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Quality Assessment of Harvested Rainwater for Domestic Uses

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Abstract

Despite continuous monitoring of public water supplies by governmental agencies, little is done for monitoring the water quality of cisterns and tanks receiving rainwater. For this reason, it is very important to evaluate the quality of rainwater collected and stored in these cisterns and storage tanks. In the present work, a comprehensive survey was carried out to cover four governorates in northern region of Jordan, where rainwater collection for domestic use is practiced on regular basis. Ninety samples of harvested rain water from various storage tanks within these four governorates were collected and analyzed for different quality parameters (pH, alkalinity, Hardness, Turbidity, TDS, COD, NO_3, NH_4, PO_4, Pb, Fe, Cr and biological contaminations). The results of the analysis were compared with valid quality guidelines to evaluate its suitability for domestic uses**.** The resulted data indicate that water quality in these tanks and cisterns varies depending on location, on catchment area, and on the availability of public sanitary systems. It was concluded that collected rainwater is unsuitable for drinking purpose while it could be used for irrigation within in houses.

Keywords: Water Harvesting; Water Quality; Cisterns; Drinking Water, Jordan .

1. Introduction

The high population growth rate in Jordan together with the rapid economic developments have been accompanied by an increase in water demand, while the available water resources are limited and decreasing. Jordan's water resources are, on per capita basis, among the lowest in the world. The available water from existing renewable sources is projected to fall from 160 m^3 /capita/ year in 2008 to 91 m^3/capita/year by the year 2025, which is very low in comparison with the international water poverty line of 1000 m^3/yr (Alzboon, *et al*., 2008, Bataineh,*et al*., 2002). Water shortage has forced Jordan to prospect for new non-traditional water resources to narrow the gap between demand and availability.. Water harvesting is considered as an attractive option for this purpose.

Rainwater harvesting is still the only source of potable water for rural communities where there are no water supply networks (MWI, 2009). Even in some areas where potable water is supplied by networks, harvested rainwater is still a significant supplemental resource for domestic uses, especially during summer season when low quantity of water is supplied. Currently in Jordan, roof top rainwater harvesting is being practiced for drinking water, domestic uses, and livestock and for garden irrigation. (MWI, 2009). Due to the importance of collected rainwater especially in the arid areas, rain water harvesting and its quality are the focal points of several ongoing researches. For example, a research study in China investigated the effect of the types of roof on rainwater quality. The study indicated that the measured inorganic compounds in the rainwater harvested from roof-yard catchments systems generally matched the WHO standards for drinking water, while the concentrations of some inorganic compounds of the rainwater collected from land and road surfaces appeared to be higher than the guideline values for drinking water (Zhu, *et al*., 2004). A similar study by Yaziz, *et al*.,(1989) concluded that there were significant variations in the concentrations of pollutants of water samples collected from tiles roofs and galvanized iron roofs. Additionally, it was found that the concentration of various pollutants were higher in the first spill of rain in comparison with the next spills. Jiries, et *al*., (2002) determined the metallic content and inorganic constituents of street sediments and street runoffs in Amman/Jordan. The highest concentrations of all constituents were detected during low rainfall and long dry periods of atmospheric deposition preceding rainfall events. However, high levels of both lead and copper were recorded which might be attributed to traffic pollution. An investigation of rainwater quality found that there is a correlation between water quality and intensity of rain. Values of pollutants (COD, BOD, N, and P) were found to be higher in case of moderate rain, while in samples taken during a heavy rainstorm; the components were less concentrated, as the rain washed the contaminants (Teemusk, *et al*., 2007). In 1985, a study was conducted in Portuguese west coast to determine seasonal variations of rainwater. It was found that the minimum concentrations of phosphate and nitrates were registered during autumn

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while the maximum were recorded during winter and spring (Pio, *et al*., 1985). Other studies showed that the location of sampling points, weather conditions, and industrial, urban or agricultural activities have significant effects on chemical composition of collected rainwater (Vazquez, *et al*., 2003, Abbas, *et al*, 1993, Meera, *et al*., 2006). Zunckel *et.al* (2003), found that there is a strong correlation between the present of contaminants in the catchments area and rainwater quality. A correlation between nitrate and ammonium is attributed mainly to livestock and fertilizer use. Correlations between fluoride and organic acids suggest a contribution from activities such as biomass burning, the use of fuel wood, agro industries and the use of crop fertilizer. Concerning the physico-chemical and microbiological determinants, a study which was conducted in New Zealand demonstrated that roof-collected rainwater systems provide potable supplies of relatively poor physicochemical and microbiological quality (Greg, *et a*l., 2001).

The majority of local & international research studies in this area have focused on the assessment of rain water quality, which is immediately collected after rainfall events. Because there is a possible change in water quality during long periods of storage, this study investigates the quality of harvested rain water after its collection and storage in tanks.

In Jordan, governmental agencies continuously monitor public water supplies, but little attention has been done for monitoring water quality of cisterns and tanks receiving rainwater. This study was conducted to identify and quantify sources of contaminations in harvested water.

2. Methodology

2.1. Study Area

Northern region of Jordan which includes Zarqa, Irbid, Ajlun and Jerash governorates has been chosen as a study area which is located at latitude of 32°05' to 32°34'(N) and longitude of 35°38' to 36°08' (E) (Figure 1) and its elevation ranges from 300 to 1100 meters above mean sea level . The climate is characterized by rainy cooled in winter and dry hot in summer. Average rainfall ranged from 140 mm/yr in Zarqa area to 582 mm/yr in Ajloun (JMD, 2006). The general specifications of the study area are listed in Table (1).

Zarqa city is classified as an industrial region with high population and heavy traffic volume, and it is the most environmentally pressured area in Jordan. Most of polluting industries including the Phosphate and Jordan Petroleum Refinery are located in this region. The area is also affected by emissions from Al-Hussein thermal power plant, and dust from brick and stone quarries. For these reasons, significant deterioration in air quality occurred, which causes accumulation of contaminants on roofs, land and streets (JEW, 2007). Irbid, Ajloun and Jerash governorates are classified as rural areas with low population density and very limited industries.

2.2. Data Collection and Analysis

Ninety samples of collected rain water from various storage tanks in these four governorates (Zarqa: 22; Irbid:

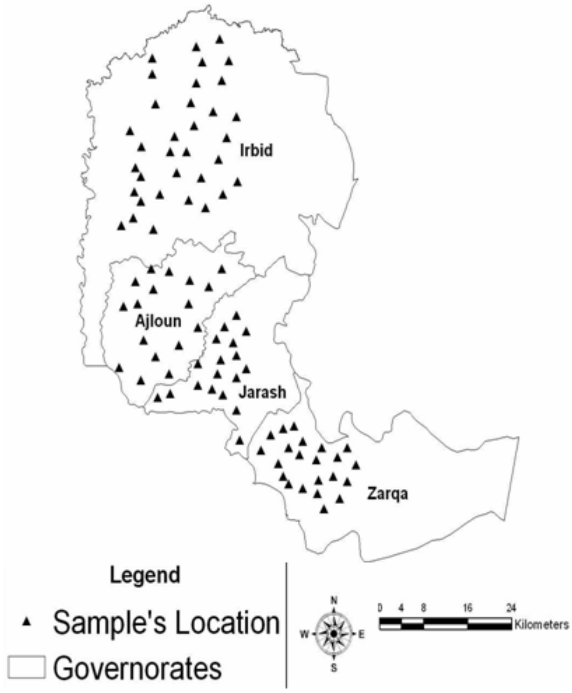

Figure 1. Study Area location.

Table 1. General characteristics of the study area (JMD, 2006, DOS, 2006).

parameter	Zarqa	Irbid	Jerash	Ajloun
Main Economic Activity	Industrial	Agricultural	Agricultural	Agricultural
Average rainfall (mm/yr)	140	455	470	582
Evaporation (mm/yr)	2520	2052	2200	1900
Average max temperature	25.5	23.03	23.1	18.2
Average min temperature	11.9	12.6	12.7	10.2
Population (thousands)	834	996	168	129
Area (Km^2)	4761	1572	410	420
% of Jordan's area	5.4	1.8	0.5	0.5

34; Jarash: 18 and Ajloun: 16) (Figure 1), were taken and analyzed for quality parameters (pH, alkalinity, Hardness, Turbidity, TDS, COD, NO_3, NH_4, PO_4, Pb, Fe, Cr). Additionally, these samples were tested for contamination of biological and microbiological contents. TCC, E.Col. and FC bacteria tests were carried out at Al Al-Bayt University laboratories according to standard methods for water and waste water examination [APHA, 1998]. Multiple tube fermentation technique sections 9221- B, E, and F was used to determine Total coliform, Fecal coliform, and E. Coli groups respectively [APHA, 1998]. The determination of heavy metals was carried out using the flame atomic spectrophotometer as described in the standard methods [APHA, 1998].

Results of analysis were further compared with valid quality guidelines to evaluate water suitability for drinking and irrigation purposes.

The investigated storage tanks were either underground or above-ground tanks and in some cases are constructed as part of the building, or may be built as a separate unit located at a distance from the building. Most of these tanks receive rainwater from roof tops, streets and catchment yards. Tanks vary in their sizes from 5 m^3 to more than 60

m^3 for private households and dwelling, but could reach 120 m^3 for larger buildings and institutions. Water can be easily extracted through a tap just above the tank's base or by water pump. This has made surface tanks popular in rural households for drinking water and irrigation. Usually the tank is made of concert, reinforced concrete, and bricks or excavated in rocks while the inner surfaces of tank are lined with cement. Roofs made with reinforced concrete usually have waterproofing course on the surface as a finishing layer. The waterproof course is done with a small slope towards the down take pipes. If there is no waterproofing layer, the roof itself is sloped with average rate of 1.5%.

In order to eliminate the effect of solids settlement, samples were taken from different depths of the tanks. The stored water includes all harvested rainwater during winter season, so that collected samples are considered representative for the whole year rainfall. The ninety samples were taken during the period of October 2006 - May 2007

In areas where public sanitary service does not exist, wastewater disposal is practiced by means of septic tanks or pits that are located also within the boundary of the residences where sewage could leak and reach the stored water, so this parameter is considered as a possible source of water contamination.

In addition to the assessment of water quality, this study investigated other conditions that could affect stored water quality. These conditions included: location of the storage tanks, type of catchments surfaces, type of tank's construction, and the availability of sanitary systems. In order to investigate these conditions, a questionnaire was distributed to 120 household owners including questions about quantifying the importance of the above mentioned conditions and other issues in regard to public awareness for rain water harvesting.

3. Results and Discussion

3.1. Suitability of Collected Water for Drinking Purposes

Table (2) illustrates the average values of measured parameters to evaluate water suitability for domestic purposes. In regard to alkalinity, Hardness, Turbidity, TDS, COD, NO_3, NH_4, PO_4, and Fe parameters, all samples comply with Jordanian Drinking Water Standards (JDWS). pH, Pb, and Cr samples exceeded the JDWS by 10%, 6.7% and 4.5% respectively.

The analyses show that 55%, 40% and 15% of samples contained detectable values of total coliform, Fecal coliform and E.Coli, respectively.

These results indicate that the collected water is heavily contaminated with microbes, so that it becomes unsuitable for direct drinking purpose. For this reason the suitability of collected water for drinking should not be taken for granted.

3.2. Suitability of Collected Rain Water for Irrigation

In order to evaluate the suitability of collected water for irrigation purposes, the results of analyses are compared with the strictest regulations (irrigation of crops that are eaten raw). The results indicate that the water complies in its physical, chemical and biological characteristics with WHO and Jordanian standards for reclaimed water (table 2).

Table2. Suitability of collected water for drinking and irrigation purposes.

Parameter	Units	Min.	Max.	Average	Max. Level mg/l JDWS	Reclaimed water standards (JS 893/2002)
pH	-----	7.1	8.9	7.96	6.5-8.5	6-9
Alkalinity	mg/l CaCO3	22	250	65.09	--------	-----
Hardness	mg/l CaCO3	16	352	108.18	500*	-------
Turbidity	NTU	0.1	4	0.7	5*	10
TDS	mg/l	26	393	138.47	1500*	1500
COD	mg/l	6	142	34.78	*	100
NO_3-N	mg/l	0.20	8.10	1.56	70*	30
NH_4-N	mg/l	0	0.1	0.06	0.5	-------
PO_4	mg/l	0.23	4.41	1.27	-------	------
Lead	mg/l	0.00	0.18	0.01	0.01	5
Iron	mg/l	0.00	0.338	0.01	1.0*	5
Chromium	mg/l	0.00	0.0988	0.012	0.05	0.1
TC	MPN/100ml	< 2.2	40	19.6	-----	-----
Fecal Colif.	MPN/100ml	<2.2	15	5	0	≤1000**
(*E.Coli*)	MPN/100ml	< 2.2	9	4.3	0	100

* In the absence of a public water source of better quality
** Source: (WHO, 1989).

3.3. Variation of Water Quality According to the Location

Average values of measured parameters in each location are presented in Table (3). The results indicated that there is a significant variation in water quality depends on the area characteristics. This result complies with the findings of other studies (Vazquez *et al*. 2003, and Abbas *et a*l 1993). Weather conditions, industrial, urban or agricultural activities, environmental cleanness, rainfall intensity, life style, and public attitude could be the reasons behind this variation.

Since that only 73 % of Zarqa governorate is served by public sanitary sewer system (WAJ, 2006), the present of cesspools and septic tanks result in further contamination of soil and subsurface water. All these parameters explain the high concentration of contaminants in samples taken from Zarqa region. A strong correlation is found between the intensity of rainfall and the contamination degree of harvested rainwater (Jiries et al. 2002), which is considered an additional reason of lower water quality in Zarqa governorate, where rainfall is less than 140mm/yr. Irbid, Ajloun and Jerash governorates had lower concentrations of heavy metals, hardness, and turbidity, but bacteria were found in collected samples because these governorates are classified as rural areas (low population density and very limited industries)

The public sanitary sewer service covers only 29% of Ajloun governorate population, while the remaining population (71%) depends on septic tanks and cesspools to manage their domestic wastewater which could be the source of high concentration of COD, NO_3 and biological contaminates found in the collected samples. Agricultural activities in Ajloun governorate is the reason for the high concentration of nitrogen and phosphor constituents in the collected samples. Type of soil and the cleanness of the

Table 3. Pollutants concentration for different governorates.

Governorate	Unit	Zarqa	Irbid	Jerash	Ajloun
pH range average	--	7.8-8.9 8.12	7.1-8.1 7.64	7.3-8.1 7.62	7.7-8.7 8.26
Alkalinity	mg/l CaCO3	92-250 143.4	22-67 44.8	31-72 48.33	51-101 76.82
Hardness	mg/l CaCO3	178-352 224.6	16-82 55.4	56-111 73.71	92-171 137
Turbidity	NTU	0.7-4 1.7	0.1-0.8 0.4	0.7-1.5 1.14	0.2-0.74 0.45
TDS	mg/l	198-393 251.4	26-117 79	72-155 110.86	135-205 169.36
COD	mg/l	55-142 80.5	16-37 21	6-24 13	21-57 36
NO3-N	mg/l	3.5-8.1 4.95	0.35-1.2 0.76	0.2-1.1 0.66	1.6-2.4 2.08
NH4-N	mg/l	0-0.1 0.08	0-.08 0.02	0-08 0.06	0-0.1 0.07
PO4	mg/l	0.23-1.3 0.90	0.85-1.5 1.15	0.95-1.65 1.3	1.3-4.41 1.78
Pb	mg/l	0-.18 0.04	0-0.1 0.026	0-.05 0.001	0-0.01 0.005
Fe	mg/l	0-0.33 0.055	0-0.1 0.02	0	0
Cr	mg/l	0-098 0.037	0-07 0.015	0	0-0.06 0.01
TC	**MPN/100ml**	**0-40 29.33**	**0-23 8.2**	**0-31 7.2**	**0-28 23.03**
Fecal Colif.	MPN/100ml	0-15 8.3	0-7 3.3	0-11 3.7	13-0 5.1
(*E.Coli*)	MPN/100ml	0-9 6.1	0-6 2.3	0-9 2.4	9-0 3.2

catchment area affect the turbidity and the concentrations of other parameters. The main source of lead (Pb) is the gasoline fuel, and its concentration in harvested water is mainly affected by the traffic volume in the area and the presence of fuel stations near storage tanks.

3.4. Effect of the Type of Catchment's Area

In houses, rainfall is usually collected from two catchments areas: house roofs and /or the land around the storage tank, so that the water quality is strongly affected by the cleanness of these areas. Roofs made of reinforced cement concrete (RCC), or roof tiles are the most common roof types in Jordan. Roofs are contaminated as a result of ambient air pollution and the emitted smokes from fireplaces and chimneys. Rooftops are usually free of organic contaminants, a reason that very low concentrations of COD and NO_3 are found in samples taken from tanks that are fed directly by these roofs. Land catchments area is exposed directly to contamination sources. Possible sources of contaminants include fertilizer, pesticides, chicken and livestock manure, dissolved minerals, sediments, sewage, decaying plants, algae, bacteria and detergents. All these pollutants are washed with rainfall to the storage tank causing an increase in water contaminants, which result in a higher concentration of COD, NO_3 and biological contaminants.

It was found, for the samples collected from rooftop catchments, that the average concentrations of TC, FC and E.Coli. are: 6.4, 2.5, and 2.2 MPN/100ml respectively, while for the samples collected from the land catchments of the storage tanks, the average concentrations for the same parameters are: 24.5, 11.2, and 5.1 MPN/100ml, respectively.

The presence of lead, Pb, iron, Fe, and chrome, Cr, in samples taken from tanks that receive water through land is attributed to the contamination of land catchments by these elements. For all quality parameters, harvested rainwater from rooftops have better quality than water collected from the catchment areas as illustrated in table 4. Similar results are reported by Zunkel *et al*. (2003) and Zhu *et al.* (2004) as they found that the quality of harvested water is strongly affected by the contamination of the catchments area.

Table 4. Water quality according to the type of the catchment area.

parameter	Land catchment	Top roof
pH	8.32	7.81
Alkalinity	132.3	54.45
Hardness	219.6	83.8
Turbidity	1.4	0.65
TDS	254.4	112.5
COD	80	37
NO3-N	4.015	1.29
NH4-N	0.1	0
PO4	4.03	0.5
Pb	0.028	0.01
Fe	0.038	0
Cr	0.032	0.01
Colif. MNP/100ml	24.5	6.4
Fecal Colif.	11.2	2.5
(*E.Coli*)	5.1	2.2

3.5. Effect of Tank's Type on Water Quality

Storage tanks are usually constructed either by using concrete or they are excavated in rocks (cistern). A difference in water quality is also found in samples depending on the type of these tanks.

The variation in quality parameters (table 5) can be reasoned according to the path of rain water until storage.

Table 5. Water quality according to the tank's type.

parameter	Concrete tanks	Rock tanks
pH	7.81	8.1
Alkalinity	58	97.53
Hardness	95.69	154.59
Turbidity	0.46	1.23
TDS	118.61	191.29
COD	37	80
NO3-N	1.35	2.62
NH4-N	0	0.1
PO4	0.7	3.7
Pb	0.01	0.013
Fe	0	0.022
Cr	0.013	0.02
TC	9.7	25.4
Fecal Colif.	3.3	7.2
(*E.Coli*)	2.7	5.6

Most of concrete tanks are included in house-buildings, while rock storage tanks are usually located in yards or gardens. As a sequence of that, concrete tanks receive water directly from roof tops, while rock storage tanks receive water that passes through land surrounding these tanks. For this reason, the higher contamination of rocky storage tanks (cistern) compared to that of rooftops is attributed to the contamination of the catchment area.

The concentration of microbes TC, FC, and E-Coli in samples taken from cisterns are found to be higher (25.4, 7.2, 5.6 MPN/100ml) than that in samples taken from concrete tanks (9.7, 3.3, 2.7 MPN/100ml).

3.6. Effect of The Sanitary Service on Water Quality

The presence of septic tanks in near distance to the rainwater tanks within the boundary of residences was also considered as a potential risk for quality of harvested water. The local regulatory authority, commonly the local municipality, issues a construction permit; but after the system is installed, there is no further oversight or requirement that it is cared for System owners are not likely to repair or replace aging or otherwise failing systems unless in sewage backup, seepage pooling on lawns, or targeted monitoring that identifies health risks occur. In most cases, these systems are installed and largely forgotten until problems arise. If any deterioration in the system of septic tank occurs, wastewater will reach to the adjacent storage tank of harvested rainwater. Table 6 shows that all considered quality parameters, (including microbial indicators) have higher concentration in samples that are taken from areas where septic tanks are used compared to samples collected from areas with public sanitary service.

Table 6. Water quality according to the availability of sanitary service.

parameter	Concrete tanks	Rock tanks
pH	8.0	7.8
Alkalinity	82.33	63
Hardness	130.74	104
Turbidity	0.92	0.57
TDS	151.81	121.67
COD	69.5	35
NO3-N	2.26	1.69
NH4-N	0.1	0
PO4	3.0	0.8.
Pb	0.016	0.014
Fe	0.014	0
Cr	0.018	0.008
Colif. MNP/100ml	21.6	16.3
Fecal Colif.	6.37	5.1
(*E.Coli)*	4.5	3.6

4. Summary and Conclusions

Rain water harvesting is an attractive option for increasing available water resources, especially in the drought and arid regions. The results of this research indicated that the collected water is heavily contaminated with microbes, so that it becomes unsuitable for direct drinking purpose. Thus, this water might be used for irrigation purposes. The harvested water is valuable source for irrigation of gardens, landscapes, fruits and crops.

The research results showed that there are variations in water quality according to the location. Harvested water in Zarqa has lower quality than water harvested in Ajloun, Jarash and Irbid because of the industrial activities in this governorate.

The quality of harvested water is found to be strongly affected by the catchment area. Harvested water from rooftops has better quality than the water harvested from the surrounding areas.

The influence of Tank's type on quality of harvested water was also investigated in this research. Concrete tanks have better water quality than cisterns. It was found that the variation in quality parameters can be reasoned according to the path of rain water until storage concrete tanks receive water directly from roof tops, while rock storage tanks receive water that passes through land surrounding these tanks

The possible impact of septic tanks on water quality was also investigated to determine whether these septic tanks pose a threat to water quality. It was found that areas served with sanitary systems have better quality of harvested water than areas with septic tanks.

Finally, public awareness has an important role in collected rain water management. Education, training, and financial supports are needed to encourage people to consider importance and quality of collected water. Clean environment produce clean water. Several environmental conditions should be taken into consideration to improve water quality such as proper design, operation and periodical maintenance of collection systems, cleanness of catchment area, and protection of collection systems against septic tanks leakages.

5. Recommendations

In order to have better quality of harvested water, it is recommended that:

1. Rooftop and catchment area must be cleaned before the rainfall season.
2. Locating cesspools at a far distance from the storage tanks to prevent any leaching of containments.
3. Water samples should be collected and analyzed on regular basis from the storage tanks before using the water for drinking purposes.
4. Adding some disinfecting agents such as chlorine might help in reducing the risk of biological contamination.

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