EFFECTS OF URBAN DEVELOPMENT ON FLOODS (A CASE STUDY FROM KESBEWA URBAN COUNCIL- COLOMBO DISTRICT– SRI LANKA)

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ABSTRACT: Over the past decades, the Sri Lanka has become an increasingly urban society. These changes are significantly observed from the rapid conversion of rural area to peri –urban or urban areas. The changes in land use associated with urban development affect flooding in many ways. The increase in artificial surfaces due to urbanization causes an increase in flooding and flash flooding frequency due to poor infiltration and reduction of flow resistance.Kesbewa Located at 20 km from Colombo, Kesbewa Urban Council (KUC) with its 152,657 inhabitants is rapidly being developed and urbanized. Historically, Kesbewahas been an agricultural area endowed with the excess water resources of the bordering Bolgoda lake. A relatively large area of paddy lands can still be found in its lower-lying zones. However, as a result of the continuous growth of Colombo and expansion of the urban boundaries of Colombo Metropolitan Region, Kesbewa Urban Council became an attractive residential area for commuters, now hosting over 244,000 inhabitants (2012 census) on 49 km^2 of land. Many of the agricultural areas were gradually converted to non-agricultural areas, resulting in about 60% of the land now being used for residential purposes and related amenities. Emerging technologies of remote sensing and GIS were integrated to estimate runoff for KUC from year 1980 – 2015. The temporal variability of runoff coefficient modeled with rainfall and flood frequency. It is found that variability of runoff coefficient, inversely proportionate to variability impermeable surfaces in KUC area. The results show that flood frequency is highly correlated with runoff coefficient at 0.95 confidence level. Increasing trend and unplanned urbanization in the region leads to flash flood risk in the future. Therefore it is recommended to that consider the infiltration capacity in further development projects.

1. INTRODUCTION

Urbanization is one of the most important anthropogenic modifications of the global environment. The world urban-dwelling population has increased rapidly since the end of the 19^{th} century and had rising overall percentages from 13% in 1900 to 49% in 2005, a figure expected to reach 60% in 2030 (World Population Prospects, 2004). The negative environmental impacts associated with urbanization, such as loss of cultivated land and biodiversity, aesthetic degradation, and rising urban flooding are linked to the patterns of land use, specifically poorly designed and coordinated development and low-density urban sprawl (Mukherjee, 2016), Urban flooding is also the major threat to many cities worldwide, with more significant impacts on developing countries.

Over the past decades Sri Lanka has become an increasingly urban society, the changes in land use associated with urban development, forested areas and grass-lands are increasingly converted to commercial, residential, or industrial uses. This conversion creates a significant increase in impermeable surfaces such as concrete, asphalt, building roofs, and even compacted vegetated sites (Sivakumaran, et al 2014). Changes in the quantity and location of impermeable surfaces have important implications for the hydrological response during high intensity rainfall events; the increase in artificial surfaces due to urbanization causes an increase in flooding frequency due to poor infiltration and reduction of flow resistance (Barnes, 2002).

1.1 Urban flood risk in Colombo District: Every urban and peri-urban region in the Colombo district has expanded substantially in area in recent decades (Majeed, 1998). Urbanization presents humans with a dilemma (Foley et al., 2005). On one hand, urban development is essential because it provides convenience of infrastructure, goods and services needed by people, government, economic development, industry, and trade (Foley et al., 2005; Lowry, 1990); on the other hand, land surface modifications occur during the process of urbanization including vegetation reduction, soil compaction, and change from previous surfaces to impervious surfaces such as roofs, roads, and parking lots. The consequences of these land surface modifications include but are not limited to: changes in-water supply from altered hydrologic processes of infiltration, groundwater recharge, and runoff.

In general, surface runoff increase when natural vegetation, especially forests, decreases as well as filling up marshy land and low lands. Impervious surfaces developed during urbanization contribute more surface runoff due to decreased infiltration. Reduced infiltration leads to higher peak flows, even for short duration low intensity rainfall, and increases the risk of flooding (Chen, 2017).

Urban flooding has been one of the most costly disasters in terms of both property damage and human casualties in Sri Lanka. The record indicates that upward trend in flood events during past decades in Colombo district which is highly effects to human lives, public and private property and the environment (Rathnayake, 2009). Meanwhile it was reported its highest scale in 2010 and 2016 with the inundation of the parliament of Sri Lanka.

Geographical Information System (GIS)-based urban flood models can be used to identify and project the flood risk with respect to the urban development. Research focused to evaluate the urbanization impacts on surface runoff and its impact on flood frequency in Kesbewa Urban Council (KUC) in Colombo district.

2. STUDY AREA

The Study is implemented in Kesbewa Urban Council (KUC), low density urbanizing peri urban city located in between 6.7953° N, 79.9386° E and 21 Km South of the Sri Lanka's capital city Colombo (Figure 03).It belongs to Low country Wet zone, receiving 2450 mm average rainfall. Average elevation is about 23m above Mean Sea Level (MSL). Low-lying areas in the Kesbewa suffers from regular food damage during periods of heavy rainfall. The topography of the area is slightly undulating with alluvium on surface of the terrain.

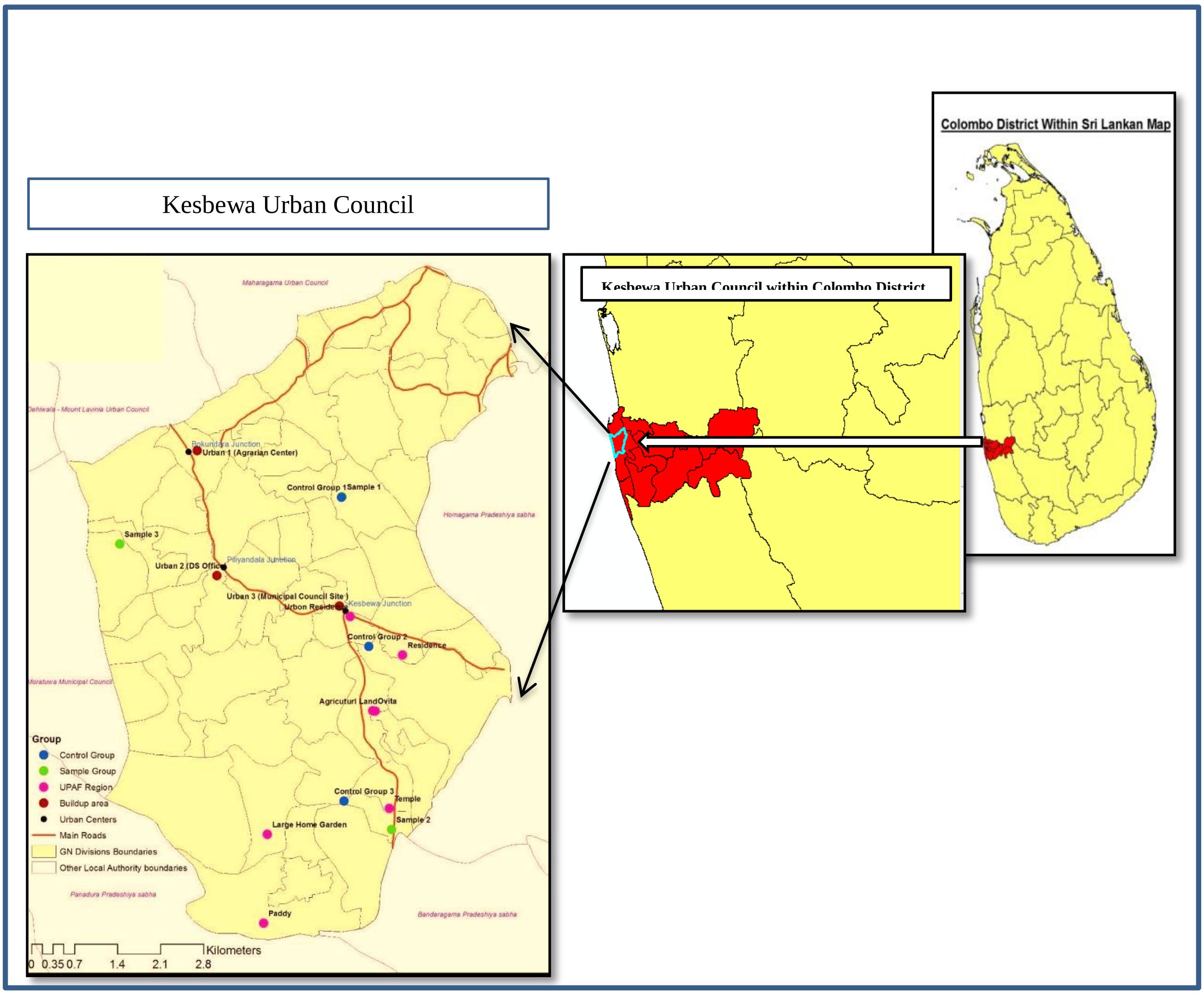


Figure 2.1 : Study Area (Kesbewa Urban Council)

3. MATIRIALS AND METHODS

The runoff coefficient depends on slope, surface condition, vegetation cover and soil type (Ysuf, 2016). However in this study it was assumed that runoff coefficient depend on soil, slope and land-use; therefore digital maps of Soil, Slope and Land cover of the study area were obtained. Flood frequency data were getting from the Disaster Management Center (DMC) of the Sri Lanka.

3.1 Development of Runoff Coefficient: As it is assumed that the impacts of the meteorological factors are uniformly distributed in the study area. Data were collected during field work as well as from secondary sources. Slope, land use and land cover maps were obtained from secondary sources. The research procedure is described in Figure 1, the vector data were converted into raster data format. Then the raster layers were weighted according to Analytical Hierarchy Process (AHP). Then run the rational method equation in ArcGIS 10, to estimate runoff coefficient for the study area.

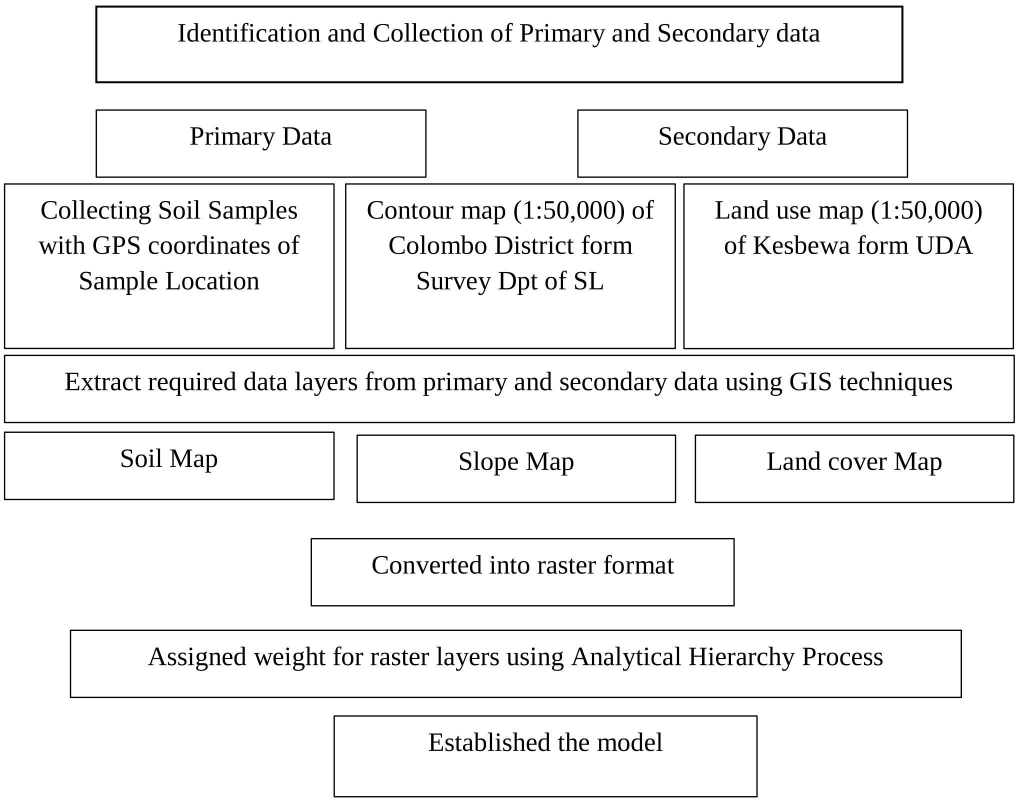


Figure 3.1 : Methodology (Conceptual framework for the runoff model building)

This process was repeated to calculate the overall runoff coefficient for each five year intervals from 1980 to 2015, then runoff coefficient maps was generated for each time intervals. Runoff coefficient values were standardized by land area and summarized into each time intervals (Table 1).

3.2 Model the Relationship between Flood Frequency and Standardized Runoff Coefficient

In this study simple linear regression model was used to describe the relationship between a dependent variable Flood frequency (*f*) and an independent variable standardized runoff coefficient (c). Following equation illustrate the regression model adopted in this study.

$$f = \alpha + \beta c - - - - - - - - - - - - - (1)$$

Where c = runoff coefficients, f = flood frequency, α *and* β *are model parameters*

3.3 Rate of Change of Runoff Coefficient : Different land use classes having different rate of change of runoff coefficient. To obtained rate of change of runoff coefficient map all the runoff maps were standardized by time. This map was used to identify the most vulnerable land use classes to increase the runoff coefficient.

4. RESULTS

The descriptive statistics shows that runoff coefficient have been distributed with 0.61 mean and 0.105 standard deviation from 1980 to 2015. The runoff coefficient indicates up-ward trend (table 01) for considered period due to decreasing of permeable surfaces because many other types of land, such as forest, shrub land, and herbaceous land, are converted to impermeable land covers due to processes of urbanization. These results revealed that runoff coefficient consistently increasing with the urbanization. International studies revealed that the spatial variability of urban development impacts spatial variation of runoff (Tang et al., 2005).

Table 01: Temporal variability of Standardized runoff coefficient, Number of flood occurrences and Maximum flood level

Time period	Runoff coefficient	Standardized Runoff coefficient	Number of flood occurrences	Maximum flood level (ft)
1980-1985	0.46	-1.46035	1	6.60
1985-1990	0.51	-0.94652	3	9.20
1990-1995	0.57	-0.37861	2	4.50
1995-2000	0.62	0.09465	4	6.20
2000-2005	0.69	0.75721	3	4.70
2005-2010	0.72	1.04117	5	5.65
2010-2015	0.73	1.13582	7	5.90

** Number of flood occurrence and Maximum flood level obtained by for KUC from Urban Development Authority (UDA) – Sri Lanka*

According to table flood events are consistently increasing, but flood level may vary while showing irregular pattern, the reason is flood level depends on not only runoff coefficient but also amount and intensity of precipitation. Because of that flood is not correlated with runoff coefficient.

Colombo District has been attributed to flood in last decades (Disaster Information Management system in Sri Lanka, 2017). KUC also shows similar pattern in flood frequency (table 01).
The results revealed that Standardized runoff coefficient and flood frequency are highly correlated having 80% correlation coefficient at 0.95 significant level. Resultant regression model is given below.

$$f = 3.515 + 1.614c - - - - - - - - - - - - -(2)$$

The graph of Standardized runoff coefficient Vs Number of flood occurrences, clearly visualized the linear correlation among variables as shown in following figure 2.

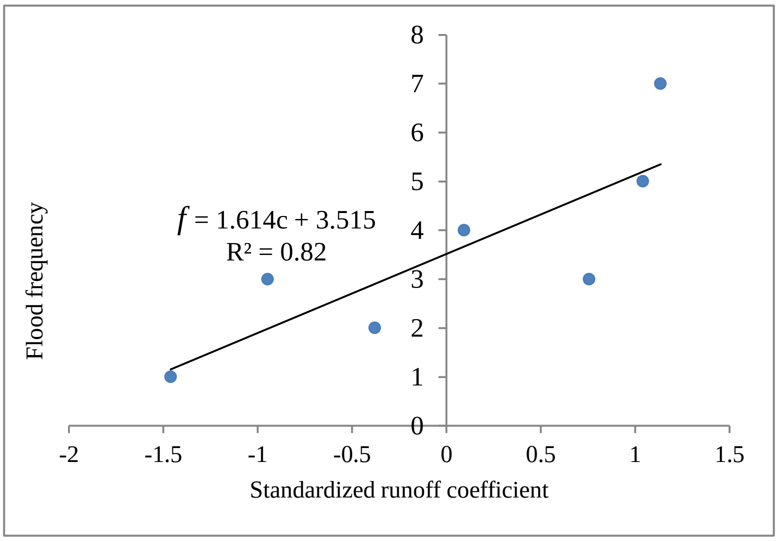
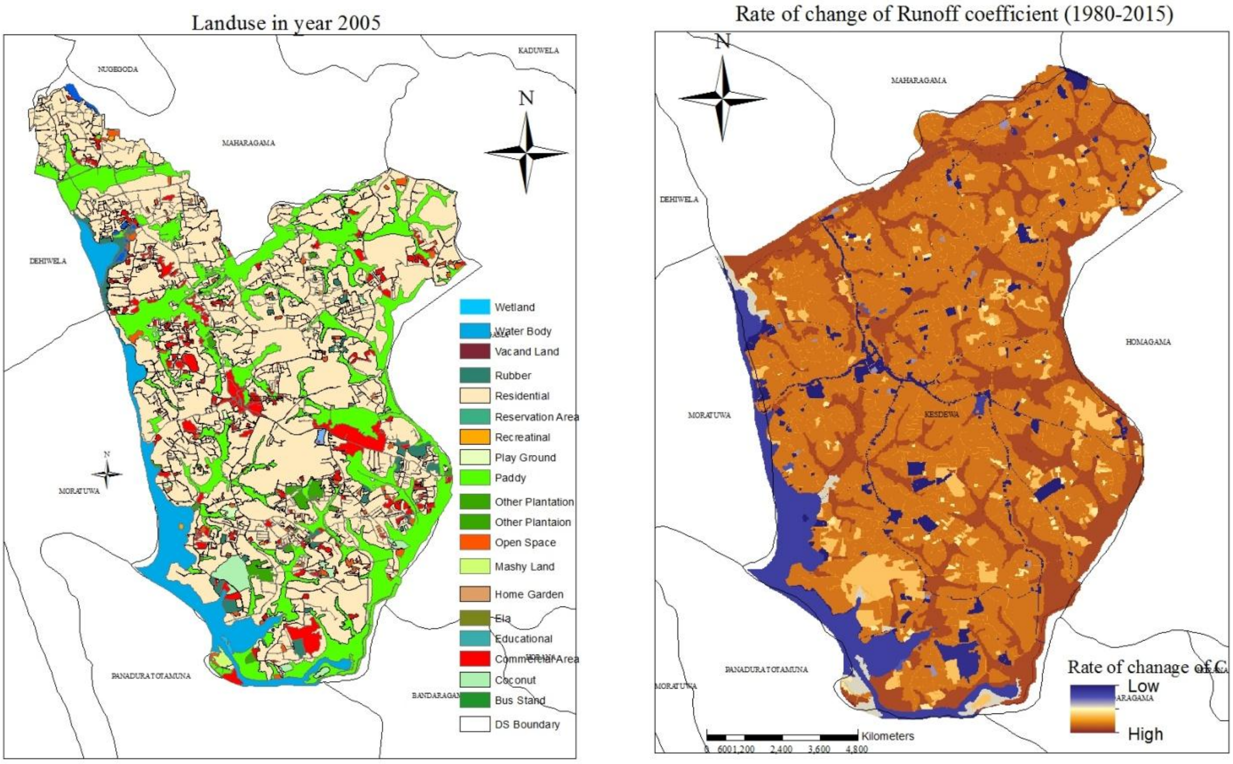


Figure 4.1: The relationship between Standardized runoff coefficient and Flood frequency

If rainfall pattern is constant, then this model can be applied to project the future flood occurrences in the region.

The study area shows a relatively uniform terrain pattern. 99% of the total area slope variation ranges from 1-6 %. As well as There were no large spatial differences in soil types throughout the study area, with basically two different soil types, boggy laterite soil and Clay soils found in the paddy fields and flood plains. Therefore the most significant factor determining runoff is land cover type, as impacts of the other two factors (slope and soil) are uniformly distributed over the study area. The land use map with and rate of change of runoff coefficient map are showing in Figure 3a and 3b.



A: Land use in 2005 B: Rate of change of runoff coefficient

Figure 4.2 : Land use and Rate of change of Runoff coefficient

Paddy lands were distributed in low-lying areas in Kesbewa and away from the city centre and most of impervious surfaces were clustered in residential areas. Residential areas were distributed in and around the city centre and in comparatively high elevation -land areas (Figure 3a)

According to above comparison highest rate of change of runoff coefficient is observed in residential, paddy lands and industrial regions. Lowest rate of change runoff distributed in water bodies, means water most of the time land use type of water bodies will not be subjected to urbanizing process.

5. DISCUSSION

Impermeable surface, in urban areas increase the amount and speed of water flowing overland during and after prolonged or heavy rainfall. Urban runoff typically flows into drainage systems for storm water, which may not be able to handle large volumes of water, potentially leading to flooding in the area. In this study, the researchers investigated that role of impermeable surfaces to reducing surface water runoff in urban areas.

Rapid urbanization has led to increases in the number of buildings, and associated decreases in natural greenery. As well as changing the visual landscape, the loss of green spaces has created various environmental issues, many of which directly affect human livelihood. For instance, removing vegetation means rain is less likely to soak into the ground and more likely to run off, thus increasing the risk of floods.

Determination of runoff coefficient is important for flood control and for possible flood zone hazard delineation. A high run-off coefficient indicates potential flash flood and flooding areas during storms and periods of intense rainfall. Depending on the water storage capacity in paddy lands and wet lands runoff coefficients is high. Indeed as most paddy lands in Kasbewa are located in low-lying areas and flood zones, any housing in these areas suffers from regular flood damage during periods of heavy rainfall. However, in contrast to abandoned paddy lands, well-maintained and well drained paddy lands function as buffer zones, storing water and controlling drainage, thus reducing flood risk in nearby areas. But highest rate of change of runoff coefficient is observed in paddy lands, it means paddy land are converting into impermeable surfaces such as concrete, asphalt and building roofs due to urbanizing, because of this trend water draining and retention capacity will be reduced. This could increase the floods risk in the area. According to the finding of study this flood risk is expected to increase in the future.

Residential areas away from the city Centre have still maintained larger amounts of green spaces and home gardens, therefore rate of change run-off coefficients of these residential areas were not excessively high. This region has a great potential to create permeable surface such as home gardens, grass lands etc. in the urbanizing process, which may contribute to mitigate the flood risk of the region.

6. CONCLUSION AND RECOMMENDATIONS

It can be conclude that increased urban land over time can significantly increase runoff volume due to increased impermeable surfaces. This can be identified as a major cause for the urban flood increasing of flood frequency while reducing return period.

The high correlation between standard runoff coefficient and flood frequency reveled that contribution of permeability degradation to the flood occurrences in KUC region. Finally it can be conclude that, if this land use change pattern continues to the future, then flood risk of the region also increasing.

Further, it can be conclude that protection and increasing of impermeable surfaces growing storm water infiltration capacity is one of the most significant attempts to control the flood risk over the region. It is recommended to implement sustainable drainage system, including vegetated areas for the region as soon as possible to mitigate flood risk through controlling storm water runoff.

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