MAPPING AND CHANGE DETECTION OF MANGROVES ALONG THE COASTLINE OF AMPARA DISTRICT FROM 2004 TO 2019

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Abstract
Mangroves provide numerous ecological and biophysical services in the tropics and subtropics that support flood regulation, carbon sequestration, and reducing erosion from storm surges. Remote sensing satellite imagery provides valuable information for mangrove mapping and monitoring. The objective of this study is to detect the spatio-temporal changes in mangroves in Ampara District from 2004 to 2019 based on Landsat data. A semi-automated image classification technique was used to delineate and detect changes of mangrove vegetation in the Ampara District from 2004, 2009 and 2019 using Landsat 5 and 8 images. The multi-index approach was constructed using: (i) water masking using Normalized Difference Water Index (NDWI), (ii) mangrove detection using red and shortwave infrared (SWIR), SWIR and near-infrared (NIR) band ratios, Normalized Difference Vegetation Index (NDVI), (iii) mangrove classification using Principle Components Analysis (PCA) and an unsupervised classification. The historic Google Earth imagery was used to validate the classified mangrove habitats. The results estimated the total mangroves in Ampara District were 424 ha in 2004, 355 ha in 2009, and 569 ha in 2019. The total mangrove habitat which was estimated through available land-use/cover maps was 770 ha. In addition, habitat suitability of mangroves for current and future (year 2050) climate change scenarios was mapped using a maximum entropy (MaxEnt) model and bioclimatic variables. The current MaxEnt was resulted in 11% area in high habitat suitability (H) and a moderately suitable (M) class in each. While the suitable habitat projection for the year 2050 was 11% (H) and 16% (M). In conclusion, a loss of mangrove was observed five years later in tsunami, and a gain of mangrove was occurred after 15 years resulting in best land management practices.

Keywords: mangrove, change detection, classification, MaxEnt

1. Introduction

Mangroves are the most productive ecosystem within the coastal and estuarine ecosystems in the tropical areas that provide ecological and social benefits to its coastal environment and people. Mangroves can sequestrate greater amounts of carbon in coastal ecosystems, hence, it called as blue carbon hotspots (Twilley et al., 2018). Mangrove forests play a vital role in protecting marine areas from sea level rise, tsunamis, hurricanes, and erosions. A small island like Sri Lanka is vulnerable to such water-related impacts within the coastal areas, where mangroves can mitigate a degree of coastal impacts acting as a natural barrier. However, disturbance of mangrove forests remains alarming in Sri Lanka. The leading causes for mangrove loss in Sri Lanka are reported as agriculture activities (Dellysse & Madurapperuma, 2018), coastal development (Madurapperuma et al., 2017a), and shrimp farming (Bournazel et al., 2015).

The multi-temporal earth observation satellite data (i.e. Landsat data) is widely used for change detection of mangroves. For example, Dan et al. (2016) analyzed the deforestation of Sundarbans mangrove forest, the largest mangrove forest in the world using time-series Landsat data. Dellysse and Madurapperuma

(2018) examined the land-use changes along the south-eastern coastal areas before and after tsunami. Moreover, Satyanarayana et al. (2017) developed a coastal vulnerability index map, which observed more than 60% vulnerability in the north and east coast in Sri Lanka. Therefore, understanding multi-scale changes of mangroves are important to make better management and conservation of coastal habitats. The objectives of this study are: (1) to detect the changes of mangroves from 2004 to 2019 in Ampara District and (ii) modeling current and future distribution (year 2050) of mangroves using a maximum entropy model (MaxEnt).

2. Literature Review

The mangrove extent in Sri Lanka is about 15,970 ha where Puttalam, Trincomalee, Jaffna, and Batticaloa Districts cover 72% of the total acreage of mangroves (CCD, 1986, de Silva & de Silva, 1998, Edirisinghe et al., 2012). Mangroves provide ecological functions, such as physical barrier against tidal and ocean influences (Dahdouh-Guebas et al., 2005), carbon sequestration (Perera, & Amarasinghe, 2019.), and breeding/nursery habitats for fish and human wellbeing (Braat & De Groot, 2012). The major factors causing degradation of mangroves were reported as shrimp farming, land-use/cover changes, agriculture, coastal development, and extraction of mangrove forest products (Harkes et al., 2015; Dellysse and Madurapperuma, 2018).

Mapping mangrove habitats precisely are valuable for detecting spatio-temporal changes of mangroves especially before and after destruction to implement best conservation practices (Dellysse & Madurapperuma, 2018). Remote sensing data are widely used for distribution mapping, deforestation, change detection, and classification of mangroves (Lam-Dao et al., 2011, Kanniah et al., 2015; Madurapperuma et al., 2017b). Although there are numerous remote sensing data available for various spatial and spectral resolutions, moderately resolution (30 m) Landsat data are widely used for mapping and monitor mangroves over the large area (Giri et al., 2011, Dellysse & Madurapperuma, 2018). There is ample literature on various topics of mangroves in Sri Lanka. For example, Pathmanandakumar (2019) surveyed the mangrove forest cover change in Trincomalee District over 20 years, historic biogeography survey of Sri Lankan mangroves (Amarasinghe & Perera, 2017), vulnerable index mapping (Satyanarayana et al., 2017) and mangrove tree classification using IKONOS in Galle-Unawatuna areas (Satyanarayana, 2011).

Mangroves have studied merely in Ampara District since the area unreachable for researchers due to civil war in the past (Prasanna et al., 2019). However, a few studies conducted on mangroves in the post-war in this area, which needs further research to make better conservation plans for mitigating climatic vulnerabilities such as tsunami and sea level rise. According to the floristic study of Prasanna et al. (2017), twelve true mangrove species were recorded in Ampara District, while Madurapperuma et al., (2017) classified mangrove habitats in Pottuvil using kite aerial photographs, and Kaleel (2013) stated the growing scarcity of mangroves in Pottuvil. Therefore, evaluating past mangrove changes, monitoring and mapping current status of mangrove forest, and future forecasting modeling of mangroves along the coastline of Ampara would be valuable for preparing our coastal zones for sustainable land management practices.

3. Materials and Methods

Study Area

The study conducted in the east coast of Sri Lanka from Karativu to Panama coastal belt in Ampara District. The mangroves ecosystems have been distributed discontinuously along the shoreline and Pottuvil and Panama are the major lagoons supported by well-grown mangrove ecosystem (Prasanna et al., 2019). The mangrove habitats in this region are largely associated with wetlands, agriculture and water bodies. The coastal belt is dominated by dry mixed evergreen forests and sand dunes (Jayasingham, 2008). The study area is located in the dry zone and it receives 1200-1500 mm annual rainfall, where the north east monsoon is the prominent seasonal rains. The mean annual temperature falls between 30-32 °C.

Data collection and Analysis

The Landsat images in 2004, 2009, and 2019 covering Ampara District were collected from USGS Earth Explore web portal (https://earthexplorer.usgs.gov/). The Landsat images were acquired on 20-12-2004, 09-06-2009, and 04-05-2019 using path 140 and raw 55 scenes. These images reflected between pre-tsunami (2004) and post-tsunami (2009 & 2019) states. The images were pre-processed for radiometric correction and then digital numbers were converted to Top of Atmosphere (ToA) reflectance values using ENVI. A semi-automated image classification technique was used to delineate and detect changes of mangrove vegetation in Ampara District from 2004, 2009 and 2019 using Landsat 5 and Landsat 8 images. An integrated method on PCA and unsupervised classification was used for mapping mangroves. The water masking was performed using the Normalized Difference Water Index. Red, shortwave infrared (SWIR), SWIR and near-infrared (NIR) band ratios, and Normalized Difference Vegetation Index (NDVI) were stacked into one composite file. Then Principle Components Analysis (PCA) was performed using a composite image and unsupervised classification was used to classify mangroves (Shapiro et al., 2015). The historic Google Earth imagery was used to validate the classified mangrove habitats. The potential suitable habitats for mangroves were mapped using the maximum entropy (MaxEnt) model for current and future (year 2050) scenarios. The model required two data inputs such as occurrence data and environmental data. The mangrove occurrence data was obtained using the recorded mangrove sites and current land cover map in Ampara. The bioclimatic data were acquired from worldclim web portal (https://www.worldclim.org/bioclim). We used seven bioclimatic data (bio 2 to bio 8) covering current (1960-1990) and future (year 2050) climate projection data.

4. Results and Discussion

The mangroves were located in close proximity to coastal habitats, however they expanded up to six kilometers, when the coast connected to estuaries. The total estimated mangrove coverage in Ampara District was 424 ha in 2004 followed by 355 ha in 2009 and 569 ha in 2019 (Fig. 1). The total mangrove area, which was estimated through available land-use/cover maps, was 770 ha. According to Legg and Jewell (1995) study, the mangrove extend in Ampara was 292 ha in 1992. Prasanna et al. (2017) recorded 618 ha of mangroves in the Ampara District. According to our study, the mangroves coverage was slightly declined from 2004 to 2009, which could be a reason of land-use cover change and tsunami wave impacts. Similarly, Dellysse and Madurapperuma (2018) reported a significant decrease in vegetation in Ampara from 2004 to 2005 resulting in post-tsunami impact. Furthermore, they found a large extent of agricultural lands (i.e. paddy) changed after the tsunami compared to the dense forest within coastline. An increase mangrove coverage in 2019 could be regeneration of mangrove forests after the tsunami disaster. Moreover, sea water inundated agricultural lands transformed to natural vegetation like mangroves due to saline contamination. Mangroves act as a barrier against coastal erosion, tsunami and sea level rise, therefore, mapping mangrove areas would be valuable to land managers to implement best coastal management practices for mitigating climatic vulnerabilities. Spatial distribution of mangroves along the coast were fragmented (Fig. 1) and thus links mangroves and dunes using coastal vegetation corridors would be valuable. As Madurapperuma et al. (2017a) reported a lack of rock barriers in Oluvil beach in Ampara and degradation of coastal vegetation due to harbor construction has caused severe coastal erosion. Therefore, rehabilitation of those degraded coastal habitats with mangrove corridors is useful.

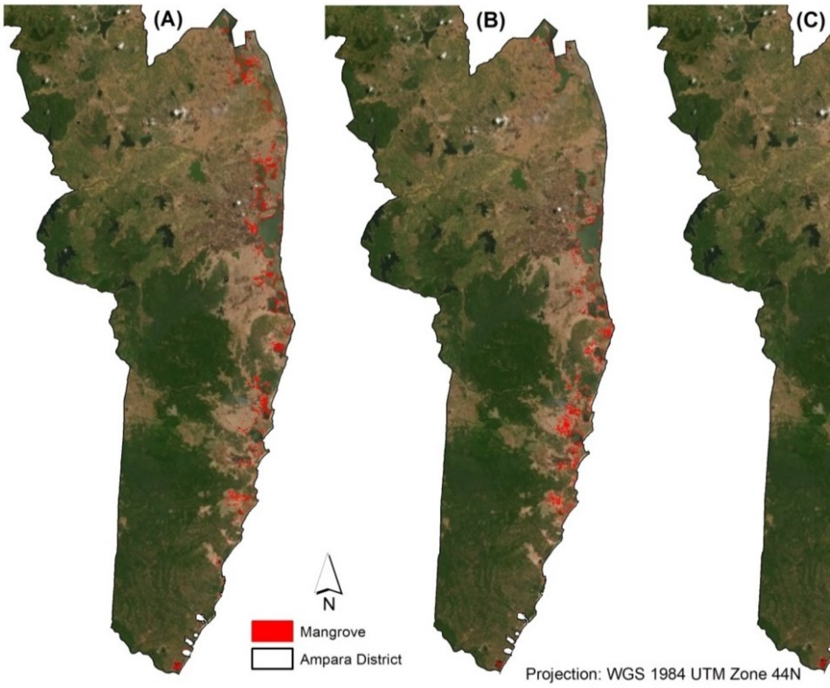

Figure 1. Comparison of mangrove distribution along the coastal habitats in Ampara in 2004 (A), 2009 (B) and 2019 (C).

To evaluate the changes of mangrove habitats in Ampara, we selected Panama Lagoon area to visualize the changes using historical Google Earth images (Fig. 2). The results showed that the mangrove extent in Panama was 85 ha in 2004 and 91ha in 2009. Our results are comparable with Ellepola and Ranawana (2015) findings, where they estimated approximately 83 ha of mangroves bordering the Panama lagoon.

Figure 2. Google Earth imagery of mangroves in Panama in 2004 (left) and 2009 (right) derived from remote sensed data.

It is important to assess how mangrove vegetation is vulnerable to climate change. The MaxEnt model predicts the habitat suitability of mangroves based on the climatic data and mangrove occurrence data. Figure 3 depicts the potential distribution of mangroves under current and future (year 2050). Of the total area, 11% of coastal habitats are highly suitable for mangroves for both scenarios. However, moderately suitable mangrove habitats are marginally higher for 2050 than current scenario. According to the MaxEnt model, there is a high degree of mangrove habitats shift towards the northern part in year 2050 in Ampara.

The environment factor contribution for MaxEnt is therefore important to understand ecosystem resilience for climate change. Although 19 bioclimatic variables available for MaxEnt modeling, we had to limit to seven variables since 2050 data only available for those seven variables covering the region of interest. Of the environmental variables, minimum temperature of the coldest month (bio 6) recorded 61% and 67% contribution for the MaxEnt for current and for the year 2050 respectively. The next important variable was the mean temperature of wettest quarter (bio 8), which contributed 32 % in current and 13% in 2050 (Table 1). The habitat suitability model is important to better preparation of our coastal lands in future climate change scenario. For example, human induced land-uses (i.e. agriculture), that close proximity to the coast can be transformed to mangroves within the mangrove gap areas while providing incentives for the land owners.

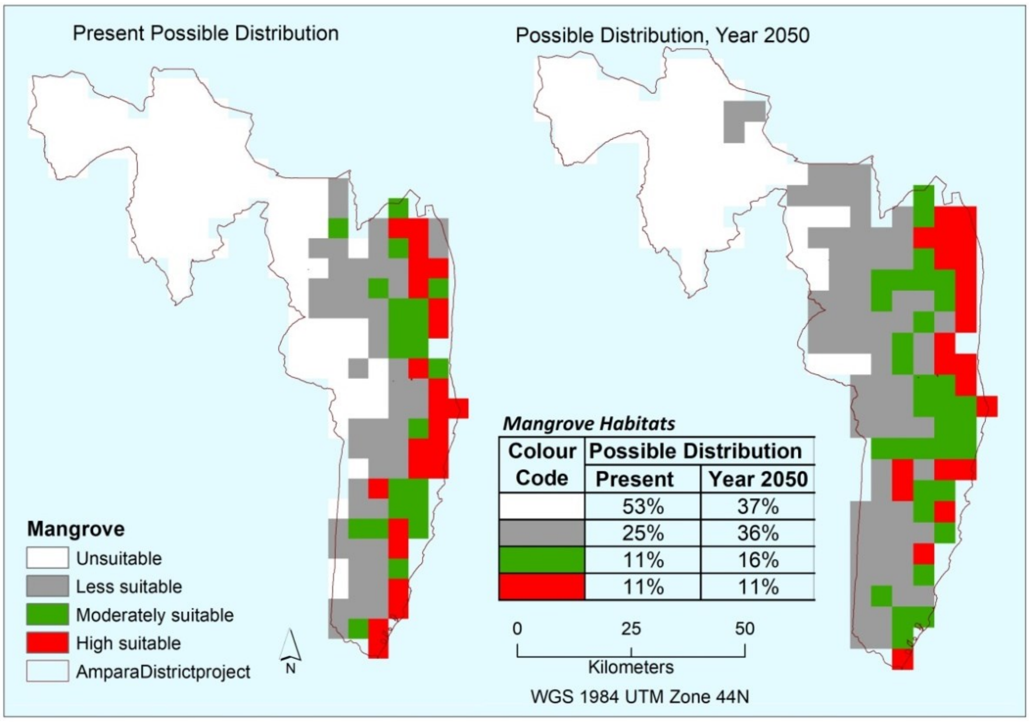

Figure 3. Potential distribution of mangrove habitats in Ampara for current and 2050 scenarios.

Table 1. MaxEnt model contributions of the environmental variables

Climatic variable	% Contribution Current	% Contribution 2050
bio6	61	67
bio8	31.7	12.5
bio4	4	9.2
bio2	3.3	7.8
bio5	0	2.9
bio3	0	0.6
bio7	0	0

bio2 = mean diurnal range
bio3 = isothermality
bio4 = temperature seasonality
bio5 = max temperature of warmest month
bio6 = min temperature of coldest month
bio7 = temperature annual range
bio8 = mean temperature of wettest quarter

5. Conclusion

This study provides the historic changes of mangroves in the past 15 years (from 2004 to 2019) and the potential suitable habitats for mangroves in next 30 years (reference to 2050). The results showed a slight decline of mangroves within five years (from 2004 to 2009) post-tsunami and then the mangrove coverage was increased to a certain extent within the next 10 years (from 2009 to 2019). These results are important to understand the degree of resilience of mangroves to tsunami disturbance in the short timescale between 2004-2009. Therefore recovery is resulting from natural regeneration and human influence planting the mangroves. The habitat suitability model of mangroves is important to implement best land management practices to prepare for climate change.

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