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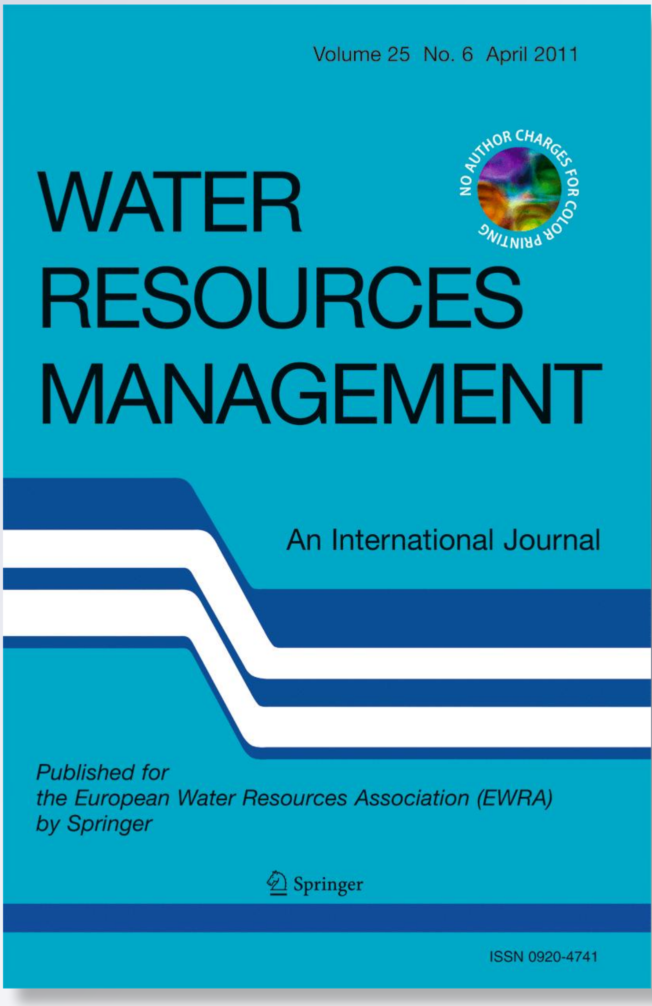

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Towards Sustainable Water Quality: Management of Rainwater Harvesting Cisterns in Southern Palestine

Adel Al-Salaymeh · Issam A. Al-Khatib · Hassan A. Arafat

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Abstract Environmental management of rainwater harvesting in southern Palestine is required to reduce the continuously increasing demand for fresh water from limited water aquifers and to reduce the adverse health impact on the people drinking harvested rainwater. This continuously increasing demand for fresh water requires the enhancement of environmental conditions surrounding the cistern owners' awareness to tackle the mismanagement that contributed to rainwater contamination. In this study, 100 cisterns were sampled and tested for physiochemical and microbiological parameters. Most of the tested physiochemical parameters were within the acceptable limits of WHO and Palestinian standards except turbidity, calcium and magnesium where 24%, 47% and 32% of the samples were non-conforming, respectively. The pH values of the collected rainwater ranged from 7.32 to 8.97 with a mean value of 8.16. The nitrate analysis results range from 1.5 to 7.0 mg/L, with a mean value of 4.2 mg/L. High percentage of cisterns were found to be contaminated with total Coliforms (TC) and faecal Coliforms (FC) with percentages of 95% and 57%, respectively, rendering the cistern water unacceptable for drinking purposes. 78% of samples had a severe degree of contamination for which water needs flocculation, sedimentation then chlorination to become suitable for drinking. On the other hand, based on FC data, none of the tested samples for FC was a "high risk", but 57% of them were categorized with "simple" to "moderate risk" and 43% were "no risk" cisterns. A cistern owner's survey was utilized to reveal the roots behind this contamination. Different remediation measures, such as cleaning cisterns

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and rainwater collection surfaces and discarding water from the first season storm, were recommended to enhance and protect the cistern water quality.

Keywords Water resources management · Rainwater harvesting · Cisterns · Developing countries · Palestine

1 Introduction

Water is considered one of the most important and sensitive issues in the Middle East, where increasing water deficiency and quality deterioration of the available water are imminent (Al-Khatib et al. 2003). Most of the middle-eastern countries, including Palestine, are characterized by arid to semi-arid climatic conditions and have very limited water resources. The majority of fresh water supplies in these countries come from scarce groundwater resources. Future population growth and its associated water demands are expected to place severe pressure on these limited groundwater reserves (Nasserdine et al. 2009). Consequently, rainwater harvesting becomes of great importance in the socio-economic development of areas like Palestine, where water sources are scarce or polluted (Appan 1999; Makoto 1999; Prinz 1999). There are many factors that contribute to water contamination in the West Bank of Palestine, the main of which are the absence of wastewater collection sewerage systems and the spread of cesspits for wastewater collection in most of the rural areas, leachate from random solid waste dumping sites, runoff from urban drainage, and fertilizer and pesticide residues.

An established goal of the World Health Organization (WHO) and its member states is that all people, whatever their stage of development and their social and economic conditions, have the right to access an adequate supply of safe drinking water (WHO 1997). According to the WHO (1997), the per capita minimal amount of water needed for household and urban needs is one hundred liters per day. Due to the chronic water shortage, water consumption in the West Bank of Palestine has dropped well below this amount. In Nablus city (northern West Bank) and the Southern Hebron Hills (southern West Bank), the figure is slightly higher than fifty liters a day. Average per capita consumption throughout the West Bank is 66 liters per day (B'Tselm 2008), which is two-thirds of the average consumption needed according to the WHO. These figures include water for livestock, meaning that the water consumed for personal use is even less. Furthermore, some 20 percent of Palestinians in the West Bank are not connected to a water supply network (B'Tselm 2008). Even in Palestinian towns and villages that have a water network, water supply is intermittent most of the year. Water is supplied only for a few hours daily, mostly on a rotational basis. In distant areas, water supply may be interrupted for days or even weeks (Abusafa et al. 2009). As an additional complication, 50% of the areas served by water distribution networks suffer from partial water loss (via leakage in the network) or low pumping pressure (Al-Khatib and Orabi 2004; Abusafa et al. 2009).

As a remedial action to combat severe water shortage, many Palestinian families construct rainwater harvesting cisterns to collect rainwater in the winter season for later use in the dry summer months. These cisterns have to be built and operated according to specific health and engineering standards. For example, once the rain season begins, rain comes in contact with the catchment surfaces, from where it can wash many types of bacteria, algae, dust, leaves, bird droppings and other contaminants into the cistern. Therefore, the first rain storm must be used to

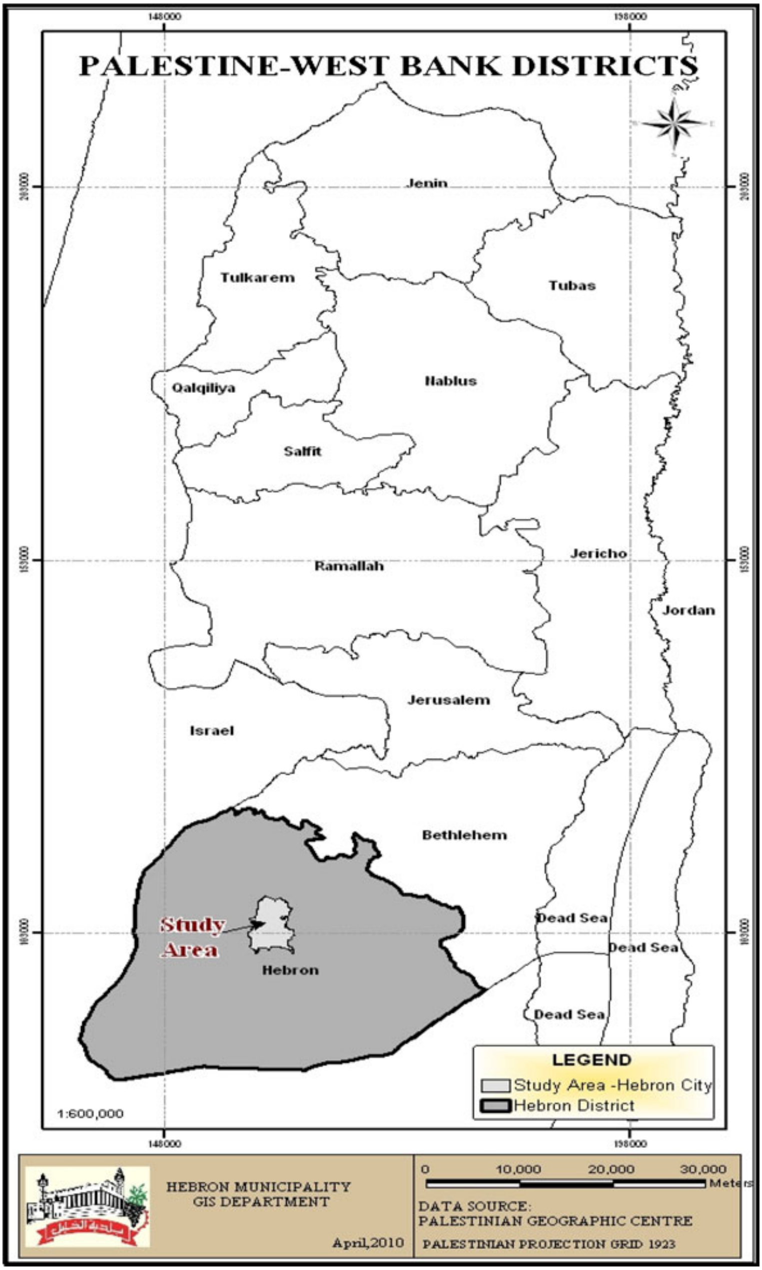

Fig. 1 Palestine map including Hebron city (Hebron municipality, GIS Unit 2010)

flush-clean the collection surface and be diverted away from the cistern (UNEP 2002; Spinks et al. 2003; Chang et al. 2004; Villarreal and Dixon 2005). The risk of microbiological contamination of drinking water during collection and storage in cisterns has long been recognized (Lye 2002; Thomas et al. 2003; Gerba and Smith 2005). Factors such as site characteristics, interval duration, and UV intensity would all impact the survival of micro-organisms on the catchment surface and their viability in the run-off (Evans et al. 2006). Septic systems have been also noted as one of the primary sources of rainwater cisterns pollution through subsurface movement of pollutants. Old cisterns may be vulnerable to contamination from subsurface flow due to the presence of cracks in the cistern's walls (Gannon et al. 1996). Similarly, the variation of roof runoff quality seems to reflect differences in roofing materials, age and management, the surrounding environment, storm duration and intensity, air quality conditions of the region, and season (where exposure of roof to direct sunlight in summer and the increase in temperature affect the survival of microbes on the roof surface) (Chang et al. 2004).

1.1 Study Area

Hebron city is located in the southern part of West Bank of Palestine, 36 kilometers south of Jerusalem (Fig. 1). Its population was about 163,150 in mid 2007 (Palestinian Central Bureau of Statistics 2009). Hebron has a Mediterranean climate, characterized by long, hot, dry summers and short, cool, rainy winters. It has a relatively rainy season from November to April, with an annual average of 600 mm of rainfall (Palestinian Metrological Department 2007), and very dry weather for the rest of the year. According to Hebron municipality, the area of Hebron city is about 25 square kilometers, with 17,055 households in 2007. About 65% of these households have cisterns with a total capacity of 1,012,135 m^3. Some of the cisterns' owners use them for rainwater harvesting only, while others use them as storage tanks, where rainwater may be mixed with water from other sources (e.g., municipal water). Additionally, 85% of these households were connected to sewage systems, as shown in Table 1.

The aims of this study were to assess the management practices of the rainwater harvesting cisterns in southern Palestinian territory, using Hebron city (the largest city of that area) as a sample locality. This was achieved by analyzing the physiochemical and microbiological quality of the harvested water, along with possible causes of water contamination. Improvements of the rainwater harvesting system were then proposed, so as to minimize potential health risks.

Table 1 General households statistics in Hebron City in 2007

Total number of households	17,055
Number of households with cistern	11,074
Percentage of households with cisterns	65%
Number of household with cistern and connected to sewerage system	9412
Percentage of households with cisterns and connected to sewerage system	85%
Total volume of cisterns	1,012,135 m^3
Average volume of cistern	91.4 m^3

Hebron Municipality, GIS Unit, 2007

2 Materials and Methods

2.1 Cisterns Owners' Survey

Using Geographical Information System (GIS) mapping as a tool, Hebron city was divided into 25 grids, one square kilometer each. Within these grids, the coordinates of the sampling sites were obtained from the GIS unit database of Hebron Municipality and the sampling sites map was created using Arc-View GIS version 3, as shown in Fig. 2. Then, during the period from December 11, 2007 until April 22, 2008, 100 water cisterns in Hebron city were sampled and their owners were surveyed,

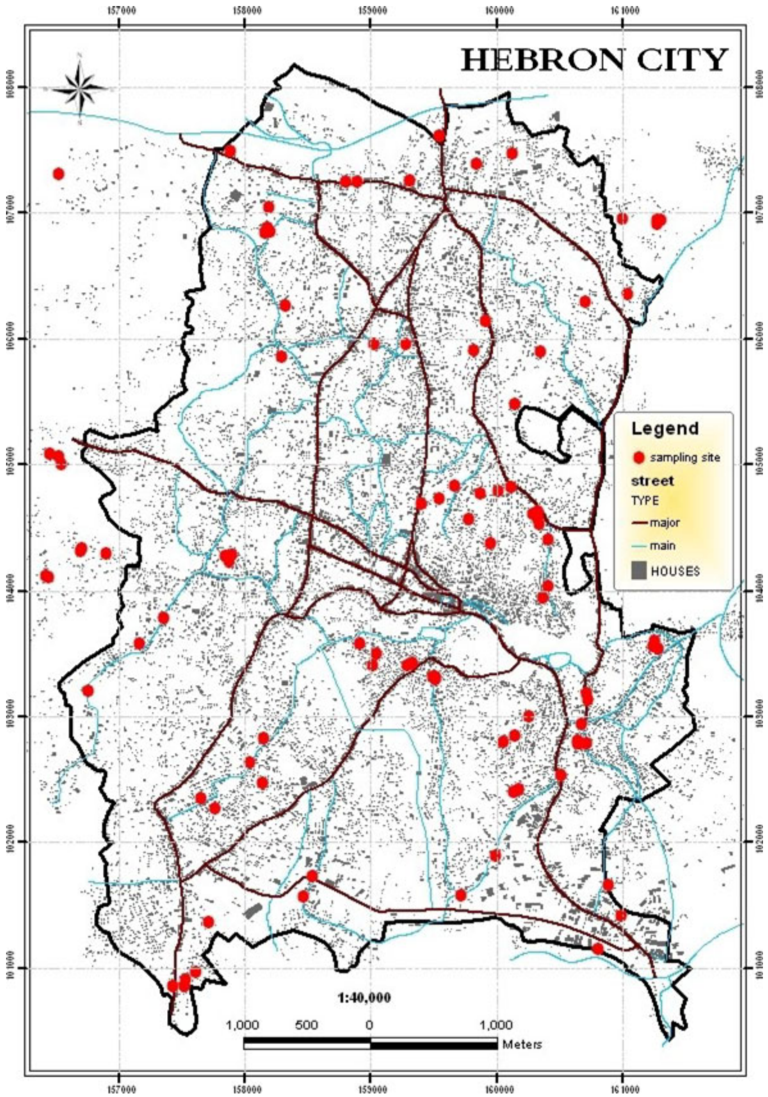

Fig. 2 GIS water cistern sampling sites map

using a pre-prepared semi structured questionnaire, covering a wide range of cistern management issues as well as environmental conditions surrounding the cisterns. The latter include cistern age, cistern capacity, source of water in the cistern, vicinity and elevation with respect to nearby septic tanks, if any, water disinfection frequency and method, water collection methods, and cleaning frequency, among other factors. The number of samples was statistically determined by using formula which relates the number of population (number of households with cisterns) and a confidence interval of 95% and confidence level of 10% (Creative Research Systems 2003). Data obtained from the cisterns owners' questionnaire were coded and processed utilizing the SPSS version 13 (Statistical Package for Social Sciences) software. The data was analyzed and cross-tabulated. The Chi-square test was mainly used in the statistical analysis of the data, to test if there was a statistically significant correlation in the cross-tabulation between variables in the questionnaire and microbiological and chemical tests. If Pearson's Chi-Square Asymp. Sig. (two-sided) value was less than 0.05, then the relation was considered statistically significant.

2.2 Water Cisterns Sampling

During the period from December 11, 2007 until April 22, 2008, 100 water samples were collected on a weekly basis (4–12 samples per week) from the cisterns at about one-half meter below water surface level into sterile 1000-ml glass bottles. At each sampling site, temperature, electrical conductivity, total dissolved substances, pH, salinity and turbidity of cistern water were measured, following applicable standard procedures (Tortora et al. 2003; APHA 1998). An EC-10 pH-meter, a CO150 conductivity meter, and a Hach 2100P Turbidimeter, a Hach CO150 salinity meter and a Hach CO150 TDS (Hach Company, Loveland, Columbia—USA) were used for those measurements. In addition to the field measurements mentioned above, additional collected samples were sent to the Water Engineering Laboratory at Birzeit University (Birzeit-Palestine), within 24 h of collection, in a chilled-cold box at 4°C for biological analysis. This was done in accordance with the standard methods for the examination of water (APHA 1998). At the Water Lab, water was analyzed for indicator organism concentrations (Total *Coliforms* and Faecal *Coliforms*) and other chemical water quality indicators (Alkalinity, Total hardness, Calcium, Magnesium, Chloride, Nitrate and Ammonia) using the applicable standard procedures (APHA 1998; Tortora et al. 2003). The parameters (pH, TDS, hardness, alkalinity, free available chlorine, sulfate and ammonia-N) could influence drinking water flavor, while the turbidity and *Coliform* were measured due to esthetic and health concerns, respectively (Lou et al. 2007). Many consumers will link the presence of offensive tastes or odors with the possibility of a health risk, though an unpleasant taste in water does not necessarily indicate that the water is unsafe to drink (Lou et al. 2007).

3 Results and Discussion

3.1 Design and Usage of Rainwater Harvesting Cisterns in Hebron City

Table 2 summarizes design and usage information of rainfall harvesting cisterns in Hebron city, as obtained from cistern owners. About 46% of the cisterns were more

Table 2 Survey response distribution regarding cistern design and usage in Hebron city

	Response distribution							
Cistern capacity (m^3)	Less than 20	20–40	41–60	61–80	81–100	More than 100		
	6%	17%	8%	16%	18%	35%		
Cistern age (year)	1–5	6–10	11–15	16–20	More than 20			
	11%	16%	11%	16%	46%			
Primary uses of cistern water	Drinking	Agricultural	Cleaning and laundry					
	100%	42%	97%					
Type of water collection surface	House roof only	House yard or garden	Street only	House roof, house yard, and garden and street	House roof and house yard	House roof and street	House yard and street	Other
	68%	1%	2%	1%	5%	2%	1%	20%

than 20 years old, and 16% were 16–20 years old. The age of the cistern is an indicator for the importance of cisterns for rainwater harvesting in the past and recently. Old cisterns are more vulnerable to leakage of polluted water into them through cracks (Abusafa et al. 2009), and require more attentive maintenance. On the other hand, the study shows that a significant number of cisterns (27%) were constructed within the last 10 years, reflecting a growing demand for this alternative water source.

As one considers cistern capacity, Table 2 reveals that the highest percentage (35%) of cisterns were larger than 100 m^3, while the smaller cisterns (less than 20 m^3) constituted the lowest percentage (6%). The smaller cisterns can be assumed to be for luxury (e.g., lawn watering) or emergency uses only. The capacity of the cistern depends on different factors, such as space availability to construct the cistern, the financial ability of the owner, and the family size and its water-consumption style. Typically, Hebron residents divert rainwater into cisterns and use this water throughout the dry summer season, and so each cistern is expected to hold an amount of water enough to satisfy minimal requirements during the rain season and then during the summer season. Therefore, the wide spread of the larger-capacity cisterns indicates heavier dependence by the population on the cisterns for water supply. As for the primary uses of cistern water, it is difficult to make definite judgments, since water usage in the surveyed households is rather diverse. All the cistern owners indicate that they use the water for drinking purposes, while 97% of them use it for other household activities too, such as cleaning and laundry. In 42% of the cases, the harvested water was used for agricultural purposes, such as irrigating plants and trees surrounding the house and for animal drinking purposes. None of the respondents stated that they used rainwater only for agricultural purposes. The heavy dependence on cistern water for drinking purposes emphasizes the need for cistern water quality protection as contaminated water can cause water borne diseases.

Finally, 68% of the cisterns' water collection surfaces were house roofs. Other owners use plastic sheets aligned on roof-top for rainwater harvesting, which are less vulnerable to contamination than streets. Others use house yard, garden, and/or streets for rainwater collection, as shown in Table 2. Except for roofs, most of these surfaces are mostly unsuitable for collecting water, as they are polluted by contaminants from different sources and their cleanness is hard to guarantee. For example, human activities cause a significant amount of contaminants to be deposited on the streets. These contaminants include heavy metals and hydrocarbons from vehicles' exhausts, oil leakage from engines, pesticides, gasoline and grease, animal waste, sand, soil, silt and others. While all human activities can be a source of contaminants, certain activities are particularly large contributors (Nolde 2007).

Table 3 summarizes some of the environmental conditions surrounding the rainwater harvesting cisterns. 30% of cisterns have trees near them. Trees can be considered a source of cistern water contamination as they provide suitable habitat for birds and pets, which may bring their feces in contact with cistern water (Vida et al. 2005; Abusafa et al. 2009), especially if the cistern's lid is not always on. Moreover, the application of biosolids to soil surrounding these plants may cause harmful substances from these solids to leach into the cistern water. One can also see that 66% of the houses surveyed were connected to a sewerage network, while the balance (34%) uses cesspits (or septic tanks). The Jordanian standards of cistern's design for rainwater harvesting specify that the cistern should be away from any nearby cesspit by at least 25 m (JISM 2008). Sewer overflows and the presence of

Table 3 Environmental conditions surrounding the rainwater harvesting cisterns

Environmental condition	Percentages of respondents (%)
Cisterns with nearby trees	30
Household wastewater disposal method Municipality sewage network	66
Cesspit	34
Occurrences of sewage flood from sewerage network in the vicinity of the cistern	
Yes	9
No	57
Not applicable	34
Cistern level with respect to cesspits	
Higher	30
The same level	4
Not applicable	66
Distance between cesspit and cistern (m)	
Less than 20 m	16
More than 20 m	18
Not applicable	66
Last time the cesspit was pumped out	
Within last year	8
One to five years ago	8
Never pumped out	18
Not applicable	66

cesspits in the vicinity of cisterns are two significant potential pollutant sources of cistern's harvested water. Nine percent of the respondents surveyed in this study reported the occurrence of sewage overflow from sewerage network in the vicinity of their cisterns. In Palestine, storm water in the streets flows into the public sewer network. As a result, sewer overflow occurs when sewers become surcharged by storm water and overflow, often through manholes or into basements. Cesspits and pipe lines connecting households with cesspits represent potential sources of nitrates and pathogens. Additionally, if improperly used, such as for disposal of paints, solvents, petroleum products and other hazardous waste, they could also be a source of toxic compounds pollution. The underground cesspits, which are usually used in the Palestinian localities where sewerage networks are not available could be a source of contamination to rainwater harvesting cisterns, especially if they are within 20 m from the cisterns (as for 16% of respondents) or on the same level of the cistern (as for 4% of respondents). Most cesspits used in Palestine are not insulated and water is allowed to diffuse through the soil to allow for more cesspit capacity before pumping is needed. It is therefore alarming to notice that 18% of the cistern owners surveyed in this study (Table 3) have never pumped out their cesspits, which means that they are totally reliant on water diffusion through soil to dissipate and degrade their wastewater.

3.2 Physiochemical and Microbiological Quality of Cistern Water

The results of the physiochemical and microbiological analysis of the water obtained from sampled cisterns are presented in Table 4, along with relevant Palestinian

Table 4 Physiochemical and microbiological analysis of the cistern water

Physiochemical character	Readings range	Readings mean	Samples above MAC[a] (%)	PSI (2004) guidelines	WHO (2004) guidelines
pH	7.32–8.97	8.2	4	6.5–8.5	6.5–8.5
Temp (°C)	9.8–26	16.8		NA[b]	NA
Conductivity (μScm^{-1})	129–802	449.5	0	Up to 2,000	Up to 2,000
Nitrates (mg NO_3-N/L)	1.5–7	4.2	0	Up to 10 as NO_3-N	Up to 10 as NO_3-N
Ammonium (mg/L)	0–13.3	1.4	35	NA	NA
Chloride (mg/L)	13.4–134	42.3	0	Up to 250	Up to 250
Hardness (mg/L $CaCO_3$)	20–292	159.2	0	500	NA
Alkalinity (mg/L CaCO3)	16–346	154.8	0	400	NA
Calcium (mg/L)	16–172	94.6	47	Up to 100	Up to 100
Magnesium (mg/L)	0–212	64.6	32	Up to 100	Up to 100
Salinity (%)	0.1–0.4	0.22	0	Up to 1.0	Up to 1.0
Total dissolved solids (mg/L)	62–384	216.2	0	Up to 500	Up to 500
Turbidity (NTU)	0.34–113	7.45	24	Up to 5.0	Up to 5.0
Total *Coliforms* (CFU/100 ml)	0–2,000	1,031.3	95	0–3	0
Faecal *Coliforms* (CFU/100ml)	0–98	8.8	57	0	0

[a] *MAC* Maximum Allowable Concentration according to PSI (2004)
[b] *NA* not available

(PSI 2004) and international (WHO 2004) guidelines. The pH values of the collected rainwater typically ranged from 7.32 to 8.97 with a mean value of 8.16. In many other parts of the world, the rain is acidic with pH values starting at 4.17 reported (Chang et al. 2004). In a low pH range, the leaching of various substances (metals) from the collection surfaces is promoted, which may deteriorate the quality of harvested rainwater. So, at the pH value observed in Table 4, the water is alkaline and such unfavorable reactions are unlikely to occur (Zhu et al. 2004). Table 4 also shows that cistern water had low mean values for conductivity (449.5 μScm^{-1}) and Chloride (42.3 ppm). The highest value of hardness measured in rainwater was 292 mg/L $CaCO_3$ and the mean value was 159.2 mg/L $CaCO_3$, as shown in Fig. 3, well below the Palestinian guidelines (500 mg/L). Table 5 shows the source of water stored in the cisterns. Of the different sources, it was found that the source of water samples that registered high hardness values in the cisterns is mostly municipal.

The results of temperature, salinity and total dissolved substances are below the maximum levels established by Palestinian and WHO standards. Since the water in most cisterns is from rain origin or mixed with it (Table 5), its salinity is not expected to be high.

The turbidity results of cistern's water ranges from 0.34 to 113 NTU with a mean value of 7.45 NTU. 24% of the tested samples had turbidity values exceeding 5 NTU, which exceeds both Palestinian and WHO standards. Although this may not constitute a health risk in itself (depending on the nature of particles causing the turbidity), the water may be aesthetically unpleasant. The high turbidity values were

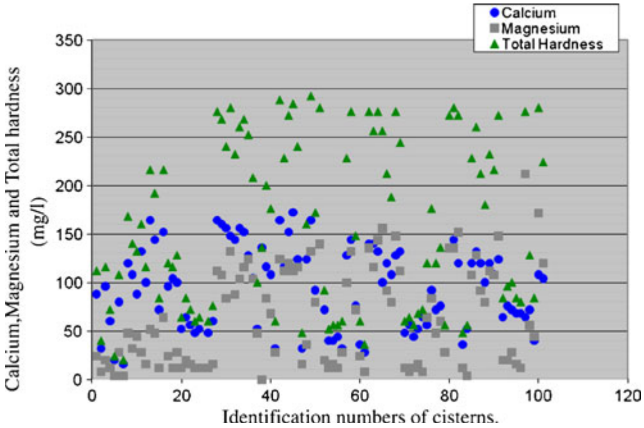

Fig. 3 Plot of water quality results (Calcium, Magnesium and total hardness) of different cisterns in Hebron—Palestine, 2008

mostly noticed in the samples collected during rain storms. The nitrate analysis results (Table 4) range from 1.5 to 7.0 mg/L, with a mean value of 4.2 mg/L. None of the tested samples exceeded the maximum allowable concentration. The results of nitrate of this study are consistent with two previous studies conducted in Palestine (Awadallah 2004; Dawod 2008), where no samples had nitrate concentration exceeding the Palestinian and WHO standard limits. Similarly, ammonia concentration results range from 0.0 to 13.3 mg/L with a mean value of 1.4 mg/L. It is worth mentioning that SPSS software results showed that there was no statistically-significant correlation between nitrate and ammonia concentrations in the water samples.

Table 4 shows that no samples exceeded the Palestinian and WHO standard chloride limits of 250 ppm. Chloride at concentrations above 250 mg/L gives salty taste to water, which is objectionable to many people (Shalash 2006). Similarly, none of the tested samples for total hardness exceeded the Palestinian and WHO standard limit of 500 mg $CaCO_3$/L. On the other hand, a high percentage of samples had calcium and magnesium exceeding the Palestinian and WHO standards. The acceptable concentrations of calcium and magnesium are 100 mg/L. Above this concentration; water becomes hard for some industrial and domestic uses. Moreover, high concentrations of magnesium are laxative and cause abdominal problems (Shalash 2006).

The microbiological quality of the collected rainwater was assessed by examination of the common microbial indices. In 95% of the cistern samples, total *Coliform*

Table 5 Sources of water in cisterns in Hebron, Palestine, 2008

Source of water	Percent (%)
Municipality water only	20.0
Rainwater only	22.0
Municipality, rainwater and distribution tanks	5.0
Municipality and rainwater	53.0
Total	100.0

Table 6 Distribution of tested cistern samples for total *Coliforms* (CFU/100 ml) according to their level of contamination and treatment procedure required

Treatment procedure	Percentage of samples (%)	Degree of contamination[a]	Range of total *Coliforms* (CFU/100 ml)
No treatment required	5	0	0–3
Chlorination only	17	1	4–50
Flocculation, sedimentation then chlorination	78	2	51–50,000
Very high contamination, need special treatment	0	3	>50,000

[a] WHO (1993)

(TC) was detected, while faecal *Coliform* (FC) was found in 57% of the tested samples. This was similar to findings by others, studying cisterns in Bani-Kenanah District–Northern Jordan, where 49% of the tested samples tested positive for total *Coliforms* and 17% for faecal *Coliform* (Abo-Shehada et al. 2004). Apparently, this trend is not exclusive to developing countries. Crabtree et al. (1996), in their study on microbiological quality of cisterns in Virgin Islands of USA, reported that 57% of the samples were found positive for total *Coliform* and 36% were positive for faecal *Coliform*. Distribution of cistern water samples according to their level of contamination and treatment procedure required, as based on their total *Coliform* content (WHO 1993), is shown in Table 6, while Table 7 shows the distribution of tested cistern samples for FC (CFU/100 ml) according to their degree of risk (WHO 1996). As can be seen from Table 6, the highest percentage (78%) of samples had a severe degree of contamination for which water needs flocculation, sedimentation then chlorination to become suitable for drinking. As sedimentation occurs, most of the present bacteria co-migrate with the settleable particles. Previous studies have reported the role of microbial partitioning in the water column, with results suggesting that sedimentation is a primary mechanism of microbial removal (Characklis et al. 2005). On the other hand, based on FC data, none of the tested samples for FC was a "high risk", but 57% of them were categorized with "simple" to "moderate risk" and 43% are "no risk" cisterns.

Despite the acceptable chemical quality of the cistern, the presence of microbial indicators makes it unsuitable for drinking, at least without treatment. The two widely used bacterial indicators, total *Coliforms* and faecal *Coliforms*, were detected in the majority of the samples. These bacteria, which can also be found in soils and other natural sources, originate in the feces of humans and warm blooded animals. In

Table 7 Distribution of tested cistern samples for faecal *Coliforms* (CFU/100 ml) according to their degree of risk

Range of faecal *Coliforms* (CFU/100 ml)	Degree of risk[a]	Percentage of samples (%)
0	No risk	43
1–10	Simple risk	33
11–100	Moderate risk	24
101–1,000	High risk	0
>1,000	Very high risk	0

[a] WHO (1996)

Table 8 Cistern owners' awareness to factors that contribute to pollution prevention in rainwater harvesting cisterns

Cistern owner awareness indicator	Percentages of respondents (%)
Owners who clean water collection surface before first season storm	71
Owners who discard water from first season storm	51
Owners who chlorinated their cisterns within the last year	12
Owners who cleaned their cisterns within the last year	12
Owners who breed animals and pets in cistern's vicinity	36
Owners who used water collection surfaces for clothes lines	64
Owners who allow solid waste to accumulate in cistern vicinity	70

order to shed light on the possible causes of this contamination, Table 8 summarizes cistern owners' responses to questions regarding some factors that contribute to pollution in rainwater harvesting cisterns. One explanation of the high percentage of contamination with microbial indicators (TC and FC) in this study is that the percentage of owners who clean their water collection surface before the first storm was only 71%, and those who discard the water from the first storm was only 51%, as shown in Table 8. Rainwater collection process should divert the dirty runoff water from the first few millimeters of rainfalls away from the cistern to avoid contamination (Villarreal and Dixon 2005). In fact, diverting the rainwater of the first storm away from the cistern may not be enough. 71% of respondants in our study indicated that they clean the collection surface and 51% divert the first storm water, but the percentage of contamination with TC and FC is still high. One study in Jordan concluded that even cleaning the surface two times a year may not be sufficient (Rabi and Abo-Shehada 1995). As another example of cistern abuse, 70% of cistern owners frequently allowed solid waste to accumulate in the vicinity of the cistern and only 12% of them cleaned the interior of their cistern within the last year. In addition, 36% and 64% of owners breed animals and pets in the vicinity of the cistern and use water collection surfaces for clothes lines, respectively, which may contribute to the microbiological contamination of the harvested rainwater. Moreover, Table 8 indicates that only 12% of cistern owners have chlorinated their cisterns within the last year, leaving large amounts of harvested water unprotected.

Through statistical correlations (cross tabulation) between the obtained TC and FC readings, on one side, and the seven major factors that contribute to harvested rainwater contamination (as listed in Table 8), on the other side, it was found that there was a statistically significant relationship (chi-square = 116.3, p value <0.05) between *Coliforms* presence and (1) not cleaning the cistern, (2) not cleaning the water collection surface before first season storm, and (3) not discarding the rainwater from the first storm. In addition, there was a statistically significant relationship (p value <0.05) between *Coliforms* presence and both the presence of turbidity and ammonia in the water (chi-square = 2337.0 and 133.9, respectively).

3.3 Remedial Actions

As this study clearly indicates, rainwater harvesting systems are being utilized more frequently in the Hebron city area, with all cistern owners using the harvested water for drinking purposes. Hence, protecting the quality of water in these cisterns is imperative. While most physiochemical quality indicators of the cisterns' water were within acceptable limits, including pH, chloride, hardness, salinity, and nitrate, the latter had an average of 4.2 mg/L, which is indicative of anthropogenic pollution. Along with turbidity, which exceeded the standard limits, these two characteristics (nitrate and turbidity) were found to correlate with a wide-spread deterioration in biological quality of the cisterns water. Faecal *Coliform*s and total *Coliform*s were found in 57% and 95% of the sampled cisterns, respectively. Therefore, the utilization of cistern water without treatment may cause health problems.

A corrective action plan to remedy this situation will stem from the roots of the contamination causes. Based on findings of this study, statistical analyses indicate a strong correlation between biological contamination and owners' practices of not cleaning the cisterns and the rainwater collection surfaces and not discarding water from the first season storm. Additional potential causes, stemming from observed cisterns' management and usage patterns, include the presence of solid waste, animals, and trees in the vicinity of the cistern. They also include the improper use of rainwater collection surfaces, whether using those surfaces for clothes lines or using inappropriate surfaces, such as streets. All these causes can be eliminated via simple actions to be taken by the cistern owners. In this regard, local government and non-governmental organizations (NGOs) can play a key role in promoting awareness among cistern owners. This role could be practiced through awareness campaigns and local media outlets.

A more elaborate engineered remedial action involves the isolation of the cistern's water from sewage, leaking in from nearby cesspits or overflowing sewage pipes. Luckily, a small fraction of cistern owners may have to take this action, since the survey showed that only 16% of cistern owners have cesspits within 20 m of their cistern and only 4% have the cesspit at the same elevation as the cistern. No cesspits were found at a higher elevation than the water cistern. What is more important, however, is that strict guidelines need to be enforced in the future when issuing construction permits to an individual desiring to build a cistern. These guidelines should specify, among other things, distance from nearby cesspits (depending on soil type), type of collection surface to be used, and the material of construction of the cistern. Such guidelines are well established in developed countries. In realization of the fact that meticulously engineered rainwater harvesting cisterns will bear a bigger price tag than haphazardly built ones, an alternative may be to build "community cisterns", where several houses, especially in villages, may share one well-designed large cistern. This will lead to cost sharing while maintaining the essential health and environmental requirements.

4 Conclusions

Rainwater harvesting is being actively used in Hebron city, where dependence on seasonal rain necessitates that water be collected and stored where and when it becomes available. The physiochemical quality of harvested rainwater in Hebron city is reasonably satisfactory with only turbidity and magnesium parameters being detected above the corresponding maximum allowable concentration for drinking purposes. On the contrary, microbial indices (total *Coliforms* and faecal *Coliforms*) were detected in the majority of samples, though at low to medium levels. It is concluded, based on the findings of this work, that the surrounding environment, cistern management practices, and the cistern owners' weak awareness of preventing rainwater contamination are the main factors that contributed to harvested rainwater contamination. Based on the existence of the microbiological contamination indicators in the harvested rainwater, a number of pollution sources were discussed in this paper, which are strongly suggested to be considered as contamination prevention strategies are developed. As a key prevention measure, harvested rainwater should be disinfected (e.g., via chlorination) before usage for drinking purposes.

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