresh, apart from the pollution in the air that the raindrops go through. Egypt's rain contributes just 1.3 billion m^3 per year, which some might see as trivial considering that Egypt's yearly need for water is 114 billion $m^{3.}$ That number is about to become even more insignificant because Egypt's actual share of rainfall, according to the Food and Agriculture Organisation (FAO)'s Egypt country profile in 2016, is estimated at 51 billion m^3 a year, which is almost the same as Egypt's share of the Nile River [7].

A very small portion of rainwater in Egypt (2.5%) falls on the existing watercourses. The remaining rainwater (97.5%) stays at the surface of the ground, waiting to be drained, evaporated, or leaked into the underground water table. Until then, the water fills the streets, sometimes to the point where it is completely flooded, delaying or even stopping traffic and making it uncomfortable for pedestrians to leave their homes, not to mention the damage this water does to the pavement of the street itself and the existing structures and machines that were not designed for such a heavy water exposure.

Egypt, suffering from water scarcity and a below-average economy, also has to deal with the financial damage from rainfall, a true recipe for disaster. Alexandria, Egypt's most famous governorate when it comes to rainfall, has had an average precipitation of 319 mm (more than 1 ft) in the last eight years, according to local weather stations. Just to put this number into perspective, a standard ruler, two steps of a staircase, and kerbs are all things listed at heights less than

319 mm of rainfall.

Here is a breakdown of Egypt's water resources. The main water source, which is of course the Nile River, provides Egypt with the lion's share of its water at 55.5 billion m^3 a year. The amount of virtual water that Egypt imports stand at 34 billion m^3 a year (virtual water is indirect water hidden in food and other goods that require water for production). Recycled water from irrigation drains and treated wastewater represents 21 billion m^3 a year. Finally, rainwater contributes a mere pittance at 1.3 billion m^3 a year [8]. Figure 1 shows the percentage of each water resource in the total available water in Egypt.

It has been reported that greywater is a good environment for the growth of six different species of bacteria [9]. The problem is that the design of the air conditioner unit does not include recycling this water, exposing it to contamination from the air. The process of making grey water safe for drinking includes a sediment and pre-carbon filter, a reverse osmosis membrane, a saline solution, three ultraviolet lamps, and an ozone system [10].

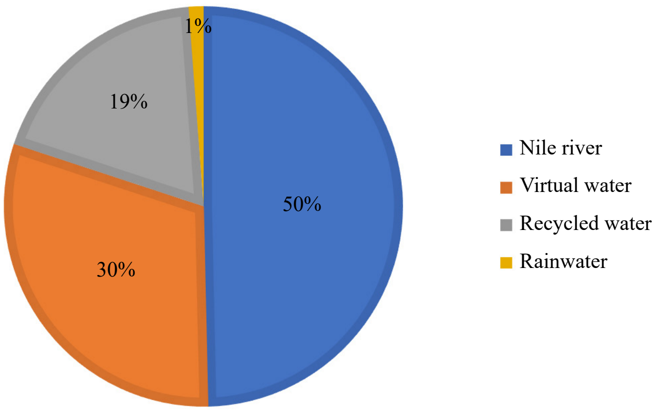

Figure 1. Egyptian water resources

As for rainwater, according to the World Health Organisation (WHO), while it is free from impurities, its quality may deteriorate during storage or harvesting. Rainwater has a relatively low pH (meaning it is slightly acidic) and low dissolved minerals. This may not seem like a problem, but it will lead to this water eating away minerals from storage tanks and other surfaces it touches to compensate for the lost minerals. Also, environmental conditions must be taken into consideration, since rainwater will probably touch roofs, trees, or other surfaces before being harvested. Faecal matter from animals and other pollutants must also be considered, but the thing that should concern people the most is the atmosphere itself, or the air that the raindrops will pass through.

Cairo, the capital of Egypt, is the world's top-ranked city for air pollution, according to the WHO urban air pollution database in 2018 [11]. Even though this is already bad news, the fact that Cairo's air pollution is 14.2 times above the WHO-established safe limit makes it even worse. A study found that air pollution from sources like fuel combustion and industrial emissions has an impact on the quality of rainwater [12], and it also advised conducting a bacteriological analysis of rainwater before use.

The risks of using rainwater and greywater have just been mentioned. However, a study in Bangladesh where grey water was collected aseptically proved that this water satisfies the standards established by Bangladesh as well as WHO for drinking, let alone other activities like fishing and irrigation [13]. Another study in India concluded that grey water is chemically and microbiologically pure water, suggesting that air conditioner manufacturers include a collection system to facilitate the use of this water and considered it a solution to water scarcity in India [14].

Another study done at a university in Nigeria discussed grey water as a solution to the water shortage in the university itself. The university had a unique situation since its only source of water was manmade wells, and in dry seasons it was a problem since the wells were nearly dry. The research concluded that grey water, although it may not be enough to satisfy the university's needs, was deemed good enough to be used in laboratories, for watering potted plants, and for cleaning purposes [15].

As for rainwater, research on the conditions in Egypt suggested that while rainwater harvesting is yet to be a thing in Egypt, it will play a vital role in providing water in the north coast cities, where rainfall is at its maximum [16]. Another research suggested that while rainwater quality is affected by the collection and storage methods, collection from galvanised steel roofs provides rainwater that meets the WHO standards for drinking in crisis, while other types of roofs still provide drinkable water but require disinfection because of high levels of bacteria [17].

Before going all in on the harvesting of condensate water (green and grey), an analysis of the volume of water to expect must be carried out first to determine whether this solution could be the answer or not to water scarcity in Egypt. Research done on air conditioners in India states that the volume of grey water can vary depending on the relative humidity of the outside air and the capacity of the unit, but also indicates that generally, for most modern air conditioners, the volume of produced water will range between 15 and 70 litres per day [14]. The same research predicts that for the active 6 million air conditioner units in India, a volume of 50 to 100 million litres of high-purity water can be collected daily. There are other parameters involved, but assuming this is the amount of water to be collected over just the 92 days of summer a year, the result is a range between 4.6 and 9.2 million m^3 a year.

Another study in Bangladesh, discussing the water shortage problem in the country, claimed that the average discharge of this underutilised grey water for a 1-tonne air conditioner (4.72 horsepower) is 1.10 litres per hour [13]. Another research in Bangladesh also tried to establish an empirical relationship to calculate the amount of generated grey water, but the study itself was limited and its results were not conclusive enough to deem this relationship usable [18]. However, the various studies agreed that the amount of grey water produced depends on the time since the air conditioner has been turned on; the temperature difference; the relative humidity; and the capacity and brand of the air conditioner unit itself.

As for rainwater, it is known to vary from year to year and from city to city. However, the variations in average annual precipitation in Egypt are great from one city to another, ranging from 0 to 200 mm per year, although some years recorded a rainfall intensity of 500 mm. Even some days recorded a rainfall intensity of 53.2 mm in Giza, which is not considered one of Egypt's rainy cities [19]. The data also showed that Egypt's highest rainy cities are the north coastal cities, specifically Alexandria, at 200 mm a year; the numbers gradually decrease to 22 mm a year in Cairo and to 1 mm in Aswan.

Global warming, a well-known issue that has been facing our planet for the past two centuries, could further increase the need for green and greywater harvesting. While there are no clear estimations or enough research on how this will affect Egyptian waters, the rise of carbon dioxide (CO_2) in the air contributes to the increase in global temperature. During the 20th century, it has been reported that the planet's temperature has risen by an average of 0.6 ˚C; this number could further rise to range between 1.4 and 5.8 ˚C [20]. This rapid temperature rise will cause more water to evaporate from the earth's surface, meaning less water in rivers and lakes and more water in the atmosphere.

4. Research methodology

4.1 *Rainwater quantity*

To estimate the amount of rainwater to be harvested, ideally, 50 years of rainfall data should be collected. However, it is allowed for as little as 10 years in case the data is not available. The more data collected, the more accurate the estimation, since years of floods or dry weather may occur out of the ordinary.

In this research, the study was made on the BUE, where the average precipitation per year, according to Visual Crossing [21], is about 162 mm. The data collected from the website were the years from 1973 to 2020, with the elimination of the years 1980 and 1981 because the data was not available, and the years 1993 and 1994, where the rainfall was extremely higher than the rest of the collected data so it is safe to assume that these years had floods that may not be repeated shortly. The collected data are demonstrated in Table 1.

When calculating rainfall, rainfall components must be studied. Any rainfall consists of precipitation, infiltration, evaporation, transpiration, initial abstractions (water intercepted from falling to the ground or stored in a surface depression), and excess rainfall (surface runoff). These parameters will be taken into consideration when calculating the amount of rainfall that can be collected.

Table 1. Total precipitation of El Shorouk City, Egypt, from 1973 to 2020

Year	Total precipitation (mm)	Year	Total precipitation (mm)	Year	Total precipitation (mm)
1973	265	1990	67.59	2007	31.29
1974	66	1991	369.92	2008	41.06
1975	77	1992	394.36	2009	106.19
1976	295	1995	13.74	2010	72.6
1977	14.2	1996	56.97	2011	54.62
1978	4	1997	187.31	2012	64.3
1979	337	1998	15.89	2013	113.8
1982	538.07	1999	0	2014	60.2
1983	25.47	2000	531.42	2015	122.2
1984	22.01	2001	53.26	2016	393.45
1985	64.79	2002	73.47	2017	172.58
1986	319.92	2003	448.79	2018	361
1987	340.18	2004	296.09	2019	28.7
1988	52.02	2005	22.4	2020	167.47
1989	35.11	2006	354.3		

To get the volume of the collected water, a series of factors will affect the runoff from the rainfall, as has been previously demonstrated. There are two methods of calculating the runoff.

The first method is the rational method, where the different factors affecting the runoff are calculated and taken into consideration, as shown in Equation 1.

$$\text{Inputs} - \text{outputs} = P_R \tag{1}$$

where P_R is the excess runoff.

By adding the inputs and outputs, the equation turns into,

$$P - ET - F - I_A = P_R \tag{2}$$

where P is the yearly average rainfall, ET is evapotranspiration (since both are hard to separate), F is infiltration and I_A is the initial abstraction.

For storm events occurring over a short period, which is the case in El Shorouk City, ET may be neglected. Also, the F and I_A may be classified according to the type of area of the collection as a proportion of the yearly average rainfall. The equation then yields:

$$CP = P_R \tag{3}$$

where C is the runoff coefficient. The C values for the catchment areas in this study are 0.7 to 0.95 for asphaltic pavement and 0.75 to 0.95 for rooftops.

The second method is the runoff curve number (RCN) method, where each catchment area is characterised by its type and a curve number is obtained from the soil conservation service tables [22]. The runoff is calculated from the following equations:

$$S = \frac{1000}{CN} - 10 \tag{4}$$

$$P_R = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{5}$$

where *CN* is the curve number (obtained from the table) and *S* is the potential maximum retention (inches).

Figures 2 and 3 are the BUE's two- and three-dimensional contour maps, respectively, and Figure 4 represents the proposed locations for rainwater collection catch basins based on ground elevations.

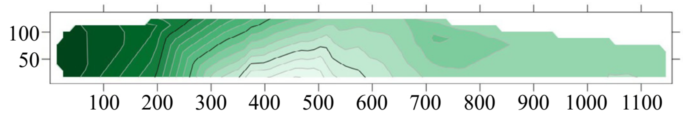

Figure 2. BUE's two-dimensional contour map

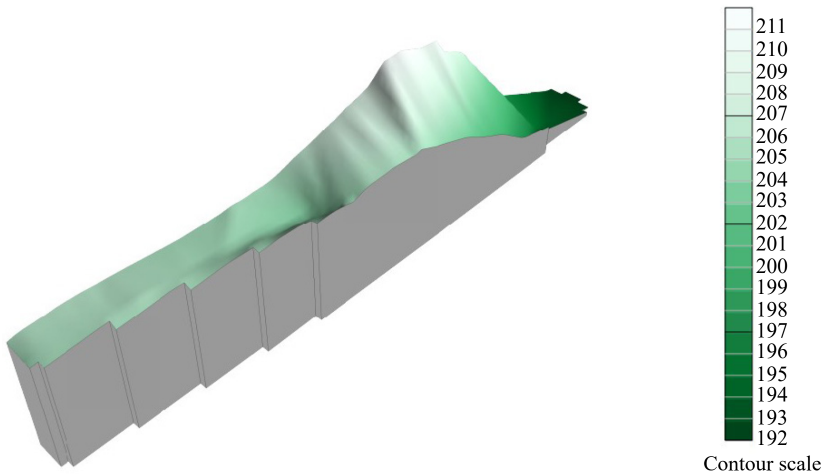

Figure 3. BUE's three-dimensional contour map

Figure 4. Proposed spots for rainwater collection catch basins

4.2 *Rainwater quantity*

In light of the discussed Egyptian pollution problem, is rainwater even safe to use at this point? If the water is polluted before it evaporates, this is not seen as a problem. The evaporation of water cleanses it from its pollutants, allowing it to condense and drop into the form of clean water. This is also the basis of thermal desalination, a certified method of producing fresh water. So, that is not the issue. The issue is the pollution this water might be exposed to in the form of rainfall drops.

However, as everyone knows, this rainfall forms the Nile River and all other drinkable freshwater courses. If these water courses are dependable when producing water, then so should the harvested rainwater, right? The answer is no. When this rainwater (if polluted) falls into a watercourse, it is mixed with the water of this watercourse. Since the rainfall event will produce a relatively low volume of water compared to the watercourse, the concentration of these pollutants becomes very low, and hence the watercourse stays clean and fresh. This is known as treatment by dilution, a method to treat sewage and wastewater.

The real issue is that harvesting prevents the water from receiving dilution treatment and, as previously mentioned, prevents it from coming into contact with the soil layers to absorb dissolved minerals. This will not completely rule out rainwater harvesting, since even if this water is polluted, depending on the quality analysis of this water, a proper treatment method could be proposed.

Samples of rainwater were obtained in El Omrania El Gharbeya, Giza, from a rainfall event that occurred on Saturday, November 20, 2021. The sample was collected in a plastic container that was kept in an isolated part of the street where traffic was low to avoid pollution coming from cars or passengers until it was filled, as shown in Figure 5. Then, it was left until the dust settled before an amount of 1.5 litres was moved to a plastic bottle to be taken to the lab for further testing. The sample was analysed and compared to the Decree of Health Ministry (No. 458) (2007). The standards are described in Section 4.4. For more information, refer to Section 4.4.

Figure 5. Collected rainwater before and after dust settling

4.3 *Grey water quantity*

While the volume of the output grey water will depend on several variables (as explained earlier), this study will focus on the effect of operation time on the output water. The study occurred in El Omrania El Gharbeya, Giza. The specifications of the air conditioner unit are as follows:

a) Brand: Sharp
b) Age: 10 years old
c) Type: Split-type room air conditioner
d) Cooling Capacity: 1 refrigeration ton (RT), 1.5 horsepower (HP), 12,000 British Thermal Units per hour (BTU/h), or 3.5 kilowatts (kW)
e) For more information on the cooling capacity units, please refer to Appendix A.

According to Carrier's Energy Department [23], people start turning on the air conditioner when the temperature gets higher than 25 ˚C. This occurs in Egypt generally from March 27 until November 18 (a total of 237 days or 33.86 weeks). During this period, the average relative humidity is about 59%, but during the day, the times at which the temperature is at its climax, the relative humidity ranges between 15 and 30%, typical conditions to study the volume of grey water.

The volume and discharge of grey water were observed every hour for several hours a day over the span of seven days in 2022 (1st of May to 3rd of May, then 30th of May to 2nd of June). The collection and measurement processes for the air conditioner water are shown in Figures 6 and 7.

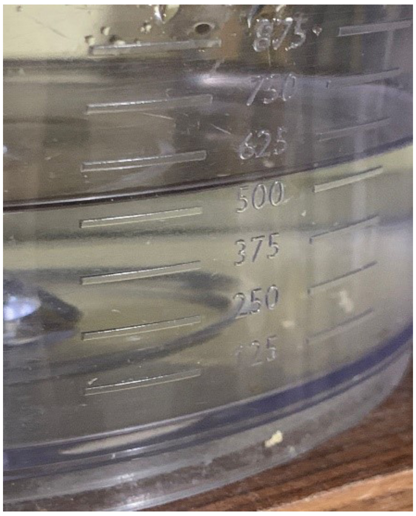

Figure 6. Measurement of grey water volume

Figure 7. Collection of grey water per day

The output data resulting from this experiment should help establish a formula linking the amount of output water to the number of operating hours and conclude whether the volume of grey water changes from one hour to the next.

The concluded formula will then be used later to provide an estimate of the total volume that can be collected from the air conditioning units in BUE.

BUE's heating, ventilation, and air conditioning (HVAC) system maps and the data written in them provided information on Building G's air conditioners. The total area of the building is 3,250 m² and the total cooling capacity of its air conditioners is 247.5 RT. For more detailed information on the building's air conditioners, please refer to Appendix B.

4.4 *Grey water quality*

Since both rainwater and greywater are produced by the phenomenon of condensation, they both should be considered distilled water. However, it is necessary to check the quality of greywater as well since its source is different than that of rainwater. While the previously discussed concerns about rainwater still apply here, there is also the concern of bacterial growth inside the air conditioner unit itself. These bacteria will affect the water quality even further, but further conclusions require further testing of the water.

A sample of grey water was collected from a personal split air conditioner in El Omrania El Gharbeya, Giza. The sample was collected in a clean plastic measuring jug and then transferred to a plastic bottle for lab analysis and further testing. The results from the sample analysis will be compared to the Decree of Health Ministry (No. 458) (2007).

The lab tests are categorised into three main categories [24]:

a) Physical parameters are characteristics that can be identified with the naked eye, such as colour and odour.
b) Physicochemical parameters are characteristics that require chemical analysis and indicate materials dissolved in water, such as salinity and pH value.
c) Undesirable substances: existing mineral content and toxins such as nitrates and phosphate.

5. Data analysis and results

5.1 *Rainwater volume (BUE case study)*

The BUE in El Shorouk City, Egypt, where the average rainfall data was calculated, extends over an estimated area of 40 feddans (166,730 m^2). However, not every bit of the campus area is valid for the rainwater harvesting procedure since there are green areas of soil with high infiltration rates and walkways where water will be directed to the nearest manhole and discharged into the wastewater system. Instead, this study assumed the collection of rainfall from the buildings' rooftops and the streets of the campus.

A total of seven catch basins were proposed along the streets of campus, along with collection pipes and vents from the rooftops of BUE's 15 buildings. Each catch basin will be responsible for the collection of rainfall from a specified area on the roads and the vents will be responsible for the collection of rainfall from the rooftop of each building. Locations of the road catch basins were chosen based on the points of lowest elevation according to the BUE contour lines survey map included in Figures 2 and 3. Areas of collection along with the locations of the catch basins are demonstrated in the BUE campus map in Figure 4.

The method used in the calculation of the runoff is the RCN method, using Equations 4 and 5. Since the *CN* value of rooftops and pavements is 98, the *S* value is:

$$S = \frac{1000}{98} - 10 = 0.204 \text{ inches} = 0.204 \times 25.4 = 5.18 \text{ mm}$$

As the *P* value is 162 mm, the P_R value is:

$$P_R = \frac{\left[162 - (0.2 \times 5.18)\right]^2}{\left[162 + (0.8 \times 5.18)\right]} = 156$$

The resulting runoff of 156 mm should be multiplied by each catchment area to produce the volume of the rainfall. The resulting water volume from each catchment area, along with the total water volume collected from the proposed collection system for the whole campus is provided in Table 2. The results yield a yearly average total collection volume of about 8,065 m^3.

Table 2. BUE's proposed rainwater collection catchment areas with collected water volume

Name	Area (m^2)	P_R (mm)	Volume (m^3)
Building C	2,808.14	156.0035	438.0798
Building D	722.73	156.0035	112.7484
Building E	722.73	156.0035	112.7484
Building A	3,390.3	156.0035	528.8988
Building B	1,471.93	156.0035	229.6263
Building H	1,515.75	156.0035	236.4624
Building G	3,237.35	156.0035	505.038
Library	1,424.38	156.0035	222.2083
Bookstore	1,062.18	156.0035	165.7038
Pharmacy	2,608.14	156.0035	406.879
Dentistry	1,334.45	156.0035	208.1789
Building 15	1,407.91	156.0035	219.6389
Building 16	1,497.72	156.0035	233.6496
Mass Communication	1,721.88	156.0035	268.6194
Building 17	2,159.52	156.0035	336.8927
Catch Basin 1	351	156.0035	54.75724
Catch Basin 2	3,894	156.0035	607.4778
Catch Basin 3	3,907	156.0035	609.5058
Catch Basin 4	3,107	156.0035	484.703
Catch Basin 5	300	156.0035	46.80106
Catch Basin 6	11,003	156.0035	1716.507
Catch Basin 7	2,050	156.0035	319.8072
Total	51,697.11	-	8,064.932

5.2 *Grey water volume*

The experiment occurred for seven days while the output water from the air conditioner was observed. The conditions of the days are as follows:

i) Day 1:
- Date: 1st May 2022
- Temperature: 31 ˚C
- Relative humidity: 25%
- Air conditioner temperature: 24 ˚C

ii) Day 2:
- Date: 2nd May 2022
- Temperature: 33 ˚C
- Relative humidity: 17%
- Air conditioner temperature: 24 ˚C

iii) Day 3:

- Date: 3rd May 2022
- Temperature: 31 ˚C
- Relative humidity: 26%
- Air conditioner temperature: 24 ˚C

iv) Day 4:

- Date: 30th May 2022
- Temperature: 39 ˚C
- Relative humidity: 13%
- Air conditioner temperature: 24 ˚C

v) Day 5:

- Date: 31st May 2022
- Temperature: 37 ˚C
- Relative humidity: 23%
- Air conditioner temperature: 24 ˚C

vi) Day 6:

- Date: 1st June 2022
- Temperature: 33 ˚C
- Relative humidity: 30%
- Air conditioner temperature: 24 ˚C

vii) Day 7:

- Date: 2nd June 2022
- Temperature: 33 ˚C
- Relative humidity: 28%
- Air conditioner temperature: 24 ˚C

The results shown in Table 3 indicate a clear rise in the output volume from the first hour of measurement to the second hour. The volume of water then remains the same for each hour after the second hour or rises slightly from one hour to the next. The best representation of this data would be the linear least squares method, as shown in Table 4.

$$V = a_0 + a_1 t \tag{6}$$

where V is the volume of discharged water (mL/RT) and t is the time of operation (hours). Let $y = V$ and $x = t$:

$$y = a_0 + a_1 x$$

$$a_0 = \frac{\Sigma x^2 \Sigma y - \Sigma x \, \Sigma xy}{n \, \Sigma x^2 - (\Sigma x)^2}, \quad a_1 = \frac{n \, \Sigma xy - \Sigma x \, \Sigma y}{n \, \Sigma x^2 - (\Sigma x)^2}$$

Table 3. Grey water volume observations

Day	Time			Volume (mL)
1	2:10 PM	to	3:10 PM	305
	3:10 PM	to	4:10 PM	530
	4:10 PM	to	5:10 PM	580
	5:10 PM	to	6:10 PM	630
	Total		4 hours	2,045
2	11:00 AM	to	12:00 PM	130
	12:00 PM	to	1:00 PM	510
	1:00 PM	to	2:00 PM	510
	2:00 PM	to	3:00 PM	510
	3:00 PM	to	4:00 PM	720
	Total		5 hours	2,380
3	12:00 PM	to	1:00 PM	125
	1:00 PM	to	2:00 PM	500
	2:00 PM	to	3:00 PM	470
	3:00 PM	to	4:00 PM	570
	Total		4 hours	1,665
4	12:30 PM	to	1:30 PM	230
	1:30 PM	to	2:30 PM	300
	2:30 PM	to	3:30 PM	320
	3:30 PM	to	4:30 PM	380
	4:30 PM	v	5:30 PM	420
	Total		5 hours	1,650
5	12:30 PM	to	1:30 PM	530
	1:30 PM	to	2:30 PM	660
	2:30 PM	to	3:30 PM	625
	3:30 PM	to	4:30 PM	630
	4:30 PM	to	5:30 PM	640
	Total		5 hours	3,085
6	2:00 PM	to	3:00 PM	680
	3:00 PM	to	4:00 PM	820
	4:00 PM	to	5:00 PM	700
	5:00 PM	to	6:00 PM	730
	6:00 PM	to	7:00 PM	710
	Total		5 hours	3,640
7	2:00 PM	to	3:00 PM	550
	3:00 PM	to	4:00 PM	740
	4:00 PM	to	5:00 PM	610
	5:00 PM	to	6:00 PM	750
	6:00 PM	to	7:00 PM	770
	Total		5 hours	3,420

Table 4. Linear least squares calculations

Day	$t = x$	$V = y$	x^2	xy
1	1	305	1	305
	2	530	4	1,060
	3	580	9	1,740
	4	630	16	2,520
Sum	10	2,045	30	5,625
2	1	130	1	130
	2	510	4	1,020
	3	510	9	1,530
	4	510	16	2,040
	5	720	25	3,600
Sum	15	2,380	55	8,320
3	1	125	1	125
	2	500	4	1,000
	3	470	9	1,410
	4	570	16	2,280
Sum	10	1,665	30	4,815
4	1	230	1	230
	2	300	4	600
	3	320	9	960
	4	380	16	1,520
	5	420	25	2,100
Sum	15	1,650	55	5,410
5	1	530	1	530
	2	660	4	1,320
	3	625	9	1,875
	4	630	16	2,520
	5	640	25	3,200
Sum	15	3,085	55	9,445
6	1	680	1	680
	2	820	4	1,640
	3	700	9	2,100
	4	730	16	2,920
	5	710	25	3,550
Sum	15	3,640	55	10,890
7	1	550	1	550
	2	740	4	1,480
	3	610	9	1,830
	4	750	16	3,000
	5	770	25	3,850
Sum	15	3,420	55	10,710

Therefore, the a_0 and a_1 values are:

Day 1: $a_0 = 255$, $a_1 = 102.5$

Day 2: $a_0 = 122$, $a_1 = 118$

Day 3: $a_0 = 90$, $a_1 = 130.5$

Day 4: $a_0 = 192$, $a_1 = 46$

Day 5: $a_0 = 560$, $a_1 = 19$

Day 6: $a_0 = 737$, $a_1 = -3$

Day 7: $a_0 = 549$, $a_1 = 45$

Taking an average of all the previous values, we get the a_0 and a_1 values of 357.8571429 and 65.42857143, respectively. Then, the final equation would be:

$$V = 357.8571429 + [65.42857143 \times t]$$

Using the equation to calculate the volume of water over the span of seven hours per 1 RT, we get the results shown in Table 5.

Table 5. The volume of output water at each hour according to the newly obtained formula

Time (hours)	Volume (mL)
1	423.2857
2	488.7143
3	554.1429
4	619.5714
5	685
6	750.4286
7	815.8571
Total	4,337

This estimation provides the volume of water per RT. The required cooling capacity for BUE was calculated using Equation 7 based on the map of Building G.

$$\text{Required cooling capacity (m}^2\text{/RT)} = \frac{\text{Area of the building (m}^2\text{)}}{\text{Total cooling capacity (RT)}} \tag{7}$$

$$\text{Required cooling capacity } = \frac{3237}{247.5} = 13.08 \text{ m}^2\text{/RT} \tag{8}$$

Applying that every 13.08 m^2 of building area requires 1 RT, we get the results shown in Table 6. Cooling capacity has been rounded up to the nearest 0.5 RT as air conditioners sold in the market have a 0.5 RT incremental increase.

Table 6. Area and cooling capacity required for each building of BUE

Name	Area (m^2)	Cooling capacity (RT)
Building C	2,808.14	215
Building D	722.73	55.5
Building E	722.73	55.5
Building A	3,390.3	259.5
Building B	1,471.93	113
Building H	1,515.75	116
Building G	3,237.35	247.5
Library	1,424.38	109
Bookstore	1,062.18	81.5
Pharmacy	2,608.14	199.5
Dentistry	1,334.45	102.5
Building 15	1,407.91	108
Building 16	1,497.72	115
Mass Communication	1,721.88	132
Building 17	2,159.52	165.5
Total	27,085.11	2,075

With the assumption that campus air conditioners will run for seven hours a day (from 9:00 a.m. to 4:00 p.m.) for a total of five days a week, while summer weeks are 33.86, we get the following:

$$V\left(\text{mL/year}\right)=V\left(\frac{\text{ml}/RT}{day}\right)\times\text{cooling capacity (RT)}\times\text{days/week}\times\text{weeks/year} \tag{9}$$

$$V=4,337\times2,075\times5\times33.86=1,523,448,696.43\frac{\text{mL}}{\text{year}}\times\frac{\text{m}^3}{1,000,000\ \text{mL}}=1,523.45\ \text{m}^3/\text{year}$$

5.3 *Water analysis*

Water samples, either from rain or from an air conditioner, were taken to the Egyptian Foundation for scientific services and analysis of water, soils, and food for lab testing. The tests were categorised into three main categories: physical parameters, physicochemical parameters, and undesirable substances. The results are shown in Table 7.

Table 7. Results of water sample analysis

Element to be analysed	Grey water	Rainwater	Units	Accepted limits (according to 458/2007)
		Physical parameters		
Colour	Colourless	Colourless	mg/L Pt Co	Colourless
Turbidity	< 1	< 1	NTU	< 1
Odour	Odourless	Odourless	Odourless	Odourless
		Physicochemical parameters		
pH	6.61	6.48		6.5 to 8.5
Conductivity	127.7	169	ppm	< 1200
Total hardness ($CaCO_3$)	30	50	mg/L	< 500
Calcium (Ca^{++})	12	20	mg/L	< 140
Magnesium (Mg^{++})	7.2	9.6	mg/L	< 36
Bicarbonate (HCO_3^-)	18	30	mg/L	-
Total alkalinity ($CaCO_3$)	9	15	mg/L	< 120
Bicarbonate alkalinity ($CaCO_3$)	9	15	mg/L	-
Carbonate alkalinity ($CaCO_3$)	0.0	0.0	mg/L	-
Hydroxide alkalinity ($CaCO_3$)	0.0	0.0	mg/L	-
Sodium (Na^+)	14	16	mg/L	< 200
Potassium (K^+)	0.9	0.11	mg/L	< 10
Chloride (Cl^-)	27	32	mg/L	< 250
Sulphate (SO_4^{--})	12	15	mg/L	< 250
Total dissolved solids	63.4	84	mg/L	< 1000
		Undesirable substances		
Ammonium (NH_4^+)	0.012	0.014	mg/L	< 0.50
Nitrates (NO_3^-)	0.021	0.023	mg/L	< 45
Nitrite (N)	0.016	0.018	mg/L	< 0.060
Phosphate (PO_4)	0.02	0.02	mg/L	< 0.40
Silica (SiO_2)	0.3	0.3	mg/L	-
Total iron (Fe)	0.04	0.04	mg/L	-
Manganese (Mn^{++})	0.02	0.02	mg/L	< 0.40
Copper (Cu^{++})	0.01	0.01	mg/L	< 2.0
Zinc (Zn^{++})	0.06	0.06	mg/L	< 3.0
Total chlorine	< 0.02	< 0.02	mg/L	-
Free chlorine	< 0.02	< 0.02	mg/L	-
Combined chlorine	< 0.02	< 0.02	mg/L	-
Cyanide (CN^-)	< 0.001	< 0.001	mg/L	< 0.05

6. Discussion

6.1 *Water quality*

Results from sample testing in the labs of the Egyptian Foundation for scientific services and analysis of water, soils, and food were compared to those of the Decree of Health Ministry (No. 458) (2007). The results shown in Table 7 for the two samples (rainwater and air conditioner water) were fairly close in quality. Most notably, the samples contained a low rate of total dissolved solids. The samples tended to be slightly acidic, as their pH numbers indicated (both had a pH below 7). There appears to be an existence of residual substances and pollutants. However, their existence is too small to cause any significant drop in water quality. Based on this information, along with the results in Table 7, the water has been deemed suitable for the irrigation of most agricultural crops as it meets the standards of the Decree of Health Ministry (No. 458) (2007). The most notable crops to be irrigated with this water are:

a) Some vegetable crops, such as onions, watercress, aubergine, radish, sugar beets, and bell peppers.
b) Some field crops, such as barley, wheat, corn, cotton, linen, and sesame.
c) Some fodder crops, such as sorghum, alfalfa, and fodder beets.
d) Some fruit trees, such as palm trees, pomegranate trees, olive trees, grape trees, and fig trees.
e) Some medicinal and aromatic plants, such as caraway, coriander, and cumin.
f) Some ornamental plants, such as bougainvillaea, municipal roses, and jojoba.

However, water has many more uses than irrigation. Since the water samples achieve the physical parameter standards of being colourless, odourless, and having low turbidity, as well as the standards for many irrigational crops, they may be used for other purposes that require the same or less stringent water quality standards [25]. Such uses include:

a) Environmental uses, such as artificial lakes and fountains, irrigation of green areas, parks, and golf courses.
b) Industrial uses, such as cooling water, the plastic manufacturing industry, and construction.
c) Urban uses, such as fire extinguishers, cleaning, and toilet flushing.

6.2 *Water volume*

The total volume of water collected from excess rainfall runoff in BUE has been estimated at 8,065 a year. In addition to the previously mentioned potential uses of water, the FAO estimates that grass requires 7.5 mm of water per day in a hot climate like Egypt [26]. So, if this rainwater is to be used in grass field irrigation, the following calculations are applied:

$$\frac{\text{Volume of water per year}}{\text{365 days}} = \text{Volume of water per day} \tag{10}$$

$$\frac{\text{Volume of water per day}}{\text{Crop water needs per days}} = \text{Area covered} \tag{11}$$

$$\frac{8065\ \text{m}^3/\text{year}}{365\ \text{days/year}} = 22.1\ \text{m}^3/\text{day}$$

$$\frac{22.1\ \text{m}^3/\text{day}}{7.5\ \text{mm/year}} \times \frac{1000\ \text{mm}}{\text{m}} = 2946.7\ \text{m}^2$$

So, an area of about 2,950 m^2 of grass fields can be irrigated annually with the volume of collected rainwater from BUE. As for the grey water, with a volume of 1523.45 m^3, the potential grass field irrigation area can be estimated as follows:

$$\frac{1523.45\ \text{m}^3/\text{year}}{365\ \text{days/year}} = 4.17\ \text{m}^3/\text{day}$$

$$\frac{4.17\ \text{m}^3/\text{day}}{7.5\ \text{mm/year}} \times \frac{1000\ \text{mm}}{\text{m}} = 556.51\ \text{m}^2$$

Adding the two sources of water together, we get that they can satisfy the irrigation of a grass field area of about 3,503.21 m^2. Other purposes and uses for this water can be in the BUE laboratories (materials lab, soil lab or chemical lab), cleaning or other non-potable uses. Storage tanks and a pipe network would be needed to collect these waters properly. The pipes may be installed at the sides of buildings, but the storage tanks will have to either be separate for each building or an underground tank at the lowest elevation part of BUE.

7. Conclusion

This research studied the possible collection of wasted rainwater and air conditioner water in the BUE. Samples of both rain and grey water were collected and taken to the Egyptian Foundation for scientific services and analysis of water, soils, and food for lab testing of their quality and potential use. An HVAC system map of BUE Building G was provided to estimate the cooling capacity of the air conditioners in the building which will affect the volume of the output grey water. Moreover, a BUE contour map has been provided to show ground elevations and the potential path for runoff water from rainfall events. Finally, the historical rainfall data of El Shorouk City (where BUE is located) has been provided to estimate the average annual rainfall.

The study has yielded a numerical equation to calculate the amount of air conditioner drain water as follows:

$$V = (\text{mL/RT}) = 357.8571429 + [65.42857143 \times t\ (\text{hours})]$$

When applied to BUE campus air conditioners, the results were a yearly output of about 1,523.45 m^3. Moreover, rain data analysis and calculations estimated a yearly income of 8,065 m^3 of rainwater for BUE. The condensation water (green and grey), if collected properly, could be enough for a total grass field irrigation capacity of about 3,503.21 m^2 a year. The waters were tested and have been deemed fit for use in so many non-drinking uses according to the Decree of Health Ministry (No. 458) (2007).

The water samples were analysed for their physical and chemical parameters as well as the existence of undesirable substances. No microbiological analysis has been performed; hence, no conclusion has been reached about these waters' eligibility for drinking. Previous research indicated that the Egyptian rainfall is at its peak up north, while this research has been performed in Cairo, a more central city in Egypt with a medium intensity of rainfall. While Cairo is Egypt's most polluted city, rainwater collected in Cairo being deemed fit for many non-potable uses could potentially mean that rainwater from other cities may be fit for the same uses as well.

8. Recommendations

Based on the findings of this study, it is recommended to adopt different strategies to solve the water scarcity problem in Egypt, as follows:

- More study on the rain and precipitation in Egypt.
- Rainier cities in Egypt should be identified and studied for their topographical nature to apply rain collection projects.
- Air conditioner manufacturers should include proper water drainage to keep the water clean.
- Air conditioners' water drainage systems should be installed in homes, and a collection network should be added to benefit from these waters.
- The collection of grey water along with rainwater and its impact should be studied more from an economic point of view to understand whether this project can be a practical solution to water scarcity.

Conflict of interest

There is no conflict of interest in this study.

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Appendix A

Table A. Most commonly used cooling capacity units

Refrigeration ton (RT)	British Thermal Units per hour (BTU/hr)	Horsepower (HP)	Kilowatt (kW)
1.00	12,000	1.50	3.50
1.50	18,000	2.00	5.27
2.00	24,000	2.50	7.03
2.50	30,000	3.00	8.79

Also, the following equations illustrate the conversion between different units of air conditioning cooling capacities:

- 1 RT = 3.51685 kW
- 1 kW = 0.284345 RT
- 1 BTU/hr = 0.00029307 kW
- 1 kW = 3412.142 BTU/hr
- 1 BTU/hr = 8.33333 × 10^{-5} RT
- 1 RT = 12,000 BTU/hr
- 1 HP = 8,000 BTU/hr
- 1 HP = 0.667 RT
- 1 HP = 2.34 kW

Appendix B

It should be noted that the observation of data from the HVAC system map happened using the following information:

- The QDMT of the air conditioner means the capacity in thousands of BTU. So, for example, air conditioner unit 1 in the basement of Building G is labelled (53QDHT60DN). Which means it has a cooling capacity of 60,000 BTU/hr.
- The air conditioner units each have a number from 1 to 8, indicating their cooling capacity as follows:
  a) No. 1 = 12,000 BTU/hr
  b) No. 2 = 18,000 BTU/hr
  c) No. 3 = 24,000 BTU/hr
  d) No. 4 = 30,000 BTU/hr
  e) No. 5 = 36,000 BTU/hr
  f) No. 6 = 42,000 BTU/hr
  g) No. 7 = 48,000 BTU/hr
  h) No. 8 = 60,000 BTU/hr

As an example, air conditioner unit 1 in the basement of Building G is labelled (I.U - 08). This means it has a cooling capacity of 60,000 BTU/hr.

Table B. Building G's (area = 3,250 m^2) air conditioners and their cooling capacity

Floor	Air conditioner unit	Cooling capacity					
Basement	1	60,000.00	BTU/hr	5.00	RT	7.50	HP
	2	48,000.00	BTU/hr	4.00	RT	6.00	HP
	3	48,000.00	BTU/hr	4.00	RT	6.00	HP
	4	60,000.00	BTU/hr	5.00	RT	7.50	HP
	5	60,000.00	BTU/hr	5.00	RT	7.50	HP
	6	60,000.00	BTU/hr	5.00	RT	7.50	HP
	7	60,000.00	BTU/hr	5.00	RT	7.50	HP
	8	60,000.00	BTU/hr	5.00	RT	7.50	HP
	9	60,000.00	BTU/hr	5.00	RT	7.50	HP
	10	36,000.00	BTU/hr	3.00	RT	4.50	HP
	11	60,000.00	BTU/hr	5.00	RT	7.50	HP
	12	60,000.00	BTU/hr	5.00	RT	7.50	HP
	13	60,000.00	BTU/hr	5.00	RT	7.50	HP
	14	60,000.00	BTU/hr	5.00	RT	7.50	HP
	15	48,000.00	BTU/hr	4.00	RT	6.00	HP
	16	48,000.00	BTU/hr	4.00	RT	6.00	HP
	17	48,000.00	BTU/hr	4.00	RT	6.00	HP
	18	48,000.00	BTU/hr	4.00	RT	6.00	HP
	19	48,000.00	BTU/hr	4.00	RT	6.00	HP
	20	48,000.00	BTU/hr	4.00	RT	6.00	HP
	23	48,000.00	BTU/hr	4.00	RT	6.00	HP
	24	48,000.00	BTU/hr	4.00	RT	6.00	HP
	25	48,000.00	BTU/hr	4.00	RT	6.00	HP
	26	48,000.00	BTU/hr	4.00	RT	6.00	HP
	27	60,000.00	BTU/hr	5.00	RT	7.50	HP
Ground floor	1	60,000.00	BTU/hr	5.00	RT	7.50	HP
	2	48,000.00	BTU/hr	4.00	RT	6.00	HP
	3	48,000.00	BTU/hr	4.00	RT	6.00	HP
	4	60,000.00	BTU/hr	5.00	RT	7.50	HP
	5	48,000.00	BTU/hr	4.00	RT	6.00	HP
	6	48,000.00	BTU/hr	4.00	RT	6.00	HP
	7	60,000.00	BTU/hr	5.00	RT	7.50	HP
	8	60,000.00	BTU/hr	5.00	RT	7.50	HP
	9	60,000.00	BTU/hr	5.00	RT	7.50	HP
	10	60,000.00	BTU/hr	5.00	RT	7.50	HP
	11	48,000.00	BTU/hr	4.00	RT	6.00	HP
	12	48,000.00	BTU/hr	4.00	RT	6.00	HP

Table B. *(Continued)*

Floor	Air conditioner unit	Cooling capacity					
First floor	1	48,000.00	BTU/hr	4.00	RT	6.00	HP
	2	48,000.00	BTU/hr	4.00	RT	6.00	HP
	3	60,000.00	BTU/hr	5.00	RT	7.50	HP
	4	60,000.00	BTU/hr	5.00	RT	7.50	HP
	5	60,000.00	BTU/hr	5.00	RT	7.50	HP
	6	60,000.00	BTU/hr	5.00	RT	7.50	HP
	7	60,000.00	BTU/hr	5.00	RT	7.50	HP
	8	60,000.00	BTU/hr	5.00	RT	7.50	HP
	9	60,000.00	BTU/hr	5.00	RT	7.50	HP
	10	60,000.00	BTU/hr	5.00	RT	7.50	HP
	11	60,000.00	BTU/hr	5.00	RT	7.50	HP
	12	48,000.00	BTU/hr	4.00	RT	6.00	HP
	13	48,000.00	BTU/hr	4.00	RT	6.00	HP
Second floor	1	60,000.00	BTU/hr	5.00	RT	7.50	HP
	2	60,000.00	BTU/hr	5.00	RT	7.50	HP
	3	18,000.00	BTU/hr	1.50	RT	2.25	HP
	4	60,000.00	BTU/hr	5.00	RT	7.50	HP
	5	60,000.00	BTU/hr	5.00	RT	7.50	HP
Total		2,970,000.00	BTU/hr	247.50	RT	371.25	HP