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AN ASSESSMENT OF LAND USE AND LAND COVER CHANGES ON URBAN FLOODING: A CASE STUDY IN SRI JAYEWARDENEPURA KOTTE

H.S.Wijesooriya [1], Manjula Chathuranga [1], K.A.Dinusha [1] and N.S.Vithanage [2]

Department of Spatial Sciences, General Sir John Kotelawala Defence University, Sri Lanka [1]
Disaster Management Center, Sri Lanka [2]

ABSTRACT

This study investigates the relationship between Land Use and Land Cover (LULC) changes and urban flooding in the Sri Jayewardenepura Kotte Divisional Secretariat Division (DSD). The research objectives include analysing flooding patterns, mapping LULC changes, and assessing the correlation between these changes and flooding occurrences. Additionally, a temporal rainfall variation analysis was conducted to provide further context. The study employed Geographic Information System (GIS) technology, specifically utilising ArcGIS for LULC classification and Inverse Distance Weighting (IDW) interpolation technique for rainfall data. The analysis reveals a clear association between heightened precipitation and major flood events. In 2010, the flood inundation area was 5.762 km² during the major flood in May, despite a monthly rainfall of over 650mm. However, in 2016, with over 700 mm of rainfall in May, the flood-inundated area was reduced to 4.046 km², highlighting the role of other factors such as wetland recovery. Moreover, it identifies significant LULC changes, emphasising rapid urbanisation and wetland decline. From 2009 to 2018, built-up areas increased from 11.49 km² to 14.18 km², while wetlands decreased from 2.29 km² in 2009 to 1.19 km² in 2015, before recovering slightly to 1.58 km² by 2018. The expansion of built-up areas is found to slightly increase flood risks, while wetland recovery acts as a natural flood buffer. This research underscores the importance of targeted interventions for urban flood resilience, such as flood-resistant infrastructure and wetland management. The findings provide critical insights for evidence-based urban planning and flood management strategies, aiming to create more resilient and sustainable urban environments.

KEYWORDS: *Land Use Land Cover, Geographic Information System, Inverse Distance Weighting*

Corresponding Author: H.S.Wijesooriya, Email: hswijesuriya20@gmail.com

https://orcid.org/0009-0002-3341-4528

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1. INTRODUCTION

As a small island in the Indian Ocean, Sri Lanka faces a range of natural disasters annually, such as floods, landslides, droughts, cyclones, lightning, coastal erosion, and tsunamis, resulting in widespread destruction and loss of life (Madhubhashini, 2019). One of the tragic natural occurrences that had a significant impact on society, the economy, and the environment is flooding. Due to its distinct topography and geographic location, Sri Lanka is a country that is very susceptible to floods (Dasandara et al., 2022). One of the most common natural hazards that caused property damage and happened in the past few decades was floods and landslides (Hemachandra et al., 2019).

Floods can have a wide variety of appearances because they can cover anything tiny or large. The floods may start slowly or quickly. There are several types of floods such as river floods, flash floods, inland floods, coastal floods, and storm surges (Nied et al., 2014). Urban flooding occurs when rainfall exceeds drainage systems, causing waterlogging in streets, homes, and infrastructure. Impervious surfaces, reduced natural floodplains, and climate change increase risks. Impacts include property damage, daily disruptions, and health and safety challenges (Kui Xu, 2023). River floods transpire when water levels surpass riverbanks, while coastal floods arise from tidal surges, high wind, and barometric pressure. Urban floods, occurring in cities due to heavy and prolonged or sudden intense rainfall, pose intricate challenges with diverse land uses, concentrated constructions, and numerous projects (Plate, 2002).

A flash flood is a sudden, intense inundation occurring within a few hours, resulting from heavy rainfall, rapid snowmelt, or the release of impounded water. Flash flood inundation involves rapidly covering usually dry areas, particularly in low-elevation zones near rivers or water bodies, leading to significant harm to infrastructure, buildings, and roads (Montz & Gruntfest, 2002). Flash floods are common in the southwest region of Sri Lanka, particularly during the monsoon season from May to September. They can cause significant damage on property and infrastructure, and they can also result in loss of life.

Land use refers to how a piece of land is used or intended to be used. The way that land is used can greatly affect the environment, the economy, and the community. It is also determined by many factors such as population growth, urbanization, landowner's wishes, public policy, and zoning rules. Land Use and Land Cover (LULC) planning is the process of making decisions about how land should be used (Foley et al., 2005).

Sri Lanka is mainly affected by the southwest and northeast monsoon rains due to its location and topography. Sri Jayewardenepura Kotte (SJK) Divisional Secretary's Division (DSD) in the Western Province is annually affected by floods. Furthermore in 2010, 2016, and 2017 major flood events were recorded in the SJK area. Those flood occurrences caused significant property losses, impacted on transportation, and communication disruptions, and posed a threat to human safety.

The study includes identifying the relationship between LULC changes and urban flooding, analysing temporal flooding trends, mapping changing LULC, and looking into the relationship between LULC alterations and flooding. Also, it investigates the rainfall patterns of the study area to identify the relationship of rainfall patterns with flood occurrences in the study area.

SJK is an area that is frequently affected by floods during the monsoon periods in Sri Lanka. This city is a rapidly developing area. In addition to floods caused by monsoon rains, flash floods and urban floods also occur suddenly because of the heavy rainfall in short durations. LULC changes also may be the cause of urban flooding. By having proper LULC management, the city can achieve sustainable development goals and mitigate flood occurrences.

The study can be defined by its objectives, which include identifying the relation between LULC changes and urban flooding, analysing temporal flooding trends and mapping changing LULC. Also, this investigates the rainfall patterns of the study area to identify the relationship of rainfall patterns with flood occurrences in the study area. Collectively, the research deepens our understanding of the dynamics of urban flooding and provides insights essential for well-informed urban planning, resilient strategies, and efficient flood management, within and across broader urban contexts.

2. METHODOLOGY

1. Study Area

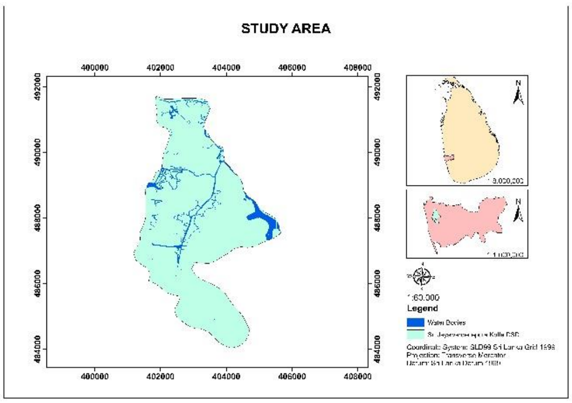

Figure 1. Study area map

SJK is the capital of Sri Lanka. This area is the DSD of the Colombo district in the Western Province. SJK has a hot, oppressive, windy, and overcast tropical climate. The average annual temperature is 26.5 °C around this area. The average annual rainfall is 2668 mm.

Sri Lanka has experienced several major floods over the years that have caused significant damage to public and private property and resulted in the loss of many lives. Colombo has been particularly affected by severe floods in 2010, 2016, and 2017, with one event causing one-eighth of the city's yearly rainfall in just 12 hours. SJK is also at risk of urban flooding due to its rapid population growth and land use changes.

2. Workflow

The workflow of the study unfolds through a systematic and comprehensive process. The general objective is to identify a relationship between the LULC changes and urban flooding in the study area. Initial data collection involves obtaining Landsat satellite images spanning from 2009 to 2018 for LULC analysis, monthly and annual rainfall data from the Meteorological Department, and flood inundation maps for significant events from Land Reclamation and Development Corporation.

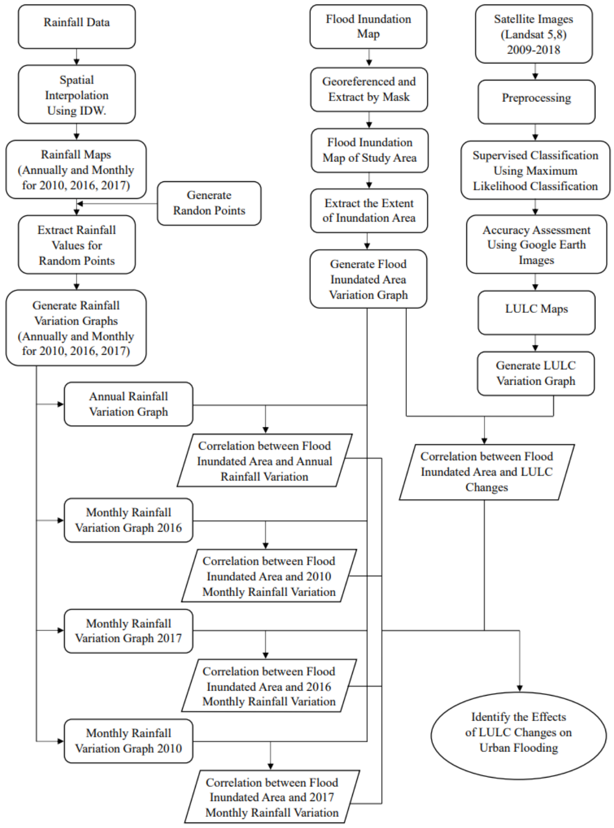

Figure 2. Workflow of the study

The methodology employs GIS and remote sensing techniques, including preprocessing steps like atmospheric correction and image classification for LULC analysis. Accuracy assessment is conducted using ArcGIS tools and Google Earth images. Rainfall analysis utilises IDW interpolation to analyse patterns, and flood inundation area analysis simulates the impact of LULC changes on floods. Correlation analysis explores the relationship between vulnerable flood areas and LULC changes. The complete process is outlined above in Figure 2 for clarity, ensuring a comprehensive investigation into how changes in LULC influence flooding in the study area.

Initial data collection involves obtaining Landsat satellite images spanning from 2009 to 2018 for LULC analysis, monthly and annual rainfall data from the Meteorological Department, and flood inundation maps for significant events from the Land Reclamation and Development Corporation.

Using Landsat satellite images from the years 2009 to 2018, the methodology of this research involved analysing LULC changes. To ensure complete temporal coverage, Landsat 5 and 8 images were acquired for the study area. The images were sent through pre-processing procedures such as atmospheric correction, radiometric calibration, and geometric correction before analysis to improve their quality and consistency. Then, using representative training samples from various land cover classes, supervised image classification was applied to the stacked images. Following that, the detected changes in land cover were interpreted within the context of the study area while considering both socio-economic and environmental factors. The accuracy assessment process of a LULC map involves evaluating the reliability and correctness of the map's classifications and spatial representations. This process is typically conducted by comparing the LULC map with reference data, which have been collected through satellite imagery. The accuracy assessment process for a LULC map using satellite images involved ArcGIS tools and Google Earth images.

Rainfall information for each year during the study period was gathered from five rainfall stations located throughout the study area for the rainfall analysis. The IDW method was then used to spatially interpolate these data points to create rainfall estimates for areas without weather stations. The IDW method gives nearby data point weights based on proximity, with closer points receiving higher weights. This enables the creation of continuous surfaces that depict annual rainfall distribution across the study area.

Monthly rainfall information for the years were collected when a significant flood occurred. To create monthly rainfall maps for those particular periods, IDW interpolation was applied to these data points. This method made it possible to comprehend the rainfall patterns both before and during flood occurrences in detail.

The identification of spatial and temporal variations was made possible by the IDW interpolation technique, which provided an extensive representation of rainfall patterns in both annual and monthly contexts. The resulting rainfall maps and interpolated surfaces were useful tools for examining rainfall distribution and amount, assisting in the evaluation of flood risk, and advancing knowledge of the connection between rainfall patterns and flooding events in the study area.

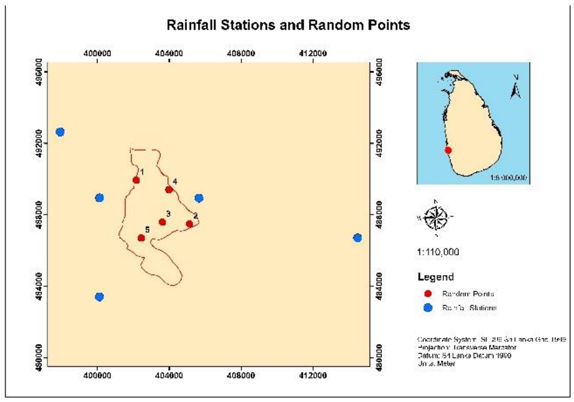

Figure 3: Rainfall Stations and Random Points

Five randomly chosen points were chosen from the study area for the analysis of the rainfall data. Data were extracted for each of these points from 2008 to 2022 for the analysis of annual rainfall. At each location, the monthly rainfall data was also gathered, specifically for the months that experienced significant flooding. The extracted rainfall values were tabulated to generate the relevant graphs. Figure 3 above shows the map that illustrates the used Rainfall Stations and generated random points.

To simulate the impact of LULC changes on flood occurrences in Sri Jayewardenepura Kotte area, the flood inundation maps of the relevant flood occurrences in 2010/05, 2010/11, 2016/05, 2017/05 were used from the Land Reclamation and Development Corporation. The first step was to obtain a flood inundation map showing the flooded areas during the flood event of interest to calculate the flood inundated extent using the map and produce a bar graph. The total area covered by the flooded regions on the map was then measured to determine the inundated area. This required measuring the size of the flooded polygons using ArcGIS software. The inundated areas were depicted on a bar graph. This bar graph made it possible to compare the areas that various significant flood occurrences had inundated visually.

3. RESULTS AND DISCUSSION

A. LULC Change Analysis

The study encompassed the creation of LULC maps spanning the years 2009 to 2018, as illustrated in Figures 4 to 13. These maps offer a comprehensive overview of the evolving land use patterns over time. The data for generating these maps were extracted from satellite imagery, specifically Landsat 5 and Landsat 8 images. The employed methodology involved a process of supervised classification using the ArcGIS software.

To ensure the accuracy and reliability of the obtained LULC maps, an accuracy assessment was conducted. ArcGIS tools and Google Earth imageries and available LULC maps were employed in this assessment, validating the classification results. This validation process ensured that the generated maps accurately represented the true land cover in the study area. The temporal coverage of these maps facilitated a comprehensive analysis of the dynamic land cover patterns and transitions over the specified ten-year period.

By examining the LULC maps, the study aimed to determine the distribution and composition of various land cover classes within the study area. This analytical approach enabled the obtaining of spatial extent and change trends associated with different land use types. The findings derived from these LULC maps serve as a fundamental basis for ensuing in-depth analysis and interpretation.

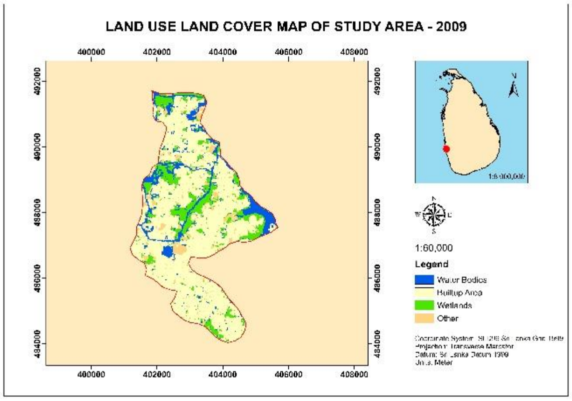

Figure 4: Land Use Land Cover map of the study area in 2009

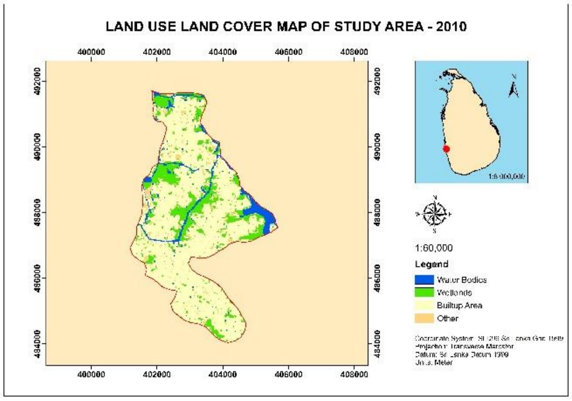

Figure 5: Land Use Land Cover map of the study area in 2010

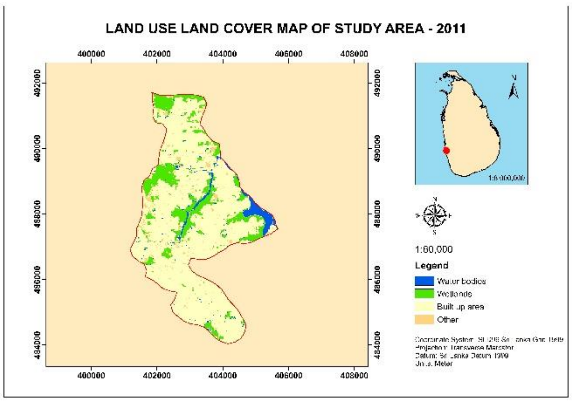

Figure 6: Land Use Land Cover map of the study area in 2011

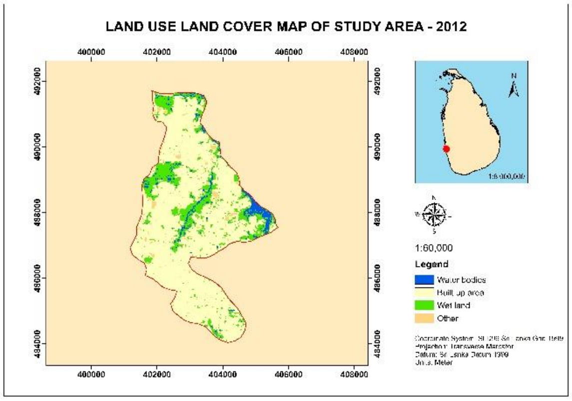

Figure 7: Land Use Land Cover map of the study area in 2012

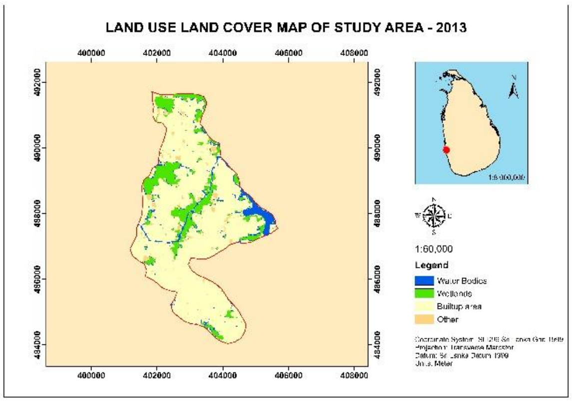

Figure 8: Land Use Land Cover map of the study area in 2013

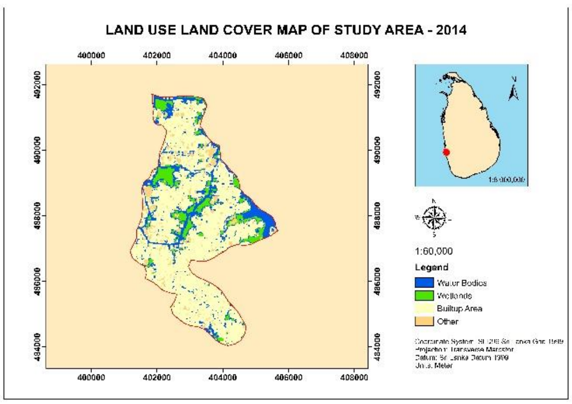

Figure 9: Land Use Land Cover map of the study area in 2014

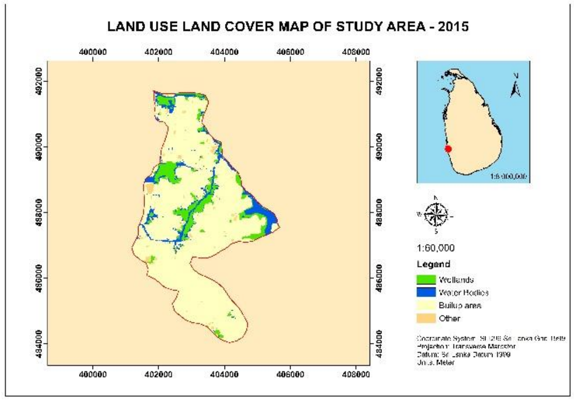

Figure 10: Land Use Land Cover map of the study area in 2015

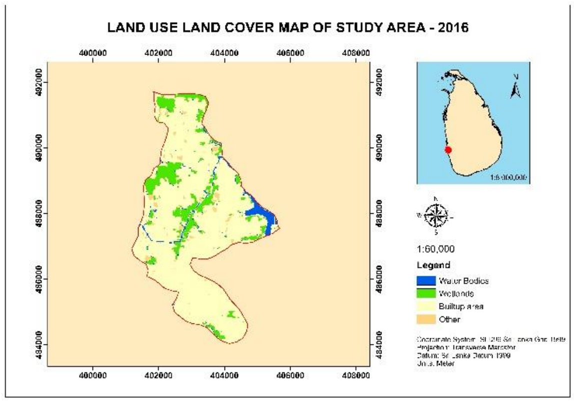

Figure 11: Land Use Land Cover map of the study area in 2016

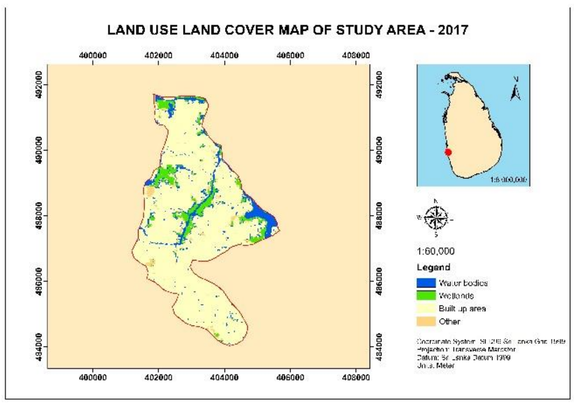

Figure 12: Land Use Land Cover map of the study area in 2017

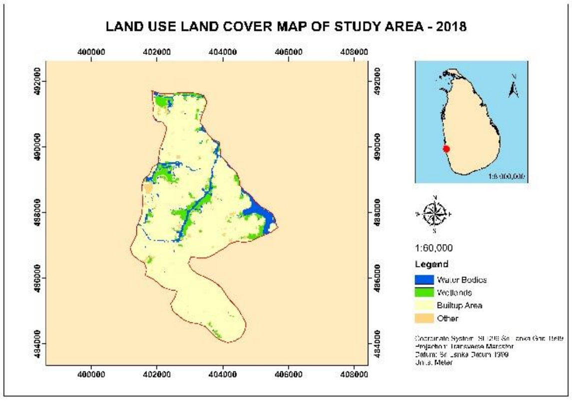

Figure 13: Land Use Land Cover map of the study area in 2018

Created LULC maps from 2009 to 2018 for the study area are shown in the above maps from Figure 4 to Figure 13. Based on the LULC maps and the data presented in Figure 14, covering the years 2009 to 2018, there has been a noticeable increase in the built-up areas and a decline in wetlands from 2009 - 2015. In 2009, 2.29 km^2 was covered by wetlands and in 2015 it decreased to 1.19 km^2. In contrast, the built-up area increased from 11.49 km^2 to 14.18 km^2 between the 2009-2018 period. From 2015 to 2018, there was a slight increase in wetlands from 1.19 km^2 to 1.58 km^2.

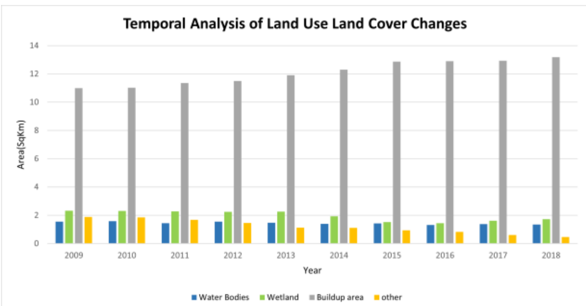

Figure 14:Temporal Analysis of LULC Changes

B. *Rainfall Analysis*

Annual rainfall maps spanning from 2008 to 2022 were meticulously generated for the study area, capturing a 15-year overview of rainfall patterns. Metrological Department data facilitated the geospatial analysis, incorporating IDW interpolation to create continuous rainfall distribution surfaces. These maps offer a comprehensive depiction of spatial and temporal rainfall variations, aiding in identifying regions with varying rainfall levels.

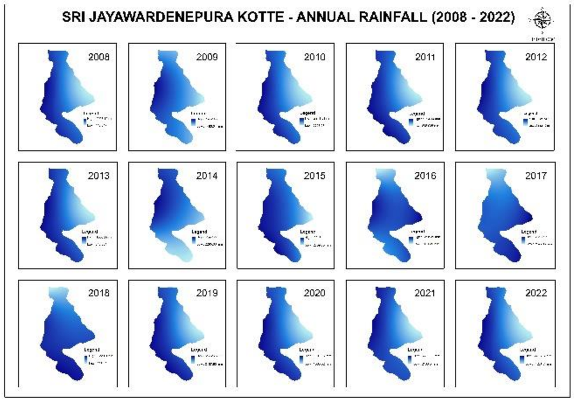

Figure 15: Annual Rainfall map of the study area from 2008 to 2022

The annual rainfall trends and their correlation with flood occurrences are visible through these maps shown in Figure 15 and the annual rainfall variation graph shown in Figure 16.

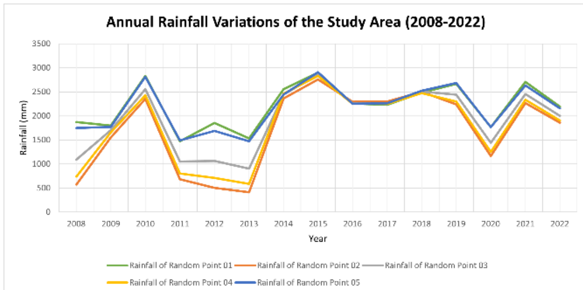

Figure 16: Annual Rainfall Variation of Study Area

Monthly rainfall maps were specifically generated for years with major floods in the study area in 2010, 2016 and 2017, offering a detailed analysis of rainfall patterns during critical periods. Figures 17, 18 and 19 show the monthly rainfall maps of 2010, 2016 and 2017 respectively. The methodology involves analysing monthly rainfall data and employing geospatial techniques to create spatially explicit maps, depicting rainfall distribution and amount. These maps provide a comprehensive understanding of monthly rainfall leading to major floods.

The graphs were generated by plotting the monthly rainfall values in millimetres on the y-axis against the corresponding months on the x-axis, specifically for the years when significant floods were recorded in the study area.

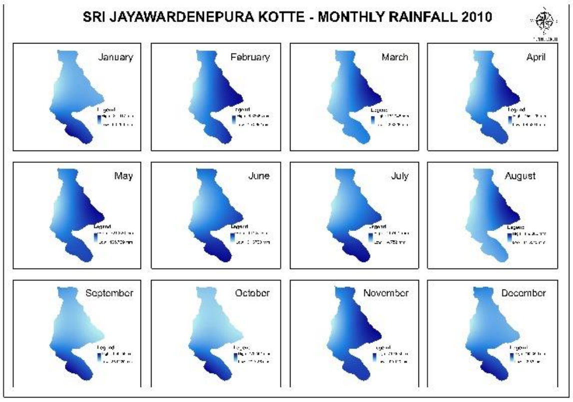

Figure 17: Monthly Rainfall map of the study area in 2010

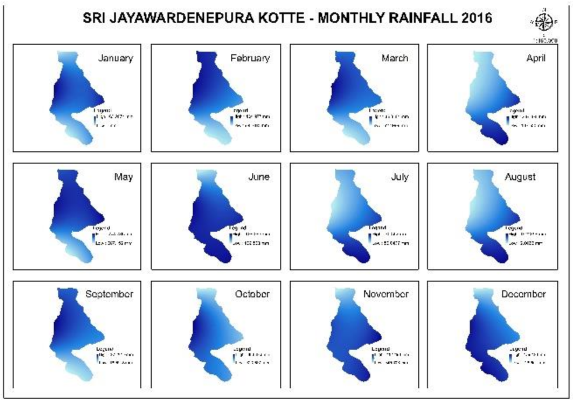

Figure 18: Monthly Rainfall map of the study area in 2016

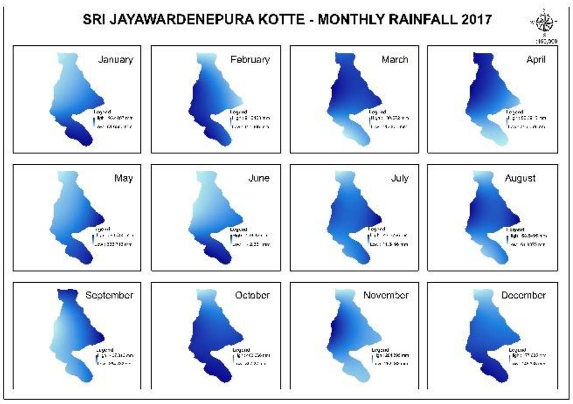

Figure 19: Monthly Rainfall map of the study area in 2017

Derived from reliable meteorological records, the graph illustrates how monthly rainfall fluctuated during flood periods, identifying months with significant rainfall contributing to the events. This visual aid enhances understanding of meteorological factors influencing floods, serving as a valuable tool for interpreting research findings and communicating rainfall patterns during flood events.

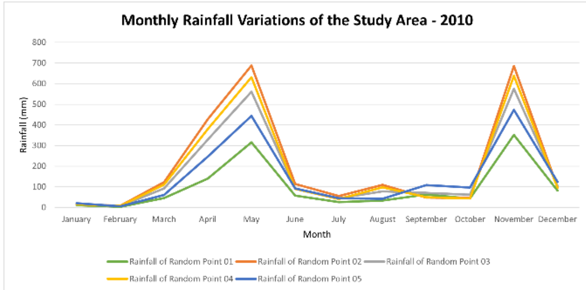

Figure 20: Monthly Rainfall map of the study area in 2010

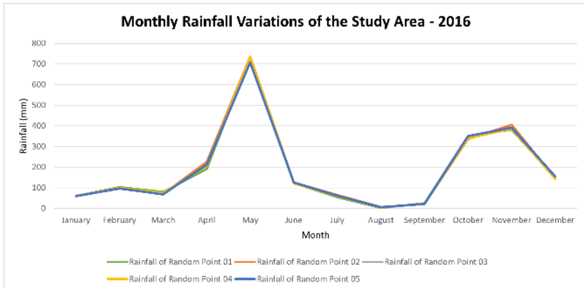

Figure 21: Monthly Rainfall map of the study area in 2016

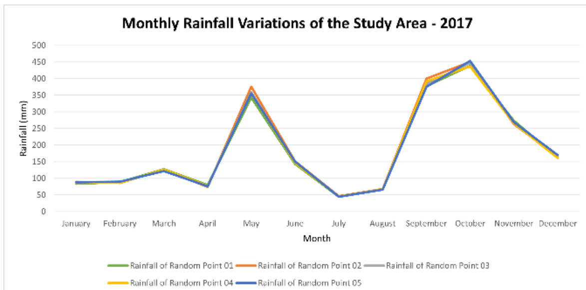

Figure 22: Monthly Rainfall map of the study area in 2017

Figures 20, 21, and 22 illustrate monthly rainfall variations during major flood events in 2010, 2016, and 2017, offering insights into rainfall patterns in the study area. These figures also reveal a bi-modal rainfall variation, typically occurring in the months of May and October, highlighting the seasonal distribution of precipitation in the region.

C. Flood Inundated Area Analysis

The flood inundation maps were specifically generated for major flood events in the study area in 2010 May 2010 November 2016 May and 2017 May. Sourced from the Land Reclamation Department, these maps in figures 23, 24, 25 and 26 offer essential insights into the extent and spatial distribution of floods during significant occurrences.

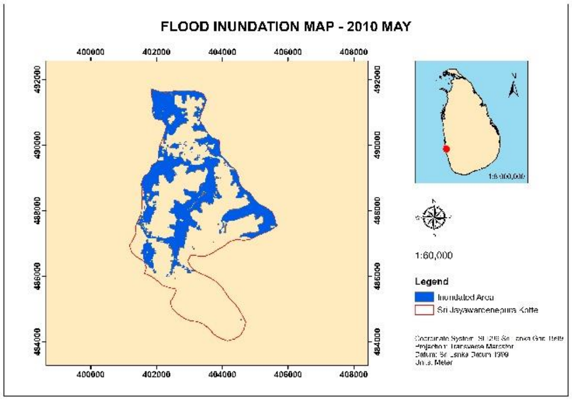

Figure 23: Flood Inundated Area of the Study Area - 2010 May

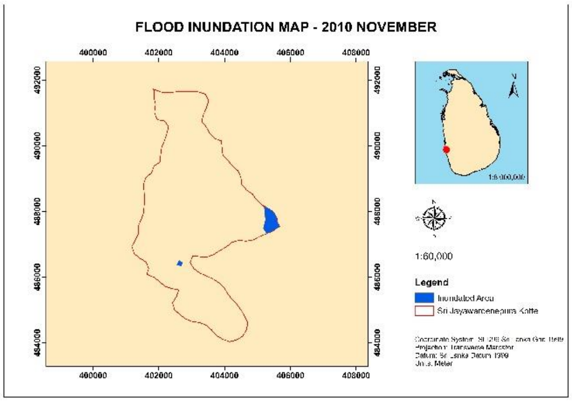

Figure 24: Flood Inundated Area of the Study Area - 2010 November

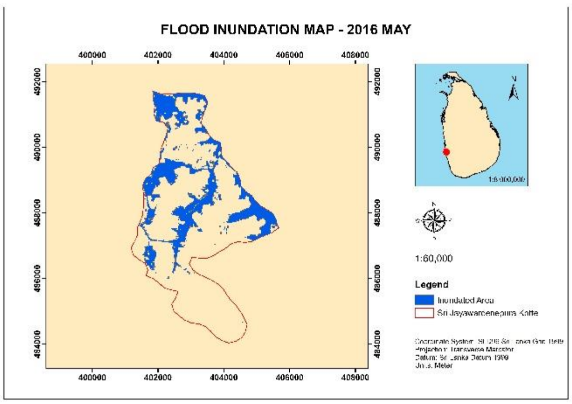

Figure 25: Flood Inundated Area of the Study Area - 2016 May

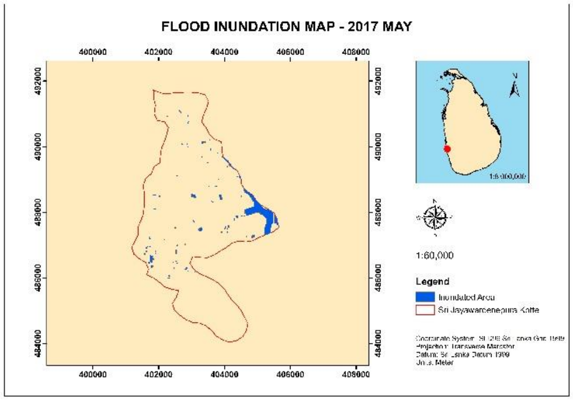

Figure 26: Flood Inundated Area of the Study Area - 2017 May

The methodology involved processing and analysing flood extents, providing valuable tools for understanding spatial flooding patterns and identifying vulnerable areas.

Figure 27 illustrates a graph depicting variations in flood inundation areas during major flood events in the study area, offering a comprehensive visualization of flooding extent over time. Derived from data in flood inundation maps, the graph illustrates temporal fluctuations in inundation areas, highlighting differences between flood events.

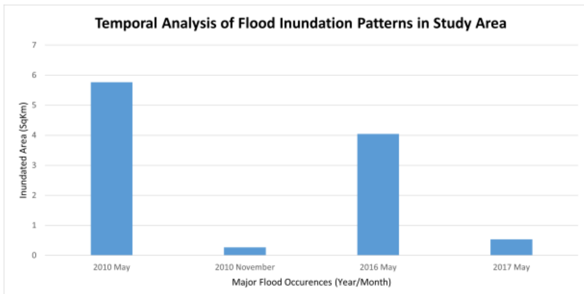

Figure 27: Temporal Analysis of Flood-Inundation Patterns

D. Correlation Analysis of the Study

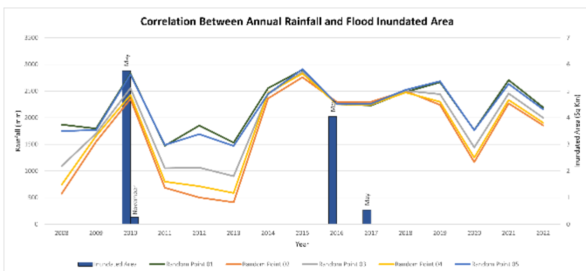

Figure 28: Correlation between annual rainfall and

In 2010, there was an identifiable increase in flood inundated areas and also in annual rainfall. In the same way, in 2016 and 2017, floods occurred with an increase in rainfall. However, in 2014, 2015, 2019, and 2021, there were major increases in the rainfall pattern, but there were no recorded major flood occurrences in those years. In 2016 and 2017, the rainfall increase was the same, but the flood extent was different. The flood extent in 2016 was greater than that in 2017, but the rainfall appeared similar according to Figure 28.

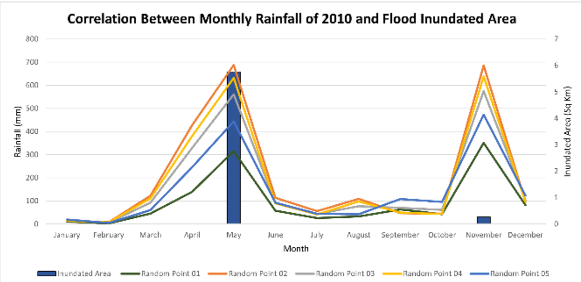

Figure 29: Correlation between monthly rainfall in 2010 and flood-inundated area

Based on the findings presented in Figure 29, it is observed that there is an increase in rainfall during May and November. In November, the rainfall is slightly higher than in May. However, it is interesting to note that despite the higher rainfall levels in November, the flood-inundated area in May is considerably more extensive.

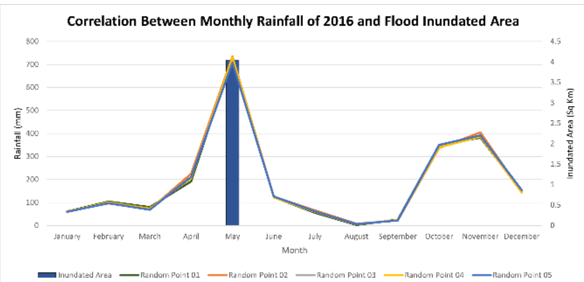

Figure 30: Correlation between monthly rainfall in 2016 and flood-inundated area

In May, there is a major incensement in rainfall than in the other months according to Figure 30. Also, a major flood happened in May 2016 in the study area. The months of October and November also have higher rainfall values than the other months but there were no flood occurrences in these months in the year 2016.

According to Figure 31, May, September, and October had higher rainfalls than in the other months in 2017. But only in May, there was a flood occurrence in the study area. According to the figure, September and October months had higher rainfall than May in 2017 but the flood occurred only in May.

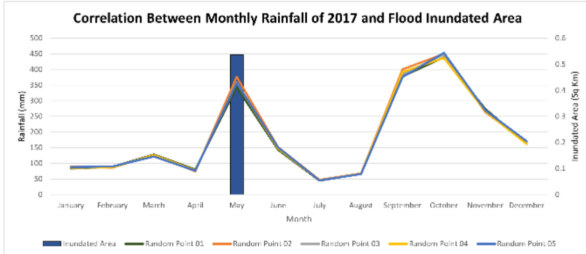

Figure 31: Correlation between monthly rainfall in 2017 and flood-inundated area

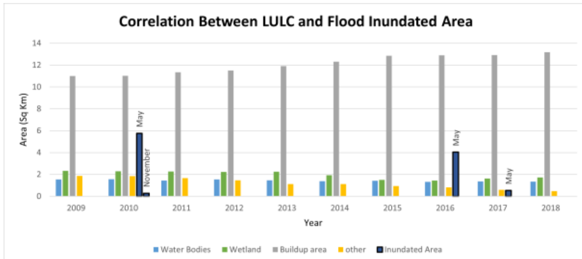

Figure 32: Correlation between LULC changes and flood-inundated area

The correlation between the variations in LULC over time and the areas affected by flood inundation is depicted in Figure 32.

The buildup area has increased steadily over time, while a slight decrease in the wetland area can be observed. But again from 2016, the wetlands have experienced a slight increase according to this graph. Additionally, the extent of waterbodies and other land use areas also changes over time. This figure offers an approximate representation of the changes in LULC categories including water bodies, wetlands, buildup areas, and other land uses.

4. CONCLUSION

The study aimed to identify a correlation between LULC changes and urban flooding in the SJK DSD. The objectives included analysing flooding patterns, mapping LULC changes, and assessing the correlation between LULC changes and flooding. Employing ArcGIS and IDW interpolation, rainfall distribution was analysed annually and monthly for 2010, 2016, and 2017.

The analysis revealed a link between heightened rainfall and major flood events. Notably, in 2010, 2016, and 2017, periods of elevated rainfall correlated with significant flood events. Examining monthly rainfall variations highlighted May as critical, indicating a strong association between intense rainfall and flooding. The accuracy of LULC classification using Landsat satellite images ranged between 74% and 92%.

LULC changes over the study period demonstrated a rise in built-up areas and a decline in wetlands, signifying rapid urbanisation. Noteworthy was the recovery of wetlands after 2016, suggesting potential shifts in environmental policies. The study indicates a relation between urban land use changes and flood inundation areas, highlighting how even minor urbanisation and wetland coverage can impact flood risks. Additionally, variations in rainfall patterns, particularly during peak months, were identified as significant contributors to flood occurrences, compounding the effects of LULC changes.

The expansion of built-up areas poses a heightened risk of flooding by contributing to the creation of impervious surfaces, restricting natural drainage, and intensifying surface runoff. On the contrary, the restoration and recovery of wetlands serve as a natural buffer against floods. Wetlands, with their absorbent nature, play a crucial role in slowing down and absorbing excess water, thereby helping to mitigate the impact of floods.

It is noteworthy that after 2016, there have been ongoing mitigation projects. These projects, including projects like the “Beddagana” and “Diyasaru” Wetland Management projects, are focused on implementing measures to manage and preserve wetland areas. Such efforts are essential for sustainable flood risk management, emphasising the importance of balancing urban development with the conservation and restoration of natural flood-mitigating ecosystems like wetlands.

The study provided insights into the relationship between LULC changes, rainfall patterns, and flood occurrences. The findings underscored the need for targeted interventions, emphasising the preservation and restoration of wetlands and stringent regulations for sustainable urban development. This research contributes to evidence-based decision-making in urban planning and flood management, aiming to create resilient and sustainable urban environments.

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