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Abstract. Land cover change is a significant issue for environmental managers for sustainable management. Remote sensing techniques have been shown to have a high probability of recognizing land cover patterns and change detection due to periodic coverage, data integrity, and provision of data in a broad range of the electromagnetic spectrum. We evaluate the applicability of remote sensing techniques for land cover pattern recognition, as well as land cover change detection of the Hatiya Island, Bangladesh, and quantify land cover changes from 1977 to 1999. A supervised classification approach was used to classify Landsat Enhanced Thematic Mapper (ETM), Thematic Mapper (TM), and Multispectral Scanner (MSS) images into eight major land cover categories. We detected major land cover changes over the 22-year study period. During this period, marshy land, mud, mud with small grass, and bare soil had decreased by 85%, 46%, 44%, and 24%, respectively, while agricultural land, medium forest, forest, and settlement had positive changes of 26%, 45%, 363%, and 59%, respectively. The primary drivers of such landscape change were erosion and accretion processes, human pressure, and the reforestation and land reclamation programs of the Bangladesh Government. [DOI: 10.1117/1.JRS.6.063608]

Keywords: land cover; change detection; image classification; Landsat; Hatiya Island.

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1 Introduction

Human intervention and natural phenomenon cause changes in land cover on a regular basis.

The availability of accurate land cover information is essential for various applications such as natural resource management, planning, and monitoring programs.[1] Land cover change is one of the most important indicators in understanding the interactions between human activities and the environment[2] and is also important information for a number of applications like agriculture, hydrology, forestry, and ecology. For example, in a reforestation program we need to identify the areas where forest is degrading or has less forest and may be suitable for revegetation, etc.

Change detection analysis becomes extremely important in order to understand the interactions and relationships between natural phenomena and human activity, through accurate change detection of the earth's surface features.[3] This provides an accurate assessment of the extent and health of the world's forests, grasslands, and agricultural resources. For studying land cover changes, some of the information sources are field surveys, existing maps, statistical data, existing documents or available literature, and remote sensing images. Although most of the developed countries are well equipped and updated with detailed land cover information, developing countries still face a lack of and/or restricted access to geospatial databases. For developing countries like Bangladesh, aerial photographs, for instance, are still critical in the mapping process.[4] Even now, the traditional methods are considered to be one of the most important methods for land cover mapping, which are time consuming, expensive, and limited to field surveys. Satellite remote sensing methods can, in principle, be used to monitor large areas in a reasonably short period of time[5] and it has also been widely applied and accepted as a powerful and effective tool for detecting land cover changes.[6–11]

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Remote sensing data, such as aerial photographs and satellite images, are undoubtedly the most ideal data for understanding the spatial and temporal dynamics of land cover as well as for extracting land cover change information.[12–15] Remotely sensed data can provide valuable multi-temporal information on the processes and patterns of land cover change, and GIS is useful for mapping and analyzing those patterns.[16] In addition, retrospective and consistent synoptic coverage from satellites is particularly useful in areas where changes have occurred rapidly.[17] Furthermore, digital archives of remotely sensed data have enabled the study of historical land cover changes and created the opportunity to understand the geographic pattern of such changes in relation to other environmental and human factors.

Coastal zones are now being gradually recognized as functional regions and the coastal areas need effective planning and management so that development takes place on a sustainable basis. One of the intentions of this work is to look into the issues and causes of coastal land cover changes. Hatiya Island is one of the offshore islands of Bangladesh that has been subject to severe erosion and accretion (redeposition of sediment) processes. Due to severe erosion hazards and comparatively less accretion prospects, and growth in population density, the island has shown significant morphological and socio-cultural changes through the years. During the last three decades, land cover of Hatiya Island has changed dramatically, and this has been mainly due to reforestation and cultivation.

Remote sensing has proved its effectiveness in providing accurate information illustrating land cover dynamics but unfortunately, no such application is available for Hatiya Island for land cover change assessment. It is necessary to mention that the island does not have any official statistics on land cover pattern, which is very important for sustainable environmental management of the island. Although recent and accurate data on land cover is a requirement for sustainably managing and planning the coastal island such as Hatiya, data scarcity and lack of current information on land cover is an issue. In the absence of such information, sustainable development cannot be achieved and may lead to the mismanagement of scarce resources. So, in this case, space-borne remotely sensed data is considered to be important for coastal islands like Hatiya, because not only this is required to comprehend the past and present condition of the land, but also used to achieve sustainable development and to drive sound environmental planning.[4]

In this study, an attempt has been made to map the status of land cover of Hatiya Island, Bangladesh and to understand changes over the last 22 years using established remote sensing data and techniques. There are many advanced techniques that are available, like object-based image analysis, fuzzy approach, decision tree analysis, artificial neural network, maximum likelihood classifier, etc. to extract information from satellite data. The approach used in this study to classify satellite images and detect changes was based on the maximum likelihood classifier approach. Although the maximum likelihood classifier technique is a conventional one with respect to other mentioned techniques, it has the ability to classify images with good accuracies. Even though this technique is fairly old, it is still used in the vast majority of land-cover monitoring approaches due to its simplicity and ease of use.[18] In this research, Hatiya Island was selected to srepresent the vast Meghna estuary area of the coastal region of Bangladesh to determine the trend and rate of this change.

2 Methods

The present study was conducted in Hatiya Island of Noakhali district of Bangladesh, lying between 22°03’N to 22°25’N latitude and 90°58’E to 91°12’E longitudes[19] (Fig. 1). To the north, the Island is bounded by river Meghna and Noakhali main land; Shahabajpur River, Monpura and Tajumuddin thana of Bhlola district to the west, in the east Meghna River and Sandwip thana of Chittagong district and the Bay of Bengal on the south. The average length of the island in the north-south direction is about 48 km and its width (east-west) is about 15 km on average. The total area of this island is 115,353 acres.[20] It is attached with Noakhali, Monpura, Tajumuddin, and Sandwip by waterways. The study area is a part of an active delta of the three mighty river systems: the Ganges (Padma), Brahmaputra (Jamuna), and the Meghna. Hatiya Island is one of many islands in this delta and is representative of the shifts in land use/

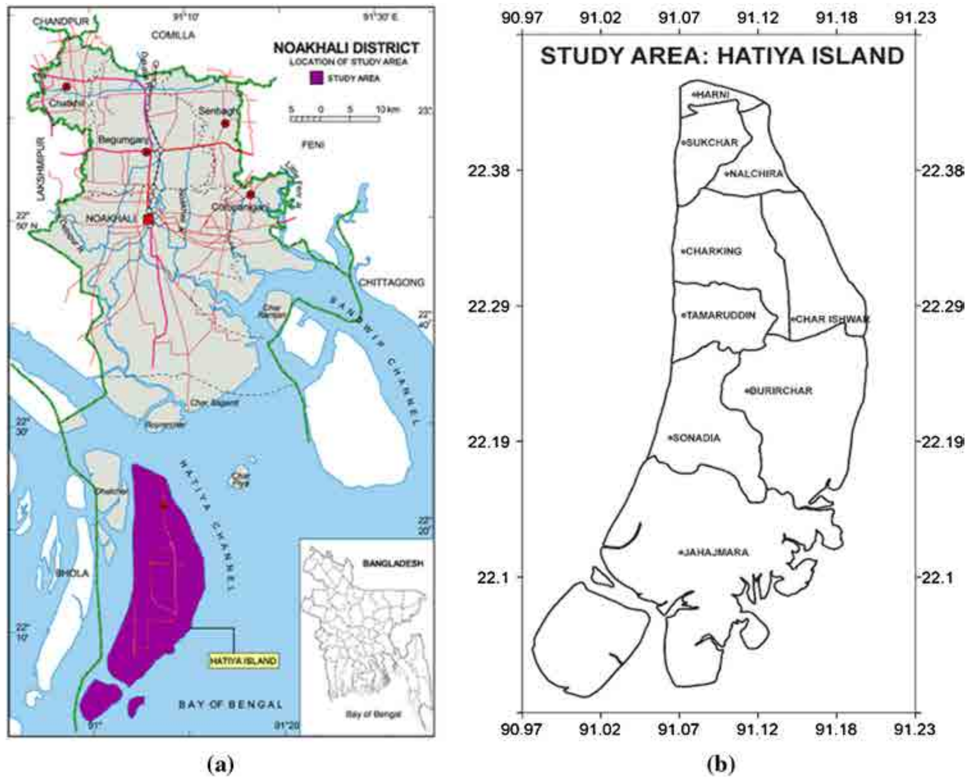

Fig. 1 (a) Location of the study area. (b) Provinces of Hatiya Island.

cover that has been occurring due to human activity and the series of floods due to the mighty river systems.

In this study, Landsat Multispectral Scanner (MSS) 1977, Landsat Thematic Mapper (TM) 1989 and 1997, and Landsat Enhanced Thematic Mapper (ETM) 1999 were used to classify land cover in the study area. Digital image processing software Idrisi 32 was used for the image processing and Arcview 3.2, Arc Info, and Cartalinx were used for analysis and integration of spatial data. Figure 2 shows the workflow for image processing and classification stages.

For image analysis, geometric and radiometric corrections were carried out to remove the influence of the atmosphere and topography on the remotely sensed data. Topographic correction was done by DEM and sun azimuth and sun elevation data that were extracted from image's header file.[21] Image registration of ETM 1999 was carried out using twenty one ground control points with a root mean square error (RMSE) of 0.002047 pixels. The image was re-sampled to a 30-m pixel size using the nearest neighbor resampling method. The other images (TM and MSS) were georeferenced using the same procedure as adopted for the ETM 1999 data.

The supervised maximum likelihood classification scheme was used to classify and extract land cover patterns. The maximum likelihood classifier was applied over normalized difference vegetation index (NDVI) images. NDVI was generated in the Idrisi environment by combining satellite images of near infrared and red frequencies.[22,23] This was done for vegetation recognition since chlorophyll in plants reflects more light in the near infrared portion of the electromagnetic spectrum than the visible portion. To create NDVI images the following equation was used:

$$\mathrm{NDVI} = \frac{\text{Near IR band} - \text{red band}}{\text{Near IR band} + \text{red band}}. \tag{1}$$

Besides NDVI, false color composite (FCC) images were also used to clarify some land cover types, which had appeared hazy in NDVI images. After the classification of the NDVI and FCC images, areas under different land cover types were calculated for all the images. Land cover sampling was done using 42 plots in heterogeneous land cover areas and data were collected

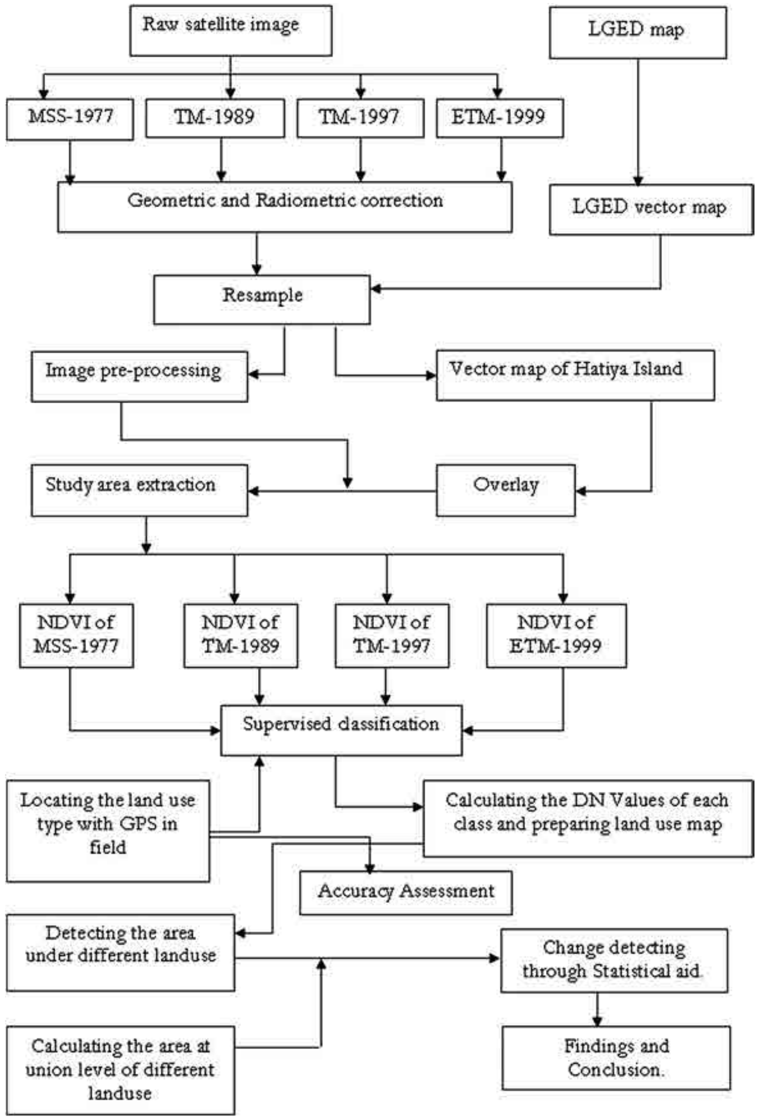

Fig. 2 Work flowchart of research.

from each land cover type. To extract the land cover patterns, 24 sample training areas for each land cover type were selected and later located with a GPS (magellan-310) during field verification. A modified version of the Anderson Scheme Level I was adopted to study the land cover changes in the study area since this classification system is suitable and can be mapped efficiently from high altitude imagery such as Landsat.[24] Eight major land cover types had been identified in this study as marshy land, mud, mud with small grass, agricultural land, bare soil, medium forest/vegetation, forest, and settlement (Table 1). In addition to supplementary information obtained from various sources,[2] the author's prior knowledge was also used to document characteristics of land cover.

Accuracy of the classification for all classified maps was assessed using kappa coefficient. Error matrices were developed to evaluate the efficacy of the classification. The available ground truth data were used to derive the accuracy assessment for the classified map of 1997 and 1999. The Local Government Engineering Department (LGED) map of 1989 and topographical map of 1974 were used to derive the accuracy assessment for the classified maps of 1989 and 1977. In order to assess thematic accuracy for each land use map, a minimum of 100 pixels were selected from each land cover category using the stratified random sampling method and then checked with ground reference data and other reference map data. Producer's and user's accuracy for

Table 1 Land cover classification scheme.

Land cover types	Description
Marshy land	Marshy lands are the accumulation of well-sorted finer sediments deposited by the inland rivers and developed at the margins of the upper tidal zone near the high tide line
Mud	In general, mud is soil highly saturated with moisture or soft clay remaining on the sides of a river or at the sea coasts
Mud with small grass	This land use type is distributed mainly in the muddy regions of the island. It is the next stage of mud in vegetation succession process in the study area
Agricultural land	Area under cultivation
Bare soil	This is uncropped land. It may be recently ploughed fields, land after crop harvesting, or permanent fallow lands like sea beach
Medium forest	Medium forest mainly consists of normal vegetation with an average of 6 to 10 m height. Keora is the main species in the study area
Forest	Forest mainly consists of tall trees with an average 10 to 50 m
Settlement	Settlements are mainly the residential areas

each class were also calculated along with the overall accuracy and kappa coefficient and presented as error matrices.

3 Result

Eight major land cover categories were identified in the study area in all the study years (1977, 1989, 1997, and 1999), which were marshy land, mud, mud with small grass, agricultural land, bare soil, medium forest/vegetation, forest, and settlement. The land cover patterns of the study area are shown in Figs. 3 and 4. The major land cover type is agricultural land. This land cover has been changing on account of increasing population and geomorphological change of Hatiya Island. Error matrices of land cover classification for 1977 are shown in Table 2 and those for 1989, 1997, and 1999 are shown in Tables 3–5, respectively. The results indicate overall accuracies of 86%, 90%, 92%, and 94% and kappa index of 0.83, 0.89, 0.89, and 0.92 for the images of 1977, 1989, 1997, and 1999, respectively (Table 6). Table 7 shows the land cover changes that have taken place between 1977 and 1999.

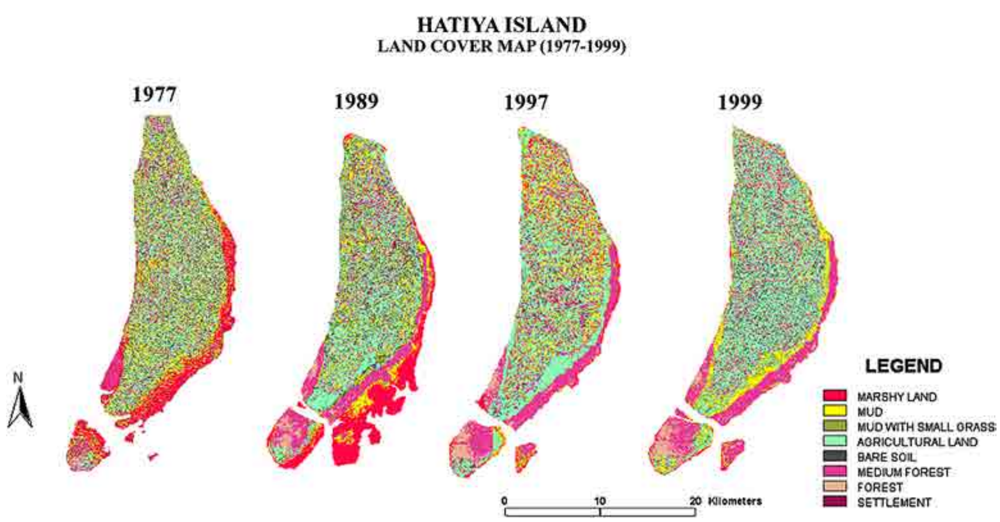

Fig. 3 Land cover details of Hatiya Island, Bangladesh.

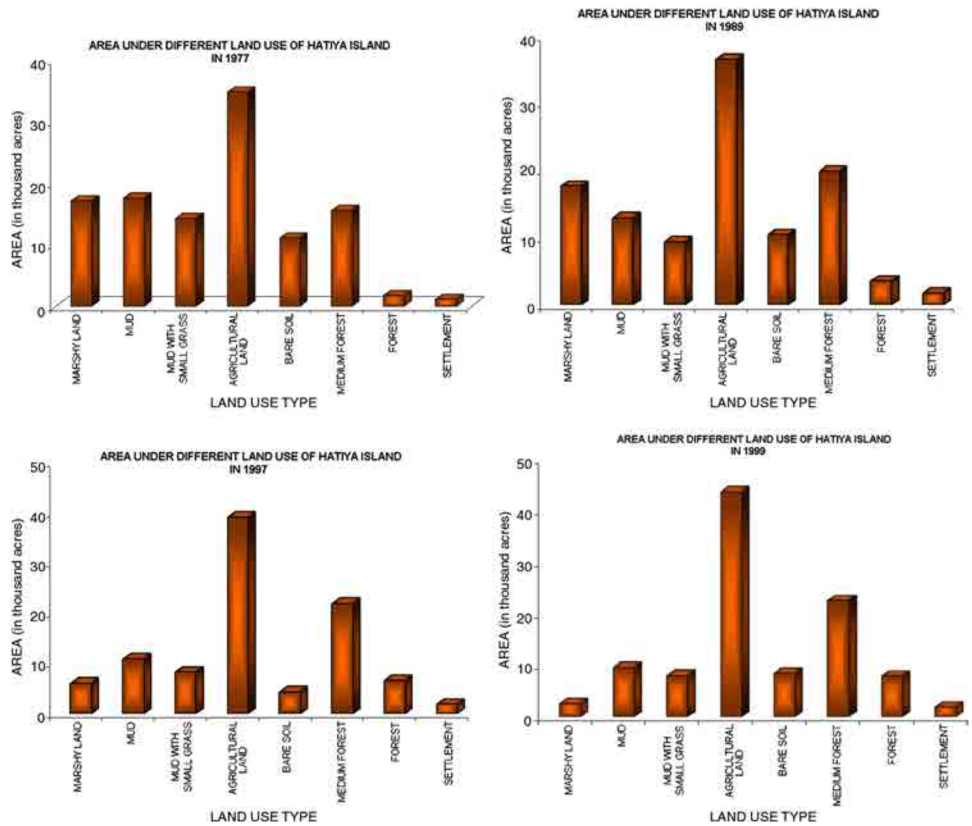

Fig. 4 Land use/cover features of the Hatiya Island, Bangladesh in 1977 to 1999.

Table 2 Error matrix for 1977 Landsat MSS image, Hatiya Island, Bangladesh.

	Marshy land	Mud	Mud with small grass	Agricultural land	Bare soil	Medium forest	Forest	Settlement	Total	User's accuracy (%)
Marshy land	**5072**	121	4	0	0	96	0	0	5293	95
Mud	324	**2625**	108	7	54	1	0	0	3119	84
Mud with small grass	44	172	**1276**	38	72	16	0	0	1618	79
Agricultural land	8	52	99	**697**	159	0	28	47	1090	64
Bare soil	16	87	100	20	**776**	25	2	0	1026	75
Medium forest	4	6	16	84	8	**2187**	177	144	2626	83
Forest	0	0	0	0	0	32	**1072**	32	1136	94
Settlement	0	0	0	4	0	0	24	**704**	732	96
Total	5468	3063	1603	850	1069	2357	1303	927	16640	
Producer's accuracy (%)	92	86	79	82	72	92	82	77		

Table 3 Error matrix for 1989 Landsat TM image, Hatiya Island, Bangladesh.

	Marshy land	Mud	Mud with small grass	Agricultural land	Bare soil	Medium forest	Forest	Settlement	Total	User's accuracy (%)
Marshy land	**664**	14	0	2	0	0	0	0	680	97
Mud	54	**507**	48	4	1	0	0	0	614	82
Mud with small grass	0	34	**274**	14	21	0	0	0	343	80
Agricultural land	0	3	5	**576**	31	0	0	11	626	92
Bare soil	0	3	26	34	**210**	0	0	0	273	77
Medium forest	0	0	0	12	0	**583**	36	66	697	83
Forest	0	0	0	0	0	37	**1369**	10	1416	96
Settlement	0	0	0	0	0	0	0	**467**	467	100
Total	718	561	353	642	263	620	1405	554	5116	
Producer's accuracy (%)	92	90	77	89	80	94	97	84		

Table 4 Error matrix for 1997 Landsat TM image, Hatiya Island, Bangladesh.

	Marshy land	Mud	Mud with small grass	Agricultural land	Bare soil	Medium forest	Forest	Settlement	Total	User's accuracy (%)
Marshy land	**418**	31	0	0	0	0	0	0	449	93
Mud	63	**670**	68	2	0	0	0	0	803	83
Mud with small grass	20	95	**324**	27	0	0	0	0	466	69
Agricultural land	0	24	69	**546**	38	0	0	0	677	80
Bare soil	0	0	0	25	**166**	0	0	0	191	86
Medium forest	28	0	0	5	0	**2750**	46	3	2832	97
Forest	0	0	0	0	0	57	**1697**	5	1758	96
Settlement	0	0	0	0	0	0	0	**91**	91	100
Total	529	820	461	605	204	2807	1743	100	7267	
Producer's accuracy (%)	79	81	70	90	81	97	97	91		

4 Discussion

Hatiya Island is in the lower Meghna estuary and consists of quaternary alluvial deposits of silt, sand, and clay. Morphological behavior of the island is changing rapidly as a result of river discharge, tide, and coastal hydrology of the region. During the period 1977 to 1999, it was found that a significant change had taken place in the island, mainly due to erosion rather than that of accretion (Table 8 and Fig. 5). During this period (1977 to 1999) erosion was predominant, which also affected the land cover of Hatiya Island. In the present research, both the physical and cultural factors affecting the land cover changes in the study area were considered,

Table 5 Error matrix for 1999 Landsat ETM image, Hatiya Island, Bangladesh.

	Marshy land	Mud	Mud with small grass	Agricultural land	Bare soil	Medium forest	Forest	Settlement	Total	User's accuracy (%)
Marshy land	**619**	24	0	0	0	0	0	0	643	96
Mud	49	**231**	22	7	0	0	0	0	309	74
Mud with small grass	0	14	**125**	23	0	0	0	0	162	77
Agricultural land	0	9	3	**1668**	27	0	0	0	1707	97
Bare soil	0	0	0	23	**119**	0	0	0	142	83
Medium forest	0	0	13	15	6	**2571**	80	11	2696	95
Forest	0	0	0	0	0	67	**1164**	27	1258	92
Settlement	0	0	0	1	0	0	0	**95**	96	99
Total	668	278	163	1737	152	2638	1244	133	7013	
Producer's accuracy (%)	92	83	76	96	78	97	93	71		

Table 6 The kappa coefficient and overall classification accuracy for the images of Landsat MSS 1977, TM 1989 and 1997, and ETM 1999.

Land cover map	Kappa coefficient	Overall classification accuracy (%)
1977	0.83	86
1989	0.89	90
1997	0.89	92
1999	0.92	94

Table 7 Land cover pattern analysis of Hatiya Island, Bangladesh (1977 to 1999).

	Area in acres				Area in percentage (%)			
Land cover category	**1977**	**1989**	**1997**	**1999**	**1977**	**1989**	**1997**	**1999**
Marshy land	17,133	17,687	6057	2572	15.1	15.8	6.1	2.5
Mud	17612	1291	10894	9544	15.5	11.5	11.0	9.1
Mud with small grass	14,290	9390	8247	7991	12.6	8.4	8.3	7.6
Agricultural land	34,876	36,526	39113	43762	30.7	32.6	39.6	41.8
Bare soil	11,136	10,446	4295	8470	9.8	9.3	4.4	8.1
Medium forest	15,565	19,865	21852	22603	13.7	17.7	22.1	21.6
Forest	1706	3525	6574	7901	1.5	3.2	6.7	7.6
Settlement	1162	1719	1817	1850	1.0	1.5	1.8	1.8
Total	113,480	112,073	98,848	104,693	100	100	100	100

Table 8 Area of Hatiya Island, Bangladesh, and its rate of change in different years (1977 to 1999).

Year	Area in acres	Change in area from 1977	Change rate (%)	Remarks
1977	113,480	—	—	Base map
1989	112,073	1407	1.24	Erosion in reference to 1977
1997	98,848	14632	12.89	Erosion in reference to 1977 and 1989
1999	104,693	8788	7.74	Erosion in reference to 1977 but Accretion in reference to 1997

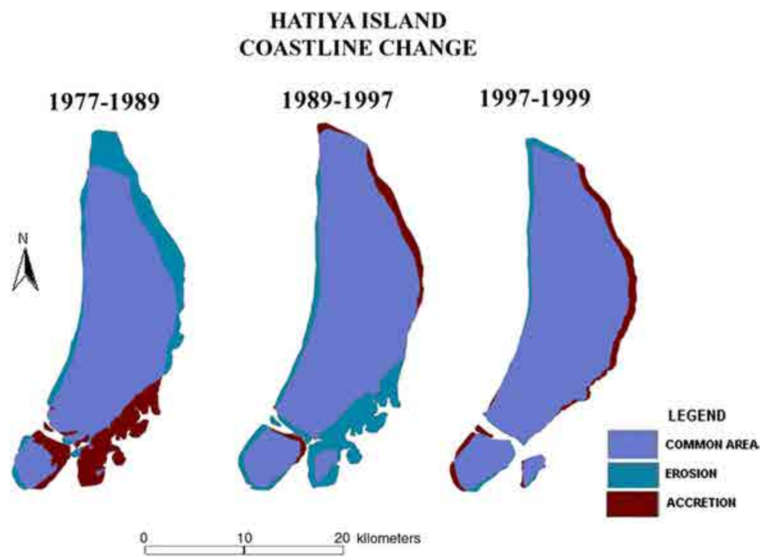

Fig. 5 Coastline change of Hatiya Island, Bangladesh, from 1997 to 1999 based on image analysis.

where physical factors include erosion and accretion processes and cultural factors include human pressure, land management systems, reforestation program of Bangladesh forest department, and land reclamation policy of the Bangladesh government.

Analysis of land cover change for the Hatiya Island shows that the land cover patterns have changed remarkably between 1977 and 1989, and 1989 and 1997. The change was also significant between 1997 and 1999 (Table 9 and Fig. 6). In the first two intervals, erosion was the dominant physical force to bring changes in land cover pattern in the study area but results suggest that the situation was different for the 1997 to 1999 time period where accretion was the primary driving force. So the accretion process had played an influential role in recent land cover changes, which is opposite to the previous scenarios. Marshy land decreased by 85.0% in 1999 with reference to 1977. Most of the marshy land was converted into mud and medium forest/vegetation classes. Mud, mud with small grass, and bare soil had also decreased by about 45.8%, 44.1%, and 24.0%, respectively during this time period, while agricultural land, medium forest/vegetation, and forest had increased by about 25.5%, 45.2%, and 363.2%, respectively.

The mud class was converted into mud with small grass, medium forest/vegetation, and agricultural land. The south-eastern and south-western parts of Hatiya Island and northern part of Nijhum dwip were the main regions where this change had occurred (Table 10 and Fig. 7). Mud with small grass also changed into medium forest/vegetation, agricultural land, and bare soil. It had decreased by about 95.5% in the Harni union. On the other hand, the least amount of change occurred in Jahajmara union (3.2%). Jahajmara was the only union where the total area under

Table 9 Analysis of land use/cover changes of Hatiya Island, Bangladesh.

Land use/cover category	Change in area (in acres)				Percentage of change			
	1977 to 1989	1989 to 1997	1997 to 1999	1977 to 1999	1977 to 1989	1989 to 1997	1997 to 1999	1977 to 1999
Marshy land	+553	−11629	−3485	−14561	+3.2	−65.8	−57.5	−85.0
Mud	−4697	−2022	−1350	−8068	−26.7	−15.7	−12.4	−45.8
Mud with small grass	−4900	−1142	−256	−6299	−34.3	−12.2	−3.1	−44.1
Agricultural land	+1650	+2587	+4659	+8886	+4.7	+7.1	+11.9	+25.5
Bare soil	−690	−6151	−4175	−2666	−6.2	−58.9	−97.2	−23.9
Medium forest	+4300	+1987	+751	+7038	+27.6	+10.0	+3.4	+45.2
Forest	+1819	+3048	+1328	+6196	+106.7	+86.5	+20.2	+363.2
Settlement	+557	+97	+33	+688	+48.0	+5.7	+1.8	+59.2

Note: (−) sign represents percentage of decreasing rate and (+) sign represents percentage of increasing rate.

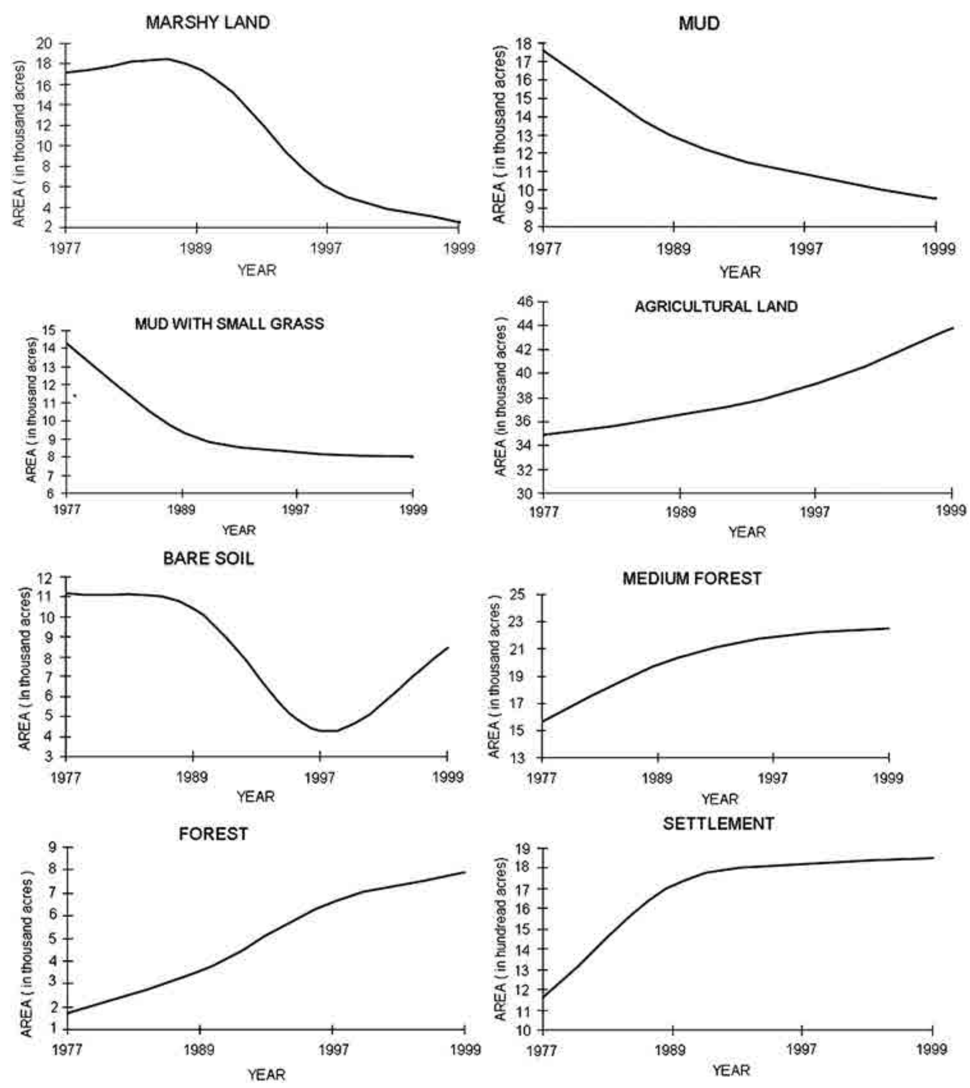

Fig. 6 Changing pattern of land use/cover of Hatiya Island, Bangladesh, from 1977 to 1999.

mud with small grass had increased. The conversion of marshy land, mud, and mud with small grass into medium forest category had been greatly influenced by the reforestation program of Bangladesh Forest Department and the land reclamation policy of Bangladesh government. Under the land reclamation policy, the Bangladesh forest department planted various mangrove species in the newly accreted land, which had a great influence on further accretion. In this process marshy land, mud, and mud with small grass were gradually converted into medium forest. The south-eastern and south-western parts of Hatiya Island and northern parts of Nijhum dwip were the main regions where this change had occurred.

Mud, mud with small grass, and bare soil converted mainly into agricultural land. This land cover change process had a large effect in Harni union (89.7%) and least amount in Nalchira union (2.6%). Sonadia, Tamaruddin, Jahajmara, Burirchar, Char Ishwar, and Char King were the unions where the agricultural land had increased in the study period. Population growth and land management system of Bangladesh government had played an important role in this positive change. The population of the island had almost doubled in the 20 year time period (1980 to 2000). To meet the food demand of the huge population, people had brought the land under intensive agriculture in the study area. The distribution of new accreted land to the poor people by the government under the land management system had also played a positive role to increase the area under agricultural land. On the other hand Harni, Sukchar, and Nalchira were the unions where the agricultural land had decreased. Erosion process played an active role to bring this negative change.

The highest and lowest amounts of change of bare soil had taken place in Harni (96.4%) and Tamaruddin (1.7%) unions, respectively. The highest amount of change in medium forest/vegetation had occurred in Jahajmara union (158.5%) especially in newly accreted areas. Mainly mud, marshy land, and mud with small grass had changed into medium forest and medium forest to forest. Forest had increased by about 363% during the study period. Harni was the only union where the forest had decreased. In the case of settlements, the highest amount of change had occurred in Burirchar union (232.9%) and the least amount of change had taken place in Nalchira union (10.0%).

From Table 10 it is clear that the extent of change of individual land cover categories was not the same in all the nine unions of the study area, which have also been visualized on maps (Fig. 7).

Table 10 Union wise analysis of land use/cover changes of Hatiya Island, Bangladesh (1977 to 1999).

	Percentage of change							
Union	Marshy land	Mud	Mud with small grass	Agricultural land	Bare soil	Medium forest	Forest	Settlement
Harni	−78.9	−97.0	−95.5	−89.7	−96.4	−100	−100	−100
Sukchar	+53.7	−69.1	−60.6	−5.9	−51.6	−49.9	+183.3	−19.0
Nalchira	−40.9	−81.9	−62.5	−2.6	−38.6	−18.1	+319.9	−10.0
Charking	−5.1	−54.6	−47.1	+19.7	−18.5	−15.6	+296.7	+28.1
Char Ishwar	−84.0	−26.0	−43.4	+28.1	−17.0	+41.1	+363.5	+190.1
Tamaruddin	−63.6	−66.8	−53.4	+29.0	−01.7	−2.8	+120.5	+121.7
Sonadia	−71.2	−56.1	−57.9	+31.9	−4.2	−17.4	+207.5	+154.6
Burirchar	−92.7	−49.6	−44.8	+54.4	−2.1	+102.3	+377.3	+232.9
Jahajmara	−86.9	−13.4	+3.2	+54.0	−41.0	+158.5	+726.0	+129.2

Note: (−) sign represents percentage of decreasing rate and (+) sign represents percentage of increasing rate.

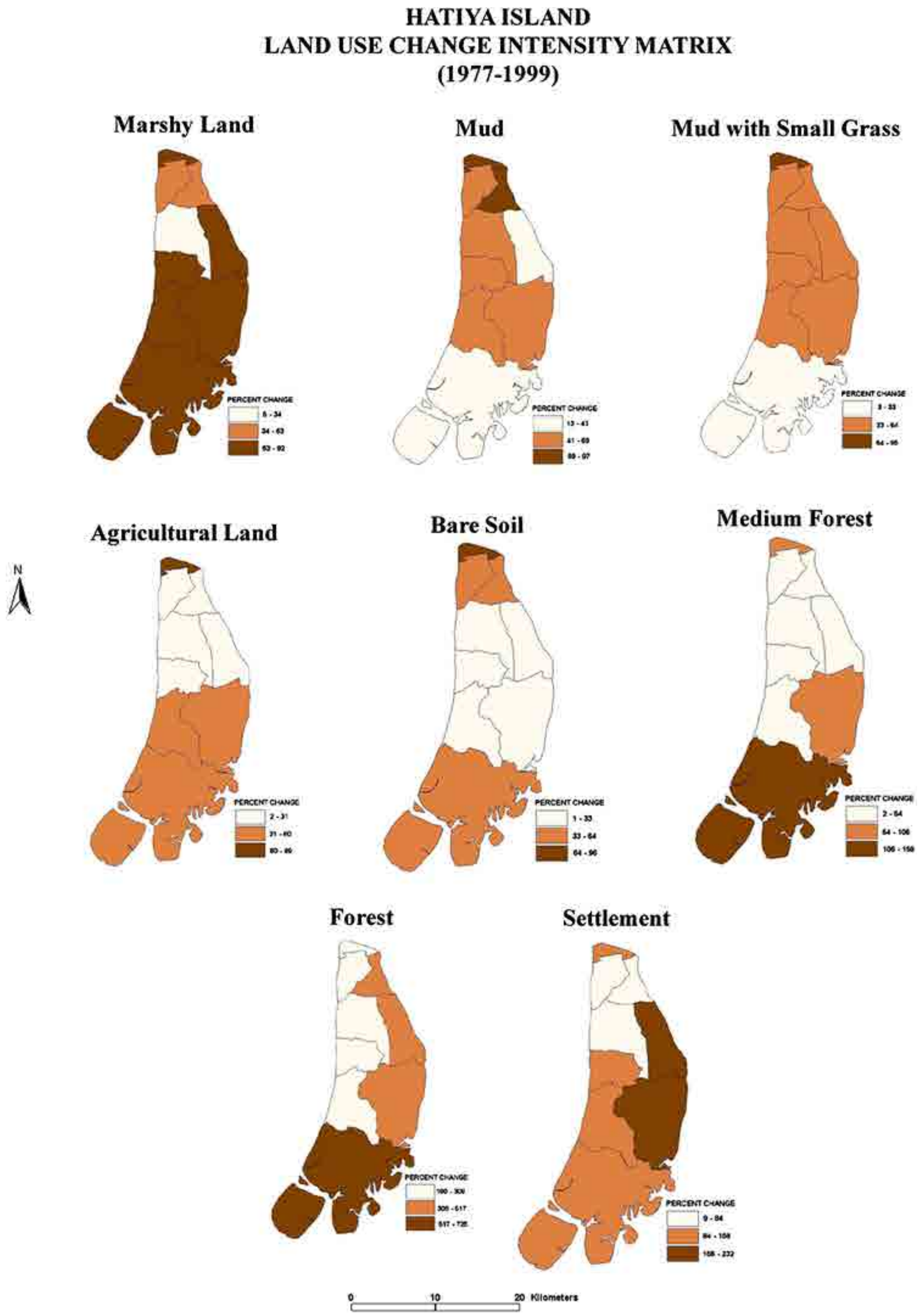

Fig. 7 Land use/cover change intensity matrix of Hatiya Island, Bangladesh in 1977 to 1999.

Hatiya Island is an erosion and accretion prone region, and these morphological processes greatly influence land cover patterns. In recent times (1977 to 1999), channel migration of Meghna Old River has been very rapid, causing severe erosion of Hatiya Island. Remote sensing data also confirms this trend and it is evident that significant changes have taken place in the island. Erosion and accretion have played an active role in this change process. Between these, the erosion process was more dominant in the study area during 1977 to 1997, however, during 1997 to 1999 the accretion process seems to be the dominant one. Major erosion has taken place in the northern part of the island and accretion has taken place in the southern parts of the island (Fig. 8). Similarly, by following these morphological processes, land cover patterns have changed dramatically in these erosion and accretion prone areas (Fig. 9). Agricultural land and

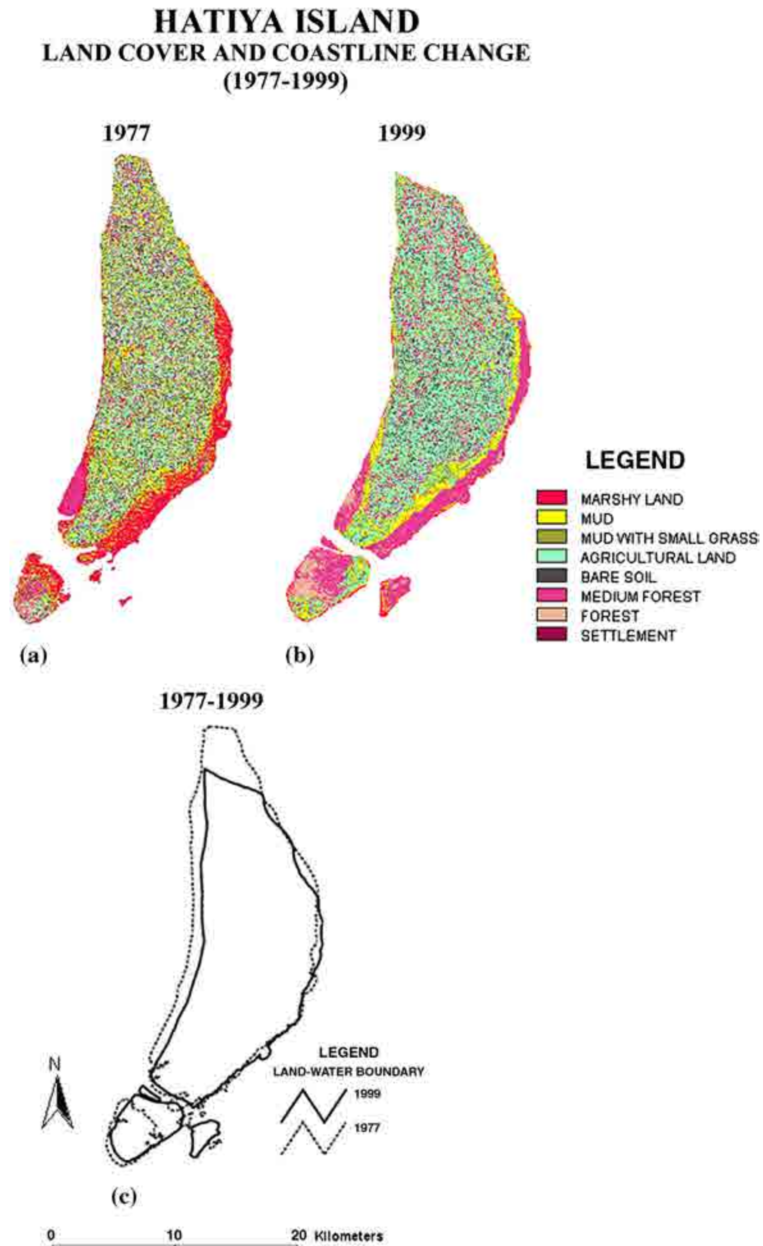

Fig. 8 Land use/cover pattern of Hatiya Island for 1977 (a), and 1999 (b). The coastline change from 1977 to 1999 is shown in (c).

settlements have increased in all the unions of the Hatiya Island except Nalchira, Sukhchar, and Harni unions, where erosion process plays an active role to oppose such change. On the other hand, in the southern part of the island, where accretion process is more dominant than erosion, medium forest/vegetation and forest classes have increased due to the reforestation program of the Bangladesh Forest Department, and mud, mud with small grass, and marshy land classes have decreased due to land reclamation policy of the Bangladesh government. To evaluate the efficacy of image classification, user and producer accuracies have been calculated for each of the eight classes for all the images and the accuracies are consistently high, ranging from 70% to 100%. Overall accuracy, the percentage of pixels classified as correct among those sampled, have been highest (94%) for the classified image of 1999 followed by the 1997 image (92%), 1989 image (90%) and 1977 image (86%). The classified image of 1999 resulted in the highest kappa coefficient value (0.92), followed by the classified images of 1997 and 1989 (0.89) and classified image of 1977 (0.83).

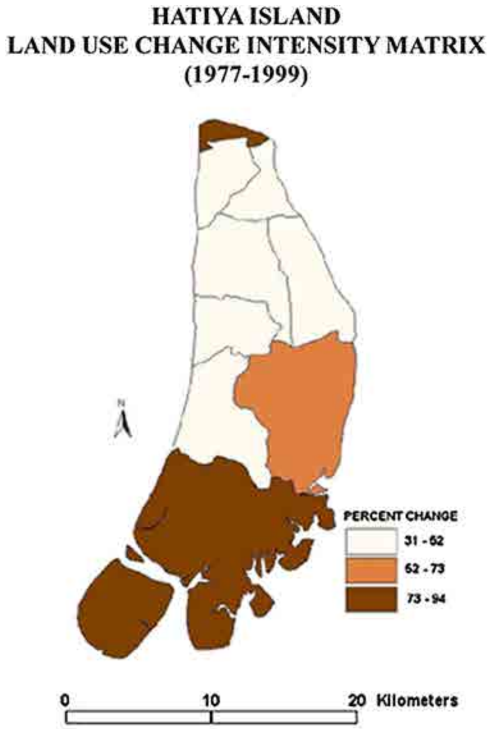

Fig. 9 Land use/cover change intensity matrix of Hatiya Island 1977 to 1999.

It is notable that the older datasets (TM 1989 and MSS 1977) have resulted in relatively lower overall accuracies and kappa coefficient values compared to the recent datasets. Among the datasets, MSS (1977) has resulted in the lowest overall accuracy and kappa coefficient value (86% and 0.83). This could be due to the fact that the MSS imagery is too coarse to study land cover changes and the accuracy gets reduced due to mixed pixels. Moreover, decreases of image spatial resolution lead to spectral mixing of different categories, producing spectral confusion between land covers.[4] In addition, the quality of the reference datasets are also an issue for older images because the training sites are developed from paper-based maps which may result in misleading classification. These could be the reasons for the lower accuracy of the land cover map of 1989 and 1977 compared to the other two maps. An examination of the accuracies of the land cover maps revealed that all the classified images had overall accuracies of more than 85%, which meets the level (85%) that the U.S. Geological Survey has recommended for acceptability of classification results.[25]

5 Conclusion

Results show that significant changes in land cover occurred during the study period in Hatiya Island. Geomorphological change of the island played an active role to bring about these observed changes. The highest amount of land cover changes were observed in the northern and southern parts of the island, where major morphological change had occurred due to erosion and accretion. Long-term, the overall trend is towards erosional loss of coastal lands such as marshes and mudflats, especially in the northern and western zones. However, seasonal or episodic meteorological events can facilitate coastal accretion that offsets erosion, at least temporarily.

During the study period, marshy land, mud, mud with small grass, and bare soil classes had decreased by 85%, 46%, 44%, and 24%, respectively. Despite the overall loss of coastal land since 1977, both the agriculture and forest\medium forest cover types have increased on the island (26%, 45%, 363%), especially on newly accreted lands. Government land-use policies governing new lands have affected both trends, including land distribution and tree-planting programs.

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Biographies and photographs of the authors are not available.