Land-Use Change and Its Impact on Urban Flooding: A Case Study on Colombo District Flood on May 2016

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Abstract—**Colombo district has become an increasingly congested urban society. It has been reported that the frequent flooding in the Colombo district occurs due to the shrinking of open spaces, illegal constructions, and lack of suitable waste disposal facilities. Therefore, this study focuses on analyzing the impact of land-use change on the flood of Colombo district in May 2016 in comparison to the land-use during the flood in 1989. Accordingly, Landsat images were utilized to identify the land-use by using NDVI, NDBI, and NDWI indices. Out of the several techniques examined, SVM classification was chosen, and change detection techniques in conjunction with remote sensing and GIS environment were adopted. SVM classification showed the highest accuracy for land-use classification, which was 99.0% in 1989 and 99.9% in 2016. The comparison of land-use changes of 1989 and 2016 with similar flood extent of the Colombo district proved that the area of the Kelani river watershed changed into urban area, having a significant impact on flood inundation. The Kelani river watershed includes 23% of the total urban area of the Colombo district. Similarly, the entire area of land-use transformation covered 37.7% of the area within the watershed region of the Colombo district. Eventually, this research identified the significant impact of Colombo district floods in May 2016 on land-use changes.**

Keywords-NDVI; NDBI; NDWI; Landsat satellite images; land-use classification; urban floods

I. INTRODUCTION

Floods in urban arrears constitute a severe risk and have become more frequent and severe along with rapid urban development. Watersheds in and around urban areas become more developed and more hydrologically active, changing the flood volume, runoff components, and the origin of stream flow [1]. Therefore, the transformation of the watersheds to urban or sub-urban land-uses creates frequent flooding more than before. Hydrologic modeling with the assessment of the effects of land-use and land cover changes on water resources is becoming one of the leading research topics [2]. The influence of land-use on storm runoff generation is highly complicated. For instance, croplands and urban lands yield more flood volumes, higher peak discharges, and shorter flow travel times than grassland or woodland [3]. Floods are identified as the most frequent natural disasters. Authors in [4] reported that in between 1994-2004, Asia accounted for one-third of 1,562 flood disasters where nearly 60,000 persons were killed. Flood occurrences in Sri Lanka are occurring mainly because of excessive rainfall during the monsoon periods [5]. Occasionally, the depressions over the Bay of Bengal bring in heavy rains causing floods [6]. According to the records, major floods have occurred in Sri-Lanka in 1913, 1940, 1947, 1957, 1967, 1968, 1978, 1989, 1992, 2003, 2016, and 2017 with severe losses of human lives, public and private property [7]. World Meteorological Organization has categorized floods as local/urban, riverine, coastal, and flash floods. Out of those, riverine and urban floods are the most common types in Sri Lankan urban and suburban areas.

In June 1989, the western part of Sri Lanka experienced a natural disaster bordering three major river basins, namely Kelani Ganga, Kalu Ganga, and Gin Ganga. High-intensity rainfall caused several earth slips in the upper catchment while lower catchment suffered from flash floods. It was reported that 300 lives were lost, 15,000 houses were damaged, and 225,000 people became homeless during this disaster. The total damage was estimated at Rs.120 million [8]. The recent flood in May 2016 is the most severe hydrological hazard after the major flood in June 1989. Rainfalls caused the onset of two floods that were similar in the magnitude (an 8-day total was around 560mm) but different in the spatial and temporal distribution pattern. In June 1989, the rainfall stations of Norton, Maussakele and Laxapana experienced total rainfalls of 1222.9mm, 1694.2mm, and 1184.8mm respectively, while the highest rainfall in May 2016 was recorded as 898.8mm at Deraniyagala (Metrological department data). However, the damage of the 2016 flood was significantly higher due to the longer durations of inundations, and the irregular developments that took place in the floodplain [9]. United Nations reported that these were the worst floods reported in 25 years, 5,037 houses have been estimated as destroyed, while 104 people are known to have died. Sri Lanka experienced the highest economic loss in South Asia with total damages exceeding Rs 82,650 million due to the floods in May 2016 [10]. Author in [9] reported that frequent flooding in the Colombo region was

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caused by the shrinking of open spaces, illegal constructions, and lack of suitable waste disposal means. Therefore, the primary goal of this study is to identify the impacts of land-use change on Colombo district on May 2016 flood by comparing with the flood and land-use situation in 1989.

II. STUDY AREA

Colombo district is the largest and the most industrialized city in Sri Lanka. It is famous for its commercial, cultural, scientific, and technological activities. It lies between the parallels of 6°52"N and meridians of 80°01"E and has an area of 699km^2 The City of Colombo is the capital of Sri Lanka, whereas Sri Jayewardenepura is the administrative capital.

III. METHODOLOGY

Satellite remote sensing image processing algorithms and geographical information system (GIS) approaches were implemented to accomplish the main objective of the study, i.e. to analyze the land-use change and its impact on the Colombo district flood on May 2016. According to the workflow summaries in Figure 1, a land-use change analysis was conducted to determine how much alterations have taken place in the Colombo district between 1989 and 2016. Further, a comparison between flood and rainfall of 2016 and 1989 was conducted to correlate the two flood conditions. The impact of land-use change on May 2016 flood was analyzed based on the findings of these investigations.

A. Study of Land-Use Change

Three indexes were used to identify the land-use classes of Kelani river watershed: normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI), and normalized difference water index (NDWI). NDVI values were calculated based on (1) varying from -1 to +1. Non-vegetated areas are generally indicated with negative values and vegetated areas with positive values [11].

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{RED})/(\mathrm{NIR} + \mathrm{RED}) \quad (1)$$

NDVI images were used to identify the green areas, agriculture, and low settlement areas for classification. NDBI values were calculated based on (2) and were used to extract built-up features. The NDBI indices range from -1 to 1, and the positive values correspond to built-up areas [12].

$$\mathrm{NDBI} = (\mathrm{SWIR} - \mathrm{NIR})/(\mathrm{SWIR} + \mathrm{NIR}) \quad (2)$$

NDWI images were derived from (3). The NDWI index was used to identify the water features of the classified image. Positive data values are typically open-water areas while negative values are typically non-water features [13].

$$\mathrm{NDWI} = (\mathrm{NIR} - \mathrm{GREEN})/(\mathrm{NIR} + \mathrm{GREEN}) \quad (3)$$

Land use classes obtained from the above indexes were used for classification. Five supervised classification methods were tested, and out of that, SVM (support vector machine) classifier showed higher accuracy. SVM, also known as support vector networks, supervise learning models with associated learning algorithms that analyze the data used for classification and regression analysis [14]. Medium resolution satellite images (Landsat) of 1989 and 2016 were used to detect the land-use change by applying post-classification change detection techniques. The post-classification comparison approach involves independent production and subsequent comparison of spectral classification for the same area at two different time periods [15]. Thematic change of the two classified images was analyzed by a facility given in ENVI software which determines the land-use differences between 1989 and 2016. Land use change map was then created in ArcGIS environment using the resultant image.

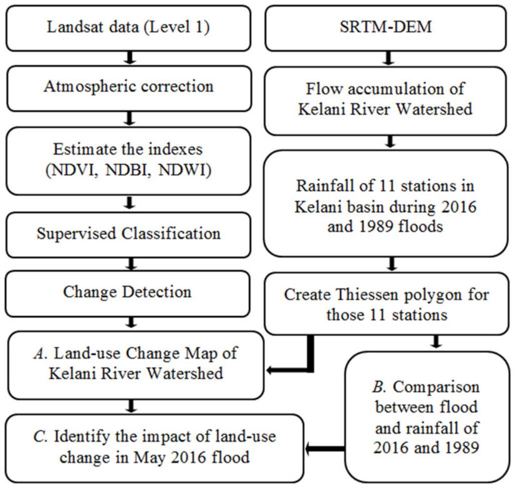

Fig. 1. Methodology flow chart.

B. Comparison of Flood and Rainfall between 1989 and 2016

Watershed is an area of land "that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel" [6]. Therefore, the changes in the watershed of an area play a leading role in its flood situation. Hence, the Thiessen polygon for the Kelani river watershed area was generated to calculate the total rainfall caught by the watershed during both floods in 1989 and 2016. Accordingly, the Kelani river watershed was created based on a 90m resolution SRTM-DEM in ArcGIS environment. Eleven rainfall stations distributed along the watershed area were used to create the Thiessen polygon, and the total rainfall impact on both floods was compared at each station. Flood maps published by the irrigation department were used to extract the flooded area of Colombo district, and the flooded area and rainfall were comparatively analyzed for 1989 and 2016 floods.

C. The Impact of Land-Use Change on Flood Inundation

The land-use change in the watershed area is expected to have a high impact on flood inundation and was the main focus of the current study. The Colombo district was divided into three sections for detailed investigation of the flooded area and the corresponding land-use change of Kelani river watershed.

IV. RESULTS AND DISCUSSION

A. Land-Use Classification and Change Detection

The resulted overall accuracy and kappa coefficient for each classification technique are listed in Table I for the tested 5 techniques of Landsat satellite image classification.

TABLE I. CLASSIFICATION TECHNIQUES COMPARISON

Classification method	Accuracy		Kappa coefficient	
	1989	2016	1989	2016
Maximum likelihood classification	92.05	92.05	0.89	0.83
Minimum distance classification	71.97	71.97	0.61	0.76
Parallelepiped classification	57.41	57.41	0.47	0.51
Mahalanobis distance classification	76.41	76.41	0.67	0.68
SVM classification	99.04	99.04	0.96	0.98

Out of the tested 5 methods, SVM produced maximum overall accuracy of 99.04 for both years, and kappa coefficient of 0.96 and 0.98 for 1989 and 2016 respectively. Therefore, the SVM linear kernel type is used to classify the urban and sub-urban compositions of the Colombo district. Accordingly, classified maps for the 5 land-use classes of Colombo district were prepared as presented in Figure 2.

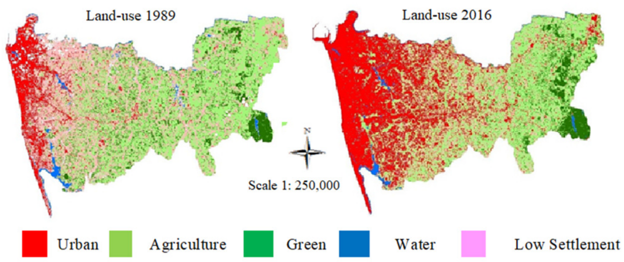

Fig. 2. Land-use map of 1989 and 2016, derived using Landsat images.

According to the land-use classification, the distribution statistics of urban, agriculture, water, green, and low settlement areas of Colombo district for both 1989 and 2016 were calculated. Urban areas increased from 10% to 36% from 1989 to 2016, which was observed to be the most significant land-use change in the area. On the other hand, agricultural areas declined from 41% to 39%, green areas reduced from 11% to 7%, and the low settlement areas decreased by 20%. The urban expansion was highly significant in the western part of the district, compressing the greenery towards the center and the eastern parts of the district. Post-classification change detection method was applied due to its direct information retrieval nature of land-use changes. The analysis helped to understand and identify the land-use classes which were turned into urban or built-up environments or other land classes. Table II lists a total of 11 class transformation statistics from 1989 to 2016.

TABLE II. CHANGE DETECTION STATISTICS

Land-use classes		Area (km^2)	Total area percentage (%)
1989	2016		
Low settlement	Urban	124.7	18.2
Agriculture	Urban	48.2	7.0
Green	Urban	6.7	1.0
Water	Urban	2.9	0.4
No change		295.8	43.3
Low settlement	Other	88.5	12.9
Agriculture	Other	64.8	9.5
Green	Other	32.0	4.7
Water	Other	1.9	0.3
Urban	Other	1.9	0.3
Cloud	Other	16.0	2.4

Accordingly, a total of 182.5km^2 (26.6% of the total area in the district) changed to urban from 1989 to 2016.For the tested 5 land classes, 43.3% of land-use remained without any change from 1989 to 2016. Besides, 27.7% of total area in the Colombo district changed from the 5 tested land classes to other land-uses including only 0.3% of urban to other land-use. The highest change was observed for low settlement, which was 31.1% for both urban and other land-uses. The change detection revealed that a total of 113km^2 and 38.7km^2 of agriculture and green areas changed to other land-uses. However, 4.8km^2 in the district changed from water to both urban and other land class. This is about 0.7% of the total area in the district. These change statistics were further analyzed by comparing the rainfall and flooded areas of 1989 and 2016.

B. Rainfall Comparison

Kelani River flows through the Colombo district, and the sea outlet is located near the city. Therefore, the overflow of the river has impacts as flooding in the Colombo city. Therefore, a comparative study of the rainfall effect on the Kelani River Watershed is essential to analyze the flooding scenarios of 1989 and 2016 of the district. A total of maximum 8-day rainfall during the floodings of 1989 and 2016 for the 11 rainfall stations distributed along the watershed is used, and the values are presented in Table III.

TABLE III. RAINFALL DATA OF THE SELECTED STATIONS

Station	8 days rainfall (mm)	
	1989	2016
Nagalagam Street	558.9	557.5
Angoda	152.4	370.6
Hanwella	332.6	364.8
Labugama	386.5	499.4
Glen course	669.1	620.7
Norwood	352.5	680.1
Norton	1222.8	304.3
Laxapana	1693.9	599.5
Maliboda	754.0	561.8
Maussakele	693.7	430.8
Udugoda	714.2	876.3

Three stations, i.e., Nagalagam Street, Angoda, and Hanwella are in the Colombo district, and the rainfall recorded in these stations would have a direct influence on the flash flood in the district. However, during the two flood conditions in Colombo, the rainfall at these stations was not significantly different except from Angoda. However, a significant difference of rainfall in higher catchment areas, especially Norton and Laxapana were recorded in 1989. This reveals that the rainfall conditions on creating flash a flood scenario in Colombo urban area is similar in 1989 and 2006. Flooding in Colombo district is not only affected by rainfall in the district area itself but also by the rainfall in the Kelani river watershed. Therefore, a “Thiessen polygon” is generated using all 11 rainfall stations data. Accordingly, the total rainfall of the watershed for both years is calculated by multiplying the rainfall data of the stations with the corresponding area relevant to that station. The resulted total rainfall was 1.424x10^{9}m^3 and 1.350x10^{9}m^3 for 1989 and 2006 respectively. In 1989, the total rainfall, which could make riverine floods in Colombo is significantly higher than in 2006. Therefore, the flood area in

1989 should be higher than 2006 if rainfall was the only considered factor. The flooded area was calculated based on the digitized flood maps obtained by the irrigation department. Accordingly, in 1989 it was 63km^2, and in 2016 it was 74.7km^2. This indicates that the rainfall is not the only reason for the major flood in 2016. Hence, the impact of land-use change on the flood of May 2016 is being investigated.

C. Impact of Land-Use Change on the Flood in May 2016

The change of land-use due to urbanization in Colombo district, especially within the Kelani River, poses a severe impact on flooding. A watershed is an area of land that feeds all the water running under it and draining it off into a water body. Further analysis was conducted to understand the land-use change of the area of Colombo district within the Kelani river watershed. Figure 3 presents the resulted land-use change map. Red color indicates land-use area which is transformed to urban, and 'no change' denotes the area which is not affected by any change. The map outlines that most western parts and the eastern part of Kelani river watershed have not undergone much land-use change compared to the middle section. The most significant land-use change was in the Colombo city and its suburban areas situated in the western part of the Kelani river watershed.

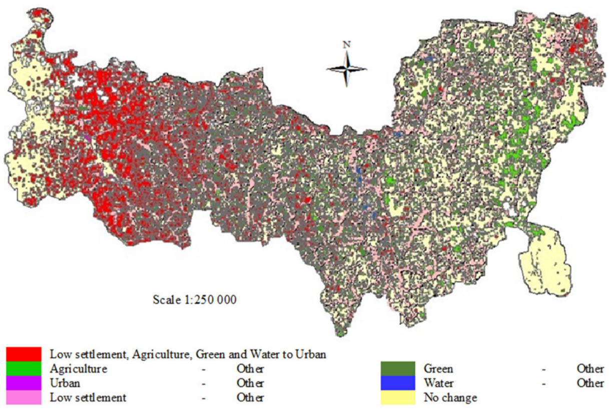

Fig. 3. Land-use change map of Kelani river watershed from 1989 to 2016

By 2016 the area of the urban land class of the district was 182.5km^2, and 57.16% of it was concentrated within the area of Kelani river watershed. The significant increases in built-up areas in the watershed created increased inundation. The area that has transformed to an urban land class in the watershed is 104.3km^2 and covers 23% of the total watershed area in the Colombo district. Agriculture and green areas that were transformed into other classes may also have influenced flood inundation since hydrological and erosion characteristics alter with the changes of land-use. Thus, the total area of land-use transformation in the watershed is 171km^2 which covers 37.7% of the watershed area in the district. As discussed above, during the floods in 1989 and 2016 the total rainfall was 1.424x10^{9}m^3 and 1.350x10^{9}m^3, and the total flood area was 63.0km^2 and 74.7km^2 respectively. Increased land-use change in the watershed contributed to the higher floods in May 2016, even though the recorded rainfall was comparatively lower than that of 1989. For a detailed analysis of these changes, the watershed and corresponding flooded area are divided into three sections as illustrated in Figure 4. Section 1 includes the heart of Colombo district including Colombo city, Section 2 consists of the suburbs and most rapidly urbanizing areas, and Section 3 is the tail of Colombo district with a comparatively lower urbanization rate than Section 2.

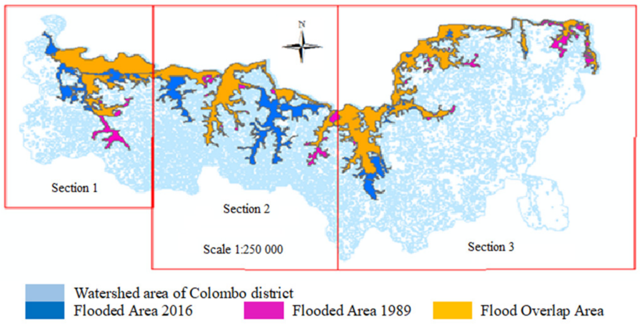

Fig. 4. Sections of Kelani river watershed

According to the flood extent and the land-use change of Section 1, the total flooded area in 2016 was only 3.3km^2 greater than the 19.4km^2 flood area of 1989. The area marked with pink color (Figure 4) indicates the flooded area only in 1989. This is the parliament area along with the Diyawanna Oya in Section 1. Comparative analysis of the two classified images of 1989 and 2016 revealed that this is due to the newly-built channel or stream in the year 2016 by Land Reclamation and Development Cooperation to prevent flood inundation of the parliament area. Further, it was linked with a special flood mitigation project of development of water retention lakes done in 2012. However, the significant land-use change of 44.2km^2 in Section 1 has created an additional flooded area in 2016, which is shown in blue color in Figure 5. In addition, water level data from the irrigation department indicate 2.79m in 1989 and 2.33m in 2016 at the Nagalagam street station. Although the water level of the station in 1989 is higher than in 2016, the recorded flooded area of 2016 is larger than the area in 1989. Hence, it is evident that the changes in land-use have an apparent influence on flooding. The suburban area of the Colombo city is included in Section 2, and a 68.2km^2 of land in this area were transformed into urban and other areas. This was the highest of the 3 sections. Also, this is the section which had the highest flood inundation area increase of 8.1km^2. This section of the Colombo district was urbanized recently. These statistics confirm the relationship between flood area enhancement and land-use change due to urbanization. This Section includes Kaduwela and part of the Homagama DS divisions where massive suburbanisation is underway. According to the analysis, 47.3km^2 area was urbanized while green and agriculture areas reduced by 20.9km^2 from 1989 to 2016. One of the best examples is the southern expressway opened in 2011 which runs through Kaduwela area. Due to the excessive demand for land for residential, commercial, and infrastructure use, the remaining agricultural, green, and low settlement lands are the only alternatives in both Homagama and Kaduwela areas. During the floods of 1989 and 2016, the water level reading at Kaduwela station was 6.24m and 6.17m

MSL respectively. Even though the recorded water level was lower in 2016, the flood inundation area changed from 17.5km^2 to 25.6km^2 from 1989 to 2016. Therefore, the land-use change has a clear and significant impact on flood inundation.

Section 3 represents Seethawaka, Padukka, and part of the Homagama DS divisions where only 0.3km^2 increase of flood area was observed from 1989 to 2016. The land-use change of this section of Colombo district is different from the other two sections. The transformation of other land-use into urban was only 20km^2, which is the minimum of the tested three sections of the district. However, the green and agriculture area that changed into other land-use increased significantly from 1989 to 2016. It was 1km^2, 20.9km^2, and 45km^2 for Sections 1, 2, and 3 respectively. An increased flooded area was shown near the Hanwella station in 2016 and a decrease in the proximity of the Glen course station. This might be due to the significantly higher discharge of 16252.6m^{3}s^{-1} observed at Glen course station in 1989, which is almost the double of the recorded 8118.9m^{3}s^{-1} in 2016. However, at Hanwella station it was the opposite: only 5865m^{3}s^{-1} in 1989 and 8394.8m^{3}s^{-1} in 2016. This confirms that not only the changing into urban areas effected the inundation, but also the change into other land-uses. The reason for less flood inundation in this section as compared to the other two sections was the existence of considerably higher extent of green and agriculture lands, because agriculture and green lands absorb water, making fewer run-offs created by undisturbed grassland and woodland areas.

V. CONCLUSION

Colombo city and the metropolitan area are imperative to the economic growth of the country, and thus, rapid urbanization, as the city is currently facing, is not a strange experience. Besides, the Kelani river watershed of the district has a significant land-use change during 1989 to 2016. The higher percentage of the land-use change incident in the Kelani river watershed was identified as the major impact on Colombo district flood on May 2016. A sharp increase of built-up areas combined with the reduction of agriculture and green areas are the main causes of increased incidence of flood inundation. Out of the entire urban area of the Colombo district, 23% of it is within the Kelani river watershed. Similarly, the total area of land-use transformation that influences the flood inundation covered an area of 37.7% within the watershed area of the Colombo district. Eventually, this research identified the significant impact of land-use changes on Colombo district flood in May 2016.

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