Operation of Rainwater Harvesting on the Roofs of Residential Buildings to Reduce of Urban Flood: A Case Study in Tehran, Iran

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Abstract: Among the natural phenomena, flood is one of the biggest destroying factors in developing countries which always bring numerous people's life, property and assets to the hazard. The flood rivers and their damages have always been the main concern of residents in developing region. Growing population, urban development and industrialization are the main factors that have undesirable consequences in the hydrology of watershed region in the cities. In developing countries, usually we have urban flood due to the rainfall. So, it's more tangible that we require some construction of transition and collection of surface runoff and integrated management to reduce the flood. As it's expected, for the control of flood in developing countries, we can use water network to collect and transfer surface runoff. Control and gathering of surface runoff from rooftops, streets and impenetrable surfaces has a great effect on controlling and collecting of surface runoff. In this paper, daily average of rainfall statistics of Tehran city in Iran during 1999 to 2008 have been used to achieve modeling of rainwater harvesting system on the roofs of residential areas and then effects of these systems in runoff reduction and flood control have been investigated. According to the result and graphs from modeling and simulation of these systems, it could be said that after implementation and building of these systems in Tehran city, they lead to runoff reduction when it's rainy and then cause a flood reduction in cities when it's rainy.

Key words: Rainwater harvesting • Residential buildings • Urban surface runoff • Urban flood

INTRODUCTION

According to the climatic conditions in developing countries, increasing water demand and the need to develop, the importance of surface water control and adopt appropriate methods of resource utilization has the added value. Increasing population and the need of health environment, establishment and implementation of projects and drainage canals and optimal use of water resources has been undeniable.

Surface runoff was collected and controlled, like water on the roofs and streets can be effective on control of urban and then can minimize flood volume in urban areas and reduce flood damages that occur to residents of cities.

Methods of rainwater harvesting from roof surfaces can be truly collected from surface waters for various purposes such as irrigation and uses non-drinkable used. In cities that there are deficient in water and buying water is very expensive for families, we can collect rain water; the water used for household consumption had an effect on the family’s economy and will raise awareness and educate people this way among the areas that are suffering from water shortages [1-3]. The method of collecting roof water can be put in place the desired reservoirs of rainwater from rooftops and overflow the remaining excess water from the tank and set the system to bring a model and reservoir volume based on storage volume, the volume of water consumed and volume of the tank is overflow; Su et al. and Villarreal et al. [4-5]. In rural locations we can also collect rain from roof surface to use for consumption; Sturm et al. [6] and also can be in multi-unit buildings from rain water storage tanks used and collected water for people living in these buildings. In addition, method of roof water supply would be appropriate for residents and then reduce runoff volume in the city; Erkusu et al. [7] and this is very important issue and a positive urban area will cause a flood in when precipitation is reduced. Method of collecting rain from the roof to provide water for washing cars at petrol
stations is appropriate and will be a good solution to reduce the purchase of water and can be cost effective for people; Ghisi et al. [8].

Green roofs on residential buildings in cities is an issue in developing and operating buildings for beauty and good sound insulation and thermal residents have created and using rain water have less need for irrigation so that the roof on them instead of gravel surfaces will use green and herbal surfaces. In addition to the benefits mentioned, they can be a useful tool to reduce urban runoff problems. Green roof is a solution to reduce the volume of surface runoff in urban areas has decreased in area 2.7 percent and 54 percent for individual buildings. The green roof is a useful tool to reduce urban surface runoff is considered; Mentens et al. [9]. This roof has a great effect on the management of runoff quality and quantity and the influence factors are: the geometric properties of the roof (slope) of soil moisture characteristics, season, weather and rainfall characteristics; old green roof; vegetation; Berndtsson et al. [10].

Methods of flood control in cities are divided into two groups. These groups are structural and non-structural. One of the methods of non-structural flood control is an integrated management of surface runoff and urban flood and ongoing management of water at ground level can be helped to reduce urban runoff. This action can be divided into seven stages. The first step: understanding the processes and components fields, the second step: identify and rank to solve problems, the third step: set clear targets, the fourth step: preparing a list of management options, the fifth step: delete impractical options, the sixth step: testing the effects of remaining options and seven step: development the final option; Seong Lee et al. [11].

Effecting Factors on the Vulnerability of Flood in Developing Countries: One of the considerable problems of the developing countries is flood in wet years which main factors are divided into two general categories. The first category is related to urban developing and creates new metropolises and the second are the problems caused by improper design of urban drainage structures or mismanagement of surface runoff in metropolises. Among the first group's factors, misuse of the forest or pasture and make them urban surfaces such as roads and also construction of homes and other impermeability surfaces play an important role. Change of natural ecosystem which the runoff coefficient is 2 percent to a residential town with a 70 percent impermeability surfaces in upstream of a metropolis is capable increase town down stream's flood levels to 5.6 times of its initial flood. This change makes some new problem in city's management and also decreases new town's ground water five times more than its initial flood. According to construction of new towns or implementation of development projects in urban areas, the runoff transport capacity should be increased in metropolises drainage structure which is usually impossible or should use the runoff transfer to make the minimum problem.

Another problem in most developing countries is the lack of wastewater systems and also lack of the necessary prediction in urban design to create a collection networks for surface runoff. So the first rainfall, disrupting the water systems and then flood will happen in many areas of city. Furthermore, the absence of such systems has caused many parts of urban land became useless because of high surface runoff and industrial wastewater and also large parts of the environmental resources will face to the risk of pollution from polluters. Finally, we can divide the effecting factors on the vulnerability of flood in developing countries into the following sections:

population Growth and Urban Development: Important factors in changing of urban hydrology are basin's penetration surfaces and characteristics of water flow paths. These two factors in areas which are under developing will significantly change and these changes make a new hydrology basin. Urban operations usually increase the intensity of rainfall. These changes improve the drainage area, shorten the time concentration and will increase the discharge of flood.

Improper Land Use and Improper Location of New Towns: Non-compliance and violation of rivers and the range of watercourse are main factors that cause vulnerability against the flood disaster. According to the growth of developing countries and increasing need for housing development on the urban of city and also construction of new towns, regardless of location, which is performed correctly, causing many building blocks located in flood zones that these actions increase their vulnerability to flood.

Intervention in the Watercourse and Manipulation Hydraulic Conditions: Intervention and manipulation in the watercourse of developing countries are greatly significant. These interventions could be such as tightening of watercourse or constructing bridge on the river for communication between the two sides river. If
such interference not be done correctly based on scientific and accurate calculation about maximum possible discharge, will lead to very dangerous flood and makes a lot of damage in the surrounding areas of watercourse.

Non-Compliance with Privacy and River Watercourse: Expansion of agricultural lands, facilities, residential areas and others closely near to stream and rivers in the developing countries not only made them vulnerable, but in many cases have been prevent the proper implementation of flood dams and other flood control facilities. In some cities, land's problems are significant and demand over the land is possible, we should establish the boundaries for rivers and watercourse. This increases the risk of creating floods in urban areas and then causing financial damage for residents near rivers and watercourse areas.

Lack of Wastewater Systems: One of the main problems in most cities is the lack of wastewater systems and lack of necessary predictions in urban design, create networks based on collection the surface runoff and the first rainfall will cause disruption in the flow of city systems. Furthermore, the absence of such systems has caused many parts of urban lands became useless because of high surface runoff, domestic and industrial wastewater. Large parts of the environmental resources at risk of pollution from polluters.

Failure to Implement the Proper Principles of Design, Flood Control Structures and Facilities: Another reason for the flood occurrence in urban areas is the lack of accuracy in urban projects to control flood and in many cases, structures and facilities that should cause flood control, became the main reason of flood occurrence. Water flows out of bounds and many flood control structures such as check dams or leaching and erosion causing obvious damage to urban and rural areas in developing countries. On the other hand, raising the floor of stream because of large sediment will cause that sediment delivery being useless and led to eject water and finally overflow in urban areas.

Rainwater Harvesting: Population growth, urban development and increased residential construction exacerbate flood volume. Increasing of impenetrable urban areas will be due to the increasing of construction area. So, this will lead to the increase of total runoff volume. Urban coated surfaces, roofs of buildings and streets act as barrier against penetration of rainwater into the soil and underground water supply and induce a greater part of surface runoff of rainfall exacerbated the flood in urban areas. One of the solutions to reduce flood and runoff is infiltration of rain water to collect them for various uses that could reduce the rate of urban runoff and while hydraulic load discharge and runoff in urban networks come to the lowest point. To achieve all this rainwater, we can collect all of waters from residential buildings, streets, sidewalks and parks with various methods.

Rainwater harvesting of residential area contain following sections (Fig (1)):

- Level of rainwater harvesting is based on roofs of buildings.
- The transfer ways which direct collected water from roofs, include rainspouts and water pipes.
- Filters (prevention from entrance of mud to tank).
- Rainwater collection tank which implement both on ground and under ground.
- Overflow valve for out of excess water from tank.

Study Area and Data: Tehran was our study area which lay in Iran. Average of annual rainfall in Tehran was 238.9 mm. based on total annual rainfall; 176 mm (73.7 percent) distributed in the first half of crop year (fall and winter) and 57.9 mm (24.2 percent) in spring and at last, 5 mm (2.1 percent) in summer.

In Table 1, investigation of Iran's floods for 59 years (1951-2009) show increases the number or frequency of flood in many cities of Iran. From 1991 to 2000, the most flood have been occurred which contains 42 percent of total flood in these 59 years. Of course, it should be noted that the most of floods occurred in recent years.

Residential area of Tehran has been considered as a type and also area of roofs in most buildings is varying between 150-350 m². In this paper, area of building's roof is equal to 200 and 300m². Runoff coefficient is 0.8 and daily water demand in toilets is considered 40 liters for every person. This means that for a family which has 5 persons, they need 200 liters in every day. All of demand
water has been ensured from rainwater harvesting systems which collected from roofs. Tank's dimensions are considered 2000, 4000 and 6000 liters. Daily precipitation data is taken from synoptic station of Mehrabad weather organization in west of Tehran. Daily average precipitation statistics selected for 10 years during 1999-2008. Precipitation statistics is shown in Figure (2); which highest precipitation is from January to April and also November and December. From June to September, there is the lowest precipitation which in most days, amount of precipitation is zero.

**Method:** The amount of volume stored on surfaces of roofs to collect rainwater depends on the parameters of hydraulic system such as: statistics of daily precipitation, runoff coefficient on the roofs, the number of residents and the daily non-potable water demand of residents. Area of harvesting surface on roofs and also tanks' volume are the main factors affecting on the volume of rainwater storage and daily precipitation have a direct relationship with amount of water storage.

Based on equation (1), the volume of rainwater harvesting from the roof of buildings could be calculated.

\[ Q_t = \varphi \times R_t \times A \]  

(1)

In equation (1), \( \varphi \) is runoff coefficient, \( R_t \) is daily precipitation (mm), \( A \) is area of rainwater harvesting (m²) and \( Q_t \) is volume of rainwater harvesting based (L).

To create a hydraulic model for rainwater harvesting tanks in residential areas, first it should be identified the main parameters which have a great impact on design of tank's volume. According to the available condition in system, a continuity equation (equation 2) is defined for design of tank's volume. In equation (2), a kind of balance is created which ratio of tank's volume to the volume of rainwater harvesting, stored volume in tank from the past, amount of non-potable water demand for residential areas and volume of overflow in tank have a relationship with each others. In Fig (3), this kind of relationship is shown.

\[ V_t = Q_t + V_{t-1} - Y_t - O_t \]  

(2)

In equation (2), \( V_t \) volume of stored water in \( t \) time (L), \( Q_t \) is volume of harvesting from roof in \( t-1 \) time (L). \( Y_t \) is past stored water in tank in \( t \) time (L), \( V_{t-1} \) is daily water demand in residential area (L) and \( O_t \) is volume of overflow from tank in \( t \) time (L).

**RESULT AND DISCUSSION**

By modeling and stimulate of rainwater harvesting system from roofs of residential area and also by using equations (1) and (2), it could be calculated easily the volume of rainwater harvesting from roofs and then estimate the volume of runoff from these systems for area of roofs which is 200 or 300 m² and could be calculated for 2000, 4000 and 6000 Liters volume of tanks. Volume of harvesting for area of roofs in residential buildings is 200 m² and runoff coefficient is 0.8 which is shown in Fig (4). According to the shape, the most rainwater harvesting is nearly 900 liters in the last of fall and rainwater harvesting from January to April is
Fig. 4: Volume of rainwater harvesting from roof of residential areas by area of 200m$^2$.

Fig. 5: Volume of rainwater harvesting from roof of residential areas by area of 300m$^2$.

Fig. 6: Overflow from tank which has 2000 liters volume when it's rainy for roofs by area of 300 and 200m$^2$.

Fig. 7: Overflow from tank which has 4000 liters volume when it's rainy for roofs by area of 300 and 200m$^2$. 
Fig. 8: Overflow from tank which has 6000 liters volume when it's rainy for roofs by area of 300 and 200 m\(^2\). Averagely 300 liters in every day. The lowest rainwater harvesting is from June to September which in most days, the amount of harvesting is zero.

In Fig (5), it's shown that volume of harvesting for area of roofs in residential buildings is equal to 300 m\(^2\) and runoff coefficient is 0.8. According to the shape, most rainwater harvesting is 450 Liters/day by average and the lowest rainwater harvesting from June to September is nearly zero.

According to Fig (4) and (5), it could be said that by increase the surface area in buildings from 200 to 300 m\(^2\), the volume of rainwater harvesting would increase nearly 150 Liters/day. This show that surface area of roofs have a great effects on the volume of rainwater harvesting when it's rainfall. This issue helps us to flood control and also have a significant effect on prevention of flood when it's rainy.

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In system modeling for estimate the volume of rainwater overflow from tank, the volume is considered 200 liters and for surface area like 200 or 300 m\(^2\), amount of rainwater overflow from tank is shown in Fig (6). According to this figure, overflow of tank by 200 m\(^2\) is very low. It means that overflow in all days of a year is nearly zero and just in December, we have overflow from tank for area of 300 m\(^2\). In the last of fall, all of winter and the first part of spring, overflow from tank is nearly 350 Liters/day. In summer, runoff is zero. In Fig (7) and (8), it's shown for volume of tanks 4000 and 6000 liters and surface area of 200 and 300 m\(^2\) respectively. Each figure show the overflow of rainwater from tank when it's rainy.

The volume of overflow from tanks 4000 and 6000 liters for surface of roof area which is 200 m\(^2\) would be zero. For surface area of 300 m\(^2\) for tank which have 400 liters volume, the most overflows are happening in February and April. For tank which have 6000 liters volume and for roofs which have 300 m\(^2\) areas, the most overflows are happening in March and April and the average of overflow's volume is 300 liters. According to this information, it could be said that by increase of roofs' area, the amount of overflow makes greater and also by increase of tank's dimensions, the capability of water store would rose which led to decrease of overflow from tank. All of these issues would result to decrease of flood in different cities when it's rainy.

**CONCLUSION**

Flood control and management, including the specific processes by providing and utilization of structures designed, destructive effects of floods which eliminate or reduce this deviation, limit or flow of flood storage to the extent that is economically justifiable, are conducted. It's noteworthy that by using rainwater harvesting systems in roofs of residential buildings in various cities, the flood could be controlled. By rainwater harvesting systems could reduce flood frequency and surface runoff when it's rainy. Increase of roofs area made more the potential of rainwater harvesting. However, by increase of tank's dimensions, the potential of store for rainwater would increase too. On the other hand, volume of rainwater overflow will decrease that led to reduce of surface runoff in different basins. So, it will be possible to reduce the flood frequency.

These goals would be achievable when all of fundamental and rainwater harvesting systems on the roofs of residential buildings is implemented correctly. In this paper, three tanks by 2000, 4000 and 6000 liters of volume have been used. By increase of tank's volume, it would be possible to reduce more runoff but it does not have any economic benefits. Finally, based on benefits from control and reduce of flood, various dimensions of tanks are usable. These dimensions are completely depending on project's goal and the kind of research.
REFERENCES