SBE16 Hamburg

International Conference
on Sustainable Built Environment
Strategies – Stakeholders – Success factors

7th - 11th March 2016

Conference Proceedings

Organised by

ZEBAU

KIT Karlsruhe Institute of Technology

Hochschule für angewandte Wissenschaften München

HCU HafenCity Universität Hamburg

Imprint

Conference organisers

ZEBAU – Centre for Energy, Construction, Architecture and the Environment GmbH

www.zebau.de

In cooperation with

Supported by

Edited by: ZEBAU – Centre for Energy, Construction, Architecture and the Environment GmbH, Große Elbstraße 146, 22767 Hamburg, Germany

This book was prepared from the input files supplied by the authors.

The publisher is not responsible for the use which might be made of the following information.

2016

Printed on 100% recycled paper.
Druckerei in St. Pauli, Große Freiheit 70, 22767 Hamburg, Germany

ISBN 978-3-00-052213-0
DOI: 10.5445/IR/1000051699

A Case Study of Rainfall Water Harvesting Effects on Runoff for Guzelyurt, Northern Cyprus

Elham Jahani
Middle East Technical University, Northern Cyprus Campus
via Mersin 10, Turkey
elham.jahani@metu.edu.tr

Co-Author without Photo: Assistant Professor, Bertug, Akintug, Middle East Technical University, Northern Cyprus Campus via Mersin 10, Turkey, bertug@metu.edu.tr

Co-Author without Photo: Professor, Wolfgang, Dickhaut, HafenCity University, Hamburg, Germany, wolfgang.dickhaut@hcu-hamburg.de

Summary

Development of the cities and growing population significantly change the natural water cycle in urban districts and consequently increase the amount of runoff water which results in higher flood risks. For mitigating the negative impacts of urbanization on runoff, rainfall water harvesting (RWH) is proposed and applied in several regions for reducing the amount of runoff. In this study, the RWH by installing storage tanks and the methodology for studying its effects on runoff are introduced. The main objective for this study is to quantify the effect of applying RWH on reducing the pressure on the existing drainage system in order to avoid the necessity of renewing the existing drainage infrastructures. The methodology is applied on a small catchment in East Guzelyurt, Northern Cyprus as a case study, in order to investigate the effectiveness of RWH for this region. The results show that considering a 6 hour rainfall with a critical intensity of 30 mm/hr, for the selected catchment the runoff can be reduced up to ~15% in first 2 hours; however before the peak rainfall, the storage tanks get full and the runoff is not significantly reduced for the next 4 hours. The results show that RWH by installing storage tank in residential buildings for this catchment is not sufficient for reducing the amount of runoff and other harvesting methods should also be considered.

Keywords: Rainfall water harvesting, sustainable development, source control, peak discharge.

1. Introduction

Under natural conditions water cycle includes precipitation, infiltration, surface runoff and evaporation. Development of the cities and growing population significantly change the natural water cycle by mainly interfering in evaporation and infiltration stages; hence higher amount of runoff water would be exposed to the conventional water management systems. The changes in water cycle not only increase the flood risk but also adversely affect the quality and quantity of the available water for different applications. The main reason for having higher runoff is the impermeable surfaces in the cities, causing lack of infiltration and rapid discharge to the public drainage system. Comparing to the rural district in which impervious coverage may only be 1% to 2%, in urban areas these numbers would increase to 10% in low density urban, 50% in multi housing communities, and 90% in dense metropolitan areas [1]. This defected cycle finally results in negative impacts on ground water recharge, the quality and quantity of water and urban climate. The quantity impact refers to increasing in flood peak and flood volumes and quality impact is associated with the higher pollutant in runoff in comparison with secondary treated domestic wastewater [2]. In addition, recent observations on climate change are another challenge for stormwater management in urban areas. As a result of the global warming, unusual extreme events are happening at different locations on the earth and the conventional systems are unable to manage them. The conventional water management systems are not designed for such extraordinary extreme events and this increases the risk of flooding, hence it is clear that the conventional water management systems are neither sustainable nor adaptable to the climate change [1].

Considering all these issues shows an increasing demand for sustainable development in cities and necessity of a real change in water systems infrastructures. For mitigating the negative impact of urbanization on water cycle and ecology, a sustainable and decentralized water management is highly demanded. Rainwater Harvesting (RWH) is one of the common techniques of the decentralized method for stormwater management which has practical advantages in reducing service demand and consequently diminish the cost throughout the time by saving resources and energy [1]. In other words, it is a promising approach towards supplementing water scarcity in areas that water resources are inadequate. There are several studies on investigating advantages and disadvantages of applying RWH as a sustainable solution to conventional water management systems.

In a study done by Aladenola and Adeboye in (2009) [3] it is stated that by harvesting rainwater in Abeokuta it is possible to meet the monthly demand for flushing and laundry in residential area except in December, January and February. Moreover, it is mentioned that the highest potential for water harvesting is in June and September which is the rainfall peak period in Southwest Nigeria. In another study done by Petrucci (2012) [4] the effect of rainwater harvesting on runoff is analyzed to investigate the potential of RWH technique for stormwater source control. In an urban catchment with 23 ha area in east of Paris, 1/3 of the private parcels have installed rainwater tanks and the rainfall and runoff were measured before and after tank installation. The results showed that the installed rainwater tanks could affect the runoff for usual rainfall events but are too insufficient to prevent sewer overflows in case of heavy rainfall events. Additionally, in a study that investigated the rainwater utilization in Germany which is done by Herrmann and Schmida (2000) [5] the objective is mentioned as quantifying the effect of rainwater usage on urban drainage system and the results showed that rainwater usage system can significantly reduce the water consumption and drainage water. In addition, for overflow events it is mentioned that the high specific service water consumption which mainly occurs in multi-story buildings and high population density will lead to reducing or even eliminating overflow runoff. Gilory and MacCuen, 2009 [6], investigated the effects of location and quantity of cisterns and bioretention pits on stormwater runoff for various return periods and different land uses. They suggested the general trend for locating cistern and bioretention as:

- The importance of efficient volume in controlling peak discharge.
- Locating bioretention in drain pervious surface would be less effective than impervious areas due to partial reduction in runoff rates and volume in grassy areas.

- Effectiveness of cistern and bioretention are highly dependent on the return period of the storm event.
- In large impervious areas with high intensity of rainfall cistern and bioretention should be located in series while for small areas and frequent events it is better to locate them independently.
- Design volume for cistern and bioretention can be based on controlling peak discharge or volume controlling [6].

In another study for investigating the effectiveness of RWH for Northern Cyprus, Okoye et al (2015) [7] investigated the optimum tank size of a single residential housing unit for rainwater harvesting. They considered a specific rainfall profile, a constant water consumption rate per capita and an assumption of average rooftop area and performed their analyses based on linear programing. The proposed model was applied on the cities in N. Cyprus and the feasibility of applying RWH as a solution for rehabilitating depleting aquifers has been investigated.

In the current study, the methodology for investigating RWH by installing storage tanks for the residential buildings in small catchments is introduced. This methodology is general and can be applied on any region if the data are provided. In this study, a small catchment in East Guzelyurt, N. Cyprus is investigated as the case study for the introduced methodology. Guzelyurt is a small city with 19800 population and old urban design which has a conventional separated sewerage system. This area recently faced flood situation in urban areas and caused serious problems such as damaging the buildings and main roads. The last flood situation happened in this area was in January 2010 after a dry period which was observed in Cyprus in 2007 and 2008. The sewerage system in this city has not been designed for such extreme events and needs some retrofits. Moreover, not only discharging water from urban area is an essential process, but also harvesting this water for different purposes is required since this area is suffering from water shortage and decreasing water ground level. The methodology introduced in this study is based on a typical rainfall pattern and the assumption of constant water consumption per capita.

2. Methodology

To accomplish the objective for this study and find the effects of applying RWH techniques on the runoff water generated from a small catchment, it is necessary to investigate the catchment surface characteristics, rainfall characteristics and water consumption of each dwelling. A small catchment located at East Guzelyurt which includes different land use characteristics is chosen to be studied based on the methodology given in this section. This catchment is selected since the required data for this study were available for it. The characteristics of the catchment are analyzed and the total amount of runoff water from the studied area is calculated based on rational method [8]. The rainfall characteristic of the region is assumed to be compatible with 6 hour rainfall SCS type II hyetograph [9]. Additionally, the dwellings in the residential section are categorized into 6 batches based on the rooftop area sizes. For simplicity of the study, the water consumption is assumed to be constant and different tank sizes are used for different dwelling categories.

2.1 Analyzing the studied area

Figure 1 shows the selected catchment for this study which is located at East Guzelyurt. The area of the catchment is 491193 m^2 and the average slope is 1%. This area has not been completely overtaken by constructing buildings yet and the main portion of the catchment is orange gardens and bare lands. The characteristics of the catchment is investigated by developing the orthophoto map using AutoCad software. The ortophoto map is developed by integrating the photos from

Google Earth software and the road map of Guzelyurt. Based on the developed orthophoto map the rooftops were selected individually as shown in Figure 1. Moreover, the statistical analysis for finding the number of dwellings in each rooftop category is performed using Arc GIS software. In addition, the surface characteristics in different parts of the catchment are also identified using the generated ortophoto.

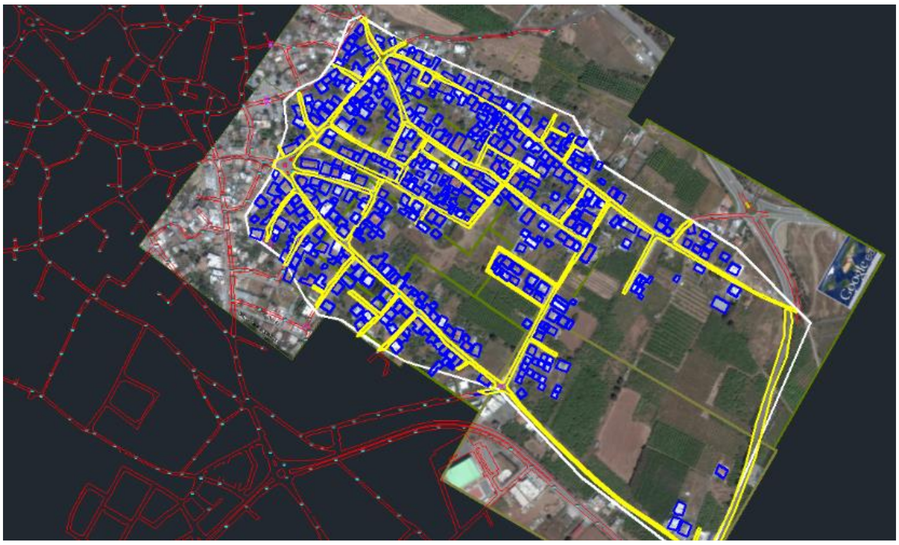

Figure 1. Dwellings are categorized based on the rooftop size for the selected catchment, Guzelyurt, N. Cyprus

2.2 Rainfall characteristics

The rainfall hyetograph is synthetically generated using 6 hours SCS type II hyetograph [9]. The critically high rainfall intensity is assumed as 30 mm/hr based on the precipitation characteristics of Guzelyurt which is obtained from the measured data provided by the local authority, and the total rainfall is calculated for a 6 hour period. Using these data as the input the hyetograph is generated in order to illustrate the rainfall intensity at each time step.

2.3 Runoff from the catchment

According to the surface characteristics of the catchment area which is analyzed by using orthophoto maps, different subareas are listed based on their surface properties and land use and the runoff coefficients for each subarea is determined in order to use the rational method. Moreover, the peak runoff is computed using Equation (1) [8]

$$Q_P = 0.278\ i\ \sum_{j=1}^{n} C_j A_j \qquad (1)$$

where Q_p is the peak flow rate in m^3/s, i is the average rainfall intensity in mm/hr, A is the drainage area in km^2 and C is the runoff coefficient which is dimensionless.

2.4 Runoff from roof tops

The volume of rainwater that could be harvested from rooftops is determined using Equation (2) [10],

$$VR = \frac{R \times TRA \times R_c}{1000} \qquad (2)$$

where VR is the volume of rainwater in m^3 in specific time step, R is the rainfall intensity in mm/hr, TRA is the total roof area in m^2, R_c is the runoff coefficient and 1000 is the conversion factor from mm to m.

2.5 Consumption

Based on a study done by Okoye et al [7], consumption in Cyprus is 0.125 m^3/day per capita. Since in this study the consumption is assumed constant at each time step hence, the daily consumption is converted to hourly consumption by dividing it to16 hours of water consumption per day assuming that water consumption is negligible for 8 hours in 24 hour. Additionally, for calculating the total consumption in the region at each specific time step, it is assumed that the number of residents per each dwelling is 5. The total consumption for each sub area is calculated by finding the total population in the subarea and multiplying by the consumption per person.

2.6 Water harvesting

It is assumed that the RWH is applied using storage tanks for each dwelling at the sub catchment. The rooftops of the dwellings in the region are categorized six different batches according to their area. Different storage tank sizes are selected for each batch based on the most frequent rooftop area in it. Considering specific tank sizes, cumulative amount of the water that can be harvested is calculated while there is a constant consumption for each time step. This calculations are continued till the tanks get full and then the runoff from the rooftops are considered to be disposed to the sewerage system.

3. Results

3.1 Characteristics of the sub catchments

The results from investigating the orthophoto map of Guzelyurt show three types of land use for this catchment which are presented in Table 1. The residential part is only 17% of the whole area while the street and paved area are about 10% and 73% of the area is mainly fruit gardens, bare land and wheat fields which are categorized as neighborhood area. The runoff coefficient for each of these characteristics are extracted from typical coefficients for design with 5 to 10 years frequencies (ASCE,1970) [8]. Moreover, the highest value for the range given for streets, asphalt and neighborhood area is considered as a runoff coefficient to maximize the confidence level of the study. The runoff coefficient for the rooftops in Guzelyurt is adapted from [7].

Table 1. Results for surface characteristics of the catchment

Category of the surface	Area (km^2)	Fraction of total area	C coefficient range	C	Q_p (m^3/s)
Roof tops	0.09	17%	.75-0.95	0.9	0.57
Streets, Asphalt	0.05	10%	0.7-0.95	0.95	0.38
neighborhood area	0.36	73%	0.5-0.7	0.7	2.09

The total number of dwellings that is recognized from the photomap is 441 units which are categorized in 6 series as shown in Table 2. As it is shown in the results, 44% of the dwellings are in the range of 100 m^2 to 200 m^2 and most frequent area in this range is the dwellings with 100 m^2 area. Based on the most frequent area size in each batch, different tank sizes are considered to be installed and the values are given in the table. The total installed tank size would be 2180 m^3.

Table 2. The categories for the dwellings

	Area range for each category					
	<= 100	100<A<=200	200<A<=300	300<A<=400	400<A<=500	500<A<=600
Number of dwellings	72	194	111	43	14	7
Fraction of the total (%)	16%	44%	25%	10%	3%	2%
Most frequent area (m^2)	75	100	200	300	400	540
Tank size (m^3)	2	5	5	7	10	10

3.2 Hyetograph

The volume which was deducted from the whole runoff by RWH is calculated and the equivalent rainfall is obtained by deviding the total harvested water volume by the total area of the catchment. The resulting hyetograph after RWH is compared with the hyetograph before RWH which is shown in Figure 2. Since the rooftop area is just 17% of the whole catchment the reduction in runoff is not significantly high, especially for the time when peak rainfall intensity occurs. Considering the total runoff in 6 hours RWH from the rooftops reduce the rainfall intensity by 2% in six hours of rain fall. Additionally, Figure 3shows the percentage of reduction in each time step of the rain fall. After nearly 2 hours of rainfall the tanks get full and since the consumption is not significantly reducing the stored water, the reduction in runoff drops significantly. After 2.7 hours the tanks are completely full and there is no reduction in runoff. This shows the fact that similar to the results of the study performed for RWH at a region in Paris [4], RWH in the storage tanks would not reduce the runoff water significantly in case of high rainfalls with high intensity at this catchment. Nevertheless, the possibility of RWH in small ponds for harvesting higher amounts of rainfall water should also be studied.

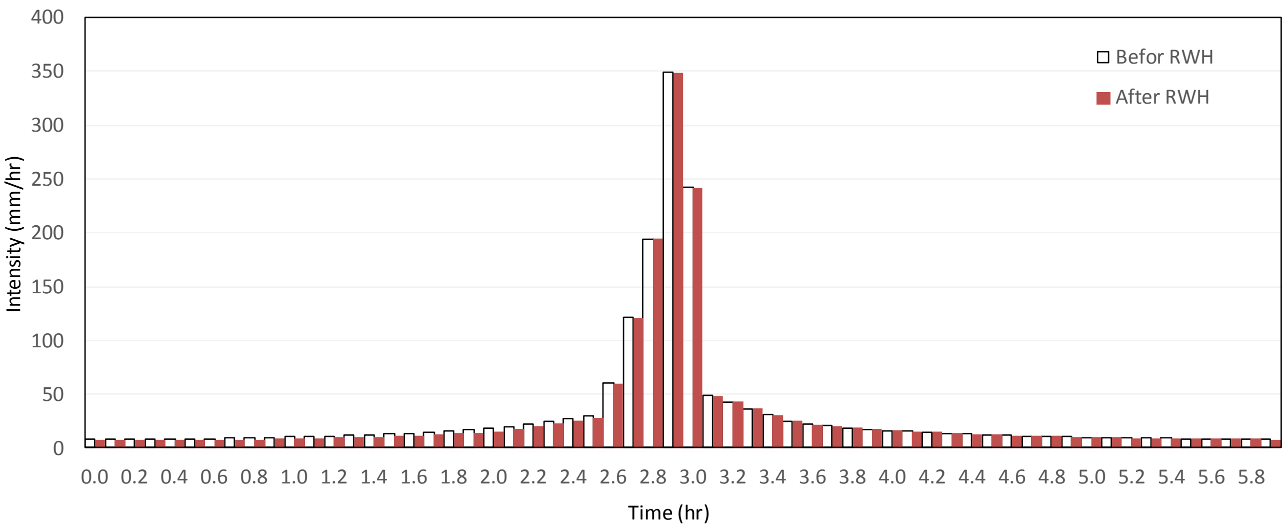

Figure 2. The hyetograph before and after rainfall water harvesting from the rooftops

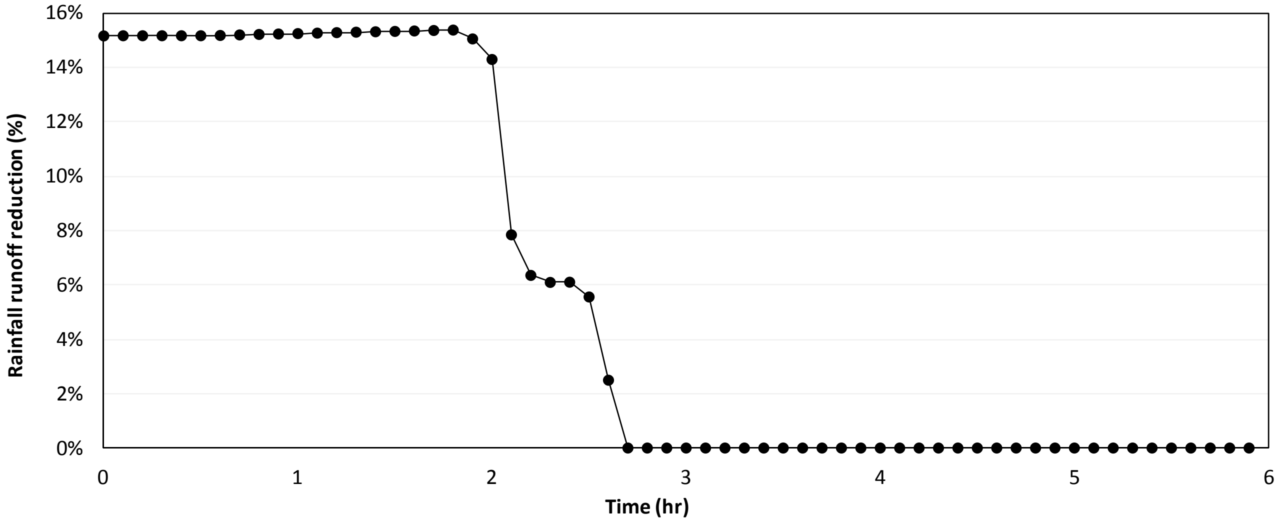

Figure 3. The reduction in the runoff after applying rainfall water harvesting from the rooftops

4. Conclusion

The effect of applying RWH in a small catchment on rainfall runoff volume was assessed. The dwellings in the catchment are categorized into 6 batches based on the rooftop size and different storage tank sizes are considered for each batch. The methodology was presented and applied to a small catchment in East Guzelyurt, N. Cyprus. Results show that only 16% of the runoff from rooftops is harvested considering 2180 m^3 installed tanks for the dwellings in the catchment. The rooftops are only 17% of the total area in the catchment and the fraction of harvested runoff would increase by escalating the tank size for each dwelling. Considering the small fraction for rooftop area, the reduction in rainfall intensity after RWH was only 2%. The results show that in order to influence the reduction in the amount of runoff water considerably, it is necessary to study and apply other methods for rainfall water harvesting including the construction of larger storage capacities. These storages can be constructed as the components of urban design such as ponds for the cities and recreational areas. In addition, the effects of urban developing and land use change on runoff volume would be investigated as the future study.

5. Acknowledgment

This research is supported by the Campus Research Fund (FEN 13-YG-5) of the Middle East Technical University, Northern Cyprus Campus. This support is gratefully acknowledged. The authors would like to thank to The Meteorological Authority of North Cyprus for the provided rainfall data used in this study.

6. References

[1] J. Hoyer, W. Dickhaut, L. Kronawitter, and B. Weber, *Water sensitive urban design: principles and inspiration for sustainable stormwater management in the city of the future*. Jovis, 2011.

[2] Goonetilleke, Ashantha, Egodawatta, Prasanna, and Liu, “Enhancing Water Sensitive Urban Design (WSUD) Practices to Mitigate Urban Stormwater Pollution and Reuse Potential,” 2011, no. January, pp. 19–21.

[3] O. O. Aladenola and O. B. Adeboye, “Assessing the Potential for Rainwater Harvesting,” *Water Resour. Manag.*, vol. 24, no. 10, pp. 2129–2137, 2010.

[4] G. Petrucci, J.-F. Deroubaix, B. de Gouvello, J.-C. Deutsch, P. Bompard, and B. Tassin, “Rainwater harvesting to control stormwater runoff in suburban areas. An experimental case-study,” *Urban Water J.*, vol. 9, no. March 2015, pp. 45–55, 2012.

[5] T. Herrmann and U. Schmida, “Rainwater utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects,” *Urban Water*, vol. 1, no. 4, pp. 307–316, 2000.

[6] K. L. Gilroy and R. H. McCuen, “Spatio-temporal effects of low impact development practices,” *J. Hydrol.*, vol. 367, no. 3–4, pp. 228–236, 2009.

[7] C. O. Okoye, O. Solyalı, and B. Akıntuğ, “Optimal sizing of storage tanks in domestic rainwater harvesting systems: A linear programming approach,” *Resour. Conserv. Recycl.*, 2015.

[8] N. Usul, *Engineering hydrology*. METU Press, 2001.

[9] A. O. Akan and R. J. Houghtalen, *Urban hydrology, hydraulics, and stormwater quality: engineering applications and computer modeling*. John Wiley & Sons, 2003.

[10] E. Ghisi, A. Montibeller, and R. W. Schmidt, “Potential for potable water savings by using rainwater: An analysis over 62 cities in southern Brazil,” *Build. Environ.*, vol. 41, no. 2, pp. 204–210, 2006.