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RESEARCH ARTICLE

Remote Sensing

Land-use and land cover changes along the coastal belt of Hambantota district, southern Sri Lanka, over the period 1996-2017

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Abstract: Through the years, the green cover has been substantially reduced and transformed into human development projects and settlements in many cities of Sri Lanka. Hambantota, a southern coastal district, has faced similar changes over the last two decades. Therefore, this study was aimed at the Land-Use and Land-Cover (LULC) changes which had taken place along its coastal belt during the period, 1996–2017. Comparison was done among LULC maps bearing fourteen different classes for the years 1996 and 2017. The results reveal that all LULC classes except coconut plantations and paddy lands show significant area changes ($p < 0.05$) during the period considered. Among the LULC changes, forest cover showed the highest area change (2341 ha loss ($p < 0.05$)) while 358 ha of scrubland has been cleared to establish housing schemes. The settlements have significantly increased (1318 ha) and a considerable amount is due to development projects including the Hambantota port. The survey results show that 63.9% of the residents in the study area agreed that the natural environment of the city had been affected by the development projects. Analysis of LULC changes and Normalized Difference Vegetation Index (NDVI) data suggests that Hambantota coastal area has developed significantly at the cost of forests and associated vegetation from 1996 to 2017. Rapid economic and population growths are identified as the main driving forces for the LULC changes. These results deliver an important decision-making reference for LULC planning and sustainable development in the Hambantota coastal region, which is, in broad sense, valid for any booming city in the country and the world. The urban forestry concept can be an ideal sustainable move to compensate the green cover loss.

Keywords: Development projects, green cover loss, LULC planning, sustainability, urban forestry.

INTRODUCTION

Over the past decades, socioeconomic activities have substantially increased in urban areas compared to rural areas, mainly due to the migration of large rural populations to urban areas and to the expansion of urban areas to accommodate such large numbers of people (Yu *et al*., 2011). During urban development, Land Use and Land Cover (LULC) changed remarkably and such changes are intense in developing countries (Chen & Zhang, 2017). In general, conversion of natural vegetation and agricultural lands into built-up areas such as settlements, buildings, roadways, and parking areas become common during many urban development projects (Van & Bao, 2010; Ranagalage *et al*., 2017). This trend causes numerous environmental impacts, such as decrease in green cover and agricultural lands, environmental pollution, habitat destruction, etc., at local, regional, and global levels

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(Alphan, 2003; Shalaby & Tateishi, 2007; Rousta *et al*., 2018). The situation in Sri Lanka is not very different from world trends (Suthakar & Bui, 2008; Dissanayake *et al*., 2019; Ranagalage *et al*., 2019).

In the Sri Lankan context, many development projects came into practice after the tsunami in 2004 and the end of the war in 2009. The coastal district of Hambantota in the Southern Province, in particular, had received quite a high number of development projects. Geographically, Hambantota is the largest district in the southern province of Sri Lanka, where both dry and arid climatic conditions are found. It is situated from 5°58'16"N to 6°34'45"N and 80°36'28"E to 81°42'24"E, and is 261,915 ha in extent, representing 4% of the whole land area of the country.

Hambantota bears a high economic importance, particularly due to salt and fishing industries. It provides 60% of the country's salt production and about 13% of national fish catch (UDA, 2019). Additionally, it is a major tourist attraction due to sites such as the Bundala Bird Sanctuary, Yala National Wildlife Park, Ridiyagama Safari Park, and Dry Zone Botanical Garden. This district inherits a long history from the ancient Rohana Kingdom. People belonging to different races and religions, with Sinhalese forming the majority of the population, live in harmony (Department of Census & Statistics, 2012). It had a total population of 599,903 in 2012, according to the last census carried out, living in both urban and rural areas of the district (Department of Census & statistics, 2012).

Hambantota district borders the Indian Ocean from its southern and eastern directions, having a long coastal belt, which includes important coastal ecosystems such as scrub forests, mangrove forests, sandy beaches, and sand dunes. The two major national parks, Yala and Bundala, are the major tourist attractions in the Hambantota district. Yala was designated as a national park in 1938, and Bundala, in 1992. Bundala was declared as a Ramsar site in Sri Lanka in 1990 and as a biosphere reserve by UNESCO in 2005 (CEA/Euroconsult, 1993). Hambantota town, the district capital, and a few other urban cities are located along the coastal belt. A fragmented land-use pattern depicted by man-made constructions and cultivations could be observed in these urban areas.

Many changes in land-use practices have taken place in the Hambantota urban area in the recent past. Major development projects had been initiated after the tsunami in 2004 as well as after the eradication of civil war in 2009. Establishment of the Hambantota port and the Mattala airport have resulted an unprecedented change in land-use architecture in the area, and the living condition of the residents has been severely affected (Mariyathas *et al*., 2016; Madarasinghe *et al*., 2018). Construction of the port commenced in 2008 and was opened in 2010 after completion of the first phase. The port plays a vital role in international shipping routes between Asia and Europe (Kotelawala, 2017).

The tsunami had destroyed 2754 houses in the Hambantota district, which included 157 houses from the Tissamaharama Divisional Secretariat Division (DSD), 299 from the Ambalantota DSD, 1167 from the Hambantota DSD, and 1131 from the Tangalle DSD (source: Hambantota District Secretary's office). Therefore the LULC of the Hambantota coast has considerably changed after the tsunami in 2004. Madarasinghe *et al*. (2018) recorded an increase of settlements by about 15%, replacing scrubland, chena, and dry forests (~21%) in the Hambantota urban area during 1996–2016. This directly indicated a rapid economic growth, but with simultaneous green cover loss.

Although several studies had been conducted to study the LULC architecture and dynamics in other parts of the country (Lindström *et al.*, 2012; Dissanayaka, 2020; Rathnayake *et al.*, 2022), the booming city of Hambantota remained understudied. Despite the fast infrastructure development, little attention had been paid to study LULC dynamics of this booming city, associated impacts on the environment, and the living status of the residents. The available literature only focused on limited areas (one Divisional Secretariat Division (DSD), the Hambantota DSD, and one housing scheme, Siribopura) in the Hambantota district. Edirisooriya *et al.* (2021) have reported LULC changes in the Hambantota DSD from 2008 to 2019, and reveal a significant loss of total forest cover in the area from 41.95% in 2008 to 23.07% in 2019, while the built-up area has significantly increased. Furthermore, Perera *et al.* (2012) has evaluated the Siribopura Resettlement Housing Program, which was one of the resettlement programmes developed to relocate the communities affected by the tsunami in 2004 and communities displaced due to development projects in Hambantota. Even though population growth and urbanization have been taking place to a great extent in the coastal zone of the island, literature on the LULC changes of the coastal zone of Hambantota district and the effects of rapid urbanization on the coastal zone are scanty.

This study, therefore, was aimed at investigating the LULC changes occurred in the coastal belt of the Hambantota district over a period of two decades (1996–2017) and their effect on the environment and the social status of the residents. The following questions were addressed in the study: a) What were the LULC changes that have taken place during the study period? b) Were the LULC changes environmentally sustainable? c) If the LULC changes were not sustainable, what possible managerial actions could be taken to restore environmental sustainability? d) How did development-oriented changes affect the social status of the residents? The main working hypothesis of the study was that the LULC changes that took place during the past two decades were not environmentally sustainable.

MATERIALS AND METHODS

Study area

Hambantota is the largest of the three districts in the Southern Province with a total area of 261,915 ha and a 151 km long shoreline. The coastal belt of a minimum of 2 km width from the shoreline (adapting to the definition of 'coastal zone' in the Coast Conservation Act No. 57 of 1981, Sri Lanka) was taken into consideration in this study. All Grama Niladhari Divisions (GNDs) located within this 2 km width of the coastal belt of Hambantota district were considered and the landward margin of the belt was taken as GND boundaries so the belt always contains whole GNDs. Thus, the belt extends beyond the 2 km limit in some instances, and the widest is, for example, about 20 km where the Yala national park is located. This total inclusion of GNDs was necessary to use available data from GNDs. The total study area under this case study consists of seventy-four GNDs covering a total area of 79,683 ha. A digital map of the GND boundaries of Sri Lanka made in 2013 was obtained from the Sri Lanka Survey Department [Figure 1(a)] and the GNDs that are located within a 2 km distance from the shoreline were extracted and it was used as the study area vector [highlighted area in Figure 1(a)] in image processing and analysis in the present study.

LULC change analysis

Digital LULC maps of the coastal belt of the Hambantota district for 2017 and 1996 were used in this study. Details of the maps used are given in Table 1(a). The extraction of the area was done using ArcMap *v.*10.3 software using the study area vector mentioned earlier (Figure 1).

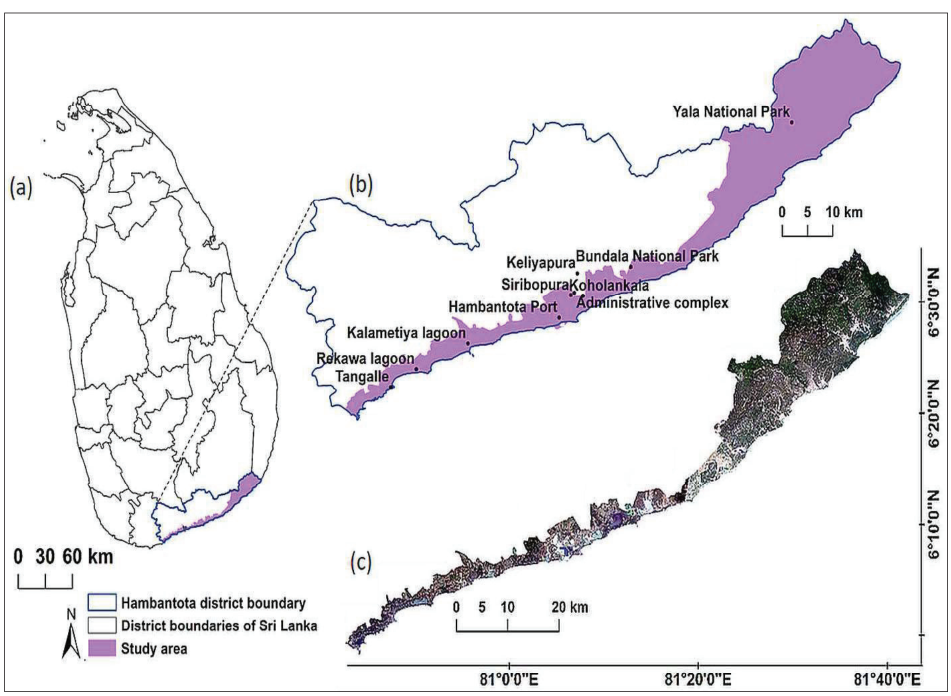


Figure 1: (a) Map of Sri Lanka showing the district boundaries and the coastal belt of Hambantota district taken into consideration in this study; (b) map of Hambantota district with some important locations along the study area; (c) Landsat 8 (2017) mosaicked satellite image showing the study area.

Thereby, fourteen LULC classes—bare lands, coconut plantations, forest, grassland and marsh, homesteads, mangroves, paddy lands, other cultivations, saltpan, sandy areas, scrubland and chena, settlements, water, and other land-uses—were identified to be studied in the LULC map of the Hambantota coastal belt in 2017. LULC maps of 1996 were bearing a classification system as reported in the Topographic Database Specifications and Data Dictionary (TDSDD), Sri Lanka Survey Department. Thus, digital maps were then reclassified into the 14-class classification system of the study through merging necessary LULC classes. For example, all the water bodies such as streams, rivers, ponds, canals, channels, reservoirs, and waterholes were merged to generate the LULC class 'water'. Subsequently, the area of each LULC class was estimated for both 1996 and 2017 through area statistics using ArcMap software. This was followed by an area loss and gain analysis (to determine area change from 1996 to 2017), carried out using the overlay analysis method in ArcMap software. Two-sample proportion test was applied using R statistical software (R *v*. 4.0.3) to test the significance of the area changes which occurred from 1996 to 2017 on the Hambantota coastal belt. Area statistics for the conversion of each LULC class from 1996 to another class by 2017 were derived by intersecting each overlay output separately with each LULC class in the two years, 1996 and 2017. For example, the area gain map of 'settlements', obtained as an overlay output, was again subjected to overlay analysis (intersecting) with the 'saltpan' LULC layer in 1996 to obtain the area of saltpan that was sacrificed for settlements by 2017. A transition matrix was generated using the area statistics obtained after overlay analysis to show all the area changes from one LULC to another during the 1996-2017 period.

Estimation of normalized difference vegetation index (NDVI)

NDVI's of the study area in 1997 and 2017 were estimated and compared in order to track the changes in greenness and vegetation health of the area over the two-decade period. This procedure was carried out merely to display the changes in vegetation of the area and to confirm

Table 1: Details of the image data used in the study.

1. Image data used for LULC change analysis

Map	Area covered	Year	Scale	Details
Digital LULC map	Coastal belt of Hambantota district	2017	1:17,500	©S.K. Madarasinghe. (Data from; Madarasinghe S.K. (2022). Investigation of land-use changes in Western and Southern coasts of Sri Lanka in the past two decades (1996-2017): A field based geo-informatics approach. PhD Thesis, University of Ruhuna, Matara, Sri Lanka. WGS 1984 UTM zone 44N coordinate system. Maps have been created applying on-screen digitization techniques for Google earth satellite images (Madarasinghe *et al*., 2020a).
Digital LULC map	Coastal belt of Hambantota district	1996	1:50,000	©Sri Lanka Survey Department- SLSD. WGS 1984 UTM zone 44N coordinate system. Maps have been created applying on-screen digitization techniques for Google earth satellite images (Madarasinghe *et al*., 2020a).

2. Image data used for NDVI analysis

Satellite name	Sensor	Resolution	Path/ row	Coordinate system	Imagery date/s	Downloaded platform
Landsat 8	OLI	30m	140/056 and 141/056	WGS 84 UTM zone 44N	13th January and 28th April 2017	United States Geological Survey (USGS) Earth Explorer
Landsat 7	ETM+	30m	140/056 and 141/056	WGS 84 UTM zone 44N	23rd February and 16th February 1997	United States Geological Survey (USGS) Earth Explorer

the area changes obtained from the overlay analysis. Landsat 8 Operational Land Imager (OLI) and Landsat 7 Enhanced Thematic Mapper plus (ETM+) satellite data, both at a resolution of 30 m, were used for this purpose for 2017 and 1997, respectively. Cloud-free Landsat images of the area were not available for the year 1996 and thus, the closest cloud-free images from 1997 were obtained. Details of data used are given in Table 1(b).

All satellite images were obtained from the dry season of the Hambantota district to avoid seasonal variations in vegetation and to avoid misclassifications due to flooding conditions mainly in the paddy lands. ArcMap 10.3 software was used to perform image processing and image analysis. Standard colour composite images were derived using green, red, and near infrared bands and those composites were then geo-referenced using 6 to 8 ground control points obtained from GPS. Two composite images of the same year were mosaicked and the study area, the coastal belt of the Hambantota district, was clipped from the mosaic using the study area vector created using the process described in section 2.1. NDVI's for 1997 and 2017 were calculated for each mosaic image and their maximum values were compared.

NDVI outputs were overlapped with their standard colour composites and three land cover types, no-vegetation areas (*e.g*., water, rocky areas, built-up areas, and bare lands), other vegetation (*e.g*., grasslands, scrublands, chena, home gardens, and sparse forests), and dense forest areas, were identified through comparisons. The tool 'Identify' in ArcMap was used to select break values to be used in classifying the NDVI outputs into the three aforementioned classes. NDVI of 0.25 was selected as the break value for the classification of NDVI output to vegetated and non-vegetated areas, after comparison of the NDVI outputs with their respective standard colour composites, the classified NDVI images were generated for 1997 and 2017. Area statistics were obtained for each NDVI class in order to detect the area change of the vegetation classes over the twenty-year period. Compatibility of NDVI results with the area statistics obtained from overlay analysis were checked and the NDVI results were then presented visually as a verification of the vegetation dynamics revealed from the overlay analysis.

Questionnaire survey and population density

To study how land-use changes observed in Hambantota urban area had affected the lives of displaced families, a comprehensive questionnaire survey was carried out in 2019 in two selected GNDs, namely, Siribopura and Keliyapura, where the dislocated communities due to Hambantota port project and the tsunami in 2004 were resettled. Maps of the two GNDs obtained from the village heads (Grama Niladhari) were used to select forty households randomly, and the questionnaire survey was carried out through interviewing the heads of the households. Demographic information on the lives of respondents were gathered through a set of close-ended questions. Additionally, a series of Likert-scale questions were included in the questionnaire covering four major areas: people's perspectives (14 questions), economy (24), goods and services (13), and the environment (16). Reliability tests followed by a principal component analysis (PCA) were performed for each category to refine the most reliable and representative Likert-scale questions for each of the four areas. Refined questions included five questions from the 'people's perspectives' section, three from 'economy', four from 'goods and services' and four from the 'environment'. Subsequently, descriptive statistics, particularly, frequency data, were generated for the responses given for these selected Likert-scale questions. All statistical tests were performed using SPSS *v*.25 statistical package.

GND-wise population data in the Hambantota district in 2001, 2012, and 2017 were gathered from the Hambantota Divisional Secretariat's office and the Department of Census and Statistics, Sri Lanka. Population data of the studied GN divisions were extracted from the data sets to study the trend of population change in the Hambantota coastal belt. The population density of each GND in 2001, 2012, and 2017 was then mapped using ArcMap *v*.10.3 software.

RESULTS AND DISCUSSION

Results

LULC change analysis

The LULC architecture of the Hambantota coastal belt has changed at an unprecedented rate over the study period of the two decades from 1996 to 2017. Out of fourteen LULC classes studied for the year 2017, all the classes except coconut plantations and paddy lands showed significant area changes (positive and negative) over the considered period. Area statistics of each LULC class and the LULC changes which occurred over the two-decade period are tabulated in Table 2, whereas the overall area loss and gain of each LULC class in Hambantota coast during the period considered are illustrated in Figure 2.

Table 2: Land-use/land-cover areas in Hambantota coastal belt in 1996 and 2017 and the area changes over the twenty one years. p value indicates the significance of the area change of each LULC class at 95% confident interval. Significant area changes are marked with an asterisk. Area gains are given as positive values while area losses are shown as negative values.

Land-use class	Area (ha)		Area change (ha)	p value (at 95% level)
	In 1996	In 2017		
Bare land	14	479	465*	< 2.2e-16
Coconut plantation	999	1060	61	0.1832
Forest	44128	41389	-2739*	< 2.2e-16
Grassland and marsh	1465	3806	2341*	< 2.2e-16
Homesteads	7140	6340	-800*	6.352e-13
Mangroves	270	477	207*	4.193e-14
Other cultivations	385	552	167*	5.358e-08
Paddy lands	4053	3972	-80	0.3595
Saltpan	2346	402	-1944*	< 2.2e-16
Sandy areas	1632	2649	1018*	< 2.2e-16
Scrubland and chena	12332	11481	-851*	2.337e-09
Settlements	36	1353	1318*	< 2.2e-16
Water	3800	4339	539*	9.252e-10
Other land-uses	1083	1384	302*	1.148e-09

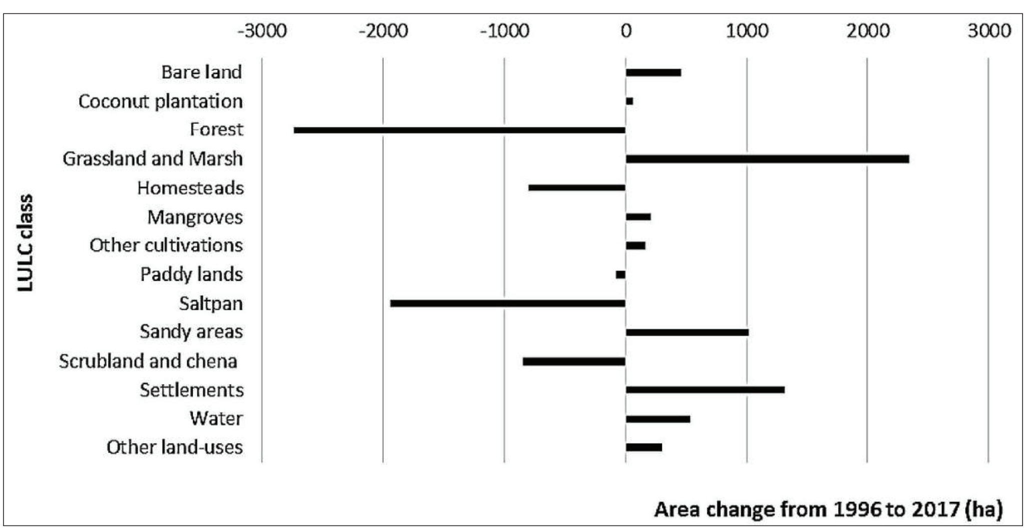


Figure 2: Area loss/gain of each land-use/cover class in the Hambantota coastal belt from 1996 to 2017. Area gains are illustrated as positive values and area losses as negative values.

The transition matrix that shows the spatial changes of LULC in Hambantota coast from 1996 to 2017 is given in Table 3. LULC maps of the Hambantota coastal belt in 2017 and 1996 are displayed in Figure 3.

Table 3: Transition matrix showing the land-use/cover changes of Hambantota coast from 1996 to 2017. The highlighted numbers on the diagonal represent unchanged land-use/cover proportions from 1996 to 2017, while the others are the areas changed from one class to another.

		1996														
		Bare land	Coconut plantation	Forest	Grassland and Marsh	Homesteads	Mangroves	Other cultivations	Paddy lands	Saltpan	Sandy areas	Scrubland and chena	Settlements	Water	Other land-uses	Total area gain (by 2017)
2017	Bare land	2	2	0	94	63	0	0	100	0	0	179	0	39	0	477
	Coconut plantation	0	493	0	23	141	2	0	202	0	0	199	0	0	0	567
	Forest	0	23	41179	0	43	0	0	0	0	82	62	0	0	0	210
	Grassland and Marsh	0	26	661	1165	126	0	0	89	147	0	631	0	941	20	2641
	Homesteads	6	74	127	0	5423	0	0	33	0	0	677	0	0	0	917
	Mangroves	0	1	0	114	0	268	0	0	0	0	8	0	86	0	209
	Other cultivations	0	13	0	0	66	0	119	52	0	0	302	0	0	0	433
	Paddy lands	0	0	0	47	52	0	129	3110	0	0	634	0	0	0	862
	Saltpan	0	0	0	0	0	0	0	0	402	0	0	0	0	0	0
	Sandy areas	0	0	0	0	0	0	0	0	0	1538	0	0	270	841	1111
	Scrubland and chena	6	197	1541	0	62	0	110	0	100	0	9465	0	0	0	2016
	Settlements	0	0	0	21	934	0	27	14	62	0	74	35	0	85	1318
	Water	0	170	0	0	0	0	0	0	1635	12	0	1	2464	57	1875
	Other land-uses	0	0	620	1	230	0	0	453	0	0	0	0	0	80	1304
	Total area loss (from 1996)	12	506	2949	300	1717	2	266	943	1944	94	2867	1	1336	1003	

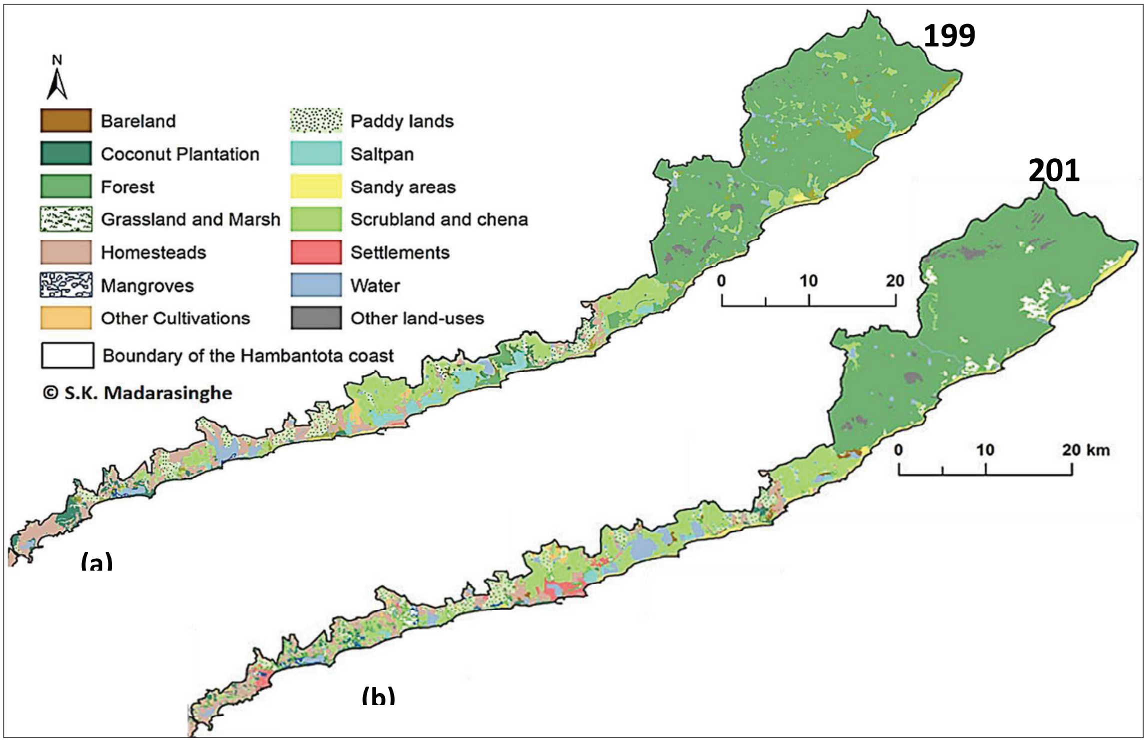


Figure 3: Land-use/land-cover maps of the coastal belt of Hambantota district in 1996 (a) and 2017 (b).

The Hambantota coastal belt includes Yala and Bundala national parks along with few other forest patches, distributed along the belt. The forest cover reduced by 2739 ha ($p < 0.05$), showing the highest area change among all the LULC changes, over the period from 1996 to 2017. Overlay analysis further revealed that most of the forest cover losses was observed in Yala and Bunadala national parks, as it had been transformed into scrubland and chena, grassland and marsh, homesteads and other land-uses by 2017 (see Table 3 for transition matrix). However, the LULC class, scrubland and chena, in the study area showed a significant overall decrease over the two decades by 851 ha. ($p < 0.05$). According to the overlay analysis, approximately 368 ha of scrubland had been cleared to establish housing schemes for relocation programme, particularly in the Keliyapura, Siribopura, and Koholankala GNDs [indicated in Figure 1 (b)], and 309 ha had been sacrificed in other GNDs of the Hambantota coast. On the other hand, the grassland and marsh LULC classes had significantly expanded, by 2341 ha, $p < 0.05$) over the period. This expansion had taken place at the expense of some areas under the LULC classes *i.e.* forests, homesteads, paddy lands, scrubland and chena, saltpan and water areas, compared to the 1996 map. Marsh vegetation and grassy plains had replaced about 153 ha of water in the Kalametiya lagoon by 2017 due to formation of land masses in the lagoon (personnel communication and field observations in September 2017).

Mangrove vegetation cover was identified in the three lagoon systems, Rekawa, Kahandamodara, and the Kalametiya-Lunama complex, as well as in Tangalle and Ambalantota. Expansion of mangrove cover had taken place in all five sites, resulting an overall increase of 207 ha ($p < 0.05$). This expansion had taken place by replacing some areas under the LULC classes coconut plantation, grassland and marsh, scrubland and chena, and water in the 1996 map. The highest expansion of mangrove cover (114 ha) has taken place by replacing grassland and marsh vegetation, and most of the replacement was observed in Kalametiya lagoon area.

Paddy remains the major crop cultivated in the Hambantota coastal belt since 1996, and covered 5% (4053 ha) of the study area. Coconut plantations covered 1.3% (999 ha) of the Hambantota coastal belt in 1996. Neither paddy nor coconut cultivated land areas show any significant change over the two decades. However, the LULC class 'other cultivations' (*e.g.*, banana, finger millet, sugarcane) had expanded its area by 167 ha ($p < 0.05$). Overlay analysis revealed that some of the areas occupied under the LULC classes, coconut plantation (13 ha), homesteads (66 ha), paddy lands (52 ha), and scrubland and chena (302 ha), in the 1996 map had been replaced with the newly established croplands, which were listed under the class 'other cultivations'.

Although the settlements in the study area had significantly increased (by 1318 ha) over the period, homestead areas had been reduced by 800 ha ($p < 0.05$). Interviews with the residents in the area revealed that many homesteads had been taken by the government to implement development projects (*e.g.*, the Hambantota port). New housing schemes were observed in several GNDs (*i.e.*, Siribopura, Keliyapura and Koholankala), within which the 'affected residents' were resettled. Establishment of new infrastructure such as the Hambantota port, new Administrative Building Complex, LAUGFS LPG Transsh6ipment Terminal, Mirijjawila cement grinding plant and oil refinery plant, International Convention Centre, and development of roads had mainly contributed to expand the area under the settlement class over the period of study. Overlay analysis revealed that fractions of areas under LULCs grassland and marsh, homesteads, other cultivations, paddy lands and scrubland and chena in the 1996 map had been replaced by these newly established settlements in the 2017 map. Similarly, scrubland and chena areas in the coastal belt had been cleared to establish homesteads and housing schemes during the period.

Another significant area reduction was observed in the LULC class 'saltpans' (1944 ha; $p < 0.05$) in the Hambantota coastal belt from 1996 to 2017. In 1996, there had been six functioning saltpans ('lewaya' in Sinhala language), namely, Kahandamodara lewaya, Karagan lewaya, Hambantota Maha lewaya, Koholankala lewaya, Bundala lewaya, and Palatupana lewaya. Although the Malala lagoon was classified as a saltpan in the 1996 LULC map obtained from the Sri Lanka Survey Department, residents living in the area for more than twenty years claimed that the lagoon had never been utilized as a saltpan (personal communication, August 2019). The Karagan lewaya, which existed in the 1996 LULC map, had been partially replaced with settlements (62 ha) by 2017 and the rest of the lewaya remains as open water and marsh.

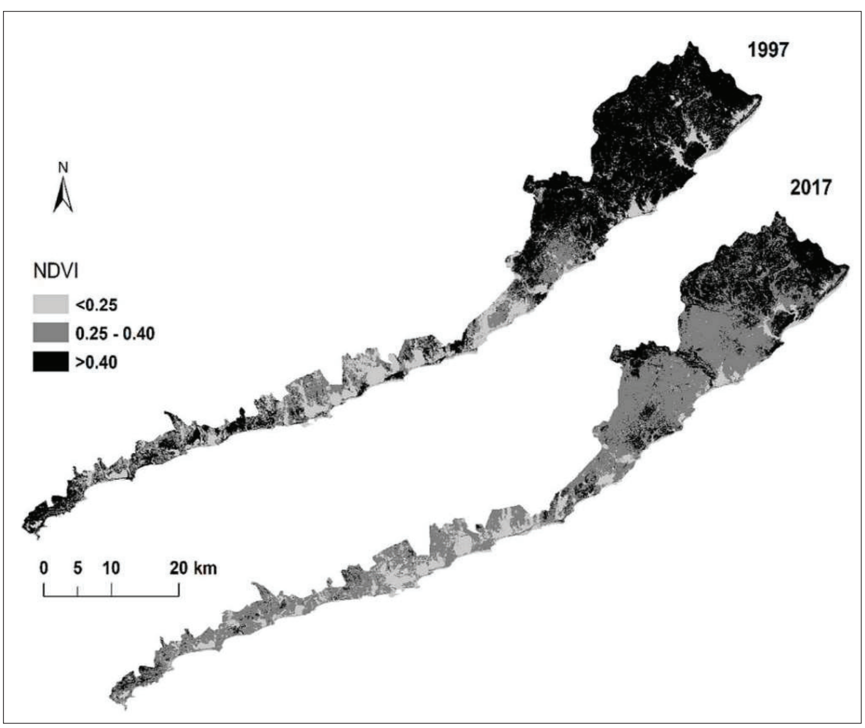


Figure 4: NDVI outputs of the coastal belt of Hambantota for 1997 and 2017. Maps are categorized into three classes (non-vegetated area: NDVI < 0.25; other vegetation: NDVI = 0.25–0.40; dense forest: NDVI > 0.40) based on the NDVI values.

The Hambantota coast bears five major lagoons, Mawalla, Rekawa, Kahandamodara, Koholankala, and Bundala, along with two lagoon complexes, Kalametiya-Lunama and Malala-Embilikanda. Two major rivers, Walawe and Menik, meet the Indian Ocean at the site of the estuaries on the Hambantota coast. Moreover, the coast bears several lakes, tanks, and reservoirs, most of which are situated inside the Bundala and Yala forest reserves. The inland water areas in the Hambantota coastal belt had significantly increased during the past twenty years (by 539 ha, $p < 0.05$).

Normalized Difference Vegetation Index (NDVI) estimation

The NDVI outputs were classified into three different classes: (1) No-vegetation area such as water, rocky areas, built-up area and bare lands (NDVI < 0.25), (2) Other Vegetation like grasslands, scrublands, chena, home gardens and sparse forests (0.25–0.40 NDVI), and (3) Dense Forest area (NDVI > 0.40). Comparison of NDVI maps of the coastal belt of Hambantota district clearly shows a decrease in dense forest cover in 2017 as compared to the status of 1997 (Figure 4 and Table 4). This dramatic reduction is significant in the Yala national forest area situated in the eastern edge of the district. The density of the forest cover has decreased since many patches of dense forest areas had been transformed into open forest areas. Also, some of the 'dense forest areas' located in the western part of the Hambantota coastal belt seen in the 1997 NDVI map are classified under 'other vegetation' areas as seen in the 2017 NDVI map.

Table 4: A summary of the NDVI results and the criterion used in classifying the map into three classes based on NDVI values.

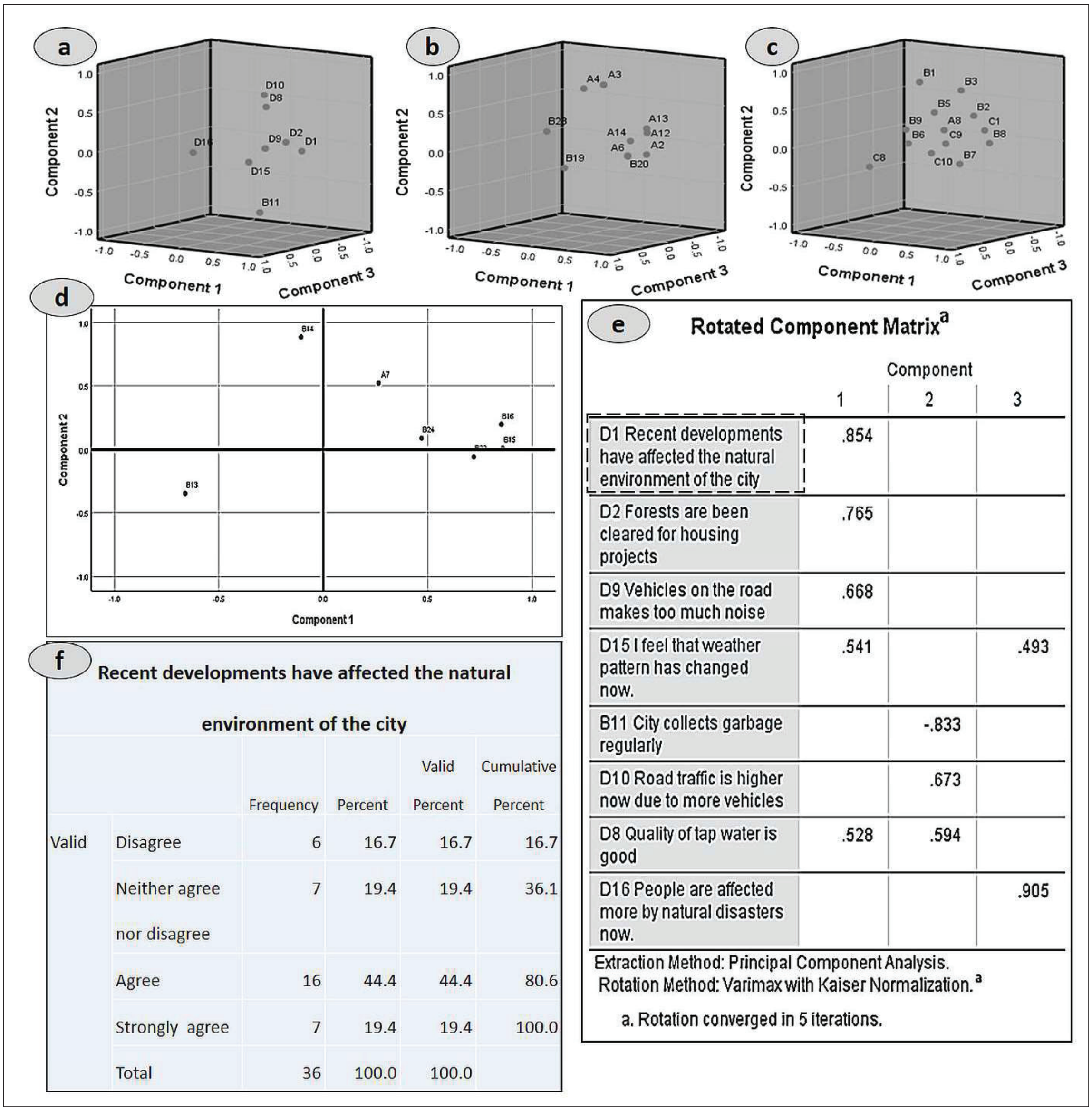
	1997	2017
NDVI values		
Upper value	0.674074	0.540695
Lower value	-0.573034	-0.347283
Area estimations / ha		
< 0.25 (No vegetation area)	14341.7	11361.6
0.25 - 0.40 (Other vegetation)	20719.9	47976.1
> 0.40 (Dense forest area)	44346.9	20070.8

Questionnaire survey

Out of the forty households selected randomly for the survey, only 36 questionnaire forms had no missing data and thus, were considered for the analyses. All the respondents have been living in the Hambantota district for more than twenty years and that included 55.6% males and 44.4% females. Surveyed houses had utilities such as electricity, drinking water and basic sanitary facilities. All houses had grid electricity and 97.2% had direct waterlines. However, the questionnaire data revealed that only 55.6% are satisfied with their new residence in the resettlement area. Out of the dissatisfied portion, 98% of the residents claimed that the greater distance from their new home to the city area and to their working places were the main reasons for dissatisfaction.

According to the PCA results (PCA outputs are given in Figure 5), agriculture and fishery industry were the main economic sectors in the city. Moreover, goods and services were available in the city and tourism was also booming. A 94.5% portion of the respondents claimed that they did not need to go outside the town to find goods and services. According to the responses given regarding the environment, the two major components (PCA 1 & PCA 2) identified from the PCA results indicated that environment had been compromised for development projects, but the provision of services by the city to keep environment clean was satisfactory. Further, 63.8% agreed that recent development projects had affected the natural environment of the city. Verbal communication with respondents revealed that the municipal council had adopted sound managerial practices for waste management in the city. Apart from 11.1% of the respondents, others had stated that they strictly follow the guidelines that were set for the recycling programme in the city. PCA results regarding the goods and services available in the city exposed that many public and private service providers were available in the city. Moreover, the health sector provides a satisfactory service to the people including facilities for elderly care, health education, and care for disabled children, and frequency data revealed that 94.4% were satisfied with the medical facilities in the city. However, only 66.7% of the respondents were satisfied with the facilities provided for education. The survey reflects that education facilities and the public transport system need further improvement.

Many respondents complained during interviews that although there was an adequate number of schools in the city, they had a small number of well-trained teachers. When people's perspectives were taken into consideration, the PCA results indicated that people appreciate the progress that the city was making in new businesses and development projects. Moreover, it was evident that people were happy about improvements taking place in fishing industry and in agriculture sector and they were feeling good about life in town. Most importantly, they were happy about available resources in the town as 63.9% of the respondents agreed that Hambantota town was better because of new development projects while 69.5% believed that the town had enough resources to attract new businesses.



e **Rotated Component Matrix**[a]

	Component 1	Component 2	Component 3
D1 Recent developments have affected the natural environment of the city	.854		
D2 Forests are been cleared for housing projects	.765		
D9 Vehicles on the road makes too much noise	.668		
D15 I feel that weather pattern has changed now.	.541		.493
B11 City collects garbage regularly		-.833	
D10 Road traffic is higher now due to more vehicles		.673	
D8 Quality of tap water is good	.528	.594	
D16 People are affected more by natural disasters now.			.905

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]

a. Rotation converged in 5 iterations.

f **Recent developments have affected the natural environment of the city**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Disagree	6	16.7	16.7	16.7
	Neither agree nor disagree	7	19.4	19.4	36.1
	Agree	16	44.4	44.4	80.6
	Strongly agree	7	19.4	19.4	100.0
	Total	36	100.0	100.0	

Figure 5: Image shows PCA outputs for the questions regarding (a) environment, (b) people's perspectives, (c) goods and services and (d) economy. Rotated component matrix for the questions regarding the environment is given in (e), while (f) shows an example for a frequency table generated for a question representing component-1 selected from the rotated component matrix.

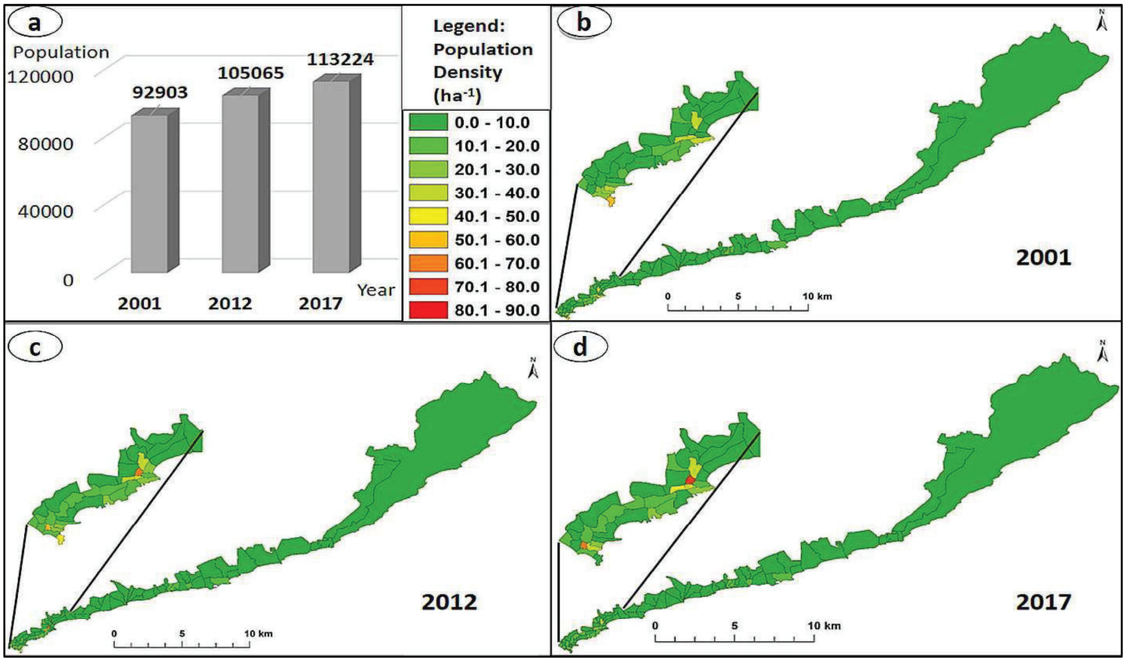


Figure 6: (a) Graph showing the population increase in Hambantota coastal belt from 2001 to 2017; Maps (b), (c), and (d) show GND-wise population densities of the study area in 2001, 2012 and 2017, respectively.

Population density

The population of the coastal belt of the Hambantota district has continuously increased from 2001 to 2017, as shown in Figure 6 (a). The population density (per ha) for the whole Hambantota coastal belt was 1.2 in 2001, 1.3 in 2012 and 1.4 in 2017. These values are low due to the fact that the Hambantota coastal belt has large non-populated forest areas such as the Yala and Bundala national parks. When the population density of each GND in 2001 was taken into consideration alone, all had values less than 30.0 ha^{-1} [Figure 6 (b)], excluding Kudawella south GND where the population density was slightly higher (33.8 ha^{-1}). In 2012, three GNDs of Tangalle DSD (divisional secretariat division) (*i.e.*, Kudawella south, Kudawella north and Indipokunagoda north) showed an increase in population density, having population densities greater than 30.0 ha^{-1}.

Discussion

Changes in LULC classes show a pattern of conversion of forest cover to other LULC types such as grassland and marsh, scrubland, and chena, indicating that the forest systems are being disturbed by human interventions. Activities that attract tourists, for example, safari tours, camping, etc., inside the Yala and Bundala national parks take place frequently, and evidently those activities also damage the forest cover disturbing the wildlife as well (Estoque & Murayama, 2017; Ranagalage *et al*., 2018). In addition, a famous Buddhist monastery, Sithulpawwa, located within the Yala national park premises, attracts large crowds of local devotees, mainly during religious activities. Increased visitor attraction could have impacted park's fauna and flora severely, due to inappropriate infrastructure developments, overcrowding, inappropriate human behaviour, and due to road accidents killing wildlife (McNeely *et al*., 1992; Ranagalage *et al*., 2018). It has been emphasized that tourism in such areas could be made sustainable, providing protection to their own unique environmental values (McKercher, 1993). The World Tourism Organization defines sustainable tourism as one that improves the quality of life of host communities, provides high quality experience for guests, and maintains the quality of the environment on which they both depend (WTO, 1993). The Department of Wildlife Conservation, which manages these national parks under the jurisdiction of the Ministry of Environment and Natral Resources (DWC, 2004) has taken some worthy actions for providing protection and freedom to the wildlife in these areas by closing the park during dry weather (from August to mid-October) due to lack of water, and also allowing animals some break from human activities during the breeding season

(Buultjens *et al*., 2005). Reduction in dense forest cover in NDVI estimations further confirms the degradation of forest quality over time. Both Yala and Bundala had been declared as national parks well before 1997, yet they had lost considerable forest cover during the two-decade period. Therefore, the government should take immediate action to prevent the illegal encroachments in the forest buffer zone and to strengthen the policies and action towards protecting these dry zone forests. In addition, forest dieback in the Bundala national park is one of the reasons for the conversion of forest cover into scrublands. Previous studies (Perera *et al*., 2007; Gunarathne & Perera, 2016) confirm the replacement of native tree species (e.g. *Manilkara hexandra*) due to invasion by *Prosopis juliflora* (Sw.) DC. and *Ganoderma* infection.

A dramatic decrease in the LULC class scrubland and chena, in the study area, was observed through the analysis. Many scrubland areas had been sacrificed to development projects which took place in the Hambantota urban area, including the establishment of the Administrative Building Complex, housing/resettlement schemes, road development/expansion and the port. Approximately 358 ha of scrubland had been cleared to establish housing schemes in the Keliyapura, Siribopura, and Koholankala GNDs for those people who were dislocated due to the port project and also due to the tsunami in 2004. How natural vegetation has been sacrificed to such establishments in the urban area is shown in Figure 7. The transformation of scrubland areas clearly indicates the degradation of natural vegetation in the Hambantota coastal belt for the development projects, even though such projects are also required during development. However, the scrubland areas located within national park territories were collectively classified under the LULC class 'forest' in the present study, as it was hard to demarcate when scrublands are located inside the national parks. Although the scrubland and chena class showed an overall decrease in area over the past two decades, NDVI analysis showed severe degradation of dense forest cover as well. The dense forest areas have been mostly replaced by scrub species such as *Securinega leucopyrus* (Willd.) Muell. (Katupila in Sinhala, the local language), *Prosopis juliflora* (Kalapu Andara in Sinhala) and *Mimosa pigra* L. (Yodha Nidikumba in Sinhala) with the secondary succession that had taken place after clear-felling and die-back scenarios.

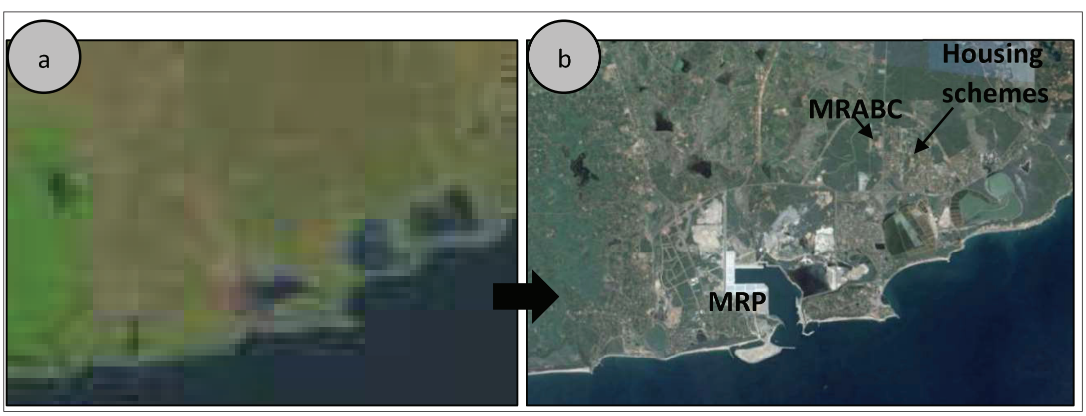


Figure 7: Satellite images showing the urbanization that has taken place during the study period of two decades in Hambantota replacing natural vegetation. (a) Landsat 5 image on 17.07.1997 and (b) Google Earth image (CNES/Air Bus) on 05.01.2017. (MRP: Magam Ruhunupura Port; MRABC: Magam Ruhunupura Administrative Building Complex; Housing schemes for tsunami affected people and communities dislocated due to development projects).

Replacement of water area by marsh vegetation in the Kalametiya lagoon, for example, had contributed to a significant increase in grassland and marsh cover from 1996 to 2017. Madarasinghe *et al*. (2020b) reported that the invasion of marshes had occurred in the newly formed landmasses in the Kalametiya lagoon due to excessive siltation. The excess of irrigated water from the Udawalawa irrigation project had been diverted to the sea through the Kalametiya lagoon, due to which siltation of the lagoon had increased, reducing the water surface area. Also, as a consequence of the construction of an artificial dyke at the lagoon mouth, the seawater influx to the lagoon had decreased, reducing the salinity of the lagoon. As a result, marsh vegetation (*i.e.*, *Typa angustifolia* L.) had invaded the newly formed landmasses in the lagoon (Madarasinghe *et al*., 2020b).

This scenario had contributed to the increased grassland and marsh cover as well as the reduction of water areas along the Hambantota coastal belt. The same scenario had contributed to the significant increase of mangrove cover as well, particularly in the Rekawa, Kahandamodara, and Kalametiya lagoons. Moreover, an increase of 282.9 ha of mangrove cover in the Kalametiya lagoon from 1982 to 2016 (Madarasinghe *et al*. 2020b), and by 1.1 ha and 19.0 ha, respectively, in the Rekawa and Kahandamodara lagoons from 1994 to 2016 (Madarasinghe *et al*., 2017) were consequences of reduction of salinity levels in the lagoons and excessive siltation resulting from irrigation projects. The overall increase of mangrove cover outshines the small-scale losses of the mangrove patches in the Rekawa and Mawella lagoons. Reclamation of lands for human settlements and agriculture as well as cutting wood for housing constructions and making fishing crafts (Katupotha, 2017; Madarasinghe *et al*., 2017) were identified as causes. Further, Jayatissa *et al*. (2002) and Madarasinghe *et al*. (2020b) showed the degradation of the quality of the mangrove forests along the Hambantota coastal belt, particularly in the Kalametiya lagoon, irrespective of the increase in total mangrove area. This scenario has been explained as 'cryptic ecological degradation' in the aforementioned research publications.

Rapid urbanization in the Hambantota coastal belt has caused abandonment of some paddy lands, especially after the tsunami in 2004. Concurrently, local people were recruited for the development projects and the newly established industries, which ultimately had indirectly forced them to abandon their traditional paddy fields. These abandoned paddy lands had then been converted to grasslands as well as to homesteads. However, the reduction of paddy land area during the study period was not so significant. Conversely, both coconut cultivation and other cultivations have increased in the area from 1996 to 2017. Abandoned paddy lands had been converted to other cultivations such as banana, and some abandoned homesteads had been utilized by the owners for coconut plantations and other cultivations such as sugarcane and finger millet, which resulted in a significant increase in the LULC class 'other cultivations' from 1996 to 2017 (personal communications and field observations in August 2019).

Karagan lewaya, which was a well-functioning saltpan, had been completely sacrificed for the establishment of the Magam Ruhunupura port, construction of which had commenced in 2008. This contributed to the reduction of the 'saltpan' area in 2017 compared to 1996. The difference in saltpan area in 1996 and 2017 includes an overestimation in area due to classification error as well, where Malala lagoon was classified as a saltpan in the 1996 LULC map, obtained from the Sri Lanka Survey Department, although it had never been used as one according to residents living in the area (*personal communication*, August 2019). A classification error in mapping Koholankala and Bundala saltpans in 2017 LULC map has led to produce an overestimation of saltpan loss from 1996 to 2017. Careful observation of Google Earth archives revealed that some large evaporation tanks filled with sea water were misclassified under the 'water' LULC class in the 2017 map, while being correctly classified under the 'saltpan' class in the 1996 map. The personal error in image interpretation can be the reason for this dissimilarity and has led to overestimating the reduction of saltpan area from 1996 to 2017.

According to the questionnaire survey, basic facilities (*i.e.*, electricity and water supply) had been provided through the resettlement programme, which was a commendable development move by the government. Greater distance from new homes to the city area and also to their working places have been identified as the main reasons for some residents' dissatisfaction about the resettlement. This indicates a shortcoming in site selection for the resettlement programme in Hambantota. Mariyathas *et al*., (2016) reports that Urban Development Authority was responsible for selecting relocation sites for the tsunami affected people. It would have been more successful if a proper need analysis of the residents were done prior to finalizing possible areas for resettlement. Due to the resettlement and major changes in the road network, the operation of many small-scale sweets shops and curd stalls, which were owned by residents living adjacent to road-side houses, had been abandoned, leaving the sellers no other option than finding jobs in construction sites (Mariyathas *et al*., 2016; personal communication with displaced residents in August 2019). Although some dissatisfaction remains in resettled communities regarding some of their life expectations, a majority is happy with the flourishing status of the city, particularly due to ongoing development programmes. This indicates that despite the shortcomings in resettling families in new areas, the government was able to make people satisfied with the development work in the town's infrastructure and facilities. It was highlighted that the green cover had been reduced due to development projects, and thus, the urban forestry concept could be an ideal sustainable move to be introduced in the urban area of Hambantota. It is also important to launch tree planting programmes and promote home gardening concepts to enhance the environmental health in the city.

CONCLUSIONS

Overlay analysis of the multi-temporal land-use/land-cover (LULC) maps of 1996 and 2017 together with a NDVI analysis and questionnaire survey to verify the results of the overlay analysis were carried out in the present study. The results reveal that the geographical areas of settlements including development projects had increased significantly (by 1318 ha compared to the area in 1996) during past two decades. In contrast, a great decline in forest cover (by 2739 ha) and scrublands and chena (by 851 ha) was seen from 1996 to 2017. NDVI results indicated a dramatic reduction of dense forest cover in the Yala national forest, which reflects a deteriorating environmental condition in the area. Thus, the study reveals that significant development along the Hambantota coastal belt has been taken place at the cost of forests and associated vegetation from 1996 to 2017. A rapid economic and population growth can be identified as the main driving forces for these LULC changes. A noteworthy increase in population has taken place in several GNDs of the coastal belt of Hambantota over the past two decades. These results deliver an important reference for authorities in proper decision-making and LULC planning for sustainable development in the Hambantota coastal belt. The urban forestry concept could be recommended as an ideal sustainable move to be introduced in the urban area of Hambantota in order to recover the greenery lost due to infrastructure development.

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