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RESEARCH ARTICLE

Coastal Dynamics

Spatial and temporal changes of land use land cover distribution in selected sites of the southern coastal zone of Sri Lanka

WMIC Wijesundara[1*], DUV Gunathilaka[1], SK Madarasinghe[1], J Andrieu[2], G Muthusankar[2], NR Kankanamge[3] and KAS Kodikara[1]

[1] *Department of Botany, Faculty of Science, University of Ruhuna, Matara, Sri Lanka.*
[2] *GEOSpatial Monitoring and Information Technology (GeoSMIT) Department, French Institute of Pondicherry (IFP), Pondicherry, 605001, India.*
[3] *Earth and Ocean Sciences, School of Natural Sciences and Ryan Institute, National University of Ireland Galway H91 TK33, Ireland.*

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Abstract: The southern coastal zone of Sri Lanka has been subjected to a variety of natural and anthropogenic influences over the past three decades. Understanding impacts of such influences on Land Use Land Cover (LULC) is vital for proper management of the coastal zone. This study, therefore, focused on mapping the change/s in the distribution of selected LULC in the selected sites, Bundala, Galle, Kalametiya, and Hambantota of the southern coastal zone, over last 24 years using satellite imagery. LULC maps of nine classes (mangrove, inland vegetation, marsh and grass, sand, bare land, built-up, cultivation, water, and unclassified) were created by employing an on-screen digitization technique achieving an accuracy of >70%. Trend analysis and two-sample proportion tests were used for statistical analyses, whereas geometric calculations were used for descriptive analyses. The results showed the highest overall change in LULC in Kalametiya, followed by Hambantota, Galle, and Bundala. The changes in the LULC classes are mainly attributed to the conversion of water to mangroves, marsh and grass areas in Kalametiya, water to built-up areas in Hambantota, cultivations to built-up areas in Galle, and marsh and grass areas to bare lands in Bundala. The causes of LULC changes were site specific. Trend analyses indicate the least LULC changes in Bundala possibly by 2025. The study highlights the significance of taking into account geographical dislocations when considering and anticipating the potential impacts of development projects over broader extents.

Keywords: Land cover distribution, mapping, satellite imagery, southern coastal zone, spatial and temporal changes.

INTRODUCTION

A coastal zone in any country can be defined as the interface between the land and water (Ahmad, 2019; Adade *et al*., 2021). Coastal architecture comprises a continuum of coastal and terrestrial lands, aquatic systems including the network of rivers and estuaries, islands, transitional and intertidal areas, salt marshes, wetlands, and beaches (Batista *et al*., 2017; Bini & Rossi, 2021). From an ecosystem perspective it harbours kelp forests, mangroves, seagrass meadows, rocky shores, sandy shores, and salt marshes along the 620,000 km of coastline on earth (Ewel *et al*., 1998). Due to high productivity and structural complexity, ecosystems residing in the coastal zone are capable of provisioning manifold goods such as wildlife resources, fisheries, agriculture resources, water supply and energy resources, and ecosystem services such as climate mitigation, erosion control, recreation, tourism, and storm protection, which are of ecological, economic and social significance. Thus, these systems are crucial habitats that are integral for the existence of life (Ewel *et al*., 1998; McLeod *et al*., 2011).

Globally, more than one third (>40%) of the population is concentrated in the coastal zone (Gedan *et al*., 2011). At present, coastal zones are undergoing tremendous anthropogenic pressures attributed to increased population density, excessive reliance on resources, and urbanization driven by development projects (Neumann *et al*., 2015; Zhao *et al*., 2021). It was estimated that over half of the world's coastal habitats and natural

[*] Corresponding author (isuruwmic@gmail.com; https://orcid.org/0000-0001-8200-458X)

landscapes have been degraded in the recent past due to human activities, making them the most threatened and vulnerable areas of land-use change (Hyndes *et al*., 2014; Macreadie *et al*., 2017). The degradation of coastal habitats has profound impacts on their capacity in provisioning goods and services (Post & Kwon, 2000; Neumann *et al*., 2015).

Sri Lanka is a tropical island with a total land extent of 65,525 km^2 located in the Indian Ocean between latitudes 5º 55' and 9º 51' and longitudes 79º 52' and 81º 51' (Rathnayake *et al*., 2020). The country has a narrow coastal belt along the coastline of 1,730 km of which the land extent can be attributed to 24% of the total land extent of the country (Senevirathna *et al*., 2018). The coastal zone of the country is occupied by a variety of ecosystems, including mangroves, saltmarshes, seagrass meadows, marshes, grasslands, sand dunes. All of them, play a crucial ecological role. Moreover, being an island nation, the economy and social life of the country is excessively reliant on the coastal zone where over 65% of the population of Sri Lanka is concentrated in the narrow coastal stretch (Senevirathna *et al*., 2018). Following the introduction of an open economic policy in the late 1970s, multiple socioeconomic and political changes have taken place within the country, which triggered the initiation of multipurpose development projects including irrigation projects, transportation and road development projects, agriculture expansion, the establishment of industrial zones and urban development projects (Mapa *et al*., 2002). The civil war which prevailed for 30 years since the 1980s afflicted negative impacts on the economy of the country, curtailing development, particularly on the Northern and Eastern coasts (Rathnayake *et al*., 2020). In 2004, the country experienced a natural catastrophic tsunami event, which hazardously affected the economy of the country as well as social life (De Alwis & Noy, 2019). Moreover, the adverse impacts the tsunami had on the coastal habitats, particularly on the Eastern and Southern coastal zones, and the post-tsunami restoration efforts of coastal ecosystems are of significant concern (Mukherjee *et al*., 2015; Kodikara *et al*., 2017). Many development projects have excessively been launched on the southern coastal zone, which primarily included highway development, tourism expansion, and exacerbated urbanization after the end of the civil war in 2009 (Rathnayake *et al*., 2020).

Considering the major historical events that occurred within the country, it is apparent that the natural land-use patterns have heavily been affected leading to manifold changes (Mapa *et al*., 2002). This is particularly true to the southern coastal zone where many past and recent development projects have been carried out. Thus, pristine coastal habitats were transformed or converted to a variety of other land uses such as infrastructure developments, tourism expansions, crop cultivations, and aquaculture developments (Gunawardena & Rowan, 2005).

The use of satellite images for mapping the land use and land cover (LULC) of landscapes is a highly recognized tool to determine LULC changes over multiple spatial and temporal scales (Kennedy *et al*., 2015). Thus, LULC maps can be used to monitor changes in natural habitats, biodiversity, natural productivity, and climate (Kennedy *et al*., 2015). Among the techniques available, the on-screen digitization is proven to be a better method for LULC mapping over pixel-based and unsupervised classification methods, particularly for areas having high fragmentation in the land-use (Herold *et al*., 2002; Madarasinghe *et al*., 2020).

Despite the wide acknowledgement of employing satellite remote sensing techniques for LULC mapping, the lack of accurate LULC maps is a major drawback for Sri Lanka, particularly to the southern coastal zone (Dissanayake, 2020). Therefore, this study focused on selected locations of the southern coastal zone of the country to address the key questions: (a) what is the present status of the LULC distribution in the coastal zone (b) what are the changes that occurred in the LULC during the past 24 years (c) what is the rate of changes in each LULC class when retrospective changes are considered, (d) what would be the area coverage of LULC for the next 5 years (by 2025) if the same rate of changes continue, and (e) which recommendations can be made for the better management of the southern coastal zone.

MATERIALS AND METHODS

Study area

The southern coastal zone of Sri Lanka is bordered by the Indian Ocean from the south and southwest and is located in the Southern province, about 116 km down south from the main city, Colombo. It covers the three districts Galle, Matara, and Hambantota, which together represents a wide range of climatic zones ranging from wet to dry climate. The wet zone receives a higher annual rainfall about 2500 mm, distributed throughout the year and the dry zone receives an annual rainfall less than 1750 mm mainly during the northeast monsoon period from December to March (Bellio & Kingsford, 2013). The four study locations were: Galle (6°1'31.84"N/80°15'11.47"E; 2,267 ha), Kalametiya (6°5'31.52"N/80°56'2.03"E; 3,063 ha), Hambantota (6°8'40.97"N/81°7'48.61"E; 3,076 ha), and Bundala (6°10'56.56"N/81°12'54.41"E; 3,003 ha) located in the Southern coastal zone of Sri Lanka (Figure 1).

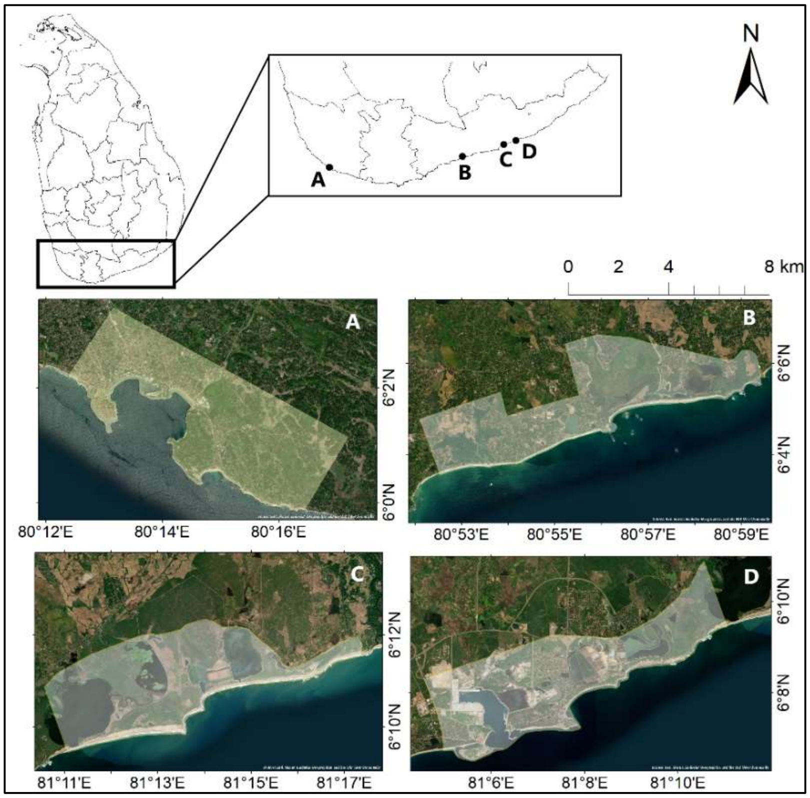

Figure 1: Study locations in the southern coastal zone of Sri Lanka. (A): Galle (B): Kalametiya (C): Hambantota, and (D): Bundala. The area demarcations of the study sites are shaded.

These locations were selected since they represent an array of diverse coastal habitats along the coastal stretch and are subjected to varying levels of protection within their ecological significance and level of conservation required. Thus, it makes a better representation of the southern coastal zone and enables to understand the effectiveness of policy measures towards conservation. Bundala is a protected area (National Park) managed under the provisions of the Fauna and Flora Protection Ordinance (FFPO) of 1993, which is administered by the Department of Wildlife Conservation (DWC) (Perera & De Vos, 2007). Further, giving consideration to its outstanding ecological value as a wetland, it was granted the Ramsar status (Piyankarage *et al*., 2004; Bellio & Kingsford, 2013). Consequently, coastal habitats in the area play a vital role in sustaining ecological significance. The study site Kalametiya is a partially protected area, where protection is enforced only to the extent of the Kalametiya sanctuary. Thus, human interference could be observed within the area beyond protection. After the civil war ended in mid-2009, the government focused on enhancing the country's infrastructure, especially through highway and reservoir construction (Rathnayake *et al*., 2020). Hambantota is an area heavily subjected to development projects since 2008 with the initiation of the Hambantota port construction (Kavirathna *et al*., 2021), followed by construction of the southern expressway and associated developments. Consequently, Galle can be considered the most urbanized compared to the other three sites, probably because those experiences intensified anthropogenic influences primarily being a tourism and heritage hotspot (Dissanayake, 2020).

Further, following the tsunami in 2004, it received greater attention where many infrastructure development projects were initiated focusing on rehabilitation of the areas affected. Thus, rapid expansion in the infrastructure was prominent compared to other sites (Dissanayake, 2020).

Satellite data collection

LULC maps available at the survey department of Sri Lanka were obtained for the two years 1996 and 2007. Further, Google Earth archive images for the year 2017 and QuickBird-2 high-resolution (0.5 m) satellite imagery for the year 2020 were obtained to create LULC maps for the study areas. The satellite image selection was done depending on the image availability. A summary of the satellite imagery used for the study is given in Table 1.

Table 1: Summary of satellite imagery used for the study

Location	Source	Satellite platform	Date of acquisition	Spatial resolution (m)
Bundala	Google Earth Pro	CNES/Airbus	15/10/2017	1.0
	Digital Globe	QuickBird-2	19/08/2020	0.5
Galle	Google Earth Pro	Maxar Technologies	07/02/2017	1.0
	Digital Globe	QuickBird-2	23/04/2020	0.5
Kalametiya	Google Earth Pro	Maxar Technologies	02/01/2017	1.0
	Digital Globe	QuickBird-2	23/04/2020	1.0
Hambantota	Google Earth Pro	CNES/Airbus	01/05/2017	1.0
	Digital Globe	QuickBird-2	19/08/2020	0.5

These images were georeferenced using 20-30 ground control points obtained by GPS (eTrex Gamin). Image processing was carried out using ArcGIS 10.3 software. Study areas were extracted from the satellite images by clipping with the boundary polygons delimitating study sites. Mosaics were created for imagery obtained from the Google Earth platform for each site, maintaining a consistent spatial resolution of 1.0 m. True colour composites were created for the QuickBird imagery prior to use for mapping.

Mapping of study sites

Mapping was carried out using ArcGIS 10.3 software. Nine LULC classes were considered which include categories; mangrove, inland vegetation, marsh and grass, sand, bare land, built-up, cultivation, water, and unclassified. The on-screen digitization technique was employed for the mapping. Digitizing of all satellite imagery was performed manually maintaining a consistent eye altitude ratio of 1:1500 (m). Each LULC type was identified using image attributes such as size, texture and tonality coupled with ground verification and was demarcated using shapefile polygons. The description of criteria used to refer LULC classes are described in Table 2.

Table 2: Description of LULC classes considered during the study

LULC class	Description of reference criteria
Built-up area	Areas of main towns, cities, build-ups, homestead and gardens
Bare land	Areas of bare soil without significant vegetation and build-up and water regions
Cultivation	Areas of main plantation crops (paddy, coconut, tea, rubber and *chena*)
Inland vegetation	Areas of natural forest, scrub and patches of vegetation larger than 0.01 ha
Mangrove	Areas of mangrove distribution
Marsh and grass	Areas of marsh and grass distribution
Sand	Areas of sand and beaches including scattered vegetation
Unclassified	Areas not belonging to any of the classes concerned
Water	Areas of natural water bodies and artificial waterways and channels

Area estimations were obtained for each polygon representing the respective LULC type, and maps were superimposed to obtain area gains and losses between the two years 1996 and 2020 using overlay analysis.

Map accuracy assessment

Accuracy Assessment for the LULC maps was carried out for the year 2020 using 50 random locations for each study site, created using ArcGIS 10.3 software. Ground verification of each random location was carried out through observations using field validation achieved by onsite visits to the study sites. Overall, accuracy was then calculated for each study site using Equation 1 (Janssen & Vanderwel, 1994).

{Overall accuracy = No. of confirmed observations / 50 * 100} … (1)

Statistical analyses

All statistical analyses, including descriptive and inferential, were performed using R statistical software with a significance level of 0.05. Mean and standard deviation for the area values was calculated as descriptive statistics. The significance in the area change of each LULC class resulting from the overlay analysis was obtained using the two-sample proportion test, considering the area statistics of 1996 and 2020 for each study site. To assess the rate of change in the LULC over the study period, a trend analysis was carried out for the area statistics of each LULC class for all years. Linear and quadratic functions were utilized for trend analysis. The inference of the rate of change of each LULC class over the period was used to predict the area cover by 2025. Separate two-sample proportion tests were carried out for each study site, considering each LULC class, to assess the significance of area change between 2020 and the area predicted for the year 2025.

RESULTS AND DISCUSSION

The overall accuracy of the maps created for all the study sites exceeded 70%; Galle reported the highest level of accuracy (84%), while Kalametiya, Bundala and Hambantota sites achieved 82.2, 79.5 and 72.3% overall accuracy, respectively. The distribution of LULC classes varied between the study locations. A high degree of dominance in the built-up areas was prominent in Galle, where over 60.9% of the distribution of the total land extent was reported at all temporal scales. In contrast, the Bundala site experienced a dominance in inland vegetation and water with 41.7 and 38.8% of distribution, respectively, compared to other categories. Comparatively intermediate dominancy was observed in the LULC class distribution for the Kalametiya and Hambantota sites.

According to the results of the two-sample proportion test, all sites reported significant changes in the LULC distribution between 1996 and 2020. The details of the overall area changes of the LULC classes of study sites are given in Table 3.

Bundala

All the classes, except the built-up area category, reported significant land cover changes during the study period in the Bundala site. The bare land class showed the highest area change with a gain of 157.4 ha, which is attributed to a 5.1% change during the reporting period. The second most dynamic land cover class was inland vegetation, which changed by a loss of 4.5%. Marsh and grass category declined by 4.0% during the period, which was the third most dynamic class. Water and sand categories indicated significant gains of 2.2% while a loss of 2.2% was reported for the cultivation category.

Galle

The highest land cover change in the Galle site was observed for cultivation, where it experienced a loss of 335.8 ha representing a change of 14.8% during the study period. A comparatively similar change was reported for the built-up area category indicating a gain of 14.4% of its land cover. The increase in the inland vegetation cover was by 2.4%. Abatement of mangrove cover was significant which reported a reduction of 1.2% of its cover during the study period. Despite being significant, comparatively less (<1.1%) area changes were reported for other LULC categories. Marsh, grass, and sand LULC classes changed insignificantly.

Kalametiya

The highest significant land cover change in Kalametiya was reported for mangrove, marsh, and grass categories, resulting in a total area gain of 633.7 ha, which attributed to a change of 20.7%. The second highest change was for water, which resulted in a loss of 569.4 ha representing a change of 18.6%. Loss of cultivation (7.5%) was observed as the third-largest change in Kalametiya. Other land-use classes, except unclassified, reported significant gains for the study period.

Table 3: Area estimations of LULC classes in 1996 and 2020 and the overall area changes from 1996 to 2020. Area gains over the period are indicated with '+' signs while area losses are with '–' signs. Significant area changes ($p < 0.05$) are marked with an asterisk (*). p values obtained through the two-sample proportion test for the area statistics in 1996 and 2020 indicate the level of significance in area change at 95% confidence level

LULC classes	Area (ha)		Area change (1996-2020)		p value
	1996	2020	ha	%	
Bundala					
Built-up areas	75.2	78.1	+2.9	+0.1	0.877
Bare land	0.0	157.4	+157.4*	+5.2	< 2.2e-16
Cultivation	66.9	0.0	-66.9*	-2.2	5.396e-16
Inland vegetation	1386.4	1252.6	-133.8*	-4.5	0.001
Marsh and grass	143.7	22.2	-121.5*	-4.0	< 2.2e-16
Sand	150.4	231.4	+81.0*	+2.7	2.328e-05
Water	1180.9	1261.9	+80.9*	+2.7	0.036
Galle					
Built-up areas	1380.9	1707.2	+326.3*	+14.4	< 2.2e-16
Bare land	0.0	16.9	+16.9*	+0.7	0.000
Cultivation	613.9	278.1	-335.8*	-14.8	< 2.2e-16
Inland vegetation	10.0	64.2	+54.2*	+2.4	4.749e-10
Mangrove	61.4	33.4	-28.0*	-1.2	0.005
Marsh and grass	91.2	112.5	+21.3	+0.9	0.1456
Sand	22.5	12.5	-10.0	-0.4	0.1267
Unclassified	32.5	13.0	-19.5*	-0.9	0.006
Water	54.7	29.1	-25.5*	-1.1	0.007
Kalametiya					
Built-up areas	937.7	809.4	-128.4*	-4.2	0.000
Bare land	0.0	44.7	+44.7*	+1.5	5.373e-11
Cultivation	590.2	361.6	-228.6*	-7.5	9.987e-16
Inland vegetation	556.5	754.2	+197.7*	+6.5	8.904e-10
Mangrove, marsh and grass	93.6	727.4	+633.7*	20.7	< 2.2e-16
Sand	40.8	88.1	+47.3*	+1.5	3.762e-05
Unclassified	2.9	6.1	+3.2	+0.1	0.463
Water	841.7	272.3	-569.4*	-18.6	< 2.2e-16
Hambantota					
Built-up areas	630.5	1346.0	+715.5*	+12.0	2.2e-16
Bare land	0.0	1.3	+1.3	+0.04	0.792
Cultivation	58.1	31.9	-26.2*	-0.9	0.007
Inland vegetation	1157.9	1055.3	-102.6*	-3.3	6.954×10^{-03}
Marsh and grass	28.0	86.2	+58.2*	+1.9	6.555e-08
Sand	164.4	85.6	-78.8*	-2.6	5.07e-07
Unclassified	60.7	31.3	-29.4*	-1.0	1.126e-06
Water	976.7	438.4	-538.5*	-17.5	2.2e-16

Hambantota

Loss of 538.3 ha of water areas (17.5%), and a gain of 715.5 ha of built-up areas (12.0%) were the significant changes observed in the Hambantota site. Changes in other LULC classes in the Hambantota site were less than 3.3% where losses were observed for the categories, cultivation, inland vegetation, sand, and unclassified, while gains were observed for marsh and grass. Although a gain was reported for the bare land category, the change was insignificant.

Further, to determine the area changes of the LULC classes, a major objective of the study was to graphically illustrate the locations where the changes (loss and gain) have occurred for each LULC class throughout the study. Such an understanding is vital to determine the relationships that exists between LULC classes within a study site. This was achieved through superimposing LULC maps of 1996 with 2020 using overlay analysis.

Bundala

The resulting LULC maps of the Bundala site together with respective area gain and loss maps are illustrated in Figure 2. The change in the LULC class distribution between years was a continuous evolution during the study period. Of the changes reported between 1996 and 2020, the transformation of marsh and grass patches located on the eastward side of the Embilikala lagoon (water body in the middle) and the southward extent of the Malala lagoon (the lagoon located further westward) to bare land was the major change observed. Over this period, the disappearance of cultivated lands was observed, which existed during 1996 on the east, north, and westward extent of the study site. They were reported to have been replaced by natural inland vegetation by 2020. Expansion of the built-up areas towards inland vegetated areas, particularly on the northward extent of the Bundala salt ponds (the largest built-up area of the site), was observed. Further, when the inland vegetation along the coast declined, the sand cover increased. Gains of water areas in the inland vegetated areas and gains of inland vegetated areas in the water areas were observed elsewhere in the map in a discontinuous manner.

Galle

LULC maps of Galle over the study period and respective area gain and loss maps are illustrated in Figure 3. The highest change in the distribution of LULC classes was reported between 1996 and 2007. Results of the overlay analysis between the years 1996 and 2020 show excessive urbanization of cultivated lands in the western part of the study site, which represents Galle's main city and adjacent towns. Moreover, built-up areas were further expanded in the cultivated areas of the eastern part to a lesser extent compared to that of the west, which primarily represents homesteads and gardens. A reduction in the built-up areas in some parts along the coast was reported, which were replaced by inland vegetation and sand; this could be attributed to destruction that occurred due to the tsunami in the year 2004. The conversion of mangrove areas to marsh and grass was a prominent observation. Further, the reduction in the overall mangrove cover during the study period is of significance. However, mangrove area gains were also reported in some areas of marsh and grass. Marsh and grass areas towards the eastward side of the study site remained unchanged.

Kalametiya

The LULC maps of the Kalametiya study site, along with the overlay gain and loss maps, are illustrated in Figure 4. The changes to the LULC classes between the years were observed as continuous changes over the study period; rapid changes were not observed. The most prominent change reported through the overlay analysis between 1996 and 2020, was the conversion of the water extent of the Kalametiya lagoon to a mixed area composed of mangrove, marsh, and grass. Further, inland vegetation and built-up areas (primarily homesteads and gardens) in the westward part of the site were transformed into a marsh and grass area. Some parts of the built-up areas in the eastward part of the site were converted to inland vegetation. Vegetated areas along the coast were converted to sandy beaches. Further, it was observed that built-up areas (140.3 ha) in close proximity to the main lagoon and marsh and grass habitats, which were inhabited by inland vegetation during 1996 showed significant gains.

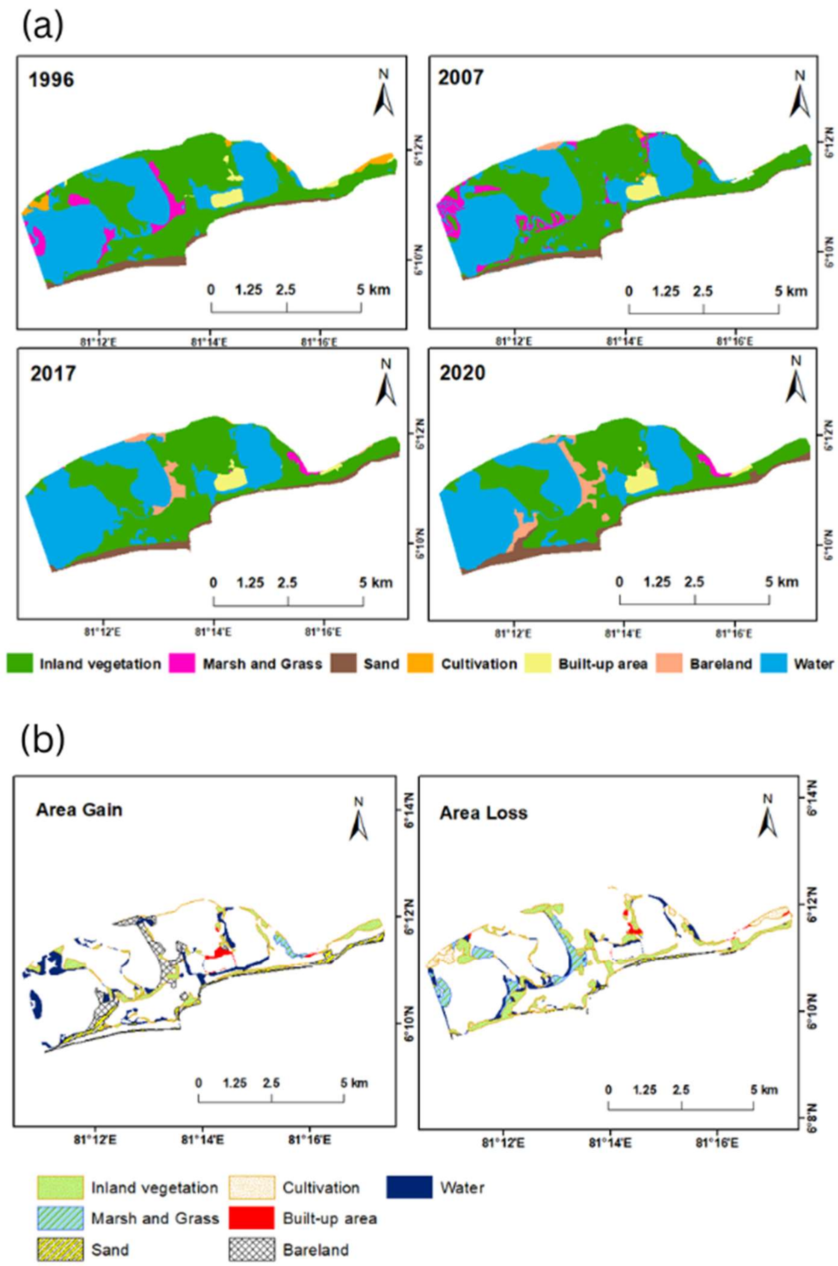

Figure 2: LULC and Overlay maps of Bundala study site. (a) LULC maps for 1996, 2007, 2017 and 2020; (b) Overlay maps representing areas of loss and gain between 1996 and 2020.

Hambantota

The resulting LULC maps of the Hambantota site, together with respective area gain and loss maps, are illustrated in Figure 5. Rapid changes in the LULC classes were observed between 1996 and 2017. A significant increase in built-up areas replacing water areas, particularly infrastructure development, was observed towards the in part of the site. Moreover, further decreases in the water areas were observed, which were replaced by built-up areas in the middle part of the site. Inland vegetation that existed in the eastward part of the site has transformed into built-up areas. Further, it was observed that to a lesser extent, inland vegetation has emerged in the areas of cultivation.

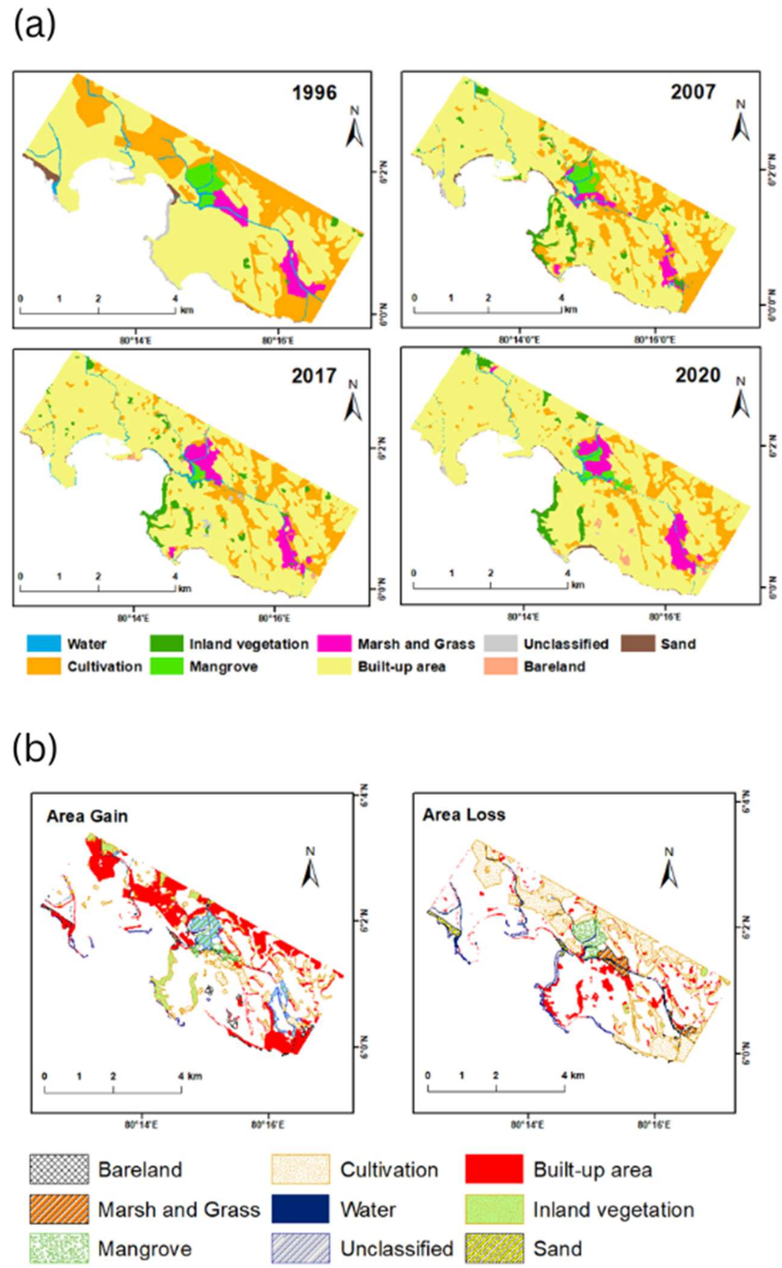

Figure 3: LULC and Overlay maps of Galle study site. (a) LULC maps for 1996, 2007, 2017, and 2020; (b) Overlay maps representing areas of loss and gain between 1996 and 2020.

The high value of the LULC change at Kalametiya is primarily related to the conversion of water areas to mangrove, marsh, and grass, which cumulatively contributed to 39.3% of the overall change. The transformation in the LULC distribution confirms the findings of Madarasinghe *et al*. (2020), who explained rapid siltation as a consequence of excessive freshwater input to the lagoon from the Udawalawa inland irrigation project, which came into operation in 1967. Rapid siltation and reduction in salinity contributed to excessive growth of *Sonneratia caseolaris* and *Typha angustifolia*, reducing the extent of mixed mangroves (Madarasinghe *et al*., 2020). The expansion of marsh and grass in the westward part of the Kalametiya site replacing inland vegetation could underlie a similar cause of sedimentation, as the area directly connects with a body of water with freshwater inputs. It was apparent from the 2007 LULC map that the built-up areas that existed during 1996 were converted to inland vegetation by 2007. From the field surveys, it was perceived that some of the tsunami-affected homesteads in the area were abandoned. Thus, the reported conversion could be mainly attributed to the 2004 tsunami event. The extent of sand along the shoreline is highly dynamic, dependent on the seasonality where narrow shorelines could be observed during the southwest monsoon spanning from May to September (Warnasuriya *et al*., 2018). The imagery of 2020 was obtained during the onset of the southwest monsoon. Thus, the gains in sand during the receding inland vegetation, particularly scattered beach vegetation, in 2020 could be explained as a natural phenomenon of beach variability. Despite the area underlying the Kalametiya lagoon being subjected to protection under the provisions of the FFPO, considerable human influences were observed at the immediate boundaries. Expansion of built-up areas in the areas of inland vegetation is evident in this aspect.

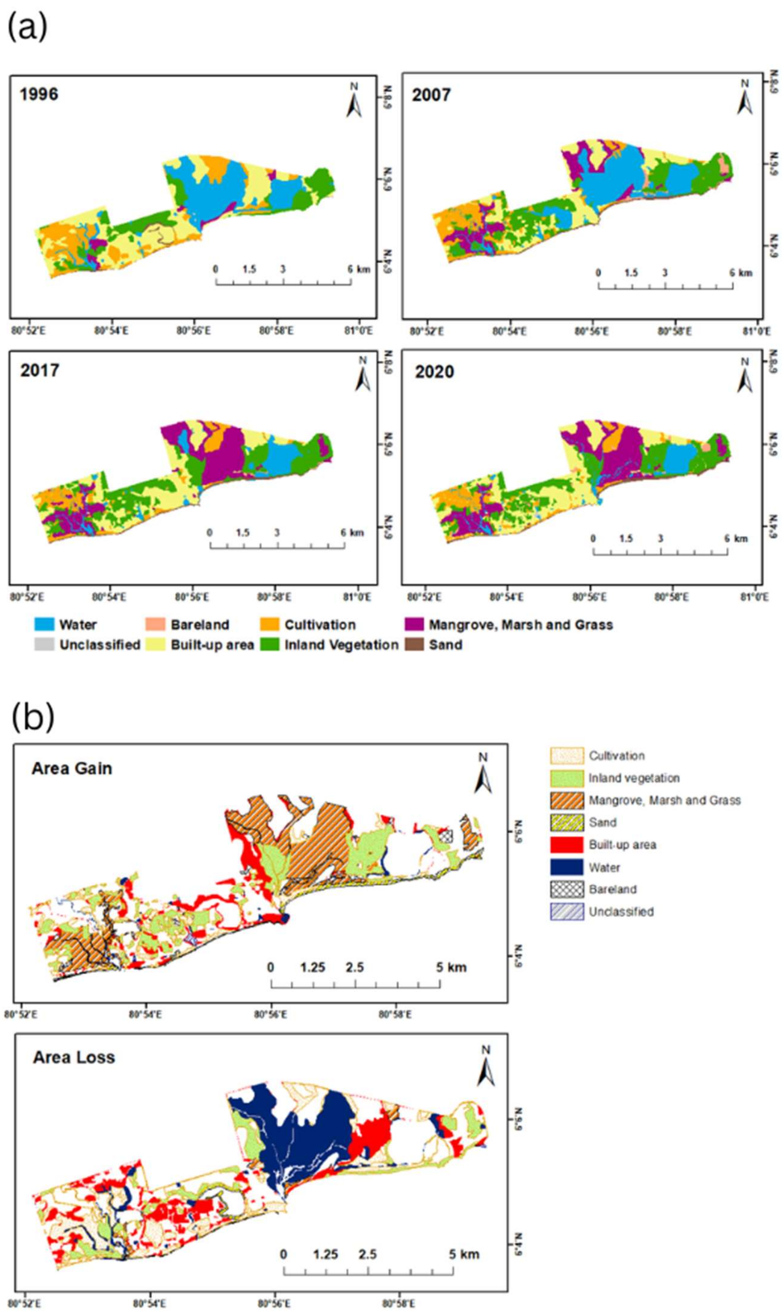

Figure 4: LULC and Overlay maps of Kalametiya study site. (a) LULC maps for 1996, 2007, 2017, and 2020; (b) Overlay maps representing areas of loss and gain between 1996 and 2020.

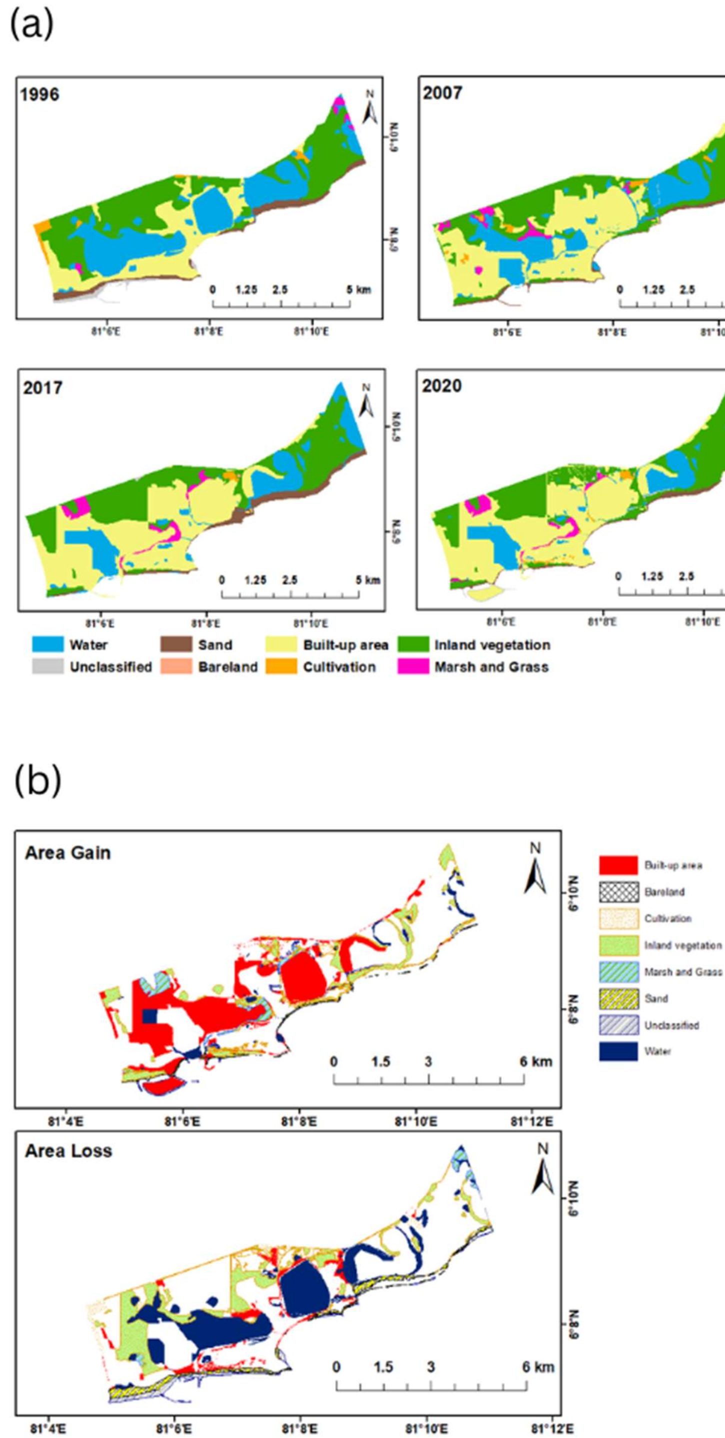

Figure 5: LULC and Overlay maps of Hambantota study site. (a) LULC maps for the 1996, 2007, 2017, and 2020; (b) Overlay maps representing areas of loss and gain between 1996 and 2020.

Most of the changes in Hambantota were attributed to an increase in built-up areas and reduction in water areas. This change in the land cover is recognisable owing to the construction of the Hambantota International Port, which was initiated during this period (Kavirathna *et al*., 2021). In the course of the port construction, the area was dredged inland to accommodate the port, such that substantial water cover of the natural water body was denied allowing the receding water. Hambantota has received substantial attention for development since 2009 after the end of the civil war. The government has initiated multiple projects such as the construction of the Hambantota-Wellawaya (CGHW) highway and the Magam Ruhunupura International Convention Centre (MRICC), which brought significant changes in the LULC distribution in the district. However, the study area was confined mostly to the area where the port was constructed. Therefore, changes attributed to other development activities were not considered during the study. Cultivated lands that existed during 1996 were reported to have receded since 2007. Thus, considering the time scale, it's difficult to emphasize that such changes are a result of the seasonality of cultivation.

The third highest overall LULC change was reported for Galle compared to the total land extent. Of this, 79.1% is attributed to the conversion of cultivated lands to built-up areas. This exemplifies the exacerbated urbanization in the area over the period. Importantly, from the study, it was perceived that most of the built-up area occurred (55.6%) during the period between 1996 and 2007. This was likely due to rehabilitation programs initiated during the post-tsunami period to develop the affected and destructed areas. Comparatively, coastal habitats conjointly confronted a less overall change accounting for 15.6% of the overall land cover change. However, the notion that coastal habitats have undergone less overall change should not be considered in light of the fact that they have been less affected, given the extent of coastal habitats compared to built-up area cover (>60.9% of the total area). Mangroves have receded by 45.6% during the period, where the highest depletion (77.6%) was recorded from 2007 to 2017. This could be primarily attributed to land reclamation for the construction of the Southern Express Highway, during the period. Following 2017, an emergence of mangrove cover was observed, which could be due to natural restoration of the area and improved efforts of mangrove conservation. The receded areas of mangroves were replaced by marsh and grass, resulting in an overall gain for marsh and grass during the period. This observation could be closely related to natural succession coming along with the gap-filling scenario as described by Wali, (1999). Thus, it is worth accentuating the significance of natural phenomena on land cover changes in the coastal habitats along with anthropogenic factors. Therefore, more comprehensive research related to natural succession is required. Replacement of inland vegetation and sand in the built-up areas, particularly close to the shoreline, which was observed after 2007 could be due to abandonment of built-up areas following damages caused by the tsunami. Significant losses in the water areas were observed. This is primarily due to seasonality changes, which cause variations in the rainfall and thus the area flooded.

Bundala reported the least overall land cover change compared with other study sites relative to the total land extent. The area consists of three main lagoons, Malala, Embilikala, and Bundala, which can be observed in the LULC maps and are located west to east of the site (Piyankarage *et al*., 2004). These water bodies primarily govern the ecology and diversity underlying the area (Piyankarage *et al*., 2004; Chandana *et al*., 2012). Malala and Embilikala lagoons receive freshwater drainage from the upstream irrigation scheme 'Kirindi Oya Irrigation settlement' (came into operation in 1989) throughout the year, preventing the water bodies from drying out during the dry season (Piyankarage *et al*., 2004; Bellio & Kingsford, 2013). However, contrastingly Bundala lagoon shows the natural flood and drying cycles following seasonal fluctuations in rainfall (Bellio & Kingsford, 2013). Among the reported changes, the major change, the conversion of marsh and grass areas to bare land, can be attributed to the hydrology of the area. Long-term drying out of certain areas at the edges of lagoons could result in barren land. Changes in the water areas could also be due to seasonal variations in the rainfall. The construction of salt ponds in the westward part of the Bundala lagoon was initiated during the 1980s, (*Rathnayake, personal communication, 15 July 2021*), which has expanded since then. The disappearance of cultivated lands could be attributed to improved enforcement of regulations hindering cultivation practices within the protected area.

Anticipated area changes by 2025

The summary results of the trend analysis predicting the areas for 2025 of each LULC class and the predicted rate of change in the LULC classes are given in Table 4. All the LULC classes of the Bundala and Hambantota sites failed to demonstrate a significant model, which enabled a precise prediction of the area change given that the p-value was less than the 95% confidence level. Moreover, according to the 2-sample proportionate test, the Bundala site did not show any significance in the predicted area change for all the LULC classes from 2020 to 2025. However, in Hambantota, there were significant losses in the LULC classes of water area (120.4 ha), cultivation (19.6 ha), and unclassified (29.2 ha), and a significant gain in the built-up areas (181.6 ha). In contrast, in Galle, there was a significant loss in the LULC class cultivation (68.2 ha), and significant gains in the LULC classes built-up areas (77.6 ha) and inland vegetation (30.9 ha) (Figure 6). Although the Galle mangroves resulted in a predicted area change (a loss of 21.6 ha), the trend analysis failed to demonstrate any significance. The LULC class marsh and grass in Kalametiya resulted in a significant area gain of 189.0 ha (Figure 6).

Table 4: Results of the trend analysis for LULC classes in the southern coastal belt. LULC classes with significant trends are indicated with an asterisk (*) based on the p values obtained through trend analysis at the 95% confidence level; significant area changes from 2020 to 2025 are indicated with a double asterisk (**) based on the p values obtained through two-sample proportion tests at the 95% confidence interval. The rate of area change for LULC classes was calculated for the 2020 – 2025 period.

LULC classes	Area (ha)				Predicted area in 2025 (ha)	p value trend analysis	Area change (2020-2025) ha	p value 2-sample proportion test	Rate of change 2020 -2025 (ha/y)
	1996	2007	2017	2020					
Bundala									
Built-up areas	75.2	61.4	65.3	78.1	70.1	0.327	-8.0	0.560	-1.6
Bare land	0.0	19.1	79.5	157.4	151.8	0.103	-5.6	0.788	-1.1
Cultivation	66.9	9.9	2.3	0.0	-20.5	0.080	-20.5	NC	-4.1
Inland vegetation	1386.4	1458.8	1371.1	1252.6	1296.8	0.224	44.2	0.259	8.8
Marsh and Grass	143.7	168.9	23.5	22.2	-0.7	0286	-23.0	NC	-4.6
Sand	150.4	119.0	231.4	231.4	203.8	0.336	203.8	0.186	40.8
Water	1180.9	1166.0	1261.9	1261.9	1302.0	0.520	1302.0	0.308	260.4
Galle									
Built-up areas*	1380.9	1565.4	1676.2	1707.2	1784.8	0.006	77.6**	0.007	15.5
Bare land	0.0	5.9	9.4	16.9	17.3	0.056	0.4	1.000	0.08
Cultivation*	613.9	434.1	239.2	278.1	210.0	0.005	-68.2**	0.001	-13.6
Inland vegetation*	10.0	94.7	79.8	64.2	95.1	0.048	30.9**	0.015	6.2
Mangrove	61.4	42.4	9.6	33.4	11.9	0.513	-21.6**	0.002	-4.3
Marsh and Grass	91.2	57.4	103.5	112.5	108.1	0.237	-4.4	0.814	-0.9
Sand	22.5	24.0	11.4	12.5	9.9	0.342	-2.6	0.735	-0.5
Unclassified	32.5	9.9	13.6	13.0	6.3	0.183	-6.7	0.194	-1.3
Water	54.7	34.1	34.4	29.1	23.8	0.090	-5.3	0.552	-1.0
Kalametiya									
Built-up areas	937.7	573.2	742.9	809.4	700.0	0.686	-109.4**	0.001	-21.9
Bare land	0.0	60.1	12.1	44.7	44.1	0.713	-0.6	1.000	-0.1
Cultivation	590.2	405.5	338.3	361.6	275.8	0.062	-85.8**	0.000	-17.1
Inland vegetation	556.5	710.4	820.9	754.2	853.1	0.080	98.9**	0.004	19.8
Mangrove, marsh and grass*	93.6	368.1	756.0	727.4	916.4	0.015	189.0**	0.000	37.8
Sand	40.8	80.3	78.0	88.1	97.9	0.106	9.7	0.512	1.9
Unclassified	2.9	2.5	0.0	6.1	3.4	0.871	-2.7	0.581	-0.5
Water	841.7	863.6	315.5	272.3	173.1	0.103	-99.2**	0.000	-19.8
Hambantota									
Built-up areas	630.5	1121.7	1279.4	1346.0	1527.6	0.141	+181.6	0.001	-25.5
Bare land	0.0	0.0	1.6	1.3	1.8	0.385	0.5	1.000	0.1
Cultivation	58.1	33.9	12.1	31.9	12.3	0.422	-19.6**	0.005	-3.9
Inland vegetation	1157.9	1030.8	1024.0	1055.3	1000.0	0.063	-55.3	0.142	-11.1
Marsh and Grass	28.0	95.0	93.1	86.2	111.0	0.050	24.9	0.085	5.0
Sand	164.4	90.3	166.7	85.6	103.5	0.879	17.9	0.212	3.6
Unclassified	60.7	3.1	2.8	31.3	2.2	0.208	-29.2**	0.000	-5.8
Water	976.7	701.8	496.9	438.4	318.0	0.170	-120.4**	0.000	37.7

NC: Not calculated

However, all other LULC classes failed to demonstrate such a trend for the Kalametiya site. Further, significant area losses between 2020 and 2025 were reported for the built-up area (109.4 ha), bare land (0.6 ha), cultivation (85.8 ha) and water (99.2 ha), and a gain for inland vegetation (98.9 ha) in Kalametiya.

Bundala, which is a protected area, has changed the least over the 24 years of the study period, and is expected to change at an insignificant rate during the next five years. This is mainly due to the level of protection provided for the area where the anthropogenic influence is minimal. Although Hambantota failed to demonstrate any significance in the prediction model, it is important to recognize that the area change between 2020 and 2025 reported significant losses in the LULC classes of water and cultivation and gains in the built-up areas. The values forecast for area gain for water could be affected by the seasonal variation of the satellite imagery used for digitization. Kalametiya resulted in gains in the marsh and grass cover in the preceding five years at a rate of 37.8 ha/year, which is a 1.2% increase per year. This could be due to continuing siltation of the area, which enables more space for the occurrence of marsh and grass. Galle was recognized as a site largely vulnerable for changes in the LULC distribution predominantly for built-up area, inland vegetation, and cultivation. This suggests, Galle will continue its urbanization converting its agricultural lands during the next 5 years at a rate of 15.5 ha/year, which represent a 0.7% increase per year.

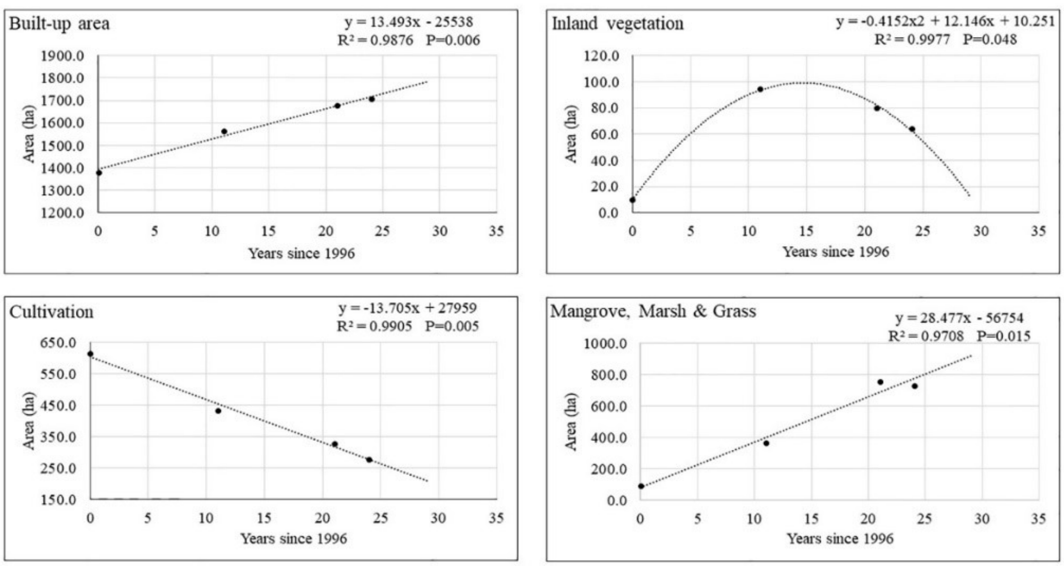

Figure 6: Graphs showing the trends of area changes in LULC classes for Galle (built-up area, inland vegetation, and cultivation) and Kalametiya (mangrove, marsh and grass). The data points of each graph align to 0, 11, 21 and 24 of the x axis, which represents the years 1996, 2007, 2017, and 2020, respectively. The trend line is forecast for the year 2025, which is 29 years after the reference year (1996).

Recommendations

This study indicated that changes in the LULC between the study sites are varied, depending on the level of anthropogenic influences, natural phenomena, and the level of protection measures imposed. Therefore, policy measures should be highly localised, addressing key drivers of LULC changes and providing solutions for areas of concern. Further, the imposition of protection measures to prevent localised human activities alone will not provide adequate resistance to changes in LULC. Rather, attention should be paid to anticipating the possible consequences of development projects despite geographical dissociation. It is apparent that anthropogenic influences are a major driving force triggering changes in habitat distribution. However, natural factors may lead to drastic changes in coastal habitats in the long term. Enhancing knowledge of natural phenomena affecting habitat alteration such as natural succession and gap-filling scenarios, is vital for a better understanding of changes associated with coastal habitats. Thus, further research on the topic should be encouraged. A monitoring scheme that is capable of reporting short-term changes at very high resolution is recommended. The use of modern technology employing drones is recommended.

Limitations of the study

Although on-screen digitization was performed between years for each site employing high-resolution satellite imagery, they represent different seasons of the monsoons. Thus, understanding the causes of some LULC changes, particularly those governed by rainfall and hydrology, was constrained. Uncertainties such as political instability, debt and financial instability, health and safety, and national security were not included in the prediction model. Thus, predictions could also be affected by these uncertainties.

CONCLUSION

This study empirically investigated the spatial-temporal changes of LULC in Bundala, Galle, Kalametiya, and Hambantota, which are located in the southern coastal zone of Sri Lanka. Changes in the LULC between different locations along the southern coastal zone are varied, depending on the level of anthropogenic influences, natural phenomena, and the level of protection measures imposed. The results of the study revealed the highest changes in the LULC in Kalametiya, followed by Hambantota, Galle, and Bundala. Bundala, being a protected area, would be the least susceptible to future LULC changes. The causes of changes in the LULC are highly localised to individual sites. Consequently, management should follow a similar trajectory. This study highlights the significance of providing considerable attention to anticipating possible consequences of development projects before initiation despite geographical dislocation.

Conflict of interest statement

Authors have no conflict of interest to disclose.

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REFERENCES

Adade R., Aibinu A.M., Ekumah B. & Asaana J. (2021). Unmanned Aerial Vehicle (UAV) applications in coastal zone management- a review. *Environmental Monitoring and Assessment* **193**(3): 1–12.
DOI: https://doi.org/10.1007/s10661-021-08949-8

Ahmad H. (2019). Bangladesh coastal zone management status and future trends. *Journal of Coastal Zone Management* **22**(1): 1–7.

Batista C.M., Suárez A. & Saltarén C.M.B. (2017). Novel method to delimitate and demarcate coastal zone boundaries. *Ocean and Coastal Management* **144**: 105–119.
DOI: https://doi.org/10.1016/j.ocecoaman.2017.04.021

Bellio M. & Kingsford R.T. (2013). Alteration of wetland hydrology in coastal lagoons: Implications for shorebird conservation and wetland restoration at a Ramsar site in Sri Lanka. *Biological Conservation* **167**: 57–68.
DOI: https://doi.org/10.1016/j.biocon.2013.07.013

Bini M. & Rossi V. (2021). Climate change and anthropogenic impact on coastal environments. *Water* **13**(9): 1182.
DOI: https://doi.org/10.3390/w13091182

Chandana E.P.S., Amarasinghe N.D.S. & Samayawardhena L.A. (2012). Factors affecting the avi-faunal distribution in the three lagoons (Malala, Embillakala and Bundala Lewaya) of Bundala National Park (A Ramsar Wetland) in Sri Lanka. *Ruhuna Journal of Science* **3**(3).

De Alwis D. & Noy I. (2019). Sri Lankan households a decade after the Indian Ocean tsunami. *Review of Development Economics* **23**(2): 1000–1026.
DOI: https://doi.org/10.1111/rode.12586

Dissanayake D.M.S.L.B. (2020). Land use change and its impacts on land surface temperature in Galle City, Sri Lanka. *Climate* **8**(5): 65.
DOI: https://doi.org/10.3390/CLI8050065

Ewel K., Twilley R. & Ong J.I.N. (1998). Different kinds of mangrove forests provide different goods and services. *Global Ecology and Biogeography Letters* **7**(1): 83–94.
DOI: https://doi.org/10.2307/2997700

Gedan K.B., Kirwan M.L., Wolanski E., Barbier E.B. & Silliman B.R. (2011). The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. *Climatic Change* **106**(1): 7–29.
DOI: https://doi.org/10.1007/s10584-010-0003-7

Gunawardena M. & Rowan J.S. (2005). Economic valuation of a mangrove ecosystem threatened by shrimp aquaculture in Sri Lanka. *Environmental Management* **36**(4): 535–550.
DOI: https://doi.org/10.1007/s00267-003-0286-9

Herold M., Scepan J. & Clarke K.C. (2002). The use of remote sensing and landscape metrics to describe structures and changes in urban land uses. *Environment and Planning* **34**(8): 1443–1458.
DOI: https://doi.org/10.1068/a3496

Hyndes G.A., Nagelkerken I., McLeod R.J., Connolly R.M., Lavery P.S. & Vanderklift M.A. (2014). Mechanisms and ecological role of carbon transfer within coastal seascapes. *Biological Reviews* **89**(1): 232–254.
DOI: https://doi.org/10.1111/brv.12055

Janssen L.L. & Vanderwel F.J. (1994). Accuracy assessment of satellite derived land-cover data: a review. *Photogrammetric Engineering and Remote Sensing (United States)* **60**(4): 419–426.

Kennedy R.E., Yang Z., Braaten J., Copass C., Antonova N., Jordan C. & Nelson P. (2015). Attribution of disturbance change agent from Landsat time-series in support of habitat monitoring in the Puget Sound region, USA. *Remote Sensing of Environment* **166**: 271–285.
DOI: https://doi.org/10.1016/j.rse.2015.05.005

Kodikara K.A.S., Mukherjee N., Jayatissa L.P., Dahdouh-Guebas F. & Koedam N. (2017). Have mangrove restoration projects worked? An in-depth study in Sri Lanka. *Restoration Ecology* **25**(5): 705–716.
DOI: https://doi.org/10.1111/rec.12492

Kavirathna C.A., Hanaoka S., Kawasaki T. & Shimada T. (2021). Port development and competition between the Colombo and Hambantota ports in Sri Lanka. *Case Studies on Transport Policy* **9**(1): 200–211.
DOI: https://doi.org/10.1016/j.cstp.2020.12.003

Macreadie P.I., Nielsen D.A., Kelleway J.J., Atwood T.B., Seymour J.R.., Petrou K., Connolly R.M., Thomson A.C., Trevathan-Tackett S.M. & Ralph P.J. (2017). Can we manage coastal ecosystems to sequester more blue carbon? *Frontiers in Ecology and the Environment* **15**(4): 206–213.
DOI: https://doi.org/10.1002/fee.1484

Madarasinghe S.K., Yapa K.K.A.S. & Jayatissa L.P. (2020). Google Earth imagery coupled with on-screen digitization for urban land use mapping: A case study of Hambantota, Sri Lanka. *Journal of the National Science Foundation of Sri Lanka* **48**(4): 357–366.
DOI: https://doi.org/10.4038/jnsfsr.v48i4.9795

Mapa R.B., Kumaragamage D., Gunarathne W.D.L. & Dassanayake A.R. (2002). Land use in Sri Lanka: Past, present and the future. In: *Proceedings of the 17th World Congress of Social Science,* Bangkok, Thailand, pp. 14–21.

Mcleod E., Chmura G.L., Bouillon S., Salm R., Björk M., Duarte C.M., Lovelock C.E., Schlesinger W.H. & Silliman B.R. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment* **9**(10): 552–560.
DOI: https://doi.org/10.1890/110004

Mukherjee N., Dahdouh-Guebas F., Koedam N. & Shanker K. (2015). An interdisciplinary framework to evaluate bioshield plantations: Insights from peninsular India. *Acta Oecologica* **63**: 91–100.
DOI: https://doi.org/10.1016/j.actao.2014.01.005

Neumann B., Vafeidis A.T., Zimmermann J. & Nicholls R.J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. *PloS one* **10**(3): e0118571.
DOI: https://doi.org/10.1371/journal.pone.0118571

Perera N. & de Vos A. (2007). Marine protected areas in Sri Lanka: a review. *Environmental Management* **40**(5): 727–738.
DOI: https://doi.org/10.1007/s00267-005-0154-x

Post W.M. & Kwon K.C. (2000). Soil carbon sequestration and land-use change: processes and potential. *Global Change Biology* **6**(3): 317–327.
DOI: https://doi.org/10.1046/j.1365-2486.2000.00308.x

Piyankarage S.C., Mallawatantri A.P., Matsuno Y. & Pathiratne K.A.S. (2004). Human impacts and the status of water quality in the Bundala RAMSAR wetland lagoon system in Southern Sri Lanka. *Wetlands Ecology and Management* **12**(5): 473–482.
DOI: https://doi.org/10.1007/s11273-004-6566-1

Priyashantha A.K.H. & Taufikurahman T. (2020). Mangroves of Sri Lanka: distribution, status and conservation requirements. *Tropical Plant Research* **7**: 654–668.
DOI: https://doi.org/10.22271/tpr.2020.v7.i3.083

Rathnayake C.W., Jones S. & Soto-Berelov M. (2020). Mapping land cover change over a 25-year period (1993–2018) in Sri Lanka using Landsat time-series. *Land* **9**(1): 27.

DOI: https://doi.org/10.3390/land9010027

Rupasinghe M.S. & Perera M.S.J. (2008). Some aspects of coastal zone management in Sri Lanka including impact of tsunami: A review. In: *Proceedings of the International Workshop on Coastal Ecosystems: Hazards, Management and Rehabilitation*, Purwokerto, Indonesia, p. 36.

Senevirathna E.M.T.K., Edirisooriya K.V.D., Uluwaduge S.P. & Wijerathna K.B.C.A. (2018). Analysis of causes and effects of coastal erosion and environmental degradation in Southern Coastal Belt of Sri Lanka special reference to unawatuna coastal area. *Procedia Engineering* **212**: 1010–1017.
DOI: https://doi.org/10.1016/j.proeng.2018.01.130

Wali M.K. (1999). Ecological succession and the rehabilitation of disturbed terrestrial ecosystems. *Plant and Soil* **213**(1): 195–220.
DOI: https://doi.org/10.1023/a:1004475206351

Warnasuriya T.W.S., Gunaalan K. & Gunasekara S.S. (2018). Google earth: A new resource for shoreline change estimation—Case study from Jaffna Peninsula, Sri Lanka. *Marine Geodesy* **41**(6): 546–580.
DOI: https://doi.org/10.1080/01490419.2018.1509160

Zhao L., Fan X. & He D. (2021). Landscape changes and their socio-economic driving factors in coastal zone. *Polish Journal of Environmental Studies* **30**(5): 4855–4869.
DOI: https://doi.org/10.15244/pjoes/133240