Assessing Role of Climate and Land Use/Land Cover on Flood Risk using a fusion of Ground Surveys and Remotely sensed Imagery – The case of Pinga Oya in Sri Lanka

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Key words: Floods, Land Cover, Remote Sensing, Risk Management

SUMMARY

Pinga Oya (PO) is a tributary reaching the mid-stream of the Mahaweli river, which is the largest river in Sri Lanka. Parts of PO has recorded multiple flooding incidents in past decades during high rainfall events. The most recent flood was recorded on the 25th of December 2022 following a storm event. The inundation was distributed mainly along Kandy - Jaffna (A9) trunk road from Akurana to Katugastota disrupting a critical artery for 4 hours. Major impact was observed in Akurana town and its periphery. In some area's inundation was raised up to 9 feet above the road level.

Over the last decades, rapid unregulated urbanization, constructions on the river margins, filling up of overflow areas and land use change in the Pinga Oya catchment (83km2) were identified. Of these factors, land cover change has a significant impact on increasing the flood frequency in rapidly urbanizing areas. Land cover changes from natural vegetation into impermeable surfaces caused to alter the natural drainage flow and reduce infiltration capacity. Thus, it increases surface runoff and that led to flooding. Floods are associated with several socio-economic and environmental issues such as rapid spread of waterborne diseases, disruption of transportation and communication systems, property damages and loss of lives.

Time series analysis was performed using Landsat 8 OLI/ TIRS images using Support Vector Machine (SVM) classification to identify the land cover changes from 2015 to 2022.Rainfall analysis was done during the period of 1978-2022 with the precipitation data obtained from the meteorological department, Sri Lanka. Flooded area was identified by a field data collection. Built up area shows a significant increment by 25% while the vegetation surface has decreased. The number of bridges across the Pinga Oya has increased up to 43 in 2019, which was 19 in 2003 in Akurana GN division. The primary goal of this study is to identify the impacts of land cover changes on flash floods in the Akurana area. Surveyors and spatial data analysts can provide quantification that is needed to help differentiate the respective roles of urbanization and climate change for supporting flood risk mitigation. These issues can be addressed integrating land surveying, remote sensing, GIS, climatic and hydrological analyses to mitigate future hazards amidst the climate crisis.

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1. INTRODUCTION

Pinga Oya catchment is a rapidly urbanizing region situated in the Central Kandy District of Sri Lanka. It is a sub-catchment of the Mahaweli river which is the longest and largest river in Sri Lanka. The urbanizing area in the PO catchment includes the towns of Katugastota, Akurana, Ambatenne and Alawatugoda (Figure 1). Parts of PO has recorded multiple flooding incidents in past decades during high rainfall events but the most frequent flooding has been in Akurana. Before 1980, the town was nearly flooded during the times of extremely heavy rainfall (264mm in 1978.10.06). In the last two decades, more than 20 flash floods are recorded with less rainfall (less than 120 mm) events. The most recent flood was recorded with 133mm rainfall causing serious damages to the properties. The damage assessment by the Divisional Secretariat of -Akurana shows the total damage from the recent floods on 25th of December 2022 as 655 billion LKR.

Three major factors are identified for the flash floods as loss of overflow areas surrounding the river corridor, loss of available volume in the river due to construction and siltation, and reduction in infiltration in the catchment causing enhanced runoff. All these three factors are directly related with the LULC change of the area. There is a loss of open space and low-lying areas such as paddy fields and wetlands over the years. These are effective in storing water. Both LULC maps of the past compared with satellite imagery since show that there has been a loss of such areas. Loss of volume arises due to illegal and illegally authorized construction into the river corridor. In addition, the breakdown of the natural processes of weathering and increase in dumping in the river causes siltation in the bed which reduces the available volume for water flows.

Infiltration is the process of water from the ground surface into the soil. Soil surface conditions and its vegetative cover, properties of the soil such as its porosity and hydraulic conductivity, current moisture content of the soil are some factors influenced in infiltration rate.[1] It is remarkable that the loss of natural vegetation and its replacement by concrete, construction and roads at such granular scale now in PO catchment specially in the Akurana GN Division. This can be identified by a time series analysis with satellite Remote sensing imagery. Due to rapid urbanization and population growth significant changes in Land Cover (LC) are caused.

Human activities are hugely effect to the Earth's vegetative cover where it directly contributes to climate change through a variety of processes. Altering the vegetation surfaces into impervious surface decreasing the infiltration and increasing the runoff.

Number of bridges along Ping Oya has rapidly increased from 2015 to 2022 narrowing the river.2-4 story constructions into the Pinga Oya with the columns built in to the river causes plastic pollutions retained from the floods are obstructing the natural flow of the river. Also, the construction debris dumping can be identified in many places along the river. All these activities have changed the LULC of the PO catchment. This analysis was performed to investigate the impact of LULC change for the flash floods of the area using remotely sensed multispectral imagery.

2. STUDY AREA

Pinga Oya (PO) is a tributary reaching the mid-stream of the Mahaweli river, which is the largest river in Sri Lanka. the catchment of Pinga oya covers 83 Km2 area consisting the subcatchments of balapitiya oya, Kurugoda oya, Wahagalla oya, Hunnan oya and Owissa oya. The catchment is covering mainly the Akurana, Poojaitiya and Harispattuwa District Secretary (DS) divisions. minor parts are included within the Pathdubara and Tumpane DS divisions. All these tributaries of Pinga Oya are well known as Pinga oya. The major impact of this Pinga Oya flash floods was observed in Akurana town and its periphery

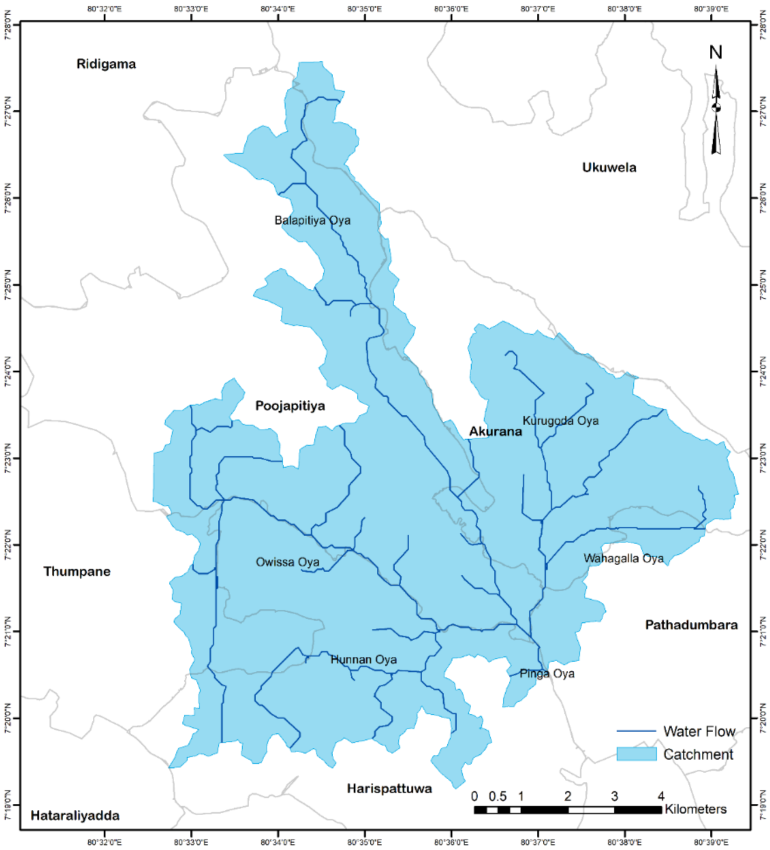

Figure 1: Pinga Oya catchment with main tributoties of Pinga Oya; Balapitiya Oya, Kurugoda oya, Wahagala oya , Owissa Oya, Hunnan oyaand Kurugoda oya

3. DATA AND METHODOLOGY

3.1. Field data collection

Pinga Oya floods several times a year inundating the Akurana town making the A-9 highway vulnerable for erosion from several places between Ambathenna and Akurana. Flooded areas were identified by field observation and a survey was carried out to measure the coordinates of each flooded area using a handheld GPS receiver. Flood levels were identified with the remaining marks on walls of damaged shops and houses. The flood map was created with overlaying the Road, stream and GN divisions layers.

Figure 2: Flooded areas in Akurana on 25th December 2022 between 9 AM to 3 PM: 9th Milepost, Akurana, Kudugala, 5 th Mile Post, Ambatenna, Welekade and 4th Mile Post at Katugastota

3.2 Watershed analysis

Pinga Oya catchment was defined by a hydrology analysis using ARCGIS .2014 STRM DEM data was used for the analysis. The SRTM 1 Arc-Second Global data offer worldwide coverage of void filled data at a resolution of 1 arc-second (30 meters) and provide open distribution of this high-resolution global data set. Drainage system of the area was delineated by determining the flow direction which water would flow out of each cell. Then the catchment area was defined with the watershed tool by locating the pour points to cells of high accumulated flow.

3.3 LULC Classification

LULC classification was performed using Landsat 8 OLI/TIRS data using Support Vector machine classification. Land cover/use classification using remotely sensed images is one of the most common applications in remote sensing, and many algorithms have been developed and applied for this purpose in the literature. Support vector machines (SVMs) are a group of supervised classification algorithms that have been recently used in the remote sensing field [2]. The support vector concept was introduced to remote sensing image classification by Gualtieri and Cromp (1998) [3]. SVM is a classification system derived from statistical learning theory which provides good classification results from complex and noisy data. It performs in a maximum accuracy in Land cover classification compared with Maximum Likelihood (ML) classification [4]. Three major land covers were considered in the study as I-V-S Impervious, Vegetation and Soil. Google earth maps and Land Use Land cover maps by the Survey Department Sri Lanka were used as the reference data for sample generating. Accuracy assessment was done to verify the accuracy of the classification results

3.4 Rainfall analysis

Daily rainfall data was collected from the nearest rainfall station by the Department of Meteorology, Katugastota and from the FECT instruments at Akurana from 1978-2022.Flood dates were estimated by literature review, social media reports and newspaper articles.

4. RESULTS

4.1 LULC Classification

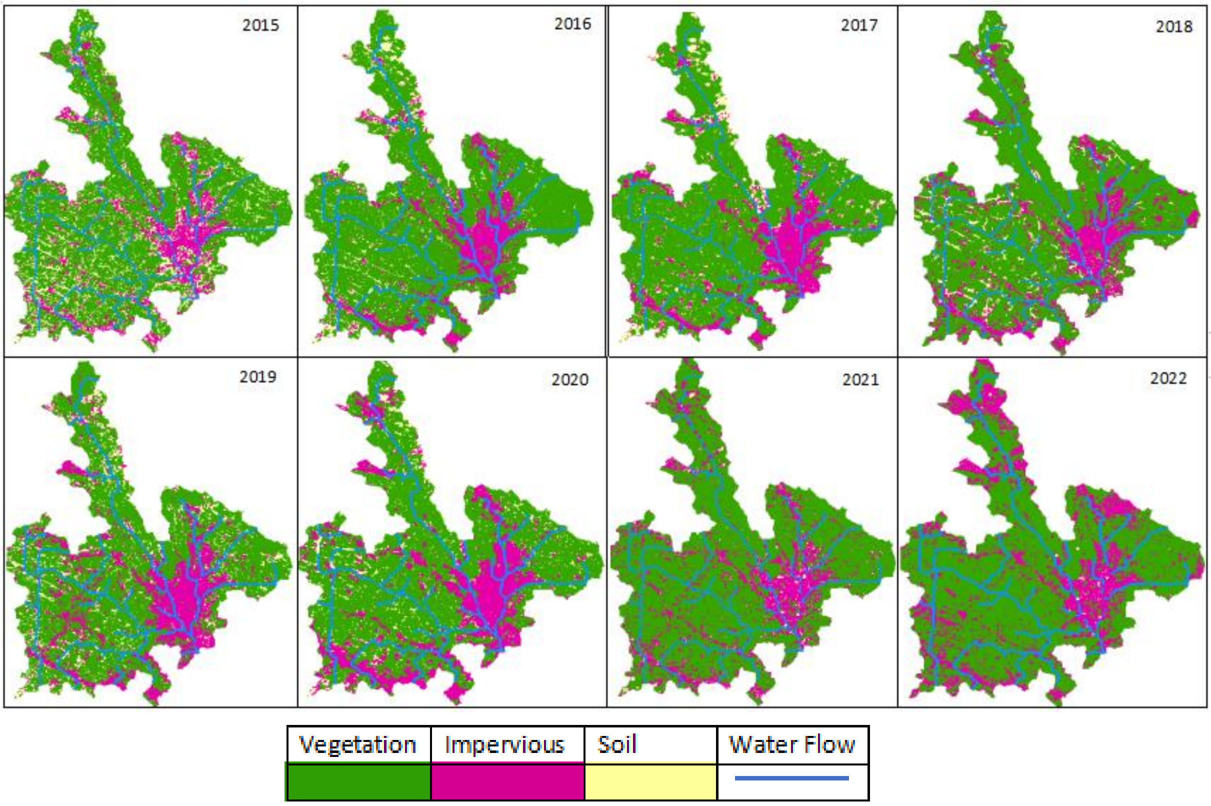

Figure 3 : LULC classification of The PO catchment 2015-2022

The classification results are showing how the land cover has changed in the PO catchment from 2015. Mainly impervious surface has increased in the Akurana and Ambathenna areas along the Balapitiya Oya and Wahagalla Oya tributaries. This area was identified as the flood prone area along Pinga oya . According to the land cover classification maps of PO catchment, 85% of the area is covered by the vegetation and soil while Impervious surface covered 15% In 2015. There is a significant increment of the impervious surface of the area from 2015-2022 period. Impervious surface has increased from 14.99% to 25.75% during the past 8 years. The number of bridges between Ambathenna and Akurana was 47 along pinga oya in 2022 which was 19 in 2015.

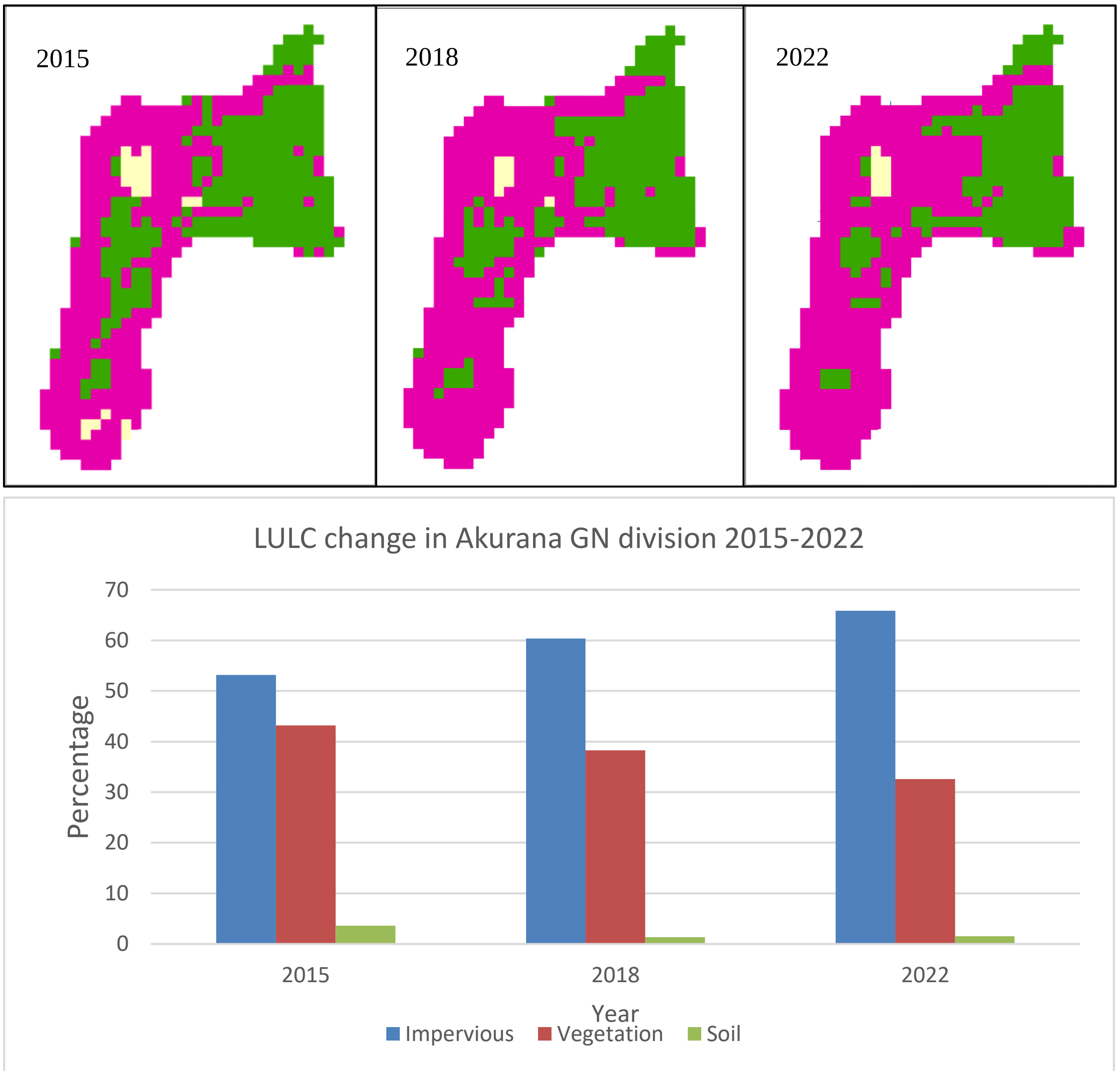

Figure 4 : LULC classification on Akurana GN division(0.51 Km^2) shows that the impervious surface has increased up to 65.87% in 2022 where it was 53.17% in 2015

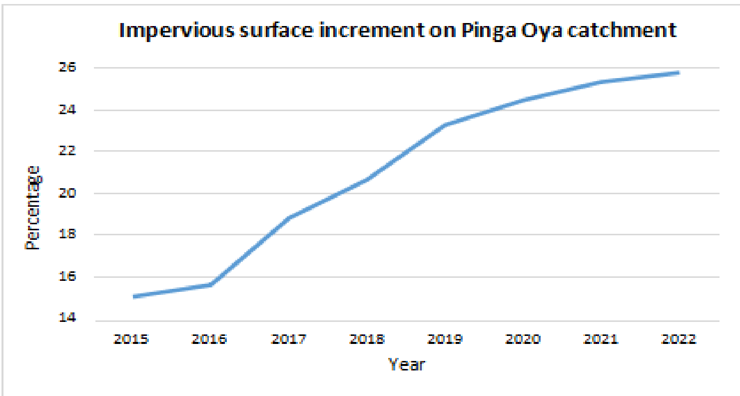

Figure 5 : Impervious surface in PO catchment has increased from 14.99% to 25.75% during the past 8 years, showing a significant increment by 2016 to 2022

4.2.1 LULC map on PO catchment 1999

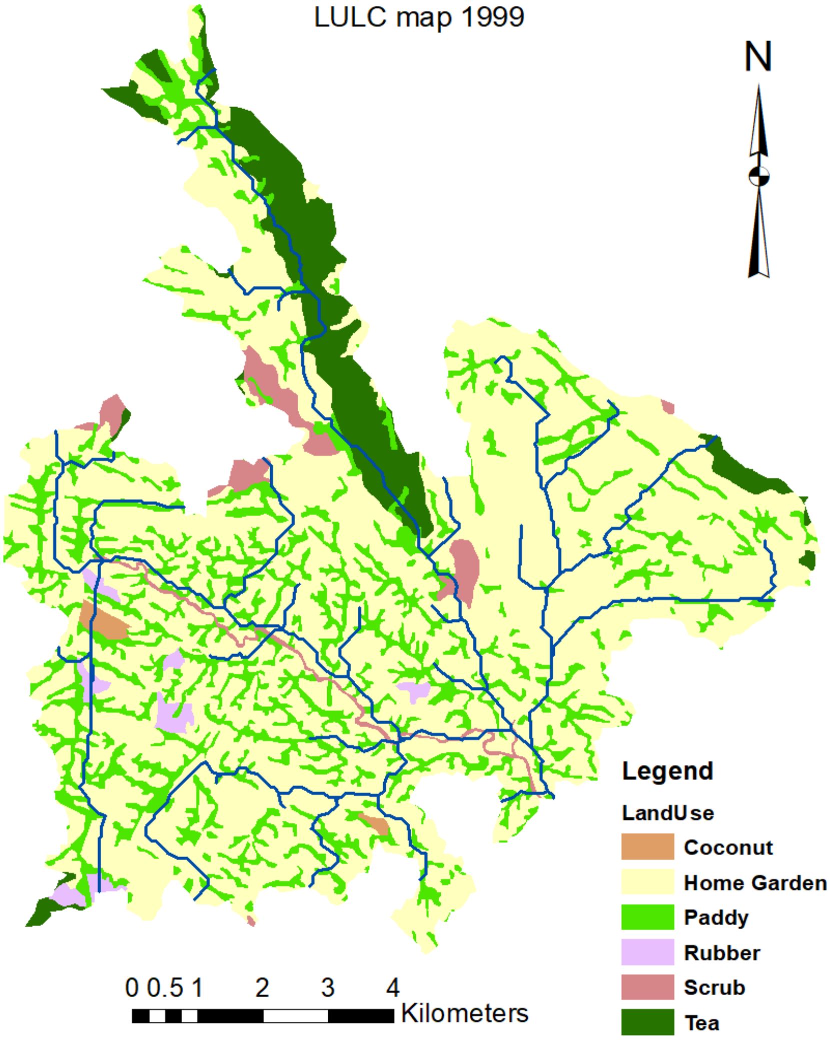

Figure 6 : LULC map on Pinga Oya catchment in 1999 with coconut, home garden, paddy , rubber, scrub and tea cultivations

According to the LULC maps by the survey department sri Lanka, in 1999 PO catchment has a diversity in vegetation as paddy , scrub tea and coconut. The majority of the area (68.81%) was considered as home gardens while there was paddy in 19.57%, Tea in 7.53% of the extent.Scrub percentage was 3.66 and the cocunet had 0.43% of the extent.

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4.3 Rainfall analysis

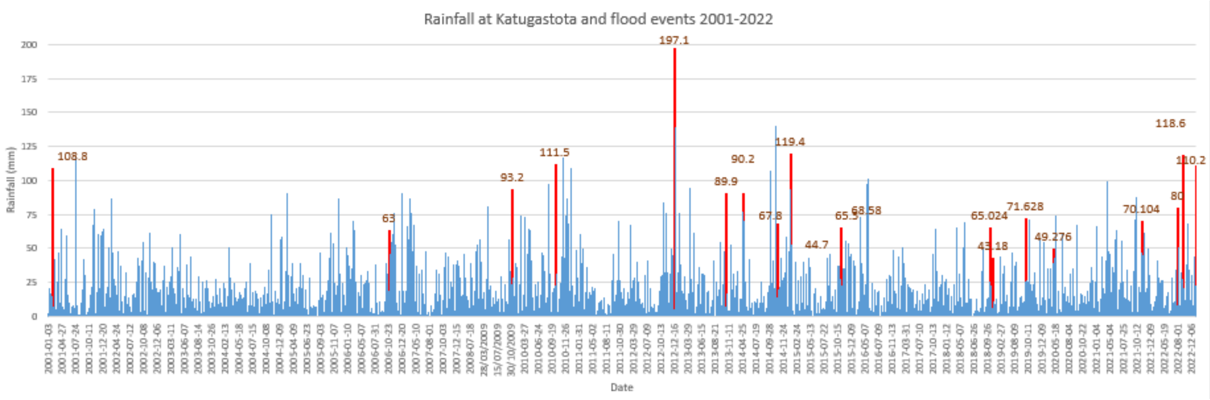

Figure 7 : Rainfall variation from 2001 to 2022 at Katugastota meteorological station

According to the rainfall analysis recent flood events were occurred with a less rainfall values compared with the past decades. Before 2001 there has been only one occurrence of flood recorded (1978), even though the rainfall was 162mm in 1990 and 161mm in 1996, there were no floods recorded. After 2001 even, rainfall of 68mm (2014) and 63mm (2006) caused flooding in Akurana [5]

5. DISCUSSION

The three main flood causes are identified as loss of river volume, loss of flood plains, and loss of infiltration in the area. We have been able to use past surveys and remote sensing images from 2015 to 2022 with ground truths to identify the changes in LULC in PO catchment. Surveying and remote sensing help to provide precise information on changes in land use.

Flooding has been restricted to the Balapitiya Oya and Wahagalla Oya catchments, which have recorded more than 20 flood events. This analysis shows that the impervious surface of the Aurana GN division has increased to 65.87% in 2022, where it was 53.17% in 2015.

Constructions into the river have increased, including bridges, buildings, and columns, causing obstacles to the river's flow during high density rainfalls. The siltaion was also identified as 1-2 meters along the river in many places. The number of bridges along PO has rapidly increased to 47 in 2022 from 19 in 2012.

Even for the small waterways in Sri Lanka, there should be a 20-meter reservation on both sides of the river. However, the local authority has not prevented the construction, even with 10m from the centerline of the river. This affects the loss of flood planes.

Akurana is the highly affected GN division by the flash floods in recent years. With the rapid urbanization of the area, the vegetation and soil surface have become impervious, resulting in a lower infiltration rate. Also, the river profile has changed due to the constructions in the Pinga Oya, mainly the unauthorized and illegally authorized constructions.

6. CONCLUSION

The resolution of the satellite images might affect the accuracy of the classification. Particularly in urban areas, vegetation becomes smaller, and those fragments cannot be identified with low-resolution images. For this study, 30m resolution images were used, and higher accuracy results can be obtained with high resolution imagery.

Spectral Angel Mapper (SAM) classification could be used for the study in subpixel estimation for vegetation, soil, and impervious class fractions. A thresholding process will not be required in this classification as all the pixels will be decomposed into fractional estimation of the V-I-S in the range 0–1, where the V-I-S endmembers are carried out by using supervised clustering of n-D scatterplots.

The study can be performed by excluding all the cloud cover effects that can cause misclassification results using techniques such as the CF mask algorithm, fog Stability Index, etc.

Image acquisition date may be subjected to the classification results in the trend analysis due to the dry and wet seasons which can be highly affected for the vegetation cover

Conveyances in streams and channels can have an undue impact. All impervious surfaces do not have the same infiltration impacts. There could be slight differences. These facts were not captured in this study.

Rainwater harvesting has not been considered in this study, which can be useful in the reduction of flood risks in urban areas.

It is better to look at urbanization because of the future changing climate. In extreme weather conditions, there may be much more serious flooding.

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BIOGRAPHICAL NOTES

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