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Management of rainwater harvesting and its impact on the health of people in the Middle East: case study from Yatta town, Palestine

Ilke Celik · Lina M.A. Tamimi · Issam A. Al-Khatib · Defne S. Apul

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Abstract Water-related diseases are a primary problem in Palestine where many residents revert to harvested rainwater as their primary water source due to water shortages within the area. From an environmental engineering perspective, it is already well known that certain situations (e.g., cross contamination) reduce drinking water quality and ultimately cause diseases in a population. In this study, we investigated the social practices and situations that may lead to lower disease occurrence. Towards this goal, we surveyed 382 residents in Yatta to collect data on the water-related diseases that they experienced and the specific situations that might affect the disease occurrences such as the residents' practices (i) for maintaining a high quality of cistern water, (ii) for maintaining the environment around the cistern, and (iii) for managing the wastewater. In addition, we measured the physicochemical and microbiological parameters in cisterns to support the qualitative survey data. The measured parameters, including turbidity, salinity, free available chlorine, total *Coliforms*, and fecal *Coliforms*, were above Palestinian Standard Institution (PSI) and World Health Organization (WHO) guideline levels, suggesting a potential infectious hazard. The poor quality of the water was also observed by residents based on change in taste and by visually noting floating impurities, turbidity, and green coloration. Survey results showed that observations of the poor quality in cisterns and surrounding environment had statistically significant correlation with most of the water-related diseases. Additionally, frequently emptying the septic tank contributes to improving the observed water qualities. Therefore, residents should be encouraged to continue to observe the water quality in the cistern, improve the surrounding environment of cistern, and empty their septic tank frequently, to keep the water diseases away from their households.

Keywords Harvested rainwater · Water management · Water quality · Water-related diseases

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I. Celik · D. S. Apul
Department of Civil Engineering, University of Toledo, 2801W. Bancroft St., MS 307, Toledo, OH 43606, USA

L. M. Tamimi
Faculty of Graduate Studies, Birzeit University, Birzeit, West Bank, Palestine

I. A. Al-Khatib (✉)
Institute of Environmental and Water Studies, Birzeit University, Birzeit, West Bank, Palestine
e-mail: ikhatib@birzeit.edu

Introduction

Humans' basic needs for water have traditionally been partially met with harvested rainwater since ancient times. In the past century, water treatment plants and centralized water distribution systems have taken over the world. Yet, as of a past couple decades, there is a renewed global interest in rainwater harvesting as a primary or complimentary water source and a storm

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water management solution especially for extreme drought and precipitation conditions that are expected to increase due to climate change (Helmreich and Horn 2009; Tavakol-Davani et al. 2016). Both the developing (Al-Salaymeh et al. 2011; Amin et al. 2013; Jasrotia et al. 2009; Karim 2010) and the developed (Anand and Apul 2011; Farreny et al. 2011; Herrmann and Schmida 2000; Nolde 2007; Zaizen et al. 2000) countries are now turning to rainwater harvesting as a sustainable water management approach with an increasing number of case studies analyzing the feasibility; water quality; and economic, social, and environmental implications of rainwater harvesting in different cities.

Palestine presents an interesting situation with respect to rainwater harvesting. Water scarcity is a common problem due to semi-arid climate of the region. Conflict between Palestine and Israel further exacerbates water availability resulting in only intermittent supply of municipal water to Palestinian residents who turn to rainwater harvesting to meet their demands. For example, in the Yatta area, there are in sufficient water quantities (34 L/capita/day) from the different sources (Tamimi 2016). Municipal water is often cutoff for a period of 6 months, so people are forced to buy water from water distribution tanks and rely on rainwater harvesting. In addition, the municipal water network is incapable of supplying the whole population with water; it serves only 60% of the Yatta area. Similarly, in Nablus, residents receive water every third or fourth day for 8–16 h (Haddad et al. 2014). Due to these conditions, both the people connected and those not connected to the water system have to rely regularly on rainwater harvesting systems to store both rainwater and piped water.

Water scarcity along with poor water quality and poor sanitation practices causes health problems in a population due to an increase in exposure pathways. Water- and sanitation-related diseases such as diarrhea, intestinal worm, jaundice, typhoid, head lice, scabies, and eye diseases can spread rapidly between people (Ashbolt 2004; Bordalo and Savva-Bordalo 2007; Falconer et al. 1994; Farooqui et al. 2009; Kanitz et al. 1996; Mermin et al. 1999). Globally, about 6% of total disability-adjusted life years and 4% of all deaths are attributed to hygiene, water, and sanitation (Prüss et al. 2002). These challenges apply to Palestinian residents as well. A study from 2006 showed that the water distribution in Gaza Strip, Palestine, was largely contaminated with fecal *Coliforms* (Yassin et al. 2006) and the prevalence of waterborne diseases is related to low water quality. A more recent study showed that in Nablus, Palestine, the water source met the Palestinian water quality standards but noted significant challenges with maintaining pathogen-free water at point of use when water is pumped intermittently (Haddad et al. 2014). Quality of harvested rainwater in Palestine can also be low due to contamination from metals and *Coliforms* (Al-Salaymeh et al. 2011; Haddad et al. 2014).

In this study, we aimed to further understand the link between water and sanitation management and water-related diseases in Palestine. We focused on Yatta because this area is suffering from one of the worst shortages of water for household needs in recent years. Harvested rainwater is the primary water source in the town, and residents regularly suffer from water-related diseases. We conducted surveys to document the use of rainwater harvesting in Yatta, water-related diseases observed by the residents, and the specific situations at the households such as sanitary practices, the environment surrounding the cistern, and wastewater management practices. We investigated the correlations of these situations with (i) the cistern water quality observed by residents and (ii) waterborne diseases observed by the residents. Apart from surveys, we also measured the physicochemical and microbiological parameters in cisterns to support qualitative survey data.

Methodology

Study site

Yatta is a Palestinian town situated nearly 8 km south of Hebron in the West Bank (Fig. 1). Yatta combines urban and rural settings with a population that has been known to be involved in agricultural activities. Yatta had a population of 67,000 in 2015 (PCBS 2011; Theis et al. 2011). The total estimated area of Yatta is 24.6 km^2, of which 9.1 km^2 is classified as "built-up" and 8 km^2 is agricultural areas. The remaining areas are livestock, non-implanted, or public lands (Abusafa et al. 2012a, b). The climate in the Yatta region can be described as temperate; temperature and the precipitation vary with altitude. It has warm to hot and dry summers and cool to mild rainy winters. The annual mean rainfall and temperature in Yatta are 303 mm and 18 °C, respectively (ARIJ 2009).

Fig. 1 Location of Yatta in Palestine and pictures of representative cistern tops

Conceptual framework and data collection

The conceptual framework for the study is shown in Fig. 2. Structured surveys were conducted with 382 Yatta residents to determine whether they experienced any water-related diseases in the past 2 months. Surveys were also used to collect data on the cistern water quality observed by the residents. These qualitative data were collected by asking residents if they observed any floating impurities, turbidity, change in taste, and green colors on the sides of the cistern. The third group of data collected from the surveys was about site-specific situations such as sanitary practices, the environment surrounding the cistern, and wastewater management methods. In sanitary practices, the residents were asked whether they took any precautions (e.g., cleaning the roof and removing the first flush) before harvesting the rainwater. To understand the surrounding environment, the residents were asked whether they bred animals at home, had trees close to the cistern, or kept their waste in the yard. To understand the wastewater management, the residents were asked about the septic tank location in relation to the cistern, whether it overflew and how often it was emptied. We hypothesized that these site-specific situations and the water quality observed by the residents would have a direct (solid lines in Fig. 2) effect on the water-related diseases. We also hypothesized that by impacting the observed water quality, the site-specific situations would indirectly (dashed lines) affect the extent of water-related diseases experienced in the surveyed population. Categorical data correlations were used to investigate these direct and indirect effects. Level of significance was determined from two-tailed Person correlation measure with 95% ($p < 0.05$) and 90% ($p < 0.1$) statistical confidence. Apart from the categorical survey-based data, we also measured and report on the physicochemical and microbiological quality data (nominal data) that we collected by sampling 50 random cisterns in Yatta.

Structured surveys to measure categorical data (rectangle boxes)

A survey was designed and administered to a sample of 382 persons. The sample size for the surveys was determined from Eq. 1 (Baayen 2001):

$$n = \frac{z^2\left(\frac{p \times (1-p)}{E^2}\right)}{1 + z^2\left(\frac{p \times (1-p)}{E^2 \times N}\right)} \quad (1)$$

where n is the sample size, z is the confidence level at 95% (standard value of 1.96), E is the error (0.05), p is the probability function that can make the n highest value possible (50%), and N is the population size of Yatta (approximately 67,000). From Eq. 1, the sample size was found to be 382.

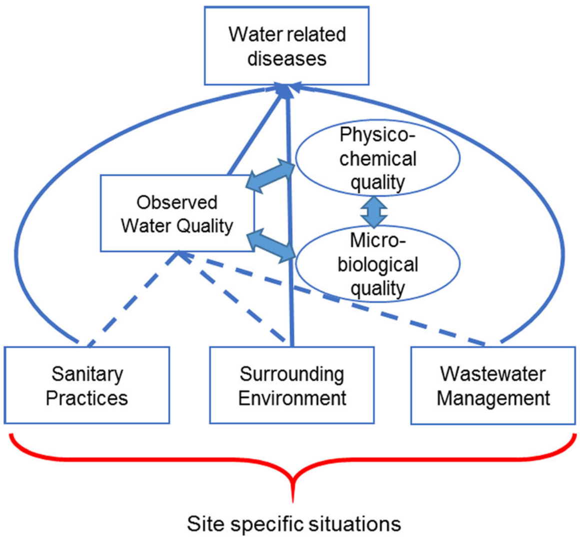

Fig. 2 Conceptual framework of the study. Water-related diseases were statistically analyzed with observed and measured water quality in the cisterns and site-specific situations near the cisterns

A simple and structured questionnaire was prepared and pretested. Some modifications were made to the questionnaire to improve clarity of some questions. Random sampling was used to determine the 382 households to be surveyed. Data were collected using semi-structured interviews over the course of field visits to Yatta between November 2014 and March 2015. Residents were asked to discuss their opinions regarding rainwater harvesting management practices, quantity, and quality of harvested water and related health risk perceptions. Data obtained from the residents' questionnaires were coded and processed using SPSS version 17 (Statistical Package for Social Sciences) software.

Rainwater sampling for nominal data (oval boxes)

Rainwater samples were drawn from the rainfed cisterns using sterilized sampling devices (Ruttner sampler). Rainwater samples were collected from the same households that were surveyed, but due to coordination problems and the ambiguity of ownership of the cisterns, the cistern water physicochemical and microbiological quality data could not be directly linked to the survey data. The sampling depth was in the middle of the existing water column. Samples for chemical analysis were kept in polyethylene bottles while samples for microbiological analysis were kept in glass bottles. These samples were transported to the Institute of Environmental and Water Studies Laboratory at Birzeit University (Birzeit-Palestine), within 24 h of rainfall events in the ice-bag containers. All of them were drawn from the rainfed cisterns that have only rainwater at that time. At each sampling site, pH, electrical conductivity, salinity, total dissolved substances, and turbidity of cistern water were measured according to applicable standard procedures (Al-Salaymeh et al. 2011; APHA 1996; Tortora et al. 2003). A CO150 conductivity meter, an EC-10 pH meter, a Hach 2100P Turbidimeter, a Hach CO150 total dissolved solid (TDS), and a Hach CO150 salinity meter (Hach Company, Loveland, Columbia, USA) were used for those measurements. In addition to the field measurements mentioned earlier, additional collected samples were sent for biological analysis. This was done in accordance with the standard methods for the examination of water (APHA 1996). The samples were analyzed for indicator organism concentrations (fecal *Coliforms* and total *Coliforms*) and other chemical water quality indicators (chloride, and alkalinity) using the applicable standard procedures (APHA 1996; Tortora et al. 2003). Some of these parameters (pH, TDS, alkalinity, and free available chlorine) can influence drinking water flavor, while the turbidity and *Coliforms* were measured due to esthetic and health concerns, respectively (Lou et al. 2007).

Results

Harvested rainwater use in Yatta

Based on survey results, the water from rainwater cisterns was predominantly used for drinking, but most of the residents also use it for agricultural purposes and for cleaning and laundry (Table 1). Only a small percentage of residents use the cistern water for livestock watering. Rainwater is typically harvested in the rainy season (winter) to be used later in the dry summer months. During the summer, some residents may also obtain their water needs from private dealers who deliver water in tankers at much higher prices (3.25–17 \$US/m^3 depending on the dealer) than the municipal water pricing (0.7–1.25 \$US/m^3).

The main characteristics of rainwater harvesting cisterns used in Yatta are shown in Fig. 3. There is a large variation (11–300 m^3) in the cistern sizes, likely due to the size of the family, family's economic situation, and the presence of suitable space. Most of the cisterns are made from reinforced concrete. Almost half of the

Table 1 Survey response distribution regarding harvested rainwater usage in Yatta town

Uses of harvested rainwater	Responses (%)
Drinking	94.5
Agricultural	88.8
Cleaning and laundry	82.3
Livestock watering	2.9

cisterns are older than 15 years. Most of the cisterns are closed at the top (86.6%). The others either have no solid cover or have a screen where contaminants can pass through to the water. The most common catchment is the roof of the house (69.6%), where 97.1% of the roofs are built from reinforced concrete. About one third (30.4%) of the harvested water is captured from surfaces (yard in front of the house and main street) that likely add pathogens and other contaminants to the cistern water.

Physicochemical and microbiological water quality in cisterns

The measured physical and chemical analyses of harvested rainwater samples in Yatta town are presented in Table 2. We also present the water quality limits established by Palestinian Standard Institution (PSI) and World Health Organization (WHO). The physicochemical analysis of the cistern water showed that most measured parameters, including pH, conductivity, total dissolved solids, alkalinity, and chloride, were well below the recommended acceptable esthetic guideline limits for drinking water by PSI. However, three parameters, namely turbidity, salinity, and free available chlorine, were found to exceed the acceptable limits. Free available chlorine data show that 74% of the harvested rainwater samples do not meet acceptable drinking water standards of PSI and WHO. The low concentrations of free available chlorine in drinking waters reflect ineffective disinfection with chlorine tablets, which is the most common treatment method among the Yatta residents. Thus, the microbiological contamination of the drinking water is present. Twenty percent of samples were found to have high salinity levels. The high levels of salinity are not very common in rainwater samples (Khan et al. 2011). In contrast, the high salinity levels were observed in drinking water samples from the deep tube wells, ponds, or rivers (Khan et al. 2011). The change in salinity can be perceived by the change in taste in drinking water. Fourteen percent of tested samples exceed the recommended levels (5 NTU) of turbidity. This level of turbidity can be noticed by the naked eye and results from inorganic and organic suspended particle or colloidal matters that obstruct light transmission (WHO 2011).

The microbiological analysis of harvested water was also evaluated. WHO guidelines (2011) were used to categorize the risk for degree of contamination (Tables 3 and 4). The distribution of measured total *Coliforms* parameters in the households is shown in Table 3. Per WHO's classification of total *Coliforms*, no samples were free of contamination (no risk), while 4 and 96% of samples were with low and intermediate risks, respectively (Table 2). The cisterns classified as low risk should be treated with chlorination. However, intermediate-degree contaminated cisterns require not only chlorination but also further treatments such as flocculation and sedimentation. None of the examined water samples was within high risk (>50,000 CFU/100 ml).

The distribution of cisterns' water contamination with fecal *Coliforms* is shown in Table 4. Thirty percent of harvested water samples were safe with no risk

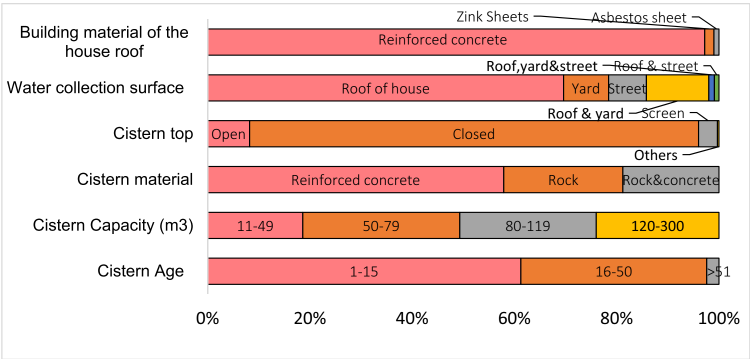

Fig. 3 Responses of interviewees about characteristics of rainwater harvesting cisterns found in Yatta town

Table 2 Physiochemical analysis of the cistern water and its relation to PSI guideline and WHO guideline in Yatta town, Palestine, 2015

Physiochemical parameter	Reading range	Reading mean	WHO	PSI	Samples above MAC of PSI (%)
Alkalinity (mg/L $CaCO_3$)	62–338	185	NA[a]	400	
Chloride (mg/L)	14–77	41.6	NA[a]	Up to 250	
Conductivity EC (μS cm^{-1})	135–633	404	NA[a]	Up to 2000	
Free available chlorine (mg/L)	0.00–0.73	0.15	0.5	0.2–0.8	74
pH	7.0–7.6	7.3	NA[a]	6.5–8.5	
Salinity (%)	0.3–1.2	0.79	Up to 1.0	Up to 1.0	20
Total dissolved solids (mg/L)	67.3–317	202	NA[a]	Up to 500	
Turbidity (NTU)	0.24–7.0	2.78	5.0	5.0	14

Principle reference data for WHO drinking water guidelines are 2003. Limit values for the presented parameters have not changed since the update in 2003

MAC maximum allowable concentration according to PSI (2004), *NTU* nephelometric turbidity units

[a] WHO did not established guideline limits for alkalinity, conductivity, pH, and TDS because these parameters are not of health concern at levels found in drinking water. These parameters are shown as NA

regarding contamination with fecal *Coliforms* (0 CFU/100 ml). Of the tested samples, 22 and 48% were contaminated with fecal *Coliforms* with low and high risks, respectively. As a result, 70% of samples were contaminated with fecal *Coliforms*. According to Hatha et al. (2013), the Indian National Sample Survey Organization (1999) reported that the most significant risk to human health related to drinking water quality is from microbiological sources through fecal contamination. Microbial pathogens may originate in fecal contamination from reptiles, mammals, and birds that have access to catchment areas or to the cisterns.

Observed water quality and water-related diseases

Survey results suggest that the observed water quality is not quite satisfactory to people in Yatta (Table 5). Floating impurities were observed by about 40% of the residents. Almost one in four households observed turbidity and change in taste in water after rainwater harvesting systems were used. Green color formation, an indicator of microbial community in the water, was also observed by 18% of the respondents. From field observations, the green color formation has also been noticed in some old rainfed cisterns in the Yatta area.

Residents of Yatta suffer from both waterborne diseases due to water contamination (diarrhea and vomiting, diarrhea, intestinal worm, jaundice, and typhoid) and water-washed diseases due to the insufficient quantity of available water (lice, scabies, and eye disease). About one third of the population experienced diarrhea (31.9%) and diarrhea with vomiting (28.8%) within the past 2 months. Intestinal worm (18.3%) and eye diseases (13.1%) were less commonly experienced. Less than 10% of the residents experienced jaundice (6.5%); typhoid (3.1%), head lice (6.5%), and scabies (6.0%) were experienced by less than 10% of the population.

Site-specific situations

Survey results suggest that the cistern users were largely aware and were practicing a variety of sanitation measures towards maintaining good-quality water in the cisterns (Table 6). About one third of the respondents (38%) treat the harvested water in the cistern. Of those who treat the water, 77.1% of them add chlorine tablets and 10.0% put filters at the pipe water entrance at the

Table 3 Number of positive total *Coliforms* for water from cisterns and its relation to range of contamination, degree of contamination, and treatment procedure in Yatta town

Range of total *Coliforms* (CFU/100 ml)	Degree of contamination[a]	Number and percentage of positive total *Coliforms* tested
0–3	No risk	0 (0%)
4–50	Low risk	2 (4%)
51–50,000	Intermediate risk	48 (96%)

[a] WHO (1996)

Table 4 Distribution of cistern's water contamination with fecal *Coliforms* and degree of risk in Yatta town

Range of FC (CFU/100 ml)	Degree of contamination	Number and percentage of tested samples
0	No risk	15 (30%)
1–10	Low risk	24 (48%)
101–1000	High risk	11 (22%)
>1000	Very high risk	0 (0%)

roof. Cleaning the cistern and diverting the first flush of the storm water were also important for maintaining good-quality water in the cisterns. Most of the respondents (~86%) do both activities. Catchment surfaces collect contaminants from different sources such as bird and rodent feces, animals, pesticides, insect bodies, dust, twigs, leaves, blooms, and other airborne residues during the summer months preceding the rainy season. Diverting the first storm water from the cistern is a recommended way to reduce the contaminant in the harvested water (Abusafa et al. 2012a, b). In the households surveyed, the residents are indeed aware of the importance of first flush and take necessary precautions by diverting the first flush and cleaning the catchment area and channels.

Almost half of the respondents indeed did breed animals or birds (Table 7) in households. Microbial contamination in cistern water can potentially result from animal feces found in catchment surfaces that surround the cistern. Almost half of the residents also had trees near the cisterns. Tree roots can penetrate cisterns deeply, causing cracks in the cistern walls, which allow polluted water to infiltrate. Moreover, trees provide suitable habitat for pets and birds, which may bring their feces in contact with cistern water (Rutkovienë et al. 2005). About one fifth of the residents keep their waste in their yards, which might have also contributed to poor water quality in cisterns.

Most of the Yatta households (87.9%) use cesspits as a method for wastewater disposal. Only 3.4% of them have a municipal sewage system, and the rest (8.8%) dispose of wastewater in streets (2.6%), in open channels (0.5%), in random sites (0.5), and in other choices (5.2%).

About half (46.7%) of the households had cesspits with 20 m or less from the cistern (Fig. 4). This can be an important reason for contamination of water in the cistern with wastewater as most of the households do not empty their septic tanks, while others empty them after long periods (58.4%). Most of the cesspits (70.4%) are lower than the cisterns, while 14.0 and 15.6% of them are higher or at the same level, respectively. Of cesspits, 16.2% overflooded during the past 12 months. Cesspits are considered significant potential biological pollutants to harvested water in cistern. Cesspits are widely used in most parts of Yatta as well as other Palestinian villages due to the absence of sewage networks. Generally, cesspits are made onto the underground excavation close to houses. Most of them are not lined, and water can disperse through the soil to delay tank evacuation as it costs too much. If a close by water cistern exists, the pollutants from the cesspits can disperse into the water cistern through cracks. The risk of this pollution increases even further if the elevation of the septic tank is higher than the water cistern or at the same level.

Correlations with water-related diseases

The residents' observations of the poor water quality in cisterns had statistically significant correlations with most of the diseases that they experienced (Table 8). Observation of turbidity correlated with all the diseases except jaundice. Observation of floating impurities correlated with all diseases except typhoid. Fewer diseases were statistically correlated with the residents' observations of change in taste and the presence of green colors on the sides of the cistern.

These results suggest that if the residents observe poor quality, and especially turbidity and floating impurities, they are likely to also experience water-related

Table 5 Perceived water quality of harvested rain water in Yatta town

Questions	Answers	Responses (%)
Do you notice floating impurities on the surface of the cistern water?	Yes	39.5
	No	60.5
Do you notice turbidity in water?	Yes	25.6
	No	74.4
Do you feel a change in water taste when it is combined with rainwater	Yes	23.3
	No	76.7
Do you notice green color on the sides of the cistern?	Yes	18.1
	No	89.9

Table 6 Cistern sanitation practices in Yatta town, Palestine

Questions	Answers	Responses (%)
Did you clean the cistern?	Yes	85.3
	No	12.3
	No answer	2.44
If yes, when did you do that last time?	Before half a year	47.5
	Before a year	26.0
	Before more than a year	26.5
Do you treat the harvested water in general?	Yes	38.0
	No	62.0
If yes, how do you do that?	Chlorine tablets	77.2
	Filters	10.0
	Chlorine tablets + filters	1.4
	Chlorine tablets + whitewash	10.0
	Chlorine tablets + Solar	1.40
Do you take specific action before rainwater harvesting?	Yes	86.6
	No	13.4
If yes, what are these actions?	Clean the roof of the house	61.6
	Divert the first flush	12.1
	Cleaning channels	1.50
	Clean the roof of the house and divert the first flush	23.3
	Clean the roof of the house, cleaning channels and divert the first flush	1.50

diseases. This is an empowering result for the residents, suggesting that even without quantitatively measuring the water quality, the visual observations can serve as a signal that a disease may accompany the use of the harvested water. Based on these observations, the residents can aim to improve the water quality before using it. The effectiveness of their options can be observed in Table 8. For example, sanitary practices did not seem to affect the water-related diseases. Many of the residents put in efforts to clean the cistern, to treat the harvested water, and to take precautions prior to a storm event. However, these efforts do not seem to be effective in preventing diseases. A few diseases, including jaundice, head lice, and eye diseases, even have negative correlations with sanitary practices. These results provide a significant message to people in Yatta. The current sanitary practices, including cleaning frequency (53% cleans the cisterns yearly or less frequent) and treatment methods (77% uses chlorine tablets), are not effective in combating water-related diseases.

Another precaution that the residents can take is to improve the environment around the cistern. Of these options, breeding animals at home seem to have an important effect as it is significantly correlated with many of the diseases. Half the population currently keeps animals at home. Since this is a common practice, changing it may not be possible. A more effective change in the surrounding environment may come from not keeping waste in their yards. Keeping waste in yards seemed to have the highest impact on the occurrences of disease as it was statistically correlated with all diseases except jaundice at 95% confidence level ($p < 0.05$).

Table 7 The survey results regarding the surrounding environments of the cisterns

Questions	Answers	Responses (%)
Do you keep animals or birds pets?	Yes	40.9
	No	59.1
Are there trees close to cistern?	Yes	48.7
	No	51.3
Do you collect the house waste in the yard?	Yes	21.5
	No	78.5

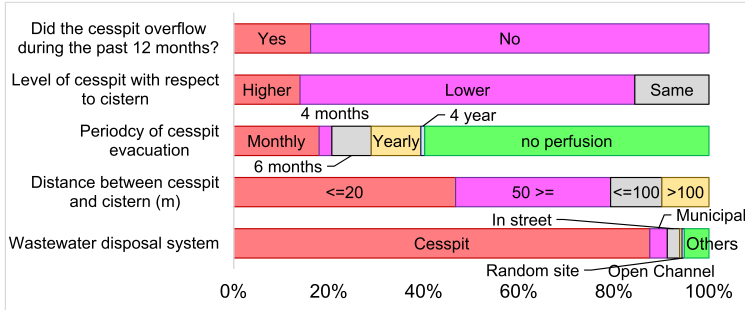

Fig. 4 Responses of study interviewees about house wastewater management systems in Yatta town

Currently, only one fifth of the residents keep their waste in their yard. A change in practice by these residents may reduce the occurrences of diseases within the Yatta population.

Poor wastewater management resulting in poor cistern water quality was anticipated. However, the results did not validate this hypothesis. Residents' responses regarding the proximity of the septic tank to the cistern, the elevation of the cesspit, whether it overflows, and how often it is emptied do not correlate with the occurrences of diseases. As such, to our surprise, focusing efforts on improving wastewater management may not be the highest priority in efforts to combat diseases in Yatta.

For sanitary practices, surrounding environment, and poor wastewater management, we additionally analyzed the correlation among all the parameters given in Figs. 3 and 4. Among them, we observed some significant

Table 8 Multivariate correlations between observed diseases and other parameters

		Diarrhea and vomiting	Diarrhea	Intestinal worm	Jaundice	Typhoid	Head lice	Scabies	Eye disease
Observed water quality	Green colors on the sides	.137	.087	.094	.096	.150	.096	.224	.120
	Turbidity	.222	.215	.264	.087	.135	.208	.254	.305
	Change in taste	.076	.086	.109	.060	.060	.195	.195	.144
	Floating impurities	.231	.135	.240	.111*	.100	.154	.201	.242
Sanitary practices	Cleaning cistern	-.010	.008	-.082	-.082	.047	-.106	.035	-.113
	Treating harvested water	.039	.031	.034	.055	.045	.120	.051	.032
	Actions before RWH	.012	.005	-.073	-.114	-.018	.011	.067	.015
Surrounding environment	Breeding animals at home	.175	-.015	.079	.102	.145	.045	.124	.108
	Closeness of trees to cisterns	.028	.097	.012	.039	.065	.123	.062	.119
	Waste in yards	.231	.135	.240	.111	.100	.154**	.201	.242
Wastewater management	Cesspit distance to cistern	-.020	.037	.058	.028	.079	.117	.087	.022
	Cesspit level	-.024	-.045	.043	.033	-.012	.083	.035	.048
	Cesspit overflow	.053	.069	.028	.103	.108	.014	.001	.086
	Frequency of emptying	.061	-.038	-.011	.080	.140	-.009	.012	-.008

Light blue depicts for no significant correlation between the parameters and the diseases. Darker and darkest blue shows the significant correlations between those at $p < 0.05$ and at $p < 0.01$, respectively correlations with cistern material and cistern ages on certain water-related diseases. As would have been expected, increasing cistern ages significantly correlated with occurrences of certain diseases such as diarrhea and vomiting ($p < 0.05$). Also, the households having reinforced concrete cistern experience less water-related diseases such as head lice ($p < 0.1$) and eye diseases ($p < 0.05$) (see Table S1).

Correlations with water quality observed by residents

The correlations between situational factors and the water quality observed by residents are shown in Table 9. These data suggest that the surrounding environment and wastewater management may indirectly affect the occurrence of water-related diseases by contributing to the green color formation, turbidity, change in taste, and floating impurities. Data from Table 9 indicate that the surrounding environment has a statistically significant impact on green color formation on the sides of the cisterns. This could be interpreted as an indirect impact on existence of diarrhea and vomiting, typhoid, scabies, and eye diseases in household (shown in Table 8). Turbidity and change in taste of water were significantly correlated with the surrounding environment and wastewater management; thus, they have indirect impact on existence of all the water-related diseases except jaundice. Particularly, frequency of emptying the septic tank seemed to affect the change in taste of water and corresponding diseases shown in Table 8 (intestinal worm, head lice, scabies, and eye diseases) more than keeping the waste in yards. This result may be an outcome of residents thinking that the change in taste would be less if the septic tank were to be more frequently emptied.

As would have been expected, cleaning the cistern had a negative correlation ($p < 0.1$) with floating impurities. However, stronger correlations were found between floating impurities and the surrounding environment, and as such, this result suggests that surrounding environment may play a greater role in causing water-related diseases.

Conclusions and recommendations

This study aimed to identify the link between water and sanitation management and water-related diseases in Yatta, Palestine. For this purpose, the most commonly used drinking water source, harvested rainwater, was investigated via surveys and measurements.

The physicochemical parameters, such as turbidity, salinity, and free available chlorine, and microbiological parameters, such as total *Coliforms* and fecal *Coliforms*, were above PSI and WHO guideline levels, suggesting a potential infectious hazard. The poor quality of the water was also observed by residents. Survey results show that observations of the poor quality in cisterns

Table 9 Correlations among situational factors and observed water quality

		Green colors on the sides	Turbidity	Change in taste	Floating impurities
Sanitary practices	Cleaning cistern	-.028	-.062	.032	-.114*
	Treating harvested water	.095	.035	.032	-.048
	Actions before RWH	-.016	.035	.032	.050
Surrounding environment	Breeding animals at home	.145**	.049	-.009	.191**
	Closeness of trees to cisterns	.114*	.051	.010	-.048
	Waste in yard	.185**	.291**	.152**	.177**
Wastewater management	Septic tank distance to cistern	-.042	-.013	.051	.068
	Septic tank level	-.063	.122*	.022	.014
	Septic tank overflow	.031	.100*	.111*	.029
	Frequency of emptying	.046	.092	.229**	-.024

had statistically significant correlation with most of the water-related diseases at 95% confidence level ($p < 0.05$). Hence, people in Yatta can reduce these diseases by continuing to pay attention to visual and taste observation and especially to turbidity and floating impurities in the cisterns.

Site-specific situations were surveyed since they were hypothesized to have direct effects on the water-related diseases. Among them, the surrounding environment had a clear direct impact on water-related diseases. Waste in yards positively correlated with almost all of the studied water diseases. The other two site-specific situations, sanitary practices and wastewater management, did not seem to affect water-related diseases significantly. We also noted that the observable water qualities and water-related diseases held strong correlations. These qualities were mostly affected by the surrounding environment. Additionally, frequently emptying the septic tank also contributed to improving the observed water quality. Therefore, people should be encouraged to improve the surrounding environment of cistern and empty their septic tank frequently to keep the water diseases away from their households. Treatment methods, such as boiling water prior to the usage or using chemicals (iodine in addition to chlorine) and filtering water (via carbon, ceramic, and sand filters or membranes), can be also considered for good maintenance of cistern water in addition to prevention methods during the construction of cisterns such as leveling the cisterns above the cesspits and locating them in certain distance away from cesspits.

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