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ORIGINAL ARTICLE

Feasibility of rainwater harvesting from residential rooftops in Jordan

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Abstract

Rainwater harvesting is adopted to face water scarcity in arid regions. Many studies were developed in Jordan to estimate the potential of water harvesting for several uses. However, the precise estimation of water saving and cost benefits for the potential of rainwater harvesting from the roofs of residential urban areas is insufficient. Therefore, the objective of this study was to investigate the feasibility of rainwater harvesting from residential rooftops in all the eighty-nine Jordanian districts. The forecast number of buildings was calculated from 2016 to 2025 using building growth rate, where the number of houses and villas was adopted only. The long-term rainfall average from 1937 to 2017 was used. Two scenarios were used to assess the potential of rainwater harvesting; numerical (as scenario 1) and tabulated by plumbing code (as scenario 2) for the years from 2019 to 2025. Also, the growth rate of one cubic meter of water cost was calculated to find the money saving potential for the water companies in Jordan. The results indicated that the water harvesting potential was different between two scenarios in the districts which have annual rainfall more than 100 mm was efficient in scenario 1 compared to scenario 2 with the projected financial return which was increased from \$5.4 million at 2019 to reach \$33.4 million at 2025, while in the districts which have annual rainfall less than 100 mm was more efficient in scenario 2 compared to scenario 1 with the projected financial return which was increased from \$2.4 million at 2019 to reach \$14.6 million at 2025.

Keywords Rainfall water harvesting · Adaptation tool · Semi-arid climate · Storage tank size · Average long-term rainfall · Houses and villas

Introduction

Water shortage is currently a universal problem facing more than eighty countries of the world, where about two billion people lack access to clean water and this percentage is increasing by time (Alois 2007). By results of many research projects, several adaptation plans in different countries were suggested one of which is implementing rainfall water harvesting. Others are collection of rainfall from the rooftops of buildings and storing it in the artificial reservoirs for using it as a backup supply for daily domestic requirements and minimizing the pressure on the natural water resources.

The potential of water harvesting is different from a country to another depending on amount of precipitations and amount of water supply in each country. Sahin and Manioğlu (2019), Summerville and Sultana (2019), Baby et al. (2019) and Abu-Zreig et al. (2013) found that for countries with low rainfall, only 3.4–8.5% of the domestic annual water requirements were covered by water harvesting, for medium rainfall reached to 14.7–17.7% (Ghisi and Ferreira 2007) and 43% in countries with heavy rainfall (Hofman-Caris et al. 2019). Most of Jordan is desert land that has 75% of the total area of Jordan with annual rainfall reaches to be less than 120 mm. The highest annual rainfall around 300–500 mm is found in the northwestern part of Jordan. In Jordan, the rainwater harvesting is one of the additional water resources that is adopted in Jordan's water demand management policy (MWI 2015), and the Jordan uniform plumbing code (JNBC 2013). In Jordan, 87% from the total water consumption in the municipal sector went to the residential uses (MWI 2012).

Several studies were developed in Jordan for estimating the potential of water harvesting for several purposes (Saidan et al. 2015; Hadadin et al. 2014; Abu-Zreig et al. 2013; Awawdeh et al. 2012). The Abu-Zreig et al. (2013) and Saidan et al. (2015) depend on the rooftops areas of the apartments to build their studies, and the Saidan et al. (2015), Awawdeh et al. (2012) and Baby et al. (2019) used

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the GIS to estimate the catchment areas of rooftops. According to the previous approaches, the number of apartments does not mean the number of buildings, where the buildings have many apartments, and they do not have enough space to build rainfall storage tanks and if storage tank was built, it cannot serve high number occupancies in those apartments. In addition to the studies that used the GIS to estimate the catchment areas of rooftops, the roads and open spaces were captured also as polygons that have areas more than the actual rooftops areas. However, the lack of precise estimation of water saving and cost benefits for the potential rainwater harvesting from the roofs of residential buildings in populated urban areas justifies this research and adopts the rooftops of the houses and villas only. The objective of this study was to investigate the feasibility of rainwater harvesting from residential rooftops in Jordan at governorates districts level.

Methodology

In this study, the estimation of potential water saving was built in the eighty-nine districts, and the estimation of potential money saving was built in the twelve governorates in whole Jordan. Jordan is located in the middle east at the crossroads of Asia, Africa and Europe as shown in Fig. 1.

Jordan is relatively small in area, semiarid and arid, almost landlocked country with an area of 89,342 km^2 and its population around ten million (DOS 2016). Jordan has twelve governorates (Amman is the capital city, Balqa, Zarqa, Irbid, Mafraq, Ajloun, Jerash, Madaba, Karak, Tafila, Maan—which is the largest province by area—and Aqaba). Amman has 42% of Jordan's total population. The country is characterized by diverse range of habitats, ecosystems and biota due to its varied landscapes and environments.

Forecasting the number of buildings

This study adopted houses and villas only, because they have enough space to build rainfall storage tank comparing with the apartments. The number of houses and villas with their areas was obtained from the department of statistic (DOS). The percentage of the houses and the villas from all buildings in all governorates was calculated and found 13%. These data were divided into the level of district per governorate, where there is a fluctuation in rainfall on the level of district and governorate. The areas of buildings in each district are important to calculate the volume of water that can be harvested. The growth rate of buildings was calculated based on census (2004) and census (2015), and then the forecasting number of buildings was calculated from 2016 to 2025.

Amount of long-term average of rainfall per district

Based on the data of the ministry of water and irrigation (MWI 2018a), there are 256 rainfall stations were distributed in the whole of Jordan. By using GIS ArcMap version 10.3, the clip method was used to match the districts with their rainfall stations. There are eight districts out of 89 districts that do not have rainfall stations. For those districts, the surrounding stations were used to interpolate the average rainfall volume as a function of global mean similar to spatial kriging analysis. Thus, the average annual rainfall (mm) in each of those eight districts was the average of the two rainfall depths of the Isohyetal lines, multiplied with their area to get on the volume between any two Isohyetal lines. All the volumes were summed and divided by the total area of each district calculated by using the following equation (Nielsen and Wendroth 2003):

$$\text{Global mean} = \sum (Avg.\ rainfall\ depth * Area) / \sum Areas\ of\ district) \quad (1)$$

Fig. 1 Map of Jordan location in relation to nearby countries and the world [captured from Atlas of Jordan (2019)]

where global mean is the mean average rainfall along the whole study area, average rainfall depth is the rainfall depth estimated from the isohyets generated from two weather stations in mm, and area is the area between two isohyets, and $\sum Areas\ of\ district$ is a total area of the whole district.

Investigation scenarios

In this study, two scenarios were used to estimate the potential of rainwater harvesting. In the first scenario, the rainfall volume for each district was calculated based on the following (Gould 1993) equation:

$$V = SUM\ (C.I.A/1000) \tag{2}$$

where V is the annual potential of rainfall that can be collected by the roofs in cubic meter, I is the average annual rainfall in mm, A is the total roofs of the same area of houses and villas, C is the runoff coefficient that 0.85 was accepted for asphalt and concrete, and 1000 is a conversion factor. In the second scenario, the water harvesting table in the Jordan uniform plumbing code (JUPC) was used. The areas of rooftops that found in the table are different about the areas of rooftops that accredited by DOS. So, the storage tank size for areas that accredited by DOS was interpolated with the storage tank size that was obtained from the JUPC table and multiplied with the total number of buildings that have the same area. The potential of water harvesting by the two scenarios was calculated for years from 2019 to 2025.

Cost-benefit assessment

The water portion for each governorate at year 2017 with its cost was obtained from the Jordan water authority (WAJ) (MWI 2018b). So the total volume of water for all governorates by WAJ reached to be 227.6 MCM. Besides, the cost of one cubic meter of water at the same year was $2.06 with growth rate reaching to 2% to get on estimation for cost of one cubic meter in years from 2019 to 2025. Based on the results of the two scenarios, the potential water saving for each governorate was calculated and multiplied with the estimation cost for each governorate. The potential of money saving for the water companies in Jordan was calculated for years from 2019 to 2025.

Results and discussion

Number of forecasted buildings

The total number of buildings in Jordan is 1776135 (DOS 2016). Most of those buildings found in the Amman with percent reached to be 42%. The growth rates of buildings were calculated and vary between the governorates. And the highest growth rate for all types of buildings is found in Amman with 14%, but the percentage of the houses and villas was the lowest there and reached to be 5%; because most of the commercial and apartment buildings are found in the capital. The growth rate and percentages of houses and villas with average size of rooftop (m^2) in each governorate are shown in Table 1. In addition to the comparison between Amman and Irbid, the number of the houses and villas in Irbid in year 2016 was larger than Amman, but with the growth rate of buildings, the number of the houses and villas in Amman will be larger than Irbid in year 2025 as shown in Table 2 and forecasts number of houses and villas in each governorate from 2016 to 2025.

Table 1 Growth rate and percentages of houses and villas with average size of rooftop (m^2) in each governorate

Governorate	Buildings growth rate (%)	Percent of houses and villas (%)	Average percentage size of rooftop (m^2) houses and villas in each governorate (%)							
			50>	50–99	100–149	150–199	200–299	300–399	400–499	500+
Amman	14	5	2	9	26	27	20	6	3	7
Balqa	5	26	4	15	32	26	15	3	1	3
Zarqa	11	8	2	24	43	20	9	1	0	1
Madaba	6	27	1	9	38	36	12	1	0	1
Irbid	9	15	1	12	39	31	13	2	1	1
Mafraq	8	38	3	14	44	28	10	1	0	0
Jarash	6	28	4	14	44	27	10	1	0	0
Ajloun	6	26	2	14	46	27	10	1	0	0
Karak	5	32	3	10	38	35	13	1	0	0
Tafeleh	4	35	2	16	50	26	6	0	0	0
Maan	4	17	1	9	52	27	10	1	0	0
Aqaba	8	17	4	28	43	17	5	1	0	1

Table 2 Forecasted number of houses and villas in each governorate from 2016 to 2025

Governorate	Amman	Balqa	Zarqa	Madaba	Irbid	Mafraq	Jarash	Ajloun	Karak	Tafileh	Ma'an	Aqaba
2016	43,465	25,770	21,873	10,868	52,130	42,673	12,947	9554	20,403	6873	4859	6744
2017	49,382	27,167	24,172	11,554	56,599	46,228	13,690	10,124	21,417	7137	5061	7307
2018	56,104	28,640	26,712	12,283	61,452	50,080	14,475	10,729	22,481	7411	5271	7917
2019	63,742	30,193	29,519	13,058	66,721	54,253	15,305	11,370	23,597	7696	5490	8578
2020	72,419	31,831	32,622	13,882	72,441	58,773	16,183	12,050	24,769	7991	5718	9294
2021	82,277	33,557	36,050	14,758	78,653	63,670	17,112	12,770	25,999	8298	5956	10,070
2022	93,477	35,377	39,839	15,690	85,396	68,974	18,093	13,533	27,291	8617	6204	10,911
2023	106,203	37,295	44,025	16,680	92,718	74,721	19,131	14,341	28,646	8948	6462	11,822
2024	120,660	39,318	48,652	17,732	100,668	80,947	20,228	15,198	30,069	9292	6730	12,809
2025	137,085	41,450	53,765	18,851	109,299	87,691	21,388	16,106	31,563	9649	7010	13,878

Distribution of rainfall in Jordan

Jordan has three topographic regions where the highlands are located on the northwestern part that have abundant rainfall with the highest annual rainfall reaching to 519 mm in Ajloun, and the Jordan rift valley is located on the west and it contains the Jordan River and the Dead Sea (the lowest point in the world) and the eastern and northeastern areas of the country are arid desert with the lowest annual rainfall reaching to 26 mm in Aqaba. So, Fig. 2 shows the average annual rainfall distribution in the governorates of Jordan.

Potential water harvesting volume from rooftops

The potential water harvesting volume has been depended on two main factors, namely number of houses and villas with their areas (m^2) and the average annual rainfall governorate. As comparison between two governorates, Amman has the highest growth rate for the number of houses and villas, while Ajloun has the highest number for annual average rainfall as explained in two previous sections. Moreover, the results show that the number of houses and villas has more effective potential of water harvesting than the average annual rainfall, and this is obvious in Amman, which the potential of water harvesting in 2019 showed as shown in Table 3. This result refer to that the large volume of rainfall found in the governorates have percentage of agricultural areas more than residential areas. In addition, the volume of harvested water in scenario 1 more than scenario 2, because the storage tank size that was calculated in scenario 1 had a maximum size, while the storage tank size that was determined by (JUPC) in scenario 2 had an optimum size as shown in Tables 3 and 4.

The third result showed that scenario 1 had more volume of harvested water than scenario 2 in the districts which have annual rainfall more than 100 mm. However, scenario 2 estimated higher water harvesting potential at districts receiving average annual rainfall less than 100 mm. Accordingly, this result is clear in Aqaba governorate where all districts have annual rainfall less than 100 mm. The results of the two scenarios are less than the results of Abu-Zreig et al. (2013) where the apartments were included in its study.

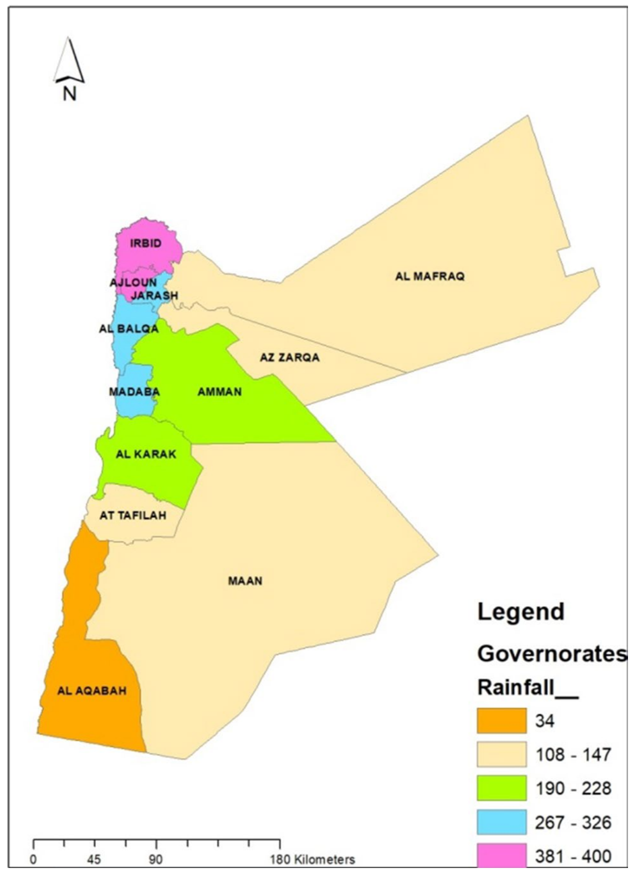

Fig. 2 Average annual rainfall distribution in the governorates of Jordan

Doing specific enumeration to collect data about urban water harvesting is important for the government to estimate actual water volume that collected and used in the

Table 3 Potential of water harvesting in scenario 1

Year	2019	2020	2021	2022	2023	2024	2025
Amman	1,028,150	1,560,483	2,154,641	2,852,533	3,672,271	4,635,128	5,766,090
Irbid	664,743	1,051,656	1,480,190	1,954,822	2,480,509	3,062,744	3,707,611
Balqa	170,868	266,392	369,344	480,302	599,889	728,776	867,686
Az-zarqa	100,399	151,513	196,864	247,936	305,453	370,227	443,175
Madaba	80,836	126,425	175,849	229,433	287,526	350,507	418,789
Mafraq	157,623	248,069	347,282	456,112	575,490	706,439	850,080
Jarash	100,459	156,559	216,978	282,048	352,127	427,600	508,882
Ajloun	93,602	145,942	202,360	263,174	328,727	399,389	475,556
Karak	78,558	121,814	167,959	217,187	269,702	325,725	385,490
Tafileh	18,593	28,772	39,587	51,079	63,290	76,265	90,052
Ma'an	8997	13,953	19,241	24,883	30,904	37,329	44,184
Aqaba	7608	12,102	17,130	22,756	29,050	36,093	43,972
Total	2,510,436	3,883,680	5,387,425	7,082,265	8,994,938	11,156,222	13,601,567

Table 4 Potential of water harvesting in scenario 2

Year	2019	2020	2021	2022	2023	2024	2025
Amman	471,745	724,630	994,708	894,629	1,641,910	2,072,134	2,578,411
Irbid	276,158	436,582	614,483	811,520	1,029,753	1,271,461	1,539,170
Balqa	72,217	112,590	156,103	203,000	253,542	308,015	366,725
Az-zarqa	43,011	65,458	86,273	109,715	136,175	165,841	199,323
Madaba	32,711	52,019	72,352	94,401	118,302	144,216	173,857
Mafraq	66,706	102,832	143,962	189,490	238,559	292,845	354,846
Jarash	43,275	67,443	93,470	121,501	151,689	184,201	219,216
Ajloun	40,015	62,392	86,512	112,511	140,536	170,745	202,618
Karak	33,826	58,246	72,324	93,682	116,137	140,261	165,994
Tafileh	8124	12,572	17,298	22,319	27,655	33,325	39,350
Ma'an	4744	7376	10,148	13,124	16,299	19,687	23,303
Aqaba	9483	15,084	21,611	28,364	36,208	44,986	54,807
Total	1,102,015	1,717,224	2,369,244	2,694,256	3,906,765	4,847,717	5,917,620

municipality sector. In particular, there are many buildings that have water harvesting tanks, but there is no information about number of tanks, their sizes and times of filling tanks in the one winter season.

Cost feasibility analysis

The total volume of water for municipality sector reached to 227.6 MCM at the year 2017 in all governorates of Jordan (MWI 2018b). Its operational cost per one cubic meter of the same year was calculated to be $2.06 with growth rate reaching to 2% (MWI 2018b). The portion of water has been differentiated between the governorates, and their growth rate has been differentiated also. Hence, the largest water portion found in Amman with growth rate reached to 2.9%, because Amman has 42% from the total population in Jordan (DOS 2016) and most of commercial activities found there. However, Mafraq governorate has the highest growth rate in water portion that reached to 5.5%, and this referred to that most of Syrian refugees have settled in Mafraq governorate. To get on the percentage of water saving in each governorate, the estimated volume of water harvesting was divided by the value of estimated water portion in each governorate from 2019 to 2025. Thus, in scenario 1, the percentage of water saving was 1% in all governorates at 2019, and increased to reach 4.6% at 2025, with a financial return of $5.4 million at 2019, and a projected return of $33.4 million at 2025. On the other hand, in scenario 2, the percentage of water saving was 0.4% at 2019, and increased to be 2% at 2025, with a financial return of $2.4 million at 2019, and projected to be $14.6 million at 2025. Supporting the government to the water harvesting approach from residential rooftops by mandatory process will reflex many benefits on it, as providing extra source for drinking purposes without having any capital or operational loads compared to dam building. On the other hand, the government will save its budgets to other its services.

Conclusion

The rainfall water harvesting is one of the several adaptation plans that can minimize the domestic annual water requirements. In Jordan, the rainwater harvesting is one of the additional water sources adopted in Jordan's water demand management policy, and the Jordan uniform plumbing code. Several studies were developed in Jordan for estimating the potential of water harvesting for several purposes. The rooftop areas of the apartments were used in those studies, but the rooftops areas of the apartments were excluded in this study for several considerations; the number of apartments does not mean the number of buildings because the buildings that have many apartments, and the buildings that have many apartments which do not have enough space to build rainfall storage tanks; then if storage tank was built, it cannot serve high number occupancy in those apartments.

The number of houses and villas had more effective potential of water harvesting than the average annual rainfall that the regions that have high annual rainfall occupy agricultural areas more than residential areas. Scenario 1 had more volume of harvested water than scenario 2 in the districts which have annual rainfall more than (100 mm), while scenario 2 estimated higher water harvesting potential at districts receiving average annual rainfall less than (100 mm).

Jordan is suffering recently from huge population growth, which causes additional stress on water demand. This study concluded that adaptation of water harvesting from residential rooftops has positive effects on the communities which encounter real pressure on water resources, and increase in percentages of water saving. These savings are reflected positively on the financial status of water supplier companies.

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Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interest.

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