Abeysinghe, U., Hewawasam, H.U.C.P. and Manatunga, J., 2025. Disaster-resilient cities: Temporal analysis of urban land use land cover changes and urban floods from 1999 to 2022: Case study of Colombo, Sri Lanka. *Proceedings of the 13th World Construction Symposium*, 15-16 August 2025, Sri Lanka. pp. 598 -609. DOI: https://doi.org/10.31705/WCS.2025.45. Available from: https://ciobwcs.com/papers/

DISASTER-RESILIENT CITIES: TEMPORAL ANALYSIS OF URBAN LAND USE LAND COVER CHANGES AND URBAN FLOODS FROM 1999 TO 2022: CASE STUDY OF COLOMBO, SRI LANKA

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ABSTRACT

This study examines the land use land cover (LULC) changes in Colombo City from 1999 to 2022, focusing on the effects of rapid urbanization on urban flood frequency and severity in the Colombo Municipal Council (CMC) area. Using high-resolution satellite imagery from Landsat 5-8, the study tracks and classifies land use over three decades, revealing significant urban expansion, a reduction in green spaces, and the loss of natural water retention zones. These changes have led to increased surface runoff, exacerbating the risk of urban floods. The research highlights that urbanization, coupled with the inadequacy of drainage infrastructure, especially in informal settlements, has contributed to the growing flood vulnerability in the city. LULC maps generated through maximum likelihood classification were validated with high accuracy, confirming the reliability of the data. Correlation analysis suggests a moderate relationship between certain land cover types (e.g., water bodies) and flood impacts, though other factors such as drainage efficiency and urban planning are more critical in determining flood risks. The study underscores the need for improved drainage systems, preservation of green spaces, and comprehensive urban planning to mitigate flood hazards. The findings emphasize the importance of integrating climate adaptation measures into urban planning, with a focus on sustainable land management and infrastructure development. The research concludes that a holistic, resilience-based approach is crucial for building a climate-resilient city capable of adapting to ongoing urbanization and climate change impacts.

Keywords: *Land Use Land Cover; Remote Sensing; Urban Floods; Urbanization.*

1. INTRODUCTION

Over the past three decades, the Colombo city area has undergone significant economic, environmental, and social changes driven by political and administrative shifts, rural-to-urban migration, and climate-induced natural disasters, which have all led to notable alterations in land use patterns (Senanayake et al., 2013; Wickramasinghe et al., 2016;).

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Particularly after the civil war (post-2014), several government-funded city remodelling initiatives, donor-funded wastewater management projects (such as the Greater Colombo Wastewater Management Plan), and infrastructure developments (like the Port City project and the Kelani Valley Highway extension) were implemented. The city remodelling program, in particular, caused significant land use transformations, including the resettlement of underserved communities into high-rise buildings, the clearance of slum areas for real estate development, the creation of new green spaces (such as pocket gardens), the establishment of tree-lined streets, and the introduction of jogging and walking paths, with many modifications to existing green spaces aimed at catering to the real estate market (Hettiarachchi, 2014). The Colombo Port City project, funded by the Chinese government, further impacted the city's land use by expanding its area. However, the economic crisis triggered by the COVID-19 pandemic and subsequent political decisions resulted in major setbacks for many of these development and beautification projects. Several were temporarily or permanently halted, and others were rolled back. (Subasinghe et al., 2021).

Rapid urbanization, a trend observed globally, has also transformed major cities in Sri Lanka, significantly altering environmental and hydrological systems. Colombo, in particular, has seen a dramatic increase in infrastructure development such as roads and buildings, reducing rainwater infiltration and amplifying surface runoff, key contributors to the rising frequency and severity of urban floods, Notable flood events in 1999, 2005, 2020, 2014, and 2022 have caused extensive disruptions, including road inundation, transportation paralysis, prolonged waterlogging, and health crises such as dengue outbreaks. In 2017, Sri Lanka ranked second in the Climate Risk Index, with Colombo highlighted as one of the most climate vulnerable cities in the developing cities. This study addresses that gap by analysing land use and land cover (LULC) changes over time in Colombo, assessing their correlation with rainfall intensity and flood impacts. Through this approach, the research offers original insights into urban planning strategies for enhancing climate resilience and sustainable development.

2. LITERATURE REVIEW

In South Asia, cities like Dhaka in Bangladesh and Mumbai in India has undergone a significant urban growth, leading to a land use changes (Hassan & Southworth., 2018). As use refers to the human activities or socio-economic functions associated with a specific land area such as residential, industrial, or agricultural use. Land cover, in contrast, denotes the physical and biological cover of the Earth’s surface, such as vegetation, water, bare soil, or built-up areas (Lambin et al., 2003). Changes in the urban atmosphere, particularly the reduction of green spaces and natural drainage systems, exacerbate flood risks by reducing water infiltration and increasing surface runoff (Ahmed et al., 2013). Colombo, the commercial capital of Sri Lanka has also experienced rapid urbanization, especially since the 1990s, with the construction of new infrastructure, expansion of residential areas, and an increase in population (Dissanayake, 2021). This urban sprawl has significantly altered Colombo’s natural drainage system and land cover, leading to the increase in urban flood events (Dahanayake & Wickramasinghe, 2022).

Urbanization leads to increased runoff, as more areas become impervious, with limited space for natural water absorption. This reduction in permeable surfaces results in quicker and higher-volume storm water flow, overwhelming drainage systems and causing urban floods (Jiang & Zhang., 2010). In Colombo, the combination of increased built-up areas, encroachment on floodplains, and poorly maintained drainage systems has increased the incidence of urban floods (Dissanayake, 2021).

According to Pelling (2010), the modification of land cover, particularly the expansion of impervious surfaces such as roads, parking lots, and buildings, directly correlates with increased risk of floods in urban areas. In Colombo, the conversion of wetlands and agriculture areas to urban zones has disrupted natural water retention and flood control mechanisms (Dona, 2025). Studies have shown that flood frequency and intensity in Colombo have increased over the past few decades. In particular, Colombo faces recurrent flooding during monsoon periods (Dahanayake & Wickramasinghe, 2022). These floods are often attributed to poor urban planning, unregulated construction in flood-prone areas, and the loss of natural flood mitigation systems like wetlands (Dona, 2025). Climate adaptation measures: Studies emphasize the need for climate adaptation planning in cities to reduce the impacts of flooding. Colombo has initiated some adaptation measures, such as the expansion of its drainage system and the implementation of flood mitigation strategies, but challenges remain, particularly in informal settlements and peri-urban areas (Wagenaar et al., 2019).

Satellite imagery has been widely used for land cover classification and monitoring urban growth. Landsat imagery, for instance, provides continuous coverage since the 1970s and has been used in numerous studies on urbanization and land cover change. In Sri Lanka, remote sensing has been used to monitor urban sprawl, land use changes, and their environment impacts (Manesha et al., 2021). In urban planning, LULC change reflects the spatial and temporal dynamics of urban expansion, infrastructure development, and the conversion of natural or agricultural lands into built environments (Seto et al., 2012; Liu et al., 2010).

GIS-based flood modelling is essential for understanding how land use changes influences flood risk. Temporal analysis refers to the examination of changes in LULC over time. This involves comparing spatial data from different time periods to identify trends, rates, and patterns of changes (Herold et al., 2003). In Colombo, studies have use GIS to analyse flood-prone areas and assess the impacts of urbanization on flood vulnerability. Intense rainfall over a short period, combined with inadequate infrastructure and the reduction of green spaces, causes urban floods in urban areas. This study focus is the urban flash floods that occurred in the CMC area.

The occurrence of these disasters can be attributed to two main factors: extreme weather events resulting from climate change and poor urban planning that fails to mitigate their adverse impacts. To date, there has been no scientific analysis of urban flash floods or urban riverine floods conducted in the CMC area.

3. METHODOLOGY

This study presents a case analysis of the Colombo Municipal Council area, focusing on land use and flood risk dynamics using medium-resolution satellite imagery with a 30 m resolution, the United States Geological Survey (USGS). The images spanned a timeline from 1999 to 2022 and were captured by the Landsat 5-8 satellites. The satellite images were selected from the year of 1999, 2005, 2010, 2014 and 2022 considering the flooding events happened those respective years. We specifically downloaded Level 2 products, which are atmospherically and radio-metrically corrected to ensure high data reliability. The Level of the satellite image indicates the degree to which the raw satellite data has been corrected and made ready for utilized. To maximize uninterrupted coverage, satellite imagery with minimal cloud cover was selected. and cloud cover were masked out using Fmask, following the approach of by Sedano et al. (2011). This process ensured the integrity of land cover classification and change detection across time. In addition to satellite based quantitative analysis, rainfall data, population density, and flood incidents recorded were assessed correlation with land use changes. Qualitative insights were gathered through referring the DesIntenver database of the Disaster Management Centre. Table 1 presents detailed metadata for each satellite images used, including sensor specifics (sensor ID refers the specific imaging instrument used on board the satellites), acquisition date, path/row (path/ row of a satellite used to identify specific geographic locations on Earth as they are captured by satellite sensors), and the percentage of land area covered by clouds.

Table 1: Details of satellite images

Year	Satellite sensor	Sensor ID	Date	Path/ Row	Land Cloud cover
1999	Landsat 5 Level 2	TM	1999-12-05	142/055	9%
2005	Landsat 7 Level 2	ETM	2005-02-05	141/055	12%
2010	Landsat 7 Level 2	ETM	2010-10-01	141/055	25%
2014	Landsat 8 Level 2	OLI-TRIS	2014-01-21	141/55	11.36%
2022	Landsat 8 Level 2	OLI-TRIS	2022-02-04	141/55	15.72%

**Time range – January 23 to March 28*

3.1 STUDY AREA

In 2023, the Western Province, including Colombo, contributed 43.7% of the national GDP, highlighting its central role in the country's economy (Central Bank of Sri Lanka[CBSL], 2024). The CMC governs the western part of Colombo, playing a key role in managing its growth and development. This highlights the strategic significance of the study area. A map of the study area us shown in Figure 1.

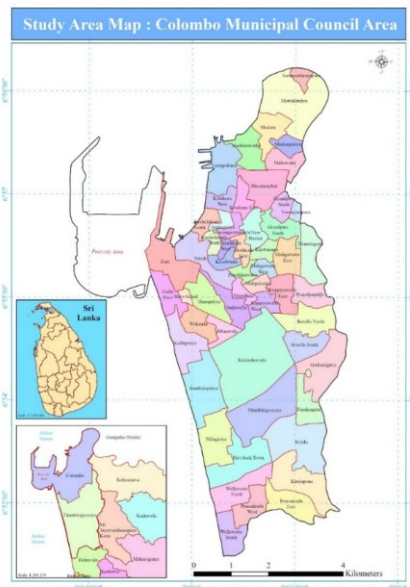

Figure 1: Colombo municipal council area

3.2 LAND USE LAND COVER CHANGE DETECTION

In this study, five LULC classes were identified within the study area: built-up areas, water bodies, barren lands, lawns & grasslands (sparse vegetation), and trees & shrubs (dense vegetation). To ensure accurate classification, we selected the highest possible number of training samples for each class, carefully considering the consistency and distribution of the satellite images over time. The land use/land cover classification was performed using the maximum likelihood classification technique, a supervised method where each image pixel is assigned to the category that most closely matches its spectral signature, corresponding to the recognized land cover types. This classification process was carried out using the ArcGIS pro 3.3 software package. To assess the accuracy of the classification, 100 random spatial points were selected for each satellite image. For historical datasets, Google Earth images (spanning from 1996 to 2023) and past land use maps available on the Google Earth platform were utilized for accuracy verification. Finally, to maintain consistency across all datasets, the classified images were resampled to a uniform spatial resolution of 30m x 30m. Following are the description of five land use classes.

- **Built-up areas**: Areas covered by man-made structures such as buildings, roads, and other infrastructure; characterized by impervious surfaces and high density.
- **Water bodies**: Includes rivers, lakes, ponds, canals, and other surface water.
- **Barren lands**: Land with little to no vegetation cover, including exposed soil, rocks, construction sites, and degraded areas.
- **Lawns and Grasslands** Areas with sparse or low-lying vegetation, including parks, fields, and recreational lawns
- **Trees and Shrubs**: Regions dominated by dense vegetation such as forests, woodlands, and plantations; typically, rich in biomass and ecological value

3.3 FLOOD IMPACT DETENTION

Flood inundation level maps, or data are not available for the study area (except for some specific locations like Kelani Valley River basin). However, the data on the area impacted (names of locations), and the number of people affected by each flood event are available from the open access DesInventar database, managed by Disaster Management Center (Disaster Management Center[DMC], 2025). These data were used as proxies for flood damage to determine the flood impact over the past 30 years in the study area, Table 2.

Table 2: Flood data used for the analysis

Data	Data type	Data source
Area impacted	Name of locations impacted	DesInventar Database
Number of people impacted	Number	DesInventar Database

3.4 CORRELATION ANALYSIS OF LAND USE LAND COVER CHANGES AND FLOODING

Correlation analysis was performed using Minitab version 20.2 to explore the relationships between key variables in the study. Specifically, the analysis aimed to identify the nature and direction of the relationships between flood locations, the number of people affected by floods, and the percentage of land use change (measured as the temporal variation in land use classes). Through this analysis, we sought to determine whether the relationships were positive or negative, providing insights into how these factors interrelate. Additionally, the strength of these relationships was evaluated, allowing us to assess whether the associations between the variables were strong or weak. By conducting this correlation analysis, we were able to gain a deeper understanding of the dynamics between flooding events and changes in land use within the study area.

4. RESULTS AND DISCUSSION

4.1 LAND USE LAND COVER MAPS AND ACCURACY ASSESSMENT

The LULC maps were developed for 1999, 2005, 2010, 2014, and 2022 year, are presented in Figure 2. The maps clearly indicate the significant land use changes the CMC area has undergone during past three decades.

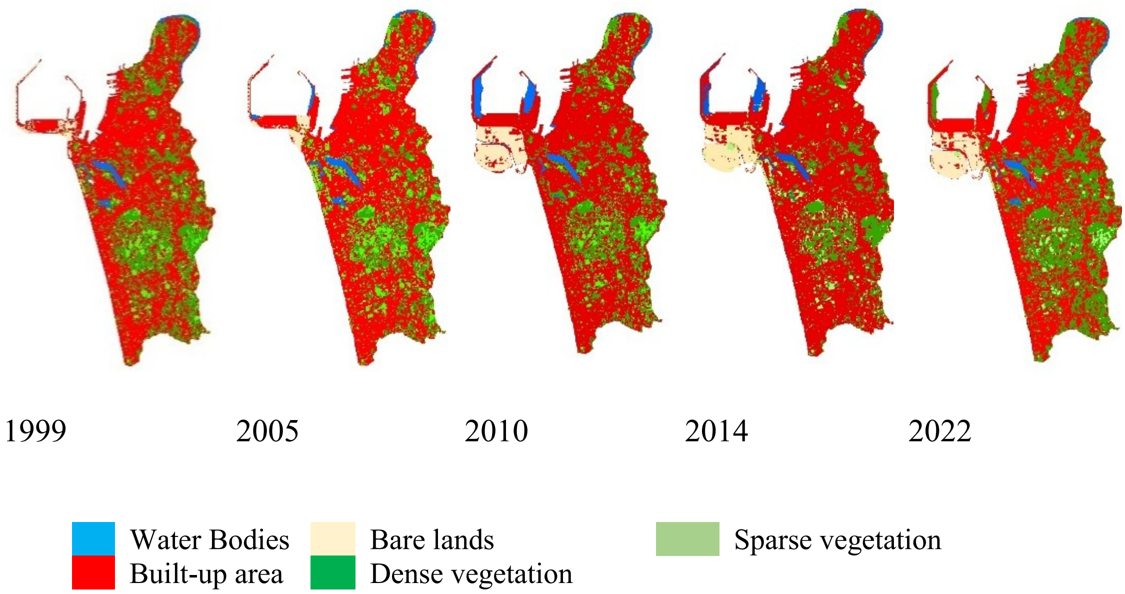

Figure 2: LULC Maps of 1999, 2005, 2010, 2014, and 2022

Table 3 presents the user accuracy, which is the is the probability that a pixel classified into a certain category on the map actually represents that category on the ground, and kappa coefficient which quantifies the agreement between the classified map and reference (ground truth) data values for each LULC map generated.

Table 3: Accuracy assessment of Land Use Land Cover maps

Year	U_Accuracy	Kappa
2022	0.930	0.855
2014	0.910	0.827
2010	0.930	0.867
2005	0.940	0.885
1999	0.910	0.817

The land use areas under five different land use categories, water bodies, built-up areas, bare lands, dense vegetation, and sparse vegetation were presented in Table 4. There is a significant increase of the urban greenery in the CMC area due to the city remodelling programs undertaken during the past war period (Abeysinghe et al., 2024).

Table 4:Land use areas under different land use categories

Year	Water bodies	Built up area	Bare lands	Dense vegetation	Sparse vegetation
2022	2.80	72.44	5.21	14.26	5.28
2014	1.43	56.65	5.18	33.20	3.54
2010	3.05	67.68	5.27	17.00	6.99
2005	2.36	67.61	1.81	14.59	13.62
1999	1.78	63.32	2.02	26.35	6.51

4.2 TEMPORAL ANALYSIS OF URBAN FLOODS IN COLOMBO MUNICIPAL COUNCIL AREA

During the period between 1999 and 2022, the CMC area experienced several major flood events, each of which had significant impacts on the local population. As shown in Figure 3, the number of people affected by floods has gradually increased over the years, with a noticeable rise in the frequency of these events. The graph provides an insightful analysis of flood-affected individuals in the CMC area, revealing an upward trend both in the number of people affected and in the frequency of flood occurrences. This increase underscores the growing vulnerability of the city to flooding, particularly urban floods, which have become a recurrent issue in the region. The map provides a detailed view of where flood events occur most frequently within the CMC area. It shows that the flood risk is not evenly distributed across the city, and only some parts are in high risk.

The most flood prone areas in Colombo include neighbourhood such as Grandpass South and North, Maradana, Nawagampura, and several others that have been consistently affected by flood events. There areas experienced severe flooding during major events in 1999, 2005, 2010, 2014, and 2022. Key contributing factors include heavy rainfall, inadequate drainage systems, and rapid urbanization. Understanding these patterns is essential for developing effective flood management strategies and enhancing the city's resilience.

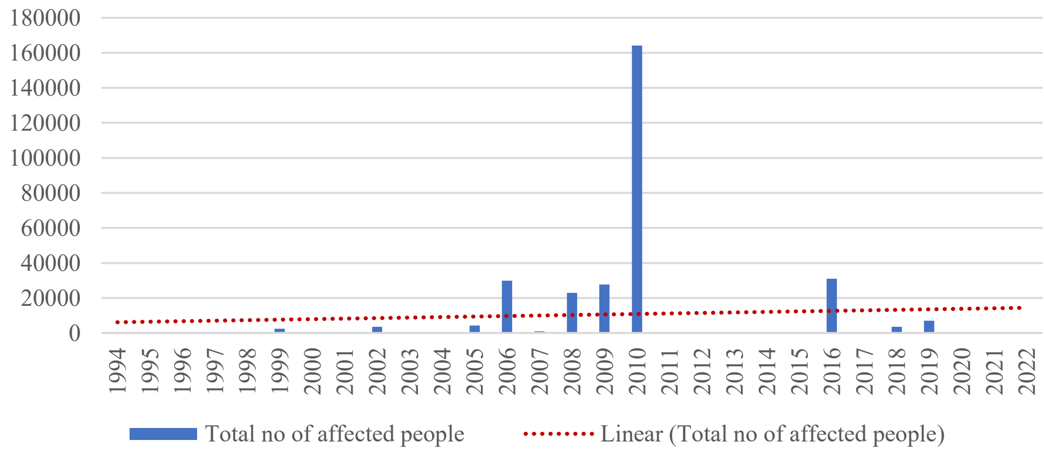

Figure 3: Flood affected people over 1994-2022

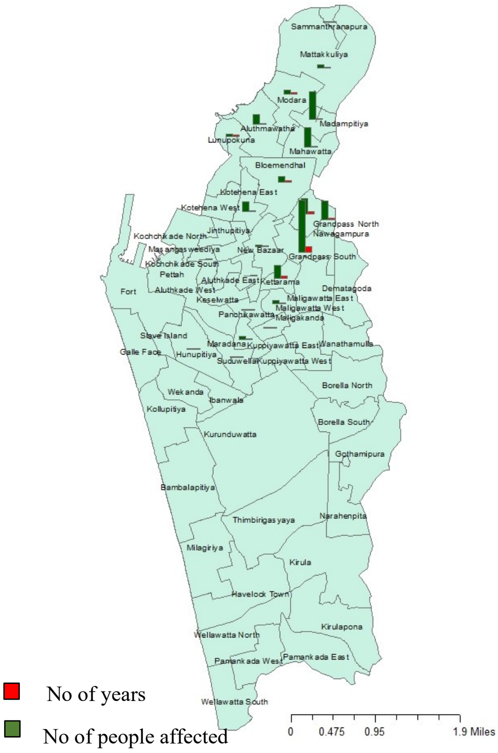

Figure 4:Flood events and severity in different locations

4.2.1 Correlation Analysis of the Land Use Changes and Urban Flood Impact

The correlation of the different land use land cover change and the number of flood affected people was assessed using minitab 20.0 software. The correlation coefficient, R-square, and the *p-value* is presented in the Table 5.

Table 5: Correlation of land use land cover change and the number of flood affected people

Land use type	Correlation coefficient	R-Square (%)	p-value
		No of people affected	
Water bodies	0.522	27.3	0.367
Built-up area	0.063	0.4	0.920
Bare lands	0.505	25.5	0.386
Dense vegetation	-0.142	2.0	0.820
Sparse vegetation	-0.117	1.4	0.851

The correlation coefficient between the extent of water bodies and the no of people affected is moderately positive, r-square is 27.3 % suggest that water bodies have modest predictive influence on the number of people affected and the p value is not statistically significant. The correlation coefficient of the built-up area extent and the number of people affected shows a very weak positive correlation, and the p-value is very high, suggesting that there is no significant relationship. There is a moderately positive relationship between bare lands and the number of flood affected people, and p-value is not statistically significant. The negative correlation suggests that areas with dense vegetation tend to experience fewer people being affected by flooding, likely because vegetation helps reduce runoff and prevents soil erosion. However, the correlation is weak, indicating that vegetation alone does not have a significant influence on the number of people affected. Dense vegetation explains only 2% of the variation in the number of people affected, confirming that dense vegetation has minimal predictive power in this scenario. The relationship between dense vegetation and the number of people affected is not statistically significant, indicating that vegetation in this case does not have a measurable impact on flood outcomes. Similar to dense vegetation, sparse vegetation shows a very weak negative correlation with the number of people affected. Sparse vegetation accounts for only 1.4% of the variation in the number of people affected, further suggesting that vegetation density (whether dense or sparse) is not a major driver of flood impacts in this case. The p-value is very high, reinforcing the idea that sparse vegetation has no statistically significant impact on the number of people affected by flooding.

4.2.2 Correlation Analysis of the Rainfall Intensity and the Flood Impact

The correlation of the intensity of the rainfall (rainfall within 24 hr) and the number of flood affected people were assessed using minitab 20.2 software. The rainfall data of the selected urban flood events were obtained from the Department of Meteorology. The correlation analysis was conducted for the rainfall intensity and the number of people affected during above mentioned flood events were presented in Table 6.

Table 6: Correlation between the rainfall intensity and the number of people affected

Variable	Correlation coefficient	R-Square (%)	p-value
		No of people affected	
Rainfall intensity	-0.342	32.4	0.317

The correlation coefficient of -0.342 indicates a weak negative relationship between rainfall intensity and the number of people affected. This means that, as rainfall intensity increases, the number of people affected tends to slightly decrease. However, the relationship is weak, and the strength of this correlation is not very strong. The p-value of 0.3174 is greater than 0.05, meaning the correlation is not statistically significant. This suggests that the weak negative correlation observed between rainfall intensity and the number of people affected is likely due to random chance. Therefore, we cannot conclude that rainfall intensity significantly influences the number of people affected.

5. CONCLUSION

This study offers a detailed examination of the LULC changes in Colombo City from 1993 to 2022, using advanced remote sensing techniques and rigorous analytical methods. The research focused on how rapid urbanization, driven by socio-political factors and infrastructure developments, has influenced the frequency and severity of urban floods in the CMC area. The study leveraged high-resolution satellite imagery from Landsat 5-8 to track and classify land use over three decades, providing an in-depth temporal perspective on the transformation of the city's landscape.

The key findings of this research highlight that Colombo has experienced significant land use changes, particularly an expansion of built-up areas and a reduction in green spaces and natural water retention areas. These changes have directly impacted the city's hydrological dynamics, with the increased urbanization contributing to higher levels of impervious surfaces, which reduce natural water absorption and lead to increased surface runoff. This alteration in land cover has exacerbated the risk of urban floods, as the city's drainage infrastructure, particularly in informal settlements, has struggled to keep up with the rising demand and urban sprawl. Moreover, the loss of wetlands and other natural flood mitigation systems has further compounded the issue.

The accuracy of the LULC maps generated through the maximum likelihood classification technique was assessed through extensive validation processes. The high user accuracy and kappa values (e.g., 0.855 in 2022) confirm the reliability and robustness of the dataset, which serves as a valuable tool for urban planners and policymakers seeking to address the city's growing vulnerability to urban floods.

Additionally, the correlation analysis provided further insights into the complex relationship between land use changes and flood impacts. As stated Sohn et al., (2020), the modification of land cover, particularly the expansion of impervious surfaces such as roads, parking lots, and buildings, directly correlates with increased risk of urban floods in urban areas. This study found that the relationship between the rainfall intensity, and LULC change, and flood impact are more complex, and influenced by multiple factors. Water bodies and barren lands showed moderate positive correlations with the number of flood-affected people, while dense vegetation showed a weak negative correlation, suggesting ta possible mitigating effect. However, these correlations were not statistically significant. The findings suggest that factors like drainage infrastructure and urban planning play a more critical role in flood outcomes than LULC alone. Additionally, the weak negative correlation between rainfall intensity and affected individuals indicates that flood severity depends more on urban response than rainfall volume alone.

Despite efforts to expand drainage systems, problems continue, especially in informal settlements that are highly vulnerable to flooding. While green spaces and water bodies provide some mitigations, they cannot fully counter the risks from unregulated construction and poorly maintained drainage. This highlights the limitations of current flood control efforts. The study emphasizes the need for integrated urban planning that combines flood management with sustainable land use and environmental practices.

This research reinforces the need for continuous monitoring of LULC changes in Colombo and highlights the importance of integrating climate adaptation measures into urban planning processes. Policymakers should prioritize sustainable land management practices, such as preserving natural flood buffers, enhancing green spaces, and improving the capacity of drainage infrastructure. Furthermore, the findings underscore the importance of adopting a holistic approach to urban resilience—one that combines infrastructure improvements with community engagement, disaster preparedness, and climate-conscious governance.

Urban flooding is a significant issue in the CMC area. However, changes in LULC patterns, along with rainfall intensity, are just two factors that exacerbate the impact of these floods. The relationship between urban floods, rainfall intensity, and LULC changes is more complex, with several additional factors that must be taken into account. These include the drainage network of the area, soil water infiltration capacity, and overall hydrological patterns, among others. Study suggest that further research is needed to explore these factors in greater detail.

In conclusion, this study provides valuable insights into the spatial-temporal dynamics of Colombo's urbanization and flood risks and offers important recommendations for building a climate-resilient city. The evidence suggests that while urbanization is inevitable, its negative impacts can be mitigated through informed decision-making, adaptive urban planning, and the integration of nature-based solutions to enhance flood resilience. As Colombo continues to evolve, it is crucial to balance development with sustainable environmental practices to ensure that future generations can live and thrive in a safer, more resilient city.

6. ACKNOWLEDGEMENT

The research received funding under SRC grant number, SRC/LT/2021/07.

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