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Assessment of Rainwater Harvesting Management in Jordan

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Abstract

Rainwater harvesting (RWH) has the potential to provide a sustainable solution to the problem of water scarcity. Therefore, this study aims to assess the management of (RWH) by distributing a questionnaire to householders in the northern region of Jordan. The questionnaire covered all the parameters that have an impact on water use, management, and quality of RWH. The results of the statistical analysis showed that 25.5% of the cisterns were constructed in the last 15-30 years. About (60.2%) of cisterns were made of concrete, and 46.6% of them have capacities between 30-50 m^3. The largest percentage of these cisterns (43.7%) are used for all purposes, including drinking, while 23.3%, 18.45%, and 10.7% are used for irrigation, washing, and cooking, respectively. HRW is mainly collected from rooftops (72.8%) while 25.2% is collected from home yards. Regarding the surrounding environment, 62.1% of the houses have no sanitary system and depend on cesspools for sewage disposal, and 8.7% have an animal barn near the cistern. Roof cleaning before the rainy season was implemented by 84.5% of the households, while 12.6% reported complaints due to water quality. 4.9% of them visited the hospital. About 24.3% visually inspected water quality, and 3.9%, 4.9%, and 2.9% of them reported abnormal pain, change of water taste, and presence of impurities in water, respectively. It is recommended to establish public awareness programs to enhance RWH management. The program should outline the best practices to collect and store rainwater and to take appropriate corrective measures to get high water quality for drinking purposes.

Keywords: Rainwater Harvesting, Water management, Jordan, Water Quality, Health Risk.

1. Introduction

In Jordan, the annual available renewable water resources are less than 100 m^3/c, which is significantly below the threshold limit of 500 cubic meters. It is classified as "absolute water scarcity (Kharabshah and Alzboon, 2021,). Until 2100, water stress levels are projected to increase at an average annual rate of 1.1%–1.4 %, exposing more than 90% of Jordan's low-income households to a critical water vulnerability (UNICEF, 2022).

In spite of Jordan, receiving low precipitation, rainwater is the key parameter in Jordan water budget. About 77% of the area receives less than 100 mm of rainfall, 90% of the area receives < 200 mm, and only 1.05% receives more than 500mm (Tabieh and Al-Horani, 2010.). The total average precipitation in Jordan is approximately 8.5 billion/year. However, 93 percent of this amount is lost due to evaporation (Barjenbruch and Alzboon, 2010). It was reported that the available water from all resources in Jordan is 1,034 million cubic meters per year (MCM/y), of which 886 MCM/y are renewable water resources while the remaining is nonrenewable. In contrast, the total demand of all sectors in Jordan is about 1,442 MCM/y, which indicates a deficit value of 408 MCM/y, representing 28.3% of the total demand and 46.05% of the total RWR for the year 2018 (Al Qatarneh and Al-Zboon, 2022, Alzboon et al., 2021). High water pressure makes Jordan among the most water-stressed countries and poses a significant environmental, social, and economic load on the country's development plans. The Jordanian government has long been under permanent pressure to find a long-term solution to the country's water problems. There are many options to bridge the gap between resources and demand, including water desalination, water reuse, better management, and water harvesting (Al Tabbal Jalal, et al., 2019).

Rainwater harvesting is a comprehensive process, which includes collecting, storage, and conservation of precipitation from the surface to be used later for drinking, irrigation, and domestic uses. The rainwater harvesting system depends on three components. The catchments area, in which tiled cement roofs are the most common in Jordan. The second component is the conveyance system, which includes the pipes or gutters that transport water to the storage facility, and the storage facility (wells or storage tanks (Abdulla and Al-Shareef, 2009). Rainwater harvesting (RWH) is a widely used technique for collecting and storing rainwater that falls on a catchment area and is connected directly to a cistern or well for future use (Kloss, 2008).

RWH is an ancient practice of collecting and storing rainwater from roofs and other surfaces. Perhaps one of the most effective methods currently applied in the world to conserve water resources is the application of various water harvesting techniques. This is because it has a clear positive impact in conserving large quantities of water through collecting, storing, and using it promptly for various purposes, instead of wasting it.

When the harvested rainwater is used domestically, its quality comes first. Many factors affect the quality of RWH.

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These factors include the environment, such as how close it is to heavy industry or main roads, as well as whether or not there are birds or rodents (Förster, 1998; Taylor et al.2000). Temperatures, past dry periods, and rainfall patterns are examples of meteorological conditions that also affect the quality of rainwater harvesting (Simmons et al. 2001; Van Metre and Mahler, 2003).

Rainwater harvesting has long been used in Jordan to provide water for domestic and agricultural use. Several historical examples of effective water harvesting systems still exist in the country, i.e., the Nabatean city of Petra’s cut-stone reservoirs, underground cisterns, and traditional village houses, etc. (Abdulla and Al-Shareef, 2009). About 81 % of rainwater harvesting wells are located in Irbid governorate, where rainwater harvesting is widely practiced. Approximately 34% of collected rainwater is used for drinking and cooking, while the remaining is used for watering gardens, cleaning indoor and outdoor spaces, and flushing toilets (DOS, 2004).

According to Almur (2016), adopting RWH systems has several advantages, including increasing water supply and providing safe, clean, and dependable drinking water, in addition to decreasing soil erosion and flooding. Furthermore, this technology is less expensive and environmentally a good choice for governments, especially when given the rising cost of water.

The main disadvantage of this system is that the supply is limited by the amount of rainfall and the size of the catchment area and wells. Therefore, it is not a dependable water source in dry weather and prolonged drought. Another disadvantage is the associated health risks. When a well is not properly sealed, it can become a mosquito breeding ground, and rainwater can become contaminated by air pollution, animal or bird droppings, insects, dirt, and organic matter, which may pose health risks. (Worm and Hattum, 2006).

Radaideh et al. (2009) conducted a study that aimed to assess the suitability of rainwater for domestic use, and the results showed that the water quality of these cisterns varies depending on their catchment area, location, and the availability of public sewer systems. The study found that the average concentrations of Fecal Coliform (FC), Total Coliform (TC), and Escherichia coli (E. Coli) in samples obtained from rooftop catchments were 2.4, 6.3, and 2.1 MPN/100ml, respectively. In contrast, the average concentrations in the samples collected from storage tanks with land catchments were 11.1, 24.6, and 5.2 MPN/100 ml, respectively. They concluded that RWH is unfit for drinking purposes, but it could be used for garden irrigation in residential areas.

Shubo et al. (2022) evaluated the quality of rainwater harvesting for a year, observingr several microbiological parameters such as (E. coli), total coliforms, human JC polyomavirus (JCPyV), and human adenovirus (HAdV), Group A rotavirus (RVA), and norovirus GII and GI. They reported the presence of total coliform in 44 samples (91.7%), E. coli was detected in 28 samples (58.2%), and HAdV and JCPyV were present in 10 samples (20.8%) and 6 samples (12 %), respectively. HAdV viral values ranged from 102 to 103 (GC/L), while JCPyV viral values ranged from 101 to 104. The samples contained no RVA, Norovirus GI, or GII. According to FIB, 15 of 16 samples (94%) contained compatible viruses.

Harvested rainwater was studied for microbial contamination by Chubaka et al. (2018). The analysis of 53 rainwater tanks from the Adelaide region was performed, using the Colilert TM IDEXX Quanti-Tray*/2000. The results showed that there is a relationship between the presence of television antennas in the rainwater harvesting area and the abundance of E. coli. On the other hand, neither seasonality nor the materials used in the roofs or tanks had any effect on the prevalence of E.coli. There was E.coli present in 28 out of the 53 tanks, and the levels in 10 samples were above the recommended recreational limit of 150 MPN/100 ml. Regarding the benefits of treatment, the results showed that a 0.45 µm filter cartridge was able to effectively remove all detectable levels of E. coli, down to 0 MPN/100 ml.

Al-Houri and Al-Omari (2022) evaluated the current status of RWH practices and public opinion in Ajloun governorate/Jordan. A structured questionnaire was prepared and distributed to randomly selected residents. It was reported that the amount of water that could be harvested in the dry year (2017) was about 0.40 (MCM), compared to a wet year with a volume of 0.97 MCM (2018). The results showed that rooftop rainwater harvesting in Ajloun governorate can provide 7.6% in the dry year and 16.8% in the wet year of the total water used for domestic purposes. Also, it was found that 14.2% of the households are currently practicing rooftop rainwater harvesting. Due to the high one-time investment required for the construction of RWH systems, almost all people (96.7%) agreed that the government should help in covering the cost of the system.

The present study aims to identify RWH management in the northern region of Jordan by distributing a questionnaire and interviews with 103 householders in the rural areas. The prepared questionnaire covers the type of catchment area, storage characteristics, water uses, the surrounding environment, water treatment, and complaints about water quality. The outcomes of this research will help in better improving the management of RWH and are expected to enhance public awareness about the importance of RWH which subsequently will provide a significant safe renewable source of water.

2. Methodology

2.1 Study area

Irbid Governorate is located in the northern part of Jordan, as shown in Figure 1. The Governorate covers a total area of approximately 1572 km^2 and lies on the geographical coordinates between 32° 45’ 48” and 35° 33’ 21” N and 32° 14’ 11” and 36° 4’ 36” E. It is bordered on the north by the Syrian Arab Republic, on the west by Palestine, on the east by the Mafraq governorate, and on the south by the governorates of Al-Balqa, Ajloun, and Jerash governorates. The governorate is divided into nine subregions: AL-Kasbah, AL-Ramtha, AL-Koora, Bani Kinanah, Bani Obaid, Northern Shuna, the Northern Mazar, the AL-Wastiyah, and the AL-Taibah (DOS, 2017).

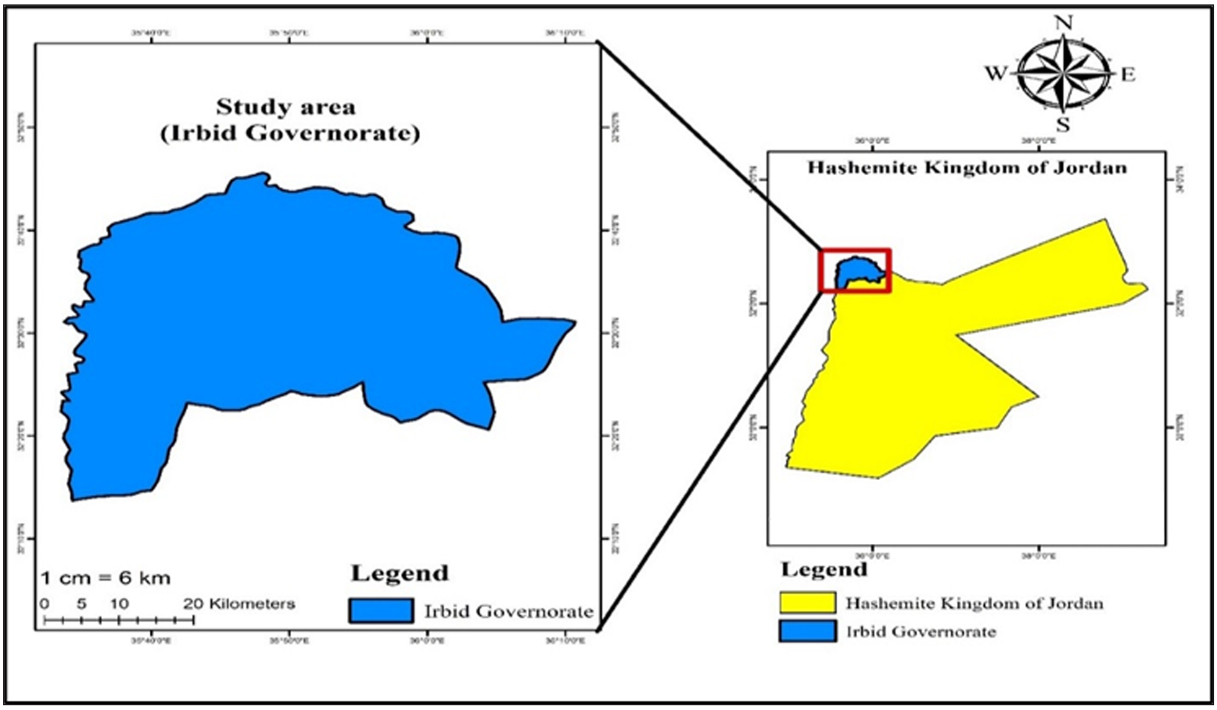

Figure 1. The Study area location.

2.2 Climate

Irbid climate, like the rest of the Levant, is a Mediterranean climate, with hot, dry summers and cold, rainy winters. In summer, temperatures reach around 35 ° C, while in winter, temperatures drop to around 5 ℃ and may drop to zero ℃, and snow rarely falls . Green grass grows, and flowers spread in the spring, especially in valleys and plains (JMD, 2022). In Irbid Governorate, the average annual precipitation ranges from 488 mm over the mountains in the west and southwest to 157 mm in the flat terrain in the east. The potential evaporation in the region ranges from 2,000 to 2,400 mm per year (Al Azzam and Al Kuisi, 2021). Figure 2 shows the cumulative rainfall of four stations in Irbid Governorate for the years 2015-2021(JMD, 2022).

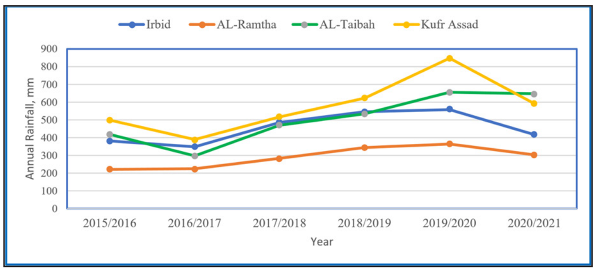

Figure 2. Cumulative rainfall period in Irbid Governorate, 2015-2021.

2.3. Materials and Method

A questionnaire was designed to assess the applied management of water harvesting in the study area. In the first round, approximately 20 questionnaires were distributed to the owners of the cisterns as a trial. This was performed to detect any weaknesses or gaps in the questionnaire. Also, the trial round would be beneficial to determine the problems that can be encountered during data collection. After that, 103 questionnaires were distributed to the targeted group of cistern owners. Yes/No questions and multiple-choice questions have been used. Personal interviews with water specialists were conducted to ensure that the questionnaire covers the required data adequately.

The questionnaire consists of three parts:

- The first part is related to demographic information, including age, education, and number of family members.
- The second part consists of questions regarding the characteristics of rainwater collection sites and a description of the surrounding environment.
- The final part comprises questions about water quality and practices related to monitoring, cleaning, complaints, and health risks.

2.4 Statistical Analysis

After the field survey, the data obtained from the answers to the questionnaires had been tabulated and analyzed using the Statistical Package for Social Sciences (SPSS) program to determine the internal interactions between the different variables that affect the rainwater harvesting management.

3. Result and Discussions

The purpose of this study was to investigate the management practices of rainwater collection from rooftops and home yards in Irbid Governorate. It also examined the characteristics of the collected rainwater, the description of the surrounding environment, and the level of residents' awareness of the factors that impact the quality of the collected rainwater.

3.1 Characteristics of the cisterns

To investigate the characteristics of the rainwater harvesting sites and to describe the surrounding environment, a descriptive statistical analysis was conducted, and the results are shown in Table 1. It was found that most of the cisterns (43.7%) have been built during the last 15 years.

This indicates the increase in population awareness of the importance of water harvesting. This may also be seen as result of the governmental programs and public awareness which encouraged residents to build water cisterns. Climate change, combined with water scarcity may be the driving force for more attention to water harvesting.

It was found that about 83.5% of the cisterns have capacities of less than 50 m^3. The larger capacity means a higher cost of construction, which may explain the smaller size of cisterns in the study area, especially for low-income households. According to the long-term metrological data, the average precipitation in the study area ranged between 221-621 mm/y, and only 60% can be harvested (0.132-0.372 m^3/m^2 of the rooftop area), so most of the cisterns are not filled during dry seasons.

As for well construction, there are mainly two methods of cisterns construction. The first is constructed using a capsulated box of reinforced concrete either underground or above ground surface. The second type is a pear-shaped cistern that is usually excavated in rocky soils. While concrete type can be built in most types of soil, rock-cut type is excavated in rocky soil. The concrete type is more costly, but it is more popular due to its reliability, durability, and it is easier to clean. This explains why 60.2% of the householders prefer concrete cisterns. Even though the rock-cut type has lower cost than the concrete type, some households are reluctant to use them due to potential leakages, which explain their limited use.

Regarding the catchment area, more than 72% of the households are relying on rooftops as a source of rainwater, while 25.2% depend on home yards. Previously, there were wide non- constructed areas which were used for rainwater harvesting. Nowadays, most of the urbanized areas are covered with houses and buildings. This population density explains the higher percentage of using rooftops as a source of rainfall water. Also, the collection of rainwater from rooftops is easier and no additional investment is required.

Table 1. Characteristics of the cisterns.

Category		Percent, %
The age of the cistern, year	(1-15)	43.7
	(15-30)	25.2
	> 30	31.1
Well capacity, m^3	< 30	36.9
	(30-50)	46.6
	> 50	16.5
Well type	Concrete	60.2
	(pear-shaped well)	37.9
	Tanks	1.9
Catchment area	rooftop	72.8
	home yard	25.2
	other	1.9

3.2 Sources of water inside the well

The results of the questionnaire analysis showed that 58% of the study population use collection wells to harvest rainwater separately. Meanwhile, 14.6% reported that they depended only on municipal water to fill the cistern. The rest (25.2%) resorted to filling the cistern with both municipal and rainwater. When the rainy season ends, the owners might use cistern for storage of municipal water and tankers which might be used in case of insufficient supply of municipal water. About (68.9%) of the study population pump water from the cisterns to the rooftop tanks and, then, use it, while the rest pump it directly to the indicated purpose.

3.3 Harvested rainwater uses

The results of the field survey revealed that 43.7% of the cisterns' owners use the water for all purposes including drinking. while 23.3%, 18.45%, and 10.7% of households use water for irrigation, washing, and cooking, respectively as shown in Table 2. Most people, especially in rural areas, strongly believe that rainwater is clean and suitable for all purposes. In contrast, some people, mainly in the cities, consider that rainwater can only be used for irrigation, cooking, and washing but not suitable for drinking.

Table 2. Uses of RWH.

Sources of cistern water	Frequency	Percent, %
Rainwater	60	58.3
municipal water	15	14.6
Rainwater + municipal water	26	25.2
Other	2	1.9
Total	103	100.0

3.4 Description of the surrounding environment

To determine the relationship between water quality and the surrounding environment, a descriptive analysis was carried out for the considered samples. The results of the questionnaire in Table 3 showed there were trees near 55.3% of the cisterns, and most of these trees were olives (45.6%), citruses (26.3%), and other types (28.1%). The roots of the trees may penetrate the cistern walls and cause water leakage from the cistern or contamination of water by organic and other contaminants. Also, the presence of trees may become an attractive habitat for birds which may increase the contamination of water by animal waste. Additionally, harvested water may become contaminated by the leaves of trees, applied fertilizers, and pesticides.

A conducted research revealed that just 8.7% of households owned pet animals, including chickens and rabbits, within their backyards. On the other hand, 13.6% of households reported that their neighbors owned such pets. The practice of keeping pets in backyards may result in the contamination of water due to animal waste.

The field survey found that there are floating materials in 51.5% of the cisterns, and there is a significant correlation between the presence of trees and the floating materials in water ($P < 0.05$).

Table 3. Characteristics of the surrounding environment.

Parameter				Count	Percent, %
Are there trees near the well.	Yes	If there are trees nearby, mention their type	Olive trees	26	45.6%
			citrus trees	15	26.3%
			Other	16	28.1%
	No		I do not have	46	100.0%
Do you raise pets or animals near the well?	Yes			9	8.7%
	No			94	91.3%
Do the neighbors raise animals near the well?	Yes			14	13.6%
	No			89	86.4%
The presence of waste	Yes			20	19.4%
	No			83	80.6%
Do you notice floating impurities	Yes			53	51.5%
	No			50	48.5%

3.5 Complaints about water quality

According to the results, a small percentage of respondents (12.6%) reported that someone in their family had complained about the water, with only (4.9%), reporting a visit to the hospital due to these complaints. The most commonly reported complaints were a change in the taste of the water (4.9%), abdominal pain (3.9%), and the presence of impurities (2.9%).

3.6 Awareness of water quality

Public awareness of water quality depends on many socioeconomic parameters including education, awareness programs, income, uses of RWH, and the surrounding environment. About 84.5% of respondents reported cleaning the roof of their house before the rainy season, suggesting that this is a common practice among the study population. During the dry season, the roof may be contaminated due to air pollution, dust, birds, and other sources. For this reason, it is necessary to clean the roof before the rainy season starts to ensure getting clean RWH. Most households (66.0%) clean the cistern and get rid of the remaining water for irrigation, of which 47.6% clean the cistern annually while 54.4% clean it biannually. A small percentage (24.3%) of the owners conducted a visual inspection of water quality inside the cistern while 75.7% didn't check. The results also showed that only 26.2% of the owners added chlorine to the cistern to control the biological growth. Based on the field survey, the identified sources of contaminants are the presence of trees and waste near the cistern, raising of animals and the cleanliness of the rooftop and the cistern. These results indicated that most people are aware of cleaning the rooftop and the cisterns while most of them are not aware of the continuous monitoring of water quality, sources of contamination, and the necessity of disinfection.

Table 4. Some indicators of public awareness.

Parameter	Answer	Percent, %
The presence of waste near the cistern	Yes	19.4%
	No	80.6%
Clean the well and get rid of the remaining water	Yes	66.0%
	No	34.0%
Is the roof of the house cleaned before the rainy season?	Yes	84.5%
	No	15.5%
Do you notice floating impurities?	Yes	51.5%
	No	48.5%
Have you ever done checks for the water quality of the well?	Yes	24.3%
	No	75.7%
Do you raise pets or animals near the well?	Yes	8.7%
	No	91.3%
Add chlorine and other materials	Yes	26.2%
	No	73.8%

4. Conclusion

Rainwater harvesting represents an attractive option to bridge the gap between supply and demand in Jordan and one of the key elements in climate change control. This study attempted to shed light on rainwater harvesting from rooftops and yards and collecting it in cisterns. A questionnaire was distributed for the owners of the cistern to assess harvested water management in the study area.

The statistical package for the social sciences (SPSS) program was used for statistical analyses. Based on the obtained results and the field survey, the following points can be concluded:

1. Water harvesting represents a significant source of water in the study area.
2. Mots of householders are interested in water harvesting, but some do not apply that due to financial constraints.
3. The presence of trees in the household yard and raising animals have significant impact on water quality.
4. Most of the owners clean the rooftop before the first rainwater splashes.
5. It is necessary to conduct a national public awareness program for management of water harvesting including emphasizing the importance of RWH, the quality of RWH, and the best practices that should be taken by households.

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Conflicts of interest

The authors declare noconflict of interest

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