Prediction of Supratidal Zones as Turtle Nesting Sites using Remote Sensing and Geographic Information System, A Case study in Pacitan, Southern Java Sea

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Abstract. Turtles, the most threatened coastal-marine fauna, are protected through both national, and global regulations. However, many of their nesting sites have been degraded in the past years. Completing natal homing, adult females emerged at night to lay-down eggs in the upper intertidal and supra-tidal zone of sandy beach from where they hatched. This study explained coastal topology of beaches usually used for nesting sites, covering 117 km coastline at Pacitan Regency, Southern Java Sea. The shift in beach morphology through times was figured out based on Landsat 8 and Sentinel 2a satellite imagery and remote sensing (GIS methods). This was combined with in-situ data on current coastline features, slope, and tide variations. Results showed a typical sandy beach, called Taman Ria Beach, a long time identified as nesting site for Lepidochelys olivacea, locally named as Penyu Lekang. Also, there was approximately 3.49 ha of supratidal area predicted in Taman Ria Beach according this study.

1. Introduction

A supratidal or supra-littoral zone can be defined as a zone near the shore but above the level of high tide [1]. In general, supratidal zone has been referred to as spray zone immediately above the highest high tide level [2]. It is also known as the splash zone in a coastal area. Furthermore, the zone sometimes splashed but not inundated or submerged by seawater. In other words, supra-littoral is a transitional region from land to sea floor above the spring high tide line [3]. As a result, supratidal zone is only covered by seawater during when very high tides or tsunamis or possibly large storm waves splash over the coastal zone.

The aim of the study was to predict the locations of supratidal zones with remote sensing and GIS approaches. Supratidal zone is well-known as an important area for completing natal homing of female sea turtles and their eggs hatching. Adult female turtles emerged at night to lay eggs in the upper intertidal and supra-tidal zone of a sandy beach from where they hatched. After several days, if the temperature and the humidity of the sand are suitable, those eggs that were left under sand will hatch as baby sea turtle or “hatchling”. On the other hand, although sea turtles were protected by both national
and global regulations, the degradation of many nesting sites in the past years has been disturbing the sea turtle life cycle. In the end, by predicting supratidal zones and measuring coastal physical characteristics, including coastline dynamics, the study could contribute to sea turtle conservation activity and coastal zone protection and serve as a baseline for further analyses related to coastal zone management in general.

2. Methodology

Morphological features such as coastline shape and type of coastal area in Pacitan directly facing to the Southern Java Sea were monitored from 2015 to 2017 via Landsat 8 OLI and Sentinel 2A remote sensing satellite images. Multi temporal Landsat 8 OLI images was acquired on 19 May 2014, 23 June 2015, 28 August 2016 and 28 June 2017. Meanwhile, Sentinel 2A images were acquired on 28 June 2017 and 25 November 2017. This study applied remote sensing techniques to obtain information through the analysis of images acquired by those satellite sensors [4]. Hence, during the process of detection and analysis, the researchers were not in contact with the investigated object or area.

According to McIntry [5], a shore is determined by the geology and topography of the coastline and adjacent land, the physical processes operating on them, the actions of rivers and waves created, the supply, and the distribution of sedimentary materials. One of the results is the presence of sand that indicates exposure to wave actions. As a consequence, the morphological type of a coastal zone serves as an important characteristic that determines whether a coastal zone is suitable for turtle nesting or not. The coastal type classification by [6] was applied. As a result, the sandy beaches surrounding Pacitan area were selected. The indication that sand beaches are much flatter than shingle beaches [5] was also used as a consideration during this process. Meanwhile, cliff and mudflat were removed because they did not meet the requirements for turtle nesting. In the end, the identification of sand beaches was carried out to predict the locations of supratidal zones, because the existing sand zones are more possible to be turtle nesting sites.

Meanwhile, the identification of sand beaches applied different methods by previous researchers [7]. In this study, multi-temporal images were used following the examples of Indian researchers [8], but IRS was substituted with Landsat 8 OLI for the mapping of physical features such as the characteristics of coastal morphology and the dynamics of coastline shapes, and for the identification of possible coastal zones for turtle nesting. Meanwhile, Sentinel 2A for June 2017 was used to detail and predict supratidal zones after the previous process with Landsat 8 OLI. Visual image interpretation methods were used on those satellite images to map physical features that could lead to the prediction of supratidal zones. Image enhancement was performed to increase the visual quality of the satellite images. Image enhancement was conducted through False Color Composite (FCC) and panchromatic sharpening (pan-sharpen). For Landsat 8 OLI, FCC RGB 567 was pan-sharpened with band 8 panchromatic. Band 8 of Landsat OLI that had better spatial resolution (15 meters) could enhance bands 5, 6, and 7 that only had 30 meter spatial resolution. Moreover, the supratidal zone prediction used Sentinel 2A images that were processed into reflectance images. Then, Band 8 and 3 of the Sentinel 2A images were selected to produce new images called Normalized Difference Sand Index (NSDI) images. In this study, NSDI algorithm [9] was applied with a modification to enhance sand features from the images. It means that Band 3 (green) of Sentinel 2A was used instead of Band 4 (red). The original NSDI algorithm [9] was formulated by rationing SWIR Band and Red Band as below:

\[ \text{NSDI} = \frac{\text{SWIR2} - R}{\text{SWIR2} + R} \]

Where:

- \( \text{SWIR2} \) = Short Wave Infra Red Band
- \( R \) = Red Band

\[ \text{NSDI} = \frac{\text{SWIR2} - \text{R}}{\text{SWIR2} + \text{R}} \]
Furthermore, NSDI images were combined with the elevation and average sea level data. In the end, the supratidal zones were predicted according to the average sea level data. We assumed that the supratidal zones would be up to the average high tide or average sea level during spring tide. The area would only be submerged if very high tide happens there.

3. Results and discussion

In the first step, the Landsat 8 OLI images acquired on 23 June 2015, 28 August 2016 and 28 June 2017 were used to delineate the coastline in the study area and to identify the locations of marine-deposition coasts to be the locations of sandy beaches where turtle would land. As a result (figure 1), there were 4 (four) locations identified as marine-deposition coasts likely to meet turtle nesting requirements, namely: (1) Teleng Ria beach, (2) Soge beach, (3) Taman Ria beach, and (4) Kunir beach. Meanwhile, from 2015 to 2017, the coastlines of Teleng Ria beach and Taman Ria beach were very dynamic, especially near the river mouth. It is believed that the sand areas near river mouth will be less visited by turtles due to rapid shift. For further investigation, Taman Ria beach was selected as the area of interest because this location had a turtle conservation area managed by the local community in cooperation with the Marine Affairs and Fisheries Office at sub-district level.

![Map of coastline dynamics and identified marine-deposition coast](image)

The NSDI images resulted from Sentinel 2A processing at Taman Ria sandy beach are as shown in figure 2 and figure 3. In figure 2 and figure 3, the NSDI images were set with pseudo color to make it easier to distinguish sand from other features such as water, vegetation and built area. Furthermore, by observing the pixel value of the NSDI image, it was found that the sand had a value of between 0.0264 and 0.100. Meanwhile, vegetation and built area had NSDI values of more than 0.1. Lastly, water body, including breaking wave, deep sea water and shallow water from the river were identified with NSDI to have negative values.
The NSDI images (figure 4) were combined with the SRTM data. Then, 3D analysis was implemented to represent the *in situ* landscape. This process resulted in the 3D perspective of Taman Ria beach landscape as seen in figure 4.a.1 to figure 4.b.2. As initial condition, figure 4.a.1 and figure 4.b.1 clearly represent the situation at Taman Ria beach when it has normal sea level based on the images acquired on 28 June and 25 November 2017. In this condition, sand spread widely from the western to the eastern part of Taman Ria beach, including the sand spit as marine-deposition feature located near the river mouth. Meanwhile, figure 4.b.1 and figure 4.b.2 serve as a simulation for predicting the situation if the sea level rises approximately 50 cm from normal condition. Figure 4.b1 and figure 4.b.2 clearly show that the sand spit feature near the river mouth disappear or is submerged by the seawater. It indicates that the sand spit or sand bar area near the river mouth is not part of supratidal zone because it has already been submerged by the water with only a 50 cm sea level rise. As the result of the simulation, it is believed that female turtles will not land there for laying their eggs due to the instability of the sand area. Meanwhile, according to that simulation, the wide area next to the sand spit feature was
surprisingly not submerged by the water. However, further investigation was still required to provide evidence for it to be predicted as a supratidal zone.

As the investigation proceeded, 3D analysis was continued by using ±100 cm and ±200 cm sea level rises in sequence. The results of this investigation are presented on figure 5.a.1 to figure 5.b.2. Those figures showed that the area located at the western part of the sand spit near the river mouth was still stable and was not submerged by the seawater. These results clearly indicated that the sandy area was close to be a supratidal zone. Furthermore, to prove the prediction of the supratidal zone at Taman Ria beach, we conducted an interview with local people who worked in the turtle conservation since its establishment by the District Government in 2013. The results of the interview were consistent with the results obtained from the 3D analysis. Adult female turtles regularly complete natal homing at night to lay their eggs in that area as predicted by the analysis. Figure 6 shows the predicted supratidal zone according to this study according to the Sentinel 2a images acquired on 28 June 2017 and 25 November 2017 and SRTM data.

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**Figure 4.** Simulation (a.1) Normal sea level condition on 28 June 2017, (a.2) Normal sea level condition 25 November 2017, (b.1) sea level rise ±50 cm for 28 June 2017 and (b.2) sea level rise ±50 cm for 25 November 2017.
Figure 5. Simulation (a.1) sea level rise ±100 cm from normal condition for 28 June 2017 and (b.1) for 25 November 2017, then (a.2) sea level rise ± 200 cm from normal condition for 28 June 2017 and (b.2) for 25 November 2017 as simulation of an extreme sea level rise condition or very high tides.

Figure 6. Predicted supratidal area at Taman Ria Beach, Pacitan according to Sentinel 2a acquired on (a) 28 June 2017, (b) 25 November 2017 and SRTM. The prediction is based on simulation of an extreme sea level rise events.
The final predicted supratidal zone according to Sentinel 2a images acquired on 28 June 2017 and 25 November 2017 is represented by figure 6. It was resulted from the overlay between the delineation in figure 6.a and figure 6.b and then subset by the existing sand area resulted by the NSDI image in figure 3 previously. The red polygon in figure 6 shows the predicted supratidal zone of approximatelly 34,986 m² or about 3.49 Ha. Furthermore, it was also the most stable part of Taman Ria sandy beach where adult female turtles likely lay their eggs during natal homing figure 6. Predicted supratidal zone at Taman Ria Beach according to this research

A study evidence shows that sea turtles lack of parental care behaviour that making nest site becomes particularly important for the survival of their eggs [10]. It seems like adult female turtles select the locations for nesting according to their instinct in a unique way. Moreover, elevation is another important factor in the determination of a place where female turtles will lay their eggs. For example, hawksbill turtles tend to place their eggs at an elevation of approximately 1.2 m, while green turtles tend to place their eggs at an elevation of 1—3 m [11]. Furthermore, a smoother beach slopes may be favourable for adult female turtles for them to approach the nesting site in a quicker and easier way [12]. Temperature [13], moisture and sand particle size are important factors considered by adult female turtles. McGehee [14] and Rubio [15] found that higher hatching success is achieved when the moisture is about 25% and lower hatching success is achieved when the moisture is below or above 25%.

GPS locations of individual nesting sites were not available due to limitation in equipment and data records from the turtle conservation community working at Taman Ria Beach. As a consequence, this research was unable to verify the predicted supratidal zone against the real nest location. Ideally, the prediction of supratidal zone using methods applied in this research should be completed in situ to obtain the data of the place where turles exactly put their eggs, supported by detailed beach profiles and detailed tide data. The researchers eventually agreed that the methods and results of this research can still be improved.

4. Conclusion
Supratidal zone is a dynamic area. Type of coast, height/elevation, and tide or sea level affect the boundary of this zone. As a result, the boundary of a supratidal zone could vary from time to time according to those variables. Furthermore, the most stable part of a supratidal zone of a sandy beach can be expected to be the main location for adult females to lay their eggs at night. However, due to the limitation of data of the site where turtle eggs are located in Taman Ria beach, tide data or sea level data, and satellite imagery spatial resolution, this study could not provide detailed prediction of supratidal zones. An improvement of those dataset is required for further studies.

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