Quality of Drinking Water from Rainwater Harvesting Cisterns of Hebron City and Factors Affecting It

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1- Introduction

An established goal of WHO and its member states is that all people, whatever their stage of development and their social and economic conditions have the right to have access to an adequate supply of safe drinking water (WHO, 1986, 1996, 1997). Water is considered one of the most important and sensitive issues in the Middle East, where increasing water deficiency and 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 in these countries and its associated water demands is expected to place severe pressure on the limited groundwater reserves (Nasserdin et al., 2009).

Rainwater harvesting is of great importance in the socio-economic development of areas where water sources are scarce or where ground-water and surface water are limited or polluted (Appan, 1999; Makoto, 1999; Prinz, 1999; Texas Water Development Board, 2005; Sazakli et al., 2007).

According to the World Health Organization, the per capita minimal amount of water needed for household and urban needs is one hundred liters a day. Due to the chronic water shortage, water consumption in the northern West Bank of Palestine has dropped to one-third this amount. In Nablus and the Southern Hebron Hills, the figure is slightly higher than fifty liters a day. Average per capita consumption throughout the West Bank is 66 liters, two-thirds of the minimal amount needed according to the WHO. These figures include water for livestock, meaning that the water consumed for personal use is even less. Some 20 percent of Palestinians in the West Bank are not connected to a water network. Even in Palestinian towns and villages that have a water network, water supply is not regular most of the year. Water is supplied only some hours of the day, and sometimes on a rotational basis. In distant areas, water supply may be disconnected for days or weeks. Residents of communities with water networks hooked up to Mekorot report that the company discriminates against them, reducing water supply to Palestinian residents to enable it to meet the increased demand in the settlements (B'Tselem, 2008). Of the remaining served by water distribution networks, 50% suffer from partial water loss (via leakage) in the network or low pumping pressure (MOPIC, 1996; GTZ 1996; Al-Khatib and Orabi 2004; Abusafa et al., 2009).

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 water tank, even though the first ‘‘heavy’’ rainfall is discarded, a practice followed globally (UNEP, 2002; Spinks et al., 2003; Villarreal and Dixon, 2005; Sazakli, 2007).

The concept of using indicator organisms as signals of faecal pollution is a well established practice in the assessment of drinking-water quality (Gleeson and Gray, 1997; Hunter, 2003; WHO, 2004; Heyworth et al., 2006; Sazakli et al., 2007). Total *Coliforms* are a non-specific indicator of fecal contamination and can originate from a number of different plant and soil sources (Al-Khatib and Orabi, 2004).

The risk of microbiological contamination of drinking water during collection and storage in the home has long been recognized (VanDerslice and Briscoe, 1995; Lye, 2002; Thomas et al., 2003; Gerba and Smith, 2005). Factors such as site characteristics, interval duration, and UV intensity would all impact on the survival of micro-organisms on the catchment surface and their viability in the run-off (Evans et al., 2006). Septic systems have been noted as one of the largest sources of pollution in the suburbs (along with construction erosion) through failing systems and subsurface movement of pollutants (Novotny, 1991; Gannon et al., 1996, Griffith et al., 1999). Water pollution induced by storm runoff from different roofing materials is considered a non point source (Chang et al., 2004).

The parameters (pH, TDS, TH, alkalinity, free available chlorine, sulfate and ammonia-N) could influence drinking water flavor, while the turbidity and coliform group 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).

The variation of roof runoff quality seems to reflect differences in roofing materials, age and management, the surrounding environment, season, storm duration and intensity, and air quality conditions of the region (Chang et al., 2004).

The aims of this study were to reduce or eliminate the physiochemical and microbiological quality of the harvested rainwater being used for domestic and drinking purposes through documenting the possible contaminants of the harvested rainwater and to propose improvements of the rainwater harvesting system, so as to minimize the potential health risks.

2. Materials and methods

2.1 Study Area

Hebron city is located in the southern part of West Bank of Palestine. It is located at a distance of 36 kilometers south of Jerusalem. Its population was projected to be 173191 at mid 2007 (Palestinian Central Bureau of Statistics, 1999). Hebron has a Mediterranean climate characterized by long, hot, dry summers and short, cool, rainy winters. It is characterized by a relatively rainy season from November to April and very dry weather for the rest of the year. Table 1 summarizes the monthly distribution of meteorological conditions in Hebron city during the year 2007.

The area of Hebron city is about 25 square kilometers, number of households was 17055 in 2007, 65% of these households have cisterns with a total volume of 1012135 m^3.

85% of these households are connected to sewerage system as shown in table 1. The stored water in cisterns is either rainwater, municipal water or mixed rainwater and municipal water from a network.

2.2 Water sampling locations

Using GIS as a tool, Hebron city was divided to 25 segments each one with an area of one square kilometer. The coordinates of the sampling sites were taken from GIS database of Hebron Municipality and the sampling sites map was created using Arc-View GIS version 3 with the help of the GIS unit at Hebron municipality.

Table 1.

Monthly distribution of meteorological conditions in Hebron city during the year 2007*

Element	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
MeanMaxTemp.	10.2	11.5	14.6	19.6	23.6	25.9	27.2	27.2	26.0	23.2	17.5	12.1
MeanMin.Temp.	4.0	4.7	6.5	9.9	13.2	15.8	17.0	17.0	15.9	14.0	9.9	5.6
Absolute Max. Temp.(C°)	21.4	21.0	23.6	32.6	34.0	33.5	38.0	33.4	34.6	31.6	31.6	22.0
Absolute Min. Temp. (C°)	-1.0	-3.0	-0.5	1.0	6.5	10.0	13.0	12.0	12.0	9.0	2.0	-0.4
Mean Temp. (C°)	7.1	8.1	10.5	14.7	18.4	20.8	22.1	22.1	20.9	18.6	13.7	8.8
Mean Wind Speed (Km/h)	12.4	12.8	12.6	11.5	9.3	9.3	9.2	8.7	8.1	8.0	8.8	10.1
Mean Atm. Pressure (mbar)	903	902	901	901	901	900	899	899	902	903	904	904
Mean Sunshine Duration (h/ day	4.7	4.8	6.4	8.1	9.0	8.3	9.6	10.9	10.3	9.8	7.0	4.7
Mean RH %	74	72	66	55	48	51	57	60	62	59	64	73
Total Rainfall (mm)	133.6	141.6	91.7	25.4	4.7	0.5	0.0	0.0	1.6	14.6	66.7	115.5
Total Evaporation (mm)	65	81	93	139	166	200	221	225	157	112	87	62
Total PET (mm)	23	25	41	67	97	106	110	106	94	87	54	30

* (Palestinian Metrological Department, 2007).
(Max = maximum, Min=minimum, Tem. = temperature, Atm. = atmospheric, RH= relative humidity, PET = potential evapotranspiration)

Table 2.

General information about households in Hebron city, 2007*.

Total number of household	17055
Number of household with cistern	11074
Number of household with cistern & connected to sewerage system	9412
Total volume of cisterns (m^3)	1012135
Average volume of cistern ($m^{3)}$	91.4

Percentage of household connected to sewerage system	85%
Percentage of household with cistern	65%

*Hebron Municipality, GIS Unit, 2007.

During the period from December 11, 2007 until April 22, 2008, the 100 water samples were collected from the cisterns in Hebron city with a confidence interval of 95% and confidence level as 10% (Creative Research Systems, 2003) covering a wide range of environmental conditions surrounding the cisterns. At each sampling site, water temperature, electrical conductivity, total dissolved substances, pH, salinity and turbidity were measured in the field using EC 10 pH meter and CO150 conductivity meter and Hach 2100 P Turbidimeter (Hach Company, Loveland, Columbia-USA,1996) using the standard procedures (Tortora et al., 2003, APHA, 1998).

Samples were collected directly from the cistern at about half meter below water level into individual sterile 1000ml glass bottles, or two sterile 330ml glass bottles (labeled by a number that was corresponded to the number given in the questionnaire) and transported to the laboratory in a chilled-cold box (Abo-Shehada et al., 2004). The containers used were in accordance to the 18th edition of Standard Methods for the Examination of Water and Wastewater (Greenberg et al., 1992). 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^0 for two hours in a dry oven.

Samples were then transported to the Water Engineering Laboratory- Birzeit University, Birzeit-Palestine, within 24 hours after collection, samples were kept at $4C^0$ in a refrigerator at night and in an ice box during transportation from Hebron to Birzeit University. In addition, for each cistern sampled, 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 standard procedures (APHA 1998; Tortora et al., 2003).

Also, for each cistern sampled, data was obtained from the cistern owner, using a pre-prepared semi structured questionnaire, personal data, cistern age, cistern capacity, source of water in the cistern, vicinity and elevation with respect to nearby septic tanks, if any, environment surrounding the cisterns, water disinfection frequency and method, water collection methods, and cleaning frequency, among other factors.

Data obtained from the cisterns owners' questionnaire were coded and entered into the computer utilizing SPSS 13 (Statistical Package for Social Sciences) software. The data was analyzed and cross-tabulated. The main test used in the statistical analysis of the data is the Chi-square test.

3. Results and Discussion:

3.1 General information on rainwater harvesting cisterns in Hebron city

Table 3 summarizes general information on rainfall harvesting cisterns in Hebron city.

About 46% of the cisterns were more than 20 years old, and 11% were one to five years old. In terms of cistern capacity, the highest percentage of cisterns was more than 100 m3, while the lowest percentage was of those that were less than 20 m^3. This depended mainly on different factors: presence of enough space to construct the cistern, economic status of the family, and finally family size. Old cisterns are more vulnerable to leakage of polluted water into them through cracks (Abusafa et al., 2009). The age of the cistern is an indicator for the importance of cisterns during the past period and still important nowadays as rainwater harvesting is critical for meeting basic water needs.

Typically, Hebron residents divert rainwater into cisterns and use this water throughout the dry season. Each cistern holds an amount of water enough to satisfy minimal requirements during the rainy season and then for an additional three to four months during the dry season (Hunt, 2001). The study shows that a significant number of cisterns (27%) were constructed within the last 10 years. It is expected that the number of rainwater harvesting cisterns is going to increase as a result of natural increase in population, water shortage, and agricultural and industrial developments needs as Hebron city is considered as one of the most important industrial areas in the West Bank of Palestine.

In terms of the most frequent uses of cistern water, the highest percentages (100.0% and 97%) were for drinking and cleaning and laundry respectively. Sometimes, the harvested water is used for agricultural purposes for irrigating plants and trees surrounding the household and for animal drink purposes. This 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 the house roofs. Other owners use roof, house yard, garden and the street for rain water harvesting. Such surfaces are mostly not suitable for collecting water as they are contaminated by different contaminants from different sources. For example, on the streets the human activity increases and the amount of contaminants deposited on the streets increases (Nolde, 2007). Such contaminants include heavy metals and hydrocarbons from vehicles' exhausts and leakage from engines, organic chemicals such as pesticides, oil, gasoline and grease, hydrocarbons and animal waste, sand, soil, silt and others. While all human activities can be a source of some contaminants, certain activities are particularly large contributors.

Table 4 summarizes some of the environmental conditions surrounding the rainwater harvesting cisterns. The percentage of cisterns within 25 meters of the nearby trees is 30.0%. Trees can be considered as a source of cisterns' water contamination as they provide a suitable habitat for birds and pets, which may bring their feces in contact with cistern water (Vida et. al. 2005; Abusafa et al., 2009).

One can see that 66.0% of the households of cisterns' owners were connected to municipality sewerage network, while 34.0% have cesspits. Nine percent of the respondents surveyed in this study reported that there was a sewage flood from a sewerage network in the vicinity of their cisterns. Sanitary sewer overflows and the presence of cesspits in the vicinity of cisterns are two significant pollutant sources to cistern harvested water. Sanitary sewer overflows occur when sanitary sewers, often because of leaks and cracks, become surcharged in wet weather and overflow, often through manholes or into basements. Sanitary sewer overflows are more of a problem with older systems and in areas with multistory buildings, as in previous times, the designers of sewerage networks did not take that into consideration. The underground cesspits that are usually used in the Palestinian localities where sewerage networks are not available have high to moderate threat level to pollute cisterns. Cesspits and sewer lines connecting households with cesspits represent potential sources of nitrates, chlorides, bacteria and viruses. In addition, if improperly used, such as for disposal of paints, solvents, petroleum products and other hazardous waste, they could be a source of organic compounds.

Table 3. Surveyed sample distribution (numbers and percentages) based on general information on rainwater harvesting cisterns in Hebron city

General information	Answers							
Cistern capacity (m^3)	Less than 20	20-40	41-60	61-80	81-100	More than 100		total
	6 (6.0)	17 (17.0)	8 (8.0)	16 (16.0)	18 (18.0)	35 (35.0)		100 (100.0)
Cistern age (year)	1-5	6-10	11-15	16-20	More than 20			
	11 (11.0)	16 (16.0)	11 (11.0)	16 (16.0)	46 (16.0)			100 (100.0)
Most frequent uses of cistern water	Drinking	Agricultural uses	Cleaning and laundry					
	100 (100.0)	42 (42.0)	97 (97.0)					
Type of cistern water collection surface	House roof	House yard or garden	Street	house roof, house yard, and garden and street	House roof and house yard	House roof and street	Hous e yard and street	other	
	68 (68.0)	1 (1.0)	2 (2.0)	1 (1.0)	5 (5.0)	2 (2.0)	1 (1.0)	20 (20.0)	100 (100.0)

Table 4. Environmental conditions surrounding the rainwater harvesting cisterns

Environmental condition		**Number of respondents**	**Percentages of respondents (%)**
Number of cisterns within 25 meters of trees		30	30.0
Household wastewater disposal method	Municipality sewerage network	66	66.0
	Cesspit	34	34.0
Occurrences of sewage flood from sewerage network in the vicinity of the cistern	Yes	9	9.0
	No	57	57.0
Cistern level with respect to cesspits	higher	30	30.0
	the same	4	4.0
Distance between cesspit and cistern (m)	< 20	16	16.0
	> 20	18	18.0
Last time of cesspit evacuation (year)	Never evacuated	18	18.0
	<1	8	8.0
	1-5	8	8.0

According to cisterns' owners, 4% of them mentioned that the cistern level was at the same level with respect to the cesspit which increases the risk of pollution. In addition, 16% of them mentioned that the distance between cesspit and cistern is less than 20 meters. Most of the cesspits are not insulated and water is allowed to diffuse through the soil to allow for more tank capacity before tank emptying is needed. That is why 18.0% of the cistern owners surveyed in this study were found to have their cesspits never evacuated. If a nearby water cistern exists, the pollutants from the septic tanks can diffuse into the water cistern through cracks.

3.2 Physiochemical and microbiological rainwater quality

The results of the physiochemical and microbiological analysis of the water samples and related Palestinian Standard Institution (PSI) (2004) and WHO (2004) guidelines are presented in Table 5. The pH values of the collected rainwater ranged from 7.32 to 8.97 with a mean value of 8.16. At this pH value the water is alkaline so unfavorable reactions will not occur (Zhu et al., 2004). Rainwater had low–mean values for conductivity (449.52 μScm^{-1}) and low–mean level Chloride (42.27 ppm). The highest value of hardness measured in rainwater was 292 mgl^{-1} $CaCO_3$ and the mean value was 159.20 mgl^{-1} $CaCO_3$. The results of temperature, salinity and total dissolved substances are below the maximum contaminant levels established by Palestinian and WHO standards. Since the water is from rain origin, not groundwater, 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 were with more than 5 NTU which exceeds both Palestinian and WHO standards. The results of nitrate ranges 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. Concentrations over 3 mg/L nitrate nitrogen are usually considered indicative of anthropogenic pollution (Madison and Brunett, 1985, Kross et al., 1993). The results of ammonia ranges from 0.0 to 13.3 mgl^{-1} with a mean value of 1.4mgl^{-1}. 35.0% of the tested rainwater samples exceeded 0.5 mg l^{-1} which is the EU standard limit. It is worth mentioning that there was no statistical significant correlation between nitrate and ammonia. The results of nitrate of this study are consistent with two studies of water quality of cisterns in West Bank (Awadallah, 2004; Dawod, 2008) that no results of nitrate exceeds the Palestinian and WHO standard limits.

No results of chloride exceeded the Palestinian and WHO standard limits of 250 ppm. The chloride concentration in cisterns water was low which indicate that there was no intrusion of wastewater into cisterns; this is supported by good construction of cisterns in Hebron city. The concrete may protect the reservoir better from being contaminated with the wastewater leaking from the adjacent seepage pit (Abo-Shehada et al., 2004). Chloride at concentrations above 250mg/L gives salty taste to water, which is objectionable to many people (Shalash, 2006).

None of the tested samples for total hardness exceeded the Palestinian and WHO standard limit of 500 mg/L as $CaCO_3$. High percentage of calcium and magnesium exceeds the Palestinian and WHO standards which may have negative impacts on the people's health.

Table 5. Physiochemical and microbiological analysis of the rainwater

	Range	Mean	Standard Deviation	Samples above MAC [a] (%)	PSI (2004) Guidelines	WHO (2004) Guidelines
pH	7.32 - 8.97	8.16	0.276	4.0	6.5-8.5	6.5-8.5
Temp (C^0)	9.80 - 26.00	16.78	3.445		NA [b]	NA
Conductivity (μScm^{-1})	129 - 802	449.52	184.337	0.0	Up to 2000	Up to 2000
Nitrates (mg l^{-1})	1.50 - 7.00	4.18	1.232	0.0	Up to 10 as NO3-N	Up to 10 as NO3-N
Ammonium (mg l^{-1})	0.00 - 13.30	1.40	2.567	35.0	NA [c]	NA
Chloride (mg l^{-1})	13.40 - 134.00	42.27	21.886	0.0	Up to 250	Up to 250
Hardness (mg l^{-1} $CaCO_3$)	20.00 - 292.00	159.20	86.114	0.0	500	NA
Alkalinity (mg l^{-1} CaCO3)	16.0 - 346.0	154.79	68.855	0.0	400	NA
Calcium (mg l^{-1})	16.00 - 172.00	94.64	42.107	47.0	Up to 100	Up to 100
Magnesium (mg l^{-1})	0.00 - 212.00	64.60	51.569	32.0	Up to 100	Up to 100
Salinity (%)	0.10 - 0.40	0.22	.0885	0.0	Up to 1.0	Up to 1.0
Total dissolved solids (mg l^{-1})	62.00 - 384.00	216.18	89.882	0.0	Up to 500	Up to 500
Turbidity (NTU)	0.34 - 113.00	7.45	16.491	24.0	Up to 5.0	Up to 5.0
Total *Coliforms* (CFU/100 ml)	0 - 2000	1031.32	914.592	95.0	0-3	0
Faecal *Coliforms* (CFU/100ml)	0 - 98	8.80	16.625	57.0	0	0

[a] MAC: Maximum Allowable Concentration [b] NA= Not Available [c] MAC = 0.5 mg l^{-1} (98/93/EU directive)

The acceptable concentrations of calcium and magnesium are 100 mgl^{-1}, above this concentration; water becomes hard for some industrial and domestic uses. High concentrations of magnesium act as a laxative and cause abdomen problems (Shalash, 2006). According to Ziadat (2005) in his study about cistern drinking water quality in Al-Karak Province, none of the chemical parameters (calcium, magnesium, chloride, sodium, potasium, bicarbonate, sulphate, nitrate, pH and electrical conductivity) tested from storage tanks water exceeded the WHO and Jordanian standards.

The microbiological quality of the collected rainwater was assessed by examination of the common microbial indices. In 95.0% of the rainwater samples, total *Coliforms* (TC) were detected, while faecal *Coliforms* (FC) were found in 57.0% of the tested samples. The percentages of water samples contamination of this study are higher than results obtained by Abo-Shehada et al. (2004) of cisterns in Bani-Kenanah District –Northern Jordan, as 49% of the tested samples were contaminated with total *Coliforms* and 17% for faecal *Coliforms*. Canadian private water supplies may pose a risk to public health; numerous studies report such water supplies in excess of the minimal acceptable standards for microbial and chemical contamination, and an estimated 45% of all waterborne disease epidemics in Canada involve non-municipal systems, largely in rural or remote areas (Yassin et al., 2006). Crabtree et al., 1996 in their study about microbiological quality of cisterns in Virgin Islands of USA reported that fifty-seven percent of the samples were positive for total *Coliforms* and 36% were positive for fecal *Coliforms* which are lower than the results of this study.

Distribution of rainwater tested samples according to their level of contamination and treatment procedure required is shown in table 6, while table 7 shows the distribution of rainwater tested samples for FC (CFU/100 ml) according to their degree of risk. As can seen from table 6, the highest percentage (78%) of degree of contamination of tested rainwater with TC was the second, and water needs flocculation, sedimentation then chlorination to make suitable for drinking. As sedimentation occurs into the water tank, 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). None of the tested samples for FC was with high risk and 57% of them were with simple to moderate risk and 43% were with no risk.

Despite the acceptable chemical quality of the rainwater, the presence of microbial indicators makes it unsuitable for drinking, at least without any treatment. The two widely used bacterial indicators, total *Coliforms* and faecal *Coliforms* were detected in the majority of the samples. These bacteria, which can be found in soils and other natural sources, originate in the feces of humans and warm blooded animals. Table 8 summarizes cistern owners' awareness to some factors that contribute to pollution prevention in rainwater harvesting cisterns. 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 water tank, even though the first ''heavy'' rainfall is discarded, a practice followed globally (Spinks et al., 2003; Villarreal and Dixon, 2005). This explains the high percentage of contamination with microbial indicators (TC and FC) in this study as, the percentage of owners who clean water collection surface before first flush was 51%, and those who discard first flush was 71% as shown in table 8. Similar studies have been performed in different countries (Zhu et al., 2004; Sazakli, 2007).

In general, the quality of rainwater in other regions is worse than in Hebron city and varies depending on the atmospheric pollution of the individual area, the proximity to pollution sources and the level of cleaning and attendance. In many cases, the rain is acid with reported pH values starting at 4.17 (Mantovan et al., 1995, Chang et al., 2004). In this pH range, the leaching of various substances (metals) from the collection surfaces is promoted and deteriorates the quality of harvested rainwater. The presence of microbial indicators and pathogens has been found to vary greatly with reported counts up to thousands CFU/100ml (Simmons et al., 2001; Zhu et al., 2004).

In our study, the microbial indicators were found in high numbers, and in a high percentage of the samples. Apparently, in the examined area of Hebron city there are some prime sources of high microbial load. For example, only 30% of cistern owners frequently cleaned solid waste from cistern vicinity to remove dust and debris and only 12% of them cleaned the interior of their cistern within the last year so as to maintain the quality of collected rainwater as high as possible. In addition, 36% and 64% of them breed animals and pets in cistern vicinity and used water collection surfaces for clothes lines respectively. This contributes to the microbiological contamination of the harvested rainwater. Collection processes should divert the very dirty runoff from the first few millimeters of rainfalls away from the tanks to avoid contamination (Villarreal and Dixon, 2005). It is worth mentioning that only 12% of cistern owners who chlorinated their cisterns within the last year. This means that disinfection strategies are absent to the stored rainwater. They should be found and applied to improve its microbiological quality.

Through the cross tabulation between TC and FC and the different factors that contribute to harvested rainwater contamination, it was found that there was a statistically significant relationship (p-value <0.05) between TC and the last time of cleaning the cistern, and situation of the door of cistern whether opened or closed; and FC and both of cleaning water collection surface before first flush, and discarding first flush respectively. In addition, there was a statistically significant relationship (p-value <0.05) between TC and electric conductivity, salinity, total dissolved solids, turbidity, ammonia, and alkalinity.

Table 6. Distribution of rainwater tested samples for TC ((CFU/100 ml) according to their level of contamination and treatment procedure required.

Range of TC	Degree of Contamination *	Number of tested samples and (%)	Treatment Procedure
0 -3	0	5 (5.0%)	No treatment required
4 - 50	1	17 (17.0%)	Chlorination only
51 – 50000	2	78 (78.0%)	Flocculation, Sedimentation then Chlorination
>50000	3	0 (0.0)	Very high contamination, need special treatment

*(Al-Khatib and Orabi, 2004).

Table 7. Distribution of rainwater tested samples for FC (CFU/100 ml) according to their level of contamination and degree of risk.

Range of FC	Degree of Risk*	Number of tested samples and (%)
0	No Risk	43 (43%)
1 – 10	Simple Risk	33 (33%)
11 – 100	Moderate Risk	24 (24%)
101 – 1000	High Risk	0 (0 %)
> 1000	Very High Risk	0 (0 %)

*(Al-Khatib and Orabi, 2004).

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

Owners' awareness indicator	Number of respondents	Percentages of respondents (%)
Number of owners who clean water collection surface before first flush	71	71.0
Number of owners who discard first flush	51	51.0
Number of owners who chlorinated their cisterns within the last year	12	12.0

Number of owners who cleaned their cisterns within the last year	12	12.0
Number of owners who breed animals and pets in cistern vicinity	36	36.0
Number of owners who used water collection surfaces for clothes lines	64	64.0
Number of owners who frequently cleaned solid waste from cistern vicinity	30	30.0

4. Conclusions

Rainwater harvesting is being actively used in Hebron city as well as many developing countries where dependence on seasonal rain necessitates that water be collected and stored where and when it becomes available. The chemical quality of harvested and stored rainwater in Hebron city is quite satisfactory with only calcium 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 numbers. In general, examination of the physicochemical and microbiological composition of the rainwater is a prerequisite before its utilization for drinking purposes. It is expected that the surrounding environment and the cistern owners low awareness of preventing rainwater contamination are the main two factors that contributed to harvested rainwater contamination. To ensure harvesting of good quality rainwater, collection processes should divert the very dirty runoff from the first few millimeters of rainfalls away from the cisterns to avoid contamination. Thus, the rainwater is only diverted into the cisterns after the catchment area and cistern interior have been washed off. In addition, residents will need to be educated about cleaning and maintaining all components of the system in addition to the investments in equipment and education. Based on the existence of the microbiological contamination in the harvested rainwater, the possible pollution sources discussed in this paper must be considered as the prevention options while faecal *Coliforms*, as a simple and inexpensive indicator of rainwater quality, are to be examined frequently.

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