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A Review on Water Quality Aspects of Urban Rainwater Harvesting in Jordan

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Abstract
Rainwater harvesting has regained importance in light of increasing water scarcity, particularly in arid and semi-arid regions such as Jordan, as it can be utilized for a variety of uses, including drinking and irrigation. However, the quality of harvested rainwater is of vital importance in determining its intended use, as it may be vulnerable to contamination from different sources during its journey from the atmosphere to storage facilities. Several studies have investigated the water quality issues of the rainwater harvesting system in Jordan, including the quality of direct rain, runoff water, and stored water in cisterns. The factors affecting water quality were also investigated. This paper reviews the rainwater quality harvesting systems in Jordan. The findings revealed that microbial contaminants were frequently reported, exceeding the allowable limits set by the Jordanian standard for drinking purposes. In contrast, direct rain was found to be of better quality. Despite the importance of organic and emerging contaminants in recent water research, minimal attention has been paid to these contaminants. Future research should also focus on options for improving water quality, such as prior treatment measures.

Keywords: *Water harvesting, Direct rain, Runoff, Cistern, Water quality, Contamination, Irrigation, Drinking, Water quality standards.*

1. Introduction

Jordan is one of the countries with the most severe water scarcity worldwide, with renewable freshwater resource availability of only 61 m^3 per capita by 2021 (Ministry of Water and Irrigation, 2023). This scarcity level is primarily attributed to the arid to semi-arid climatic conditions that prevail in the country, with 80% of Jordan receiving an average annual rainfall of less than 100 mm (Hadadin et al., 2010).

Rapid population growth in recent years, due to both natural growth and immigration, has further exacerbated the water scarcity situation (Al-Shibli et al., 2017; Food and Agriculture Organization of the United Nations (FAO), 2016). This increase in water scarcity has resulted in increasing pressure on the limited availability of water resources and a corresponding continuous decrease in per capita access to safe and reliable supplies of potable water.

To address this issue, Jordan has implemented various strategies and plans, including promoting the use of non-conventional water resources, such as the expansion of the reuse of treated wastewater in agriculture, desalinated seawater, and investing more in rainwater harvesting in rural and urban areas, particularly from rooftops (Ministry of Water and Irrigation, 2016). Rainwater harvesting is a traditional, common, and socially acceptable solution for Jordanian communities, and has been widely practiced throughout history for irrigation and water supply.

Rainwater harvesting is the process of collecting and storing rainwater in tanks and other storage facilities. Thereby, roof runoff water refers to the flow of water that is generated when rain falls on the rooftop of a building and then moves downward through the gutters into a tank or cistern, whereas ground or surface runoff is generated when rain falls on urban ground such as roads, parking lots, courtyards, pavements, and other impervious surfaces. The collected rainwater can be used for different domestic and non-domestic purposes, such as drinking, washing, cleaning, toilet flushing, and irrigation. However, the quality of the collected rainwater is crucial because it is a limiting factor in determining its intended use. Contrary to the common belief that rainwater is pure and uncontaminated, research has revealed that rainwater can contain a wide variety of contaminants, such as physical, chemical, microbiological, organic compounds, trace, and heavy metals, as well as emerging contaminants (i.e., pharmaceutical, and personal care product residues, pesticide residues, microplastics, per- and poly-fluoroalkyl substances (PFAS), and others) (Deng, 2021). This is because there are many potential sources of contamination to which rainwater can be exposed during its journey from the atmosphere to the roofs and storage facilities.

Throughout the years, many studies in Jordan have explored the water quality of urban rainwater harvesting systems in terms of the main sources of contamination, chemical composition, and potential use of water. However, there remains a lack of comprehensive overviews. Therefore, there is a need to provide a holistic picture of published articles on the water quality of urban rainwater harvesting systems, with a focus on evaluating and reviewing the findings and identifying gaps in the research in this field, which can be beneficial for researchers, scientists for future

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research, and policymakers.

This paper presents a systematic literature review that addresses the water quality, collected through urban rainwater harvesting systems, more specifically, the main sources of contamination and the chemical composition and potential uses of water. The present review includes 21 studies that were published in international databases, followed by a narrative and quantitative data synthesis and suggestions for further studies.

2. Materials and Methods

2.1 Search strategy

The search for articles was conducted using the following bibliographic databases: ScienceDirect, Springer, EBSCOhost, ProQuest, WorldCat, and Worldwide Science. The searches were also performed using Google Scholar, which included relevant articles that were not recorded in bibliographic databases. The search used specific keywords and terms related to urban rainwater harvesting (Figure 1).

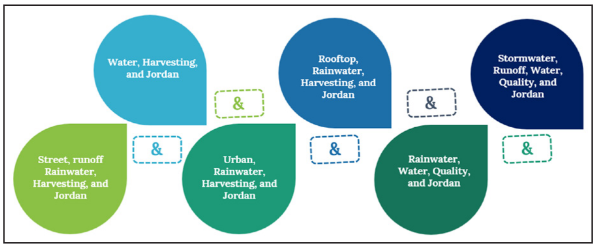
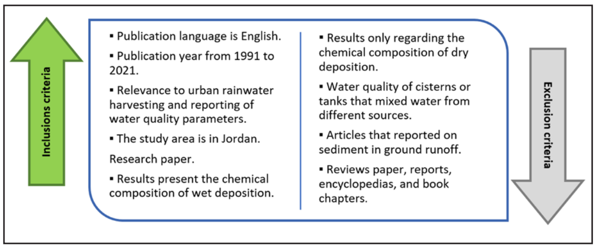


Figure 1. Specific keywords used in the search of bibliographic databases.

2.2 Inclusions and exclusion criteria of research articles

Explicit inclusion and exclusion criteria were set to screen the search and select articles. These criteria outlined the specific characteristics that the articles needed to be included in the review, such as publication date, language, and relevance to the research topic (Figure 2).



- Publication language is English.
- Publication year from 1991 to 2021.
- Relevance to urban rainwater harvesting and reporting of water quality parameters.
- The study area is in Jordan.

Research paper.

- Results present the chemical composition of wet deposition.

- Results only regarding the chemical composition of dry deposition.
- Water quality of cisterns or tanks that mixed water from different sources.
- Articles that reported on sediment in ground runoff.
- Reviews paper, reports, encyclopedias, and book chapters.

Figure 2. Inclusions and exclusion criteria

2.3 Extraction, synthesis, and presentation of data

Twenty-one articles were selected based on the inclusion criteria described above. Unique Identification Codes (IDs) from WQ-1 to WQ-21 were assigned to these articles, which were then grouped into four main water quality (WQ) categories according to the investigated water quality: rainwater, roof runoff, ground runoff, and stored water in cisterns. Out of each article, information about the authors, year of publication, study area, average annual rainfall amount, source of tested water, sampling period, number of samples, investigated factors, and conditions, was extracted and summarized in tables in the supplementary material.

In a quantitative synthesis, the reported average concentrations of water quality variables were extracted and tabulated in an Excel spreadsheet for each WQ category. Thereafter, the reported water quality variables were converted to the same units as stated in Jordanian standards for drinking and irrigation water. Basic descriptive statistics (including minimum, maximum, average, and count values) were calculated and tabulated for each investigated water quality variable. Subsequently, the extracted values of the water quality parameters for each WQ category were compared with the limits specified in the Jordanian standards for drinking and irrigation. For this purpose, the percentage of compliance with drinking and irrigation standards for physical, chemical, microbial, trace, and heavy metals was calculated, and water quality parameters that exceeded the standard limits were identified. Additionally, the ionic balance was calculated for all the reported anions and cations in each study to ensure analytical quality (the results are available in the supplementary materials). In a qualitative synthesis, the potential factors that affect the quality of rainwater, roof runoff, ground runoff, and water stored in the cistern were discussed. Figure 3 summarizes the extraction, synthesis, and presentation processes of the data.

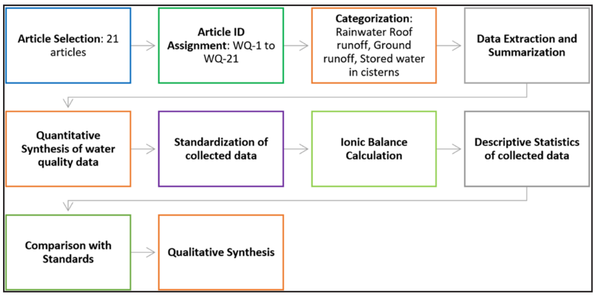


Figure 3. The flowchart for the process of extraction, synthesis, and presentation of data

3. Results and Discussion

The following sections present a meta-analysis of the results, collected from the selected studies regarding the study areas, the investigated water quality parameters, and the investigated water sources. This section also includes a discussion of the factors that affect different water quality parameters and a comparison with Jordanian standards to assess the suitability of rainwater harvesting for drinking and irrigation purposes. However, the comparison between different water quality categories was not conducted due to the heterogeneity of test methods and units, as well as the limited number of results for each WQ parameter, which precludes statistical analysis.

3.1. Characteristics of reviewed articles

The investigated locations in the reviewed articles revealed the following frequency: Amman was the most frequent, followed by Irbid, Jerash, and Maan. After that, Ajloun and Karak had equal frequencies, and, then, Zarqa and Mafraq had the same frequency as well (Figure 4). Most studies focused on the quality of rainwater rather than on runoff and rainwater stored in the cisterns. Studies, investigating the quality of harvested rainwater in cisterns, mainly focused on the northern and middle parts of Jordan, particularly Irbid, Ajloun, Jerash, Zarqa, and Amman. This focus can be attributed to the spatial variation of rainfall amounts in Jordan, where the western, northern, and middle regions receive higher amounts of rainfall, whereas the eastern and southern regions receive less (Tarawneh and Şen, 2012). Thus, rainwater harvesting systems at the household level are more common in northern and central Jordan. According to the 2015 Jordan National Census, the Irbid Governorate had the highest percentage of houses that depended on water harvesting as their main source of drinking water (21%), followed by the Ajloun Governorate (Figure 4).

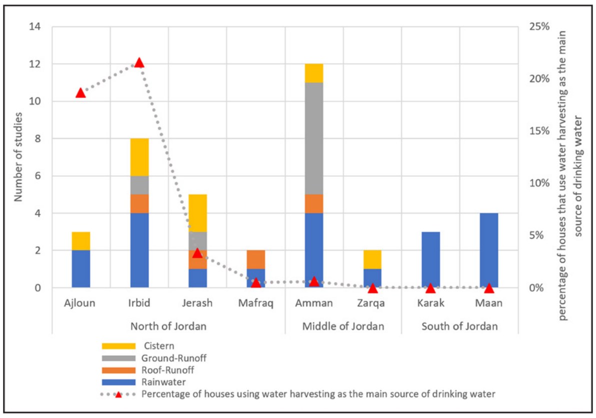


Figure 4. Distribution of study areas in the reviewed articles within Jordanian governorates, water type, and percentage of houses that use water harvesting as the main source of drinking water (Department of Statistics (DOS), 2015).

Chemical water quality parameters, such as pH, Chloride (Cl), Total Dissolved Solids (TDS), Electrical conductivity (EC), Sulfate (SO_4), Calcium (Ca), Magnesium (Mg), Sodium (Na), and Potassium (K), received most attention in the reviewed articles, as indicated in Figure 5. For the heavy metals, the focus was on lead (Pb) and iron (Fe). In terms of microbial indicators, faecal coliforms were the most often tested, as they are considered a better indicator of animal or human waste than total coliforms. Overall, microbial indicators were mainly examined in rainwater stored in cisterns rather than in rainfall or runoff water. Organic compounds (polycyclic aromatic hydrocarbons (PAHs), dissolved organic compounds (DOC), and others) were only investigated in two articles on ground runoff water and direct rain.

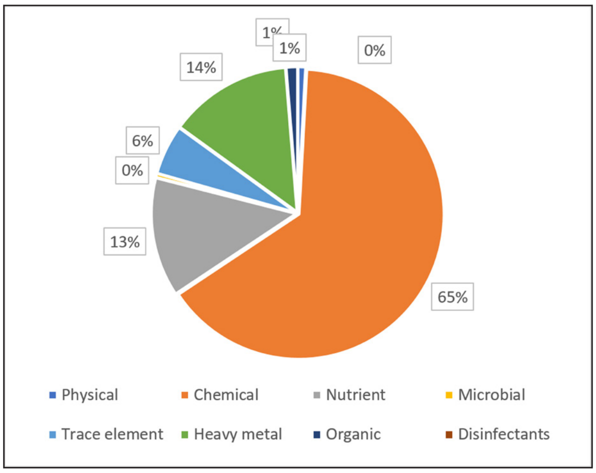


Figure 5. Categorization of water quality parameters reported in reviewed articles.

Figure 6 shows a mind map of the distribution of the selected articles according to the investigated water source, where most of the selected articles focused on assessing the quality of rainwater (direct rain). Only a few studies, such as those conducted by Al-Amoush et al., (2018); Almanaseer (2019) compared rainwater quality with roof runoff. Jiries et al. (2003) compared the quality of rainwater with ground runoff water, whereas Awawdeh et al. (2012) compared the quality of roof runoff with ground runoff water.

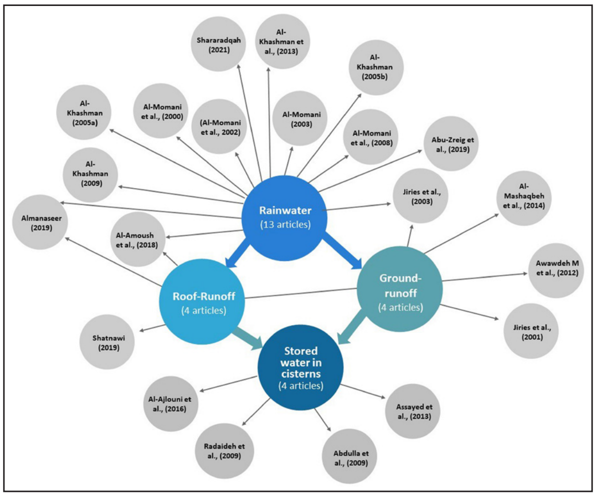


Figure 6. Mind map of the distribution of selected articles according to the investigated water sources.

3.2. Investigated factors affecting the quality of rainwater harvesting categories.

3.2.1 Rainwater (direct rain)

The quality of direct rain was a major concern in the selected articles, and several factors were found to have an impact. The reviewed studies mainly focused on the impact of rainfall event characteristics, anthropogenic sources, and natural sources. For rainfall event characteristics, temporal variations in rainwater quality during the rainfall season were observed, with elevated concentrations in all investigated water quality parameters at the beginning of the rainfall season. These elevated concentrations were attributed to the accumulation of large amounts of dust and contaminants in the atmosphere during the dry summer period, which were scavenged by rainfall (Abu-Zreig et al., 2019; Al-Khashman 2005b, 2009; Al-Khashman et al., 2013; Jiries et al., 2003). The number of rainy days and rain events was also found to be a decisive factor affecting rainwater chemistry, whereas the non-continuity of rain events, followed by dry days, resulted in the release of pollutants into the atmosphere before the next event (Al-Momani et al., 2002).

Studies on the natural sources, conducted by Al-Khashman (2005b, 2005a, 2009); Al-Khashman et al., (2013); Al-Momani (2003); Al-Momani et al. (2000, 2002), found that atmospheric neutralization processes were the main factors contributing to neutral or alkaline pH in rainwater samples. These processes were attributed to local alkaline dust that contained large amounts of Calcium carbonate ($CaCO_3$), calcite, and dolomite. In addition, the studies, conducted by Al-Momani (2003) and Al-Momani et al. (2000, 2002, 2008) highlighted the impact of Saharan soil dust, which was indicated by the high concentrations of calcium (Ca) in rainwater samples. The Dead Sea also affected the chemical composition of rainwater, particularly in areas closest to the Dead Sea (Al-Khashman (2005b, 2009); Al-Khashman et al., 2013; Shararadqah 2021). Sulfate (SO_4) was attributed to both natural and anthropogenic sources (Al-Momani et al., 2000, 2002, 2008).

Regarding the influence of anthropogenic sources, agricultural activities were identified as influencing factors to rainwater chemistry, particularly in the area close to the Jordan Valley (Ghour), with fertilizers as a potential source of high concentrations of Ammonium (NH_4) and Nitrate (NO_3) (Al-Khashman (2005a, 2009); Al-Khashman et al., 2013; Al-Momani et al., 2000; Shararadqah 2021). Al-Khashman (2009) found that agricultural activities affected rainwater quality throughout the year. Local industries, such as cement and phosphate mining activities, refineries, thermal power stations, wastewater treatment plants, solid waste landfills and other light industries, were also identified as potential sources that influence the chemical composition of rainwater, particularly in terms of trace and heavy metal content (Al-Khashman (2005b, 2009); Al-Khashman et al., 2013; Al-Momani et al., 2002). Road traffic emissions and fuel consumption also led to high concentrations of Nitrate (NO_3) in rainwater samples (Al-Khashman 2009; Al-Momani et al., 2000; Shararadqah 2021). Al-Momani (2003) reported that heavy metal concentrations in rainwater, particularly Lead (Pb) and, Zinc (Zn), could be related to road traffic sources, whereas Al-Amoush et al., (2018) attributed heavy metal concentrations in rainwater samples to industrial emissions. Heating activities during the cold period were also identified as anthropogenic sources of heavy and trace metals in rainwater (Al-Khashman 2005b; Al-Khashman et al., 2013).

Also in a worldwide context, rainwater chemistry varies between different geographical locations. According to Keresztesi et al., (2020), anthropogenic activities, including coal-fired power plants, oil refineries, significant industries, agricultural activities, terrestrial sources, and marine sources, had an impact on the chemical composition of precipitation in contemporary United States. Due to the buildup of significant amounts of dust in the atmosphere that rain scavenges, Chakrabortyand Gupta (2018) conducted a study in India and discovered that rainwater had the highest concentration of contaminants at the start of the rainfall season. In addition, industrial activities, vehicular emissions, and other anthropogenic activities were found to affect Indian rainwater quality. On Upolu Island, Imo et al., (2021) revealed that marine sources had a larger influence on rainwater composition than anthropogenic and terrestrial sources. In China, Zengand Han (2021) identified terrestrial sources (dust) and anthropogenic emissions (long-distance transport) as the main factors influencing rainwater quality in Guiyang City, China. According to research by Rivera-Rivera et al., (2020), the characteristics of air masses, local transportation, regional advection, and the solubility of trace metals all have a significant impact on the quality of rainwater in Mexico City.

3.2.2 Roof -runoff water

In Jordan, less attention was paid to factors that influence the quality of roof runoff (the impact of roof materials and first flush only) compared to direct rain. The impact of roof materials on water quality was studied by Al-Amoush et al., (2018). They found that runoff from metal insulation had the lowest water quality, followed by mixed concrete, mixed asphalt, concrete, water, seal coat, roll asphalt, and thermal insulation. Almanaseer (2019) reported the effects of the first flush by contrasting the quality of roof runoff water between the first and second storms. The results revealed that the water quality improved in the second storm owing to the wash-off of accumulated substances and dust from the roof. Shatnawi (2019) examined the relationship between the length of the dry period before rainfall and the runoff water quality and found that this was not significant. She then successfully tested a manually designed filtration system to reduce turbidity and suspended solid levels.

International studies provide a broader view of roof runoff quality. According to Förster (1996), decisive factors include roof material (chemical characteristics, roughness, surface coating, age, weather ability, etc.), the physical boundary condition of the roof (size, inclination, and exposure), precipitation event intensity, wind, pollutant concentration in the rain, and other meteorological factors (season, weather characteristics, and antecedent dry time). In addition, the chemical properties of the pollutants (vapor pressure, solubility in water, Henry's constant, etc.), concentrations of pollutants in the atmospheric boundary layer (emission, transport, half-life, phase distribution, etc.), and location of the roof (proximity to pollution sources) were found to affect water quality. Furthermore, the age of the roof and the operation and maintenance strategy of the catchments were found to have a significant influence, as reported by Meera and Ahammed (2018); Emmanuel et al., (2021).

3.2.3 Ground runoff water

Factors, affecting Jordanian ground runoff water quality, were discussed in two studies. Al-Mashaqbeh et al. (2014) found that a higher traffic density in an urban area led to higher concentrations in organic pollutants and heavy metals compared to rural areas. There, the use of chemical and natural fertilizers in agriculture could be attributed to higher levels of total suspended solids, nutrients, and microbial indicators. Jiries et al. (2001) reported that anthropogenic activities and vehicle emissions were contributing factors in lowering the quality of street runoff water in the city center area of Amman as compared to residential areas. Thereby, high concentrations of all constituents, including polycyclic aromatic hydrocarbons (PAHs), were most prominent in the first rainy month of sampling, mainly due to low rainfall and a protracted dry period (Jiries et al., 2001, and 2003).

In worldwide studies, land use was found to significantly influence runoff water quality, such as the case in the capital state of Kuwait (Al-Jaralla and Al-Fares, 2009). More specifically, the ratio of agricultural area to total land use area was identified as the main contributing factor in the Geum River Basin, Korea (Kim et al., 2007). Nearby, Lee et al. (2016) identified the main sources of runoff pollution in the Geumhak watershed to be agrochemicals and road traffic, apart from groundwater, native soils, domestic sewage, and other urban sources.

3.2.4 Stored water in cisterns

In Jordan, Radaideh et al. (2009) found a significant impact of geographical location and rainfall intensity on water quality in cisterns. Abdulla et al. (2009) reported that rainfall intensity and the number of dry days preceding a rainfall event significantly affected the quality of harvested rainwater. Al-Ajlouni, et al. (2016) observed higher contamination of samples when they were collected shortly after rain.

Radaideh et al. (2009) found that cistern water harvested from rooftops generally tended to have better quality than water collected from other catchment areas, because the latter were exposed to many additional contamination sources, including fertilizers, pesticides, chicken and livestock manure, dissolved minerals, sediments, sewage, decaying plants, algae, bacteria, and detergents. Yet, Assayed et al. (2013) identified fecal deposits from birds on roofs as a possible source of microbial contamination. According to both Assayed et al. (2013) and Radaideh et al. (2009), microbial contamination was more likely when the rainwater tanks were situated near cesspits. Finally, using a rope and bucket to retrieve water from the cistern could cause microbial contamination (Assayed et al., 2013).

It is generally important to ensure that stored water stays safe for consumption, particularly for drinking and other domestic purposes. Therefore, a set of recommendations and measures were suggested by Abdulla et al., (2009), which included chlorinating the stored water at least once per rainy season, cleaning the catchment area before the start of the rainy season and raising awareness on the importance of regular cistern maintenance to prevent contamination.

Worldwide literature has identified additional factors affecting the quality of cistern waters. Despins et al. (2009) revealed that the water stored in plastic tanks tended to have a slightly acidic pH, whereas the water in concrete tanks was more alkaline. Similarly, Simmons et al. (2001) found that water stored in ferrocement tanks tends to have higher pH values. Furthermore, Despins et al. (2009) found that some tank materials might affect water quality by leaching chemicals (e.g., metal from metal tanks and organic compounds from plastic tanks). Thereby, warmer temperatures may accelerate the rate of metal leaching from galvanized iron tanks (Martin et al., 2010). Both Abbasi and Abbasi (2011) and Sung et al. (2010) found that the cistern water quality tended to decline as the storage period increased.

Abbasi and Abbasi (2011) suggested extracting water from the top of the tank to avoid disturbing sediments at the bottom, where water tended to be the dirtiest. They additionally recommended tank designs with overflows that flush the dirtiest water at the bottom. Lee et al. (2010) and Meeraand Ahammed (2006) also suggested diverting the first flush of rainfall away from the rainwater harvesting system. Several researchers indicated that regular maintenance and cleaning of catchment surfaces, gutters, and storage tanks can improve cistern water quality (Domènechand Saurí 2011; Lee et al., 2010; Meeraand Ahammed 2006).

4. Suitability of rainwater harvesting categories for drinking and irrigation purposes according to Jordanian standards

4.1 Rainwater (direct rain)

In general, 86% of the reported water quality parameters were within the allowable limits for drinking water in Jordan (Table 1). Exceptions included pH values, reported by Al-Momani et al., (2000), turbidity values reported by Abu-Zreig et al., (2019), and the Ammonium (NH_4) values reported by Al-Khashman (2005a, 2005b, 2009), (Al-Khashman et al., (2013); Al-Momani (2003); Al-Momani et al., (2000). For trace and heavy metals, the Aluminum (Al) concentrations, reported by Al-Khashman et al. (2013), Al-Momani (2003), and Al-Momani et al. (2000) exceeded the standard limit, as did the lead (Pb) values, reported by Al-Khashman et al. (2013) and Al-Momani (2003). For irrigation purposes, all reported values of the water quality parameters were within the limits of the standard, except for the Cadmium (Cd) value reported by Al-Momani (2003).

4.2 Roof runoff water

For drinking purposes, 86% of the reported water quality parameters in the reviewed articles were within the Jordanian standard limits (Table 2). Exceptions were the turbidity value, reported by Shatnawi (2019) and nitrate concentrations reported by Awawdeh et al., (2012). In addition, the reported lead (Pb) concentrations, reported by Awawdeh et al. (2012), were higher than the maximum standard limit. Regarding irrigation use, 71% of the investigated water quality parameters were suitable for all irrigation purposes. 82% of these values were suitable for both a slight to moderate degree of restricted irrigation and severely restricted irrigation, and 92% were suitable for severely restricted irrigation (Table 2). Prominent exceptions include the Total Suspended Solids (TSS) value, reported by Shatnawi (2019), which was only suitable for a severe degree of restricted irrigation and the Sodium (Na) and Bicarbonate (HCO_3) values by Al-Amoush et al., (2018) which were suitable for both slightly to moderately restricted irrigation and severely restricted irrigation. The Nitrate (NO_3) value, reported by Awawdeh et al. (2012), was only suitable for severely restricted irrigation, whereas the value of Zinc (Zn), reported by Awawdeh et al. (2012), exceeded the allowable limit for all irrigation purposes.

Table 1. Summary for the compliance of the quality of rainwater (direct rain) with the Jordanian standards

Jordanian Standards		% of compliance with water quality parameters	Rainwater (Direct rain)
Drinking water standard (JS 286:2015)		Physical and chemical parameters	83%
		Microbial parameters	Not investigated
		Metals and other parameters	88%
		Overall WQ parameters	86%
		Exceeded WQ parameters	pH, Turbidity, NH_4, Al, Cd, Pb
Irrigation water quality guideline (JS 1766:2014)	Non-restricted	Physical and chemical parameters	100%
		Microbial parameters	Not investigated
		Metals and other parameters	98%
		Overall WQ parameters	99%
		Exceeded WQ parameters	Cd
	Slight to moderate degree in restriction	Physical and chemical parameters	100%
		Microbial parameters	Not investigated
		Metals and other parameters	98%
		Overall WQ parameters	99%
		Exceeded WQ parameters	Cd
	Severe degree in restriction	Physical and chemical parameters	100%
		Microbial parameters	Not investigated
		Metals and other parameters	98%
		Overall WQ parameters	99%
		Exceeded WQ parameters	Cd

Table 2. Summary of the compliance of the quality of roof-runoff with the Jordanian standards

Jordanian Standards		% of compliance with water quality parameters	Roof Runoff water
Drinking water standard (JS 286:2015)		Physical and chemical parameters	83%
		Microbial parameters	Not investigated
		Metals and other parameters	90%
		Overall WQ parameters	86%
		Exceeded WQ parameters	Turbidity, NO_3, Pb
Irrigation water quality guideline (JS 1766:2014)	Non-restricted	Physical and chemical parameters	74%
		Microbial parameters	Not investigated
		Metals and other parameters	80%
		Overall WQ parameters	71%
		Exceeded WQ parameters	TSS, NO_3, Na, HCO_3, Zn
	Slight to moderate degree in restriction	Physical and chemical parameters	81%
		Microbial parameters	Not investigated
		Metals and other parameters	80%
		Overall WQ parameters	82%
		Exceeded WQ parameters	TSS, NO_3, Zn
	Severe degree in restriction	Physical and chemical parameters	100%
		Microbial parameters	Not investigated
		Metals and other parameters	80%
		Overall WQ parameters	92%
		Exceeded WQ parameters	Zn

4.3 Ground runoff water

The assessment of this category was limited to irrigation purposes only, as this type of water was not considered an appropriate source for drinking without prior treatment. Still, only 36% of the values were suitable for all irrigation purposes, 59% were suitable for a slight to moderate degree of restricted irrigation and a severe degree of restricted irrigation, and 66% were suitable for a severe degree of restricted irrigation (Table 3). The electrical conductivity (EC) values for street runoff water at Amman's city center were only suitable for restricted irrigation (Jiries et al., 2001), whereas the Total Suspended Solids (TSS), Chemical oxygen demand (COD) and Biochemical oxygen demand (BOD_5) values at another urban site in Amman were suitable for slightly, to moderately, but mostly only for severely restricted irrigation (Al-Mashaqbeh et al., 2014). For the metal concentrations, the values, reported by Al-Mashaqbeh et al.

(2014) and Awawdeh et al. (2012) were within the irrigation guidelines, whereas the values for all metals in street runoff water in the study conducted by Jiries et al. (2001) exceeded the limits for all irrigation purposes. According to microbial indicators, ground runoff at an urban site of Amman was only suitable for severely restricted irrigation, whereas a rural site of Jerash was more suitable for irrigation (Al-Mashaqbeh et al., 2014).

Table 3. Summary of the compliance of the quality of ground runoff water with the Jordanian standards

Jordanian Standards		% of compliance with water quality parameters	Ground runoff water
Irrigation water quality guideline (JS 1766:2014)	Non-restricted	Physical and chemical parameters	43%
		Microbial parameters	0%
		Metals and other parameters	33%
		Overall WQ parameters	36%
		Exceeded WQ parameters	EC, TSS, COD, BOD_5, NO_3, HCO_3, Na, Cl, Pb, Cu, Mn, Cr, Fe, Ni, Cd, *E. coli*
	Slight to moderate degree in restriction	Physical and chemical parameters	81%
		Microbial parameters	50%
		Metals and other parameters	33%
		Overall WQ parameters	59%
		Exceeded WQ parameters	TSS, COD, NO_3, Pb, Cu, Mn, Cr, Fe, Ni, Cd, *E. coli*
	Severe degree in restriction	Physical and chemical parameters	95%
		Microbial parameters	50%
		Metals and other parameters	33%
		Overall WQ parameters	66%
		Exceeded WQ parameters	Pb, Cu, Mn, Cr, Fe, Ni, Cd

4.4 Stored water in cisterns

In general, 78% of the reported water quality parameters were within the allowable limits of the drinking water standard (Table 4). Exceptions include the pH value, reported by Assayed et al. (2013) and the lead (Pb) value, reported by Radaideh et al., (2009). In terms of microbial indicators, most of the reported values for total coliforms, fecal coliforms, and Escherichia coli (E. coli) exceeded the maximum limits of the standard. For compliance with the irrigation guideline, all the reported physical and chemical, microbial, and heavy metal parameters were within the allowable ranges in the guidelines for different irrigation aspects (non-restricted, slight to moderate degree of restriction, and severe degree of restriction).

Table 4. Summary of the compliance of the quality of stored water in cisterns with the Jordanian Standards

Jordanian Standards		% of compliance with water quality parameters	Stored water in cisterns
Drinking water standard (JS 286:2015)		Physical and chemical parameters	98%
		Microbial parameters	6%
		Metals and other parameters	92%
		Overall WQ parameters	78%
		Exceeded WQ parameters	pH, total coliforms, Fecal coliforms, E. coli, Pb
Irrigation water quality guideline (JS 1766:2014)	Non-restricted	Physical and chemical parameters	100%
		Microbial parameters	100%
		Metals and other parameters	100%
		Overall WQ parameters	100%
		Exceeded WQ parameters	**None**
	Slight to moderate degree in restriction	Physical and chemical parameters	100%
		Microbial parameters	100%
		Metals and other parameters	100%
		Overall WQ parameters	100%
		Exceeded WQ parameters	**None**
	Severe degree in restriction	Physical and chemical parameters	100%
		Microbial parameters	100%
		Metals and other parameters	100%
		Overall WQ parameters	100%
		Exceeded WQ parameters	**None**

5. Study limitations

Direct comparisons of water quality parameters between different water source categories were limited, mainly because test methods and units were different. Many studies investigating rainwater (direct rain) permitted a detailed analysis,comparing diverse geographical regions in Jordan. Less information was available on stored water or ground runoff quality. Overall, the investigated water quality parameters lacked consistency between categories, with heavy metal concentrations being a primary focus in rainwater (direct rain), while mainly microbial indicators were addressed in studies of stored water quality. Finally, it became clear that there is a lack of studies investigating treatment measures to improve water quality. Therefore, further research in this crucial area is inevitable.

6. Conclusion

This study aimed to investigate the water quality of rainwater harvesting systems through a review of studies conducted in Jordan. An analysis of the literature revealed that the quality of rainwater harvesting systems was influenced by natural and anthropogenic factors in addition to the characteristics of the system (catchment areas, storage facilities, etc.). Microbial contamination appeared to be the main factor limiting the use of harvested rainwater, especially for drinking purposes, while physical, chemical, and metal constituents mostly met Jordanian quality standards. Only a single study investigated the impact of applying prior treatment measures to improve water quality. Among the different sources of rainwater for harvesting, rainwater (direct rain) consistently had the highest water quality, and ground runoff had the lowest. Further research is needed to explore methods to improve the quality of harvested rainwater, including investigations of the impact of first-flush treatment, required diversion volumes, tank designs, and testing treatment options. Additionally, more attention is required to assess and improve the quality of ground runoff since it is becoming an increasingly viable resource in sponge cities and urban green infrastructure concepts for managing urban water and providing additional water for urban agriculture. Furthermore, more research is required on threats from emerging contaminants, as there is a growing concern related to these contaminants.

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Conflicts of interest:

The authors declare no conflict of interest

References

Abbasi, T., and Abbasi, S. A. (2011). Sources of pollution in rooftop rainwater harvesting systems and their control. Critical Reviews in Environmental Science and Technology, 41(23): 2097-2167. https://doi.org/10.1080/10643389.2010.497438.

Abdulla, F. A., Al-Shareef, A. W., Abdulla, F. A., and Al, A. W. (2009). Roof rainwater harvesting systems for household water supply in Jordan. Desalination, 243 (1-3) : 195-207. https://doi.org/10.1016/j.desal.200.

Abu-Zreig, M., Ababneh, F., and Abdulla, F. (2019). Assessment of rooftop rainwater harvesting in northern Jordan. Physics and Chemistry of the Earth, 114. https://doi.org/10.1016/j.pce.2019.08.002.

Al-Ajlouni, E., Hamid, S. A., Saad, L., Subbarini, M., and Wahdan, A. (2016). The Effect of Water Shortage on Water Quality of Different Resources in Jerash Governorate/Jordan, Based on New Water Quality Index. Journal of Engineering Research and Application, 6(6): 36-48.

Al-Amoush, H., Al-Ayyash, S., and Shdeifat, A. (2018). Harvested Rainwater Quality of Different Roofing Material Types in Water Harvesting System at Al al-Bayt University/Jordan. Jordan Journal of Civil Engineering, 12(2): 2018-2228.

Al-Jaralla, R., and Al-Fares, R. (2009). Quality of stormwater runoff in the State of Kuwait, Al-Asema governorate. International Journal of Environmental Studies, 66(2): 227-239. https://doi.org/10.1080/00207230902859838.

Al-Khashman, O. A. (2005a). Ionic composition of wet precipitation in the Petra Region, Jordan. Atmospheric Research, 78(1–2): 1-12. https://doi.org/10.1016/j.atmosres.2005.02.003.

Al-Khashman, O. A. (2005b). Study of chemical composition in wet atmospheric precipitation in Eshidiya area, Jordan. Atmospheric Environment, 39(33): 6175-6183. https://doi.org/10.1016/j.atmosenv.2005.06.056.

Al-Khashman, O. A. (2009). Chemical characteristics of rainwater collected at a western site of Jordan. Atmospheric Research, 91(1): 53-61. https://doi.org/10.1016/j.atmosres.2008.05.007.

Al-Khashman, O. A., Jaradat, A. Q., and Salameh, E. (2013). Five-year monitoring study of chemical characteristics of Wet atmospheric precipitation in the southern region of Jordan. Environmental Monitoring and Assessment, 185(7): 5715-5727. https://doi.org/10.1007/s10661-012-2978-1.

Almanaseer, N. (2019). Rainwater Harvesting for Adaptation to Water Scarcity in Refugees Camps in Jordan. Journal of Engineering and Applied Sciences, 15(5): 1180-1189. https://doi.org/10.36478/jeasci.2020.1180.1189.

Al-Mashaqbeh, O., Jiries, A., and El-Hajali, Z. (2014). Stormwater runoff quality generated from an urban and a rural area in the Amman-Zarqa basin. WIT Transactions on Ecology and the Environment, 182: 379-390. https://doi.org/10.2495/WP140331.

Al-Momani, I. F. (2003). Trace elements in atmospheric precipitation at Northern Jordan measured by ICP-MS: Acidity and possible sources. Atmospheric Environment, 37(32) : 4507-4515. https://doi.org/10.1016/S1352-2310(03)00562-4.

Al-Momani, I. F., Momani, K. A., and Jaradat, Q. M. (2000). Chemical Composition of Wet Precipitation in Irbid, Jordan. Journal of Atmospheric Chemistry, 35: 47–57.

Al-Momani, I. F., Momani, K. A., Jaradat, Q. M., Massadeh, A. M., Yousef, Y. A., and Alomary, A. A. (2008). Atmospheric deposition of major and trace elements in Amman, Jordan. Environmental Monitoring and Assessment, 136(1–3): 209–218. https://doi.org/10.1007/s10661-007-9676-4.

Al-Momani, I. F., Ya'qoub, A. R. A., and Al-Bataineh, B. M. (2002). Atmospheric deposition of major ions and trace metals near an industrial area, Jordan. Journal of Environmental Monitoring, 4(6): 985–989. https://doi.org/10.1039/b208697b.

Al-Shibli, F., Maher, W., and Thompson, R. (2017). The Need for a Quantitative Analysis of Risk and Reliability for Formulation of Water Budget in Jordan. Jordan Journal of Earth and Environmental Sciences, 8(2): 77-89.

Assayed, A., Hatokay, Z., Al-Zoubi, R., Azzam, S., Qbailat, M., Al-Ulayyan, A., Saleem, M. A., Bushnaq, S., and Maroni, R. (2013). On-site rainwater harvesting to achieve household water security among rural and peri-urban communities in Jordan. Resources, Conservation and Recycling, 73:72–77. https://doi.org/10.1016/j.resconrec.2013.01.010.

Awawdeh M, Al-Shraideh S, Al-Qudah K, and Jaradat R. (2012). Rainwater harvesting assessment for a small size urban area in Jordan. International Journal of Water Resources and Environmental Engineering, 4(12): 415–422. https://doi.org/10.5897/IJWREE10.025.

Chakraborty, B., and Gupta, A. (2018). Study and interpretation of chemical composition of rainwater in selected urban and rural locations in India using multivariate analysis. AIP Conference Proceedings, 1952. https://doi.org/10.1063/1.5031996.

Deng, Y. (2021). Pollution in rainwater harvesting: A challenge for sustainability and resilience of urban agriculture. Journal of Hazardous Materials Letters. 100037, 2. https://doi.org/10.1016/j.hazl.2021.100037.

Department of Statistics (DOS). (2015). Department of Statistics Website. Population and Housing Census. https://dosweb.dos.gov.jo/. (July. 29, 2023)

Despins, C., Farahbakhsh, K., and Leidl, C. (2009). Assessment of rainwater quality from rainwater harvesting systems in Ontario, Canada. Journal of Water Supply: Research and Technology - AQUA, 58(2): 117-134. https://doi.org/10.2166/aqua.2009.013.

Domènech, L., and Saurí, D. (2011). A comparative appraisal of the use of rainwater harvesting in single and multi-family buildings of the Metropolitan Area of Barcelona (Spain): Social experience, drinking water savings and economic costs. Journal of Cleaner Production, 19(6–7): 598-608. https://doi.org/10.1016/j.jclepro.2010.11.010.

Emmanuel, U., Samuel, K., and Ugona, U. (2021). Assessment of the Suitability of Urban Residential Roof Catchments for Rainwater Capturing in Umuahia, Southeastern Nigeria. Jordan Journal of Earth and Environmental Sciences, 12(1): 22-35.

Food and Agriculture Organization of the United Nations (FAO). (2016). Assessment of the water harvesting sector in Jordan. Final report. Retrieved from: https://www.fao.org/3/i5390e/i5390e.pdf.

Förster, J. (1996). Patterns of roof runoff contamination and their potential implications on practice and regulation of treatment and local infiltration. Water Science and Technology, 33(6): 39-48. https://doi.org/10.2166/wst.1996.0079.

Imo, T., Amosa, P., Latu, F., Vaurasi, V., and Ieremia, R. (2021). Chemical Composition of Rainwater at Selected Sites on Upolu Island, Samoa. Atmospheric and Climate Sciences, 11(03): 458–468. https://doi.org/10.4236/acs.2021.113027.

Jiries, A. G., Hussein, H. H., and Halaseh, Z. (2001). The quality of water and sediments of street runoff in Amman, Jordan. Hydrological Processes, 15(5): 815–824. https://doi.org/10.1002/hyp.186.

Jiries, A. G., Hussein, H. H., and Lintelmann, J. (2003). Polycyclic aromatic hydrocarbon in rain and street runoff in Amman, Jordan. Journal of Environmental Sciences, 15(6): 848-853.

Jordan standards and metrology organization (JSMO). (2014). Jordanian Irrigation water quality guideline, First edition (JS 1766:2014)..

Jordan Standards and Metrology Organization (JSMO). (2015). Jordanian drinking water standard, Sixth edition (JS 286:2015).

Keresztesi, Á., Nita, I. A., Boga, R., Birsan, M. V., Bodor, Z., and Szép, R. (2020). Spatial and long-term analysis of rainwater chemistry over the conterminous United States. Environmental Research, 188. https://doi.org/10.1016/j.envres.2020.109872.

Kim, G., Chung, S., and Lee, C. (2007). Water quality of runoff from agricultural-forestry watersheds in the Geum River Basin, Korea. Environmental Monitoring and Assessment, 134(1–3): 441-452. https://doi.org/10.1007/s10661-007-9635-0.

Lee, D. H., Kim, J. H., Mendoza, J. A., Lee, C. H., and Kang, J. H. (2016). Characterization and source identification of pollutants in runoff from a mixed land use watershed using ordination analyses. Environmental Science and Pollution Research, 23(10): 9774-9790. https://doi.org/10.1007/s11356-016-6155-x.

Lee, J. Y., Yang, J. S., Han, M., and Choi, J. (2010). Comparison of the microbiological and chemical characterization of harvested rainwater and reservoir water as alternative water resources. Science of the Total Environment, 408(4): 896-905. https://doi.org/10.1016/j.scitotenv.2009.11.001.

Martin, A. R., Coombes, P. J., and Dunstan, R. H. (2010). Investigating the influences of season and coastal proximity on the elemental composition of harvested rainwater. Water Science and Technology, 61(1): 25-36. https://doi.org/10.2166/wst.2010.775.

Meera, V., Ahammed, M. (2006). Water quality of rooftop rainwater harvesting systems: A review. Journal of Water Supply: Research and Technology - AQUA, 55(4): 257-268. https://doi.org/10.2166/aqua.2006.0010.

Meera, V., Ahammed, M. (2018). Factors Affecting the Quality of Roof-Harvested Rainwater. Urban Ecology, Water Quality and Climate Change. Water Science and Technology Library, 84: 195-202. https://doi.org/10.1007/978-3-319-74494-0_15.

Ministry of Water and Irrigation. (2016). Jordan National Water Strategy 2016-2025. Retrieved from: https://faolex.fao.org/docs/pdf/jor156264E.pdf.

Ministry of Water and Irrigation. (2023). Jordan National Water Strategy 2023-2040. Retrieved from: https://www.mwi.gov.jo/EBV4.0/Root_Storage/AR/EB_List_Page/national_water_strategy_2023-2040.pdf.

Radaideh, J., Al-Zboon, K., Al-Harahsheh, A., and Al-Adamat, R. (2009). Quality Assessment of Harvested Rainwater for Domestic Uses. Jordan Journal of Earth and Environmental Sciences, 2(1): 26-31.

Rivera-Rivera, D. M., Escobedo-Urías, D. C., Jonathan, M. P., Sujitha, S. B., and Chidambaram, S. (2020). Evidence of natural and anthropogenic impacts on rainwater trace metal geochemistry in central Mexico: A statistical approach. Water 2020, 12(1): 192. https://doi.org/10.3390/w12010192.

Shararadqah, S. (2021). The Dead Sea and Geo-Environmental Trace Influence on the Rainwater Quality in Jordan. International Journal of Agriculture and Environmental Science, 8(1): 61–65. https://doi.org/10.14445/23942568/ijaes-v8i1p110.

Shatnawi, R. S. (2019). Rooftop runoff water quality in university buildings, case study at Jordan Applied Science Private University. Journal of Engineering Science and Technology, 14(2): 987-997.

Simmons, G., Hope, V., Lewis, G., Whitmore, J., and Gao, W. (2001). Contamination of potable roof-collected rainwater in Auckland, New Zealand. Water Research, 35(6): 1518-1524. https://doi.org/10.1016/S0043-1354(00)00420-6.

Sung, M., Kan, C. C., Wan, M. W., Yang, C. R., Wang, J. C., Yu, K. C., and Lee, S. Z. (2010). Rainwater harvesting in schools in Taiwan: System characteristics and water quality. Water Science and Technology, 61(7): 1767-1778. https://doi.org/10.2166/wst.2010.107.

Tarawneh, Q., and Şen, Z. (2012). Spatial climate variation pattern and regional prediction of rainfall in Jordan. Water and Environment Journal, 26(2): 252-260. https://doi.org/10.1111/j.1747-6593.2011.00284.x.

Zeng, J., and Han, G. (2021). Rainwater chemistry observation in a karst city: Variations, influence factors, sources, and potential environmental effects. PeerJ, 9. https://doi.org/10.7717/peerj.11167.