

GIS Analysis for Urban Flood Hazard Mitigation in Kaduwela Municipal Council Area

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Abstract

Urban flood hazard is a typical natural disaster that occurs due to the reduction of permeable surfaces as a result of land use conversion and changes in rainfall intensity. It ensures the need of different mitigation strategies such as sufficient drainage system, and it is a simple mitigation measure that can be applied in the ground. This paper is timely due to the lack of research studies undertaken that are related to the study area. Natural disasters, flood hazard, influence of urbanization for urban flood, and negative influence of urban flood in the context of the world and Asian region have been discussed in the available literature. Limited research has been undertaken on urban flood mitigation based on hydrological analysis and run off volume calculation in Kaduwela Municipal Council (KMC) area. With this limitation, this paper focuses on analysing the runoff rainwater volume to mitigate urban flood in 2030 (predicted land use) by calculating the rainwater volume in natural and artificial possible outfalls of each watersheds in KMC. The analysis consists of three phases such as: land use prediction, hydrological analysis, and calculation. A GIS-based land use prediction is simulated to analyse the land use changes in relation to green, blue, and brown fills. The revealed land use conversion is also processing day by day as a result of land use conversion and rapid urbanization which will increase the runoff volume in 2030. A GIS-based Hydrological analysis was carried out to identify the outfalls and watersheds of the study area. The possible outfalls function as outlets of runoff water which were collected in each watershed. Runoff volume was calculated by using rational formula ($Q = 0.0028CIA$) and the parameters of the equation used were the coefficient of land use in 2030, rainfall intensity, and 90 acres portion of the watersheds. A sufficient drainage system was also designed to make KMC a disaster resilient municipality. This research will be important in the process of decision-making and policy implementation in the fields of urban planning and flood mitigation.

Keywords: Urban Flood, Disaster Mitigation, Geographical Information System (GIS), Runoff Volume, Rational Formula, Hydrological Analysis

Introduction

Flood is a disaster that occurs due to the hydro meteorological reasons, and over 195 million people in more than 19 countries of the world are exposed to flood every year between 1980 to 2000 (Bhattacharya, 2012). Flood has been identified as one of the most recurring and frequent disasters in the world thereby resulting to economic losses and life damages due to the recurrent prevalence. This is because flood has affected the economy negatively than any other natural disaster (Tripathi, 2015; Ashley et al., 2007). Flood can be defined as “an overflowing of a great body of water over land which is not usually submerged”. It can also be defined as “a very large amount of water that covers an area that is usually dry” or “overflowing of water to a land that is normally dry”.

Within the natural hazards, urban flood hazard can be identified as a water-related natural hazard in urban areas which has an effect on human activities as well as social and physical infrastructure. Urban flood is also known as localized flood or drain congestion (Ministry of Disaster Management, 2012). Urban flood (urban pluvial flood) occurs as a result of urbanization and it destroys vegetation cover on the ground and replaces the ground cover with concrete, asphalt, and roofing materials. These impervious areas prevent rainwater absorption into the soil profile which causes rapid runoff into drainage systems. When an intense storm generates runoff that is greater than drainage capacity, urban flooding occurs. This is a special case of the pluvial flood when it occurs in an urban area (Han, 2011).

According to Mukherjee (2016), developments such as increasing roads, roofs, and paving and increasing the density due to developments cover the permeable surfaces that usually function as water absorption areas. As a result, there is an increase in the amount of rainwater running on the surfaces. The increase of impermeable surfaces in urban context is another reason for the urban flood. Due to the rapid urbanization or developments, the context will convert into impermeable surfaces. This situation minimizes the surfaces that function as permeable surfaces. Thus, those surfaces are no longer sufficient for the absorption of high intensity of rainwater. As a result, rainwater becomes surface runoff (Handapangoda & Wijesekera, 2011). The volume of runoff generated in underdeveloped areas is 20 times less than the volume of runoff generated by impervious surfaces (Parkinson & Mark, 2005; Ashley et al., 2007; Chukwuocha & Igbokwe, 2014; Handapangoda & Wijesekera, 2011). Urban flood occurs where the runoff exceeds the capacity of the existing drainage systems. The duration of heavy rainfall from minutes

to several days or high rainfall intensity is the major factor that creates urban flood (Fatti & Patel, 2013; Parkinson & Mark, 2015; Torgersen, 2017). The Surat city mainly developed drainage network as a solution for the urban flood. The objective is to solve urban flood of the Surat city because it will affect both physical and social infrastructure. The drainage system was identified as a good solution for the urban context which can be used as a mitigation measure for urban flood (Desai & Patel, 2014; Gamit et al., 2017). Handapangoda and Wijesekera (2011) stated that an insufficient drainage system is a major issue in most part of Sri Lanka, and this is a major cause of urban flood. This has resulted to an increase of many flood-prone areas in urban context. Urban areas are located in regions with low contour variations and due to the flat terrain or fewer slopes, water flow is slow. This causes retaining water rather than flowing water. Therefore, more attention has been paid to consider the ability of urban drainage measures to reduce the urban flood risk in recent years (Moufar & Perera, 2018).

Urbanization causes spatiotemporal changes, and it is analysed by using open source GIS (Quantum GIS: QGIS). Molusce QGIS plugin is developed to analyse, model, and simulate land use/land cover changes. It has the capability to analyse and distinguish land use characteristics between two different years. Also, it is useful to predict and simulate future land use by understanding the past land use patterns (Statuto et al., 2018; Alrubkhi, 2017). Land use change analysis and modeling use open source (QGIS) – case study on Boasher Willyat – explored land use changes between 2000 and 2010 to project future land uses (Alrubkhi, 2017). Ibrahim and Ludin (2015) carried out a research on spatiotemporal land use change analysis using open-source GIS and web-based application to identify land use changes between 1994 and 2011 and to analyse the spatial pattern changes. Statuto et al. (2019) conducted a study titled “GIS-based Analysis of Temporal Evolution of Rural Landscape: A Case Study in Southern Italy”. However, their study is focused on land use changes in Basilicata region while analysing the land use data of 1829 and 2017.

Desai and Patel (2014) effectively used Digital Elevation Model, a GIS tool, to compute stormwater drainage network and identify the catchments. The pipe networks were delineated based on the floor direction, flow accumulation, streamline, condition streams, stream order, and stream shape. Consequently, the author of Stormwater Management, Using RS and GIS, used DEM for analysis purposes. It also used the mathematical equation for flood probability analysis and rational equation, while the manning equation was used for the calculation of rainfall intensity and designing of the drainage lines (Gamit et al., 2017). The report titled “Weathering the Storm: Analysing Stormwater Runoff from the Tufts University Medford Campus” also analyse digital elevation model, slope, flow direction, and flow accumulation to layout

the drainage system (Sexton, 2012). Akajiak and Igbokwe (2014) also follow the steps in terms of flow direction, flow accumulation, stream link, and catchment grid delineation to demarcate sub-catchments. The rational method was introduced by engineers in 1889 in the United States of America. Thus, this method is a simple mathematical equation that is accepted by all expertise to design the drainage network. In cases when the urban catchments are not complex, it will be 90 acres or less than it. As a result, the catchments are acceptable for using the rational method in design storm analysis (Urban Drainage & Flood Control District, 2018). By reviewing the available literature in this area, it was noted that limited research has been undertaken on urban flood mitigation based on hydrological analysis and run off volume calculation in KMC area. However, mitigation of urban flood hazard is very important in KMC area because it develops rapidly. This led to the transformation of the wetlands of Kaduwela into impermeable surfaces. Also, the existing drainage system is not sufficient for the water to flow during high intensity of rainfall. To mitigate the adverse effect of flooding in KMC, there is a need for sufficient and well-maintained drainage system. This is because the function of a drainage system is essential for the water to flow continuously towards outfalls at the first stage of high intensity of rainfall. Thus, this paper focuses on analysing the runoff rainwater volume for mitigating urban flood by calculating and predicting the rainwater volume, use of existing land use, and the natural and artificial possible outfalls of watersheds in KMC.

Methodology

KMC area was selected as the study area. It is located in the Western Province in Colombo District, which is 17.5 km away from Colombo city of Sri Lanka. KMC is undergoing development on a daily basis due to its strategic location, in terms of connectivity via Colombo Avissawella main road and Kotte-Gampaha road, and pull factors (key government institutes, schools and higher education centres). This scenario has a significant direct influence to increase the residential, commercial, and mix development demand (the second highest population in Colombo district - 252,041) (Census & Statistics Department, www.statistics.gov.lk, 2016). On the other hand, it is located in geographically flat terrain and is frequently inundated with flood hazard. Kaduwela DSD is one of the DSDs of the Metro Colombo basin which has an extent of 150 km². In addition, the geographical terrain of Metro Colombo basin is almost flat and it varies from 0 MSL to 35 MSL (most parts are laid below 3 MSL). It is laid in the wet zone of the country and it receives a mean annual rainfall of 2300 mm because the area is subjected to frequent flood during Southwest monsoon. Moreover, Colombo recorded the highest rainfall intensity as 150 mm rain per hour and it shows a significant increase of rainfall intensity by 30 mm when compared to the 2010 rainfall intensity of

120 mm (Wijemanna, 2018) The flood hazard worsened when the water level of the Kalani River rises due to rainfall in the upper catchment area. Remarkable inundation can be identified within 50 years occurrence intervals with high intensity of rainfall (Moufar & Perera, 2018). According to their study, Kaduwela was affected by river flood, as well as urban flood. This study mainly focuses on the area which is inundated due to urban flood. Therefore, study area was identified by demarcating the boundary which is not inundated in 2018 for river flood.

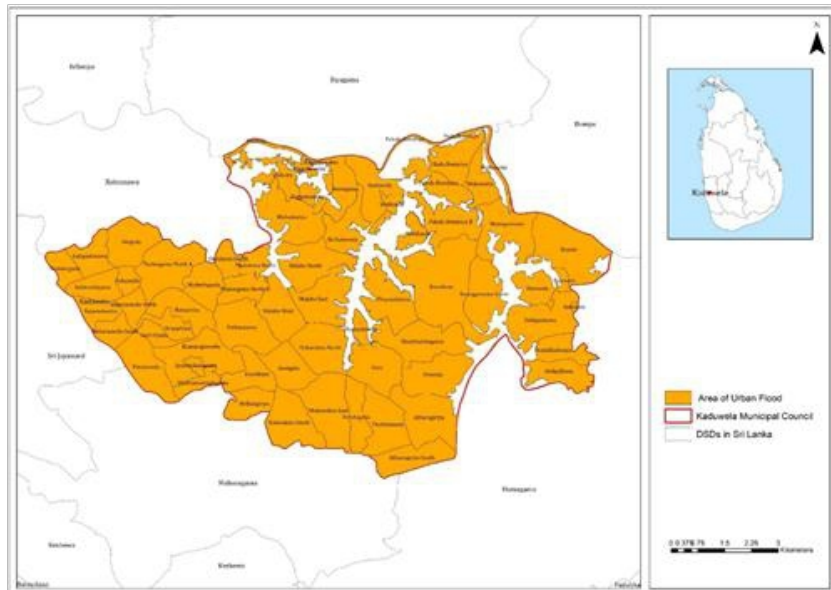


Figure 1. Boundary Demarcation of the Study Area - Except River Flood Area
Source: Conceptualize by Author; Based on Survey Department, Sri Lanka (2016)

Both primary and secondary data collection was undertaken. Preliminary observation and photographic surveys were carried out to familiarize with the study area. Secondary data were collected as input data of the analysis and rain fall intensity data. Contour/land use shape files were collected as secondary data. The analysis of the study was performed based on spatial analysis and non-spatial analysis. Spatial data was analysed using GIS applications while non-spatial data was analysed using rational formula. GIS mapping technique (Molusce QGIS Plugin) was used to predict the land use pattern of 2030, slope of the terrain through analysing contour variation and the watershed of the site, and possible outfalls of specific watersheds. Rational Formula ($Q = 0.0028CIA$) was used to calculate the peak discharge of storm water that constitutes the non-flood hazard. Therefore, this study is limited to the first stage of drainage design (Rational Formula).

$$Q = 0.0028CIA$$

Q = Peak Discharge rate in Cubic feet/seconds from a watershed of the area.

0.0028 = Constant Value

C = Runoff Coefficient (State Water Resources Control Board, Canada, 2011; Hoyer, 2011)

I = Rain Fall Intensity (inch/hr) (Ponraja, 1984)

A = Drainage Area (Hectares) (Urban Drainage & Flood Control District, 2018)

A research design is illustrated in Figure 2.

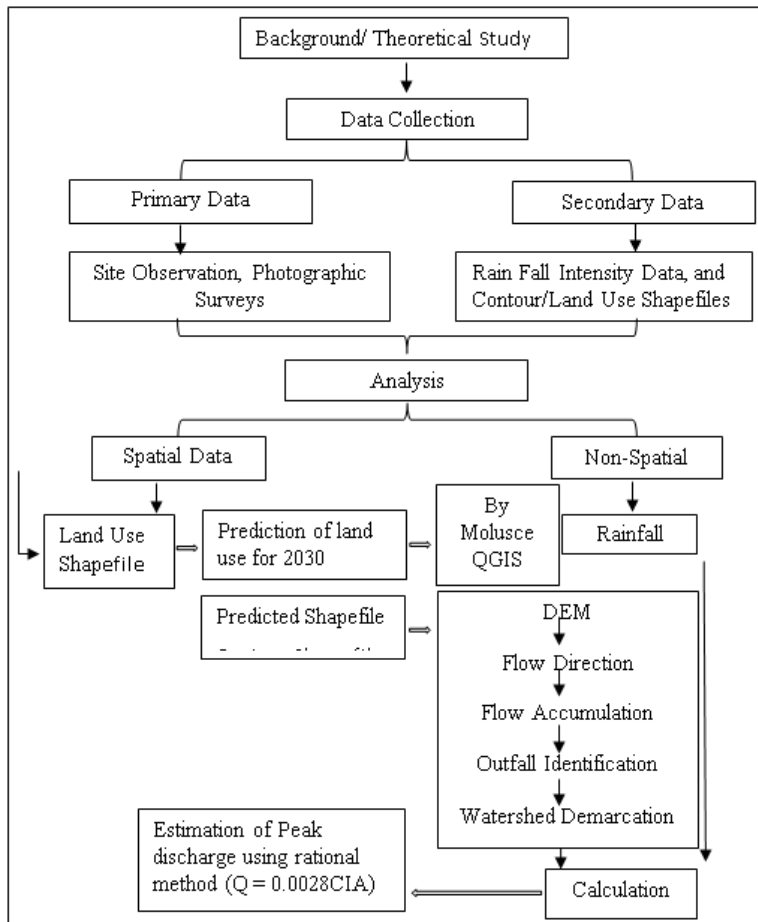


Figure 2. Research Design
Source: Conceptualize by Author

Results and Discussion

Agricultural lands distributed as green patches in the whole DSD, and the reduction of agricultural lands, can be seen in Western and Eastern parts towards the centre of the DSD from the boundary. Thus, this shows a drastic reduction in agricultural lands. Figures 3, 4, and 6 depict the changing land

use pattern in KMC in 2006 and 2016. As shown in both figures, in 2006, agricultural lands represent 3163.07 ha but it reduced by 1260.45 ha in 2016. It indicates 14.392% reduction of agricultural lands when compared to 2006. What affects the reduction of agricultural lands and the positive trend of wide spread built-up area can be identified as a parallel process. This is because built-up area increased significantly in 2016 and it represents 921.73 ha increase in 2016 when compared to the built area in 2006. Therefore, this means 10.525% increase of built-up area within KMC. Observed land use (paddy and home garden, residential) changes in this study tally with the findings of the research undertaken by the study of Rathnayake and Ranaweera (2017).) Water bodies and wetlands show a gradual increase in 2016. In 2016, water body increased by 148.60 ha when compared to 2006 and it represents 1.697%. On the other hand, the analysis shows a positive trend of wetlands. It represents 148.60 ha in 2016, which means 2.171% increase when compared to 2006 (Figures 3, 4, and 6).

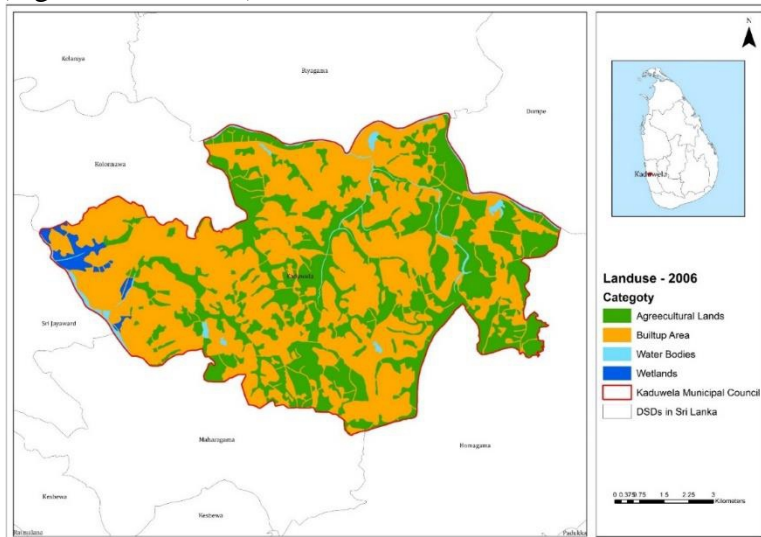


Figure 3. Land Use Pattern of 2006 in Kaduwela Municipal Council
Source: Conceptualize by Author; Based on Survey Department, Sri Lanka (2016)

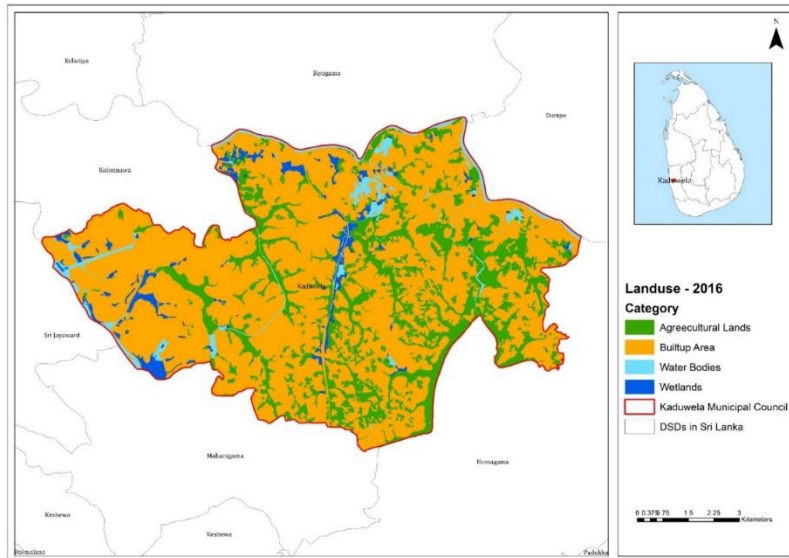


Figure 4. Land Use Pattern of 2016 in Kaduwela Municipal Council
Source: Conceptualize by Author; Based on Survey Department, Sri Lanka (2016)

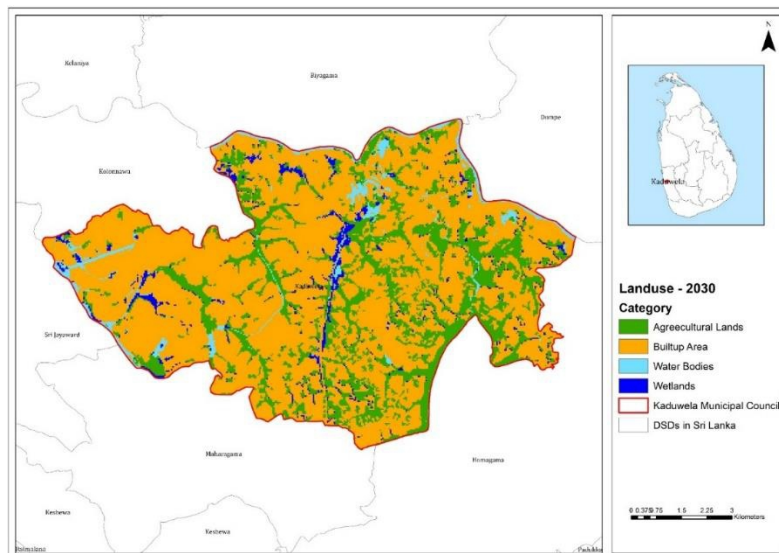


Figure 5. Predicted Land Use Pattern of 2030 in Kaduwela Municipal Council
Source: Conceptualize by Author; Based on Survey Department, Sri Lanka (2016)

The predicted land use pattern of 2030 in KMC area is shown in Figure 5. The results show that KMC would experience a continuous reduction of agricultural lands by 2030. In 2016, agricultural lands represent 1902.62 ha but it would reduce by -95.57 ha in 2030. This indicates -1.091% reduction of agricultural lands when compared to 2016. This calls for the positive trend of the spread of built-up area. It can be identified as a parallel process because

built-up area would significantly increase in 2030. The predicted results for 2030 also indicate an increase of 101.15 ha in built-up area and it means 1.115% increase when compared to 2016. Water bodies and wetland are the other land use categories, which show a decline in 2030. It indicates -11.73 ha of decline when compared to the 2016 land use pattern of water bodies. This means 0.134% reduction. On the other hand, the analysis shows a positive trend of wetlands. The predicted land use also represent 6.15 ha increase and it means 0.070% when compared to the wetland distribution in 2016 (Figures 4, 5, and 6).

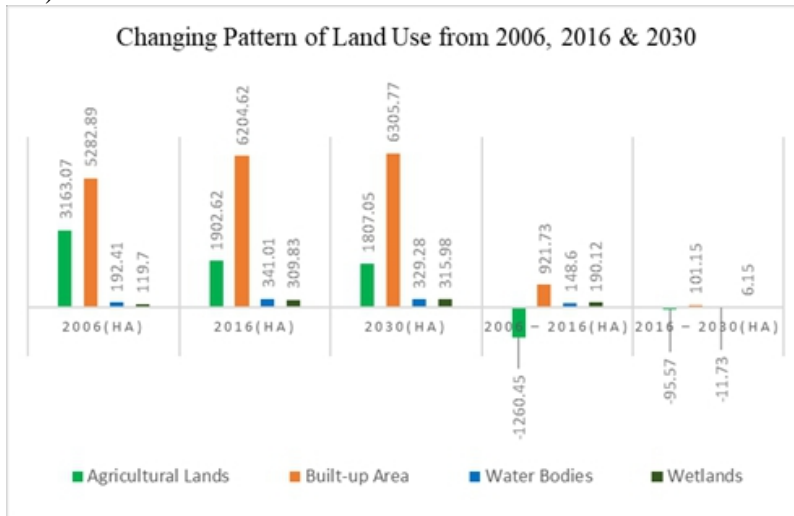


Figure 6. Changing Pattern of Land Use from 2006, 2016 & 2030
Source: Output Data from QGIS Analysis, 2019

This scenario revealed continuous increase of built-up area. Since there is an increase of water bodies in 2016, 2030 will likely experience same result due to manmade innovations of urban planning. Also, land use daily conversion led to a reduction in the agricultural lands and water bodies. Thus, they are functioning as water detention and retention areas. This would result in an increase in the runoff volume in 2030. Simultaneously, this has conveyed the need of sufficient drainage system for Kaduwela in 2030 to mitigate the urban flood hazard within KMC.

Consequently, terrain and the variation of low-lying areas in KMC was analysed using 5m contour DEM layer as the whole process based on the slope. The analysis has sequence and it goes through flow direction, flow accumulation, outfalls identification, and watershed demarcation. The possible outfalls were identified based on the flow accumulation and it is needed to demarcate the watersheds (Figure 7). The possible outfalls functioned as outlets of runoff water which were collected in each watershed.

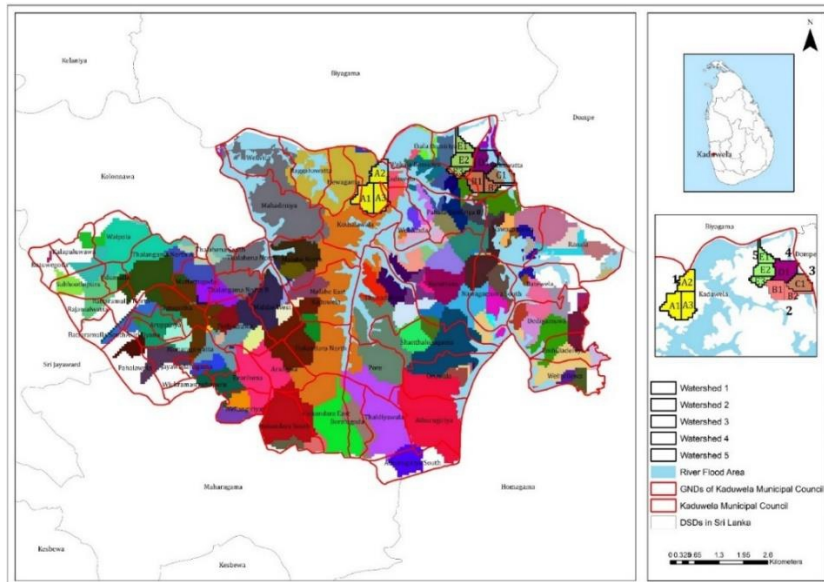


Figure 7. Selected Watersheds within Urban Flood Area of Kaduwela Municipal Council
Source: Conceptualize by Author; Based on Survey Department, Sri Lanka (2016)

Runoff volume was calculated according to the coefficient of 2030 land use. The calculation depended on the coefficient of the land use surfaces and land use is mainly categorized into four categories, namely: agricultural land, built-up area, water bodies, and wetlands. Agricultural lands, water bodies, and wetlands functioned as permeable surfaces and it represents less coefficient value compared to the built-up area. Water bodies, especially, indicate minus value. Area was calculated by dividing a watershed into 90 acres portions. Hence, watersheds were demarcated according to the out falls (limitation of the equation: Calculation can be done for > 90 acres. Therefore, the watershed has to be subdivided for areas > 90 acres). Rainfall intensity which is also a factor that is needed to calculate the runoff volume can be calculated by the intensity curves practiced by the Irrigation Department of Sri Lanka. It concerns one-hour rainfall period for zone 3 (Colombo), and it also concerns 25 occurrence intervals (Table 1). Sufficient drainage system can be designed according to the results of the calculation (Q) which will make KMC a disaster resilient municipality.

Runoff Volume of Selected Watersheds						
Name of Watersheds	Sub Parts of Watershed	Q	Conversion Factor 0.0028	C	I	A
A	A1	9.3069	0.0028	0.4127	120	67.116094
	A2	5.6170	0.0028	0.66763902	120	25.039529
	A3	3.8706	0.0028	0.39186897	120	29.396466
B						
B	B1	6.9315	0.0028	0.821315	120	25.117435
	B2	3.274213613	0.0028	0.63731725	120	15.290161
C						
C	C1	5.27156404	0.0028	0.56008195	120	28.012291
D						
D	D2	8.806022757	0.0028	0.72706343	120	36.046925
E						
E	E1	4.1227	0.0028	0.7591	120	16.163266
	E2	6.3627	0.0028	0.89259816	120	21.215052
	E3	3.6243	0.0028	0.84684838	120	12.737311

Table 1. Runoff Volume of Selected Watersheds

Conclusion

This paper focuses on urban flood mitigation in KMC. The literature explored that there is no specific literature which concerns urban flood mitigation measures in KMC area. As a result, this research aims to fill in the gap as it focuses on urban flood and mitigation measures for KMC. The analysis of the research was undertaken and the research objectives were achieved by calculating the runoff volume of each watershed. The runoff volume was calculated as the first stage of the drainage planning and it was applied as the mitigation method of urban flood in KMC. The analysis was divided into three phases and the first phase was land use prediction. It was simulated to analyse the land use changes in relation to green, blue, and brown fills. The analysis was able to find the results related to continuous increase of brown layer. However, it showed an increase of blue layer in 2016 and same is predicted for 2030 as a result of manmade innovations of urban planning. This scenario revealed that land use conversion was processing day by day and reducing the green and blue patches which were functioning as water detention and retention areas. Consequently, this will result in an increase in the runoff volume in 2030. Simultaneously, it conveyed the need of sufficient

drainage system for KMC in 2030 to mitigate the urban flood hazard within the area. Secondly, the possible outfalls identified through the flow accumulation are needed to demarcate the watersheds. The possible outfalls functioned as outlets of runoff water which were collected in each watershed. The whole process based on the slope analysis, however, depends on the DEM layer. With the completion of the first and second phases, it moves to the third phase of the methodology. Under this phase, runoff volume was calculated as per the coefficient of 2030. Land use and area was calculated by dividing a watershed into 90 acres portions and watersheds were demarcated according to the out falls. Finally, water volume that was collected during rainfall to the watershed was calculated to mitigate the urban flood hazard by providing a sufficient drainage system.

References:

1. Alrubkhi, A. (2017). Research Gate. Retrieved from <https://www.researchgate.net>:
https://www.researchgate.net/publication/317357966_Land_Use_Change_Analysis_and_Modeling_Using_Open_Source_QGIS_Case_Study_Boasher_Willayat
2. Ashley, R., Garvin, S., Pasche, E., Vassilopoulos, A., & Zevenbergen, C. (2007). *Advances in Urban Flood Management*. London: Taylor & Francis.
3. Bhattacharya, T. (2012). *Disaster Science and Management*. New Delhi: Tata McGraw Hill Education Private Limited.
4. Census & Statistics Department (2016). Retrieved from www.statistics.gov.lk:
<http://www.statistics.gov.lk/Abstract2016/CHAP2/2.7.pdf>
5. Chukwuocha, A. C. & Igbokwe, J. I. (2014). Delineation and Characterization of Sub-catchments of Owerri, South East Nigeria, Using GIS. *American Journal of Geographic Information System*, 3(1): 1-9.
6. Desai, M&Patel,D.(2014). Use of Digital Elevation Model to compute Storm Water Drainage Network. *IJESRT*, ISSN: 2277-9655, 8.
7. Fatti, C. E. & Patel, Z. B. (2013). *Perceptions and Responses to Urban Flood Risk: Implications for Climate Governance in the South*. Elsevier, 13-22.
8. Gamit, A., Lodha, P., Prakash, I., & Mehmood, K. (2017). Research Gate. Retrieved from <https://www.researchgate.net>:
https://www.researchgate.net/publication/317041494_Storm_Water_Management_Using_Remote_Sensing_And_Gis-A_Case_Study_Of_Surat_City

9. Han, D. (2011). Flood Risk Assessment and Management. Bristol: University of Bristol.
10. Handapangoda, H.&Wijesekera,S.N.(2011). Stormwater Management Modelling for Stormwater Management Modelling for. Journal of the Institution of Engineers, Sri Lanka, Vol. XXXIV, No. 04,, 9.
11. Hoyer, W. (2011). Agricultural Drainage and Wetlands: Can They Co-exist? Iowa City.
12. Ibrahim , W. Y.&Ludin,A.N.(2015).Spatiotemporal Land Use Change Analysis Using Open-source GIS and Web Based Application. International Journal of Built Environment and Sustainability, 101-107.
13. LMNO Engineering Research and Software Ltd. (2018). LMNO Engineering, Research, and Software, Ltd. Retrieved from LMNO Engineering, Research, and Software, Ltd.: <https://www.lmnoeng.com/manning.php>
14. Ministry of Disaster Management (2012). Floods Hazards Profile of Sri Lanka. Colombo: Ministry of Disaster Management, Sri Lanka.
15. Moufar, M. & Perera, E. D. (2018). Floods and Countermeasures Impact Assessment for the Metro Colombo Canal System, Sri Lanka. MDPI, 20.
16. Mukherjee, D. (2016). Effect of Urbanization on Flood - A Review with Recent Flood in Chennai. International Journal of Engineering Sciences & Research Technology.
17. Parkinson, J. & Mark, O. (2005). Urban Storm Water Management in Developing Countries (First Edition ed.). Turnbridge Wells: Gray Publishing.
18. Ponraja, A. (1984). Design of Irrigation Headworks for Small Catchments. Colombo: Irrigation Department, Sri Lanka.
19. Rathnayake, R. & Ranaweera, D. (2017). Changing Pattern of Land Use from 2006, 2016 & 2030. International Journal of Inovative Research and Development, Vol 6 Issue 6 .
20. Sexton, A. (2012). Weathering the Storm: Analyzing stormwater runoff from the Tufts University Medford campus. Tufts University.
21. State Water Resources Control Board (2011). California State Water Resources Control Board. Retrieved from <https://www.waterboards.ca.gov/>:https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/513.pdf
22. Statuto, D., Cillis, G., & Picu, P. (2019). GIS-based Analysis of Temporal Evolution of Rural Landscape: A Case Study in Southern Italy. Natural Resources Research, 61-75.

23. Statuto, D., Cillis, G., & Picuno, P. (2018). GIS-based Analysis of Temporal Evolution of Rural Landscape: A Case Study in Southern Italy. *Natural Resources Research*.
24. Torgersen, G. (2017). *Sustainable Planning to Reduce Urban Flooding – an Interdisciplinary Approach*. Philosophiae Doctor (PhD), Norwegian University of Life Sciences Faculty of Science and Technology, pp. 148 (ISBN 978-82-575-1458-7).
25. Tripathi, P. (2015). Flood Disaster in India: An Analysis of trend and Preparedness. *Interdisciplinary Journal of Contemporary Research*, Vol. 2, No. 4,.
26. Urban Drainage & Flood Control District (2018). *Urban Drainage and Flood Control District*. Retrieved from <https://udfcd.org:https://udfcd.org/wpcontent/uploads/uploads/vol1%20criteria%20manual/USDCM%20Volume%201.pdf>
27. Wijemanna, A. (2018). *Rainfall Intensity Changes in Colombo District and Its Impact on Flood*. (Author, Interviewer)