A Study on the Potenil of Rainwater Harvesting Practices to Mitigate Urban Floods

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Abstract

Floods are a prominent issue and the challenge of urban flooding can be turned into an opportunity by adopting rainwater harvesting practices. Rainwater harvesting (RWH) works asa more reliable, cost effective and sustainable way. It is a mean of public contribution to mitigate urban floods rather than provide a supplementary source of water. The catchment area, maximum rainfall intensity, extent of building roofs, potential runoff, and outflowof water and estimated capacity of rainwater system are the highlighted six important factors through the literature. Arc GIS hydrology tools, IDF curves, rational method, the Manning formula and water balance equation were adopted to calculate the above factors. The relationship between capacity of a rainwater harvesting system (y) and the extent of roof area (x) has been derived by an equation of y=0.024x. This proposed rainwater harvesting system is potentially applied either in the form of individual building units or as a common water detention pond. This study has focused on identifying an appropriate mechanism to practice rainwater harvesting to mitigate urban floods in Colombo.

Key words: *Urban Floods, Run-off Control,Volume of RWH System*

1. INTRODUCTION

Floods are a prominent issue caused by increasing impervious surface in the urban environment (Mhonda, 2013). The world disaster report(2011) shows that events of flooding accounted for 47% of all reported natural disaster events in the world in year 2010 and it is believed that the amount and scale of flood events will continuously increase in the next 50 years due to the fast urbanization trend and desirable environmental changeswhich are attributed to climate change.With changes in global climate and the process of urbanization, the incidence of natural disasters and resultant damage is increasing because of interactions between natural and artificial factors (Barbosa, Fernandes, & David, 2012). Therefore, intense storms in an urban area can cause disastrous flooding and enormous human and economic losses(Zhang and Boazhu, 2006). Numerous strategies have been applied for the prevention of urban floods which includes structural strategies and non-structural strategies (Mhonda, 2013). The problems which are emerging in urban areas constraint to the natural phenomenon. It has caused to need of an involvement of manmade in cooperation to management of storm runoff. The priority of an integrated view of storm water management should have given to the water quality itself meanwhile the erosionand flood control being considered. As expected, Runoff picks up sediments and pollutants in drainages and carries these to receiving water bodies. Effective management is needed at the base point where storm water generated.

Consequently, it is effective to use a source controlling method while tapping the potential of rainfalls. Kim and Han (2008) state that decentralized rainwater tank systems can be a simple and reliable solution to urban floods caused by climate change or urbanization. In the urbanization process, the emerging challenge is control storm runoff in developed built environments with limited space(Dormouth). Rain water harvesting technique can be applied to control floods as a mitigationstrategy in the urban context consideration with the rainfall pattern.Rain water harvesting as the best management practice to align with limited space while having economic benefits besides ecological benefits. Since the research is focused on how rainwater harvesting can be integrated to mitigate local floods in site level planning practices in the urban context,as a substitute method for source control to reduce urban flood in the built environment.

2. LITERATURE REVIEW

2.1. Types of floods

Urban floods can be divided into four categories as riverine floods,flash floods,coastal flood and local flood based on different combinations of casual factors and on their impacts (A Tool for Integrated Flood Management,2008). Concentrated on the local flooding in urban context, it spreads from localized micro-drainage problems, inundating streets and troubling pedestrians and urban traffic due to the inundation of a large part of the city(Miguez & de Magalhães, 2010). Furthermore, these problems lead to material losses in buildings, damages to urban infrastructure, relocatingvulnerable people, increasing risk of diseases and deterioration of water quality.

2.2 Causes and impacts of flooding

Hossein, Mehrabadi, & Motevalli(2012)divide the factors that result in flood occurrence into two main categories. The first category is related to urban development and the second to problems caused by improper design of urban drainage structures or mismanagement of surface runoff in cities(Hossein et al., 2012). When heavy rainfall occursthe existing drainage network is unable to support the volume of water overflow and it results in urban flooding. In addition, the intense of flood occurrences, especially in urban areas, are largely due to the urbanization process that results in increase of impervious surface which shortened the time of concentration and increase the magnitude of the runoff discharge(Becker 1998).

Regarding the impacts over urban floods, it disrupts social systems and causes significant economic losses (Petersen, 2001). Among the impacts, there are losses of human and animal lives and health hazards, flooding of housing, commercial and industrial properties, flooding of streets and junctions, causing traffic delays, disruption of services such as water supply, power supply and sewerage(Jha, Bloch, & Lamond, 2011). (Petersen, 2001) explains thatflood impacts are evaluated on the extent of inundation in the catchment, velocity of flow, fluctuations of flood levels. Further, he classifies the flood damages as direct and indirect damages, secondary damages and intangible damages.Direct damages are losses due to exposure of property to flood water, including replacing and repairing private property and infrastructure. Indirect damages include the lossof business and services, measures to safeguard health, traffic delays. Secondary damages include adverse impacts on people who depend on output produced by damaged property or services. Intangible damages include impacts on environmental quality, social comfortand aesthetic values.

2.3 Flood mitigating strategies

The concept of flood control has been evolving continuously, accompanying historical demands of urbanization and its consequences(Miguez & de Magalhães, 2010). Mhonda (2013) states there are two main categories of flood mitigating strategies, namely, structural and non-structural. Structural strategies are engineering works (e.g. canalization and rectification, dredging and dike construction). Nonstructural strategies are non-engineering based strategies (loss sharing, disaster aid, flood hazard mapping, flood forecasting and warning, flood risk management, institutional arrangement and preparedness). Walesh (1989) presents two runoff quantity control approaches on mitigating floods which are conveyance oriented approaches including culverts, sewer systems, drainage channels etc. and storage oriented approach including detention, retention, rain water harvesting etc.

Regarding the flood controlling strategies, the storage oriented approach can be identified as a sustainable, more reliable and cost effective strategy than the conventional approach(Walesh, 1989). Sinceclassical drainage design concepts are intensive methods that focus on improving runoff(Petersen, 2001)explains that management of storm runoff is necessary to compensate for possible impacts of impervious surfaces such as increased frequency of flooding. Builders, developers, and engineers can utilize rainwater harvesting systems complying with storm water management regulations. With the increaseof land prices and scarcityof land, otherstorm water management practiceslike wetlands and wet ponds, become too costly and sometimes even impossible to incorporate into a project (Hunt &Szpir,2011). Rainwater harvesting systems, being either completely underground or taking up a small amount of space on the perimeter of the catchment zone, help topreserve the natural hydrologic cycle and contribute to low impact development (Hunt &Szpir, 2011).

2.4 Rain water harvesting

Rain water harvesting was used by old civilizationsas a drinking water supply and for irrigation purposes, by collecting natural rainstorms. Prinz (1996) mentionedthat RWHis still in practice in some rural and urban parts of the world and the recent technologies have gained more attentiveness as effective water conservation and management methods. Hossein, Mehrabadi, and Motevalli (2012) explain that rainwater can be collected from residential buildings, sidewalks, streets and parks by applying various methods. Basinger (2010) states that RWH systems can reduce volume of roof runoff discharged to the drainage. Mahmoud et al. (2014) explains that RWH structures reduce the water velocity during flooding events by increasing the concentration time of the hydrographic basins while reducing the flood peak.

2.5. RWH practices to mitigate urban floods

Kim (2014) has showed the potentials of RWH practices to mitigate local flooding in urban areas by modeling the volume of rainwater storage tanks,considering factors of catchment area,rainfall conditions, design of the rooftop surface and volume of peak outflow of storm water.Hossein, Mehrabadi, and Motevalli (2012) have operated RWH on the roofs of residential buildings to reduce urban floods in Tehran in Iran, considering factors of average annual rainfall, frequency of flood occurrence, area of roofs, coefficient of water runoff and daily demand for water.Petruccia et al (2012) have practiced RWH to control storm water runoff in suburban areas in Paris as an experimental study. The type of the house, rainfalls and extent, slop and the use of land have been taken in to account.

3. METHODOLOGY

The literature highlighted six important factors such as the catchment area, maximum rainfall intensity (frequency of flood occurrence), extent of building roofs, potential runoff, and water outflow and estimated capacity of rainwater system. First, the process of the catchment delineation was run by manipulating DEM, fill, flow direction, flow accumulation, flow length, snap pour points and water shed toidentify the flood affected area using Arc GIS hydro tools.Then, determination of maximum rainfall is important to controlrunoff from the catchments of building roof areas which determine the flood. Using the previous rainfall data,Intensity – Duration - Frequency (IDF) curveswere developed for the selected catchment area. For a flood return period of T years, the rainfall intensity (i) is the average rate of rainfall from a storm having duration equal to the time of concentration (t) of the catchment. The average rainfall intensity (i) can be obtained from the Intensity – Duration - Frequency (IDF) curves.

Thirdly, a database was prepared by categorizing the material of roofs and calculating the areas of rooftops. Afterwards, an estimation of peak runoff from the rooftops can be calculated by applying Rationale method. The depth of rainfall of the selected catchment was determined by analyzing meteorological characteristics of rainfall intensity, duration, evaporation and physical characteristics of slope andimperviousness.As the fifth step, the volume of water outflow through drains was calculated applying Manning's Equationthat is a function of the channel velocity, flow area and channel slope. Volume of required RWH systems was calculated using water balance equation developed by Kim (2004). Finally the relationship between the capacity of RWH system (y) and the extent of roof area (x) was derived through simple linear regression analysis.

4. ANALYSIS

As a result of rapid urbanization process, most of the areas in western region in Sri Lanka are vulnerable to flood occurrences. The Wijerama-Horton place junction and the surrounding areas in the Colombo MCwereselected as the case study area for the research.Furthermore, this area is highly vulnerable for local floodingonce a year, due to the lack of drainage capacity in the area and it has been affected to make heavy traffic jam on the roads and damages on infrastructure.Interviews and field observations were carried out to collect necessary primary data and secondary data was collected through the sources indicated in Table 1.

Table1: Secondary Data collection, type and source

Data	Data Type	Source
Flood inundation Data	Flooding locations, flood depth	SLLRDC/ CMC
Rainfall	Depth of rainfall different return periods	Recent rainfall studies in Colombo district(Suthakaran, Perera, & Wikramanayake, 2014)
Drainage network of selected site	Flow velocity, Diameter of cannels	Metro Colombo Urban development Project
Digitized maps(2010)	Built up area, shape file	Survey Department of Sri Lanka

Step one- Delineation of Catchment

The following method of study was used to delineate the catchment of the case study area as 200.39 ha using Arc GIS 10.1.

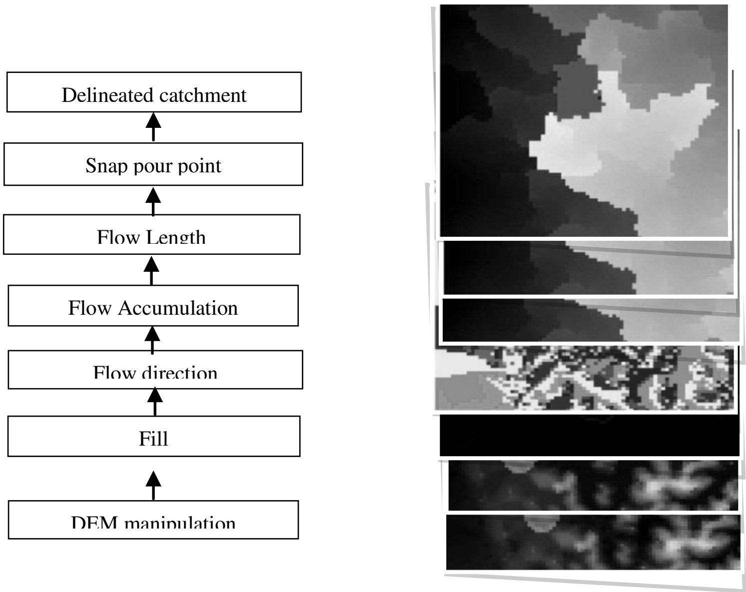


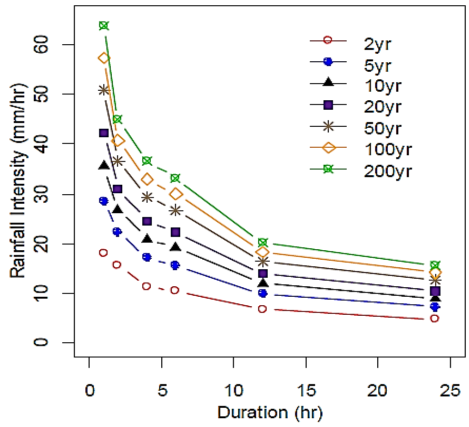
Figure 1: The Process of Catchment Delineation

Step two- Analysis of Rainfall Data

The Metro Colombo urban development project highlighted that the above delineated catchment area was affected by 1 year, 2 year, 10 year and 20 year flood returns. Relationships of the intensity of rain, duration and frequency for each flood return years in the Colombo region was identified by analyzing over 65 years of rainfall data. This study was done considering IDF curve values for one hour rain fall duration of 2 years, 5 years and 10 years of flood return periods.

Table 2: Maximum rainfall intensity at different duration and each return period

Flood Return Periods (years)	Duration (h)					
	1	2	4	6	12	24
2	18.01	15.76	11.42	10.48	6.84	4.95
5	28.53	22.44	17.18	15.70	9.94	7.44
10	35.49	26.86	21.00	19.16	12.00	9.09
20	42.17	31.10	24.66	22.47	13.97	10.67
50	50.82	36.59	29.39	26.76	16.52	12.72
100	57.30	40.70	32.94	29.98	18.43	14.25
200	63.76	44.80	36.48	33.18	20.34	15.78



Source: Relationship of Rainfall Intensity-Duration-Frequency for Colombo Region

Step three-Analyze building roofs

1299 buildings were identified for the study located within the catchment area and majority of them was residential. Type of the constructed material of the roof top of the building was identified through field observation and the area of the rooftop of each building was calculated using digitized maps and field calculator of Arc GIS.

Step four-Potential runoff calculation

Rational method was used to calculate the potential runoff from the building rooftops.

$$Q = C * I * A$$

C= Runoff coefficient (3rd step- types of building roofs)
I= Rainfall Intensity(2nd step- maximum rainfall mm/h)
A= Area (3rd step- roof area by m^2)

Potential water runoffs were calculated considering the area of each rooftop, rainfall intensity values of 18.01mm, 28.53mm, and 35.49 mm consequently for 2 years, 5 yearsand 10 years flood return periods. One hour rainfall intensity was used because the IDF curve illustrates the reduction of intensity with the time interval of the rainfalls. The Runoff coefficient values were identified based on the roof types. Accordingly 0.85, 0.82 and 0.50 coefficient values are consequently respect to Asbestos, Tile and Concrete materiel. Based on the determined values of factors of the rational formula the potential runoffs from each building under each flood return period were calculated. The total runoffs from all buildings in the study area were 9533.33 m^3/h, 15101.94m^3/h and 18786.12 m^3/hwith respect to 2 years, 5 years and 10 years rainfall returns.

Step five-Water out flow calculation

The capacity of the respective drain of each buildingis considered as the outflow for the potential runoff generation of each building. Measures relevant to drainage length, diameter of the open cannels and slope of cannels were obtained from the Report of Metro Colombo Urban development project.Manning's coefficient of roughness was considered as 0.015 since all drains of the study area have been constructed by using concrete material. Capacity of outflow was calculated using Manning Formula with respect to each building.

$$Q = \frac{1 * (3.118 * 10^{-6}) * (D^{\frac{8}{3}}) * \left(S^{1/2}\right)}{n}$$

Where: Q = runoff (m^3/s)
V= velocity
S= slope of hydraulic gradient (generally slope in SWD)
D= Internal diameter of pipeline in mm
n= Manning's coefficient of roughness

The total outflow capacity of the selected catchment was calculated as 3263.22 m^3/h to the total drainage length of 23.14 Km.

Step Six- Estimate volume of RWH system and developing a Simple Linear Regression Model (SLRM)

Appropriate volumes of RWH systems for each building wereestimated using the water balance equationon the reduction of outflow from the total inflow starting the rooftop by the following equation.

$$V_{t_i} = \int_{t_0}^{t_i} (Q_{in} - Q_{out} - Q_{Sup})\, dt$$

$Q_{in}$is defined as the volume of water runoff from the roof during one hour. $Q_{out}$is defined as the volume of water outflow or capacity of the existing drainswith respective to each building. $Q_{sup}$is considered as 0 volume.It was assumed that people are not tendency to use rainwater during the raining period since pipe born water supply is available.$Vt_i$is defined as the volume of the RWH system which can be calculated by integrating the volume of balanced water with comparing to one hour time duration. Propertank size of the RWH system for each building for preventing 10 years flood return can be categorized in to six categories as indicated in figure 02. If tank volumes can bear the 10 year flood return, it has already achieved the 1years, 2 years and 5 years flood returns.

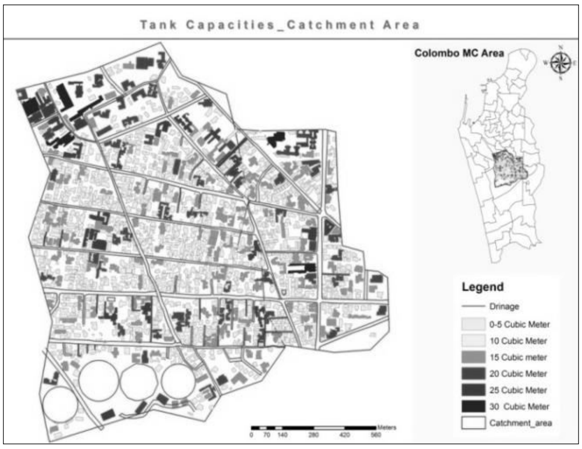


Figure2: distribution of Tank volumes to the buildings *Source*: Prepared by Author

The relationship between capacity of rainwater harvesting system (y) and the extent of roof area (x) can be derived through SLRM as an equation of y=0.024x (where constant is equal to -7.583E $^{-11}$).R square value of 1.0 indicates that the model is adequate to the context. Data on the estimated volume of RWH system and the extent of roof area of

1299 buildings were used to develop this SLR model using SPSS software. This SLRM can be used to estimate the size of the RWH system when the extent of the roof is known with respective to the future residential or commercial use in the catchment of Wijerama- Horton place junction and surrounding area.

5. CONCLUSIONS

5.1 Findings of theAnalysis

According to the flooding locations,the delineated catchment was 200.39 ha including 1299 buildings and it was highly developed residential area. Frequency analysis of the maximum daily rainfall over the period illustrates that 18.01mm/h, 28.53mm/h, 35.45mm/h respect to the 2yr, 5yr and 10 year maximum return of rainfall affected for flooding in Horton place and surrounding area of Colombo. Total potential runoff was calculated as6298m^3, 11884m^3, 15580 m^3 to the 2years, 5 yearsand 10 years maximum return. The capacity of the current storm water drainage system of the selected catchmenthas found as 3264 m^3 by applying the Manning formula. Appropriate sizes of RWH systems was decided in to 6 categories toavoid 2,5 and10 years return flood in the catchment by 90%. The developed equation of y=0.024x can be used to determine the volume of the RWH system for future residential or commercial use in this area.

5.2 Implication and Contribution

The identified method would be useful to planners, engineers and decision makers who are in search of solutions to address emerging issues onurban flooding in Sri Lanka. Although the rainwater harvesting policy established in 2005 in Sri Lanka it is not much attracted in planning practice since the policy was not interpreted how and which volume RWHsystem should be established in commercial and residential premises. Furthermore,this developed method will be attractive to the planning practice when providing the building approvals.

5.3 Research Limitations and further research

The study was conceded using the impervious building's rooftops of the area and garden area. It was assumed as there is no considerable runoff at the peak precipitation at the previous areas. This method can be developedtoward as a more reliable method by conducting the field surveys.Considering the holistic view of the catchment area, using different RWH methods determine what type of water harvesting method can mitigate local flooding within residential and commercial premises.

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