Modeling the impact of rainwater harvesting on stormwater runoff

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Abstract. One way to save water is rainwater harvesting (RWH). For highly urbanized areas, the advantages of RWH include not only collecting water but also mitigating the negative impacts of stormwater runoff on receiving water bodies. In this research, the use of RWH is investigated along with Permeable Pavement to reduce runoff volume and peak flow in Al-Huryai city, a small watershed in central Baghdad, Iraq as a case study using a Personalized Computer Storm Water Management Model (PCSWMM). The simulation results showed that RWH has a significant impact on runoff reduction when compiled with Al-Huryai-PP scenario. The peak flow rates for Al-Huryai as-is scenario and Al-Huryai-PP+RWH scenario were 0.004 m³/s and 0.0038 respectively. Thus, the predevelopment conditions were met and flooding was controlled.

Keywords: Water harvested, PCSWMM, water conservation, land development

1. Introduction
Water conservation has significantly grown across Iraq as much of the country has recently suffered severe drought conditions. These conditions are mainly under the impact of climate change. Although Iraq has infrequent rainfall events, they generate a huge amount of surface runoff [17]. Saving water for later use is an old practice and has been used 3000 BC in Jorden [1]. This technique has spread out to many countries nowadays like Canada, Germany, the United States, Jordan, Japan, India, etc., due to recognition of the importance of reusing RW could have on municipal storm water management [2]. Rain Water Harvesting (RWH) is a technique used for capturing water from different hard surfaces and storing it in a cistern or any natural reservoir or tank for landscape irrigation and other household purposes [15]. It is one of the most important applications in Low Impact Development (LID) as innovative stormwater management practices that help to minimize water crises. It has a positive impact on the environment in many ways. For example, it can lead to reduction in local flood problems, decreases in dependence on main water supplies, and reduction of water bills. LID seeks to restore the
pre-development hydrology to a target site by increasing the natural hydrologic landscape such as increasing infiltration, enhancing aesthetics, and lengthening the flow path and runoff time [3,4].

Rain water harvesting has been studied by many researchers and there is a consensus that the RWH system is a good practice for saving water [5]. [6] Installed a 500 liter tank to a 50 square meter roof area that collected approximately 23,000 L of water a year. Large amount of water can be harvested even from a small tank. In addition, [7] applied a Continuous Monitoring and Adoptive Control (CMAC) approach to a conventional rainwater harvesting system to mitigate combined sewer overflow (CSOs) in New York City. They developed a hydrologic and hydraulic model using SWMM version 5.1. a hydrologic model is for predicting the runoff volume while the hydraulic model is to determine flood effect. A historic rainfall data of ten years were simulated in two sub catchments. The first one consists of 100% impervious, 2.0% slope drain entirely to the cistern. The second one represent 40% impervious, 3.5% slope. Four simulations were conducted, Base Scenario, Timed Scenario, Moisture Scenario, and Active Scenario. The Base Scenario was developed to simulate the existing conditions where all sub catchment runoff was routed directly to the site outfall. The model results showed that the CMAC was able to capture 85% to 93% of all roofs runoff to the cistern on average for rainfall events less than or equal to 3.8 cm during the period of records. The Active Scenario retained 69.8% of site runoff on an annual average basis as compared to 64.6% and 61.9% for the Timed and Moisture Scenario respectively. [8] estimated the urbanization effect on stream flow on 16 watersheds by correlating average hydrologic metrics, flow distribution, daily variation in stream flow and frequency of high stream flow events, and an impervious surface area fraction (ISA). The watersheds were classified as high and low density urban development. Low density (single-family residents) consists of 20% to 40% impervious area and high density (Commercial and industrial) consist of 80% to 100% impervious area. Results showed that urban intensity has the greatest impact on all three hydrologic metrics.

Recently, many fields in Baghdad were replaced with building due to population growth. Therefore, Curve Numbers, a function of soil and land use cover, for these areas also increased causing more runoff and less infiltration [9]. Urbanization has increased the efficiency of RWH because it allows for greater cover of impervious areas due to the development of streets, parking lots, and storm water collection systems and thus increased surface water flow which differs greatly from non-urban environments [4-10]. If RWH is a good investment more areas of Iraq will be able to benefit from this technology. A study done by [10] assessed how urbanization affected the surface runoff. Two periods of urbanization were studied from 1950s to 1980 and from 1980s to 2006 as shown in figure 1. The results indicated that the percentage of impervious surface had increased from 26% in 1955 to 39% in 1985, whereas it increased from 39% in 1985 to 47% in 2006.

![Figure 1](image-url). Evolution of the average percent imperviousness of the Brussels Capital Region 1955 to 2006 [11].
Moreover severe climate change like drought, floods, cyclones and stormy rainfall are expected to have an impact on human society. [12] Optimized the utility of rain water harvesting by reviewing recent evidence for climate change during the Holocene, and tested these data with historical data to examine the India climate change-rain water harvest hypothesis. They found that there is a connection between historic human activities for installing rainwater harvesting system in response to dramatic climate changes. [13] Implemented a Domestic Rainwater Harvesting (DRWH) system in the hydrologic hydraulic model using EPASWMM for urban block located in Genon, Italy. Historic rainfall events of 2125 were used to test the site. The peak and volume reduction were equal to 33 and 26 percent respectively. On average with maximum value of 65 percent for peak and 51 percent for volume. The results showed that even for return period T=10 years and rainfall depth greater than 20mm, the impact of the systems in storm water runoff control is noticeable. There are two different techniques that can be used for water harvesting. The first technique is collecting rainwater from roofs and ground surfaces and the second is collecting water from valleys [14].

In this study, PCSWMM, a comprehensive program for advanced storm water, sanitary sewer and watershed management modeling, has been used to examine if RWH with permeable pavement can restore the predevelopment hydrology and mitigate runoff to a highly urban area (Al-Huryai city), Baghdad, Iraq. Results will help influence design recommendation to be established in Iraq. The hypothesis the study will test is that the RWH alone will not cause significant reduction in storm water runoff and will therefore not increase the probability of stormwater reduction. This hypothesis is based on the geographic qualities of the urban areas in Al-Huryai City. Therefore, The RWH was combined with permeable pavement technique for better results. LIDs such as permeable pavement and RWH can fully address these storm events by dealing with the excess runoff volume near the source of runoff through infiltration. The flow frequency and duration for the post development conditions should be almost identical to those for the predevelopment condition [4-15].

2. Case study description
This paper deals with the impact of RWH on storm water runoff on a 1.8 ha Al-Huryai City located in Baghdad, Iraq. Combined sewer network was used for collecting both storm and sanitary flow. Currently, the system is insufficient during heavy rain [15]. The city parameters are as shown in Table 1.

| Site description | Area (ha) | Pervious area (%) | Impervious area (%) | NRCS soil group |
|------------------|-----------|-------------------|---------------------|-----------------|
| Residential area | 1.8       | 76                | 24                  | B               |

Because data on storm runoff volume in specific areas are not available and climate change in the flow characteristic cannot be measured directly, researchers have come to rely on computerized models for this information. Furthermore, modeling has been found to be one of the best tools for simulating the response of watersheds to different scenarios [9-16].

PCSWMM is used in this study to model pre and post-development scenarios as well as the implementation of conventional and LID stormwater management techniques to evaluate the impact of
RWH on drainage streams of urban areas. The model inputs are a historic precipitation from 2014-2015, Station # 40650 in Baghdad as shown in figure 2, return period, duration, and antecedent moisture condition (AMC), and storm type in order for PCSWMM to provide representation results to match the conditions that the user is trying to simulate. Additional information that is needed in this model is:

- percentage of impervious cover that includes roof surface areas, streets and driveways, (76%) and percentage of pervious cover which includes the grass areas and open areas in the urban environment (24%).
- The soil type was B based on NRCS (Natural Recourses Conservation Services) [15].

The output produced by the model is the values of runoff volume at the exit of the case study area. Using this model to evaluate the impact RWH could have on both storm water flows and municipal water conservation was very helpful.

3. Results and discussion
Baghdad city has street flooding issues which required post construction runoff control. In recent years, specifically on February 16, 2018, flooding occurred in many areas of the city because of the severe rain. The main objective of this study is to increase the percentage of non-directly impervious areas (NDIA) by implementing RWH and Permeable Pavement techniques. The predevelopment scenario (Al-Huryai as-is) was created for comparison with the other models. It is the control scenario. The other two scenarios (Al-Huryai-PP and Al-Huryai-PP+RWH or the active scenario) were modeled with continuous time series data using PCSWMM. This type of simulation analyzes the performance of the three models mentioned above over a long period of time to see the effects of stormwater controls. The results at the beginning, the middle, and the end of the simulation are shown in Figures 3, 4, 5, and 6 respectively.
The post-development hydrograph shown in figures 3, 4, and 5 displayed a significant increase in peak discharge and a more rapid decline once the rainfall ceases. The narrow hydrograph (Al-Huryai-PP) shows that rain waters reach the outlet quickly and do not infiltrate into the ground. However, the wide hydrograph (Al-Huryai as-is) illustrates that an enormous amount of rainwater gain access to the ground. This incidence occurs because the land surface in the pre-development mainly consists of grass that allows water to infiltrate quickly, while the post-development mostly consists of paved area that does not permit water to infiltrate.

Figure 3, 4, 5 and 6 clearly demonstrate that the Al-Huryai-PP scenario was able to reduce the total runoff and peak discharge and thus reduce flooding in the neighborhood. However, it does not meet the pre-development runoff condition. The peak flow rate for Al-Huryai as-is scenario in the middle of the simulation was 0.004m³/s, while the peak flow rate for Al-Huryai-PP was 0.009m³/s and for Al-Huryai PP+RWH was 0.0038m³/s which mimics the predevelopment condition. The RWH performance typically varies with rainfall event size. Permeable pavement and RWH controls are typically more effective at reducing runoff for smaller events that are more frequent as shown in figures 4, 5 and 6.
New stormwater management strategies are needed for mitigating the negative impact of urbanization and climate change. LID technique tends to retain water on site as much as possible to promote infiltration and evaporation in order to bring the post-development conditions runoff closer to predevelopment conditions and thus control flooding issues. Three scenarios are modeled in this study, Al-Huryai-PP, Al-Huryai PP+RWH (active scenario) and Al-Huryai as-is (control scenario). The former approach was able to reduce the peak flowrate and total runoff but it does not meet the target. The peak flow rate for Al-Huryai as-is was 0.004 m³/s and the peak flow rate for Al-Huryai-PP was 0.009 m³/s as shown in figure 4. Therefore, the Al-Huryai_PP+RWH approach was created. The simulation showed better results when the two approaches were gathered. The Peak flow rate for Al-Huryai PP+RWH was equal to 0.0038 m³/s which is very close to the predevelopment conditions (Al-Huryai as-is). The models were suitable to predict the peak flow rate and total runoff for small watershed such as Al-Huryai and thus meet the target.

**Figure 5** Comparisons simulation between Al-Huryai -PP and Al-Huryai PP-+RWH at the end of simulation period

**Figure 6** Comparisons simulation between Al-Huryai as-is , Al-Huryai -PP and Al-Huryai -PP-+RWH at the end of simulation period.

### 4. Summary and conclusions

New stormwater management strategies are needed for mitigating the negative impact of urbanization and climate change. LID technique tends to retain water on site as much as possible to promote infiltration and evaporation in order to bring the post-development conditions runoff closer to predevelopment conditions and thus control flooding issues. Three scenarios are modeled in this study, Al-Huryai-PP, Al-Huryai PP+RWH (active scenario) and Al-Huryai as-is (control scenario). The former approach was able to reduce the peak flowrate and total runoff but it does not meet the target. The peak flow rate for Al-Huryai as-is was 0.004 m³/s and the peak flow rate for Al-Huryai-PP was 0.009 m³/s as shown in figure 4. Therefore, the Al-Huryai_PP+RWH approach was created. The simulation showed better results when the two approaches were gathered. The Peak flow rate for Al-Huryai PP+RWH was equal to 0.0038 m³/s which is very close to the predevelopment conditions (Al-Huryai as-is). The models were suitable to predict the peak flow rate and total runoff for small watershed such as Al-Huryai and thus meet the target.
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References

[1] AbdelKhaleq R A and AlhajAhmed I 2007 Rainwater harvesting in ancient civilizations in Jordan Wa. Sci. Technol 7, 1, pp 85-93.
[2] Farahbakhsh K, Depins C and Leidl C 2009 Developing capacity for large-scale rainwater harvesting in Canada. Water Quality Research Journal of Canada, 44, 1, pp 92-102.
[3] Wang W L, Zhao W W and Li H Y 2010 Infiltration and Emission Reduction Measures: Beijing case study. Redefining Water in the City, ASCE: pp 702-713.
[4] Prince George’s County. 1999 Low impact development design strategies: An integration design approach. Largo, MD: Prince George’s County, Maryland. Retrieved from: <http://water.epa.gov/powaste/green/upload/lidatlpdf>.
[5] Viswanath S 2007 July 14. Rain tank for harvesting. The HIDU. Retrieved from http://www.hindu.com/pp/2007/07/14/stories/2007071450580300.htm
[6] Cheng C L and Liao M C 2009 Regional rainfall level zoning for rainwater harvesting systems in northern Taiwan. Resources Conservation and recycling. 53 pp 421-428.
[7] Roman D, Braga A, Shetty N and Culligan P 2017 Design and modeling an adaptively controlled rainwater harvesting system. J. of Water. 9 p 974 doi:10.3390/w9120974.
[8] Yang G et al. 2010 Hydroclimatic response of watersheds to urban intensity: An observational and modeling-based analysis for the White River Basin, Indiana. J. Hydrometeorology. 11 pp 122-138.
[9] Shukur H K 2017 Estimation of curve numbers using GIS and Heg-GeoHMS. J. Engineering.5 23 pp 1-11. https://www.iasj.net/iasj?func=fulltext&aid=124412
[10] Harold M 2007 The effect of urbanization on surface water flows. A study of West Houston. Surface Water Hydrology. CE394K. 2 pp 1-8.
[11] Hamdi R, Termonia and Baguis 2010 Effects of urbanization and climate change on surface runoff of the Brussels Capital Region: a case study using an urban soil-vegetation – atmosphere- transfer model. International. J. climate. doi:10.1002/joc.2207.
[12] Pandey D N, Gupta A K and Anderson D M 2003 Rainwater harvesting as an adaption to climate change. Indian Institute of Forest Management. 85 pp 46-59.
[13] Palla A, Gnecco I and La Barabers P 2017 The impact of domestic rainwater harvesting systems in storm water runoff mitigation at the urban block scale. J. Env. Management. 191 pp 297-305. DOI: 10.1016/j.jenvman.2017.01.025.
[14] Rahi K A, Al-Madhhaichi A T and Al-Hussaini S N 2019 Assessment of surface water resources of eastern Iraq. Hydrology. 6(3), 57. https://doi.org/10.3390/hydrology6030057
[15] Azawi H and Sachit D E 2018 Investigation of permeable pavement implementation in Baghdad using PCSWMM Model Environment and Natural Resources Research Canadian Center of Science and Education. 8 pp 117-125(ISSN 1927-0488).
[16] Al-Abed, N and Al-Sharif, M. (2008). Hydrological modeling of Zarqa River Basin- Jordan using the Hydrological Simulation program-Fortran-HSPF model. Water Resource Management. 22 pp 1203-1220.
[17] Almazroui M Islam M N Balkhair kh S Sen Z and Masood A 2017 Rainwater harvesting possibility under climate change: a basin-scale case study over western province of Saudi Arabia. Atmospheric Research.189 pp 11-23.