Quality assessment of roof-harvested rainwater in the West Bank, Palestinian Authority

A. K. Daoud, K. M. Swaileh, R. M. Hussein and M. Matani

ABSTRACT

Rain harvesting is becoming more common in the Palestinian Territories as a result of drinking water scarcity. Although it might pose serious human health risk, this water is being consumed without treatment in many areas of the West Bank. The present study evaluates the physicochemical and microbial quality of harvested rainwater that is used as potable water in the West Bank. Samples from roof-harvested rainwater storage tanks ($n = 42$) were collected in summer (SS) 2006/winter (WS) 2007. Physicochemical parameters measured were: temperature, pH, electrical conductivity, salinity, total dissolved solids, turbidity, nitrate, copper and lead. With few exceptions, all these parameters were within WHO guideline values. All samples (100%) were found to contain coliforms and to be heavily contaminated with heterotrophic bacteria. About 67% of all samples were contaminated with fecal coliforms. Specific PCR technique confirmed the presence of five pathogenic microorganisms that can be ordered according to their prevalence as: *Citrobacter* (83%) > *Acinetobacter* (78%) > *Aeromonas* (52%) > *Pseudomonas* and *Campylobacter* (7%). Prevalence of microorganisms in SS was higher than in WS. Although the physicochemical quality of most harvested rainwater samples was in accordance with WHO guidelines for drinking water, stored rainwater was significantly contaminated with bacteria resulting in significant human health risk from infectious diseases.

Key words | chemical, harvesting, microbial, quality, rainwater, roof

A. K. Daoud
K. M. Swaileh (corresponding author)
R. M. Hussein
M. Matani
Department of Biology and Biochemistry,
Birzeit University,
PO Box 14, West Bank,
Palestinian Authority
E-mail: *kswaileh@birzeit.edu*

ABBREVIATIONS AND NOTATIONS

CFU	colony-forming unit
DNA	deoxyribonucleic acid
EC	electrical conductivity
FC	fecal coliform
HPC	heterotrophic plate count
NTU	nephelometric turbidity unit
PCR	polymerase chain reaction
SS	summer samples
STEX	shiga toxin-producing *E. coli*
TC	total coliform
TDS	total dissolved solids
WS	winter samples

INTRODUCTION

Water scarcity is becoming one of the greatest problems facing the world today. Ongoing drought and the increasing demand of growing populations have reduced water reservoirs (Sazakli *et al.* 2007). As a result, alternative sources of water supply, such as rainwater harvesting, are becoming increasingly important (Meera & Ahammed 2006; Schets *et al.* 2010). Rainwater harvesting is the capture, diversion and storage of rainwater for a number of different purposes including landscape irrigation, drinking and domestic use, aquifer recharge, and storm water abatement (TWDB 2005).

The depletion of groundwater sources, poor quality of some groundwater and surface waters, high tap fees

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for isolated properties, inadequate tap water supply, flexibility of rainwater harvesting systems, and modern methods of treatment provide excellent reasons to harvest rainwater for domestic use (TWDB 2005; Radaideh *et al.* 2009). The scope of rain harvesting, method, technologies, system complexity, purpose and end uses vary from rain barrels for garden irrigation in urban areas, to large-scale collection of rainwater for all domestic uses. The roof of a building or house is the obvious first choice for catchment.

Water quality from different roof catchments is a function of the type of roof material, climatic conditions, the surrounding environment and the storage time of harvested water (Vasudevan 2002; WHO 2006). Hoque *et al.* (2006) found that the contamination rate for water samples from covered household storage containers was significantly lower than that from uncovered containers. Sazakli *et al.* (2007) studied the quality of rainwater harvested for drinking purposes in Greece. They found that all rainwater samples were within the guidelines for chemical parameters. As far as microbiological quality is concerned, total coliforms, *Escherichia coli* and enterococci were detected in the rainwater samples, although they were found in low concentrations. Evans *et al.* (2005) studied roof run-off water at an urban housing development in Newcastle, on the east coast of Australia. They found that airborne microorganisms represented a significant contribution to the bacterial load of roof water. Efe (2006) assessed rainwater samples harvested from catchment roofs in six rural communities of Delta State in Nigeria and found that most physicochemical and biological characteristics of rainwater samples were generally below the WHO threshold. In addition, a number of studies (Gould 1999; Lye 2002; Evans *et al.* 2005) have identified various pathogens including *Salmonella, Shigella, Vibrio, Clostridium, Legionella, Campylobacter, Cryptosporidium* and *Giardia* spp. in samples taken from rainwater tanks.

Contamination of rainwater with microbes and the possible health risks caused by these microbes necessitated the development of accurate and reliable tests on harvested rainwater to evaluate its suitability for human consumption. This led to the development of the 'index organisms' concept as a signal of fecal pollution (WHO 2008). The predominant fecal index organism is *E. coli*.

In the West Bank, water scarcity and interrupted municipal water supply are common especially in summer. According to UNESCO (2005), the water supply–demand gap in the West Bank is estimated to reach a deficit value of 212 million cubic meters (MCM)/year in 2010. This is expected to rise to 260 MCM/year in 2015. In addition, municipal water prices are high and many villages and isolated populations lack water distribution systems. As a result, rain harvesting is becoming a common practice in most regions of the West Bank. Many municipalities refuse to approve building plans that do not include rain harvesting wells. Roof-harvested rainwater is mostly used for household purposes and mainly as a source of drinking water. However, the quality of harvested rainwater receives very little attention and, in most cases, harvested rainwater is consumed without any treatment. Besides, many people believe that rainwater is a source of clean water that does not need to be treated.

Therefore, the present study aimed at evaluating the physicochemical and microbial quality of rainwater harvested in the West Bank through roof catchment systems. The physicochemical parameters included: temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, turbidity, nitrate, copper and lead. The microbial quality tests included: total coliform (TC), fecal coliform (FC) and heterotrophic plate count (HPC). In addition, molecular biology techniques were used to detect the presence of the following 11 frank or opportunistic pathogenic bacteria: *Acinetobacter, Citrobacter, Aeromonas, Pseudomonas, Mycobacterium*, *Shigella, Legionella, Salmonella, E. coli* (STEX), *Helicobacter* and *Campylobacter.*

METHODS

The study area and water sampling

Harvested rainwater samples were collected from storage tanks in different locations in the West Bank. Sampling of harvested rainwater was performed in August (summer sample 'SS') 2006 and in March (winter sample 'WS') 2007. Each season, a total of 21 covered storage tanks were sampled using sterile glass bottles. Samples were taken from the middle of the storage tank. After taking some *in situ* measurements, samples were transported in

an ice box directly to the laboratory for chemical and microbiological analysis.

Chemical analysis

Temperature, pH, turbidity, TDS, EC and salinity levels in harvested rainwater were measured *in situ*. Temperature and pH were measured using sensION1 pH/mv meter (HACH Company, Loveland, CO, USA), turbidity was tested using a portable turbidity meter (HACH Company), and TDS, EC and salinity were measured using sensION4-band conductivity cell (HACH Company). Nitrate levels were measured using a capillary ion analyzer (Millipore Water Instruments, USA) and levels of copper and lead were measured using AAnalyst 600 atomic absorption spectrophotometer (Perkin Elmer, USA).

Microbiological analysis

TC, FC and HPC were determined in all rainwater samples by the membrane filtration technique as described in Standard Methods (APHA/AWWA/WEF 2005). Media used for these tests were Endo broth, mFC broth and m-HPC agar (Difco Laboratories, Detroit, MI, USA) for TCs, FCs and HPC organisms, respectively.

The presence of six pathogenic (*Campylobacter*, STEX *E. coli*, *Helicobacter pylori, Legionella, Shigella* and *Salmonella*) and five opportunistic (*Citrobacter, Acinetobacter, Aeromonas, Pseudomonas aeruginosa* and *Mycobacterium*) bacteria in harvested rainwater samples was tested using specific polymerase chain reaction (PCR) as described below.

DNA extraction

A 100 mL aliquot from each rainwater sample was filtered using a 0.45 μm pore size membrane filter (Sartorius, Goettingen, Germany) and enriched overnight in peptone water (Merck, Darmstadt, Germany). Thereafter, bacteria were collected by centrifugation and the pellet obtained was used for DNA extraction.

The DNA extraction method was according to Oude-Elferink *et al*. (1997) with minor changes as follows: the bacterial pellet was dissolved in 400 μL sterile TRIS EDTA (TE) (10 mmol/L TRIS/HCl + 1 mmol/L EDTA, pH = 8) in a 2.0 mL tube. Then, 200 μL TRIS/HCl buffered phenol, pH = 8, were added to the tube and vortexed for 1 min. The aqueous phase was separated by centrifugation for 10 min at maximum speed (in a pre-cooled centrifuge) and transferred to a new sterile tube. Thereafter, the aqueous phase was extracted with 500 μL phenol/chloroform/isoamylalcohol 25:24:1 (v:v:v) and the DNA was separated from proteins by another centrifugation as above. The upper layer was extracted again with phenol/chloroform/isoamylalcohol 25:24:1 (v:v:v), centrifuged and extracted with 500 μL chloroform/isoamylalcohol 24:1 (v:v). After that, another centrifugation for 5 min at maximum speed was carried out. The water phase was transferred to a new tube and the volume adjusted to 0.5 mL. Consequently, DNA was precipitated with 1 mL of 96% ice-cold ethanol and 40 μL sodium acetate (3 mol/L, pH = 5.2) and stored overnight at −20 °C. After storage, DNA samples were subjected to centrifugation for 15 min at maximum speed (in a pre-cooled centrifuge), then, the pellet was washed with 70% ice-cold ethanol, dried and dissolve in 100 μL TE buffer.

For *Legionella* detection, a volume of 500 mL was filtered and enriched in buffered charcoal yeast extract BBL BCYE Agar Base (Becton, Dickinson & Co, Franklin Lakes, NJ, USA) (Presti *et al*. 1998). For *H. pylori* detection, samples were filtered as above and enriched in blood agar base (Oxoid, Basingstoke, UK). Thereafter, DNA was extracted as described above (Flanigan & Rodgers 2003).

All *Helicobacter* strains were grown on trypticase soy agar plates with 5% sheep blood under microaerophilic growth conditions using a BBL CampyPak Plus microaerophilic system (McDaniels *et al*. 2005).

PCR reaction

The PCR amplification reaction volume was 50 μL and contained 0.2 mM dNTPs, 1.5 mM $MgCl_2$, 1.25 U Taq DNA polymerase (Promega, Madison, WI) and 0.4 μM of one of the primers listed in Table 1. The thermocycler used was the Hybaid Omni-Gene thermocycler. The PCR product was separated in 1.5% agarose, stained with ethidium bromide, visualized with UV transluminator and documented with Kodak Polaroid Gelcam (UK).

Table 1 | Primers used to detect microorganisms by PCR

Microbe	Primer sequence (5′ → 3′)	Product band	Reference
Shigella	H8: TTCCTTGACCGCCTTTCCGATAC; H15: CCGGTCAGCCACCCC	620 bp	Theron *et al.* (2000)
Legionella	LEG1: TCATGAGGAATCTCGCTG; LEG2: TGGCTTCTTCCAGCTTCA	900 bp	Persing *et al.* (1993)
$STEX_1$	F: TAAATCGCCATTCGTTGACTAC; R: GAACG CCCACTGAGATCATC	180 bp	Paton & Paton (1997)
$STEX_2$	F: GCACTGTCTGAAACTGCTCC; R: TCGCCAGTTATCTGACATTCTG	255 bp	Paton & Paton (1997)
Campylobacter	F: ATCTAATGGCTTAACCATTAAAC; R: GGACGGTAACTAGTTTAGTATT	857 bp	Denis *et al.* (1999)
Salmonella	139: GTGAAATATCGCCACGTTCGGGC AA; 141: TCATCGCACCGTCAAAGGAACC	284 bp	Rahn *et al.* (1992)
Citrobacter	Crt4F: TTGGCGTCCAGCGCATTCA; Crt4R: AATTCCAGCCTTCGGCAAACG	100 bp	Kaclíkova *et al.* (2005)
Acinetobacter	rA1: CCTGAATCTTCTGGTAAAAC; rA2: GTTTCTGGGCTGCCAAAC TTAC	425 bp	Krawczyk *et al.* (2001)
P. aeruginosa	F: TTCCCTCGCAGAGAA AACATC; R: CCTGGTTGATCAGGTCGATCT	339 bp	Khan & Cerniglia (1994)
Mycobacterium	65 kDaf2: TAGGTCGGGACGGTGAG; 65PCR kDar3: TTGCGAAGTGATTCCTCC	Var	Tobler *et al.* (2005)
H. pylori	F: GCTAAGAGATCAGCCTATGTCC; R: GCGCAATCAGCGTCAGTAATG	520 bp	Hoshina *et al.* (1990)
A. hydrophila	F: GCAGTGGTTTATGACAAAGACG; R: TTAGAAGTTGTATTGCAGGGC	1,008 bp	Khushiramani *et al.* (2006)

RESULTS AND DISCUSSION

Chemical quality of rainwater

Results of the physicochemical parameters of harvested rainwater are summarized in Table 2. The mean temperature for all water samples was 20.2 °C and the mean temperature in SS exceeded that for WS by 7.5 °C. Cool water is generally more palatable than warm water. Water temperature affects a number of inorganic constituents and chemical contaminants that may affect the taste of drinking water, and high water temperature enhances the growth of microorganisms and corrosion of pipes (WHO 2008). The pH values for all rainwater samples collected in summer were within the basic range 7.4–9.9. In winter, 38% of the samples had acidic pH values. The pH of rainwater ranges from 4.5 to 6.5 but increases slightly after falling on roofs and during storage in tanks (Meera & Ahammed 2006). In the West Bank, the increase in pH of stored rainwater could be due to the alkaline nature of the roof material (mainly concrete) and the storage tank material, which is either concrete or limestone rock (excavated storage tanks). The pH values of 28% of the samples were not within the WHO guideline range set for drinking water of 6.5–8.5 (WHO 2008).

Mean EC value for SS (286.4 μS/cm) was less than that found in WS (378.5 μS/cm). These values are much less than the EC value for tap water in the West Bank, reported as 760 μS/cm (Abdul-Hamid 2008). Salinity mean values for rainwater samples were generally low (all samples average was 0.16‰). More than 50% of the samples had salinity ≤0.1‰. Harvested rainwater salinity is clearly lower than tap water salinity found in the West Bank, typically 0.4‰ (Abdul-Hamid 2008). All TDS values measured for rainwater samples were well below the WHO guideline value of 1,000 mg/L (WHO 2008). The mean TDS value for all samples was 157.5 mg/L and WS had higher TDS values than SS (Table 2). Turbidity measurements in rainwater samples were well below the guideline value set by WHO of 5 NTU (WHO 2008). Out of 42 harvested rainwater samples analyzed, only one sample exceeded the WHO guideline value. The mean turbidity of all samples was 0.85 NTU and mean turbidity value for SS was more than that for WS. Rainwater turbidity values seem to be lower than those found in tap water samples from the West Bank at 1.72 NTU (Abdul-Hamid 2008). Nitrate levels were determined for WS. The mean value for rainwater samples was 3.06 mg/L and the highest value recorded was 5.8 mg/L.

Table 2 | Physicochemical quality of harvested rainwater samples ($n = 42$) collected from the West Bank in summer and winter 2006/2007

Parameter		Range	Mean ± SE	WHO GV
Temp. (°C)	All	12.0–28.8	20.2 ± 0.99	–
	SS	20.0–28.8	24.0 ± 0.60	
	WS	12.0–19.0	16.5 ± 0.50	
pH	All	4.8–9.9	7.84 ± 0.25	6.5–9.5
	SS	7.4–9.9	8.5 ± 0.02	
	WS	4.8–8.6	7.2 ± 0.25	
EC (μS/cm)	All	121.5–834	332.5 ± 36.4	–
	SS	180.5–834	286.4 ± 30.3	
	WS	121.5–628	378.5 ± 39.8	
Salinity (‰)	All	0.10–0.40	0.16 ± 0.02	–
	SS	0.10–0.40	0.15 ± 0.01	
	WS	0.10–0.30	0.17 ± 0.02	
TDS (mg/L)	All	57.6–394	157.5 ± 17.3	1,000
	SS	83.8–394	137.5 ± 14.7	
	WS	57.6–303	177.6 ± 18.9	
Turbidity (NTU)	All	0.13–5.31	0.85 ± 0.22	5
	SS	0.13–1.84	1.11 ± 0.28	
	WS	0.23–5.31	0.59 ± 0.10	
Nitrate (mg/L)	All	NA	NA	50
	SS	NA	NA	
	WS	0.01–5.78	3.06 ± 0.37	
Copper (μg/L)	All	0.62–30.84	8.27 ± 1.99	200
	SS	0.62–54.35	7.77 ± 2.48	
	WS	2.62–30.84	8.76 ± 1.39	
Lead (μg/L)	All	0.37–30.67	2.64 ± 1.14	10
	SS	0.37–3.54	1.20 ± 0.15	
	WS	0.84–30.67	4.08 ± 1.60	

SS, summer samples; WS, winter samples; (All) all samples combined; GV, guideline value.

Nitrate levels are well below the guideline value of 50 mg/L set by WHO (2006). This indicates that harvested rainwater is not contaminated with nitrate and no health hazard could result from the consumption of this water. Concentrations of copper in harvested rainwater samples were below the WHO guideline value of 200 μg/L (WHO 2008). The highest Cu concentration recorded was 54.35 μg/L from a reservoir during the summer period. Rainwater from two reservoirs was found to have Pb concentrations that exceed the WHO (2008) guideline value of 10 μg/L. The highest value recorded was during the winter period and contained 30.67 μg Pb/L.

Generally, the physicochemical quality of harvested rainwater in the West Bank meets the drinking water quality guidelines set by WHO (2008) with few exceptions regarding pH, turbidity and Pb. Compared with tap water quality in the West Bank, harvested rainwater samples were mostly of better quality with regard to physicochemical characteristics. Some parameters (Table 2) were found to be higher in WS than in SS. This could be due to the input of rainwater along with atmospheric and roof contaminants into the storage wells during the winter months and the mixing effect caused by rainwater falling from the roof into the storage wells. This is important especially in wells that are cleaned regularly. In summer, settling of particles and chelation of some ions cause a decrease in their concentration in harvested rainwater.

The results of the present study seem to be comparable with the results of other studies from different regions of the world (Table 3). Although some physicochemical parameters (Pb and pH) of harvested rainwater samples exceeded the WHO guideline values for drinking water, the quality of harvested rainwater samples is generally acceptable as potable water. High concentrations of Pb in some harvested rainwater in Palestine, Jordan and Zambia might be related to the continuing use of leaded fuel in some old automobiles.

Microbial quality of rainwater

Results for TC, FC and HPC are summarized in Table 4. All harvested rainwater samples were found to be contaminated with TCs. The number of colonies/100 mL ranged between 2 and >1,000. WS were found to contain higher numbers of TC colonies than SS. About half the WS (10/21) were found to contain more than 1,000 CFU/100 mL whereas, only 2/21 SS had TC counts that exceeded 1,000 CFU/100 mL. This might be caused by the influx of coliforms from the catchment surface with rainwater during winter. Total coliform bacteria include both fecal and environmental species. *E. coli* and other thermotolerant coliforms are subsets of the TCs (WHO 2008). Total coliforms include organisms that can survive and grow in water. Hence, they are not useful as an index of fecal pathogens, but they can be used as an indicator of treatment effectiveness and to assess the cleanliness and integrity of distribution systems and the potential presence of biofilms (WHO 2008). *E. coli* is considered the most suitable index of fecal contamination. In most circumstances, populations of thermotolerant coliforms are composed predominantly of *E. coli*; as a result,

Table 3 | Comparison between some physicochemical characteristics of roof-harvested rainwater from the West Bank (Palestine) and some other countries

Reference-country	pH	Turbidity (NTU)	TDS (mg/L)	NO_3 (mg/L)	Lead (μg/L)
Present study, Palestine	4.8–9.9	0.1–5.3	57.6–394	0.01–5.8	0.37–30.67
Schets *et al.* (2010), The Netherlands	6.1–7.2	0.0–2.3	–	–	–
Handia *et al.* (2003), Zambia	6.1–10.2	0.2–2.1	6.5–102	–	0.001–14.0
Zhu *et al.* (2004), China	–	2.0–3.5	185–750	–	0.003–0.04
Radaideh *et al.* (2009), Jordan	7.1–8.9	0.1–4.0	26–393	0.2–8.1	0.0–0.18.0
Sazakli *et al.* (2007), Greece	7.6–8.8	–	–	5.3–13.0	2.0–6.9
Simmons *et al.* (2001), New Zealand	5.2–11.4	0.04–4.7	–	–	0.003–0.14

this group is regarded as a less reliable but acceptable index of fecal pollution (WHO 2008).

In the present study, FC bacteria were detected in about 71% of SS, 62% of WS and in 66.7% of all samples, although all water samples were negative for STEX *E. coli*. Thus, most of the harvested rainwater samples were not in accordance with the WHO guideline value of 0 CFU FC/100 mL in any water intended to be used for drinking purposes (WHO 2008). The distribution of these bacteria is summarized in Table 4. Most samples (62%) had FC counts between 0 and 10 CFU/100 mL and one WS had FCs that exceeded 1,000 CFU/100 mL. All harvested rainwater samples were heavily contaminated with HPC microorganisms. HPC detects a wide range of heterotrophic microorganisms, including bacteria and fungi that can multiply in the water and soil environment (WHO 2008). The test has little value as an index of pathogen presence, but it can be used in assessing the cleanliness of water sources and the presence of biofilms (WHO 2008).

Out of 11 bacterial species tested by molecular biology techniques (specific PCR, Figure 1), the presence of five species in harvested rainwater was confirmed (Figure 2). *Citrobacter* was the most common in harvested rainwater samples (100% of SS), while the least common were *Pseudomonas* and *Campylobacter* (10% of SS). The results indicate more bacterial prevalence in SS than in WS. The absence of many pathogenic bacteria such as *Shigella, Salmonella* and STEX *E. coli* indicates that roof-harvested rainwater in the West Bank is not contaminated with human and other animal wastes. This is because most citizens practice roof cleaning and diverting first flush out of the reservoir and all wells studied were covered in one way or another. In addition, reservoir walls are usually concrete or hard rock, which prevent wastewater infiltration. However, bird feces are a continuous source of fecal contamination for roof-catchment systems; hence the presence of *Campylobacter* in some reservoirs.

The comparison between the microbial quality of harvested rainwater from Palestine and other countries (Table 5) indicates that almost all water samples contain TC, FC and HPC. In addition, certain pathogens or opportunistic pathogens, including *E. coli*, *Campylobacter*,

Table 4 | Distribution of bacterial counts for each indicator group in summer (SS), winter (WS) and all harvested rainwater samples (All) expressed as a percentage of the total number of samples; total number of samples = 42

	% of samples								
	TC			FC			HPC		
Count[a]	SS	WS	All	SS	WS	All	SS	WS	All
0–10	14.3	9.5	11.9	61.9	61.9	61.9	14.3	9.5	11.9
11–100	52.4	33.3	42.9	33.3	28.5	30.9	47.6	23.8	35.7
101–500	9.5	4.8	7.1	4.8	4.8	4.8	33.3	57.2	45.2
501–1,000	14.3	4.8	9.5	0.0	0.0	0.0	4.8	0.0	2.4
>1,000	9.5	47.6	28.6	0.0	4.8	2.4	0.0	9.5	4.8

[a]CFU/100 mL for TC and FC; CFU/1 mL for HPC.

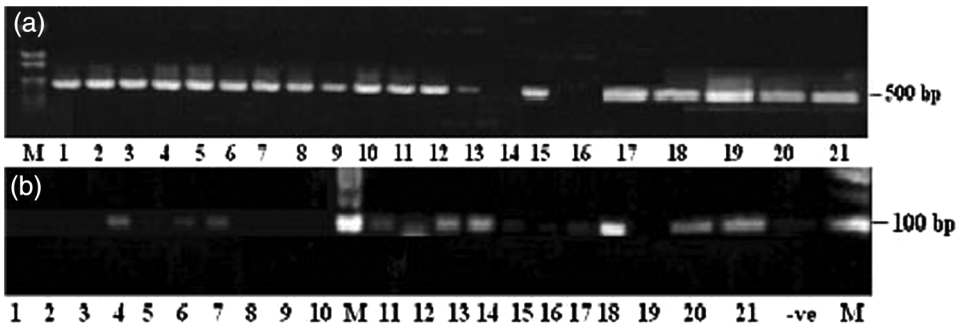

Figure 1 | RAPD fingerprints for *Acinetobacter* (a, summer) and *Citrobacter* (b, winter) in harvested rainwater samples collected from storage wells in the West Bank during summer 2006 and winter 2007. Lane (M) is a ladder marker, −ve: negative control, other lanes are DNA samples.

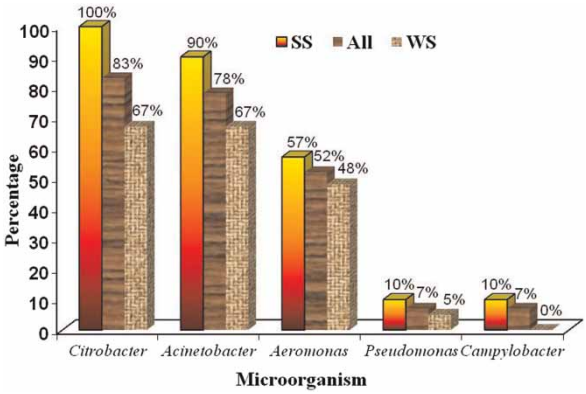

Figure 2 | Prevalence of some bacteria in harvested rainwater samples collected from the West Bank in summer (SS) and winter (WS) and in both seasons combined (All); total number of samples = 42.

Clostridium and *Legionella*, were recorded in harvested rainwater samples from different countries. In the present study, 67% of all rainwater samples contained FC, although STEX *E. coli* was not detected in any water sample. Generally, the results indicate clearly the poor microbial quality of most harvested rainwater samples in Palestine and elsewhere. Thus, harvested rainwater should not be consumed without suitable pre-treatment that improves the quality of this water to potable water quality.

CONCLUSIONS AND RECOMMENDATIONS

The physicochemical quality of roof-harvested rainwater in the Palestinian Territories is generally good enough for it to be used as drinking water. However, the microbial analysis of stored rainwater samples indicated significant microbial contamination with TC and FC, HPC and some other bacteria. The presence of these pathogens/potential pathogens indicates clearly that this water is not suitable for direct consumption without any treatment.

Reducing health risks posed by microbes in stored water requires some actions to be taken before filling the storage tanks and during the storage period. These measures include keeping animals away from the roof and cleaning up bird droppings, diverting the first flush out of the storage tank

Table 5 | Comparison between the microbial quality of roof-harvested rainwater from the West Bank (Palestine) and some other countries

Reference-country	TC (CFU/100 mL)	FC (CFU/100 mL)	HPC (CFU/1 mL)	Other microorganisms
Present study, Palestine	415 (2–>1,000) (100%)	55 (0–>1,000) (67%)	170 (6–>1,000) (100%)	*Citrobacter, Acinetobacter, Aeromonas, Campylobacter, Pseudomonas*
Schets *et al.* (2010), The Netherlands	15–480 (100%)	–	91–1,314 (100%)	*E. coli*, enterococci, *Aeromonas, Clostridium perfringens, Legionella*
Radaideh *et al.* (2009), Jordan	20 (2–40)	5 (2–15)	–	*E. coli*
Evans *et al.* (2007), Australia	1,266 (0–20,000)	–	7 (0–120)	*Pseudomonas, Bacillus, Sphingomonas, Acidovorax, Serratia*
Coombs *et al.* (2006), Australia	834	119	33	*Pseudomonas*

and regularly cleaning and disinfecting the storage tank and stored water. This is important to prevent the formation of biofilms in the storage tank. Finally, openings in storage tanks should be kept properly closed to minimize microbial contamination during storage and keep the stored water in good microbial quality.

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