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Article

Assessment of Rainwater Harvesting Systems in Poor Rural Communities: A Case Study from Yatta Area, Palestine

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Abstract: Yatta is a town located nine kilometers south of Hebron city in the West Bank of Palestine. The town houses over 100,000 people of which 49% are females and has a population that doubles every 15 years. Yatta has been connected to a water network since 1974 serving nearly 85% of its households. The water network is old and inadequate to meet the needs of the population. Water supply made available to the area is limited, estimated at 20 L/capita/day. Residents are thus forced to rely on water vendors who supply water that is 400% more expensive with a lower quality compared to municipal water. Therefore, rainwater harvesting is a common practice in the area, with the majority of households owning at least one cistern. Rainwater harvesting is of great socio-economic importance in areas where water sources are scarce and/or polluted. In this research, the quality of harvested rainwater used for drinking and domestic purposes in Yatta was assessed throughout one year. A total of 100 samples were collected from cisterns with an average capacity of 69 m^3, which are adjacent to cement-roof catchment areas of 145 m^2 average surface area. Samples were analyzed for a number of parameters including temperature, pH, alkalinity, hardness, turbidity, total dissolved solids, NO_3, NH_4, chloride and salinity. Results showed that most of the rainwater samples were within World Health Organization (WHO) and Environment Protection Agency (EPA) guidelines for chemical parameters. Microbiological contents such as total Coliforms and faecal Coliforms bacteria were tested. The research also addressed the impact of rainwater harvesting systems on different socio-economic attributes of the local community through a questionnaire that had been filled out before any sample was collected.

Keywords: rainwater harvesting; cisterns; water quality; socio-economic; Yatta

1. Introduction

Water is essential for life and deterioration of its quality or its quantity affects every living being severely. As population of the world increases, demand on water significantly increases too [1].

Together with poor water quality and inadequate sanitation, water scarcity threatens the lives of millions around the world [2,3]. According to statistics of World Health Organization (WHO) and United Nations Children's Fund (UNICEF) [4], 663 million people still lack access to safe water. Spearheaded by the United Nations, governments have set an ambitious goal within the framework of sustainable development goals to achieve an equitable access to safe and affordable drinking water for all people by 2030 [5]. To succeed in these challenging endeavors, practitioners have to consider both conventional and nonconventional water resources [5].

In areas such as Palestine, where water resources are scarce, optimal resource management becomes especially essential [6,7]. With the rising water demand results from growing population and consequent higher consumption of food supplies, pressure on conventional resources has greatly amplified [8–10]. For a more sustainable approach, water strategies need to integrate non-conventional resources as part of the national water balance to counter the decrease in reserves while at the same time to protect the environment.

Rainwater harvesting should be considered an important element to augment water supply in both urban and rural areas, prevent flooding and alleviate the impact of climate change [11–16]. Rainwater harvesting, henceforth Rainwater Harvesting (RWH), is defined as the collection of water from a catchment area on which rain falls and a conveyance system to a subsequent storage facility for later use [17]. In arid and semi-arid regions, RWH has been used for several years for many purposes especially in providing water for agricultural and domestic uses [18–22].

The rainwater cistern system (RWCS) consists of the following components: catchment, conveyance, purification, storage and distribution. In this context, assessment of both quantitative potential of RWH and quality of rainwater runoff is essential in order to set up criteria for (re)designing cities from the perspective of sustainable rainwater management. Three things are essential to control the amount of water accumulated from rain: amount of rainfall in the region, size of catchment area and proportion of rainfall you can collect. In order to calculate the potential RWH, rainfall data from Yatta Municipality for one rainy season (2014–2015) were collected so that storage requirements could be estimated. The potential RWH (PRWH) of a roof can be estimated based on local precipitation (P), catchment area (A) and runoff coefficient (RC) as shown in Equation (1):

$$\text{PRWH} = \text{P} \times \text{A} \times \text{RC}. \quad (1)$$

The main objectives of this paper are to address the impact of RWH on different socio-economic attributes of the local community through the questionnaire method and to assess the quality of harvested rainwater used for drinking and domestic purposes in the Yatta area throughout one full year. The specific objectives are to: (1) study the water situation in the Yatta area and determine the socio-economic impact of RWH, (2) verify if available cisterns are sufficient for the quantity of rainwater received, (3) examine physicochemical pollution of existing cisterns, (4) analyze quality of water stored in cisterns of the Yatta area and the effect of RWCS on water quality, (5) specify reasons for RWCS pollution, if any, explore how to limit the spread of pollution and suggest measures to limit pollution for RWCS, (6) determine the willingness to pay for treatment of polluted RWCS and finally (7) conduct a quantitative assessment of RWH.

2. Materials and Methods

2.1. Study Area

The study area is located nine kilometers south of Hebron city, in the southern part of the West Bank in Palestine. Six localities (Al-Hadidia, Al-Hila, Khallet Saleh, Um Saqhan, Wadi Alma and Yatta town) were chosen as the study area based on topography, elevation, population density and sources of water supply (Figure 1). Surveyed households were chosen randomly in each of these six localities in order to assess the socio-economic impact, quality and quantity of harvested rainwater in the Yatta area.

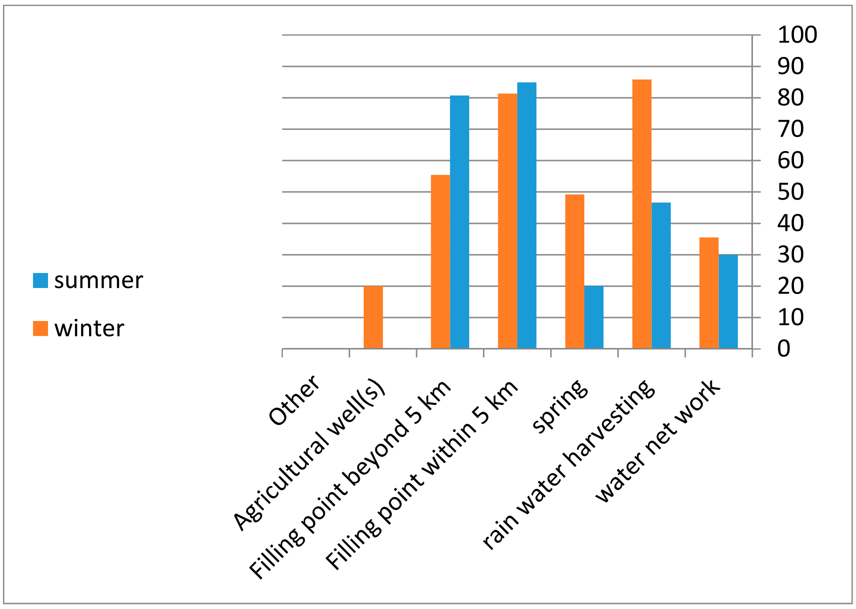

Figure 1. Water resources used by surveyed households depending on the season.

2.2. Methods of Research

Household questionnaire: A set of indicators was designed to define the main socio-economic characteristics of the local community and look into different water aspects. The researchers had used the descriptive, analytical approach to analyze the data and obtain the results of the study. The data were subjected to descriptive analysis in addition to chi-square and bivariate correlation tests so that the influence of each independent variable was investigated.

The questionnaires were used and pre-tested before actual samples were collected. Almost 600 questionnaires were filled out by 600 households and 100 water samples from cisterns in the study area were collected and analyzed (Al-Hadidia: 16, Al-Hila: 20, Khallet Saleh: 12, Um Saqhan: 12, Wadi Alma: 12 and Yatta town: 28). The 100 water samples included 50 harvested rainwater samples during the winter and 50 mixed water samples (harvested rainwater and water from other sources) during the autumn. Samples were collected directly from the cistern at about a half meter below the water level into individual sterile 1000 mL glass bottles and transported to the laboratory in a chilled-cold box [23]. The containers used were in accordance with the 18th edition of Standard Methods for the Examination of Water and Wastewater [24]. Samples were collected in glass bottles that had been cleansed and rinsed carefully, given a final rinse with distilled water, and sterilized at 200 °C for two hours in a dry oven.

The samples were analyzed for different quality parameters (temperature, pH, alkalinity, hardness, turbidity, total dissolved solids, NO_3, NH_4, chloride and salinity). The samples were also tested for pollution of microbiological contents: total Coliforms and faecal Coliforms bacteria. The 100 samples were taken during the rainfall year period between November 2014 and May 2015.

Structured interviews were also conducted with members from the Municipal Council in the local community, the official governmental line ministry, and the Palestinian Water Authority. Field visits were conducted to water sources in order to assess the overall status of the source and land use as well as to take real photos.

These specific cases were selected for several reasons such as: the difficult economic and water situations of local families that represent a large portion of residents in the Yatta area, the large family size which is the case of most households in the area, the inefficient water supplies through municipal networks and the poor handling of RWH.

3. Results and Discussion

3.1. Household Questionnaire: General Information on Rainwater Harvesting Cisterns in the Yatta Area

From the questionnaire results, it was noticed that the percentage of households sampled depending on the water network in the winter (36%) was higher than that in the summer (30%). One of the main water resources in the study area was the RWH, accounting for 86% of the water in the winter and 47% in the summer using cisterns as a main facility for collection and storage of water (see Figure 1). Regarding the availability of cisterns, results showed that most of the households (83%) had cisterns [23] found that 88% of the population surveyed in Hebron had cisterns. Local households typically had one, two, three or four cisterns.

Table 1 depicts general information about RWH cisterns in the Yatta area. As for the shape of cisterns, 61% of them were square-shaped tank cisterns while the rest of them (39%) were pear-shaped cisterns. In addition, 16 households had two cisterns; half of them were tank-shaped and the other half were pear-shaped. Regarding the capacity of cisterns, the average capacity volumes of the cisterns for households who had one, two, three or four cisterns were 90, 118, 230 and 160 m^3, respectively. Al Salaymeh et al. (2011) [23] found that 34% of the cisterns in Hebron area had capacities more than 100 m^3; however, 61% of them had capacities of 61–80 m^3.

Table 1. Description of surveyed cisterns.

		Cistern 1 Count (%)	**Cistern 2 Count (%)**	**Cistern 3 Count (%)**	**Cistern 4 Count (%)**	**Cistern 1 Mean**	**Cistern 2 Mean**	**Cistern 3 Mean**	**Cistern 4 Mean**
Type	Tank	251 (61%)	8 (50%)	2 (67%)	1 (100%)				
	Pear shape	161 (39%)	8 (50%)	1 (33%)	0 (0%)				
Capacity (m^3)						90	118	230	160
Catchment type	Roof area	392 (98%)	13 (87%)	2 (67%)	1 (100%)				
	Road	5 (1%)	0 (0%)	0 (0%)	0 (0%)				
	Open area	3 (1%)	1 (7%)	0 (0%)	0 (0%)				
	Concrete floor	1 (0%)	1 (7%)	1 (33%)	0 (0%)				
Catchment area (m^2)						231.3	360.8		
Construction cost (NIS)						15,728.5	24,923.1	72,666.7	160,000

Regarding the type of the catchment area for the cisterns (which directly receives the rainwater and provides water to the system), the vast majority of the households (98%) used rooftops to collect rainwater. Only one cistern had a concrete floor, which is unfavorable and may cause contamination as it contains heavy metals [25]. Regarding the catchment area for the households that had one or two cisterns, the average areas were 231 and 361 m^2, respectively. These results agree well with the findings of the study [23].

Table 2 summarizes some environmental conditions surrounding the RWH cisterns and their sanitation practices. Almost all respondents (99%) used cistern water during the winter. The vast majority of the households (96%) used cistern water for domestic purposes including bathrooms and utilized cisterns to store water from some other sources.

Table 2. Some environmental conditions surrounding the RWH cisterns.

Practice		Count	Percentage (%)	Mean
Using rainwater from cisterns during the winter	Yes	416	99	
	No	4	1	
Storing water from some other sources in cisterns	Yes	401	96	
	No	19	4	
Using harvested rainwater in bathrooms	Yes	404	96	
	No	17	4	
Cleaning cisterns	Yes	410	98	
	No	7	2	
Annual cleaning frequency of cisterns				1.8
Cleaning method of cisterns	Water alone	377	94	
	Soap	12	3	
	Disinfectant (e.g., chlorine)	4	3	
	Kerosene	0	0	
	Other	0	0	
Cleaning catchment area prior to rainwater harvesting	Yes	410	100	
	No	2	0	
Discarding first rainfall prior to harvesting	Yes	408	99	
	No	5	1	
Being satisfied with rainwater quality	Yes	399	98	
	No	7	2	

The vast majority of the respondents (98%) did clean their cisterns every two years, on average, and this agrees with what indicated in the Hebron area [23]. Almost all respondents cleaned the catchment areas prior to RWH and discarded the first rain shower prior to harvesting. While most of the households (93%) used water alone, only 4% of them used disinfectants such as chlorine and 3% of them used soap for cleaning their cisterns.

Almost all households (99%) kept doors of cisterns locked and did not have wastewater flooding near the cisterns. The majority of the households (98%) were satisfied with the quality of harvested rainwater. Treating harvested rainwater prior to use was not a common practice in the Yatta area. Only <4% of the households treated cistern water while a higher percentage (25%) was indicated by Al-Salaymeh et al. (2011) [23]. For those who did treat harvested rainwater, more than half of them (58%) used chlorination, 25% of them used filters, 8% of them used boiling and 8% of them used some other methods.

Almost half of the households (54%) did not test harvested water prior to use. The vast majority of the respondents (98%) stated that their children never had any diarrheal infection. We can see that having a cistern had had a positive impact on the daily activities of the household members. Most of the household samples showed that their behavioral attitudes (e.g., water saving) and cleaning activities (e.g., bathing frequency) had significantly improved.

3.2. *Quality Assessment*

3.2.1. Physicochemical Contamination

Tables 3 and 4 show the difference between the results of physical, chemical and microbiological characteristics of the two types of water samples: mixed water and rainwater. The pH values of the mixed water ranged from 6.9 to 8.7 with an average value of 7.6. The rainwater had lower pH values than those of the mixed water ranging from 7.0 to 7.6 with an average value of 7.2. In addition, the average value of conductivity for the rainwater (389 μS cm^{-1}) was lower than that of the mixed water (464 μS cm^{-1}) and so was the salinity.

Table 3. Physical, chemical and microbiological characteristics of the rainwater.

Parameter	Range	Mean	Standard Deviation	Samples above MAC [a] (%)	PSI (2004) [26] Guidelines	WHO (2004) [27] Guidelines
pH	7–7.6	7.2	0.1	2	6.5–8.5	6.5–8.5
Temp. (°C)	20.7–22.6	22.6	0.97		NA[b]	NA
Conductivity (µS cm^{-1})	189–632	389	131	0	Up to 2000	Up to 2000
Ammonium (mg/L)	0–13	1.5	3	6		
Chloride (mg/L)	26–140	55	26	0	Up to 250	Up to 250
Alkalinity (mg/L $CaCO_3$)	74–350	182	95	0	400	NA
Salinity (%)	0.4–1.2	0.75	0.24	32	Up to 1.0	Up to 1.0
Total dissolved solids (mg/L)	94–316	200	67	0	Up to 500	Up to 500
Turbidity (NTU)	0.18–7.83	0.88	1.5	14	Up to 5.0	Up to 5.0
Total Coliforms (CFU/100 mL)	19–2300	696	631	98	0-3	0
Faecal Coliforms (CFU/100 mL)	0–316	35	73	44	0	0

[a] Maximum Allowable Concentration. [b] Not Available.

Table 4. Physical, chemical and microbiological characteristics of the mixed water.

Parameters	Range	Mean	Standard Deviation	Samples above MAC (%)	PSI (2004) [26] Guidelines	WHO (2004) [27] Guidelines
pH	6.9–8.7	7.6	0.45	2	6.5–8.5	6.5–8.5
Temp (°C)	8.5–19.7	16.2	4.2		NA	NA
Conductivity (µS cm^{-1})	178–1066	464	200	0	Up to 2000	Up to 2000
Ammonium (mg/L)	3–17	2.5	4	12		
Chloride (mg/L)	26-140	57	26	0	Up to 250	Up to 250
Alkalinity (mg/L $CaCO_3$)	74–350	187	71	0	400	NA
Salinity (%)	0.3–1.9	0.84	0.35	32	Up to 1.0	Up to 1.0
Total dissolved solids (mg/L)	89–484	229	92	0	Up to 500	Up to 500
Turbidity (NTU)	0.39–65.2	4.9	12.9	14	Up to 5.0	Up to 5.0
Total Coliforms (CFU/100 mL)	2–2200	392	530	98	0–3	0
Faecal Coliforms (CFU/100 mL)	0–650	42	129	44	0	0

The highest value of total dissolved solids measured in the rainwater was 316 mg/L with an average value of 200 mg/L. As for the rainwater, almost all measurements of physicochemical parameters were within the PSI (2004) [26] and WHO (2004) [27] guidelines, except salinity and turbidity of which only few samples exceeded the limits. Similar trends were noticed for the mixed water samples with a minor violation to pH limits. Average values of physicochemical parameters had been always in compliance with the national and international standards for both rainwater and mixed water (see Tables 3 and 4).

The pH of the rainwater ranged from 4.5 to 6.5 but increased slightly after falling on roofs and during storage in tanks [28]. The increase in pH of the stored rainwater could be due to the alkaline nature of roof materials (mainly concrete) and storage tank materials, which are either concrete or limestone rock (excavated storage tanks), as indicated by Daoud et al. (2011) [29].

3.2.2. Microbiological Contamination

In 100 samples of the rainwater and mixed water, the percentages of contamination to cisterns in the Yatta area with faecal and total Coliforms were 52% and 99%, respectively. These results are close to those obtained through similar research [23] conducted in Hebron city where 57% and 95% of samples were contaminated with faecal and total Coliforms, respectively. Another study conducted by Al-Khatib et al. (2004) [30] in Tulkarm city showed that 9% and 34% of samples were polluted by faecal and total Coliforms, respectively.

In a study to assess the rainwater quality in the West Bank, Daoud et al. (2011) [29] found that 90% and 93% of the sampled cisterns were contaminated with faecal and total Coliforms, respectively. Contamination happens in different ways and locations from collection and storage of water to the water tap. Rainwater is often contaminated from the moment it falls onto the rooftop or any other catchment surface and facilities (rooftops, tunnels, small channels, etc.).

It is important to make sure that the inlet and the catchment area are cleaned before water is taken into the cistern. Dust and debris are washed away during the first flush in the initial period of rainfall events. Research shows that diverting the initial runoff can increase the quality of RWH by reducing turbidity as well as faecal and total Coliforms (see [31–34].

All samples were examined for two commonly used bacterial indicators: faecal Coliforms and total Coliforms. Results varied widely between the rainwater and mixed water samples. The highest value of faecal Coliforms, for instance, was detected in rainwater samples at 316 CFU/100 mL with an average value of 35 CFU/100 mL, while the highest value in the mixed water was 650 CFU/100 mL with an average value of 42 CFU/100 mL.

After a period of stabilization, however, the water becomes significantly cleaner. In Yatta, almost all households sampled (99.5%) disposed the first rainfall prior to harvesting. Despite this, contamination rates of water in cisterns remain high as a result of the way cisterns are cleaned. Faecal Coliforms values ranged between 0 to 316 CFU/100 mL with an average value of 35 CFU/100 mL, exceeding the WHO standard. Samples should be completely free from faecal Coliforms (null) as shown in Table 5. Most of the cisterns (93.5%) were contaminated and cistern water needed to be treated for safe uses. The majority of samples was also found to be contaminated with total Coliforms as shown in Table 6.

Table 5. Water contamination with faecal Coliforms in Yatta cisterns.

Range of Faecal Coliforms (CFU/100 mL)	Degree of Contamination for Mixed Water (% of Samples)	Degree of Contamination for Rainwater (% of Samples)	Degree of Risk
0	38	58	No risk
1–10	14	12	Simple risk
11–100	42	20	Moderate risk
101–1000	6	8	High risk
>1000	0	0	Very high risk

Table 6. Water contamination with total Coliforms in Yatta cisterns.

Range of Total Coliforms (CFU/100 mL)	Degree of Contamination for Mixed Water (% of Samples)	Degree of Contamination for Rainwater (% of Samples)	Degree of Contamination
0–3	0	2	0
4–50	6	24	1
51–5000	94	74	2
>5000	0	0	3

Sustainable, efficient water quality disinfection methods should be applied to the water stored in cisterns. Chlorination is the most common, easily applied method for disinfection in the study area. To ensure proper use, instructions should be given to consumers for cleaning and disinfecting storage tanks and cisterns. The gate of the cistern must be raised over the cesspit or septic tank to avoid flooding wastewater from entering the cistern. Cistern users must test its water quality frequently to ensure cleanliness and safety for drinking purposes, in particular.

3.2.3. Physical and Chemical Contamination

The physical characteristics of the rainwater samples including color, smell, temperature and taste were acceptable. However, the turbidity was found to be high in 14 out of the 50 samples with values ranging between 0.2 and 7.8 Nephelometric Turbidity Units (NTU) (see Table 3). This contamination was a result of deposition from traffic emissions and agricultural waste between rainfall events on the catchment area. These are simple examples of how dust accumulates on rooftops and soil organic waste on ground-level catchment areas. Turbidity ranged between 0.4 and 65 NTU (see Table 4) in the mixed water samples and figures were greatly higher than those of the rainwater. This contamination was a result of water purchased from tankers due to the scarcity of water. Tankers typically distributed water from unknown sources that were usually poor in quality and suffered from improper handling during the distribution cycle [35].

Furthermore, the chemical composition of the rainwater samples was accepted in terms of pH values, ranging from 7.0 to 7.6 (see Table 3). This is to indicate that the rainfall is not acidic in the study area and thus eliminates the possibility of any undesirable chemical reaction. While pH values of the mixed water ranged between 6.9 and 8.7, only 4% out of the 50 tested samples exceeded 8.5 and did not comply with both the Palestinian and the WHO standards.

Furthermore, the conductivity of the rainwater samples fell within an acceptable range of 189–632 $\mu S\ cm^{-1}$ (see Table 3). In the West Bank, conductivity values for the rainwater were less than those for the tap water, reported at 760 $\mu S\ cm^{-1}$ [36]; however, the mixed water gave higher values in some samples.

The chloride values were acceptable, ranging from 28–140 mg/L with an average value of 26 mg/L. None of the samples had a chloride value that exceeded the WHO standard. The source of chloride is the sedimentary rock as most of the cisterns are constructed using reinforced concrete. Chloride levels exceeding 250 mg/L cause a salty taste and may also result in a physiological damage [37]. Chloride concentrations in the mixed water ranged from 26 to 140 mg/L with an average value of 57 mg/L. None of the samples exceeded the Palestinian or the WHO standards of chloride.

The alkalinity values ranged from 74 to 350 mg/L $CaCO_3$ with an average value of 182 mg/L $CaCO_3$, and all values were acceptable. Alkalinity is a very important parameter for safe drinking water as it buffers against rapid pH changes. It also measures how much acid can be added to the water without either causing big changes in pH or producing acidic water. The alkalinity values of the mixed water ranged from 74–350 mg/L $CaCO_3$ and these values were within the acceptable range of PSI (<400 mg/L $CaCO_3$).

Salinity values of the rainwater ranged between 0.4% and 1.2% with an average value of 0.8% and some of these values fell beyond the WHO guidelines. The values of salinity in the mixed water ranged from 0.3% to 1.9% with an average value of 0.8%. This means that the concentration of salts in water sources such as tanks and the municipal network is higher than that of rainwater. Salinity is an indicator to measure the concentration of dissolved salts in a given volume of water. High levels of salts may affect the taste of drinking water.

Harvested rainwater salinity is clearly lower than tap water salinity found in the West Bank, typically 0.4% [36]. Values of total dissolved solids in the rainwater samples ranged between 94 to 316 mg/L with an average value of 200 mg/L and all values were within both the Palestinian and the WHO standards. Total dissolved solids are considered as an indicator of the mineral constituent dissolved in water. A value exceeding 500 mg/L is undesirable for drinking water causing a bitter and salty taste.

3.3. Quantity Assessment

Three elements are essential to control the amount of water accumulated from rainwater: (1) the amount of rainfall in the region (P), (2) the size of catchment area (A) and (3) the proportion of rainfall you can collect. As not all rainfall will be captured and stored, a collection efficiency coefficient (C) to estimate actual quantities is to be considered. The potential annual rainwater (PRWH) that can be harvested is to be estimated using Equation (2):

$$\text{PRWH} = \text{P} \times \text{A} \times \text{C}. \quad (2)$$

The coefficient C is a factor of a number of conditions related to the catchment area (type, porosity, permeability, etc.), collection system components and seasonal factors (rainfall intensity, frequency, type of rainfall, etc.). The total amount of available water is a product of the total annual rainfall and the roof or collection surface area. This determines the potential value for RWH. Usually there is a loss caused mostly by evaporation (sunshine), leakage (roof surface), and overflow (rainwater that splashes over the gutters and transportation (guttering and pipes). The local climatic conditions are the starting point for any design.

3.3.1. Calculating Monthly Rainwater Collection (2014–2015)

Table 7 summarizes the monthly rainwater supply for a house in the Yatta area with a 146 m^2 catchment area. Collection efficiency figures are typical for houses in the Yatta area that have concrete roofs, and are relatively located in open sites. The low collection percentages in April to September assume that the system is shut down and cleaned after the pollen season. The figures in Table 7 represent the actual amount of rainwater that could be collected each month.

Table 7. Rainfall collected in the Yatta area.

Month	Average Water Usage (L)	Assumed Rainfall (mm)	Assumed Collection Efficiency	Rainfall Collected (L)
January	19,746	155	0.80	18,079
February	19,746	185	0.80	21,578
March	19,746	131	0.80	15,280
April	19,746	15	0.75	1640
May	19,746	0	0.70	0
June	19,746	0	0.70	0
July	19,746	0	0.70	0
August	19,746	0	0.70	0
September	19,746	0	0.70	0
October	19,746	0	0.70	0
November	19,746	31	0.75	3390
December	19,746	29	0.75	3171
Total	236,952	546		63,139
	Demand		Supply	

3.3.2. Estimating Domestic Water Consumption

The first step in designing a RWH system is to consider the annual household water demand. The water demand can be calculated using Equation (3):

$$\text{Consumption} = \text{No. of household members} \times \text{Daily water use} \times 365\ \text{Days}. \quad (3)$$

For the Yatta area, the water consumption is approximately 20 L/day) and the average household size is 10 family members (survey results) as follows:

Water use in Yatta = quantity of water received/population

= 2000 m^3/100,000

= 20 L/day.

Thus, water consumption = 20 × 10 × 30

= 6000 L per month.

However, this value is really low, and, therefore, we use the average consumption for the West Bank, which equals 64 L/capita/day (see UNICEF and PHG 2011) [38]:

Water consumption = 64 × 30 × 10

= 19,746 L per month.

3.3.3. Rainwater Storage Capacity

The RWH can be a reliable source to fulfill water needs, especially during the fall and winter seasons. However, storage facilities need to be constructed in order to help reduce water deficits as a result of limited supply during the summer. Determining the size of a storage facility requires a balance between demand that cisterns are expected to fill and available/potential size of the catchment area. In order to better understand the water balance in the study area, two scenarios are proposed:

Scenario (1)

Yatta area with a 20 L/capita/day water consumption (see Table 8),
Roof catchment area: 146 m^2,
Assumed precipitation level: 370 mm on average,
Roof type: Concrete roof,
Operational storage capacity: 69,000 L or 69 m^3.

Scenario (2)

Yatta area with 64 L/capita/day water consumption (see Table 8),
Roof catchment area: 146 m^2,
Assumed precipitation level: 370 mm on average,
Roof type: Concrete roof,
Operational storage capacity: 69,000 L or 69 m^3.

Table 8. Monthly rainwater supply for scenarios (1) and (2).

Month	Rainfall Collected (L)	Scenario (1)		Scenario (2)	
		Average Water Usage (L)	Month End Storage Volume (L)	Average Water Usage (L)	Month End Storage Volume (L)
January	18,079	6000	12,079	19,746	−1667
February	21,578	6000	27,657	19,746	165
March	15,280	6000	36,937	19,746	−4301
April	1,640	6000	32,577	19,746	−22,407
May	0	6000	26,577	19,746	−42,153
June	0	6000	20,577	19,746	−61,899
July	0	6000	14,577	19,746	−81,645
August	0	6000	8,577	19,746	−101,391
September	0	6000	2577	19,746	−121,137
October	0	6000	−3423	19,746	−140,883
November	3390	6000	−6033	19,746	−157,239
December	3171	6000	−8862	19,746	−173,814
Total	63,138 Supply	72,000 Demand	163,817	236,952 Demand	−908,371

3.3.4. Calculation Results

The calculation results can be summarized as follows:

- The amount of water collected depends on the size of the catchment area.
- An average of 69 m^3 cistern volume is sufficient to collect rainfall under current circumstances.
- There is a need for other water sources for domestic use.
- The amount of rainfall is not even sufficient to meet the requirement of 20 L/capita/day given the existing infrastructure.

3.4. Case Study: A Palestinian Family from the Yatta Area

3.4.1. The Socio-Economic Situation of the Family

A detailed case study was prepared as an example of the samples that had been taken for the socio-economic and water quality analysis. The family consists of the head of the family, four illiterate wives and 28 children. It includes 14 females and 14 males, mostly in primary and secondary education levels. The house covers an area of 100 m^2 and consists of two rooms, a kitchen, a bathroom and an external area of 200 m^2. The father and the eldest son both work as laborers in the construction sector. This is the main source of income for the family, which ranges between $300 and $900 a month. However, availability of work opportunities is not guaranteed and hence there are months (e.g., in the winter) in which the family does not have any income at all. The family falls well below the poverty line according to the Palestinian rating. Additional sources, which are very limited, are mainly agricultural activities of which income does not exceed $15 to $60 in the growing seasons of olives, almonds and plums.

3.4.2. The Water Situation of the Family

The family mainly relies on RWH where water is stored in a cistern with a capacity of 60 m^3. Water is collected from the roof surface every year in the winter [39]. Although the household is connected to the water network, they are not supplied with water in the summer due to the limited resources existing in the area. In the summer, hence, the family relies on tankers as an alternative source of water at which the family purchases a total of 10 tanks of water at a price of $60 each. This is a big burden on the family to provide sufficient quantities of water and meet all its needs. Water scarcity is a significant problem facing the family and surrounding community. A serious issue is that the cistern is located in an animal shed, which includes oxen and sheep barn. Animals also drink water from the cistern. The cistern is contaminated, physically and biologically, exceeding the local and international standards. Rainwater collected in the catchment area might contain dust, pesticide traces and animal feces that all find their ways into the water stream to the cistern.

Two types of bacteria (faecal and total Coliforms) were tested to detect any biological contamination indicating the presence of animal wastes and feces (see Table 9). The results show that the biological contamination is considerably high due to several reasons:

1. The cistern site is located within the animal barn where animals are kept.
2. The RWH system put in place to collecting rainwater is inappropriate starting from the roof to the cistern. The practices applied by the family are also problematic as water is sometimes collected from outside the roof area. Cistern water is neither collected necessarily from clean areas nor disinfected for safe domestic uses.
3. The lack of awareness of the family on optimal use of the cistern water. The family is poor and unconscious about the different consequences that may result from any water pollution.
4. Poverty is a main reason for the lack of maintaining the cistern and disinfecting its water.
5. The large number of children, making the first priority of the family head to secure water quantity rather than its quality.
6. The lack of water refineries at the entrance of the cistern to collect dirt and dust, which both constitute a key reason for the transfer of biological contaminants.

Table 9. Contamination of faecal and total Coliforms for the case study.

Stage	Faecal Coliforms (CFU/100 mL)	Total Coliforms (CFU/100 mL)
Mixed water 1	316	650
Rainwater 2	240	470

3.4.3. Requirements for a Rainwater Harvesting System

A RWH system should consist of the following components:

1. Catchment area: local families use rooftops as a catchment area. The average rooftop area is about 160 m^2.
2. Conveyance system: this includes gutters, downspouts and pipes conveying runoff to the storage cistern.
3. Storage capacity: water is stored in a concrete cistern with a capacity of 60 m^3 on average.
4. Distribution network: a pressurized system is used to distribute water from the cistern.

4. Conclusions and Recommendations

Rainwater harvesting (RWH) is the most common method used to help mitigate water scarcity problems in the Yatta area by supplying freshwater for potable and non-potable uses. RWH can reduce demands on public water network and subsidize irrigation at critical stages when deficit between water requirement for agriculture and rainfall occurs. Rainwater harvesting (RWH) is important for irrigation to enhance financial security and provide supplemental income for local households. The main advantage of RWH is the low operation and management costs needed.

Families in Yatta are characterized by large family sizes with an average of four males and five females per family. Local family members have, in general, low academic achievements and their incomes are highly dependent on heavy-duty jobs such as the construction. Most of the families have cisterns to store water for the dry season. However, according to the analysis of collected data and interviews, house owners were found to have insufficient awareness on best practices for the collection and storage of rainwater.

It is therefore recommended to conduct workshops and projects that deal with proper RWH methods to prevent pollution in cisterns and maintain their water quality to comply with the drinking water standards. RWH appears to be one of the most promising alternatives for supplying freshwater to counter the increasing water scarcity and escalating demand due to the high population growth. The chemical quality of harvested and stored rainwater in the Yatta area was quite satisfactory with no parameters being detected above the corresponding maximum allowable concentration for drinking purposes. Despite the relatively good physicochemical quality of the samples taken from cisterns, high values of biological contamination, both faecal and total Coliforms, did alarmingly exist in the majority of the samples. These results overrule the suitability of using the harvested rainwater for domestic purposes without prior treatment.

The physicochemical quality of the harvested rainwater in the Yatta area was generally good enough to be used for drinking purposes. However, the microbiological analysis of stored rainwater samples indicated significant microbiological contamination with faecal and total Coliforms. The presence of these pathogens clearly indicates that this cistern water was not suitable for direct consumption without proper treatments. Reducing health risks posed by microbes in stored water requires some actions to be taken before filling the cisterns and during the storage period. These measures include:

- Constructing the cistern at least 15 m away from cesspits and septic tanks.
- Keeping the door of the cistern at a higher level of the floor. Place fine screens on the inlets and outlets to prevent animal access.

- Protecting openings in the collection and storage systems to prevent contamination of stored water. This includes doors, overflow pipes and settling chambers.
- Cleaning the RWH system should take place annually.
- Cleaning the catchment area (house roof) before collecting water in the cistern.
- Keeping animals away from the roof and the cistern and cleaning up bird droppings.
- Diverting the first flush of rainwater and regularly cleaning and disinfecting stored water in cisterns.
- Exposing cisterns to sufficient sunlight to prevent formation/growth of bio-films.
- Using a proper disinfection method such as chlorination or boiling.
- Using filtration on the tap.

Yatta area also needs special attention from Non-Government Organizations (NGOs) to support households suffering from water scarcity but would probably be unable or unwilling to develop their own solution especially in the area around Yatta, namely Khallet Saleh and Um Saqhan. RWH can also be applied for agricultural purposes by constructing ponds that could be used for irrigation. This would improve the standard of living and the economic status for the local families in the Yatta area.

Integrated water resources management must consist of regular cleaning of catchment areas and storage tanks. The employment of automated mechanical systems to discard the first portion of each rainfall event and the application of disinfectants in the tanker trucks after removing water from cisterns to avoid the formation of by-products are both essential. Yatta Municipality could have played a positive role in assuring the compliance of RWH systems with construction specifications placed by the Palestinian Water Authority taking into account public and private conditions surrounding the cistern.

5. Future Work

Further studies should be conducted on first-flush systems to provide proper recommendations to users of RWH systems in the Yatta area. The geological nature of Yatta area contributes to the increase of construction costs attributed to RWH cisterns. Alternative storage mechanisms that are cheaper need to be investigated. Once capital costs are decreased, RWH can be an affordable source that is accessible to all community members, especially marginalized groups in such rural areas.

The concept of "Do-it-yourself" RWH system in the Yatta area is fairly widespread. Finding ways to improve quantity and quality of informal harvesting systems is a potential means to providing water supplies for many low income households in the Yatta area.

The authors recommend the use of a filter, such as sand filters. If distributed in conjunction with RWH tanks, it only represents a small fraction of the total cost of the system. Furthermore, filters could be used to treat the contaminated supplies of water to the local community of such rural areas.

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