Chapter

GIS and Remote Sensing for Mangroves Mapping and Monitoring

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Abstract

Malaysia is one of the few South East Asian counties with large tracts of mangroves. They provide ecosystem goods and services to the environment and the surroundings regarding shoreline stabilization, storm protection, water quality maintenance, micro-climate stabilization, recreation, tourism, fishing and supply of various forest products. Despite extensive distribution of the mangroves, threats posed by different land use activities are inevitable. Therefore, knowledge on mangroves distribution and change is importance for effective management and making protection policies. Although remote sensing (RS) and geographic information system (GIS) has been widely used to characterize and monitor mangroves change over a range of spatial and temporal scales, studies on mangroves change in Malaysia is lacking. Effective mangrove management is vital via acquiring knowledge on forest distribution and changes to establish protection policies. This chapter will elaborate technically how GIS and RS were utilized to identify, map, and monitor changes of mangroves ecosystem in Malaysia. It also highlights how GIS can enhance the current governance and regulations related to forestry in Malaysia.

Keywords: mangrove ecosystem, Landsat satellites, monitoring, deforestation, carbon emission

1. Introduction

Mangroves act as frontiers that protect the coastal land against destruction of ocean waves, tsunamis and storms. Mangroves also provide habitat for various aquatic life forms and function as natural filter, which improves the quality of water. Mangroves also play important roles as a significant carbon sink in coastal environment. It is interesting fact that despite only 0.05% of plant biomass stored in the ocean and coastal areas out of the total plant biomass on land, it can absorb a comparable amount of carbon every year. A study demonstrated that primary productivity in mangroves is higher than other types of forests. Biomass carbon in mangroves stands is among the highest in the tropics. Mangroves can store up to four times more carbon (C) as compared to other tropical forests around the world [1].

A mangroves ecosystem has an ability to absorb carbon dioxide (CO_2) and store carbon 40% more than the dry land forest ecosystem. Due to this ability, the total carbon deposited in a square kilometer of mangrove ecosystem is 50 times faster than those of the same area in a dryland tropical forest ecosystem. The absorbed CO_2 is stored not only in the plants, but in layers of soils underneath [2]. Therefore, mangroves are playing a crucial role in global carbon budgets and thus mitigating climate change.

However, despite being realized the importance of mangroves in the global carbon cycle and climate change, the extents of mangroves have inevitably declined since the last few decades. Unfortunately, the declines have been resulting mainly from human activities such as aquaculture expansion, coastal development, and over-harvesting [3]. Malaysia is one of the countries in South East Asia that has among the largest extents of mangroves. Despite its extensive distribution of mangrove ecosystem, this forest is inevitable from threats by various land use activities. The total area of mangrove forest was approximately 2% (650,000 ha) of the total land area in Malaysia in the 1990s [4].

However, the mangroves in Malaysia have been gradually diminishing, where the total area of mangrove forest has reduced to approximately 580,000 ha in the last decade [5]. Other reports indicated that the extent of mangrove areas in Malaysia is decreasing, from about 700,000 ha in 1975 to 572,000 ha in 2000 due to the intensive harvesting and natural wave actions [6, 7]. Globally, mangroves have also declined from 18.8 million ha to 15.6 million ha between years 1980 and 2005 [8]. Overall Asia was the largest net loss of mangroves since 1980, with about 1.9 million ha have loss, mainly due to conversion of mangrove forest to other land uses. However, there has been a slowdown in the annual rate of mangrove loss, from about 187,000 ha in the 1980s to 102,000 ha between 2000 and 2005. This reflects an increased awareness and an improved management system in mangroves ecosystem.

Major threats towards the mangroves that are triggered by human activities can generalized into six [9], which are (i) conversion to other uses, (ii) overharvesting, (iii) overfishing, (iv) pollution, (v) sedimentation and (vi) alteration of flow regimes. Direct conversion to other uses was identified as the major factor that changes the world's mangroves. This includes conversions to (i) urban and industrial areas, (ii) aquaculture, and (iii) agriculture. Additionally, natural phenomena such as coastal erosion, storm and lightning strikes are also the natural impacts that kill mangroves in Peninsular Malaysia, including the tragic tsunami on 24 December 2004.

Despite widespread concern and numerous case studies describing local issues and challenges, comprehensive information on the global extent of mangroves and trends of deforestation is largely lacking [10]. It is because determining the precise area of mangroves is not always easy. Measurement is affected by varying definitions of what constitutes mangroves; inclusion only on the basis of official recognition such as gazetted forest reserves; scattered or sparse areas considered too inconsequential for inclusion; and the accuracy of the returns made by the responsible authorities. Each of these can create uncertainty and produce significant variation depending on the timing and purpose of the assessment exercise.

Recently, RS satellites have been widely used for mangrove monitoring. They greatest reasons why is because the RS can (i) acquire information over large areas, (ii) produce repeated measurement over a place, and (iii) make full use of electromagnetic spectrum for quantitative and qualitative measurements over mangroves [11]. Satellites also provide information on spatial distribution and temporal changes of mangrove forests. When this information is gathered over decades, the mangrove monitoring over the large area will become possible. There are studies on the assessment of mangroves changes and identifying threats, for example in Terengganu [12], Selangor [13], and Peninsular Malaysia [14]. However, these studies are unable to represent the holistic conditions at national level. Therefore, this study was conducted to provide the information pertaining status of mangroves and changes that occurred since the last three decades.

2. The identification from remotely sensed data

2.1 The study area

The study area covers the entire mangroves ecosystem in Malaysia, which can be divided into two regions, which are Peninsular Malaysia and East Malaysia (i.e. Malay Borneo). Forests in these regions can be divided into three major types, which are inland dipterocarps (dryland), peat swamp, mangrove forests (wetlands). The mangrove forest is a unique ecosystem and the second largest wetland forest type after the peat swamp forest. Ecologically based on elevation the mangrove forest is located at the lowest elevation, which is equivalent to the sea level. The mangrove forest is generally found along sheltered coasts where it grows abundantly in saline soil and brackish water dominated mainly by trees from the *Rhizophoraceae* family. Mangroves are fringing the coastlines (up to 5 km landward) and major estuaries of the regions and they reside on wetlands ecosystem of not more than 20 m land altitude.

2.2 Satellite data

Images from Landsat-5 Thematic Mapper (TM), Landsat-7 Enhanced Thematic Mapper (ETM+), and Landsat-8 Operational Land Imager (OLI) satellite were used in this study. Images from three different epochs, which are 1990, 2000 and 2017 were acquired to conduct the work. For the respective years were utilized in this study. All images are available at https://earthexplorer.usgs.gov/ and were downloaded free of charge. At least 23 scenes of Landsat images were used for a single epoch (**Figure 1**). Therefore, to complete the series, the study has acquired at least 69 scenes of Landsat images, assuming that all images are free from cloud cover. However, cloud cover are presence on some of the images, hence, more than one scene of images over the same year were acquired to remove the clouds.

2.3 Production of seamless mosaic images

Cloud cover is inevitable on the images acquired by the satellites. However, cloud patching process can eliminate the cloud covers that appear on a single-date observation data. Images of particular scenes that were acquired on different dates were used for cloud patching process as shown in **Figure 2**. F_mask algorithm was used to perform this process [15, 16]. Seamless mosaics product (i.e. images without cloud covers and atmospherically corrected) were used as input for subsequent processes.

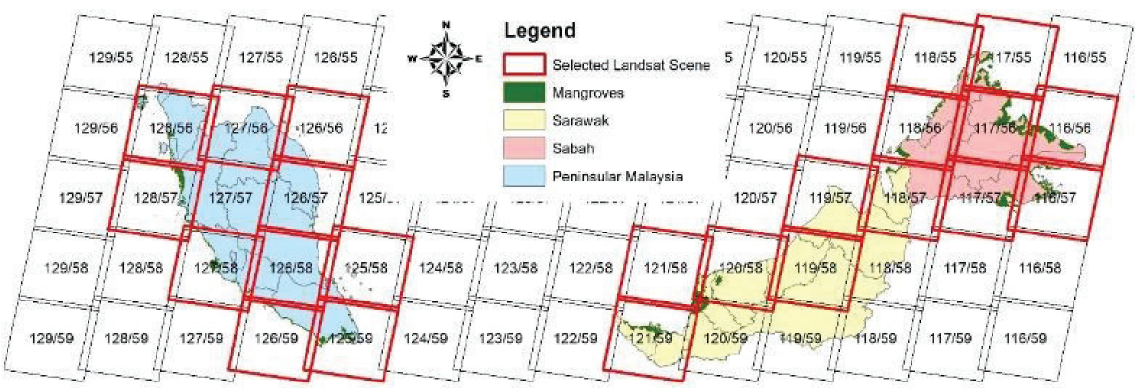

Figure 1.
Landsat scenes that were used for the classification. Numbers within the scene boundary indicates path/row ID of Landsat satellites.

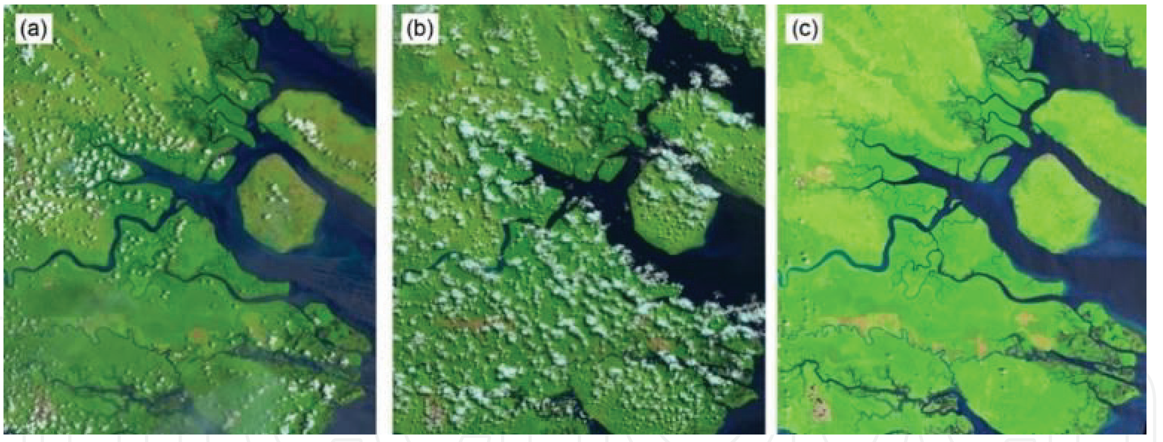

Figure 2.
Cloud detection and removal process. Individual Landsat scene that was captured on 26 January 2017 (a) was merged with that captured on 14 June 2017 (b), where both produced a cloud-free images for the year 2017 (c).

2.4 Images classification

Appropriate enhancement techniques were applied to the images to make the mangroves appear better on the images [17]. In addition to the individual spectral bands of Landsat images, vegetation indices such as Normalized Different Vegetation Index (NDVI), Green Atmospherically Resistant Index (GARI), and Normalized Difference Infrared Index (NDII) were also derived from the images to improve quality of classification. The vegetation indices that were used in this study are summarized in **Table 1**.

Most spectral-based image classifications are performed using traditional methods such as maximum likelihood, linear discriminant analysis, and spectral angle mapper classifiers. These methods are applied to the spectral bands to produce a classified feature in images [18]. Instead of using these approaches, this study attempted a new approach to classify the images. R Package, which is free, open source software with the RandomForest algorithm [19] was used.

RandomForest implements Breiman's RandomForest algorithm, based on Breiman and Cutler's original FORTRAN code for classification and regression [20]. It can also be used for assessing proximities among data points without necessarily a training set. All sampling points that were collected on the ground were connected to the corresponding pixels on the image through this algorithm. Classification was done by searching the most important variables i.e. which spectral bands are used in decision tree approach [21–23]. RandomForest applies four major steps of looking at the importance of variables as follow:

1. Step 1: to determine the significance of the m^{th} variable. In the left out cases for the k^{th} tree, randomly permute all values of the m^{th} variable. Put these new covariate values down the tree and get classifications.

2. Steps 2 and 3: for the n^{th} case in the data, its margin at the end of a run is the proportion of votes for its true class minus the maximum of the proportion of votes for each of the other classes. The 2nd measure of importance of the m^{th} variable is the average lowering of the margin across all cases when the m^{th} variable is randomly permuted as in Step 1. Step 3 then count the margins that was shrank.

3. Step 4: the splitting criterion used in RandomForest is the Gini criterion, a mechanism that can measure the most to least importance of variables used in

Vegetation indices	Formula	Description
NDVI	$\text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}}$	Commonly used to delineate vegetation from other features on images and to measure vegetation vigor. It is sensitive to atmospheric effects
GARI	$\text{GARI} = \frac{\text{NIR} - [\text{G} - 1.7 * (\text{B} - \text{R})]}{\text{NIR} + [\text{G} - 1.7 * (\text{B} - \text{R})]}$	Normally used for detection of green pigment concentration and differentiate chlorophyll levels. It is more sensitive to chlorophyll concentrations than the atmospheric effects
NDII	$\text{NDII} = \frac{\text{NIR} - \text{MidIR}}{\text{NIR} + \text{MidIR}}$	It uses near- and mid-infrared bands to detect changes in plant biomass and water stress in wetlands like mangroves

Note: NIR = near infrared, G = green, B = blue, R = red, and MidIR = middle wave infrared channels.

Table 1.
Vegetation indices that were used derived from the images.

decision tree. At every split, one of the mth variables is used to form the split and there is a resulting decrease in the Gini. The sum of all will decrease the forest due to a given variable, normalized by the number of trees.

All images have been classified to distinguish mangroves from the other land uses. The classification results were transformed into vector shapefile for further refinement and editing. The accuracy of the classification results were assessed by using a number of ground truth points. The GIS platform was used to carry out post-classification analysis. Post-classification analysis is usually used for quantifying changes of land uses. Changes of mangroves were identified from the conversions of mangroves to other landuse classes, which are (i) urban, settlement, and industrial areas, (ii) agricultural, (iii) aquaculture activities, and (iv) coastal erosion.

2.5 Estimation of CO_2 emission

Carbon dioxide (CO_2) is defined as natural, colorless and odorless greenhouse gas that is emitted when fossil fuels (i.e. natural gas, oil, coal, etc.) are burnt. In this study, the CO_2 emission is expressed as C loss, assuming that the gas is emitted when deforestation occur. The units of metric tons C was converted to CO_2 by multiplying the ratio of the molecular weight of carbon dioxide to that of carbon (44/12 = 3.67) [24].

The CO_2 resulted from deforestation is one of the important elements in greenhouse gases emissions. Therefore, it is also essential to quantify the contribution of mangrove deforestation towards the CO_2 emission. Net emission as resulted from deforestation of mangroves can be estimated based stock-difference method, which can be expressed as Eq. (1) as follow [24];

$$\Delta C = \frac{(C_{t1} - C_{t2})}{(t_2 - t_1)} \tag{1}$$

where ΔC is changes in carbon stock (Mg C yr^{-1}), C_{t1} and C_{t2} (Mg C) is carbon stock at time t_1 and t_2 (year), respectively. In this case, the C_{t1} and C_{t2} was quantified from the changes analysis that have been carried out earlier this study.

3. Mangroves mapping and monitoring in Malaysia

3.1 Production of seamless image mosaic

F mask algorithm successfully removed almost 100% of cloud covers and their shadows on the images. The algorithm also managed to detect thin, low temperature clouds in the high altitude by thermal sensors onboard the Landsat TM, ETM+ and OLI. The algorithm somehow failed to detect small scattering clouds that occurred in small patches on the images. Nevertheless, the algorithm has facilitated the cloud removal process and make the mangroves mapping and monitoring work at landscape-level practical. **Figure 2** shows a portion of mangroves on two different images that were captured on different dates with clouds. These images were used to produce seamless mosaic of images without cloud covers.

3.2 Identification of mangrove ecosystem and images classification

The study indicated that the suitable spectral bands for species discrimination varied with scale. However, near-infrared (700–1327 nm) bands were consistently important spectrum across all scales and the visible bands (437–700 nm) were more important at pixel and crown scales. By using the RandomForest algorithm, the most important bands in the classification were represented by a mean decrease Gini values. The most important bands in mangroves discrimination, from most to least, are; MidIR, NIR-2, NIR, Green, Blue, Red. Spectral profile of the images also showed that the NIR channels separate the mangroves from the other land covers very well (**Figure 3**). On the other hands, the vegetation indices that were used in this study played similar important role in mangroves classification.

The image classification approach that has been applied in this study was found to be effective only at large coverage of mangroves. The accuracy for all classifications were ranging from 83 to 91%, which were acceptable and reliable for monitoring purpose. Mangroves are normally appear dark on any combination of spectral bands of multispectral image. This is due to the natural ecosystem of mangroves, which is covered by swamps and sometimes inundated by tidal water. The chlorophyll content of the mangrove leaves, which is higher than those of trees and crops, tends to make them appear darker on satellite images [25], as depicted in **Figure 4**. Each mangrove species has a unique configuration of trunks, prop roots and

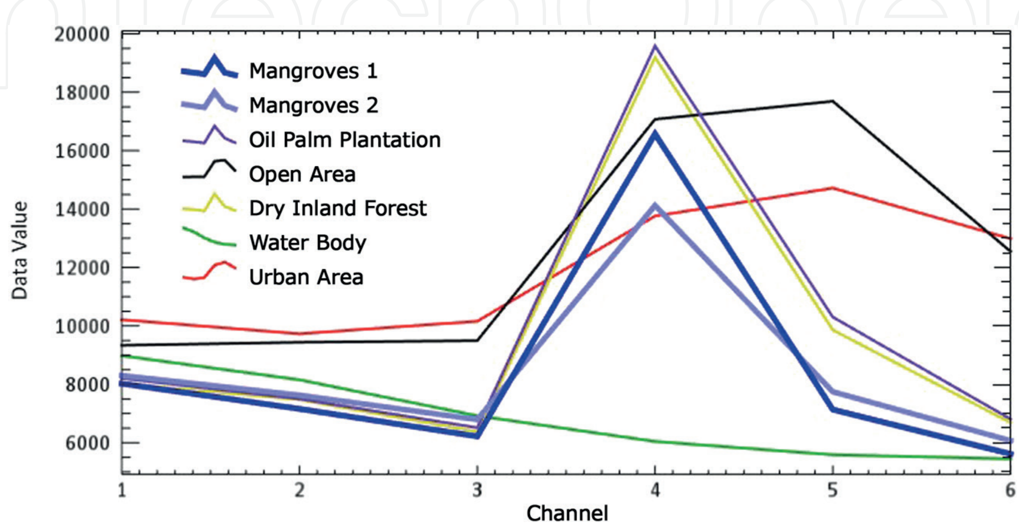

Figure 3.
Spectral profiles of several land covers extracted from the images. Channel 1 through 6 on the y-axis are blue, green, red, NIR, NIR-2 and MidIR, respectively.

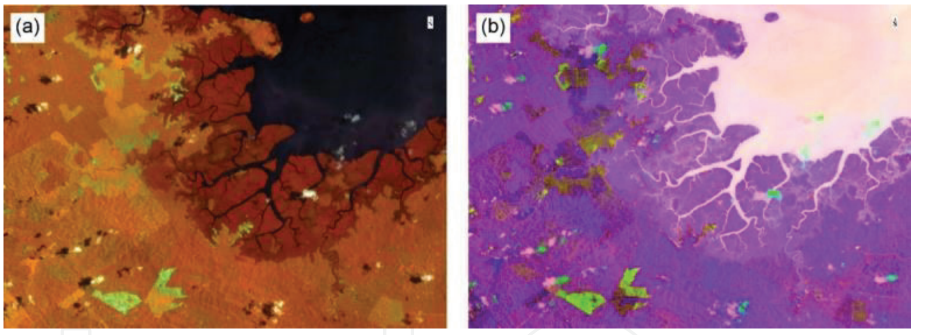

Figure 4.
Images showing (a) combination of bands 5, 6 and 4 of Landsat-8 OLI and (b) combination of vegetation indices, NDVI, GARI and NDII. These images were selected for the classification process.

pneumatophores that works as a different drag force therefore resulting in a different reduction rate of sea waves (**Figure 5**). Not only this, the wet floor of the forest gives special spectral characteristics on satellites images that can be differentiated easily from other features (**Figure 6**).

3.3 Spatial data editing for mangroves mapping

The classification results were further edited to refine the shapes and accuracy. This process was conducted manually on the vector shapefile by visual interpretation on GIS platform. Finally the spatial distribution of the mangroves were mapped properly (**Figure 7**). The mangroves in Malaysia were mostly found in Sabah (60%), followed by Sarawak (22%) and Peninsular Malaysia (18%). **Table 2** summarizes the total extents of mangroves in the respective regions that have been produced from the classification. It is notable that the total extents of mangroves have been decreasing throughout the monitoring period. **Figure 8** shows spatially explicit map of mangroves distribution in Malaysia as of year 2017. Mangroves are found mainly along the west coast of Peninsular Malaysia, west coast of Sarawak and the east coast of Sabah.

3.4 Monitoring of mangroves changes

Table 3 reports the changes of mangroves that occurred over the 27 years of monitoring period. The total loss of mangroves was about 21,274 ha where majority of the mangroves loss were outside the Permanent Forest Reserve or within the

Figure 5.
Roots and successive stands of Rhizophora apiculata in a common mature mangrove forest.

Figure 6.
Mangroves as they appeared on Landsat-8 image. The dark green areas represent the mangrove areas. The image classification process, either automated or manual digitizing, is usually easier for mangrove areas than for other vegetation. The image is displayed using a combination of bands 543 (RGB) over the Kapar area in Klang, Selangor. The central bottom is Klang port complex and the bottom left is Pulau Klang, which is predominantly covered by mangroves.

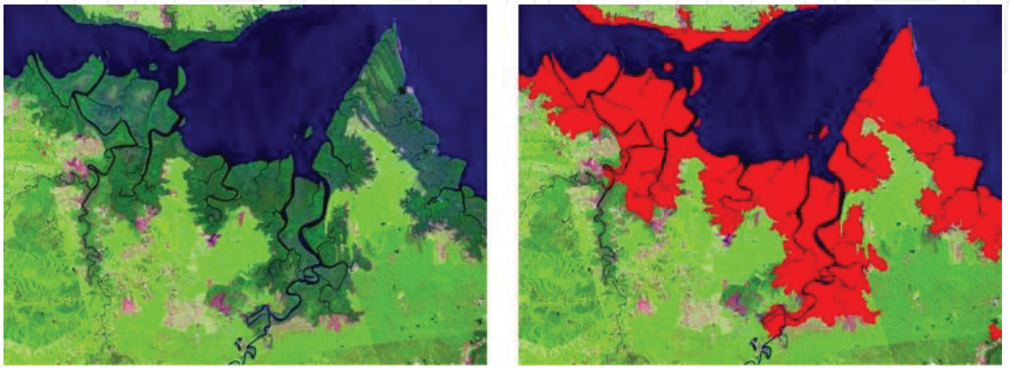

Figure 7.
Mangroves appear dark green on the original image (left) and the classified mangroves, indicated as red polygons (right).

stateland areas. These areas are actually the land bank for the states developments, which are principally included in the State's Structural Planning. Example of mangroves changes detected from the multi-temporal mapping process is shown in

Region	Mangroves 1990 (ha)	Mangroves 2000 (ha)	Mangroves 2017 (ha)
Peninsular Malaysia	116,746	114,353	110,953
Sabah	385,630	382,448	378,195
Sarawak	147,936	145,263	139,890
Total	650,311	642,063	629,038

Table 2.
Extents of mangroves in Malaysia.

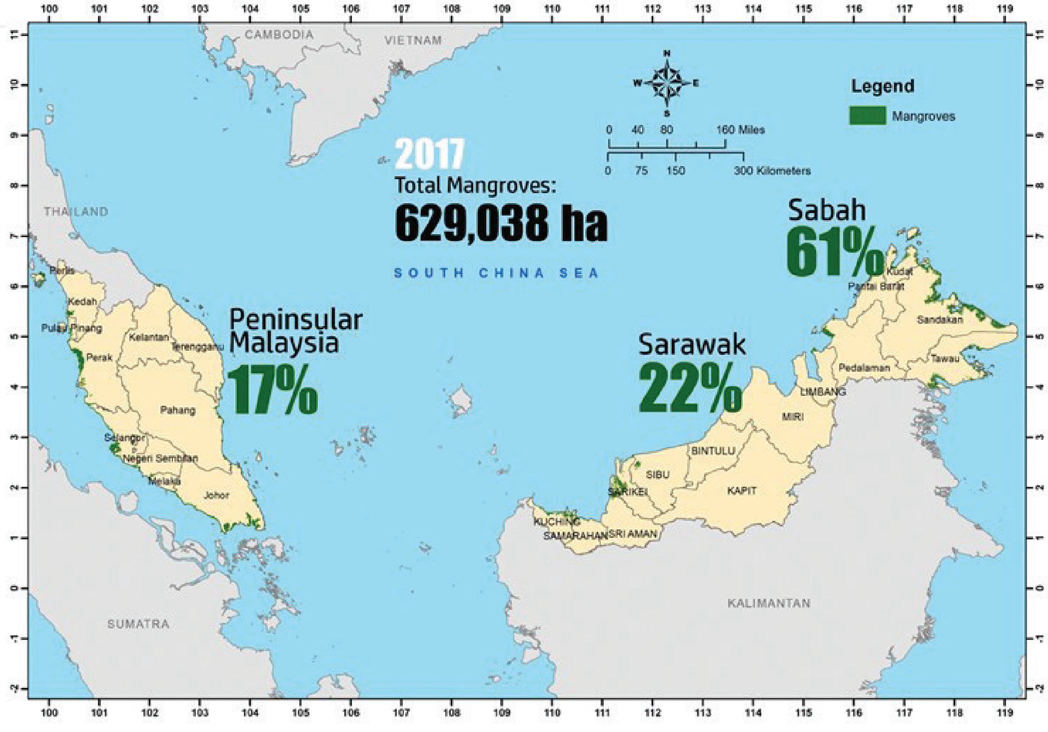

Figure 8.
Distribution of mangroves in Malaysia over the year 2017.

Region	Mangrove loss 1990–2000 (ha)	Mangrove loss 2000–2017 (ha)	Rate of deforestation 1990–2000 (ha yr^{-1}) | (% yr^{-1})	Rate of deforestation 2000–2017 (ha yr^{-1}) | (% yr^{-1})	Average rate of deforestation 1990–2017 (ha yr^{-1}) | (% yr^{-1})
Peninsular Malaysia	2393	3400	239 | 0.20	200 | 0.17	215 | 0.19
Sabah	3182	4253	318 | 0.08	250 | 0.07	275 | 0.07
Sarawak	2673	5373	267 | 0.18	316 | 0.22	298 | 0.21
Total	8227	13,190	823 | 0.13	776 | 0.12	793 | 0.13

Table 3.
Mangroves deforestation in Malaysia between years 1990 and 2017.

Figure 9. From this information, it can be concluded that the annual decrease rate of mangroves was about 788 ha per year or about 0.13% per annum since year 1990. Major factors that contributed to these changes have been identified as: (i) direct conversion to other land uses (**Figure 10**), predominantly for commercial-scale

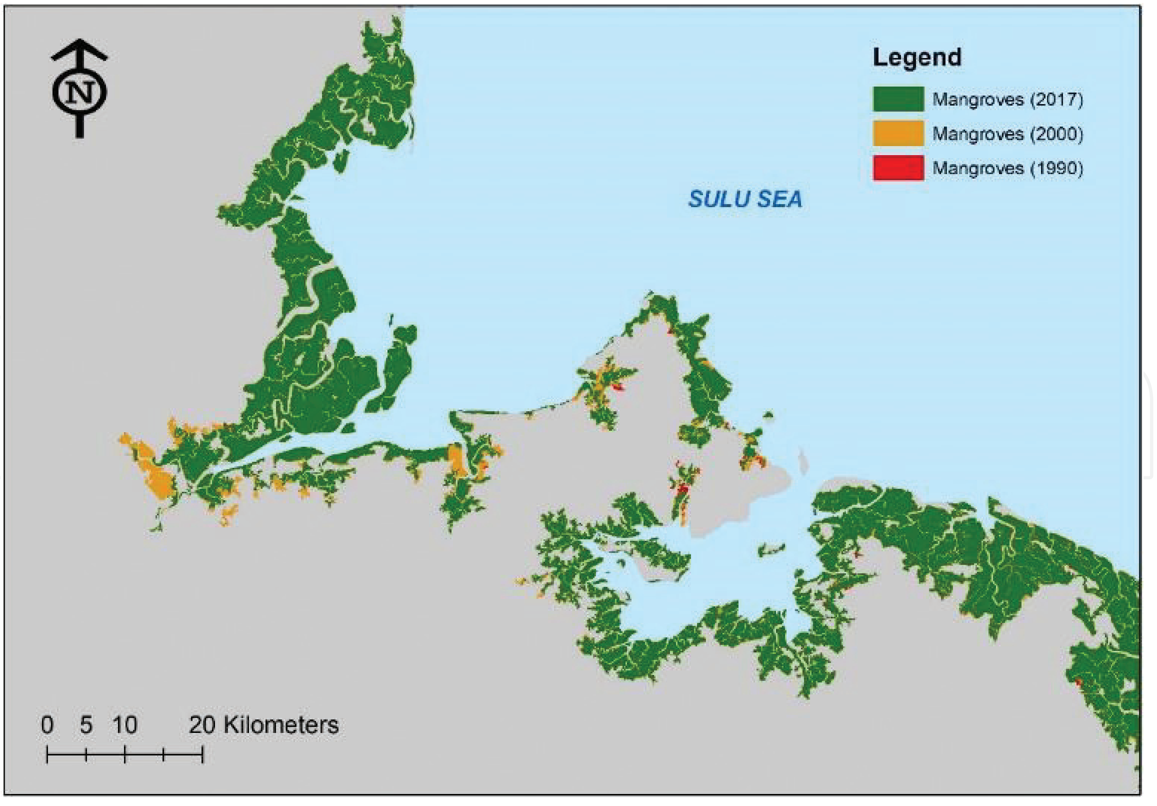

Figure 9.
Changes of mangroves that occurred between 1990 and 2017 overlaid on GIS platform.

agriculture (**Figure 11**) and aquaculture (**Figure 12**), and (ii) coastal erosion (**Figure 13**). The other factors such as overharvesting and pollution affect the mangroves to a lesser degree.

Although coastal erosion was identified as one of the factors of mangroves loss, there were some accretions occurred in some other places. Erosion and accretion is a dynamic process and takes place along the coastlines and major estuaries, where suspended sediments are likely to settle. These phenomena also lead to species succession when the existing plant species die due to unsuitable soil and new species emerge. Besides, mangrove roots can act as wave breaker and promote flocculation and sedimentation, eventually forming mudflats that allow positive accretion (**Figure 14**). Coastal erosion occurs when the waves hit perpendicular to the coastlines and when the rapid flow of sea currents wash away the sand or soil particles. The frequency and height of waves hitting the coastlines contribute to the harshness of coastal erosion. Thus, the presence of mangroves can reduce the coastal erosion significantly. This condition is obvious particularly in the areas facing the sea [26, 27].

Figure 10.
Land developments on mangroves. Reddish color represents newly opened areas for development purposes that were cleared from the original mangroves areas (dark green color).

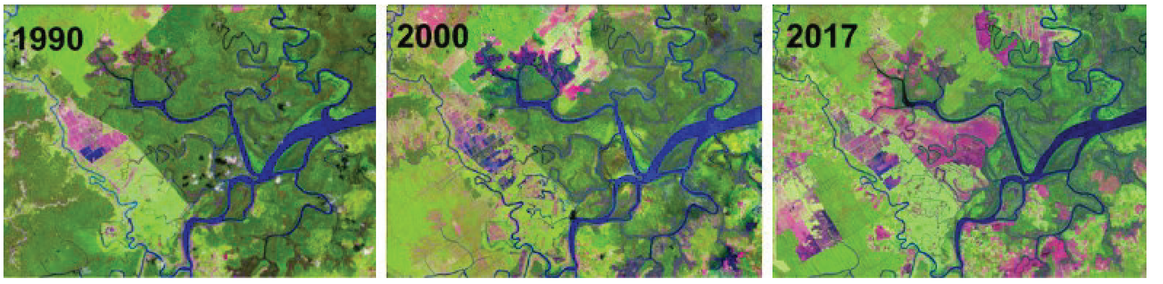

Figure 11.
Expansion of oil palm plantation on mangroves. Reddish color represents newly opened plantations from the original mangroves areas (dark green color). The bright green represents existing plantations.

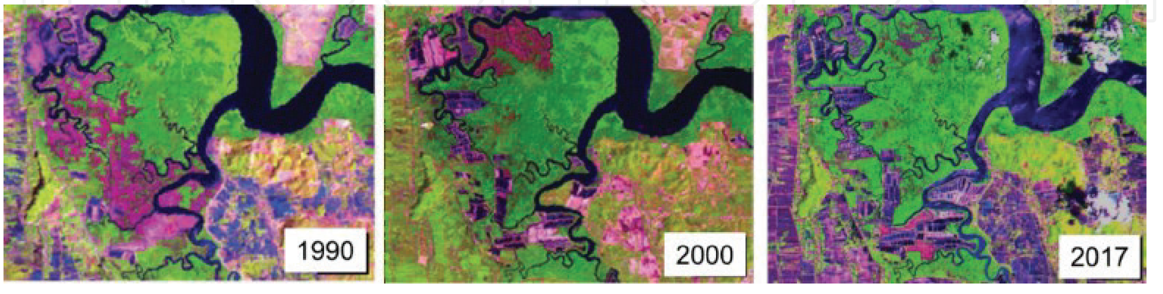

Figure 12.
Expansion of aquaculture industries on mangroves. Dark blue patches represents newly opened aquaculture ponds from the original mangroves areas (dark green color).

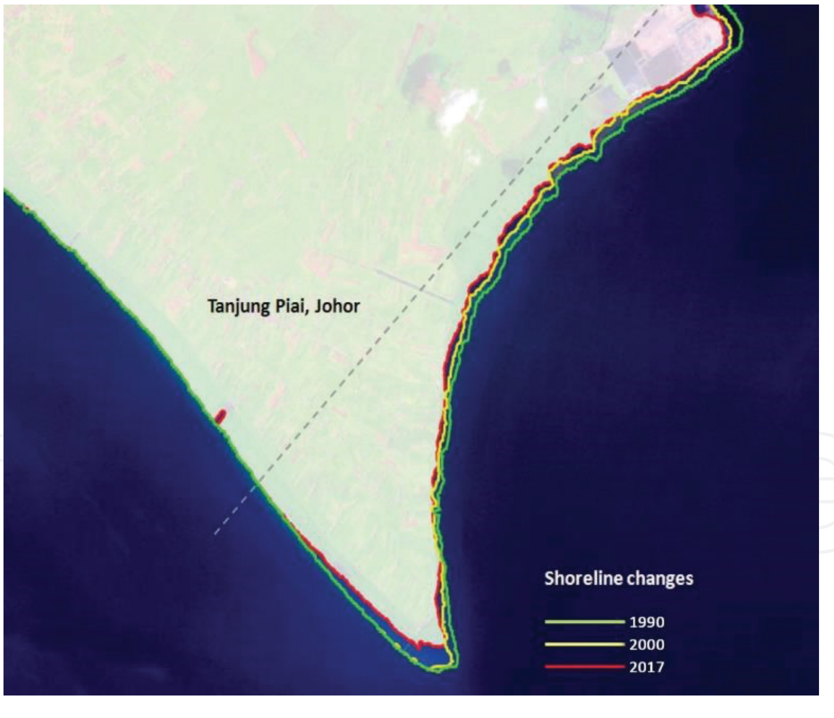

Figure 13.
Shoreline changes that resulted from coastal erosion along the coast of south Pontian, Johor. The study indicated that 14.2 km stretches have been facing serious coastal erosion within the last two decades with the rate of erosion ranging from 3.2 to 12.5 m per year.

3.5 The estimated carbon emission

A study has indicated that the average C stock (aboveground and belowground) in mangroves in Malaysia is about 181 Mg C ha^{-1} [28]. The extents of mangroves loss for each epoch were multiplied by this average carbon stocks. The study demonstrated that the total loss of carbon due to the loss of mangroves was about 2.6 million

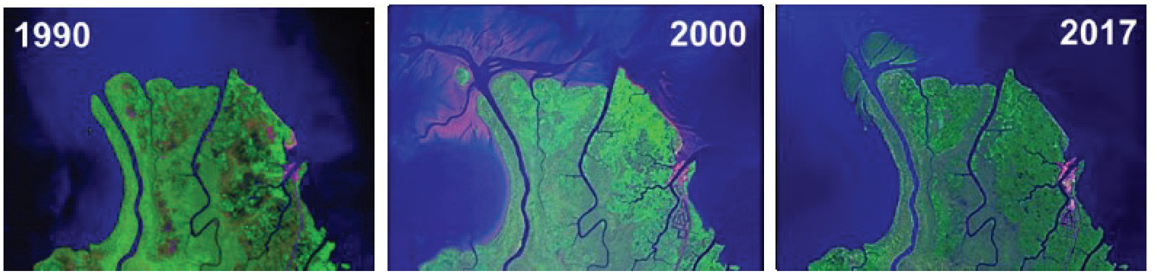

Figure 14.
Positive accretion of mangroves at estuaries. The new formations at the river mouths were colonized by mangroves trees forming a naturally generated forest.

Region	Mangrove loss (ha)	Carbon loss (Mg C)	CO_2 emission (Mg CO_2)	Rate of CO_2 emission (Mg CO_2 yr^{-1})
Peninsular Malaysia	5793	1,048,567	3,848,242	142,527
Sabah	7435	1,345,672	4,938,617	182,912
Sarawak	8046	1,456,288	5,344,578	197,947
Total	21,417	3,876,409	14,226,422	526,905

Table 4.
CO_2 emission resulted from mangroves loss between years 1990 and 2017.

Mg C. Subsequently, this has led to the CO_2 emission at about 14.2 million Mg CO_2, with an average of about 0.5 million Mg CO_2 emission per year, along the monitoring period. **Table 4** summarizes the impact of mangroves loss in terms of CO_2 emission. Although the figures are generally crude, the study provided some ideas for further studies, especially which related to carbon cycles and climate change.

4. Conclusion

This study has successfully assessed the current state of mangroves and determined the rate of mangroves loss in Malaysia since the last decade. Total mangroves in Malaysia has decreased from 650,311 ha in 1990 to 629,038 ha in 2017. Total deforestation was accounted at 21,274 ha or 3.3% with the annual rate of deforestation of 788 ha yr^{-1} or 0.13% yr^{-1}, between 1990 and 2017. The study also quantified the C stock changes and estimated CO_2 emission due to the loss of mangroves in Malaysia. Total emission caused by the mangroves deforestation was accounted at about 14 million Mg CO_2 with annual emission rate of around 0.5 million Mg CO_2 yr^{-1}.

The study found that the Landsat-based mapping and monitoring of mangroves was very practical. It provides a reliable information on mangroves distribution, both qualitatively and quantitatively. Landsat missions provide a very useful RS tool for monitoring changes of mangroves over time. The study suggests that appropriate actions should be taken by the Government of Malaysia to protect the mangroves and keep their ecosystem intact forever. The most effective way to conserve the mangroves is to gazette the remaining stateland forest as Permanent Reserved Forests (PRFs). These PRFs should then be maintained as amenity for current and future generations, while contributing to the mitigation of climate change impacts at the local level. Any development in PRFs should be prohibited or implemented with caution.

Overall, there is great potential in the application of Landsat-based data with appropriate GIS technique for mapping and monitoring of mangroves in Malaysia.

Although there are cloud covers problems on some of the images, this has not hindered the assessment of mangroves at landscape and regional levels. The accuracy and precision also vary depending on the objective of the application. However, the ability to detect major changes in the ecosystem that can cause profound and irreversible damage far outweighs a perfectly or highly accurate and precise RS based method at this point.

Currently, Malaysia has reserved about 85% (~535,000 ha) out of the total areas of mangroves as Permanent Forest Reserve and State/National Parks. The remaining 15% is under the state-lands and alienated lands. By far, the most effective way to preserve these mangroves is through gazzeting into permanent forest reserves.

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Conflict of interest

The authors declare no 'conflict of interest' for this chapter.

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