water

MDPI

Article

Developing a Strategy to Recover Condensate Water from Air Conditioners in Palestine

Lubna Siam [1], Issam A. Al-Khatib [2,*], Fathi Anayah [3], Shehdeh Jodeh [4,*], Ghadir Hanbali [4], Bayan Khalaf [4] and Abdalhadi Deghles [5]

1 Faculty of Graduate Studies, Birzeit University, P.O. Box 14, Birzeit 00970, Palestine
2 Institute of Environmental and Water Studies, Birzeit University, P.O. Box 14, Birzeit 00970, Palestine
3 College of Engineering and Technology, Palestine Technical University-Kadoorie, Tulkarm 00970, Palestine
4 Department of Chemistry, An-Najah National University, P.O. Box 7, Nablus 00970, Palestine
5 Graduate Studies Department, Al-Istiqlal University, Jericho 00970, Palestine
* Correspondence: ikhatib@birzeit.edu (I.A.A.-K.); sjodeh@hotmail.com (S.J.);
Tel.: +97-0-2298-2120 (I.A.A.-K.); +97-059-959-0498 (S.J.);
Fax: +97-0-2298-2120 (I.A.A.-K.); +97-092-995-982 (S.J.)

Received: 4 July 2019; Accepted: 30 July 2019; Published: 15 August 2019

Abstract: As the need for water is increasing in Palestine, and the available water resources are barely sufficient to meet the demands of the current quality of life and the economy, air conditioner condensate water could be explored as an alternative water source. The objective of this study is to better understand the potential for recovery of condensate water from air conditioning systems in two Palestinian cities. In addition, this study aims to evaluate this water source in terms of quality and quantity. Generally, it was found that the condensate water has good quality, which conforms to the Palestinian standards for reused water for irrigation, except for turbidity, biological oxygen demand (BOD) and chemical oxygen demand (COD) measurements. Reflecting the heavy metal occurrence in the collected condensate water, no particular risk was recognized for drinking water or reused irrigation standards, except for manganese occurrence of 0.19 mg/L in one sample. From a single unit capacity, high quantities of water were observed of approximately 259 L and 453 L per month in Ramallah and Jericho cities, respectively. These figures should draw the attention of decision and policy makers to put in place strict technical guidelines to be followed for potential reuse of condensate water at the local level.

Keywords: condensate water recovery; air conditioner; water quality; water quantity; Palestine

1. Introduction

In Palestine, the need for water is increasing with the current political situation, population growth, and high rate of urbanization. The depletion of fresh water resources continues as the demand for irrigation, industrial and municipal water keeps escalating [1–6] Exploring alternative sources of water plays a vital role in the water supply, when fresh water, including surface- and ground-water, becomes limited. Recently, water quality has been further studied for effective water resource management, given such resources' variability and vulnerability due to natural and anthropogenic changes [3–8].

The present water supplies in Palestine are neither adequate to provide acceptable decent living standards for the locals, nor sufficient to facilitate development of their economic status [9]. The need for exploring new sustainable water sources has started to be of great importance, where new techniques should be tested and developed at every level. In the meantime, cooling systems generate significant condensate water volume, which most of the time is connected to the drainage system. This source of water is considered to be significant and under-utilized in Palestine, and which at least could be collected and reused for landscape irrigation purposes. Condensate water is predictable, reliable and of high quality, and occurs during summer months when irrigation demand is high.

The current unstable political conditions are leading to scarcity of water resources in Palestine. Israeli occupation utilizes more than 85% of groundwater resources in the West Bank and denies access of Palestinians to their natural and historical water rights in the Jordan River [5,10]. Water reuse and recycling are considered good environmental practices, although their implementation is highly dependent on the economics and hence can be challenging to implement [6,11–13].

Atmospheric water harvesting or atmospheric water vapor processing has been experienced as an emerging technology in which atmospheric water vapor is condensed and collected [14]. Different techniques have been developed to extract the water vapor from air, examining larger scale schemes. Experiments have been carried out in Sweden, Tanzania, Tunisia, France, Bahrain, Chile and Saudi Arabia. Some of the techniques were considered as being not economically feasible for large scales. Therefore, in general, atmospheric water harvesting or atmospheric water vapor processing is a relatively new technology for small-scale, locally managed water supplies [15].

Air conditioner condensate is a relatively untapped alternative source of water that might be readily available, especially in hot arid climates [16,17]. One of the experiments was conducted in Qatar, where high economic growth and migrating population are posing challenges for the country to meet water demands in the near future. The main objective of the initiative was to establish the feasibility of condensate water as an alternative source of water in Qatar [18].

Water condensate from air conditioning systems can be reused efficiently either by circulating it again to be used for cooling towers or any other purposes such as outdoor irrigation [19]. Water efficiency can be applied in many facilities, where cooling towers are used. Increasing the rate of condensate recycling in the cooling towers results in multiple savings, at the level of water and sewer costs to savings on purchase of chemicals used to treat both incoming and discharged water [20].

Some examples of the projects that have been carried out can be summarized as follows:

- In San Antonio, the experiments yield surprising quantities of water. The downtown mall generates 250 gallons (946 L) each day from its air handlers. A central library system produces 0.06 L/second or 41,655 US gallons per month [21].
- Bahrain Airport Services in the Middle East uses 2.3 million gallons (~8.7 million L) per year of condensate water for diverse purposes such as toilet flushing, washing and maintaining the landscape [21].
- At the University of Texas in Austin, the massive central cooling systems include condensate recovery for cost savings [21].
- In Qatar, an experiment found that over 1.6 million gallons (~6 million L) of condensate water can be potentially captured each year from air conditioning systems in one of its buildings [22].

The aim of this study is to better understand the potential for recovery of condensate water from air conditioning systems in Palestine. The research also aims to investigate this water source by assessing its quality and measuring attainable quantities of generated condensate water.

2. Methodology

2.1. Study Area

The West Bank is divided into eleven districts: Jenin, Tubas, Tulkarm, Qalqilya, Salfit, Nablus, Jericho, Ramallah and Al-Bireh, Jerusalem, Bethlehem, and Hebron (see Figure 1). The West Bank has an area of 5800 km^2, a 130 km length from north to south, and width of between 40 and 65 km from east to west [5]. The West Bank is mostly composed of limestone hills that are between 700 and 900 m high [5]. The lowest point of the study area is the Dead Sea at 400 m below sea level, and the highest the Tall Asur at 1022 m above sea level [6]. The climate in the Mediterranean region has four months of hot, dry summer and a short mild winter with rain from November to March [5]. The climate in the West Bank can be characterized as hot and dry during the summer and cool and wet in winter [6]. The climate becomes more arid to the east and south [5].

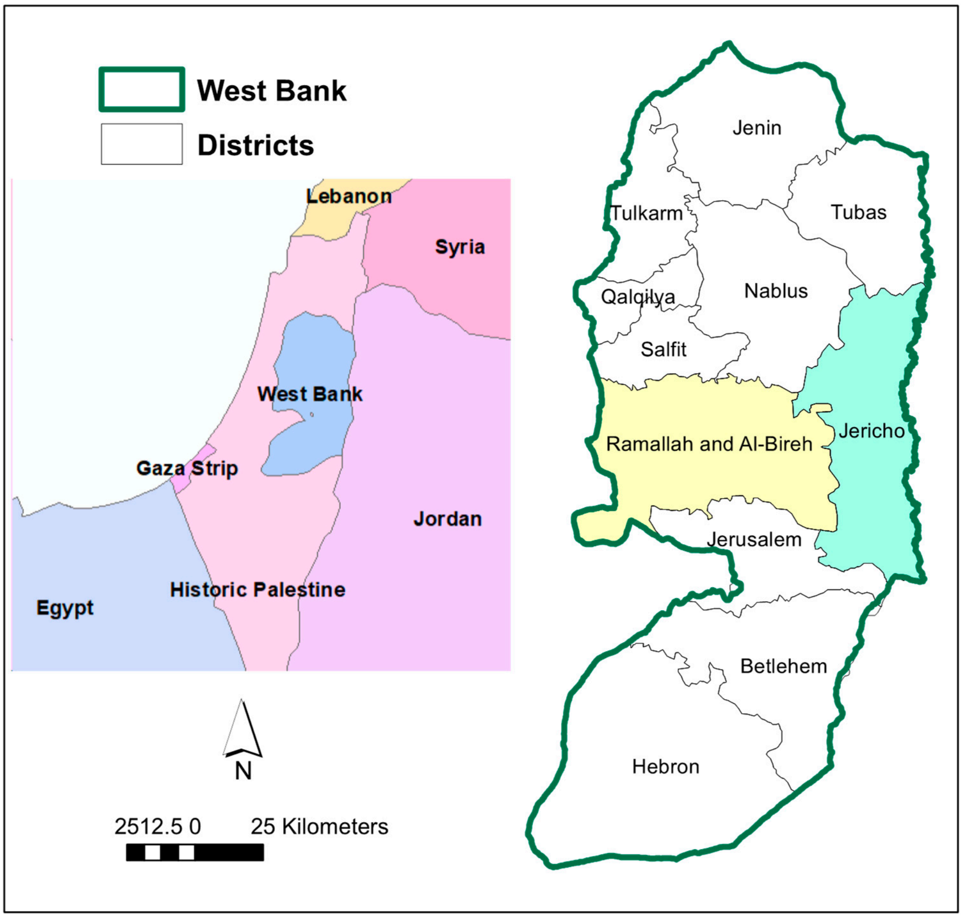


Figure 1. The study area.

Annual precipitation on the central highlands averages 700 mm and becomes less than 100 mm at the Dead Sea, however, great variations in precipitation amount and distribution exist [5]. Precipitation decreases from north to south and from high to low altitude and tends to fall in intense storms [5,6]. Evaporation is high in summer when there is always a water deficit [5]. The mean summer temperatures range from 30 °C at Jericho to 22 °C at Hebron, which is 850 m above sea level [6]. In winter, the mean temperatures range from 13 °C at Jericho to 7 °C at Hebron [6]. The annual average relative humidity is about 52 percent at Jericho [6]. It is worth mentioning that the climate in Ramallah city is similar to that in Hebron city.

2.2. Water Quality Sampling

In order to obtain a clear idea about the condensate water characteristics, an assessment of this water quality against the two main defined guidelines issued by the Palestinian Standards Institution (PSI) was conducted. This assessment basically comprised a condensate sampling campaign, which was carried out in the two cities of Ramallah and Jericho in the West Bank. Each collected water sample was accompanied by an appropriate collection form that clearly indicated the following: sample site, sample number, location, place, date and time. Water samples were labeled by a number which orderly reflected the information contained in the form.

From the two cities of Ramallah and Jericho, a total of 65 condensate water samples were collected in plastic one-liter capacity bottles (32 samples from Ramallah and 33 samples from Jericho).

The selection of the samples to be collected was made randomly. Cluster sampling was used, which is a random sampling technique wherein households in each of the two cities were divided into clusters, of which a few were chosen randomly for the questionnaire study. This was to ensure the coverage of a wide range of geographical locations and socio-economic conditions of the residents. The dwellings were first stratified according to the socio-economic status (low, lower-middle, upper-middle and high). The stratification criteria were based on the general status of the housing unit and the type of residence. From each stratum, a predetermined number of households were randomly selected to be surveyed [23].

For the 65 samples, analysis for two of the physical variables (temperature and pH) was run in the field using appropriate apparatus either in situ or very soon after collecting the sample. All used instruments were calibrated and operated according to the laboratory guidelines. Field analysis was carried out measuring the following physical parameters: temperature (T), acidity (pH), electric conductivity (EC), dissolved oxygen (DO) and total dissolved solids (TDS). Other tests were run after transporting the samples to the laboratories of Birzeit University (BZU) after a period of time that did not exceed 6–24 h. Further water testing was completely according to the procedures of the Standard Methods and the Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) including: turbidity, biological oxygen demand (BOD), chemical oxygen demand (COD), sulfate, copper, iron, lead, cadmium, arsenic, selenium, stannum, molybdenum, nickel, cobalt, aluminum, manganese, lithium, chromium, barium and silver.

Cluster sampling was used for the selection of samples for heavy metal analysis, and the procedure described in [24] was followed. Water samples were collected in one-liter high-density polyethylene bottles (pre-cleaned with 10% nitric acid followed by repeated rinsing with bi-distilled water), stabilized with a few drops of ultrapure nitric acid (0.5% HNO_3) that were added to prevent additional microbial growth. All water samples were then preserved in a refrigerator at 4 °C and transported to the laboratories of BZU for examination and analysis purposes.

2.3. Water Quantity Assessment

In order to provide an overview of the condensate water yield generated from air conditioning systems, a quantity assessment process was conducted in the two cities of Ramallah and Jericho. Samples were collected from different kinds and types of locations including: (1) commercial businesses (grocery stores, restaurants, cloths shops, pharmacies and bakeries), (2) residential households (apartments and houses) and (3) office buildings. Following the same steps stated in the water quality sampling process, collected water samples were accompanied by an appropriate form that clearly indicated the following: sample site, type and area of the served location, date, time, location, capacity of air conditioning unit (1 Ton, 2 Tons and 3 Tons) and operational working temperature (16 °C, 18 °C or 20 °C). From the two locations of Ramallah and Jericho, a total number of 84 one-liter plastic bottles were collected. Table 1 shows the distribution of collected samples from the different capacities of air conditioning units.

Table 1. Distribution of condensate water quality samples.

City	Operational Temperature	1 Ton	2 Tons	3 Tons
Ramallah	16 °C	7	7	7
	18 °C	7	7	7
Jericho	18 °C	7	7	7
	20 °C	7	7	7
Total		28	28	28

Through the process, the condensate water was routed from the drain plastic pipe that is connected to the outer unit of the air conditioning system. Water was retrieved in the plastic bottles and in parallel the time of collection was recorded, to be averaged and plotted.

2.4. Household Questionnaire

To gather supplementary data on the local users' perceptions, knowledge, behaviors, attitudes and opinions regarding the use and the management of the condensate water as a new water source, a structured questionnaire was prepared. Using the cluster sampling method, 85 residents were selected randomly and interviewed. The questionnaires were distributed as 50 in Ramallah and 35 in Jericho to reflect the behaviors and opinions of locals under the different contexts and circumstances. The questions asked were aimed to gather information on the number, capacity, age and served area of air conditioning units used, as well as their operational hours and operating temperature, management mechanisms of dealing with generated water, common possible methods to conserve condensate water, and recognition of users' perceptions in regards to potential uses of this water.

The main purpose of the household questionnaire was to obtain indicators for the possible generated volume of condensate water based on the daily working hours, capacities and operating temperature of the air conditioning units. Furthermore, the questionnaire was aimed at better understanding the users' perceptions regarding the management of the condensate water generated from air conditioning units. In addition, the questionnaire highlighted the question of users' awareness in regard to the quality of the generated water, and hence the in-situ methods used to benefit from this source of water efficiently.

2.5. Semi-Structured Interviews

In addition, two semi-structured interviews with the key persons of the main suppliers of air conditioning systems in Palestine were conducted in order to get some information about the most used units' brands, capacities, constraints, installation rules and guidelines. The key questions posed to the main local suppliers included: are recent purchases of air conditioning systems limited toupper class people?; which brand is the most popular in the local market?; which capacities are mostly sold to the consumers?; are there any brands available in the local market that provides a condensate water collecting system?; what are the major rules and guidelines for installing cooling systems in Palestine?; and, is there any statistic that correlates number of cooling units sold out with geographic location?

3. Results and Discussion

3.1. Condensate Water Quality Assessment

3.1.1. Chemical and Physical Parameters

Based on the collected samples generated from 65 air conditioning units in the two cities of Ramallah and Jericho, the main chemical and physical parameters were tested. The results of the tests were then plotted against the PSI standard values to analyze the compliance of the condensate water with the PSI drinking water and the treated water reused for irrigation purposes. The analysis depicted in Table 2 was conducted to detect the condensate water quality in regard to the selected physical and chemical parameters for the 65 samples (S1–S65). The selected parameters are necessary for water quality monitoring programs and public health regulations. Table 2 also presents the relevant Palestinian standards for the quality of drinking water and the reused irrigation water.

Table 2. Physical and chemical analysis for the condensate water samples.

Parameter *	Reading Range	Reading Mean	PSI (2005) Drinking Water Guidelines [19]	PSI (2012) Reused Irrigation Water Guidelines [20]
T (°C)	15.5–22.5	18.05	20	25
pH	6.4–7.59	7.12	6.5–8.5	6–9
TDS (ppm)	15.2–76.4	42.48	<1000	1200
EC (µs/cm)	30–220.4	79.40	-	700–3000

Table 2. *Cont.*

Parameter *	Reading Range	Reading Mean	PSI (2005) Drinking Water Guidelines [19]	PSI (2012) Reused Irrigation Water Guidelines [20]
DO (mg/L)	0.36–5.9	2.52	-	>0.5
Turbidity (NTU)	0.55–6.69	1.97	1	5
BOD (mg/L)	1–6	2.23	-	20 (A Category)
COD (mg/L)	18–150	101.71	-	50 (A Category)
SO_4 (mg/L)	0.001–0.006	0.0033	200	300

* Temperature (T), acidity (pH), total dissolved solids (TDS), electric conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD) and sulfate (SO_4).

By comparing the obtained results shown with the PSI standards demonstrated in Table 2, the following analysis can be developed in regard to the major parameters occurrence:

- *Temperature:* The results of the temperature measurements for the condensate water samples show that the samples fall approximately within the acceptable ranges of both the drinking water guidelines (less than 20 °C) and treated water reused for irrigation (less than 25 °C), and range at (15.5–22.5 °C). Some exceptions related to the drinking water comparison were demonstrated among the water samples: S9 = 21 °C, S16 = 21.5 °C, S20 = 21.5 °C, S28 = 20.8 °C, S39 = 20.1 °C, S46 = 22.5 °C and S64 = 20.4 °C.
- *pH:* The values of pH for the 65 collected samples fall within the range of 6.4–7.59, with an average value of 7.12. Therefore, the pH measurements performed in this part of the research indicate that the condensate water is considered to be approximately neutral. The neutral point occurred at many of the collected condensate water samples.
- *TDS:* The above demonstrated analysis shows that the TDS in the condensate water samples ranges between 15.2 and 76.4 ppm, with an average value of 42.48 ppm. This indicates that all measured values fall below the values of PSI standards for both drinking water and treated water reused for irrigation. It can be noted that the TDS occurrence in the collected condensate water samples are nearly valued at zero and can be neglected in comparison to the maximum allowable standards stated by the PSI for drinking water (i.e., 1000 mg/L) and treated water reused in irrigation A category (i.e., 1200 mg/L).
- *EC:* The measurements of EC confirm the above results of measured TDS values which all fall near zero. The EC typically estimates the total amount of solids dissolved in water. Very low values of EC were presented during the measurements, with a range of 30–220.4 µs/cm, and an average value of 79.40 µs/cm.
- *DO:* The dissolved oxygen concentrations in the 65 condensate water samples ranged from 0.36 to 5.9 mg/L) with an average value of 2.52 mg/L. This indicates that 66% of the collected samples were under anaerobic water conditions. Almost 44 water samples revealed that they can be used for drinking water with DO concentration less than 5 mg/L, whereas 37 water samples demonstrated that the DO concentrations fall above the minimum requirements of the PSI for irrigation purposes (DO above 1 mg/L).
- *Turbidity:* The turbidity analysis for the tested samples show that the range of the measured turbidity was 0.55–6.69 NTU, with an average value of 1.97 NTU. According to the PSI, the acceptable limit of turbidity for drinking water is 1 NTU. High turbidity in drinking water means that it may not be acceptable for consumers due to high amounts of sediment, most probably sand and other unappealing matter. For agricultural purposes, water with a maximum turbidity of 50 NTU is allowed to be used, and therefore, turbidity measurements for all samples fall under the acceptable limits of agricultural water.
- *BOD:* the tested condensate water samples for the BOD level ranged from 1 to 6 mg/L, with an average value of 2.23 mg/L. Out of all water samples collected, 44 samples were considered as

clean water based on the BOD calculations, which ranged between 1 and 2 mg/L. This places almost 100% of the collected samples within the range of the acceptable water used for agricultural purposes. The PSI standards state that a concentration of 20 mg/L BOD places the water within the A Category of the water quality used for agricultural purposes.

- *COD:* As shown in Figure 2, the tested condensate water samples for the COD level ranged from 13 to 150 mg/L, with an average value of 101.7 mg/L. Of all the water samples collected, 7 samples were placed within the range of the A Category of the water quality limits used for agricultural purposes with COD levels less than 50 mg/L. Within all water samples, it was noted that 19 water samples were placed within the acceptable range of the agricultural water standards with a water quality ranked at the C Category, in which all COD concentrations were less than 100 mg/L. Moreover, the COD concentrations of 39 water samples ranged between 100 mg/L and 150 mg/L, placing these samples under the D Category of water used for agricultural purposes.
- *Sulfate (SO_4):* The sulfate concentrations found in the condensate water samples were in very low concentrations ranging from 0.001 to 0.006 mg/L, with an average value of 0.0033 mg/L. This result demonstrates that the tested condensate water samples fall within the PSI acceptable limits of the drinking water (i.e., 200 mg/L) and the agricultural water (i.e., 300 mg/L).

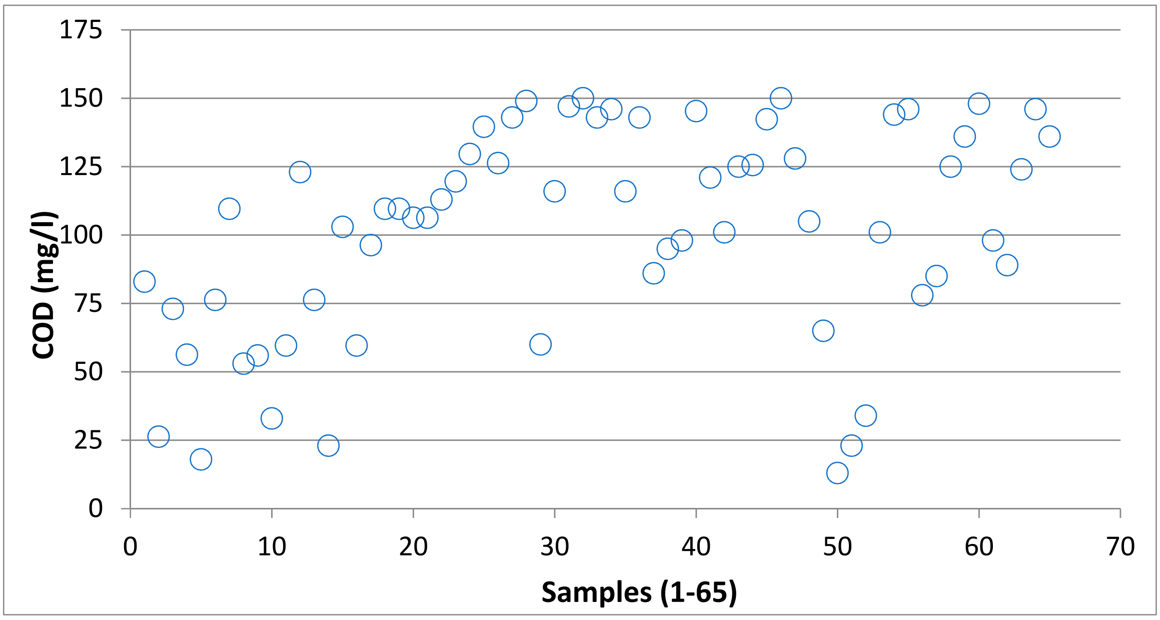


Figure 2. COD concentration in the tested condensate water samples.

3.1.2. Heavy Metal Concentrations

Identification and quantification of heavy metal concentrations in the condensate water are of great importance in the development of this research. Heavy metals were detected in 17condensate water samples. Table 3 displays the selected heavy metal tests for the water samples with the corresponding Palestinian water quality standards.

Table 3. PSI drinking water and treated water reused for irrigation standards.

Parameter	Drinking Water (mg/L) [19]	Reused Irrigation Water (mg/L) [20]
Cu	1	0.2
Fe	0.3	5
Pb	0.01	0.2
Cd	0.005	0.01
As	0.05	0.1

Table 3. *Cont.*

Parameter	Drinking Water (mg/L) [19]	Reused Irrigation Water (mg/L) [20]
Se	0.01	0.02
Sn(Tin)	-	-
Mo	-	-
Ni	0.05	0.2
Co	-	0.05
Al	0.2	5
Mn	0.01	0.2
Li	-	-
Cr	0.05	0.1
Ba	2	2
Ag	0.01	-
Zn	5	2

The results obtained from the heavy metal detection tests for the 17 condensate water samples are shown in Table 4 and summarized as follows:

- The results of the heavy metal examination show that the tested condensate water samples were not contaminated with elements Pb, Cd, As, Se, Sn, Mo, Ni, Co or Li. The results of the tests were either "BDL = Below Detection Limit" or "ND = Not Detected."
- Other results concluded that some samples contained other heavy metals, such as Cu, Fe, Al, Cr, Ba, Zn and Mn. From the figures in Table 4, it can be noted that the Cu concentration levels that occurred in the condensate water samples were of very low magnitude. All Cu concentrations were found to be in parts per million (ppm), and were less than the maximum allowable limits of drinking and agricultural water according to the PSI standards [25,26].
- The concentrations of Fe, Al, Cr, Ba and Zn were found to be smaller than the acceptable limits for both the drinking and agricultural water standards stated by the PSI [25,26].
- Higher levels of Mn were found among the tested condensate water samples, of which only one sample (No. 17) fell above the acceptable limits of drinking water. All other samples were found to be within the acceptable ranges of the PSI drinking and agricultural water standards.

3.2. Condensate Water Quantity Assessment

3.2.1. Observed Water Quantity in Ramallah

In the city of Ramallah, the water quantity of the air conditioning units was measured by observing the volume of the generated condensate water from a total number of 21 units (1, 2 and 3 Tons) operating at 16 °C and 18 °C. The observed measurements of water condensate in Figure 3 show that at 16 °C operating temperature, the 1-, 2- and 3-Ton air conditioning units generated, on average, 1.45, 2.78 and 3.78 L/h, respectively. The observed condensate volumes were considered to be significantly high. A high R-squared value (R^2) of 0.99 was obtained from the developed linear regression which showed a close proximity of the fitted data between the water volume generated and the unit capacity. If these rates were calculated for an average working day of 6.64 h per day, the volumes of the collected condensate water would reach 9.63, 18.46 and 25.1 L per day for the 1-, 2- and 3-Ton units, respectively. The relationship developed through collected data showed clearly the proportional increase between the condensate water volume and the air conditioning capacity in Tons. Moreover, based on the field-collected data the computed condensate water volumes can be realized by the linear equation indicated in Figure 3a.

Table 4. Heavy metal concentrations of the collected condensate water samples.

(mg/L)	S1	S4	S6	S8	S9	S10	S11	S13	S17	S19	S28	S29	S33	S41	S48	S55	S59
Cu	BDL	BDL	1.81 *	BDL	BDL	BDL	0.068 *	0.85 *	BDL	BDL	BDL	BDL	BDL	1.55 *	BDL	BDL	0.56 *
Fe	BDL	BDL	9.29 *	BDL	BDL	BDL	ND	0.069	0.056	BDL	0.032	BDL	BDL	0.092	ND	BDL	0.098
Pb	ND	ND	ND	BDL	ND	ND	ND	BDL	ND	ND	ND	ND	ND	BD	ND	ND	BDL
Cd	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	BDL
As	ND	ND	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	BDL	ND	ND
Se	ND	ND	ND	ND	ND	ND	ND	BDL	ND	ND	ND	ND	ND	BDL	ND	ND	ND
Mo	ND	ND	ND	ND	ND	ND	ND	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND
Ni	BDL	BDL	BDL	BDL	BDL	BDL	ND	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Co	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Al	BDL	BDL	11.5 *	BDL	BDL	BDL	ND	8.9 *	0.078	BDL	0.086	BDL	BDL	0.056	0.068	0.079	BDL
Mn	BDL	BDL	0.013	ND	BDL	BDL	ND	0.013	0.19	BDL	0.034	BDL	ND	0.086	BDL	0.021	BDL
Li	ND	ND	ND	ND	ND	ND	ND	BDL	ND	BDL	ND	ND	ND	BDL	BDL	ND	ND
Cr	BDL	BDL	0.19	0.05	BDL	BDL	ND	0.03	BD	0.042	BDL	BDL	BDL	0.03	0.021	BDL	BDL
Ba	0.079	0.033	0.092	0.053	0.061	0.053	0.05	0.1	0.048	ND	0.048	0.077	0.046	0.09	ND	BDL	0.75
Ag	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn	0.105	0.022	0.02	0.101	0.021	0.046	ND	0.56	0.358	BDL	0.278	0.055	ND	0.56	0.352	0.01	0.49

* Concentrations in ppm, BDL: Below Detection Limits and ND: Not Detected.

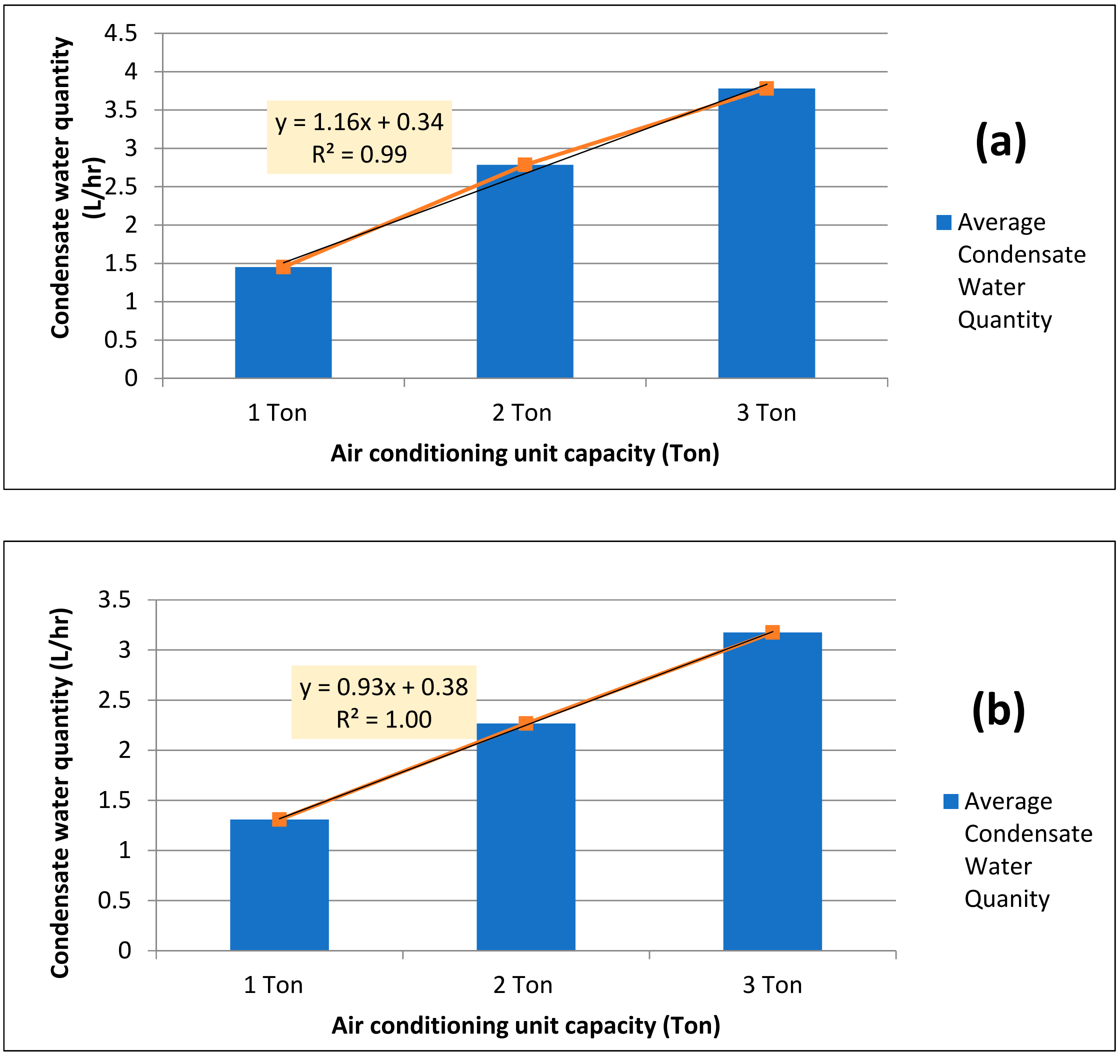


Figure 3. Quantities of condensate water in Ramallah city at: (**a**) 16 °C operating temperature and (**b**) 18 °C operating temperature.

The observed condensate water measurements in Figure 3b shows that at 18 °C operating temperature the 1-, 2- and 3-Ton air conditioning units generated, on average, 1.30, 2.26 and 3.17 L/h, respectively. The observed condensate water volumes were considered to be significantly high; nevertheless, these rates were less than rates generated at lower operating temperatures (see Figure 3). A high R-squared value (R^2) of 0.999 (~1.00) was obtained from the developed linear regression, which showed a close proximity of the fitted data between the water volume generated and the unit capacity. If these rates are calculated for an average working day of 6.64 h per day, the water volumes of the collected condensate water would reach 8.63, 15.00 and 21.10 L per day for the 1-, 2- and 3-Ton units, respectively. The relationship developed through the collected data confirmed the proportional increase between the condensate water volume and the air conditioning capacity in Tons.

Figure 4 shows the relationship between the condensate water quantities at the different operating temperatures for the same unit capacity. Figure 4 shows the condensate water generated at both 16 °C and 18 °C operating temperatures. It can be noted that as the operating temperature decreases, the volume of the condensate water increases. Conceptually, it can be said that a slight decrease in the generated water volume of 10% is caused by an increase of 2 degrees Celsius in the operating temperature.

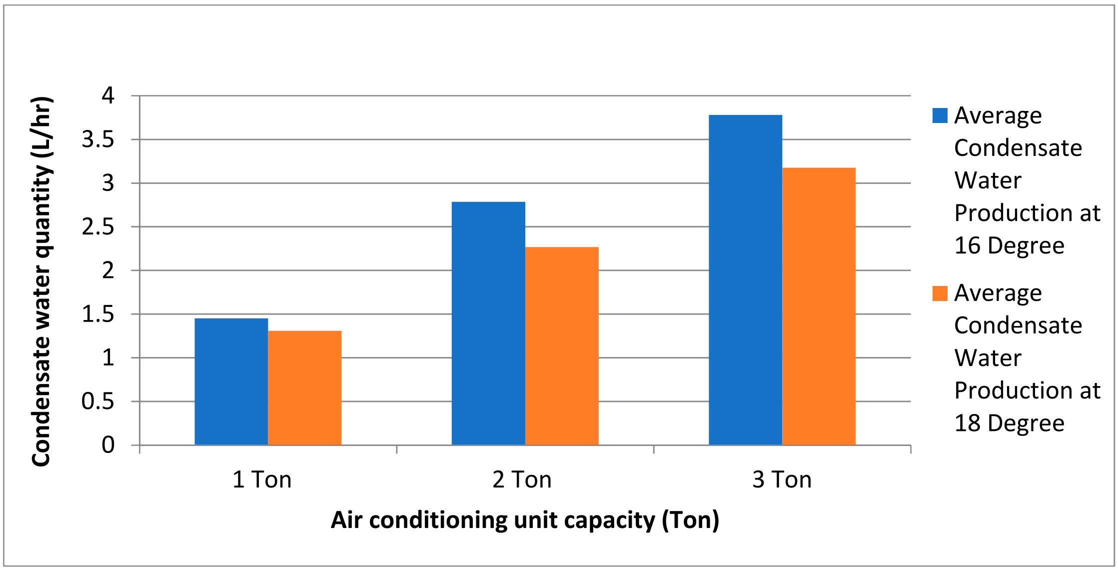


Figure 4. Quantities of condensate water at both 16 °C and 18 °C operating temperatures in Ramallah city.

3.2.2. Water Quantity in Jericho

In the city of Jericho, the water quantity of the air conditioning units was measured by observing the volume of the generated condensate water from a total of 21 units (1, 2 and 3 Tons) operating at 18 °C and 20 °C. The average of the measured quantities generated was calculated and is presented in Figure 5. The analysis of the water quantities included the calculations of the generated water volumes based on the average working hours for the tested units.

The observed water condensate measurements in Figure 5a show that at 18 °C operating temperature the 1-, 2- and 3-Ton air conditioning units generated, on average, 1.02, 2.39 and 2.87 L/h, respectively. The observed condensate volumes were considered to be significantly high; nevertheless, these rates are considered to be less than the rates produced at the same operating temperatures in Ramallah city. A high R-squared value (R^2) of 0.93 was obtained from the developed linear regression, which showed a close proximity of the fitted data between the volume generated and the air conditioning unit capacity. If these rates were calculated for an average working day of 15.1 h per day, the volume of the total collected condensate water would reach 15.40, 36.09 and 43.34 L per day for the 1-, 2- and 3-Ton units, respectively. The relationship developed through the collected data confirmed again the proportional increase between the condensate water volume and the air conditioning capacity in Tons.

The second tested operating temperature in Jericho city was 20 °C, where the examined air conditioning unit capacities were 1, 2 and 3 Tons. As shown in Figure 5b, the 1-Ton air conditioning unit generated 0.98 L/h, while the 2- and 3-Ton units generated 2.10 and 2.72 L/h, respectively. The observed volumes were still considered to be significantly high, but less than volumes in the previous case (18 °C operating temperature). A high R-squared value (R^2) of 0.97 was obtained from the developed linear regression, which showed a close proximity of the fitted data between the volume generated and the air conditioning unit capacity. Moreover, if these rates were calculated for an average working day of 15.1 h per day, the volume of the total collected condensate water would reach 14.80, 31.71 and 41.072 L per day for the 1-, 2- and 3-Ton units, respectively.

Figure 6 shows the relationship between the condensate water quantities at different operating temperatures for the same unit capacity. It can be noted that as the operating temperature decreases, the volume of the condensate water increases. Figure 6 shows the condensate water volume generated at both 18 °C and 20 °C operating temperatures. Conceptually, it can be said that a slight decrease in the generated condensate water volume of 9% was caused by an increase of 2 degrees Celsius in the operating temperature.

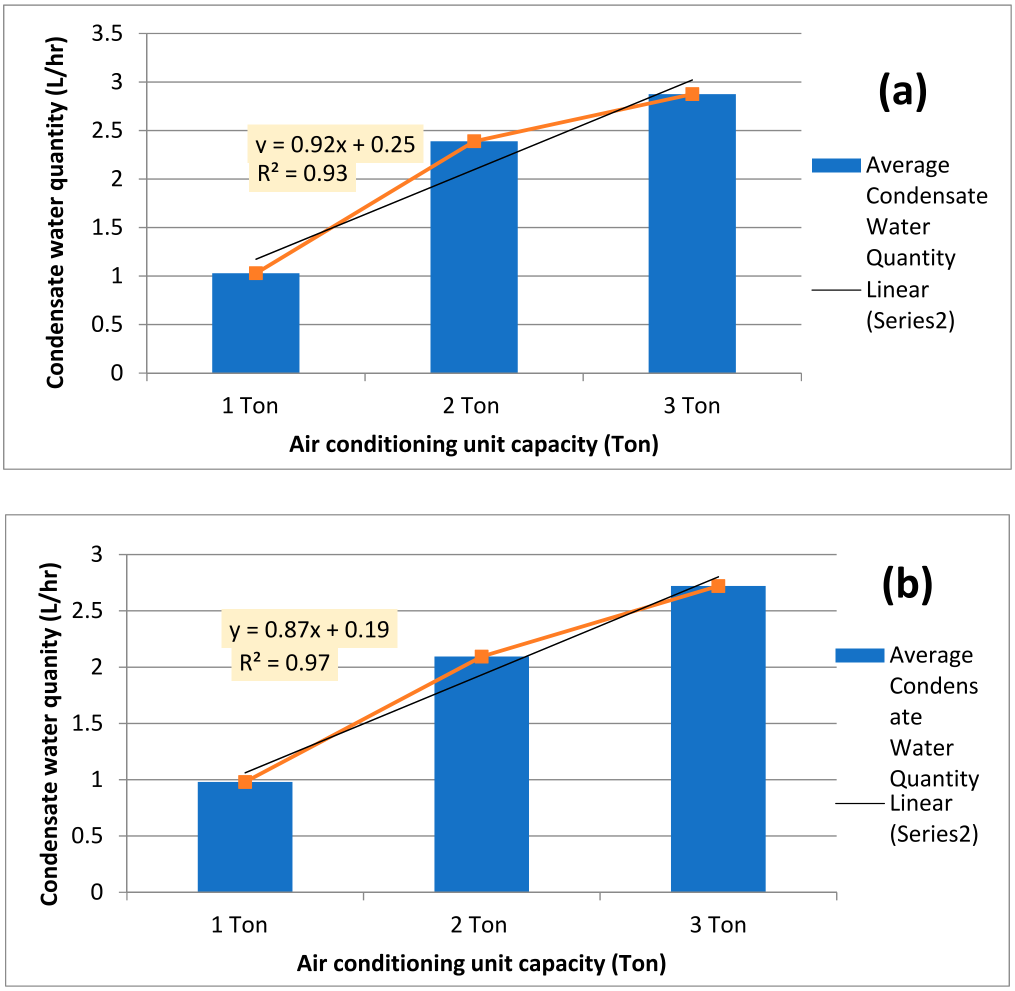


Figure 5. Quantities of condensate water in Jericho city at: (**a**) 18 °C operating temperature and (**b**) 20 °C operating temperature.

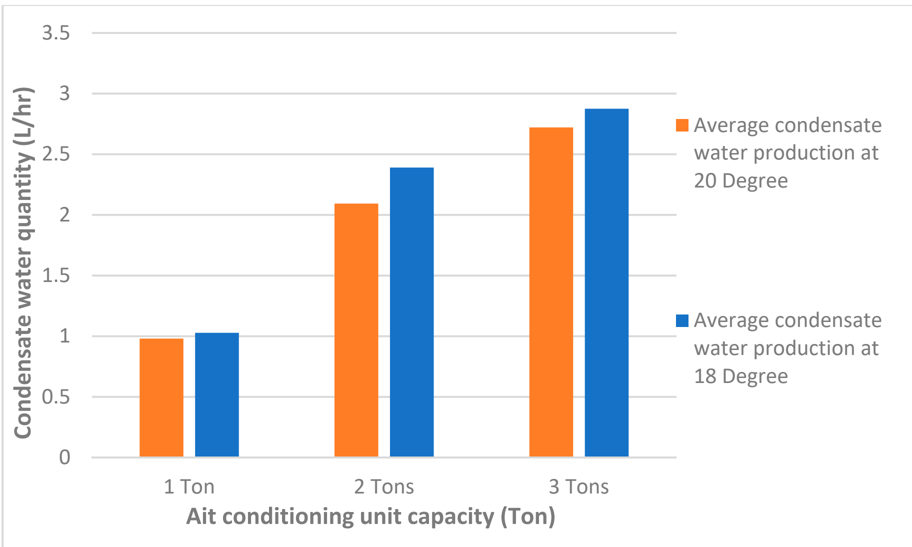


Figure 6. Quantities of condensate water at both 18 °C and 20 °C operating temperatures in Jericho city.

3.2.3. Comparison of Water Quantities

To compare the two different volumes generated in Ramallah and Jericho cities, the results shown in Figures 3b and 5a were combined. Figure 7 shows the two quantities generated in Ramallah and Jericho cities, by the same unit capacities at the same operating temperature of 18 °C.

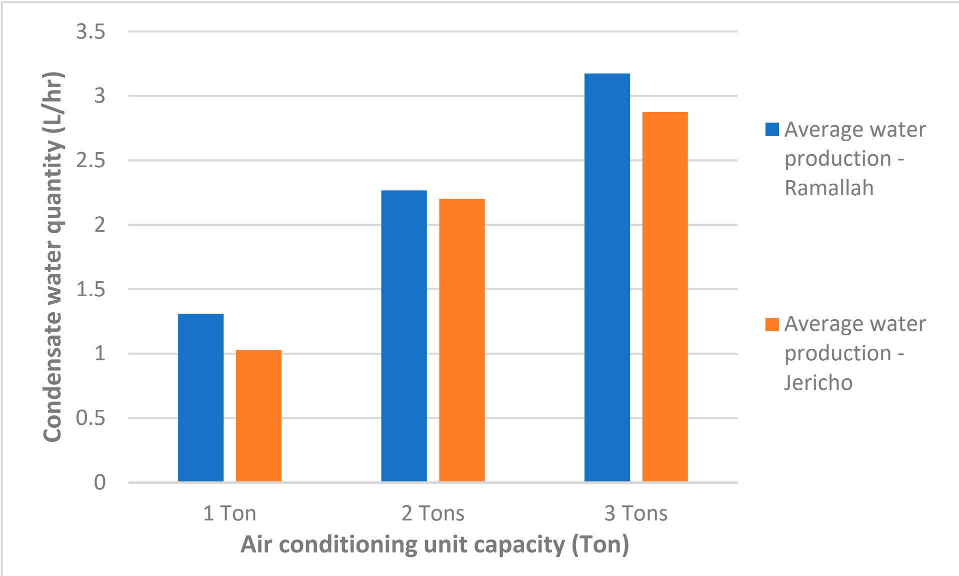


Figure 7. Quantities of condensate water at 18 °C operating temperature in Ramallah and Jericho cities.

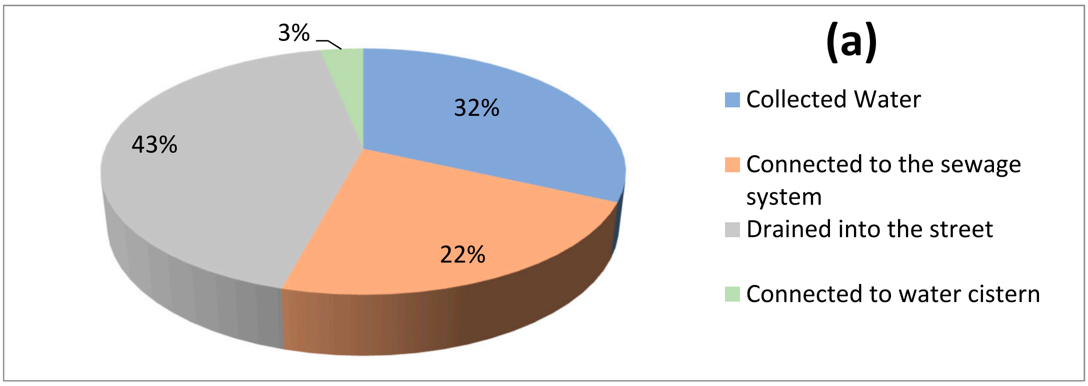
Based on the collected data presented in Figure 7, it can be noted that the generated condensate water rates were higher in Ramallah city than those in Jericho city, knowing that the operating temperature was fixed at 18 °C. This difference in the generated water rates corresponded to an increase of 10% in the water volume generated in Ramallah compared to Jericho. This difference in the volume rates of the condensate water depends on a number of factors, including the age of the unit, and hence the cooling capacity, room surface area and relative air humidity.

3.3. Household Questionnaire Analysis

3.3.1. Current Condensate Water Management

Within the selected samples interviewed in both cities, the distribution of the common methods used to deal with the generated condensate water is shown in Figure 8. Almost 51.76% of the interviewed samples drained the condensate water into the street, whereas 36.47% of the generated condensate water was used for different purposes, and the remaining 11.75% of respondents installed a special piping system to connect the generated condensate water from the split unit to a cistern or a sewage system. Among the indicated 11.75%, the study shows that only 1.17% of interviewees connected the generated condensate water to a rainwater harvesting cistern. Based on the interviewees' perception, water can be conserved and reused for gardening purposes.

Figure 8a shows that 43% of the sample from Ramallah city drained the condensate water into the street, while 22% of the sample connected the condensate water to a sewage system. It was found that 3% of the sample connected the condensate water to a rainwater harvesting cistern. This management method was exclusively used in one five-floor new building rented to 10 companies and organizations in Ramallah city.



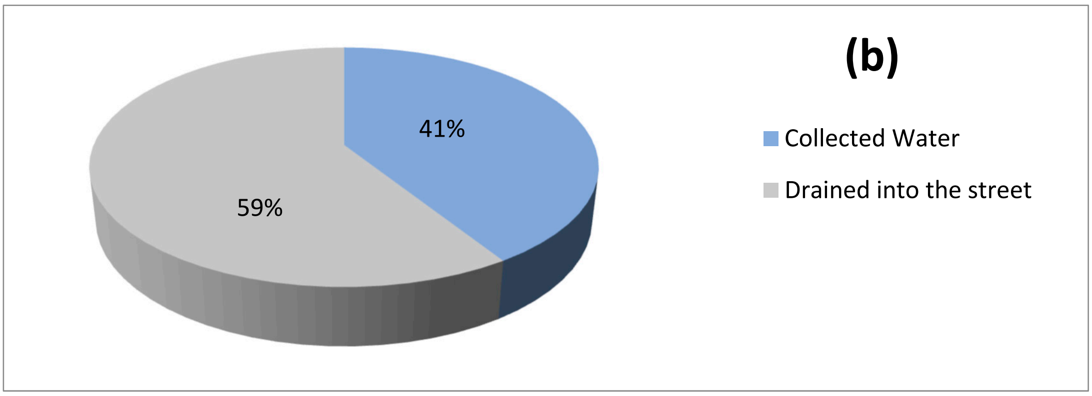


Figure 8. Common methods used to manage the condensate water: (**a**) in Ramallah city and (**b**) in Jericho city.

Figure 8b shows the results of the analyzed questionnaires indicating that in the city of Jericho, 41% of the interviewed sample collected the condensate water, while 59% of the sample drained the condensate water into the street. The potential to better manage the condensate water is still high in Jericho city, in which an arid climate prevails and extremely high temperatures are experienced during the summer semester.

It is important to note that the questionnaire highlighted the users' conservation initiatives in terms of possible uses of the collected condensate water. Among the users who collected the condensate water, two possible ways of using the condensate water were reported: irrigation and cleaning. It was indicated that 50% of the sample had used the water to water the plants (indoor green plants in the offices, shops and houses). The other half of the sample had used condensate water for cleaning purposes. Furthermore, it was found that only 12.12% of the users connected the collected condensate water directly to their home outdoor gardens, which were reported to be owned by 38.8% of the interviewed people in the two cities. Mostly in the commercial businesses, the condensate water collected is used to clean the floors and toilets at the end of each day.

3.3.2. Users' Perceptions

Generally speaking, 100% of the interviewed sample confirmed that the condensate water cannot be used for drinking or domestic purposes, 84.7% of the sample stated that the water cannot be used for irrigation purposes and 25% of the sample thought that it cannot be used even for cleaning. Among the interviewed sample in both cities, only 14.1% of the users thought that the condensate water can be used safely for agricultural and cleaning purposes. It can be concluded that the conflicting perceptions of the users in regards to the safety of the condensate water are highly influenced by the lack of awareness and definitely not based on any shock experience faced by the users.

4. Conclusions and Recommendations

Air conditioning systems are used to provide conditioned indoor environments. These cooling systems generate a significant and under-utilized source of water for landscape irrigation and other uses. In light of the water resource scarcity in Palestine, the condensate water could be considered as an alternative source of water, which could play a vital role in the water supply when fresh water becomes limited.

The assessment of physical, chemical and microbial water quality data for the condensate water showed that, in general, the condensate water has a good water quality, which conforms to the Palestinian standards for reused irrigation water. In comparison with drinking water standards, some concerns are discussed related to the turbidity, BOD and COD measurements. Reflecting the heavy metal occurrence in the collected condensate water, no particular risk was recognized for both the drinking water and the reused irrigation standards, except for the Mn occurrence of 0.19 mg/L in only one of the 65 samples.

The results show that a high quantity of condensate water could be collected from the air conditioning systems. More specifically, from a single air conditioning unit capacity, almost 8.63 and 15.1 L/day of water were observed in the cities of Ramallah and Jericho, respectively. These quantities of water should be collected and reused to maintain environmental sustainability for Palestinians by both minimizing fresh water use and decreasing dependency on fresh water resources.

With respect to the questionnaire of the users' perceptions regarding the condensate water, almost 51.76% of the interviewed sample drained the condensate water into the street, whereas 36.47% of the sample used the generated condensate water for different purposes and 11.75% of the sample installed a special piping system to connect the generated water from the split unit to a cistern or a sewage system. It was obvious that 68% of the sample lacked awareness of the benefits of the condensate water and its corresponding volume. About 32% of the sample declared that the condensate water generated by air conditioning units is considered to be of "good quantities." In effect, the results of this study indicate that this topic needs to be further studied in dry climates such as Palestine. The uncertainty of results can be due to many reasons, including previous knowledge and experience of users, age of cooling systems, efficiency of air conditioning units, surrounding climate, atmospheric air quality, operating temperature, seasonality and time dependency.

It is apparent from this research that a general lack of awareness of the condensate water quality and quantity is leading many users to neglect and waste this significant source of water. Some particular recommendations are derived from this research, as follows:

1. Conduct of a condensate water quality testing assessment, including of microbiological parameters, mainly pathogenic bacteria (e.g., *Legionella*, *Bacilli*, *Staphylococci* or *Streptococci*) and viruses (e.g., respiratory tract viruses) by official authorities.
2. Raise the awareness of local users in regard to the actual quantities generated by air conditioning systems, and thus encourage insitu simple and efficient mechanisms to collect and reuse this source of water, for at least cleaning, non-domestic uses or landscape irrigation asa first step.
3. Include condensate water conservation in ongoing and implemented campaigns for raising awareness of water conservation.
4. Conduct a comprehensive questionnaire study in all Palestinian districts to estimate the total volume of air conditioner condensate water which may be generated from each district, and compare these data with quantities of drinking water and irrigation water consumed in each district.
5. Investigate economic feasibility and convenience, including associated costs, for condensate water collection systems, transmission systems and treatment plants, in order to justify condensate water recovery from air conditioners in Palestine.

Author Contributions: L.S.: methodology, I.A.A.-K. supervision and drafting the manuscript; F.A. and A.D. results discussion and funding acquisition, S.J. review and editing; G.H. and B.K. data curation and results.

Funding: This study was funded by USAID-USGS grants number G17AS00001.

Acknowledgments: The authors would like to express the gratitude to Maher Abu Madi for providing the inspiration for the topic of this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Al-Salaymeh, A.; Al Khatib, I.; Arafat, H. Towards sustainable water quality: Management of rainwater harvesting cisterns in southern Palestine. *Water Resour. Manag.* **2011**, *25*, 1721–1736. [CrossRef]
2. Beltrán, M.J.; Kallis, G. How does virtual water flow in Palestine? A political ecology Analysis. *Ecol. Econ.* **2018**, *143*, 17–26. [CrossRef]
3. Duan, W.; Chen, Y.; Zou, S.; Nover, D. Managing the water-climate-food nexus for sustainable development in Turkmenistan. *J. Clean. Prod.* **2019**, *220*, 212–224. [CrossRef]
4. Zou, S.; Jilili, A.; Duan, W.; Maeyer, P.D.; de Voorde, T.V. Human and natural impacts on the water resources in the Syr Darya River basin, Central Asia. *Sustainability* **2019**, *11*, 3084. [CrossRef]
5. Anayah, F. Assessment of the Nitrate and Chloride in the West. Bank Groundwater Resources Using GIS. Master's Thesis, An-Najah National University, Nablus, Palestine, 2007.
6. United Nations Environment Programme (UNEP). *Desk Study on the Environment in the Occupied Palestinian Territories*; United Nations Environment Programme: Nairobi, Kenya, 2003.
7. Duan, W.; He, B.; Nover, D.; Yang, G.; Chen, W.; Meng, H.; Zou, S.; Liu, C. Water quality assessment and pollution source identification of the eastern Poyang Lake basin using multivariate statistical methods. *Sustainability* **2016**, *8*, 133. [CrossRef]
8. Duan, W.; He, B.; Chen, Y.; Zou, S.; Wang, Y.; Nover, D.; Chen, W.; Yang, G. Identification of long-term trends and seasonality in high-frequency water quality data from the Yangtze River basin, China. *PLoS ONE* **2018**, *13*, e0188889. [CrossRef] [PubMed]
9. Shadeed, S.; Lange, J. Rainwater harvesting to alleviate water scarcity in dry conditions: A case study in Faria catchment, Palestine. *Water Sci. Eng.* **2010**, *3*, 132–143.
10. Aliewi, A.; Nofel, I. Water Saving Practices at Household Level in Palestine: A Case Study from Jayyous Village Qalqilia Governorate Palestine. In Proceedings of the First Symposium on Wastewater Reclamation and Reuse for Water Demand Management in Palestine, Palestine, Birzeit, 2–3 April 2008.
11. Environmental Protection Agency (EPA). *An Innovative Transport Membrane Condenser for Water Recovery from Gas and its Reuse*; EPD07053; Media and Process Technology Inc.: Allegheny, PA, USA, 2007.
12. Pandey, R.P.; Surjan, A.; Kapshe, M. Exploring linkages between sustainable consumption and prevailing green practices in reuse and recycling of household waste: Case of Bhopal city in India. *J. Clean. Prod.* **2018**, *173*, 49–59. [CrossRef]
13. Salgot, M.; Folch, M. Wastewater treatment and water reuse. *Curr. Opin. Environ. Sci. Health* **2018**, *2*, 64–74. [CrossRef]
14. Liu, N.; Li, Z. The feasibility on the case that the air conditioning condensate water is used as the make-up water of cooling tower. *Procedia Eng.* **2017**, *205*, 3557–3562. [CrossRef]
15. Habeebullah, B.A. Potential use of evaporator coils for water extraction in hot and humid areas. *Desalination* **2009**, *237*, 330–345. [CrossRef]
16. Algarnia, S.; Saleel, C.A.; Abdul Mujeebu, M. Air-conditioning condensate recovery and applications–Current developments and challenges ahead. *Sustain. Cities Soc.* **2018**, *37*, 263–274. [CrossRef]
17. Licina, D.; Sekhar, C. Energy and water conservation from air handling unit condensate in hot and humid climates. *Energy Build.* **2012**, *45*, 257–263. [CrossRef]
18. Kant, S.; Jaber, F.H.; Qiblawey, A.M.H. A/C Condensate for Water Reuse: An Approach towards Environmental Sustainability in Doha. In Proceedings of the ASABE Annual International Meeting Presentation, Dallas, TX, USA, 29 July–1 August 2012; ASABE: St. Joseph, MI, USA, 2012. Paper Number: 12-1338151.
19. Al–Farayedhi, A.A.; Ibrahim, N.I.; Gandhidasan, P. Condensate as a water source from vapor compression systems in hot and humid regions. *Desalination* **2014**, *349*, 60–67. [CrossRef]
20. General Electric (GE). Water Process Technologies: Sustainability Playbook Reaching Significant Water Savings. 2008. Available online: www.gewater.com/water-footprint.jsp (accessed on 15 March 2019).

21. Guz, K. Sustainability-Condensate Water Recovery. American Society of Heating, Refrigerating and Air Conditioning Engineers. 2005. Available online: www.ASHRAE.org (accessed on 15 March 2019).
22. Bryant, A.J.; Ahmed, T. Condensate water collection for an institutional building in Doha, Qatar: An opportunity for water sustainability. In Proceedings of the Sixteenth Symposium on Improving Building Systems in Hot and Humid Climates, Plano, TX, USA, 15–17 December 2008.
23. Scheaffer, R.L. *Elementary Survey Sampling*, 4th ed.; PWS-Kent: Boston, MA, USA, 1990.
24. Malassa, H.; Al-Qutob, M.; Al-Khatib, M.; Al-Rimawi, F. Determination of different trace heavy metals in ground water of south West Bank/Palestine by ICP/MS. *J. Environ. Prot.* **2013**, *4*, 818–827. [CrossRef]
25. Palestinian Standards Institute (PSI). *Drinking Water Specifications*; PSI 41-2005PSI; Palestine: Ramallah, West Bank, 2005.
26. Palestinian Standards Institute (PSI). *Reused Irrigation Water Specifications*; PSI 34-2012; Palestine: Ramallah, West Bank, 2012.