Spatiotemporal Analysis of Land Use, Land Cover and Flood Extents in Colombo District (2017–2023) Using Remote Sensing and GIS

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Key words: Change Detection, Colombo District, Flood Risk Assessment, Land Use Land Cover (LULC), Remote Sensing

SUMMARY

This study examines the impact of rapid Land Use and Land Cover (LULC) changes on flood exposure in the Colombo District, Sri Lanka, between 2017 and 2023. Using a multi-sensor Earth Observation (EO) approach, Moderate Resolution Imaging Spectroradiometer (MODIS), European Space Agency (ESA) WorldCover, Dynamic World, and Sentinel-1 SAR data were integrated to overcome spatial-temporal limitations of individual datasets. MODIS provided long-term coverage for earlier years, while Sentinel-1 enabled reliable flood mapping under persistent monsoon cloud cover. A four-detector majority-vote algorithm was applied to map flood extents, and all datasets were harmonised into a consistent nine-class LULC scheme.

Findings reveal significant urban expansion alongside a decline in agricultural land. Urban areas nearly doubled during the study period, while farmland decreased by more than 12%. This transformation coincided with a sharp rise in flood exposure: inundated areas increased from 0.012 km² in 2017 to 0.043 km² in 2023, quadrupling in just six years. The most flood-prone divisions were Kolonnawa, Kaduwela, and Colombo, where urban sprawl has replaced wetlands and farmland, diminishing natural flood buffers. Although wetlands remain critical for water retention, their continued reduction heightens vulnerability.

This study emphasises that urban growth is directly amplifying flood hazards in Sri Lanka's most densely populated and economically vital region. The reproducible workflow not only demonstrates the strong link between LULC dynamics and flooding but also provides a transferable framework for other data-scarce urban areas. Policy recommendations highlight the urgency of integrating flood hazard layers into zoning regulations, restoring wetlands, and prioritising adaptation strategies in high-risk divisions. The work contributes to advancing sustainable urban management and resilience planning in line with Sustainable Development Goals (SDGs) 11, 13, and 15.

Spatiotemporal Analysis of Land Use, Land Cover and Flood Extents in Colombo District (2017–2023) Using Remote Sensing and GIS

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ABSTRACT

Flood disasters are among the most frequent and damaging natural hazards worldwide, with their impacts increasingly intensified by rapid urbanisation, land-use change, and climate variability. Across Asia, expanding exposure in densely populated cities presents growing challenges for sustainable urban management. Colombo District, Sri Lanka's primary economic hub, exemplifies these pressures; however, spatiotemporal assessments that explicitly link Land Use and Land Cover (LULC) dynamics with flood exposure remain limited, despite their importance for urban planning, wetland conservation, and disaster risk reduction. This study quantifies LULC transitions and associated flood extents across thirteen Divisional Secretariat Divisions (DSDs) in Colombo District for 2017, 2020, and 2023, capturing both pre- and post-pandemic urban expansion and enabling comparison using recent high-resolution land-cover products. A multi-sensor Earth Observation (EO) framework was employed to overcome spatial-temporal trade-offs of individual datasets: the Moderate Resolution Imaging Spectroradiometer (MODIS) provides long-term continuity (2017, 2020) at coarse resolution, while European Space Agency (ESA) WorldCover and Dynamic World deliver fine-scale LULC detail for 2023. These datasets were integrated with Sentinel-1 Synthetic Aperture Radar (SAR) to enable reliable flood detection under persistent cloud cover. Flood inundation was mapped using a four-detector majority-vote algorithm, and all analyses were conducted within a Geographic Information System (GIS) environment. Results reveal substantial land-cover transformation between 2017 and 2023, with agricultural land decreasing by more than 12% and urban areas nearly doubling, particularly within Colombo, Dehiwala, and Kolonnawa DSDs. Correspondingly, the flooded area increased from approximately 0.012 km² in 2017 to 0.031 km² in 2020 and 0.043 km² in 2023. Flood impacts were consistently concentrated in urbanised and low-lying DSDs, including Kolonnawa and Kaduwela, while wetlands, despite their reduction, remained disproportionately exposed. By explicitly coupling LULC change with flood-extent mapping, this study demonstrates how rapid urban expansion amplifies flood vulnerability in Colombo District. The proposed workflow is transferable to data-scarce urban regions and highlights the urgency of enforcing sustainable land-use controls, conserving wetland buffers, and strengthening resilience strategies to mitigate escalating flood risks in Sri Lanka's most urbanised district.

Keywords: Change Detection, Colombo District, Flood Risk Assessment, Land Use Land Cover (LULC), Remote Sensing.

1. INTRODUCTION

Flooding is one of the most frequent and damaging natural hazards worldwide, affecting nearly 913 million people globally and exposing United States Dollar (USD) 1.3 trillion in assets (Dasgupta et al., 2021). Climate variability, accelerated urbanisation, and land cover change intensify the frequency and severity of floods, particularly in low-lying and densely populated regions (Herath & Ratnayake, 2016; Gunawardena & Wedage, 2017). Remote sensing provides indispensable support for flood monitoring by delivering consistent and synoptic observations that complement sparse ground-based hydrological networks (Chini et al., 2018). Synthetic Aperture Radar (SAR) data, with all-weather, day-night capability, has proven highly effective for flood detection and monitoring (Mujumdar & Ghosh, 2011; Vargas et al., 2022).

South Asia ranks among the most vulnerable regions to flooding due to monsoonal rainfall, riverine overflows, and rapid land use transitions (Perera & Bandara, 2019). Sri Lanka, located in the Indian Ocean, has experienced recurrent floods in recent decades, generating substantial human and economic losses. Colombo District, the country's commercial capital, remains particularly exposed because of low-lying terrain, unplanned urban expansion, and conversion of wetlands into built-up areas (Gunawardena & Wedage, 2017). Inadequate drainage infrastructure further compounds vulnerability, leading to prolonged waterlogging during heavy rainfall events (Perera & Bandara, 2019).

Recurrent floods disrupt socio-economic activity and highlight the urgent need for spatially explicit flood risk assessments in rapidly urbanising tropical cities. Land Use and Land Cover (LULC), which describes how land is used and what physically covers the ground, plays a central role in determining urban flood exposure. Deforestation, agricultural decline, and urban expansion modify runoff and infiltration, directly shaping flood inundation (Friedl et al., 2010; Poulter et al., 2019; the European Space Agency [ESA], Europe's intergovernmental organisation for space research and Earth observation, 2021). Global land-cover datasets such as the Moderate Resolution Imaging Spectroradiometer (MODIS), a long-running satellite sensor providing consistent global observations, include the MODIS Land Cover Type product (MCD12Q1), an annual global land-cover classification dataset produced at 500 m resolution and commonly reported using the International Geosphere-Biosphere Programme (IGBP) scheme (Friedl et al., 2010), alongside ESA WorldCover (ESA, 2021) and Dynamic World (Brown et al., 2022); together, these products support consistent multi-resolution monitoring, and their integration with SAR-derived flood maps helps clarify how land transitions influence inundation patterns (Jarihani et al., 2023).
SAR-based flood mapping has been widely applied through thresholding (Schumann et al., 2015), change detection (Tarpanelli et al., 2019), machine learning (Cao et al., 2021), and multi-sensor fusion (Martinis & Kersten, 2019; Middleton et al., 2021). Few studies in South Asia connect multi-temporal LULC transitions with flood exposure, despite rapid land change and growing urban risk. Colombo District represents a critical case due to its dense population,

economic significance, and fast urban growth. Linking LULC transitions with flood impacts informs sustainable land-use planning, wetland conservation, and resilient infrastructure. The study supports global goals by advancing the Sustainable Development Goals (SDGs), the United Nations' 17-goal framework for sustainable development to 2030, specifically SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 15 (Life on Land) (United Nations, 2015). Against this background, this study quantifies spatiotemporal LULC change and associated flood extents across Colombo District, Sri Lanka, for 2017, 2020, and 2023 by integrating multi-source land-cover products with Sentinel-1 SAR–derived inundation mapping under cloud-prone tropical conditions. The specific aims are to (i) map LULC dynamics consistently across years, (ii) delineate flood extents using a robust SAR-based approach, and (iii) assess flood exposure patterns across DSDs, Sri Lanka's key sub-district administrative units within a district, through spatial overlays and zonal statistics. The principal contribution is a transferable, multi-sensor workflow that links land-cover transitions with flood exposure at the sub-district scale, providing decision-relevant evidence to support sustainable land-use planning and urban flood risk reduction in rapidly urbanising tropical regions.

2. METHODOLOGY

2.1 Study Area

Colombo District (Fig. 1) is located on the western seaboard of Sri Lanka and covers approximately 699 km², accommodating a population exceeding 2.4 million, making it the country's most urbanised district.

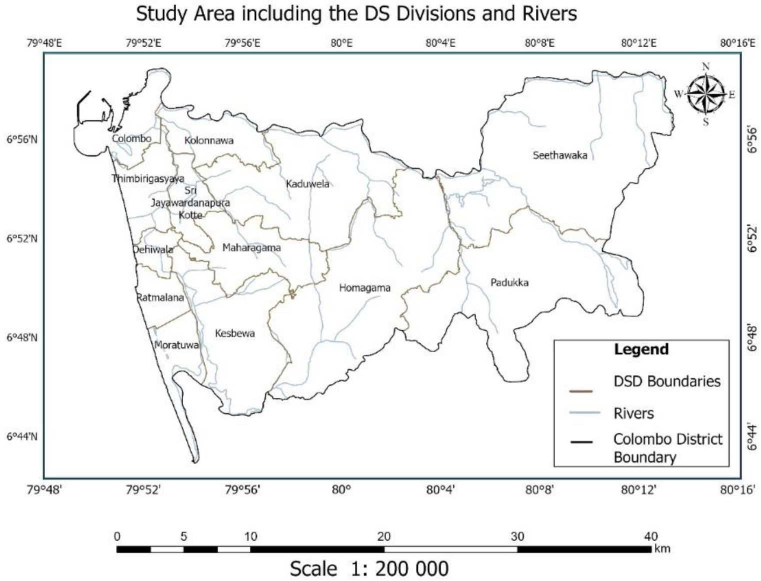

Fig. 1: Study area map of Colombo District, Sri Lanka, showing Divisional Secretariat Division (DSD) boundaries and the major river network within the district boundary.

Administratively, the district comprises thirteen Divisional Secretariat Divisions (DSDs), including Colombo, Dehiwala, Kolonnawa, Kaduwela, Seethawaka, and Padukka. Highly urbanised and low-lying DSDs dominate the western and central parts of the district, while eastern divisions remain relatively agricultural and forested. The district lies within Sri Lanka's wet climatic zone, receiving more than 2,500 mm of annual rainfall, with recurrent flooding during the southwest (May) and inter-monsoon (October) periods. Low elevations, extensive wetland modification, and rapid land conversion have increased flood susceptibility, making Colombo District an appropriate case for analysing the interaction between LULC dynamics and flood exposure. Low elevations (<30 m) intensify inundation across the urban core. As Sri Lanka's commercial hub, rapid wetland and farmland conversion has heightened flood vulnerability (Gunawardena & Wedage, 2017), making flood–LULC analysis vital for sustainable land management and climate adaptation.

2.2 Data Sources

Earth Observation (EO) refers to the acquisition of information about the Earth's surface and atmosphere using satellite and airborne sensors, enabling consistent, repeatable monitoring of environmental conditions across space and time. In this study, flood mapping utilised Sentinel-

1 Ground Range Detected (GRD) imagery, acquired in Interferometric Wide (IW) mode with vertical–vertical (VV) polarisation. GRD refers to the Sentinel-1 SAR product processed to ground-range geometry and suitable for backscatter-based flood analysis. IW mode is the standard Sentinel-1 acquisition mode providing wide spatial coverage at 10 m resolution. Vertical–vertical polarisation (VV) denotes radar signals transmitted and received in the vertical orientation, commonly used for surface water and flood detection. Level-2A Sentinel-2 products represent atmospherically corrected surface reflectance imagery suitable for spectral index computation.

Table 1: Earth Observation datasets used for flood and LULC analysis

Dataset	Platform/ Sensor	Product/ Level	Source	Spatial resoluti-on	Temporal coverage	Coordinate System
Sentinel-1 SAR(VV)	Sentinel-1A	GRD(Ground Range Detected) - IW(Interferometric Wide) mode	Copernicus Open Access Hub	10 m	Flood periods in 2017, 2020, 2023	WGS 84 / UTM zone 44N
Sentinel-2 MSI	Sentinel-2A	Level-2A (Surface Reflectance)	Copernicus Open Access Hub	10–20 m	Dates corresponding to flood events	WGS 84 / UTM zone 44N
MODIS LULC	Terra	MCD12Q1	NASA LP	500 m	2017, 2020	WGS 84 / UTM zone 44N
ESA WorldCover	Sentinel-1 & Sentinel-2 (derived product)	WorldCover v1.0	ESA WorldCover portal	10 m	2023	WGS 84 / UTM zone 44N

.This study integrates multi-sensor EO datasets to analyse LULC dynamics and flood inundation for 2017, 2020, and 2023. The datasets were selected to balance temporal continuity, spatial resolution, and robustness under cloud-prone tropical conditions. Table 1 summarises the EO datasets used, including their spatial resolution, temporal coverage, and analytical purpose. All raster datasets were reprojected to a common coordinate reference system(WGS 84) and spatially harmonised before analysis.

2.3 Analytical Workflow and Methodological Approach

LULC mapping for 2017 and 2020 was based on the MODIS Combined Land Cover product (MCD12Q1), which provides consistent long-term land-cover information. For 2023, the ESA WorldCover v2.0 dataset was used to capture recent high-resolution land-cover conditions derived from Sentinel-1 and Sentinel-2 data. To ensure inter-annual comparability, both MODIS and WorldCover datasets were harmonised into a nine-class LULC scheme, aggregating original classes into Forest, Agriculture, Grassland, Shrubland, Urban, Wetland, Water, and Barren categories. MODIS rasters (500 m) were resampled to 10 m resolution using nearest-neighbour interpolation to match the spatial resolution of Sentinel-1 and WorldCover products. Flooded extents for 2017, 2020, and 2023 were derived exclusively from Sentinel-1 Synthetic Aperture Radar (SAR) Ground Range Detected (GRD) imagery, selected for its cloud-penetrating capability and suitability for flood mapping in monsoonal environments. Flood detection was performed using a four-detector majority-vote algorithm, a strategy commonly adopted to improve robustness in SAR-based flood mapping by combining multiple complementary detectors (Martin et al., 2016; Li et al., 2019). applied to VV-polarised backscatter from Sentinel-1 SAR imagery. Flood inundation was mapped using a four-detector majority-vote ensemble, where multiple complementary SAR-based water detectors are combined and a pixel is labelled as flooded when at least two detectors agree, which has been shown to improve robustness relative to single-threshold approaches in operational SAR flood mapping (Martinis et al., 2015; Twele et al., 2016; Martinis & Kersten, 2019). The first detector employed absolute backscatter thresholding, classifying pixels with VV values lower than −15 dB as inundated, following common SAR flood-mapping practices (Martinis et al., 2009; Henry et al., 2006). The second detector applied change detection relative to a two-year pre-event baseline, identifying flooded pixels where a VV backscatter decrease exceeded 3 dB (Notti et al., 2018). The third detector used VV (vertical–vertical) and VH (vertical–horizontal) polarisation backscatter ratio thresholding, with ratios below 1 indicating surface water (Twele et al., 2016). The fourth detector implemented statistical thresholding, classifying pixels as flooded when VV backscatter values fell below the mean minus 1.5 standard deviations of the scene-specific VV distribution (Martinis et al., 2015). Pixels identified as flooded by at least two of the four detectors were retained in the final flood extent map. Pixels classified as flooded by at least two detectors were retained. Permanent water bodies, identified using MODIS or WorldCover water classes, were excluded to isolate temporary inundation. Flood masks derived from Sentinel-1 SAR were validated using water indices computed from Sentinel-2 Multispectral Instrument (MSI) imagery. The Normalised Difference Water Index (NDWI), which highlights surface water by contrasting green and near-infrared reflectance, and the Modified Normalised Difference Water Index (MNDWI), which replaces near-infrared with shortwave-infrared to better suppress built-up land and enhance open water, were calculated from cloud-free Sentinel-2 composites acquired during the corresponding flood periods. Validation was conducted through spatial overlay and visual agreement assessment, comparing Sentinel-1 SAR–derived flood masks with water indices (NDWI and MNDWI) computed from cloud-free Sentinel-2 MSI imagery acquired during corresponding flood periods. External validation was supported using official flood situation reports issued by the Disaster Management Centre (DMC) of Sri Lanka (Disaster Management Centre, 2023). Flood extent masks were intersected with harmonised LULC rasters to generate flood-by-class layers for each study year. Unique identifiers were assigned to flooded and non-flooded states within each LULC class, enabling the derivation of transition state maps. These maps supported the derivation of transition probabilities for Markov chain–based flood susceptibility modelling, a widely applied approach for analysing land-cover and hazard transitions (Eastman, 2016; Arsanjani et al., 2013). Zonal statistics were computed for each DSD, extracting total pixel counts, flooded pixel counts, and inundated areas by LULC class. These outputs supported comparative spatiotemporal analysis across 2017, 2020, and 2023, and provided inputs for subsequent Markov chain–based flood susceptibility modelling. All processing was implemented using Google Earth Engine (GEE), a cloud-based geospatial analysis platform (Gorelick et al., 2017), with visualisation and statistical summarisation performed in ArcGIS Pro (Esri, 2022).

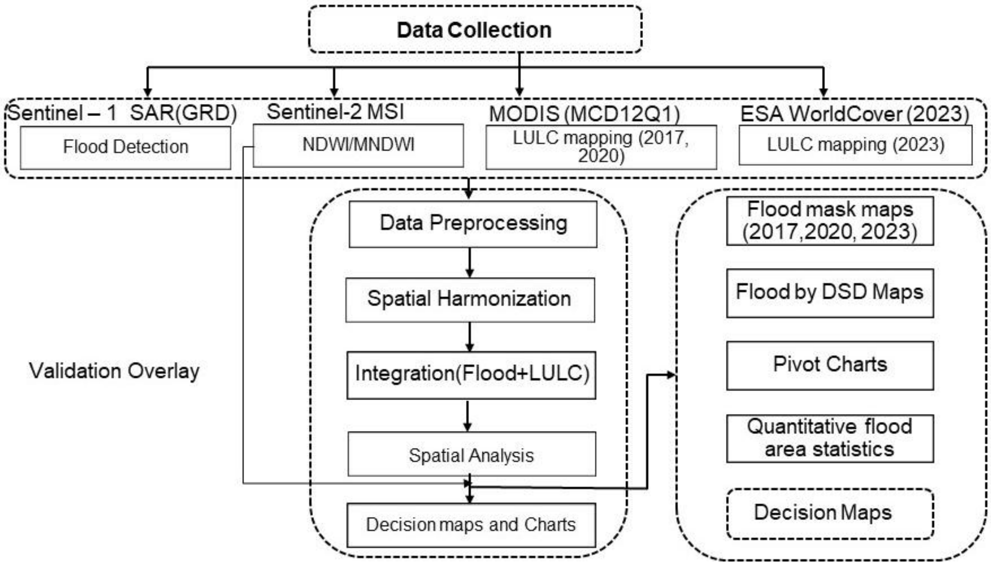

Fig. 2: Methodology Flowchart

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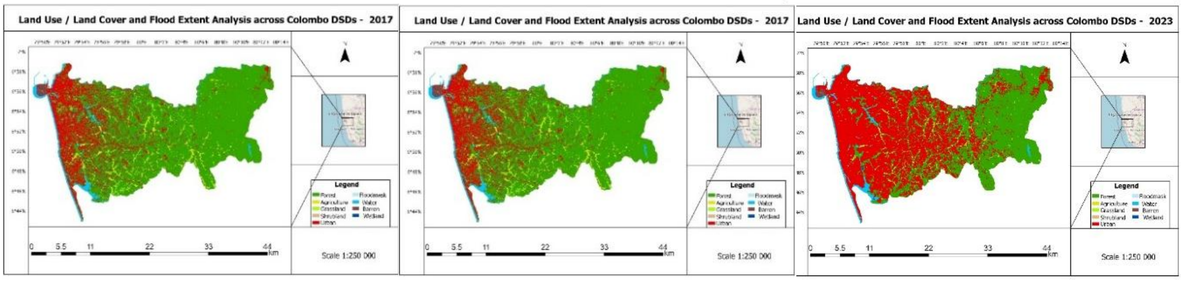
3. RESULTS AND DISCUSSION

Flood extent masks were intersected with the harmonised LULC layers to quantify inundation by land-cover class for each study year. Zonal statistics were computed at the Divisional Secretariat Division (DSD) level to extract total area and flooded area by LULC class, providing the quantitative basis for the spatiotemporal comparisons reported in Section 3.

3.1 Land Use and Land Cover (LULC).

Thematic maps for 2017, 2020, and 2023 of Fig. 3 reveal major LULC shifts in Colombo District, with agriculture declining by over 12% and urban land nearly doubling.



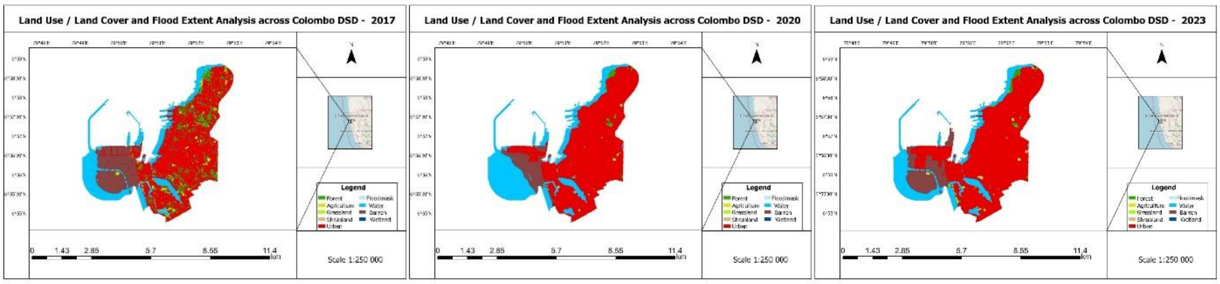
(a) *(b)* *(c)*

Fig. 3: Spatial distribution of Land Use and Land Cover (LULC) and corresponding flood extents in Colombo District for (a) 2017, (b) 2020, and (c) 2023, derived from harmonised EO datasets and Sentinel-1 SAR.

Flooded extents, derived from Sentinel-1 SAR, rose from 0.012 km² in 2017 to 0.031 km² in 2020 and 0.043 km² in 2023, marking a fourfold increase in six years. Spatial overlays show urban growth encroaching into agricultural and wetland zones, intensifying flood exposure. These thematic maps establish a clear link between rapid land conversion and increasing vulnerability to pluvial and fluvial flooding.

3.2 DSD Analysis

Detailed analysis of Colombo DSD across 2017, 2020, and 2023, interpreted in Fig. 4, reveals progressive inland flood expansion, with 2023 showing severe overlap between inundation and newly urbanised zones. The results highlight how urban growth and wetland loss amplify flood risk by reducing infiltration and natural buffering. This approach can be systematically applied to the remaining 12 DSDs, where preliminary patterns already indicate



(a) (b) (c)

Fig. 4: LULC, and Flood Extent – Colombo DSD (a)2017, (b)2020, (c)2023.

3.3 Quantitative Evidence from Statistics and Charts

The quantitative analysis reveals a progressive increase in flood extent across the study period.

Total inundated area increased from approximately 0.012 km² in 2017 to 0.031 km² in 2020 and 0.043 km² in 2023. Flood exposure increased most prominently within urban land-cover classes, while wetland and agricultural classes exhibited declining spatial extents but remained exposed to inundation. Figures 5 and 6 present the quantitative assessment of flooded areas by the DSD and LULC class for the years 2017, 2020, and 2023.

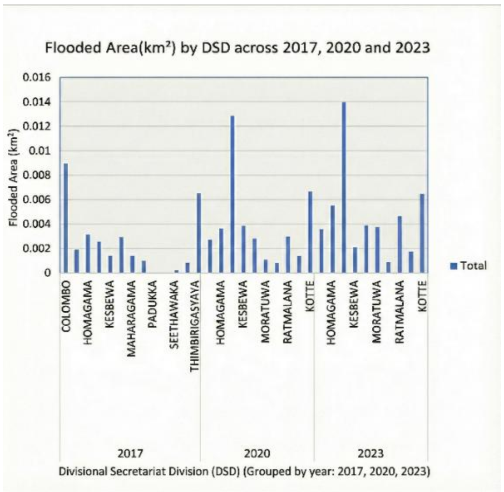


Fig. 5. Flooded Area by DSD.

Flooding is primarily concentrated within low-lying and urbanised divisions, with Colombo, Kolonnawa, and Kaduwela consistently recording greater flooded extents across the assessed years. In contrast, divisions such as Padukka exhibit comparatively limited flooded areas throughout the study period. Figure 6 shows the distribution of flooded areas by LULC class. In 2017, flooding was limited mainly to urban areas, affecting approximately 3 ha, with no notable inundation observed in forest or barren land classes. In 2020, the total flooded area increased to approximately 3.8 ha, distributed across multiple land-cover types, including urban (~2 ha), forest (~1.3 ha), and barren land (~0.5 ha). By 2023, flooding occurred predominantly within urban areas, reaching nearly 4.5 ha, while forest areas experienced only limited inundation of approximately 0.25 ha, and barren land showed negligible impact.

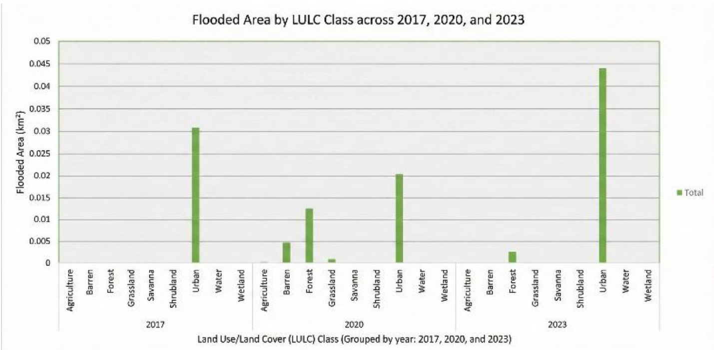


Fig. 6. Flooded Area by LULC.

4. CONCLUSIONS

This study examined the spatiotemporal relationship between Land Use and Land Cover (LULC) change and flood exposure in Colombo District, Sri Lanka, for 2017, 2020, and 2023 using an integrated multi-sensor Earth Observation (EO) and GIS-based framework. By combining Sentinel-1 SAR–derived flood extents with harmonised LULC datasets, the analysis provides spatially explicit evidence that flood exposure has increased over time and has become increasingly concentrated within highly urbanised Divisional Secretariat Divisions (DSDs), particularly Colombo, Kolonnawa, and Kaduwela.

The observed shift toward more urban-dominated inundation patterns is consistent with earlier findings in Colombo and comparable tropical coastal cities, where impervious surface expansion and wetland loss amplify surface runoff and reduce natural retention capacity (Gunawardena & Wedage, 2017; Jarihani et al., 2023). The comparatively limited inundation in less urbanised and upland DSDs further supports the role of terrain and remaining natural land covers in moderating flood propagation. Although wetlands occupy a reduced spatial extent, their continued inundation highlights their persistent hydrological function, reinforcing the need to protect remaining wetland buffers (Dassanayake et al., 2023).

From a flood-management perspective, the results imply that prevailing development trajectories are increasing exposure faster than flood-mitigation capacity. These findings support the need to integrate flood hazard information into zoning and development controls, prioritise drainage upgrades in repeatedly affected DSDs, and strengthen wetland conservation and restoration as nature-based flood mitigation measures. The DSD-level evidence produced here provides a practical basis for targeting interventions and monitoring whether land-use controls are reducing exposure over time.

Several limitations should be acknowledged. Historical LULC mapping relied on MODIS MCD12Q1 at coarse spatial resolution, while flood validation was based on visual agreement with Sentinel-2 water indices and official flood situation reports rather than quantitative in-situ accuracy assessment. In addition, the analysis focused on selected flood periods rather than continuous event monitoring. Future research should incorporate higher-resolution elevation data, SAR time-series based event analysis, and socio-economic exposure indicators to support impact-based risk assessment and scenario-oriented planning. Extending this workflow to other rapidly urbanising districts in Sri Lanka and South Asia would further test its transferability and planning value. Overall, the findings confirm that rapid urban expansion is a key driver of increasing flood exposure in Colombo District and demonstrate the utility of multi-sensor EO approaches for evidence-based, scalable flood risk management in tropical urban regions.

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BIOGRAPHICAL NOTES

HSR Hettikankanama

Srimani Rojitha Hettikankanama is a PhD candidate whose research focuses on urban heat island effects, sustainable urban planning, and Climate-Responsive Design. She holds a BSc in Surveying Sciences and possesses a strong academic foundation in Geospatial Analysis, Remote Sensing, and Urban Climate Studies. She was honoured as the Best Student of the Year (Gold Medalist) at the Faculty of Geomatics, Sabaragamuwa University of Sri Lanka, in recognition of her outstanding academic achievements and excellence in extra-curricular activities. Srimani further expanded her professional expertise through an internationally sponsored internship in the Maldives, and she later served as the first Geospatial Surveyor in the Division of Business Development, International Relations, Climate and Geospatial Engineering at Central Engineering Services Pvt Ltd, where she contributed to geospatial applications in industry. Her doctoral research integrates geospatial technologies to address pressing urban environmental challenges, with a particular emphasis on developing sustainable planning strategies for climate-resilient cities. Beyond her research, Srimani is an active member of the IEEE GRSS Sri Lanka Chapter, where she is committed to knowledge sharing, student mentorship, and fostering interdisciplinary collaboration. She continues to contribute to the academic and professional geospatial community through research dissemination, outreach, and capacity-building initiatives, bridging the gap between science, technology, and practical urban solutions. She has presented her research at RESCON and has presented an accepted abstract at IGARSS 2025 in Brisbane, Australia, where she also received an IEEE GRSS travel grant.

SM Dassanayake

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