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# The Potential of Roof Top Rain Water Harvesting as a Water Resource in Jordan: Featuring Two Application Case Studies

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***Abstract*—**Roof top rainwater harvesting (RWH) has been carried out worldwide to provide an inexpensive source of water for many people. This research aims at evaluating the potential of roof top rain water harvesting as a resource in Jordan. For the purpose of this work, two case studies at Al-Jubiha and Shafa-Badran districts in Amman city were selected. All existing rooftops in both districts were identified by digitizing 2012 satellite images of the two districts using Google earth and ArcGIS tools. Rational method was used to estimate the potential volume of rainwater that can be harvested from the digitized rooftops. Results indicated that 1.17 and 0.526 MCM/yr can be harvested in Al-Jubiha and Shafa-Badran districts, respectively. This study should increase the attention to the importance of implementing RWH technique in Jordanian residences as a viable alternative for ensuring a continued source of non-potable water.

***Keywords*—**Amman districts, ArcGIS, Rational method, Roof top rain water harvesting.

## I. Introduction

WATER is a one of the most vital requirements for economic and social development. In Jordan, the availability of this resource represents a challenge for engineers and water planners since Jordan ranks on the world's 10 most water stressed countries. Renewable freshwater resources are about 850 million cubic meters (MCM) with approximately 65% derived from surface water and 35% from groundwater sources [1]. The scarcity of water resources in Jordan is imposed by climatic conditions, such as aridity, and urban development [2]. In addition, the human population in Jordan is increasing thereby increasing the demand for water for domestic, agricultural and industrial uses. To meet the increasing demand, more pressure has been put on existing water resources such as over-exploitation of groundwater, and deterioration of water quality. The pressures on water are marked in Amman the capital where the vast majority of households receive water only on one or two days per week [3], [4]. Attention is now focusing on developing a strategy to manage Amman's water resources sustainability making full use of all available water resources. Rainwater harvesting (RWH) from rooftops, roads and other impervious surfaces, or catchments can be a supplementary water source with multipurpose functions.

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Roof top rain water harvesting consists of collecting domestic rain water from rooftops and storing it in tanks and cisterns. Water harvested from rooftops can replace potable water for several domestic uses such toilet flushing and watering domestic gardens [5]. The greater attraction of rain water harvesting system is its low cost, accessibility and easy maintenance at the household level. Rain water harvesting from building roof tops can be considered as an important step towards maximizing the water availability for domestic and landscape uses.

Rainwater harvesting has a significant role to play in water saving. Numerous articles have been published concerning the water harvesting and its role in promoting significant water saving in residences in different countries [6]-[12].

In Jordan, the absence of stormwater systems in many rural and urban areas within the country made the rain water harvesting an excellent source of water for potable and non-potable applications. Rain water harvesting has been practiced by individuals in many rural and urban areas within the country for thousands of years [13]. However, its significance as a source of water in Jordan has not been taken into consideration by the government among the implemented water management strategies till recently. A number of researchers investigated the potential of water saving using rain water harvesting by applying different approaches [14]-[16]. In this work, Google earth and ArcGIS tools are used to identify the roof tops that can be used for rain water harvesting. The potential volume of rainwater that can be harvested from building roof tops is then estimated. The study should encourage the residents in Jordan to use this technology, and increase the awareness of decision makers to implement this technique among the water management plans.

## II. Methodology

### A. Study Area

For the purpose of this research, two districts; Shafa-Badran and Al-Jubiha within Amman city have been chosen as two application case studies (Fig. 1). Table I illustrates the general specification of the study area. Both districts consist of a number of administrative sub zones as shown in Fig. 2. Table II presents the sub districts within each district. The average annual rainfall in the study area ranges from 450 mm to 550 mm falls mainly between September and May. The summer maximum temperatures average 32$^{o}$C. The winter maximum temperatures average 14-17$^{o}$C, while minimum temperatures average 1-40C [17].


Fig. 1 Satellite images for a) Shafa-Badran, and b) Al-Jubiha districts in Amman, Jordan


Fig. 2 The administrative subzones within a) Al-Jubiha, and b) Shafa-Badran districts

TABLE I
GENERAL SPECIFICATIONS OF THE STUDY AREA

| | Al-Jubiha | Shafa-Badran |
|---|---|---|
| Area ($km^2$) | 25.92 | 45.76 |
| Population | 64849 | 19528 |
| No. of sub districts | 9 | 17 |

### *B. Google Earth*

In this work, recent satellite images that cover the two areas of interest in this work are obtained from Google Earth 2012. The acquired satellite images are used to digitize all the building's rooftops in each study area using the polygon tool available in Google Earth. The digitizing process involves tracing of building roof tops directly on top of the satellite imagery in order to classify the rooftops from other objects within each district (Fig. 3). This process resulted in digitized maps with thousands of boundaries that have been saved as several KMZ files each representing the building roof tops of an administrative sub district. Figs. 4 and 5 show the final digitized maps for both Shafa-Badran and Al-Jubiha districts, respectively.

TABLE II
ADMINISTRATIVE SUB DISTRICTS WITH THEIR ASSOCIATED AREAS

| Sub-District Name | District | Area $km^2$ | Sub-District Name | District | Area $km^2$ |
|---|---|---|---|---|---|
| Um Hjair | SB | 1.22 | Thehebah | SB | 2.08 |
| Al Qasbat | SB | 1.70 | Um Balanah | SB | 1.71 |
| Yajouz | SB | 2.03 | Um Shterat | SB | 2.78 |
| Al Ameer Hamzh | SB | 2.39 | Al Moroj | SB | 3.34 |
| Vun 1 | SB | 3.93 | Al Baldyah | J | 1.65 |
| Al Shoroq | SB | 10.7 | Al Kolyah Aleslamyah | J | 2.65 |
| Alkoam Al Sharqi | SB | 1.69 | Al Mansour | J | 3.54 |
| Ubo Al Qeram | SB | 1.85 | Al Rashead | J | 2.51 |
| Um Aloroq | SB | 1.12 | Al Jamah | J | 3.16 |
| Almohdian | SB | 1.96 | Al Sedq | J | 37.64 |
| MarjAlfars | SB | 3.71 | Al Zaytonah | J | 4.97 |
| Tab Kra'a | SB | 1.13 | Qotnah | J | 2.44 |
| AlkoamAlgharbi | SB | 2.27 | Ubn Oaf | J | 1.20 |

SB=SHAFA-BADRAN, J= JUBIHA

Fig. 3 An example output digitized map for Al-Mansour Sub district building rooftops

*A. Roof Top Area Calculation Using Arc-GIS Tool*

Geographic Information System (GIS) has become a critical tool in hydrological modeling in view of its capacity to handle digital information for which various digitized data creation methods are used. In this work, digitization and geo-referencing capabilities in ArcGIS are used. The KMZ files for each sub district are converted to shape files. The coordinate system for each shape file is defined as WGS 1984 UTM Zone 36N to be able to compute the areas of the digitized features automatically by the geometry calculation tool available in ArcGIS model (Fig. 6).

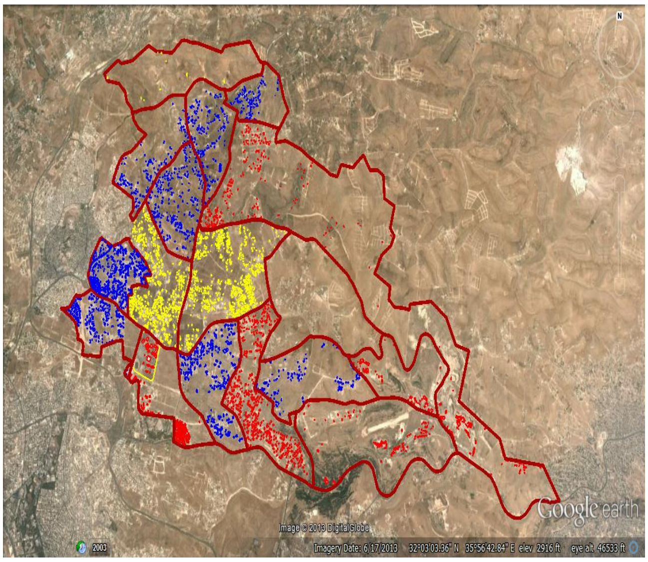



Fig. 4 Digitized Building roof tops in Shafa-Badran district

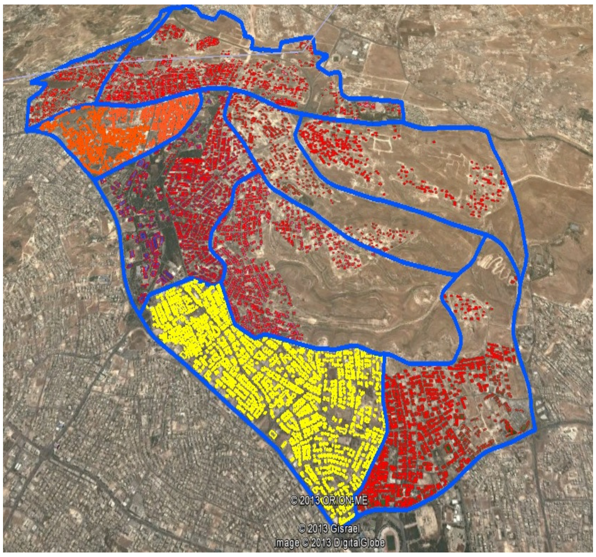


Fig. 5 Digitized Building roof tops in Al-Jubiha district

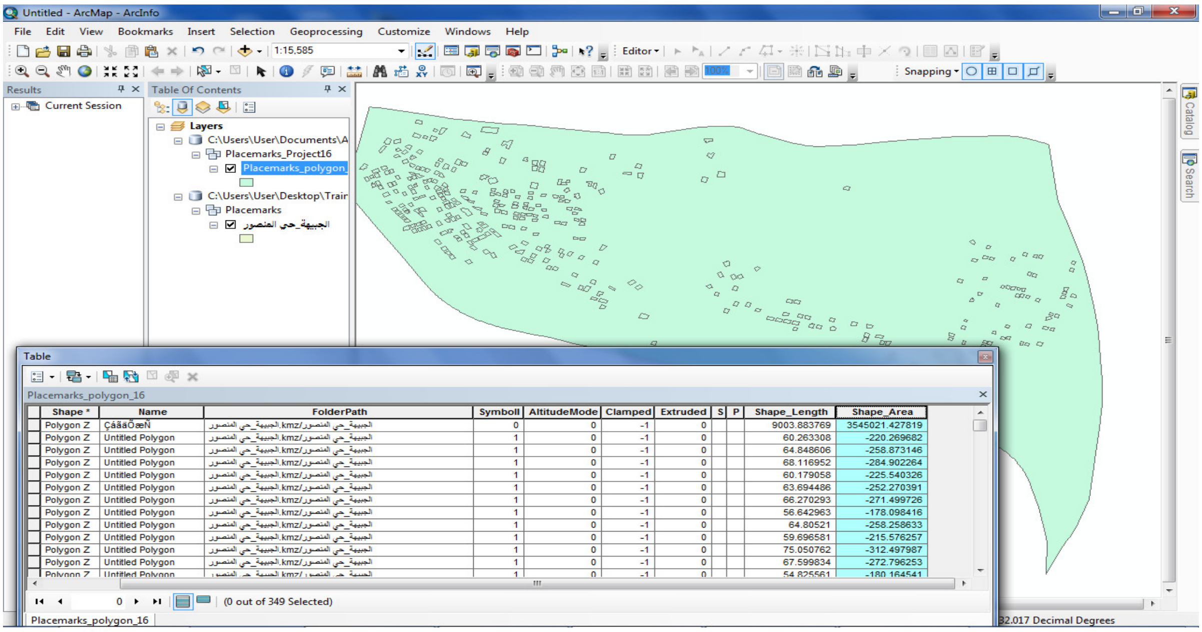



Fig. 6 An example layer for Al-Mansour sub district using ArcGIS, and the associated attribute table

*B. Corrections of Digitized Areas*

To verify the accuracy of the digitized areas obtained by the approach of this work, actual roof area for several selected buildings within the districts are measured and compared to its associated digitized area obtained by ArcGIS geometry calculation tool (Fig. 7). Table III presents a comparison between the actual measured roof tops with its associated digitized areas using the digitization tool for selected building roof tops. Based on this comparison, an average correction factor of the digitized area is estimated as 1.032.

TABLE III
COMPARISON BETWEEN ACTUAL MEASURED AND DIGITIZED AREAS FOR SELECTED BUILDINGS

| Rooftop number | Digitized Area ($m^2$) | Actual Measured Area ($m^2$) | Calculated Correction factor |
|---|---|---|---|
| 1 | 404.5 | 436 | 1.078 |
| 2 | 432.1 | 448.5 | 1.038 |
| 3 | 311.6 | 311 | 0.998 |
| 4 | 331 | 336 | 1.015 |

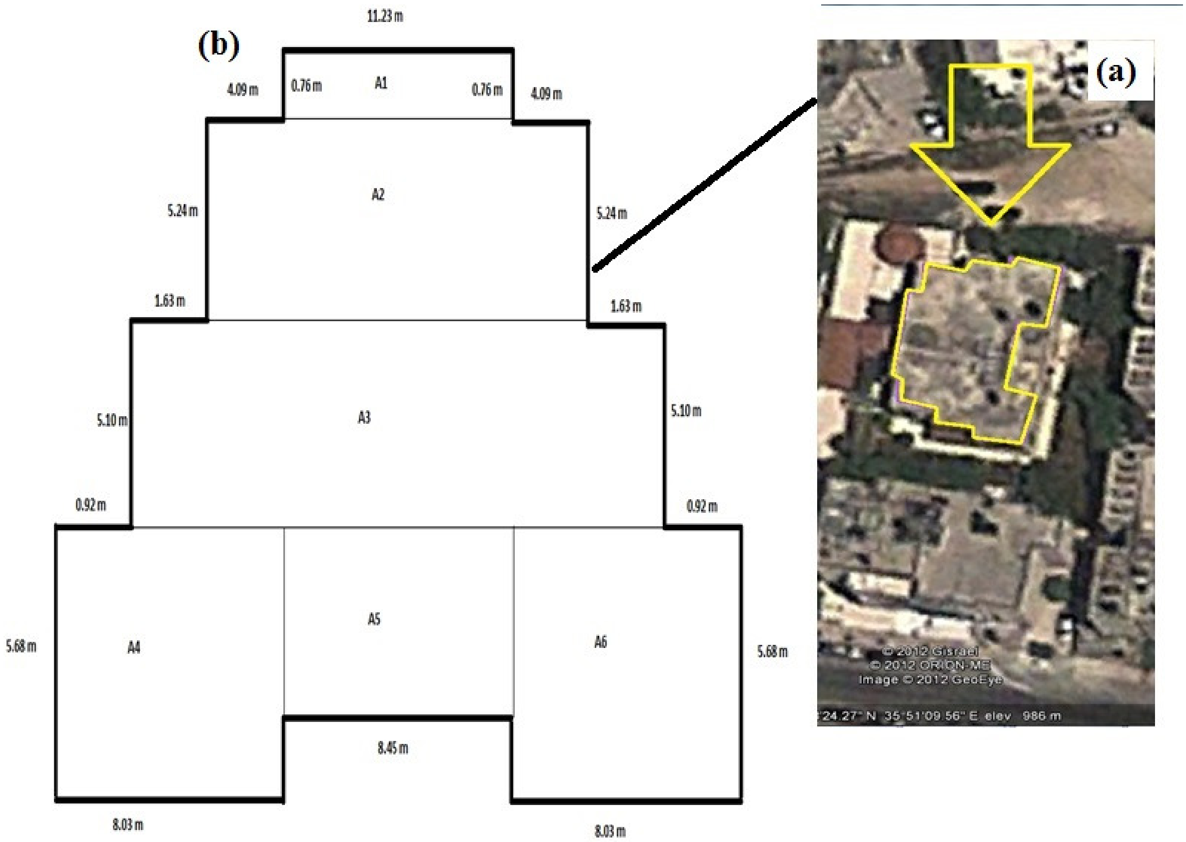
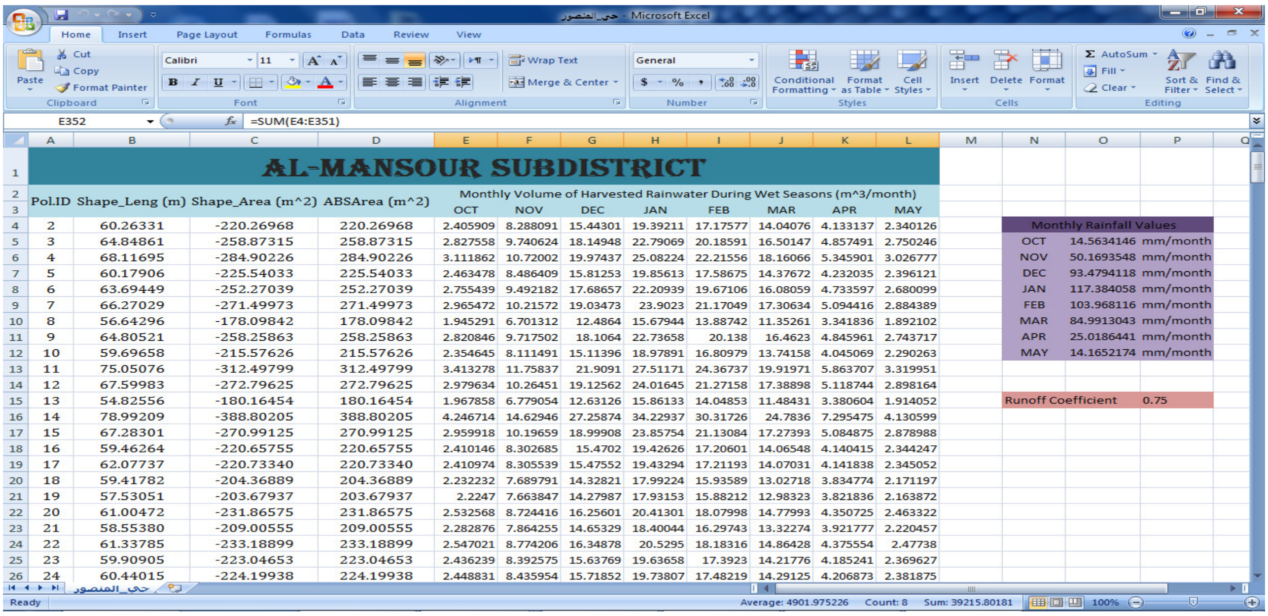



Fig. 7 An example area correction factor for a building roof top; a) Digitized building roof top, b) Actual measured building rooftop



AL-MANSOUR SUBDISTRICT

| Pol.ID | Shape_Leng (m) | Shape_Area (m^2) | ABSArea (m^2) | Monthly Volume of Harvested Rainwater During Wet Seasons (m^3/month) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY |
| 2 | 60.26331 | -220.26968 | 220.26968 | 2.405909 | 8.288091 | 15.44301 | 19.39211 | 17.17577 | 14.04076 | 4.133137 | 2.340126 |
| 3 | 64.84861 | -258.87315 | 258.87315 | 2.827558 | 9.740624 | 18.14948 | 22.79069 | 20.18591 | 16.50147 | 4.857491 | 2.750246 |
| 4 | 68.11695 | -284.90226 | 284.90226 | 3.111862 | 10.72002 | 19.97437 | 25.08224 | 22.21556 | 18.16066 | 5.345901 | 3.026777 |
| 5 | 60.17906 | -225.54033 | 225.54033 | 2.463478 | 8.486409 | 15.81253 | 19.85613 | 17.58675 | 14.37672 | 4.232035 | 2.396121 |
| 6 | 63.69449 | -252.27039 | 252.27039 | 2.755439 | 9.492182 | 17.68657 | 22.20939 | 19.67106 | 16.08059 | 4.733597 | 2.680099 |
| 7 | 66.27029 | -271.49973 | 271.49973 | 2.965472 | 10.21572 | 19.03473 | 23.9023 | 21.17049 | 17.30634 | 5.094416 | 2.884389 |
| 8 | 56.64296 | -178.09842 | 178.09842 | 1.945291 | 6.701312 | 12.4864 | 15.67944 | 13.88742 | 11.35261 | 3.341836 | 1.892102 |
| 9 | 64.80521 | -258.25863 | 258.25863 | 2.820846 | 9.717502 | 18.1064 | 22.73658 | 20.138 | 16.4623 | 4.845961 | 2.743717 |
| 10 | 59.69658 | -215.57626 | 215.57626 | 2.354645 | 8.111491 | 15.11396 | 18.97891 | 16.80979 | 13.74158 | 4.045069 | 2.290263 |
| 11 | 75.05076 | -312.49799 | 312.49799 | 3.413278 | 11.75837 | 21.9091 | 27.51171 | 24.36737 | 19.91971 | 5.863707 | 3.319951 |
| 12 | 67.59983 | -272.79625 | 272.79625 | 2.979634 | 10.26451 | 19.12562 | 24.01645 | 21.27158 | 17.38898 | 5.118744 | 2.898164 |
| 13 | 54.82556 | -180.16454 | 180.16454 | 1.967858 | 6.779054 | 12.63126 | 15.86133 | 14.04853 | 11.48431 | 3.380604 | 1.914052 |
| 14 | 78.99209 | -388.80205 | 388.80205 | 4.246714 | 14.62946 | 27.25874 | 34.22937 | 30.31726 | 24.7836 | 7.295475 | 4.130599 |
| 15 | 67.28301 | -270.99125 | 270.99125 | 2.959918 | 10.19659 | 18.99908 | 23.85754 | 21.13084 | 17.27393 | 5.084875 | 2.878988 |
| 16 | 59.46264 | -220.65755 | 220.65755 | 2.410146 | 8.302685 | 15.4702 | 19.42626 | 17.20601 | 14.06548 | 4.140415 | 2.344247 |
| 17 | 62.07737 | -220.73340 | 220.73340 | 2.410974 | 8.305539 | 15.47552 | 19.43294 | 17.21193 | 14.07031 | 4.141838 | 2.345052 |
| 18 | 59.41782 | -204.36889 | 204.36889 | 2.232232 | 7.689791 | 14.32821 | 17.99224 | 15.93589 | 13.02718 | 3.834774 | 2.171197 |
| 19 | 57.53051 | -203.67937 | 203.67937 | 2.2247 | 7.663847 | 14.27987 | 17.93153 | 15.88212 | 12.98323 | 3.821836 | 2.163872 |
| 20 | 61.00472 | -231.86575 | 231.86575 | 2.532568 | 8.724416 | 16.25601 | 20.41301 | 18.07998 | 14.77993 | 4.350725 | 2.463322 |
| 21 | 58.55380 | -209.00555 | 209.00555 | 2.282876 | 7.864255 | 14.65329 | 18.40044 | 16.29743 | 13.32274 | 3.921777 | 2.220457 |
| 22 | 61.33785 | -233.18899 | 233.18899 | 2.547021 | 8.774206 | 16.34878 | 20.5295 | 18.18316 | 14.86428 | 4.375554 | 2.47738 |
| 23 | 59.90905 | -223.04653 | 223.04653 | 2.436239 | 8.392575 | 15.63769 | 19.63658 | 17.3923 | 14.21776 | 4.185241 | 2.369627 |
| 24 | 60.44015 | -224.19938 | 224.19938 | 2.448831 | 8.435954 | 15.71852 | 19.73807 | 17.48219 | 14.29125 | 4.206873 | 2.381875 |

| Monthly Rainfall Values | | |
|---|---|---|
| OCT | 14.5634146 | mm/month |
| NOV | 50.1693548 | mm/month |
| DEC | 93.4794118 | mm/month |
| JAN | 117.384058 | mm/month |
| FEB | 103.968116 | mm/month |
| MAR | 84.9913043 | mm/month |
| APR | 25.0186441 | mm/month |
| MAY | 14.1652174 | mm/month |

| Runoff Coefficient | 0.75 |
|---|---|

Fig. 8 A picture illustrates part of the automated Excel Spread Sheet used in calculating the potential harvested rainwater volumes

## III. Calculation of Potential Harvested Rainwater Volumes

Using the areas computed by ArcGIS, the rational Method is then used in an automated excel sheet to estimate the volumes of rainwater that can be collected from buildings' rooftops during winter in each sub district (Fig. 8). The harvested volumes are evaluated by using the rainfall intensities presented in Table IV. A runoff coefficient value of 0.85 is used to describe the concrete roofing, commonly used, in Jordan.

TABLE IV
AVERAGE MONTHLY RAINFALL INTENSITY (SOURCE [18])

| Month | Intensity (mm/month) |
|---|---|
| December | 93.5 |
| January | 117.4 |
| February | 104 |
| March | 85 |
| April | 25 |
| May | 14.2 |
| December | 93.5 |

## IV. RESULTS AND DISCUSSION

In this study, rain water harvesting for residential roofs in two districts in Amman was estimated to evaluate the potential of filling the gap between the water demand and water supply, hence mitigating the problems of water scarcity. The volumes of rainwater that can be harvested in each of the sub districts within Al Jubiha and Shafa-Badran districts were calculated considering the monthly rainfall data, the roof area, and a runoff coefficient value of 0.85. The total volumes of harvested rainwater that can be collected from each sub district within Al- Jubiha and Shafa-Badran districts are presented in Tables V and VI, respectively. Results revealed that the maximum volumes of harvested rainwater can be collected in the month of January since the average monthly rainfall value is the highest during this month. Figs. 9 and 10 illustrate the total potential monthly harvested volumes for Al-Jubiha and Shafa-Badran districts.

Volumes of harvested rainwater from building rooftops during winter will significantly affect the problem of water shortage. Harvested rainwater can be used to conserve potable water and help reduce the impact of restrictions on outdoor water uses such as irrigation, vehicle washing, toilet flushing and other non-potable uses.

TABLE V
TOTAL HARVESTED RAINWATER VOLUMES FOR AL- JUBIHA DISTRICT

| Sub-districts Name | Total Harvested volumes ($m^3$) |
|---|---|
| Baladeyah | 107163.3 |
| Ibn Ouf | 54694.8 |
| Al-Jama'a | 235516.7 |
| Al-Koliyeh | 65001.2 |
| AlMansour | 45111.2 |
| Qutnah | 127219.3 |
| Al-Rashed | 206916.5 |
| Al-Siddeeq | 126830.3 |
| Zaiton | 198679.1 |
| ∑ *Summation* | 1167132.5 |

TABLE VI
TOTAL HARVESTED RAINWATER VOLUMES FOR SHAFA-BADRAN DISTRICT

| Sub-districts Name | Total harvested volumes ($m^3$) |
|---|---|
| Um Hjair | 36616.51 |
| Al Qasbat | 35813.69 |
| Yajouz | 39637.12 |
| Al Ameer Hamzh | 59647.26 |
| Vun 1 | 15073.19 |
| Al Shoroq | 34472.74 |
| Alkoam Al Sharqi | 8718.605 |
| Ubo Al Qeram | 27424.54 |
| Um Aloroq | 8972.204 |
| Almohdian | 14450.65 |
| MarjAlfars | 24309.28 |
| Tab Kra'a | 53348.12 |
| AlkoamAlgharbi | 13449.07 |
| Thehebah | 70403.2 |
| Um Balanah | 17121.16 |
| Um Shterat | 995.4659 |
| Al Moroj | 65479.01 |
| ∑ *Summation* | 525931.8 |

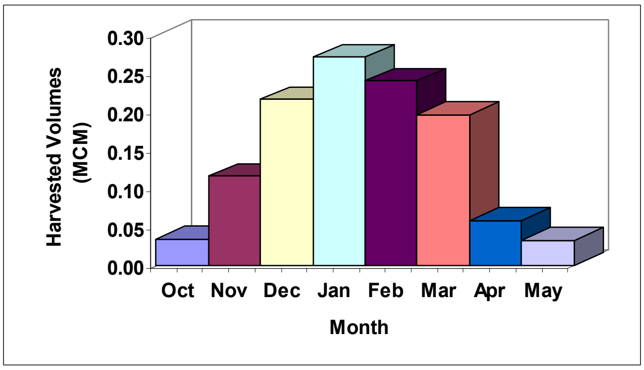



Fig. 9 Monthly potential volumes of harvested rainwater in Al-Jubiha district

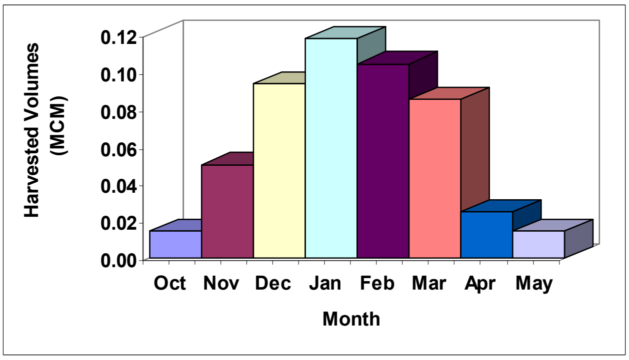



Fig. 10 Monthly potential volumes of harvested rainwater in Shafa-Badran district

## V. CONCLUSION

The most severe environmental challenge that Jordan faces today is water scarcity. Many techniques have been suggested to increase the water supply and mitigate the problem of water scarcity. Among these is rainwater harvesting. In this study, two case studies; 1) Al-Jubiha, and 2) Shafa-Badran districts have been selected to investigate the potential of building rooftops water harvesting as a resource in Amman city. To achieve the goal of this work, Google Earth, ArcGIS and the rational method tools were used to estimate the volumes of water that can be harvested from building rooftops within each district. Results showed that approximately 1.17 and 0.526 MCM can be harvested annually in Al-Jubiha and Shafa-Badran districts, respectively. A rainwater harvesting systems can be constructed from inexpensive local materials, and is likely to be successful in most housing sites. Rainwater collected from rooftops and local institutions can provide an important contribution to the provision of potable water, and can be also considered an effective way to solve the problem of water shortage to some extent if implemented and managed appropriately.

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## REFERENCES

[1] S. Nortcliff, G. Carr, R. Potter, K. Darmame, "Jordan's Water Resources: Challenges for the Future," Geographical Paper No. 185, 2008.
[2] E. Salameh and H. Bannayan," Water Resources of Jordan, Present Status and Future Potential," Friedrich Ebert Stiftung, Amman, 1993.
[3] R. Potter, N. Barham, and K. Darmame, "The polarized social and residential structure of the city of Amman : a contemporary view using GIS," Bulletin of the Council for British Research in the Levant, 2, 2007, pp. 48-5224.
[4] R. Potter,K. Darmame, and S. Nortcliff, "The provision of urban water under conditions of 'water stress', privatization and deprivatisation in Amman," Bulletin of the Council for British Research in the Levant, 2, 2007, pp. 52-54
[5] USEP," A Guideline for Water Reuse", EPA Report 625-R-04-108, US Environmental Protection Agency, Washington, DC, USA.
[6] T. Herrmann and U. Schmida," Urban Water", 1 (1999), pp. 307–316.
[7] P.J. Coombes, J.R. Argue and G. Kuczera, "Urban Water", 1 (1999), pp. 335–343.
[8] E. Ghisi, A. Montibeller and R. Schmidt, "Building Environment", 41, (2006), pp. 204–210.
[9] M. Amin, and A. Alazba," Probable Sources of Rainwater Contamination In A Rainwater Harvesting System and Remedial Options," Australian Journal of Basic and Applied Sciences, 5(12), 2011, pp.1054-1064.
[10] R. K. Sivanappan." Rain Water Harvesting, Conservation and Management Strategies for Urban and Rural Sectors," National Seminar on Rainwater Harvesting and Water Management, 11-12 Nov., 2006, Nagpur.
[11] Y.J Kim, M.Y. Han, and Y.H. Kim., "A study on the rainwater tank design in RSR system for urban drain capacity improvement" in 2006 Proc. of Korean Society of Water and Wastewater and of Water Quality Conference, Vol.1. pp.601-622.
[12] A. S. Jasrotia, A. Majhi, and S. Singh, "Water Balance Approach for Rainwater Harvesting using Remote Sensing and GIS Techniques," Jammu Himalaya, India, Water Resources Management, (2009), 23, pp. 3035–3055.
[13] D. Prinz, "Water harvesting in the Mediterranean environment—Its past role and future prospect," in: N. Tsiourtis, ed., Water Resources Management in the Mediterranean under Drought of Water Shortage Conditions, International Symposium., Nicosia, Cyprus, 1995, pp. 135–144.
[14] F.A. Abdulla, A.W. Al-Shareef, "Roof rainwater harvesting systems for household water supply in Jordan. Desalination, 243, 2009, pp.195–207.
[15] M. Abu-Zreig, and A. Hazaymeh, "Urban Rainfall Harvesting to Alleviate Water Shortages and Combat Desertification in the Arid Land of Jordan," Journal of Arid Land Studies, 22 (1), 2012, pp.87 -90.
[16] J. Radaideh , K. Al-Zboon , A. Al-Harahsheh, and R. Al-Adamat," Quality Assessment of Harvested Rainwater for Domestic Uses," 2(1), 2009, pp.26 -31.
[17] JMD, Jordan Metrological Department, climate in Jordan, annual report 2010.
[18] MWI, Ministry of Water and Irrigation, Annual Report, Amman, Jordan, 2004, www.mwi.gov.jo.