Effect of the Eco-Based Flood Mitigation Projects on Urban Flooding: A Case Study in Sri Jayawardenepura Kotte

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Abstract

This study investigates the impact of eco-based flood mitigation projects on urban flooding in the Sri Jayewardenepura Kotte Divisional Secretariat Division (DSD). Urban flooding has become a critical issue due to rapid urbanisation and climate change, necessitating effective flood mitigation strategies. Objectives of the research are to analyse flooding patterns, map land use and land cover (LULC) changes associated with eco-based mitigation projects and assess the correlation between these changes and flooding occurrences in the study area. Additionally, a temporal analysis of rainfall variations was conducted to provide further context to the flooding events. To achieve these objectives, the study employs advanced Geographic Information System (GIS) technology. ArcGIS was utilised for detailed LULC classification with 84.4% overall accuracy, enabling the identification of temporal changes in LULC. The Inverse Distance Weighting (IDW) interpolation technique was applied to analyse rainfall data, offering insights into precipitation patterns and their relationship to flooding incidents. The analysis reveals a significant association between increased precipitation and major flood events, indicating that higher rainfall intensities contribute to urban flooding. Furthermore, the study identifies substantial LULC changes related to mitigation projects, highlighting rapid urbanisation, wetland decline, and the restoration of wetlands through eco-based mitigation efforts. It was found that the expansion of built-up areas exacerbates flood risks, while wetland recovery through eco-based flood mitigation programs acts as a natural buffer against flooding. The findings underscore the importance of targeted interventions for urban flood resilience. This research offers critical insights for sustainable urban planning and flood management, emphasising the need for integrated approaches that incorporate ecological solutions to enhance urban resilience. In conclusion, the study provides a comprehensive understanding of how eco-based flood mitigation projects, such as "Beddagana" and "Diyasaru" wetland management projects, influence urban flooding. Incorporating ecological strategies from projects such as "Beddagana" and "Diyasaru" enables cities to more effectively manage urban flooding, offering vital insights for policymakers and planners to develop resilient and sustainable urban environments.

Keywords: Eco-based flood mitigation, Geographic Information System, Inverse Distance Weighting, Land Use Land Cover.

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Introduction

1.2 Background

Urban flooding is becoming a major concern in rapidly urbanising areas, particularly in the Sri Jayewardenepura Kotte Divisional Secretariat Division (DSD). Climate change and uncontrolled urban expansion have exacerbated this phenomenon, resulting in significant changes in land use and land cover (LULC). In response to these challenges, eco-based flood mitigation projects have emerged as long-term solutions for reducing flood risks while promoting environmental conservation.

Sri Lankans are primarily concentrated in Sri Lankan households, which live on an exploitable plateau. Flooding occurs often in natural disaster-prone regions like Sri Lanka. The island's geographical features and weather conditions contribute to frequent floods, which can be destructive to property, infrastructure, and human life. As a result, efforts have been focused on flood mitigation, as well as encouraging the employment of dedicated flood control organisations to mitigate flood occurrences. Cities such as Sri Jayewardenepura and Kotte have experienced fast transformation, resulting in the loss of wetlands, which serve as a natural buffer for storage of returning water via evapotranspiration. This, combined with an expansion in asphalt roads and structures, has significantly reduced the land's natural water retention properties, resulting in increased rain runoff and looming flooding risks.

As a solution to the aforementioned challenges, it has been possible to develop flood mitigation projects with the ultimate objective of enhancing and restoring ecological systems as an urban flood management strategy. Eco-based flood mitigation strategies have been shown to be effective in overcoming urban flooding issues. These use the functional features of ecosystems in the built environment, such as managing wetlands and green spaces, as well as hydrological control, peak flood reduction, and urban resilience. According to the studies, wetlands restoration aims to increase the area's ability to hold water during periods of heavy rainfall, reducing the risk of floods. Furthermore, these projects provide ecosystem services such as biodiversity enhancement, urban green space improvement, and other benefits such as carbon storage and recreation.

This is intended to provide information about the eco-friendly flood mitigation projects in Sri Jayewardenepura Kotte DSD. Thus, the research will cover LULC modifications that accompany flood mitigation strategies in order to determine their contribution to urban flood relief and improve the implementation of ecological measures into urban planning. The results will add to the existing literature on urban flooding variables such as environmental sustainability and offer applicable policies and guidelines to promote urban development.

1.3 Statement of the Problem

Sri Jayewardenepura Kotte DSD, Sri Lanka's administrative capital, is frequently affected by flooding, especially during the monsoon period. Rapid urbanisation in the area has resulted in major LULC changes, notably the removal of natural wetlands, which has increased flood risk. In response, eco-friendly flood mitigation programs have been launched to restore these wetlands and lessen flood damage. However, the usefulness of these efforts in preventing urban flooding has yet to be determined. This study aims to close this gap by investigating the link between eco-based flood mitigation activities and urban flood occurrences in the study area.

1.4 Research Questions

- How do eco-based flood mitigation projects influence urban flooding in the study area?
- What are the key LULC changes associated with the area?
- How do these LULC changes correlate with the frequency and severity of urban flooding?
- What role do rainfall patterns play in the effectiveness of eco-based flood mitigation projects?

1.5 Research Objectives

General Objective:

- To assess the impact of eco-based flood mitigation projects on urban flooding in the Sri Jayewardenepura Kotte DSD.

Specific Objectives:

- To analyse the patterns of urban flooding before and after the implementation of eco-based mitigation projects.
- To map the LULC changes associated with the area using advanced GIS techniques.
- To evaluate the correlation between LULC changes and urban flooding incidents.
- To examine the influence of rainfall variations on the effectiveness of eco-based flood mitigation efforts.

1.6 Significance of the Study

This study is significant because it extends to our understanding of how eco-friendly flood mitigation projects might improve urban resilience to flooding. By analysing the effectiveness of these projects in Sri Jayewardenepura Kotte, the study gives valuable information for establishing long-term urban flood management measures. The findings will be useful for policymakers, urban planners, and environmental professionals in Sri Lanka and other regions experiencing comparable difficulties, since they provide a paradigm for incorporating ecological solutions into urban development to effectively mitigate flood risk.

Literature Review

Flooding in urban areas such as Sri Jayewardenepura Kotte is becoming more common as a result of rapid urbanisation and changing land use patterns. To overcome these issues, several flood mitigation projects are being undertaken in such areas. This study seeks to investigate the association between changes in LULC and flood occurrences in Sri Jayewardenepura Kotte. This chapter examines existing theories and prior research findings relevant to this study, giving an overview for understanding the impact of LULC alterations on urban flooding.

2.1 LULC Change Detection Using GIS

Geographic Information Systems (GIS), Remote Sensing, and advanced spatial analysis techniques play a crucial role in detecting and analysing LULC changes, particularly concerning flood occurrences. The integration of remote sensing data with GIS allows for the creation of detailed maps that can illustrate the changes in LULC over time and their impact on flood risk. Studies have shown that changes in LULC, such as urbanisation and deforestation, significantly influence the hydrological characteristics of an area, thereby affecting the potential for flooding. For instance, in the Zăbala River catchment, the area with high or very high potential for surface runoff increased from 34% in 1989 to 46% in 2019, indicating a strong correlation between LULC changes and flood risk (Costache et al., 2020). The use of GIS-based methodologies has also been applied effectively in other regions, such as Gampaha in Sri Lanka, where evacuation plans were designed to minimise the risk during flash floods (Edirisinghe et al., 2021).

2.2 Impact of LULC Change on Flood Occurrences

LULC changes have a profound impact on flood dynamics, particularly in urban areas where impervious surfaces increase runoff and reduce infiltration. In the Sosiani River basin in Kenya, for example, urbanisation and deforestation were found to significantly increase the frequency of flash floods due to the resulting changes in land cover (Barasa & Perera, 2018). Similar studies in other regions, such as Spain and China, have highlighted the critical role of LULC changes in flood prediction and management. The findings from these studies emphasise the importance of incorporating LULC data into flood risk assessments to improve the accuracy of flood forecasting and the effectiveness of flood mitigation strategies (Jodar-Abellan et al., 2019; Zhai et al., 2021). Additionally, urban areas like Handan City, China, have seen significant impacts from LULC changes on the geographical distribution of urban floods, further underscoring the need for comprehensive urban planning and flood management (Liu et al., 2022).

2.3 Impact of Rainfall on Flooding

The relationship between rainfall and flooding is complex and influenced by various factors, including LULC changes. Accurate rainfall data is crucial for flood risk assessment and management, particularly in urban areas where spatial variability in rainfall intensity can significantly affect flood outcomes. Studies have employed methods like Monte Carlo simulations to account for uncertainties in rainfall data, revealing the importance of spatial variation in flood assessments(Lin et al., 2022). Understanding these dynamics is essential for developing robust flood management strategies that can adapt to changing rainfall patterns, especially in the context of climate change.

2.4 Interpolation Techniques

To analyse spatial rainfall data, various interpolation techniques are employed, with Inverse Distance Weighting (IDW) being one of the most widely used due to its simplicity and effectiveness in generating smooth spatial distributions. However, other techniques like Ordinary Kriging (OK) and Co-Kriging (CoK) have been found to provide more statistically accurate results, particularly in areas with strong spatial dependence or trends (Madurasinghe, 2022). The choice of interpolation method should be guided by the specific characteristics of the dataset and the research objectives. For instance, while IDW offers computational efficiency and localised pattern representation, OK and CoK offer improved accuracy in areas with complex spatial structures (Fung et al., 2022; Neha Pandey, 2016).

2.5 Landsat Image Processing

Landsat satellite imagery is a valuable tool for monitoring ecological and environmental changes, including LULC alterations. The preprocessing of Landsat data is critical for ensuring the accuracy and reliability of the resulting analyses. The workflows and decision trees outlined by Young et al. (2017) provide a comprehensive approach to preprocessing Landsat data, tailored to the specific needs of ecological and environmental studies. This is particularly relevant for urban flood studies, where accurate LULC data is essential for assessing the impact of urbanisation on flood risk.

The insights gained from these studies are directly applicable to the proposed research on the impact of LULC changes on urban flooding in Sri Jayewardenepura Kotte. By leveraging GIS, remote sensing, and advanced spatial analysis techniques, this study aims to build on existing research to provide a comprehensive understanding of how changing urban landscapes influence flooding patterns in Sri Jayewardenepura Kotte. The findings of this research will not only contribute to the academic discourse on urban flood resilience but also offer practical solutions for sustainable urban planning and disaster management in the region.

Methodology

3.1 Study Area and Workflow

The study area serves as the administrative capital of Sri Lanka and lies within the Colombo district of the Western Province. It experiences a tropical climate characterised by high temperatures and significant rainfall throughout the year. The area's rapid urbanisation and ongoing land use changes have heightened its vulnerability to urban flooding, making it an ideal subject for examining the effects of eco-based flood mitigation projects.

This chapter outlines the methodology used to analyse the relationship between LULC changes, influenced by eco-based flood mitigation projects, and urban flooding in Sri Jayewardenepura Kotte. The analysis involved a series of systematic steps to collect, process, and interpret data using GIS technology and remote sensing techniques.

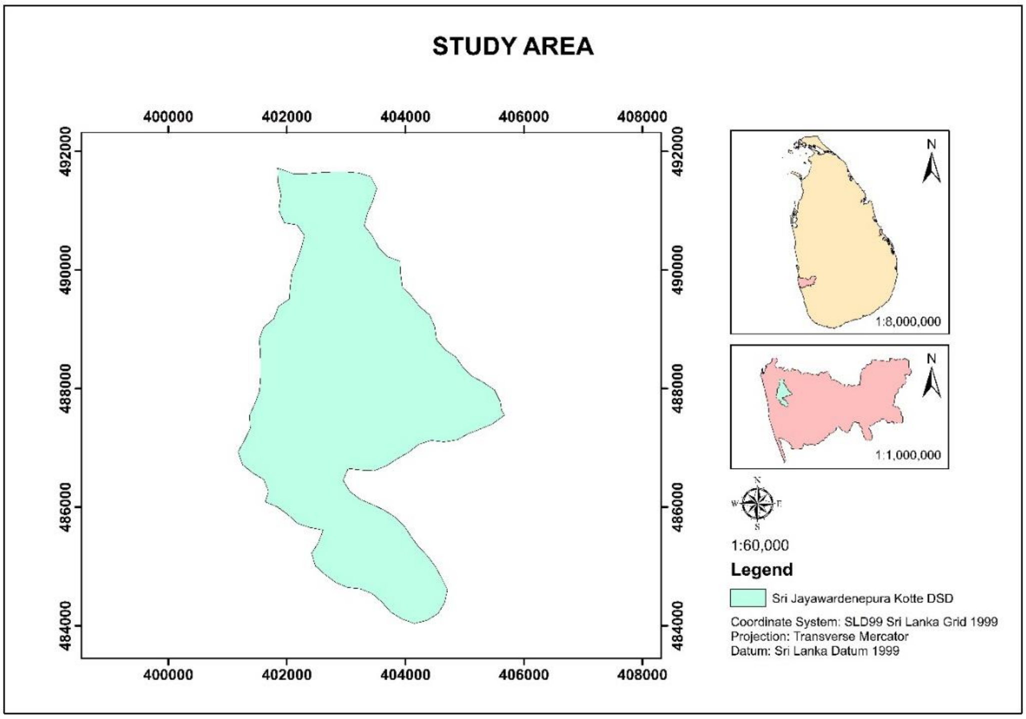

Figure 1: Study Area Map

Figure 1 shows the study area, while Figure 2 provides a workflow diagram of the study process, ensuring clarity and comprehensiveness in the investigation.

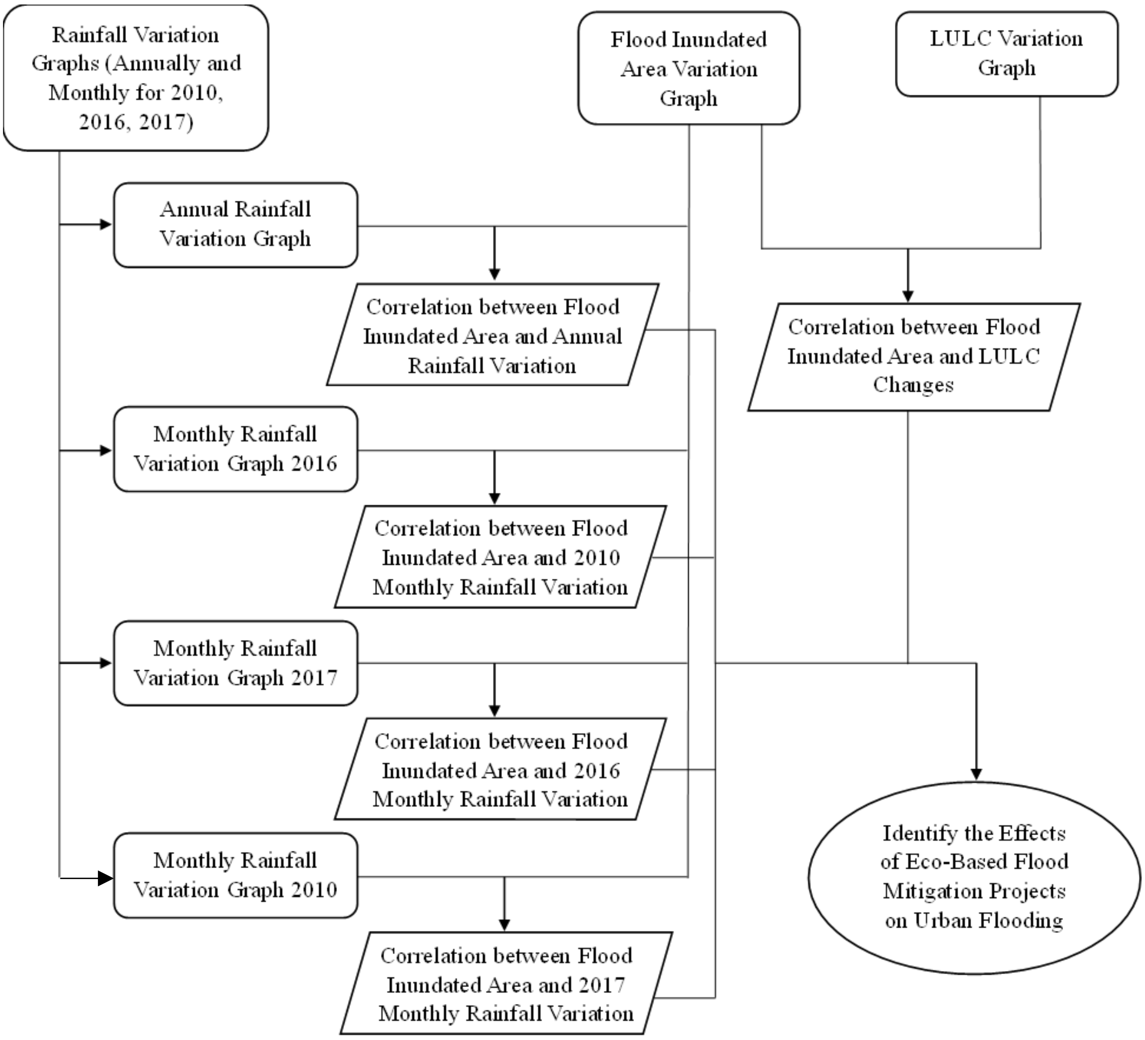

Figure 2: Workflow of the Study

3.2 Data Collection

3.2.1 Satellite Imagery Acquisition and Preprocessing

For the LULC analysis, Landsat satellite images were obtained for the years 2009 to 2022. Landsat 5, 7, and 8 images were used to ensure temporal continuity and comprehensive coverage of the study period. The satellite images underwent preprocessing steps to enhance their quality and reliability:

- Radiometric Calibration: The raw Digital Numbers (DN) from the satellite images were converted into radiance and reflectance values using calibration coefficients specific to each Landsat sensor.
- Atmospheric Correction: This step corrected for atmospheric disturbances such as aerosols, water vapor, and ozone, which can affect the quality of the imagery.
- Geometric Correction: Applied to align the satellite images with the Earth's surface accurately, ensuring that the imagery could be reliably used for spatial analysis.

The preprocessing steps were crucial to obtaining accurate LULC classifications and were conducted using ENVI and ArcGIS software.

3.2.2 LULC Classification and Accuracy Assessment

Supervised classification was performed on the pre-processed Landsat images using representative training samples from various land cover classes, such as built-up areas, vegetation, water bodies, and wetlands. The classification process utilized the Maximum Likelihood Classification (MLC) algorithm, which considers the statistical probability of each pixel belonging to a particular land cover class.

To validate the accuracy of the LULC maps, an accuracy assessment was conducted using Google Earth images and ground-truth data. Accuracy metrics such as overall accuracy, producer's accuracy, user’s accuracy, and the kappa coefficient were calculated using the confusion matrix tool in ArcGIS. These metrics provided a quantitative measure of the reliability of the LULC classifications.

3.3 Rainfall Analysis

Monthly and annual rainfall data were collected from the Sri Lanka Meteorological Department for the study period (2008–2022). The data was arranged in Excel and analysed using the IDW interpolation technique to assess spatial and temporal rainfall patterns across the study area. For the IDW analysis, rainfall data from meteorological stations across Sri Jayewardenepura Kotte was interpolated to generate continuous surfaces, representing rainfall distribution. This method assigns higher weights to data points that are closer to each other, creating a more accurate representation of rainfall across the study area.

Monthly rainfall data corresponding to major flood events was also analysed to understand the precipitation patterns leading up to and during these flood events. Line graphs were created to visualise the rainfall patterns at various random points within the study area, allowing for a detailed comparison of rainfall intensity and distribution during flood events. Figure 3 shows the randomly generated points created for data analysis and the meteorological stations utilised for the study for rainfall interpolation.

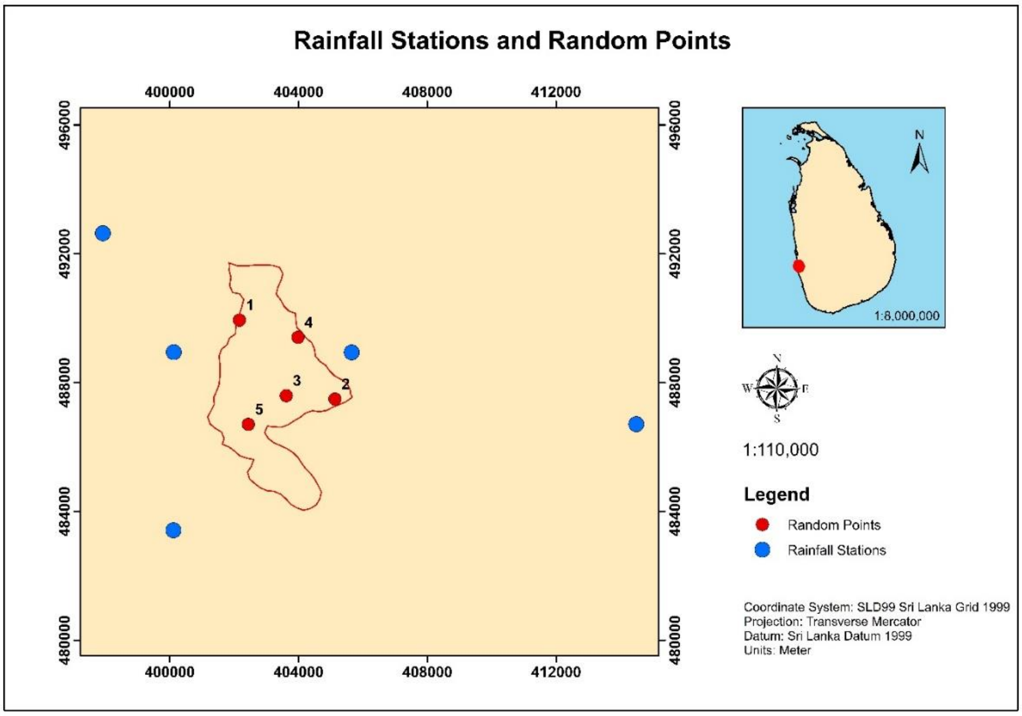

Figure 3: Rainfall Stations and Random Points

3.4 Flood Inundation Area Analysis

Flood inundation maps for significant flood events (2010/05, 2010/11, 2016/05, and 2017/05) were obtained from the Land Reclamation and Development Corporation. These maps were used to simulate the impact of LULC changes on flood occurrences in the Sri Jayewardenepura Kotte area. The inundated areas were digitised and measured using ArcGIS software to determine the extent of flooding during each event. The areas were then plotted on bar graphs, with flood occurrences on the x-axis and inundated areas on the y-axis, allowing for a comparative analysis of the spatial extent of flooding across different events.

3.5 Eco-based Flood Mitigation Projects Analysis

Data on various interventions undertaken in the study area were gathered to evaluate the efficacy of eco-based flood mitigation efforts. These initiatives include creating wetlands, restoring natural waterways, and afforestation efforts. GIS was used to map the projects' locations and spatial extent, and its effects on LULC changes and flood occurrences were examined. The study employed a correlation analysis to explore the relationship between the areas influenced by eco-based projects and the frequency, extent, and volume of flooding. The analysis aimed to identify the effectiveness of these interventions in reducing flood risks in Sri Jayewardenepura Kotte.

3.6 Temporal Analysis of Rainfall and Flood Patterns

A temporal analysis of rainfall variations and their correlation with major flood events was conducted. The analysis explored the frequency and intensity of flooding events in relation to changes in precipitation patterns over the years. This helped in understanding the temporal dynamics of flooding in Sri Jayewardenepura Kotte and the role of changing rainfall patterns influenced by climate variability.

The final step involved visualising the findings through maps, tables, and graphs. LULC maps, rainfall distribution maps, and flood inundation maps were created to illustrate the spatial and temporal patterns observed in the study. These visualisations, along with tables and figures, provided a comprehensive representation of the study's outcomes, supporting the analysis of the impact of eco-based flood mitigation projects on urban flooding in Sri Jayewardenepura Kotte.

Results and Discussion

The chapter presents the findings and analysis of the study, which includes LULC maps from 2009 to 2018, flood inundation maps for significant flood events in 2010, 2016, and 2017, as well as annual rainfall maps covering the period from 2008 to 2022, and monthly rainfall maps for the years 2010, 2016, and 2017. In addition, the chapter includes relevant graphs illustrating correlations between the variables as well as variations in rainfall, fluctuations in flood patterns, and variations in LULC.

4.1 LULC Changes

The study involved the generation of LULC maps spanning the years 2009 to 2018, as shown in Figures 4 to 13. These maps provide a detailed depiction of the changing land use and land cover patterns over time.

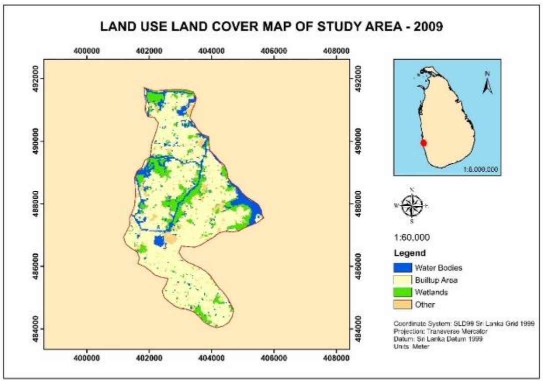

Figure 4: Land Use Land Cover Map of Study Area 2009

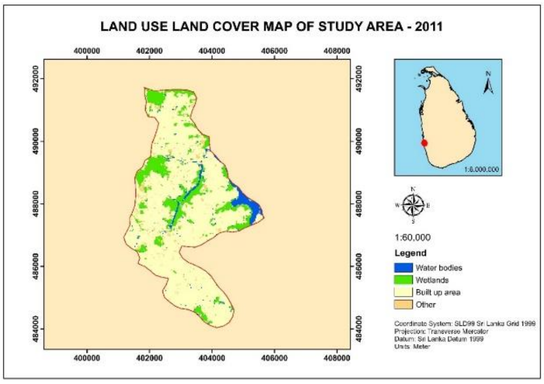

Figure 6: Land Use Land Cover Map of Study Area 2011

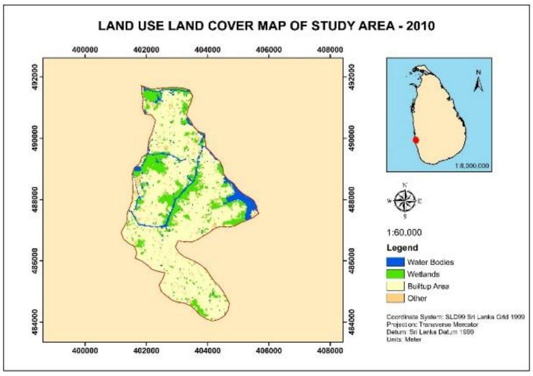

Figure 5: Land Use Land Cover Map of Study Area 2010

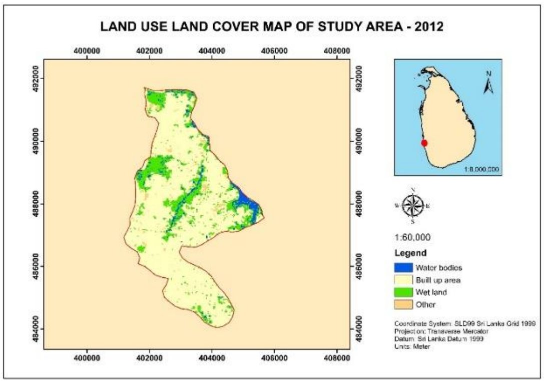

Figure 7: Land Use Land Cover Map of Study Area 2012

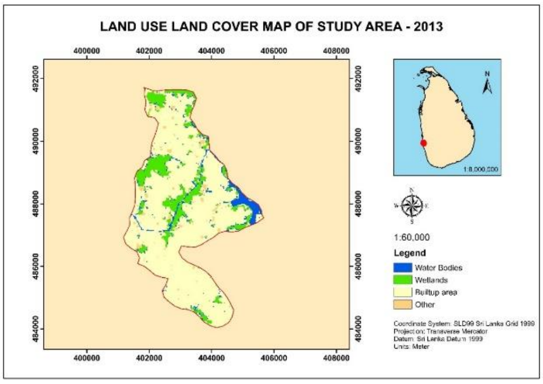

Figure 8: Land Use Land Cover Map of Study Area 2013

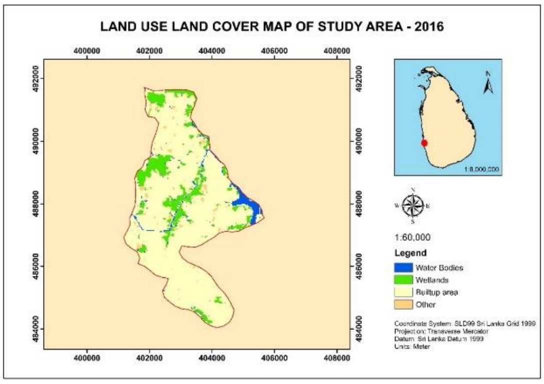

Figure 11: Land Use Land Cover Map of Study Area 2016

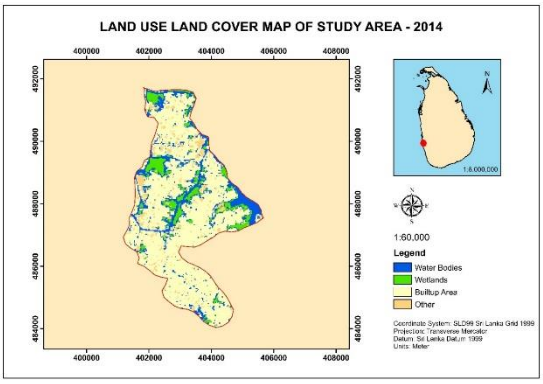

Figure 9: Land Use Land Cover Map of Study Area 2014

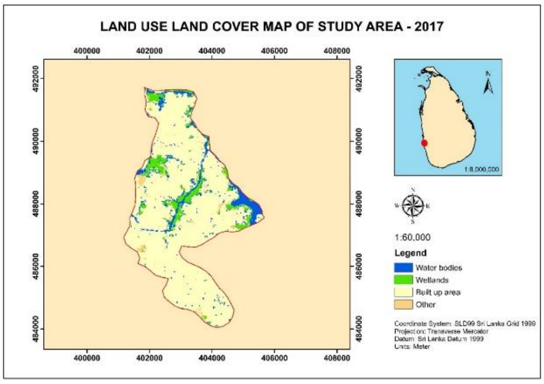

Figure 12: Land Use Land Cover Map of Study Area 2017

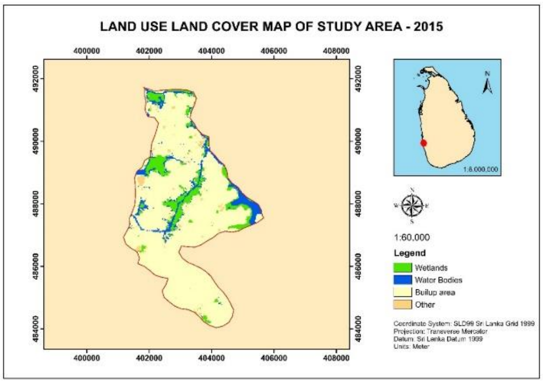

Figure 10: Land Use Land Cover Map of Study Area 2015

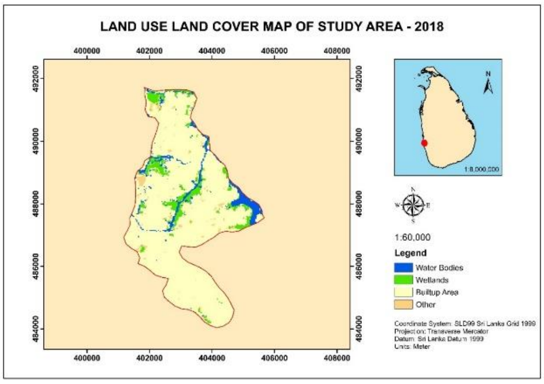

Figure 13: Land Use Land Cover Map of Study Area 2018

The data used to create these maps were derived from Landsat 5 and Landsat 8 satellite imagery. The methodology employed included a supervised classification process utilising ArcGIS software.

To ensure the accuracy and reliability of the LULC maps, an accuracy assessment was conducted. This assessment involved with the ArcGIS tools, Google Earth imagery, and existing LULC maps to validate the classification results. This validation process confirmed that the generated maps accurately reflect the actual land cover in the study area. The temporal scope of these maps allowed for a thorough analysis of the dynamic changes in land cover patterns and transitions over the ten years.

By analysing the LULC maps, the study aimed to identify the distribution and composition of different land cover classes within the study area. This analytical approach enabled the assessment of spatial extent and change trends associated with various land use types. The insights gained from these LULC maps form the foundation for the subsequent in-depth analysis and interpretation.

Within the Sri Jayewardenepura Kotte DSD, the dynamic changes in land use and land cover are visually represented by the graph showing the fluctuations in LULC from 2009 to 2018. The graph was created by plotting the area (in square kilometres) of each LULC class on the y-axis against the corresponding years on the x-axis. The data for this graph were obtained from satellite imagery through a maximum likelihood supervised classification and analysis process.

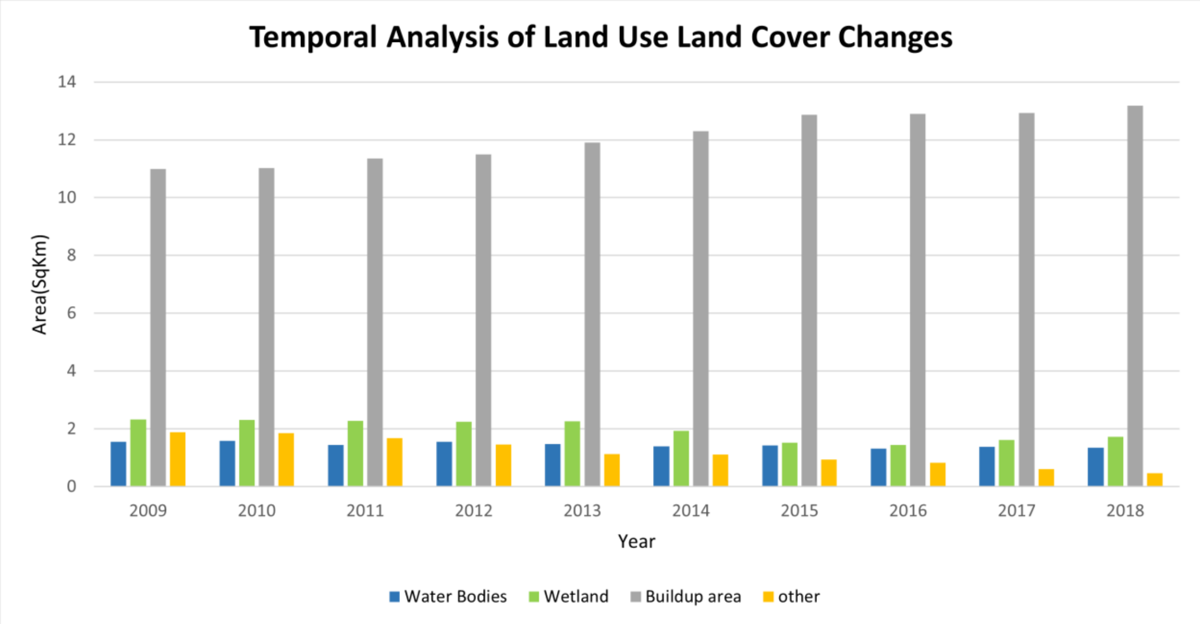

Figure 14: Temporal Analysis of Land Use Land Cover Changes

Analysing the data reveals significant trends, particularly in the built-up area within the specified timeframe. Notably, the period between 2010 and 2015 experienced a rapid increase in the extent of the built-up area, indicating substantial urban development or expansion. This surge may reflect increased infrastructure, and residential, or commercial developments during this time, contributing to the area's urbanisation. In contrast, the coverage of wetlands and water bodies during this period shows a different pattern. Until 2015, there was a notable decrease in these land uses, suggesting potential alterations in environmental features such as drainage systems or land reclamation efforts. However, post-2015, there appears to be a recovery or stabilisation in wetland coverage and water bodies, possibly reflecting the impact of eco-based flood mitigation projects or other conservation efforts.

Additionally, the graph highlights the behaviour of other land use categories, such as barren lands, which show a consistent reduction over the specified timeframe. This decline in barren lands could be attributed to factors such as land reclamation, reforestation efforts, or changes in land management practices. These insights into LULC variations are crucial for understanding the impacts of land use changes on urban flooding and the environment. Moreover, they provide valuable information for making informed decisions in urban planning and flood management. The detailed analysis of these LULC dynamics unravels a complex interplay of urbanization, environmental changes, and land use practices, offering essential insights into the evolving landscape of the study area. The graph serves as a valuable tool for conveying these temporal changes, supporting the analysis and interpretation of the research findings.

4.2 Annual Rainfall Variations

This section presents the annual rainfall variations across the Sri Jayawardenepura Kotte DSD from 2008 to 2022, offering a detailed illustration of rainfall patterns over these 15 years. The rainfall data, sourced from the Meteorological Department, ensure accuracy and reliability. Geospatial analysis was conducted using advanced techniques to capture both the spatial distribution and temporal variations of rainfall across the study area. To achieve this, the IDW interpolation technique was employed, which allowed for the creation of continuous surfaces representing rainfall distribution across the study area. The resulting annual rainfall maps serve as critical tools, providing insights into the nuanced variations in rainfall over the specified period.

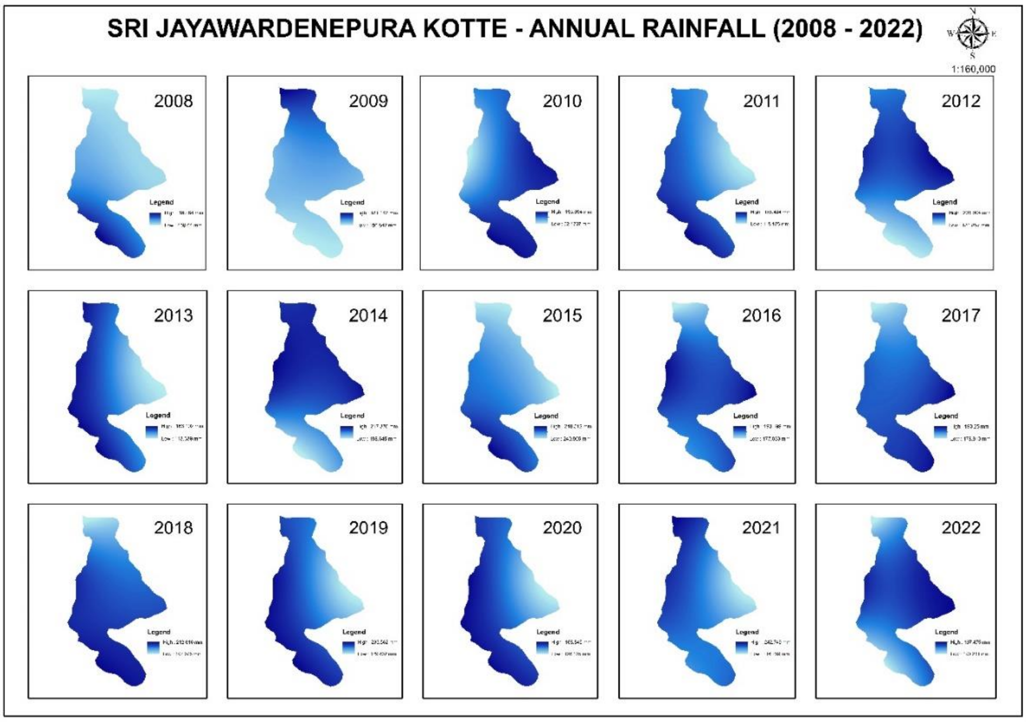

Figure 15: Annual Rainfall Map from 2008 to 2022

The detailed examination of these maps facilitated the identification of areas with both high and low rainfall, allowing for the analysis of trends within the study area. Understanding these spatial and temporal dynamics of rainfall is essential for unravelling the relationship between rainfall patterns and flood occurrences in the region. The findings derived from this analysis underscore the importance of rainfall patterns in influencing urban flooding events. Figure 15 illustrates the annual rainfall variations for the years 2008 to 2022, providing a comprehensive overview of precipitation patterns within the study area. The graph plots annual rainfall values in millimetres on the y-axis against the corresponding years on the x-axis. The data for this graph were obtained from reliable meteorological records, including rain gauge measurements. By examining the graph, the interannual variability in precipitation becomes evident, highlighting any notable trends or anomalies.

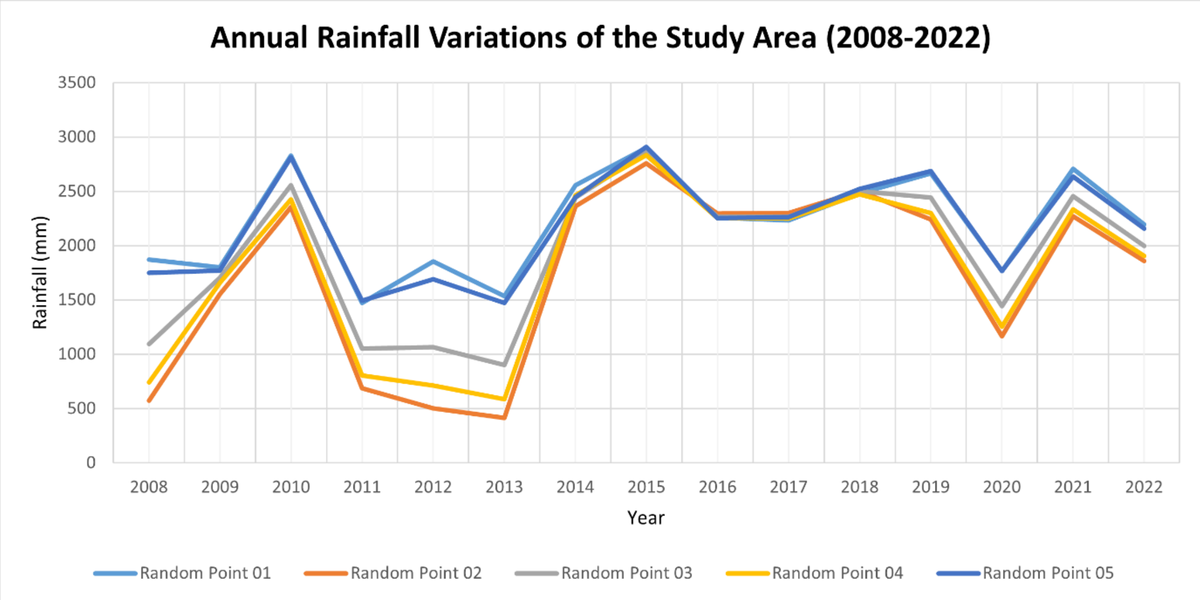

Figure 16: Annual Rainfall Variation of Study Area

Figure 16 provides a visualization of annual rainfall patterns, revealing significant increases in the years 2010, 2015, 2016, 2017, 2018, 2019, and 2021. These peaks indicate a substantial increase in rainfall during these specific years, which has critical implications for the hydrological dynamics of the area. The correlation between elevated rainfall in these years and major flood events, particularly in 2010, 2016, and 2017, is noteworthy. This correlation underscores the vital relationship between rainfall patterns and flood occurrences, offering key insights into the climatic factors that influence flood events in the region.

4.3 Monthly Rainfall Variations of 2010, 2016, and 2017

The study closely examined the monthly rainfall patterns during the years 2010, 2016, and 2017, all of which were marked by significant flood events within the Sri Jayawardenepura Kotte DSD. The rainfall data for these critical years were meticulously sourced from the

Meteorological Department to ensure precision and reliability. A detailed analysis of the monthly rainfall data was conducted, integrating geospatial techniques to generate spatially explicit rainfall maps for each month.

These maps provided a clear illustration of the distribution and intensity of rainfall monthly, offering a comprehensive understanding of the patterns that contributed to significant flood events. Through this examination, it was possible to identify periods characterised by heavy rainfall, determine temporal variations in rainfall intensity, and evaluate the potential correlation between these patterns and the occurrence of major floods in the study area. The importance of these monthly rainfall maps lies in their role as valuable tools for assessing climatic conditions leading up to and during flood events. Their spatially explicit nature contributes crucial insights for flood forecasting, mitigation, and management strategies within the study area. By unravelling the details of rainfall variations on a monthly scale, this analysis enhances the understanding of climatic factors influencing major flood occurrences and supports more effective flood management approaches.

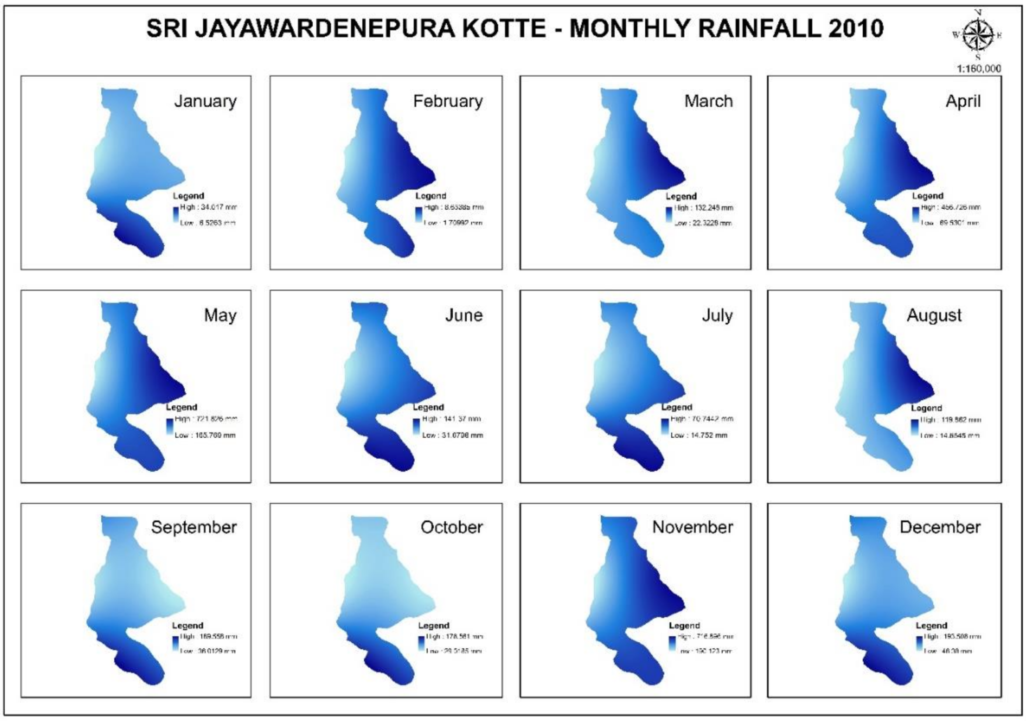

Figure 17: Monthly Rainfall Map of Study Area in 2010

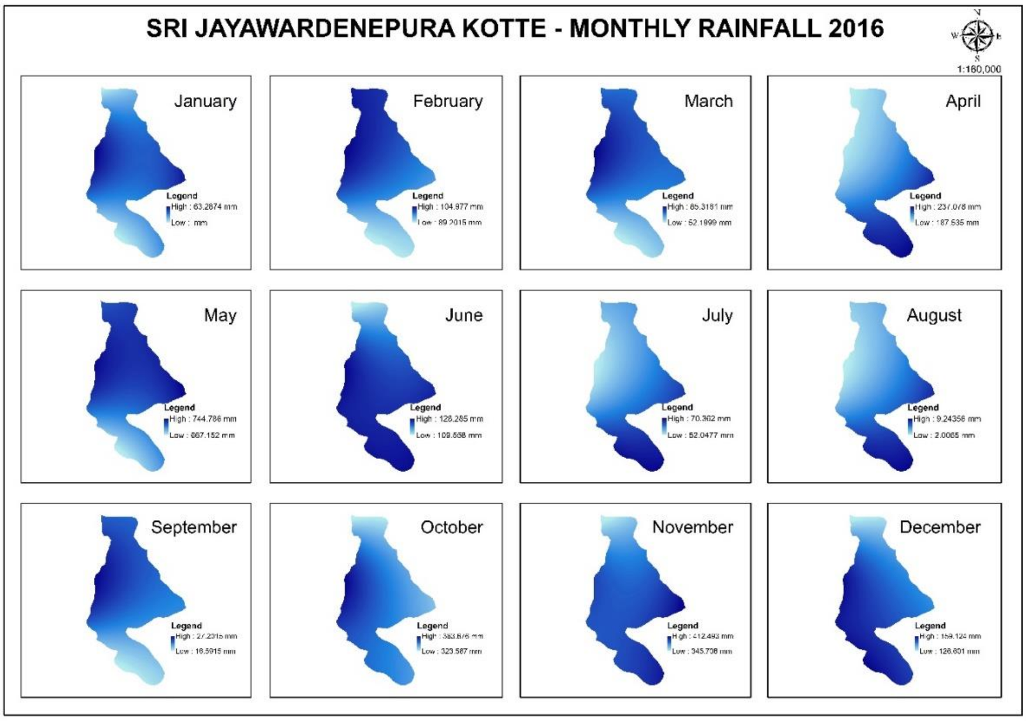

Figure 18: Monthly Rainfall Map of Study Area in 2016

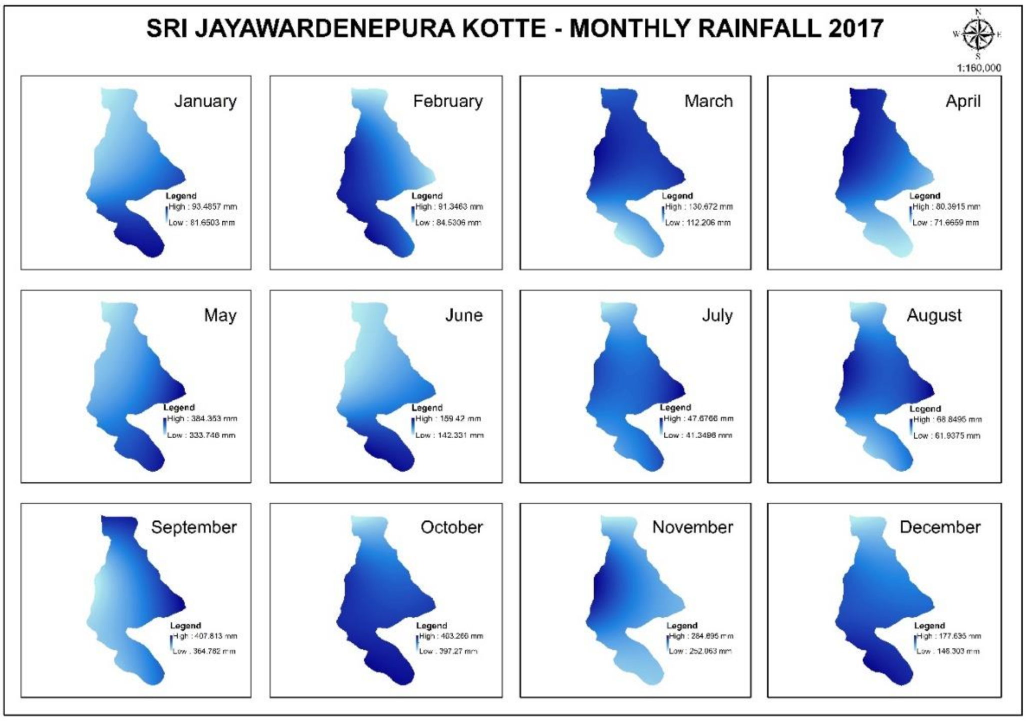

Figure 19: Monthly Rainfall Map of Study Area in 2017

Figures 17, 18, and 19 illustrate the variations in monthly rainfall for the years when major floods occurred, providing valuable insights into the rainfall patterns associated with these flood events. These graphs were generated by plotting the monthly rainfall values in millimetres on the y-axis against the corresponding months on the x-axis. The data used to construct these graphs were derived from reliable meteorological records within the study area.

By examining these graphs, it becomes evident how the monthly rainfall varied during the periods leading up to and during significant flood events. The distribution of rainfall across different months is showcased, allowing for the identification of months with particularly heavy rainfall that may have contributed to the floods. This visual representation aids in interpreting the temporal variations in rainfall, providing crucial information for understanding the meteorological factors that influenced these flood events.

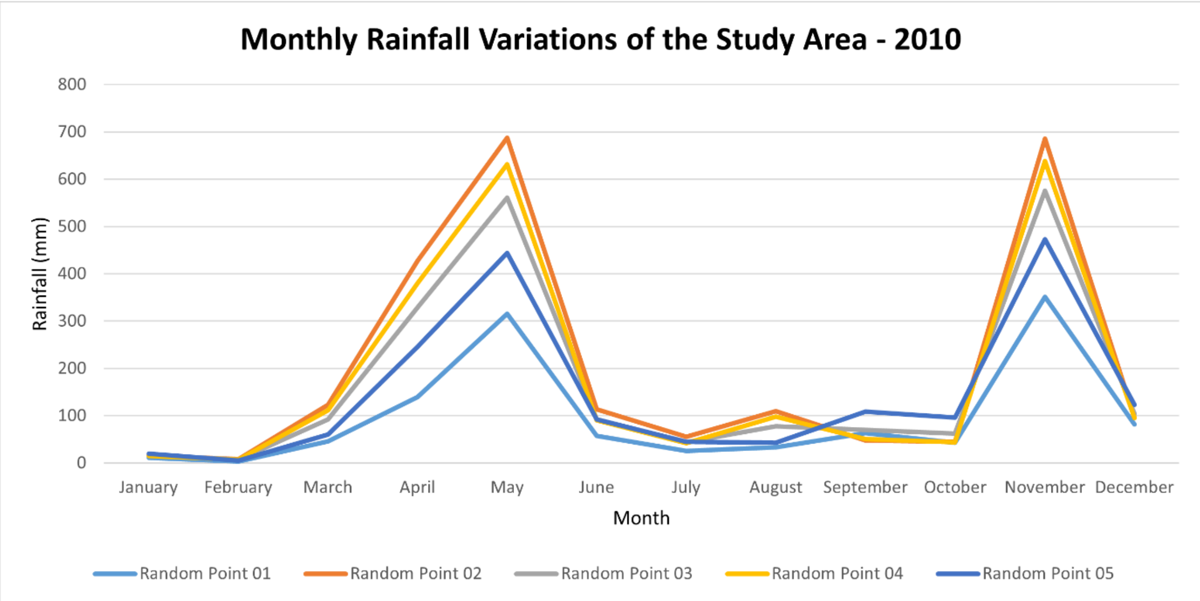

Figure 20: Monthly Rainfall Variation of the Study Area in 2010

Figure 20 visualises the monthly rainfall variation in 2010, highlighting distinct increases in May and November, where there was a rapid rise in rainfall compared to other months.

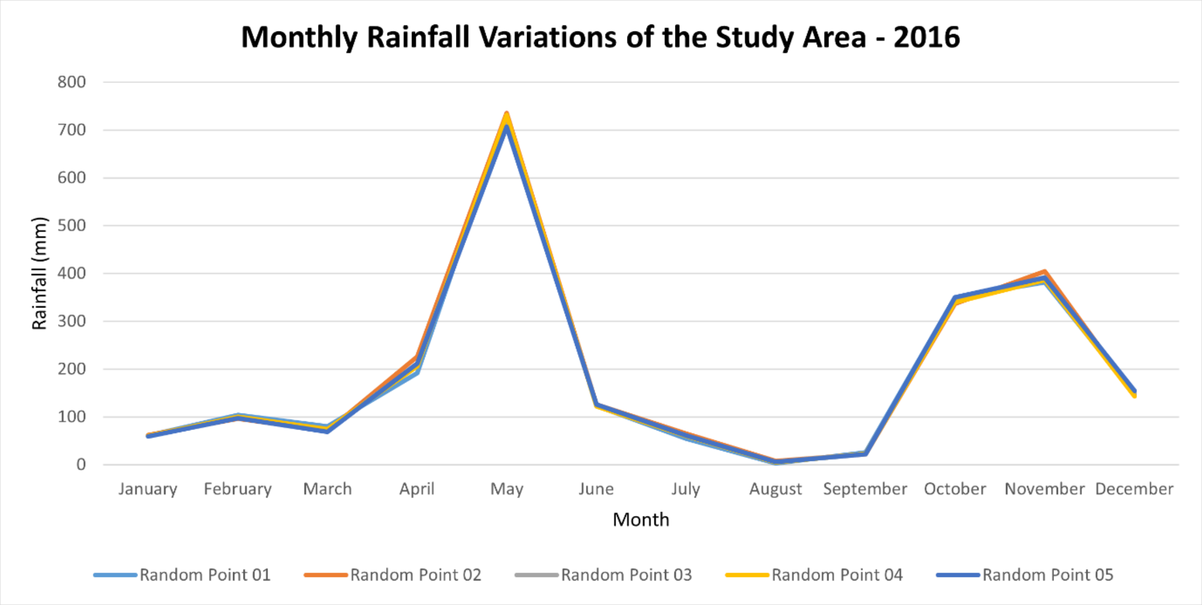

Figure 21: Monthly Rainfall Variation of the Study Area in 2016

Figure 21 shows a significant increase in rainfall in May 2016, with additional slight increases observed in October and November.

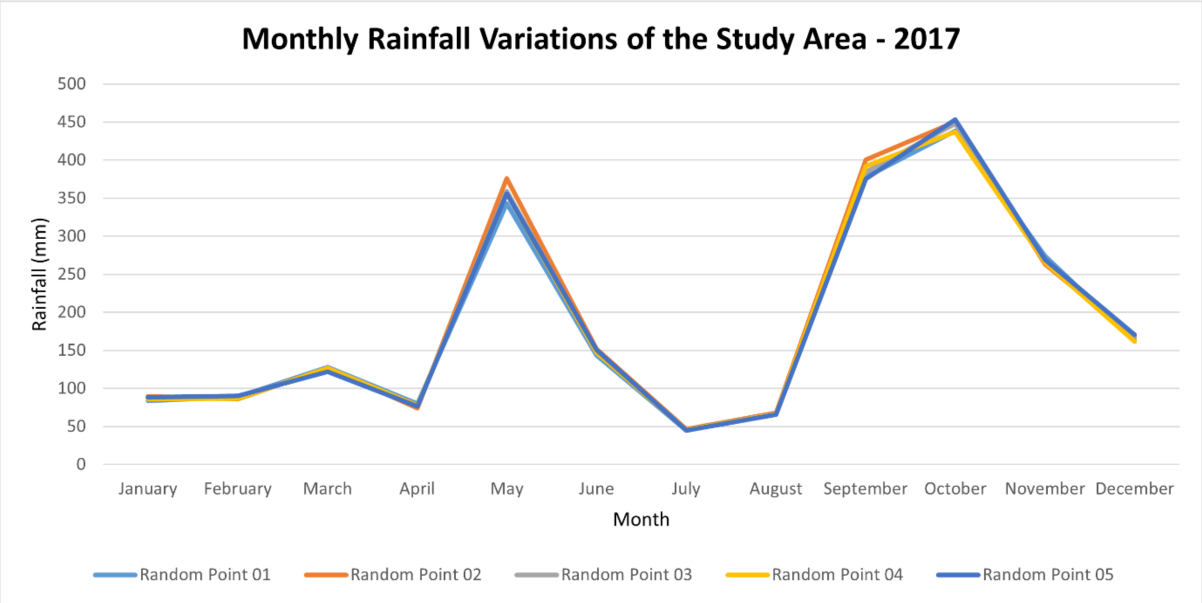

Figure 22: Monthly Rainfall Variation of the Study Area in 2017

Figure 22 displays the monthly rainfall variation for 2017, revealing significant increases in May, September, and November compared to other months.

These insights into the monthly rainfall variations during flood events contribute to a better understanding of the meteorological factors influencing flood occurrences and support the analysis and interpretation of the research findings.

4.4 Variations of Flood Inundation Area

Flood inundation maps for significant flood events within the Sri Jayawardenepura Kotte DSD, as shown in Figures 23 to 26, were meticulously generated to provide a detailed understanding of the extent and spatial distribution of flooding during these events. These maps, obtained from the Land Reclamation Department, serve as invaluable resources for analysing the comprehensive spread of floodwaters across the study area. The methodology involved a thorough process of analysing flood extents, offering a precise visualisation of flood patterns. These maps play a crucial role in identifying areas prone to inundation, thereby facilitating targeted flood risk assessments and the development of effective flood management strategies. The spatially explicit nature of these flood inundation maps makes them essential tools for informed decision-making, particularly in the realms of flood forecasting, mitigation, and overall flood management within the study area.

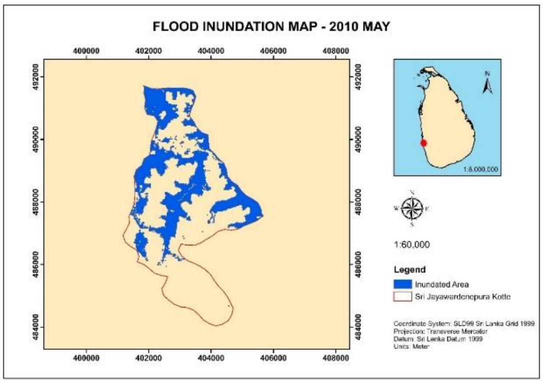

Figure 23: Flood Inundated Area of the Study Area - 2010 May

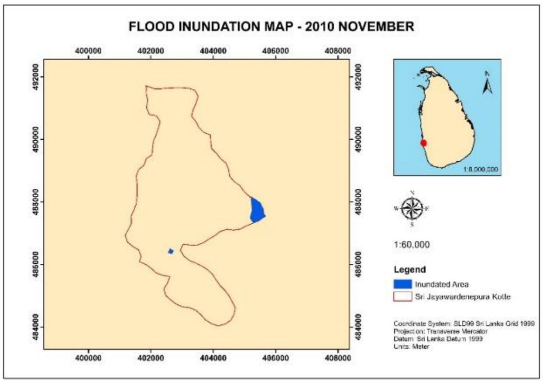

Figure 24: Flood Inundated Area of the Study Area - 2010 November

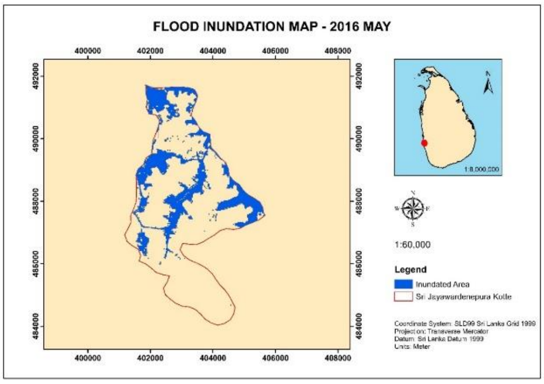

Figure 25: Flood Inundated Area of the Study Area - 2016 May

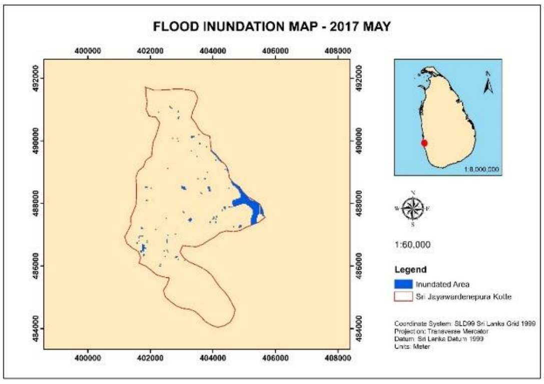

Figure 26: Flood Inundated Area of the Study Area - 2017 Ma

Figure 27 provides a comprehensive visualisation of the variations in flood inundation areas over time. The graph, created by plotting the inundation area in square kilometres on the y-axis against the dates of major flood events on the x-axis, clearly illustrates the temporal fluctuations in flood extent within the study area. The data used to generate this graph were obtained from the flood inundation maps provided by the Land Reclamation Department.

By examining the graph, it becomes evident how the extent of flood inundation varied over time, with certain years experiencing more extensive flooding than others. These variations offer valuable insights into the evolving flood patterns and the potential factors influencing these changes, such as rainfall intensity, land use modifications, or developments in hydraulic infrastructure. The graph serves as a visual representation of flood variations within the study area, supporting a deeper understanding of flood behaviour during major events.

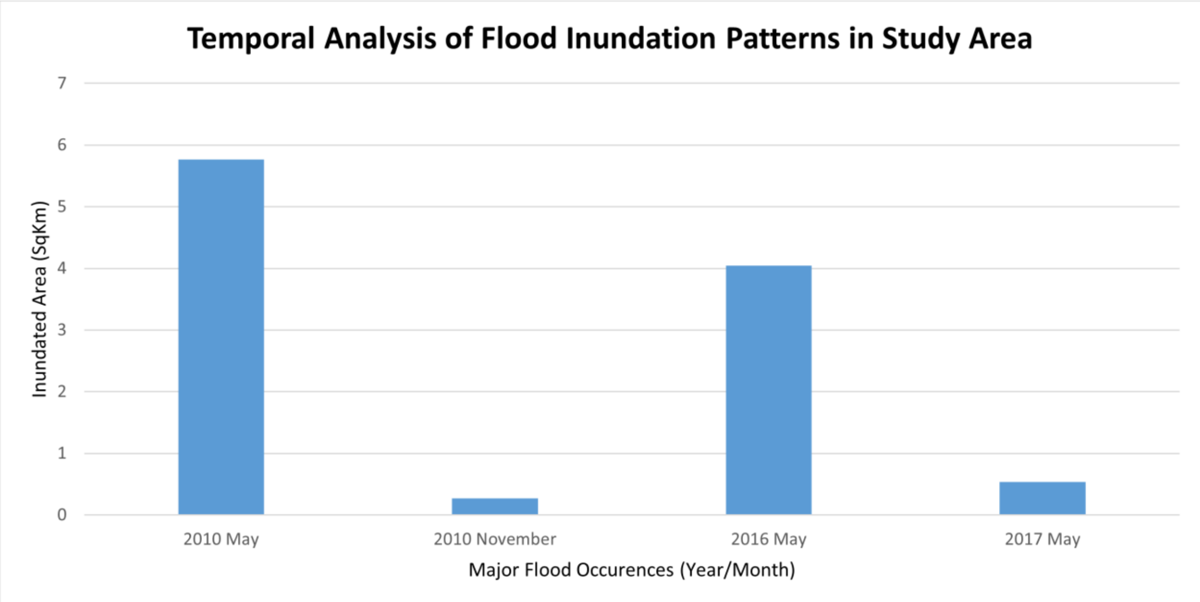

Figure 27: Temporal Analysis of Flood Inundation Patterns

Table 1: Flood Inundation Area of Major Flood Occurrences

Flood Occurrence	**Flooded Inundated Area (Sq Km)**
2010 May	5.762287
2010 November	0.268007
2016 May	4.046631
2017 May	0.535979

According to Figure 27 and Table 1, significant flood events occurred in May 2010, November 2010, May 2016, and May 2017. The floods in May 2010 and May 2016 had larger inundated areas compared to the other events. Specifically, the May 2010 flood covered an area of 5.76 square kilometres, while the May 2016 flood inundated 4.04 square kilometres. In contrast, the November 2010 and May 2017 floods resulted in much smaller inundation areas, each covering less than 1 square kilometre. These findings underscore the varying impact of flood events over time and provide critical insights into the factors contributing to these differences in flood extent.

4.5 Correlation Between Annual Rainfall and Flood Inundation Area

Figure 28 analyses the relationship between annual rainfall and the extent of flood inundation within the Sri Jayawardenepura Kotte DSD. By displaying yearly rainfall data concerning the corresponding flood-inundated areas, the graph visually represents the correlation between these two variables. This analysis provides insights into how variations in annual rainfall influence urban flooding, identifying years with high rainfall that correspond to significant flood events.

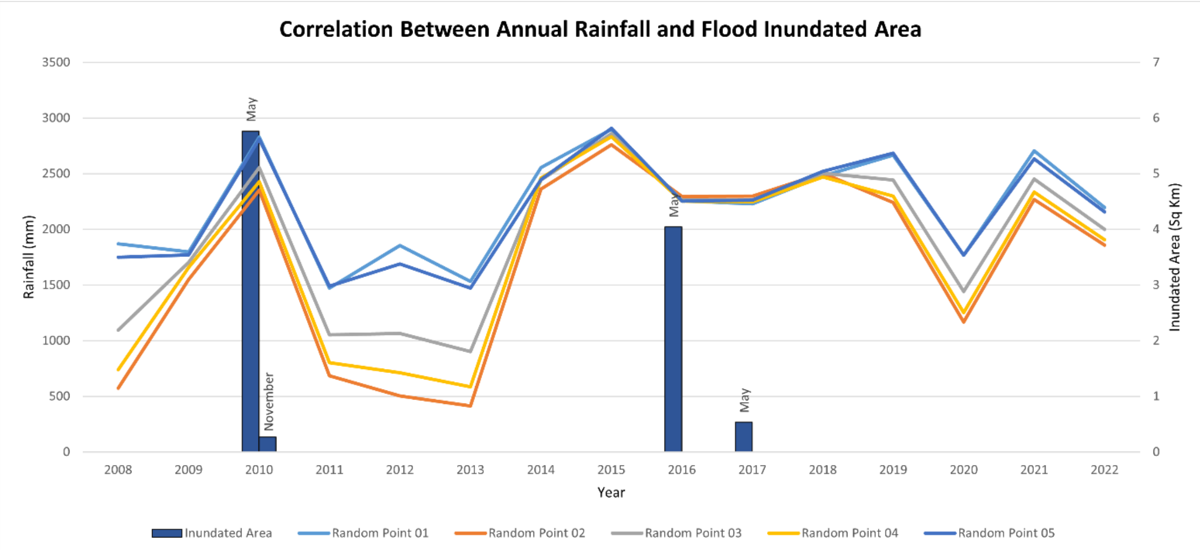

Figure 28: Correlation Between Annual Rainfall and Flood Inundated Area

The graph highlights a noticeable increase in flood inundation in 2010, which coincides with a substantial rise in annual rainfall, establishing a clear correlation between heightened rainfall and increased flooding. Similarly, significant floods in 2016 and 2017 are linked to increased rainfall. Additionally, notable increases in rainfall were observed in 2014, 2015, 2019, and 2021. An intriguing observation is the comparison between 2016 and 2017. Despite similar increases in rainfall during these years, the extent of flooding in 2016 was greater than in 2017. This suggests that factors beyond rainfall volume, such as land use changes, topographical variations, or drainage infrastructure, may contribute to differences in flood extent. Further exploration of these factors could help explain the observed variations.

4.6 Correlation Between Monthly Rainfall and Flood Inundation Area

The correlation between monthly rainfall patterns and flood inundation during the years 2010, 2016, and 2017 is examined through the graphs presented in Figure 29. By comparing monthly rainfall data with the corresponding flood-inundated areas, these graphs aim to identify consistent patterns or trends that may have influenced the extent of flooding. The findings reveal an increase in precipitation during May and November, with November showing slightly higher rainfall than May. However, despite the higher rainfall in November, the flood inundation area in May is considerably larger. This discrepancy suggests that factors other than rainfall volume might influence flood extent.

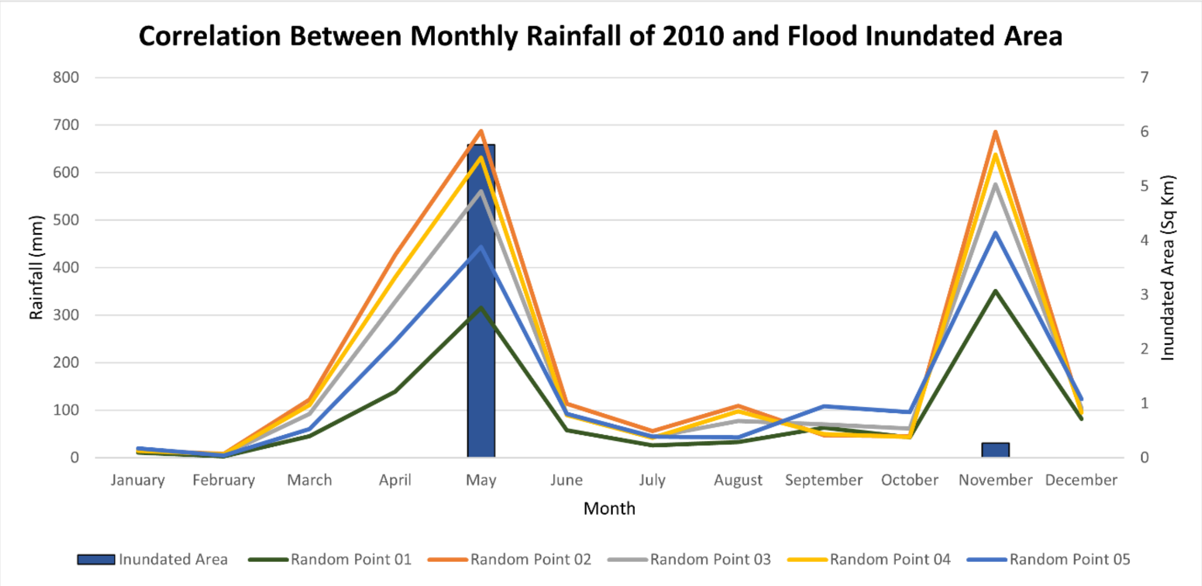

Figure 29: Correlation Between Monthly Rainfall of 2010 and Flood Inundated Area

Figure 30 shows that May experienced a significant increase in rainfall compared to other months in 2016, corresponding to a major flood in the study area. Although October and November also had higher rainfall values, there were no flood events during these months in 2016.

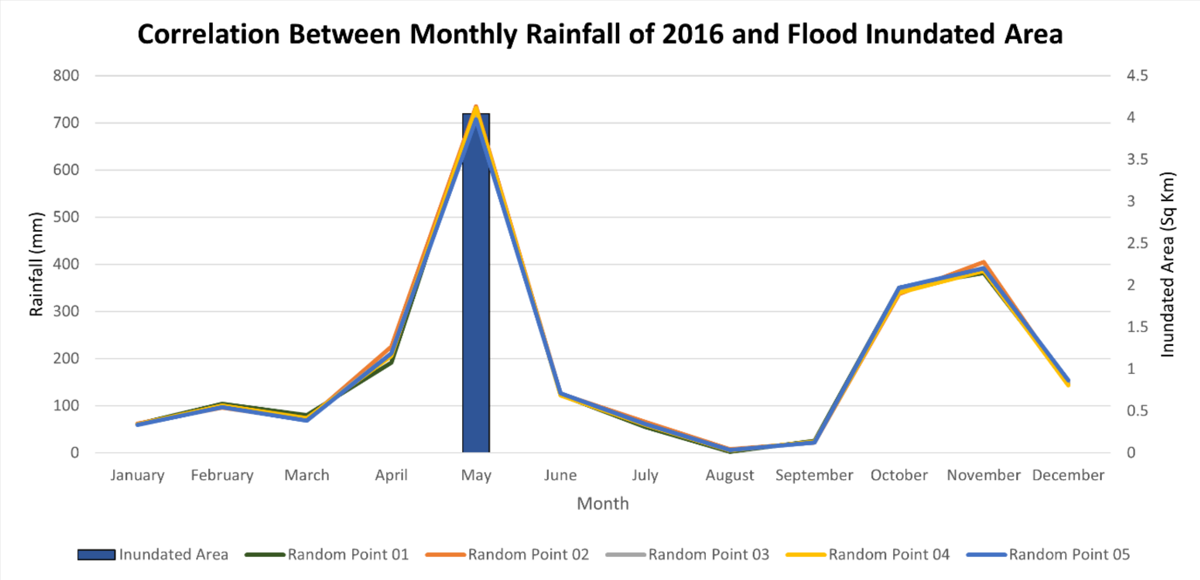

Figure 30: Correlation Between Monthly Rainfall of 2016 and Flood Inundated Area

According to Figure 31, May, September, and October had higher rainfall than other months in 2017, but only May saw a flood event in the study area. Notably, rainfall in September and October was higher than in May, yet flooding occurred only in May. This suggests that other factors besides rainfall might play a role in determining flood occurrence.

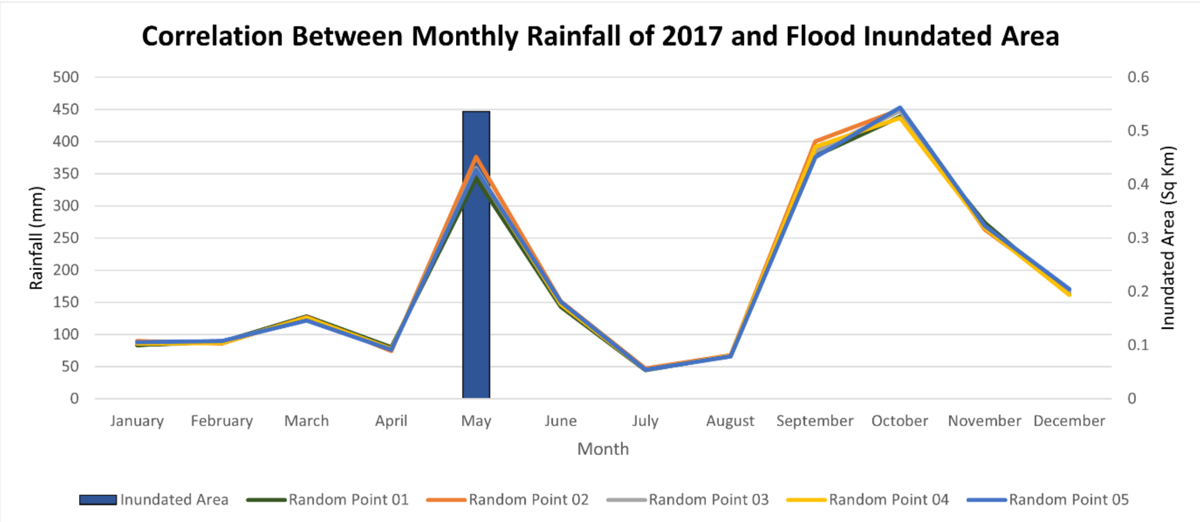

Figure 31: Correlation Between Monthly Rainfall of 2017 and Flood Inundated Area

4.7 Correlation Between LULC and Flood Inundation Area

Figure 32 explores the relationship between LULC changes and flood inundation extent in the study area. By plotting different LULC categories against the corresponding flood-inundated areas, the graph reveals how variations in land cover types influence urban flooding. This analysis provides insights into which LULC types contribute to or mitigate flooding, helping to identify vulnerable areas and inform strategies for flood risk reduction and urban planning.

The graph illustrates key trends in LULC over time, notably the consistent increase in built-up areas, indicative of urban expansion and infrastructure development, leading to more impervious surfaces. Simultaneously, a marked decrease in wetland areas highlights the impact of urbanisation on natural ecosystems. After 2016, a notable reversal in the decline of wetlands was observed, possibly reflecting environmental conservation efforts or natural regrowth processes. Fluctuations in water bodies and other land use areas further contribute to the dynamic LULC changes depicted in Figure 32. These trends underscore the delicate balance between urban development and ecological preservation. A deeper understanding of the drivers behind these LULC variations, such as urban planning policies, infrastructure projects, and environmental conservation programs, is crucial for comprehensive flood management.

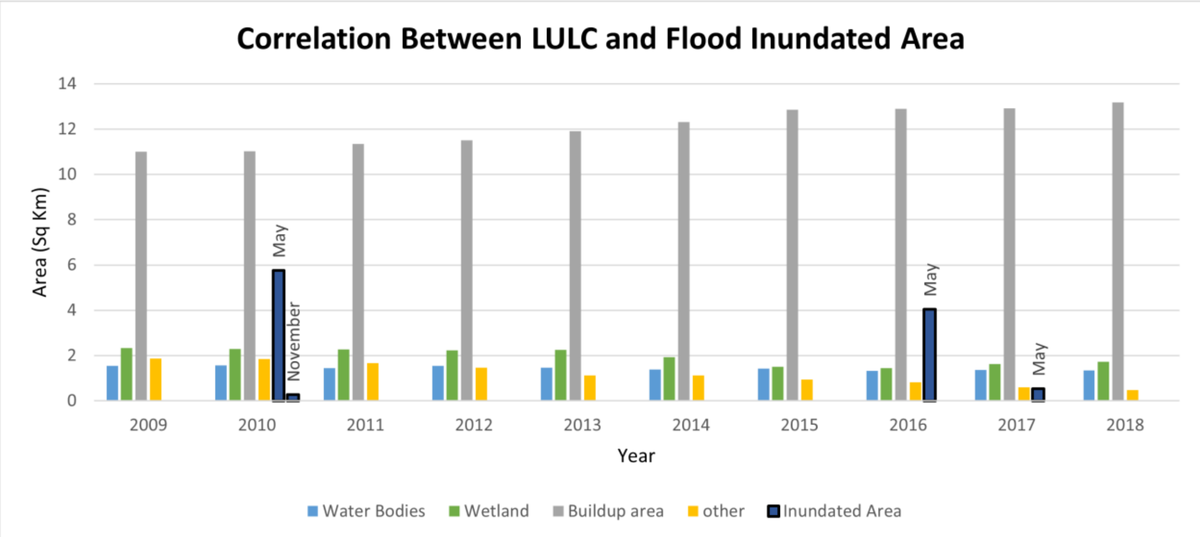

Figure 32: Correlation Between LULC and Flood Inundated Area

Conclusion and Recommendation

In this concluding chapter, we reflect on the key findings and insights derived from the comprehensive analysis of eco-based flood mitigation projects in relation to urban flooding. This study delves into the intricate dynamics between LULC patterns, eco-based interventions, rainfall variations, and flood occurrences, offering a nuanced perspective on urban flood risk.

5.1 Conclusion

The primary objective of this study was to evaluate the impact of eco-based flood mitigation projects on urban flooding within the Sri Jayawardenepura Kotte DSD. This study successfully achieved its main objective by focusing on the specific goals outlined below:

- Assess flooding patterns in the study area
- Map LULC changes associated with the area
- Analyse the correlation between these LULC changes and flooding occurrences
- Conduct a temporal analysis of rainfall variations and their relationship to flooding

The analysis highlights an association between increased precipitation and significant flood events, particularly in 2010, 2016, 2017, 2018, 2019, and 2021. It was found that heightened rainfall intensities, such as the over 700mm rainfall in May 2016, correspond to increased flood risks. However, the study emphasises that rainfall alone is insufficient to explain the variations in flood extent. In 2017, for example, similar rainfall patterns resulted in different flood extents (0.536 km^2 in 2017 vs. 4.046 km^2 in 2016), indicating that additional factors, such as LULC changes, also play a significant role in flood dynamics. The eco-based flood mitigation projects, such as the restoration and expansion of wetlands, have demonstrated a measurable impact in reducing flood inundation. The study's temporal LULC analysis, using satellite data and maximum likelihood classification, identified significant transitions in land cover from 2009 to 2018. Built-up areas expanded from 11.49 km^2 to 14.18 km^2, while wetlands declined from 2.29 km^2 to 1.19 km^2 by 2015. However, a recovery in wetlands to 1.58 km^2 between 2015 and 2018 coincided with reduced flood extents despite similar rainfall conditions, highlighting the effectiveness of eco-based mitigation strategies.

The findings underscore the importance of eco-based approaches, such as wetland restoration, for urban flood resilience. Projects like "Beddagana" and "Diyasaru" have proven effective in acting as natural buffers against flooding by enhancing natural drainage capacity.

This research provides critical insights for sustainable urban planning, advocating for integrated ecological strategies to mitigate flood risks. Policymakers and planners should consider incorporating such nature-based solutions to create more resilient and sustainable urban environments.

5.2 Recommendations

Based on the study's findings, several recommendations are proposed to enhance urban flood resilience. Prioritising continued investment in wetland restoration and other eco-based flood mitigation projects is essential, as these have proven effective in reducing flood risks. Additionally, urban planning policies should focus on reducing impervious surfaces and promoting sustainable development practices that align with flood risk reduction goals. Expanding the study's methodologies to other urban areas would also allow for a broader assessment of the effectiveness of eco-based flood mitigation strategies in diverse urban settings, further supporting flood resilience initiatives.

5.3 Limitations

This study, while providing valuable insights, is not without limitations. The analysis is based on available data for the Sri Jayawardenepura Kotte DSD and may not be directly generalisable to other regions. Additionally, the accuracy of LULC classifications was constrained by the resolution and availability of satellite imagery, particularly for years before 2018. Furthermore, detailed information on ongoing mitigation projects was inaccessible, limiting the study’s ability to fully assess the impact of flood management efforts in the area.

5.4 Further Developments

Future research could explore the long-term impacts of eco-based flood mitigation projects on urban resilience, including socio-economic considerations. Additionally, integrating hydrological modelling with multi-sensor data fusion and employing advanced machine learning algorithms for more precise LULC classification and flood extent mapping will significantly enhance the robustness of such studies. A thorough examination of the ongoing ecosystem-based mitigation projects within the study area could provide deeper insights and enhance the understanding of the research findings.

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