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UGV application for modelling and forecasting the Tidal fluctuation: With reference to coastal strip from Nintavur to Addalaichenai areas of Ampara District, Sri Lanka

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Abstract

Modelling tidal fluctuation with Unmanned Ground Vehicle (UGV) is a groundbreaking idea with an innovative approach which can be applicable to forecast and assess the inundation of coastal lands because of the tidal fluctuations in coastal environment. Albeit the aerial images are utilized for the same purpose, it is an initial step to collect random GPS points of the locations where the aerial survey is not accessible and challengeable. Therefore, this study is to create Tidal Fluctuation Model (TFM) with the remotely-controlled UGV using customized GPS tool which was employed along the study area. The waypoints were automatically collected while the UGV was running along study area. Then, having extracted the elevations from the collected GPS points, contours were created and consequently, Digital Elevation Model (DEM) was generated using Arc GIS 10.4 software. Finally, the prediction was done to show the inundation along the study area relative to the Sea water rise in the ranges viz. 0.5m, 01m, 1.5m, and 02m. Based on the forecasting, the future marine infrastructure developments and other human activities could be proceeded in a sustainable manner considering the inundation and fluctuation ranges. Also, the UGV can further be switched as Robot with the embedding system which could definitely be operated from the long distance to collect the real-time and more accurate data in future.

Keywords: TFM, UGV, forecast, coastal environment, RC, GPS, DEM

1. Introduction

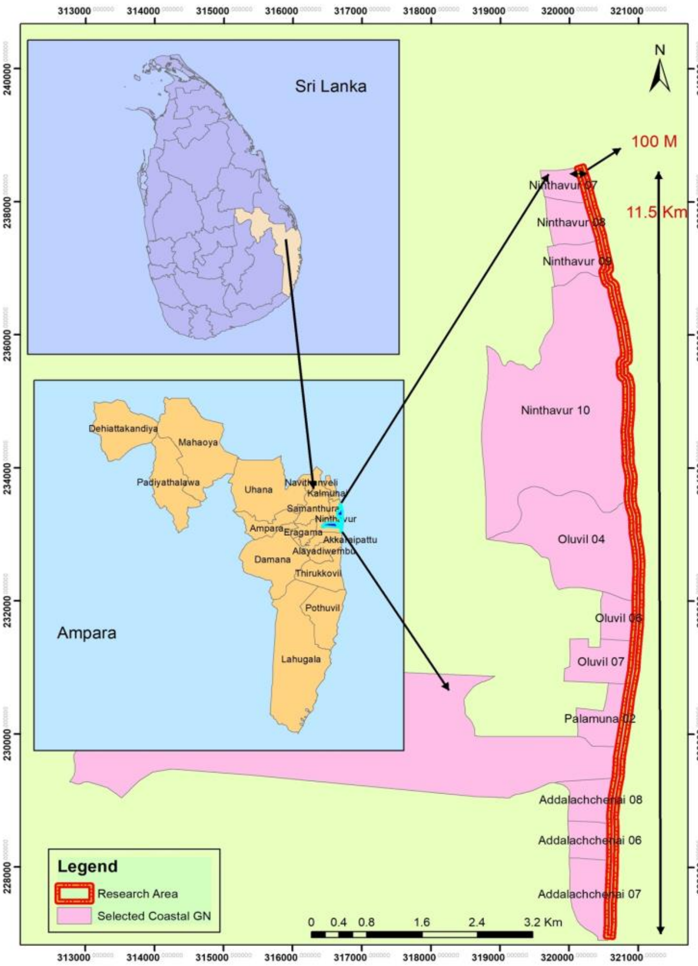
Modelling and forecasting the tidal fluctuations are vital to the coastal environment particularly to the marine infrastructure development in order to lessen the low-land inundation in coastal areas and loss of beach. Remote Sensing (RS) technology provides an extensive flatform to do so with the state-of-the-art technology. Lidar and micro band satellite images are costly elements for the modelling and forecasting process. However, as an innovative idea with low-cost methods, TFM was created using customized remotely-operated UGV, mounted with high accuracy GPS software-installed smart phone which collected thousands of random GPS points with elevation. GPS can provide the latitude, longitude and elevation information for the 3-Dimensional (3D) view of the terrain through DEM (Fry et al., 2015).

Based on the collected GPS points, DEM was generated using the Arc GIS software. The DEM is called as the terrain surface elevation which is represented in a regular spaced interval. It is used for multipurpose in terms of the disciplines. In coastal morphological studies, it is used for vulnerability analysis, hazard assessment, erosion and sedimentation, sea level rise and for modelling (Almeida et al., 2019).

Further, the TFM was simulated having created the contours and subsequent DEM with the collected GPS points. Based on the TFM, it was predicted that; if the Sea water rises to a certain range along the study area, at what extent the coast would gradually be inundated to the Sea. This forecast method would be an initial step to conserve the coastal environment which goes through the severe coastal morphodynamics by erosion and accretion. Moreover, the risk and hazard assessment with the TFM could be made for sustainable marine infrastructure development (Maduraperuma et al., 2017).

This study was conducted in the coastal strip of selected Grama Niladhari Divisions (GND) in Nintavur and Addalaichenai Divisional Secretariat Divisions (DSD) according to the figure 01. 12 GNDs were selected as the study area of which 04 GNDs were selected from the Nintavur DSD and 08 GNDs were picked from Addalaichenai DSD. The study area is a sensitive locality with 04 estuaries and their environs namely Wavvalodai, Nochchiyadi, Kaliodai and Konawatta. Also, the Oluvil harbor which is presently standstill due to the longshore sedimentation effect within the port entrance is located in the study area. The coastal area of the South Eastern University of Sri Lanka is also located within the study area. The total length of the study area is 11.5 Km with the 100m range from shoreline.

Figure 01: The study area



Source: Retrieved from Arc GIS 10.4

The tidal fluctuation in the study area is causing unstable coastal process, challengeable fishing activities, and yet it creates the shoreline morphological changes in the form of erosion and accretion. During the high tide, the inundation in the coastal areas increase as well as during the low tide, the sea recess leaving the overwhelmed coastal lands according to the long-term observation. This episodic process in the study area has destroyed the coastal environment heavily. Therefore, the TFM would paw the way for the proper coastal zone management with the forecasted ranges of the sea water rise.

2. Problem statement

Coastal zones are the sensitive environment where human interaction mostly in active in multifaceted ways. Micro changes in physical process have the potential to cause huge impacts over the long period of time. Tidal fluctuation; the forward and backward movement of the sea water during the high and low tides respectively make sporadic changes in the coastal environment which likely to cause many ramifications to the coastal zones. Mapping and forecasting the tidal fluctuation would paw the way for preventive measures in coastal environment and proper planning for marine infrastructure development. The UGV operation is a low-cost method with high accuracy for data collection and modelling compared to the aerial survey which is inaccessible due to the security concerns and also the micro band satellite imageries are costly materials to afford for the image analysis.

03. Objective of the study

The objective of the study is to create a TFM to the study area. Thus, the TFM for 0.5m, 01m, 1.5m and 02m were created to show and forecast the inundation respective to each range of fluctuation.

04. Literature review

The marine environment which is perpetually submerged and exposed because of the tidal fluctuation is a part of coastal zone where the wave action in process (Flemming, 2005). Real time tidal forecasting and tidal currents are vital for human activities and coastal zone management process such as coastal hazard assessment, coastal development, recreation, military and port operations (Byun et al., 2009).

Fry et al., (2015) in his study on "A Low-Cost GPS-Based Protocol to Create High-Resolution Digital Elevation Models for Remote Mountain Areas" has used the hand-held GPS tool to collect the GPS points to create DEM for mountainous areas. Nonetheless, this study has not concentrated on the UGV's application and the prediction from remotely collected GPS points.

UGVs are used for many purposes such as military and civilian use to perform dangerous, dirty and dull activities. They are the effective tools for continuous usage where the human labour is too expensive and the task is risky. The UGVs are used for topographical survey, vegetation monitoring, coastal zone monitoring, and etc. (Kurkin et al., 2016). However, in this study, the future forecasting was not considered using UGV application and collected GPS points.

Understanding the tidal fluctuation is vital to show the inundation in the coastal areas. Madurapperuma et al., (2017) has studied about the Sea level rise using Kite aerial photographs. He used two light-weight automatic cameras with Red-near infrared filters, Picavet rig for stabilizing the cameras, and a parafoil kite. The collected images were subjected to the mosaic process and DEM was generated to find the sea level rise and he created the inundation map forecasting at what extent inundation would take place when the Sea level rises in certain heights. Nevertheless, this study has used Geo-tagged Kite aerial images in place of the application of UGV.

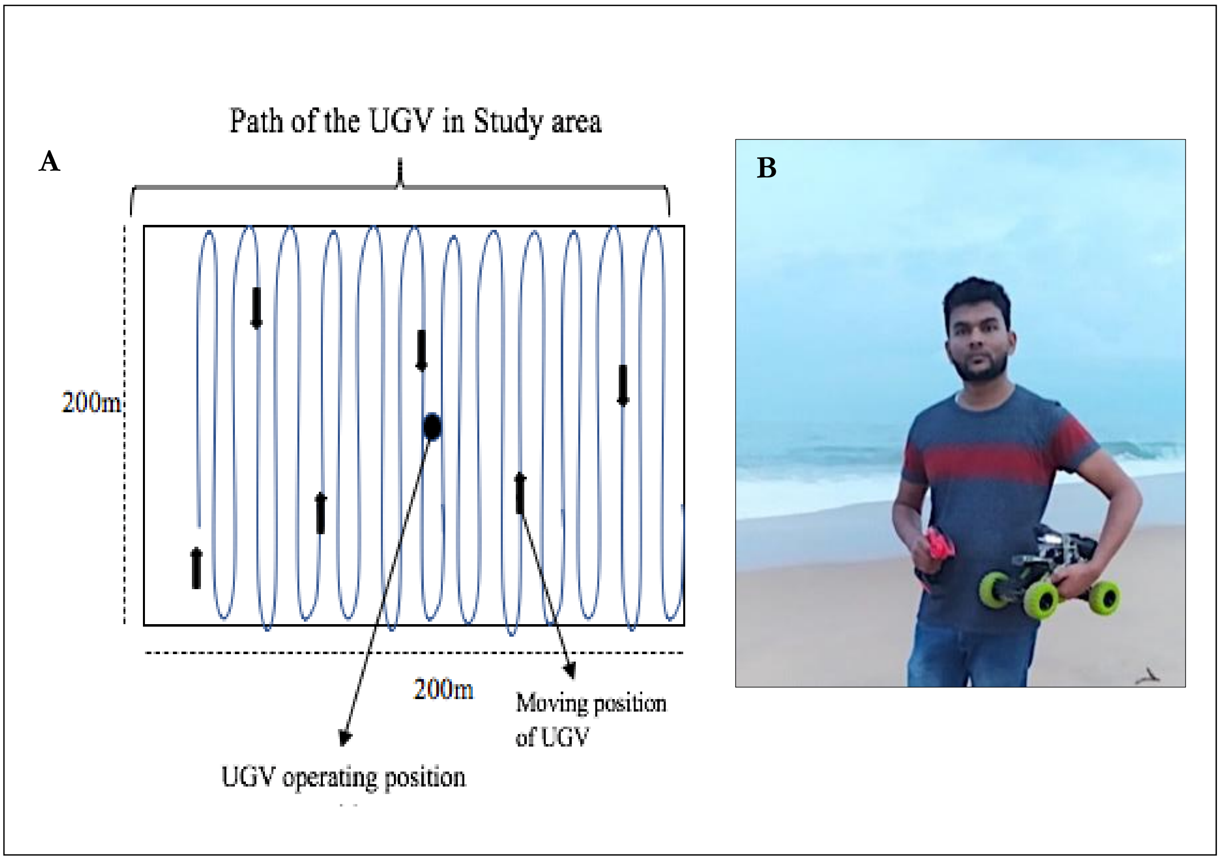
Unmanned Aerial Vehicles (UAVs) are extensively used for the coastal morphological examination for long-term observation with RS tools. Since the usage of drone imageries provide high resolution images, the security clearance is very difficult in using the quadcopters and it is rather difficult in using the localities in which the Army or Military points are located. For the ground level observation and data collection, the UGV is utilized to collect the data in particular area. UGV is a modern and innovative tool to collect the data in a safe manner. It is a better solution to collect the GPS points in order to create the DEM and subsequent models.

05. Materials and methods

To collect the GPS points, UGV was employed with the mounted smart phone to which the high accuracy GPS software was installed. While the UGV was running, the GPS software collected the random points with elevation which were stored automatically.

It was a novel and innovative idea to collect the GPS points from which the DEM and TFM were generated. Also, the UGV was run to the localities where researcher was unable to walk or access such as mud land, delicate sand dunes, bogs, and other remote areas. Kurkin et al., (2016) has used UGV for simultaneous video survey, coastal vegetation survey and monitoring erosion & sedimentation.

Figure 02: Diagram "A"- UGV operation model and "B"- UGV



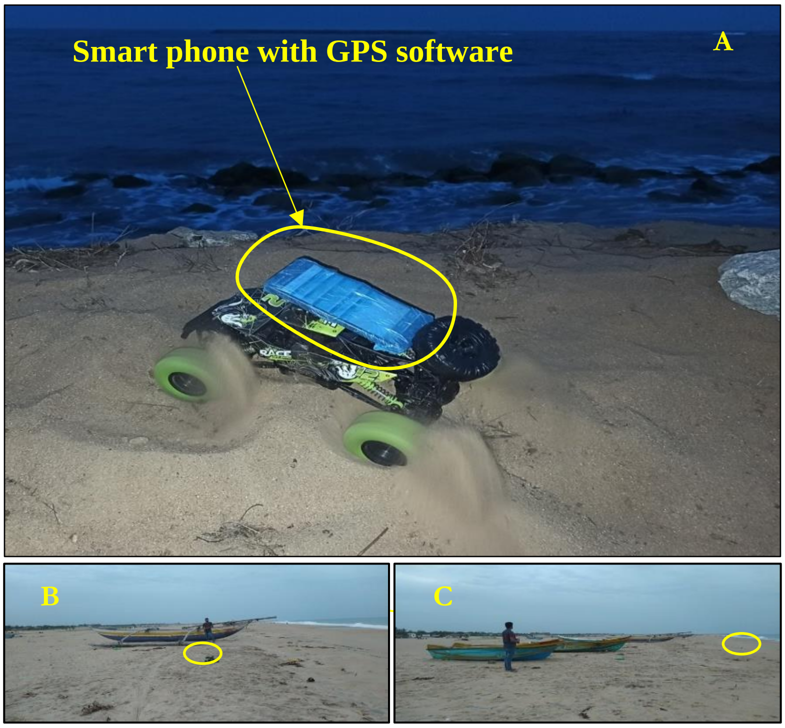
5.1 UGV operation

The GPS points were collected from a fixed location according to the diagram "A", figure 02. Then, UGV was employed to the study area in the range of 100m radius. In some places, the researcher took GPS point manually and merged them all as a single file. Then, the DEM was generated using the collected GPS points having extracted the elevation data. For the GPS tool, the smart phone was mounted with GPS waypoint software which has high accuracy and automatic storing function.

According to the figure 02, the diagram 'A' shows how the UGV was operated and the image 'B' shows the UGV with researcher. The UGV operating position shows the point from which the UGV was operated. The arrows in the diagram "A" show the direction of the movement of UGV.

According to the figure 03, the image "A" shows the UGV's closest view during the operation in the study area, the images "B" and "C" show the UGV operation from a point in the study area.

Figure 03: The UGV operation with smart phone

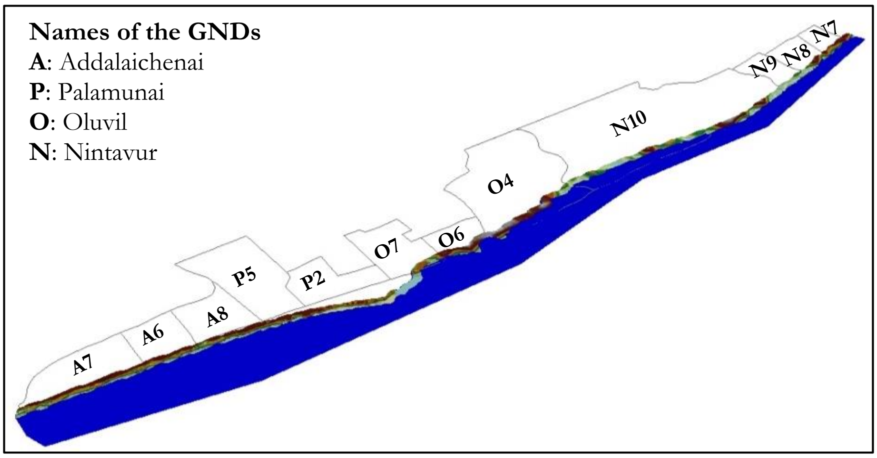


06. Result and discussion

6.1 Simulation of TFM

Small changes in coastal process have the potential to cause massive destruction because of the sensitiveness of coastal environment. The tidal fluctuation also influences the coastal morphodynamics and it should be forecasted to reduce the resultant impacts. In this sense, the TMF was created to the coastal strip in the study area in the ranges of 0.5m, 01m, 1.5m and 02m based on the data collected employing UGV.

Figure 04: 100 m focus area (to show the tidal fluctuations)



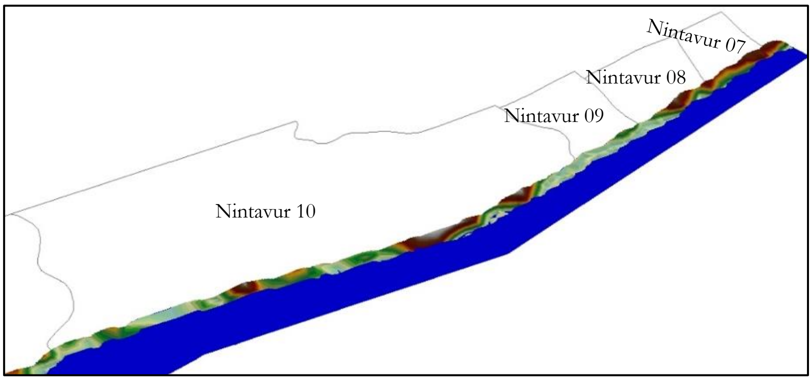
Source: Retrieved from Arc GIS 10.4

Figure 04 shows the 100m range of the study area from the selected GNDs. DEM was created to the 100m focused area and the ranges were fixed.

6.1.1 TFM for 0.5m range in the study area

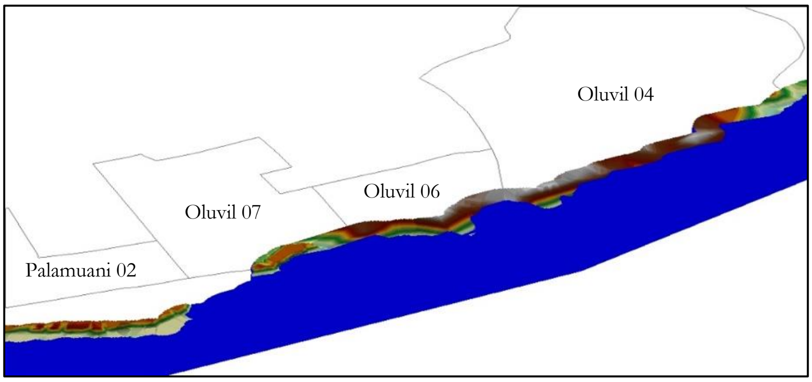
TFM to the study area for 0.5m range was created and it clearly shows that if the water level increases by 0.5 m, at what extend the landform will be inundated. Based on that criterion, the modelling has been done.

Figure 05: TFM of 0.5 m range for Nintavur coastal area



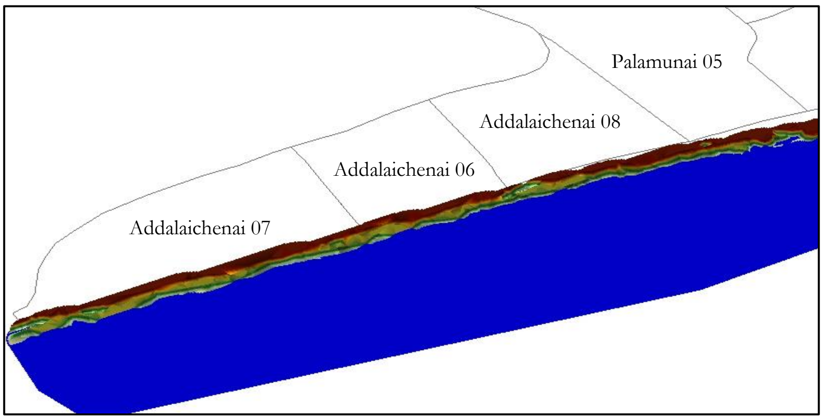
Source: Retrieved from Arc GIS 10.4

Figure 06: TFM of 0.5m range for Oluvil and Palamunai – 02 GND coastal areas



Source: Retrieved from Arc GIS 10.4

Figure 07: TFM of 0.5 m range for Palamunai – 05 GND and Addalaichenai coastal areas



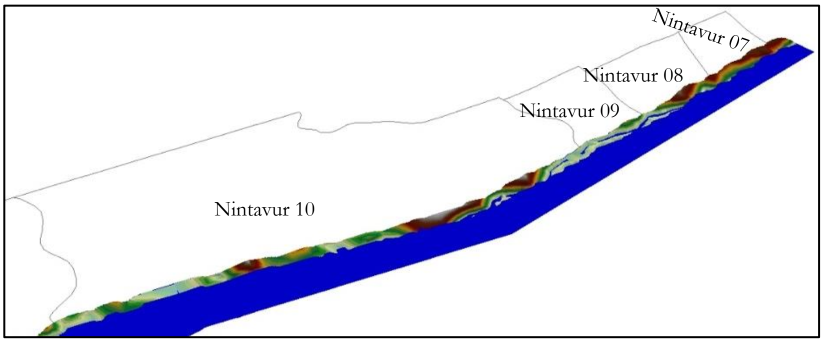
Source: Retrieved from Arc GIS 10.4

The figures 05, 06 and 07 depict the TFM for 0.5m range whether the Sea water level increases in the study area to such range. According to the figures, most of the low-lands have been inundated in 0.5m range rise. In particular, the low-lands, very closed to the coast susceptible to be inundated for such minimal rise of Sea water.

6.1.2 TFM for 01m range in the study area

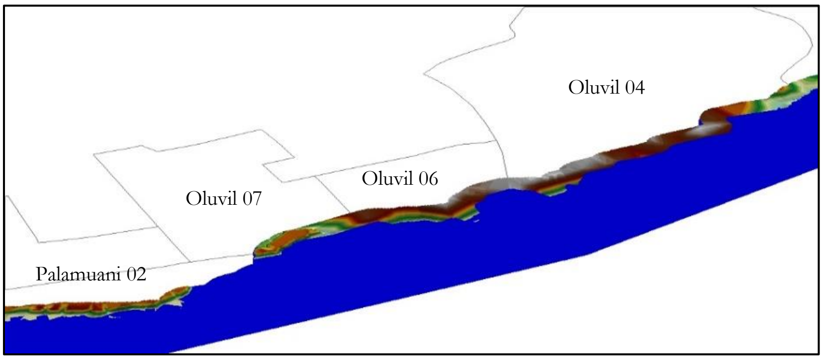
TFM for 01m range was generated to the study area. This range shows the inundation when the Sea water rises for 01m range. Low-lands plus the sandbars, closed to the river mouths have partially been inundated to 01m range.

Figure 08: TFM of 01 m range for Nintavur coastal area



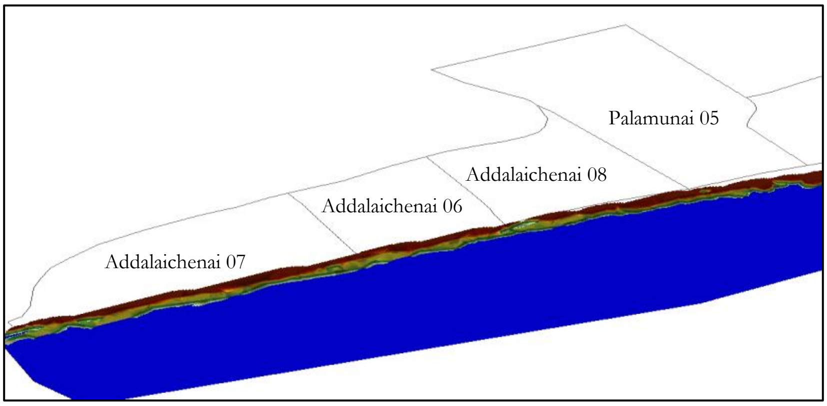
Source: Retrieved from Arc GIS 10.4

Figure 09: TFM of 01m range for Oluvil and Palamunai – 02 GND coastal area



Source: Retrieved from Arc GIS 10.4

Figure 10: TFM of 01m range for Palamunai – 05 GND and Addalaichenai coastal area



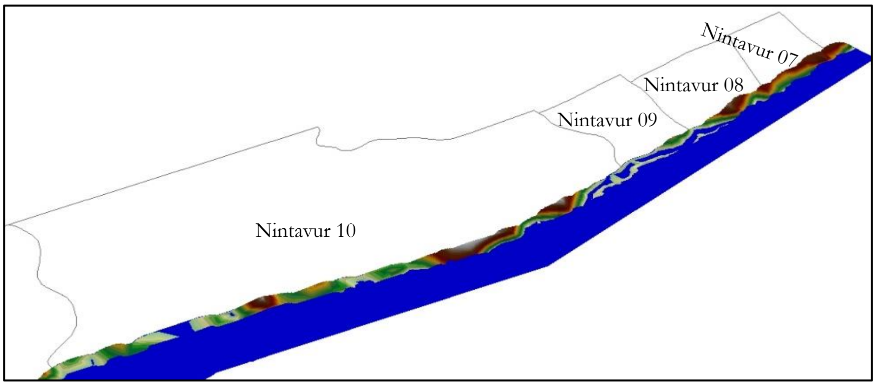
Source: Retrieved from Arc GIS 10.4

The figures 08, 09 and 10 show the TFM for 01m range. Accordingly, significant changes can be seen in figure 09, closed to the port. Sedimentation in Palamunai - 02 GND shows increased inundation compared to the 0.5m range of Sea water rise along the study area.

6.1.3 TFM for 1.5m range in the study area

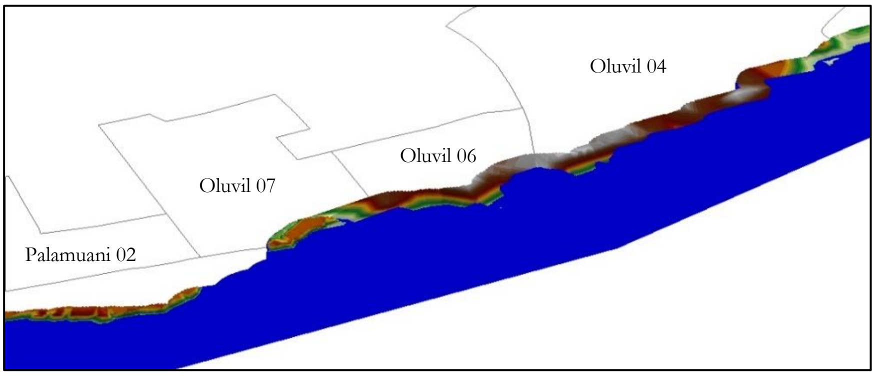
TFM for 1.5m range was created to find the inundation in the study area. Since the tidal range of Sri Lanka coast is less than 01m, the tidal fluctuation model for 1.5 range was projected in the event of any increase in Sea water level in future, such model could be applicable to the study area for any marine infrastructure development.

Figure 11: TFM of 1.5m range for Nintavur coastal area



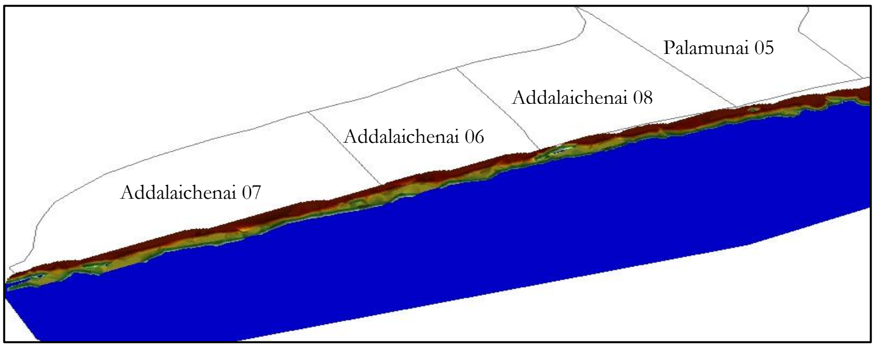
Source: Retrieved from Arc GIS 10.4

Figure 12: TFM of 1.5m range for Oluvil and Palamunai – 02 GND coastal area



Source: Retrieved from Arc GIS 10.4

Figure 13: TFM of 01m range for Palamunai -05 GND and Addalaichenai coastal area



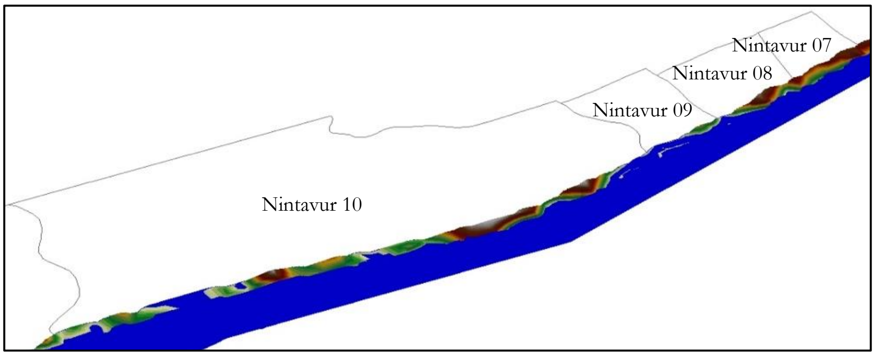
Source: Retrieved from Arc GIS 10.4

The figures 11, 12 and 13 show the tidal fluctuation in the study area for 1.5m range. Inshore beaches are susceptible to be inundated for such ranges of the Sea water rise. Vegetations are also vulnerable whether the Sea water reaches the range of 1.5m.

6.1.4 TFM for 02m range in the study area

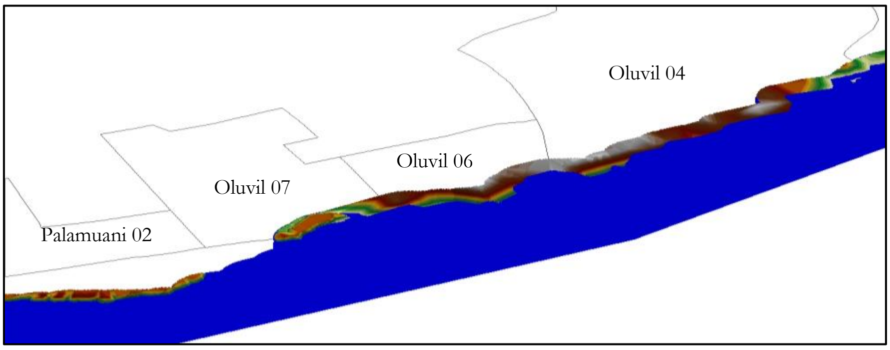
TFM for 02m range was projected to show the scenario when the tidal fluctuation anomalously increasing in the study area in future. This phenomenon can inundate large extent of the study area because of the increased sea water level.

Figure 14: Tidal fluctuation model of 02m for Nintavur coastal area



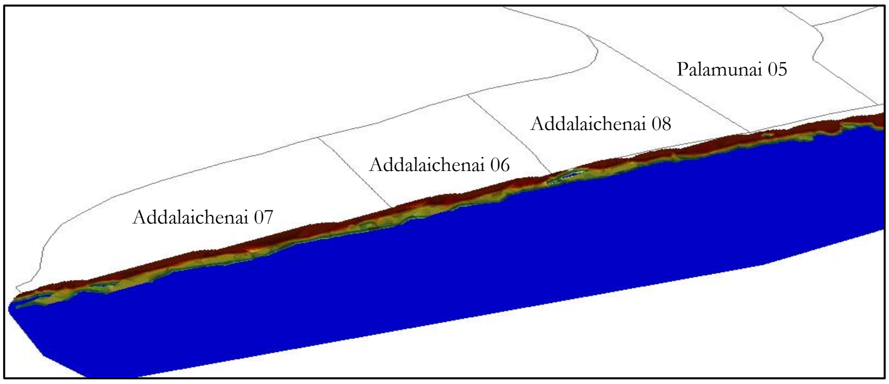
Source: Retrieved from Arc GIS 10.4

Figure 15: TFM of 02m for Oluvil and Palamunai – 02 coastal area



Source: Retrieved from Arc GIS 10.4

Figure 16: TFM of 02m for Palamunai - 05 and Addalaichenai area



Source: Retrieved from Arc GIS 10.4

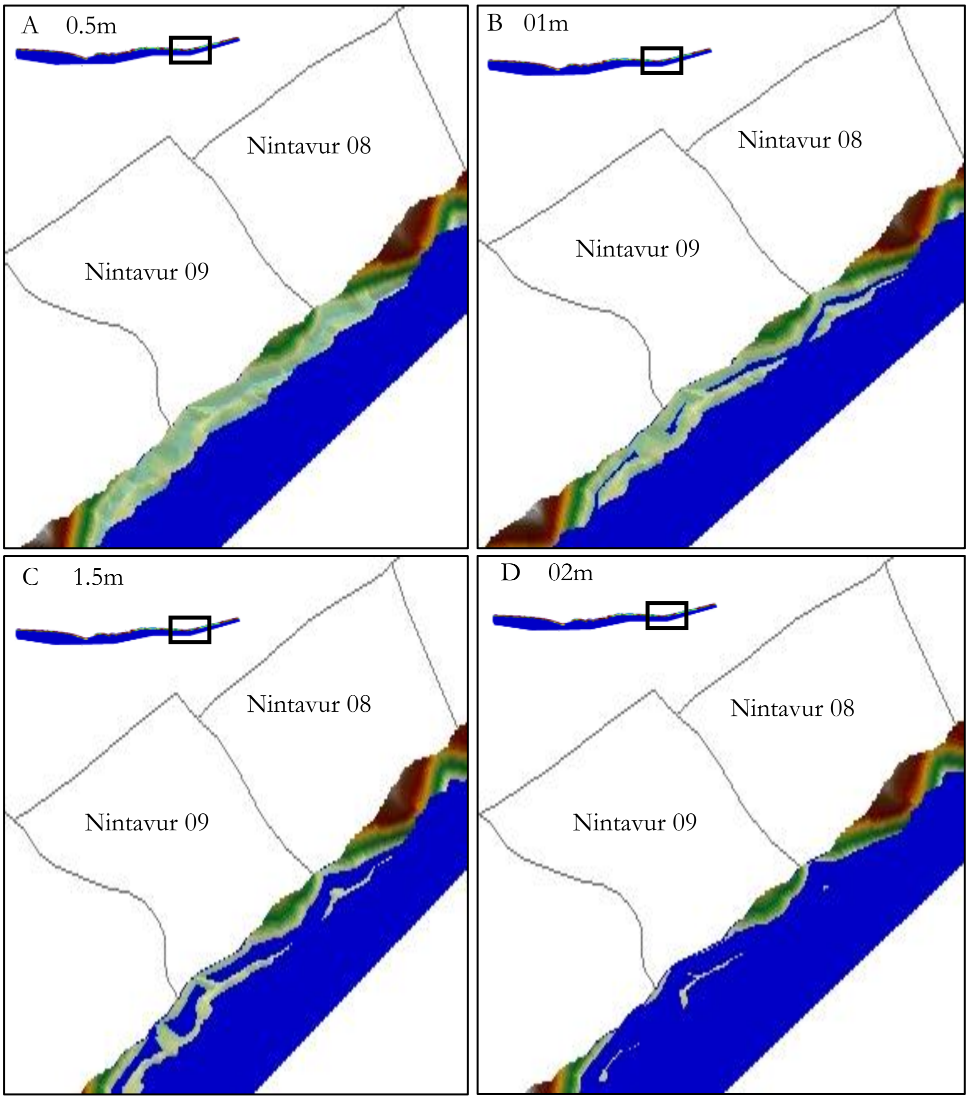
The figures 14, 15 and 16 show the TFM for 02m range which were projected to forecast the anomalous situation when the Sea water level rises up to 02m. The forecast has been projected up to 02m with the view to show the future threat to the coastal areas of the study area. This inundation map will definitely paw the way for maritime infrastructure development in the study area in the years to come.

6.2 Random verification of the tidal fluctuation in selected GNDs in the study area

Randomly selected GNDs from the study area have been magnified to informatively show the tidal fluctuation and submersion in the coastal area.

Inundation because of the Sea water rise in Nintavur 09 and Nintavur 08 GNDs

Figure 17: Enlarged scene of the inundation because of the tidal fluctuation in Nintavur 09 and Nintavur 08 GNDs in the study area

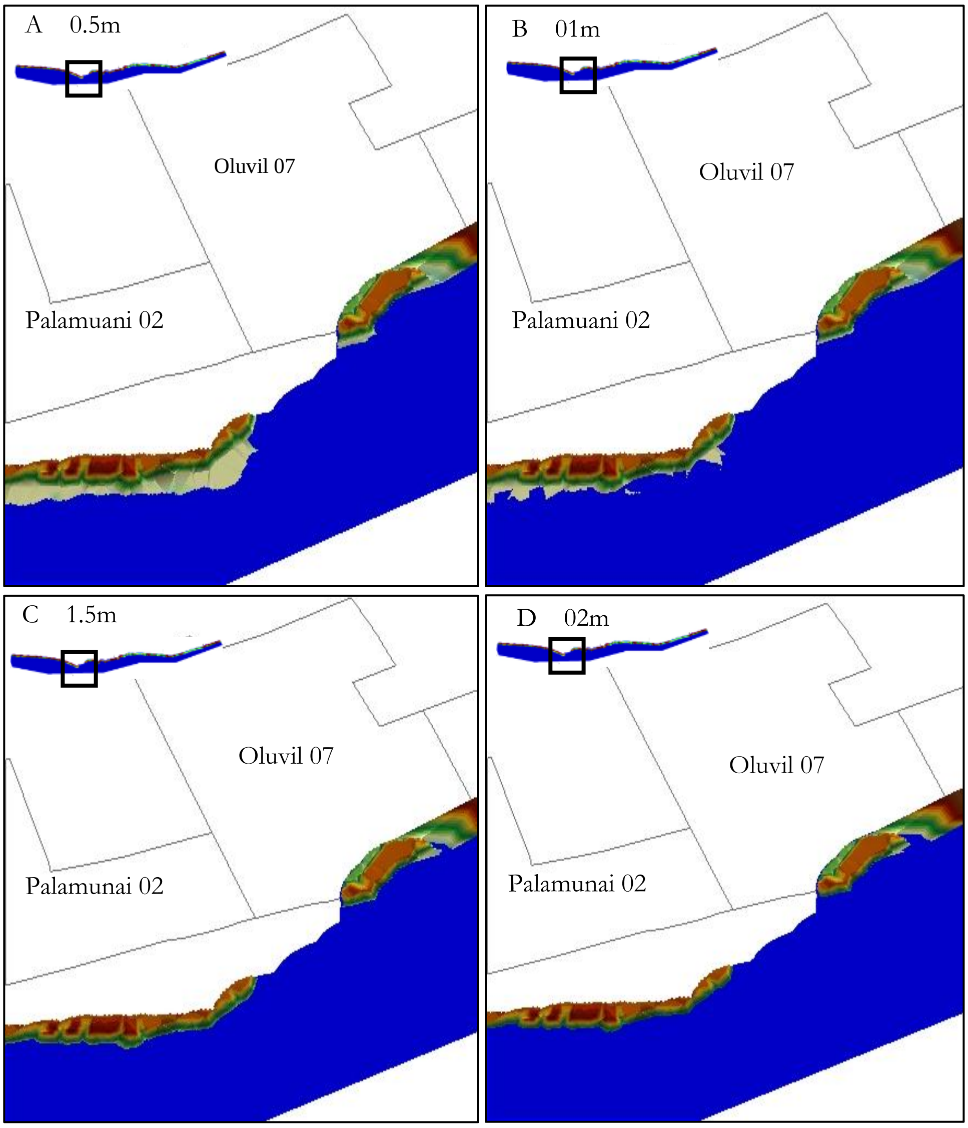


Source: Retrieved from Arc GIS 10.4

Figure 17 depicts the enlarged view of the inundation as a result of tidal fluctuation in different ranges. Accordingly, 0.5m, 01m, 1.5m and 02m ranges have been compared to the same location. The inundation can clearly be understood according to the images, A, B, C and D in the figure. In 0.5m range, the beach is lengthy with voluminous sand, then in 01m range, it is reducing and 1.5m and in 02m ranges, according to the image "D", the major part of the beach has been overwhelmed because of the Sea water rise.

Inundation because of the Sea water rise in Palamunai 02 and Oluvil 07 GNDs

Figure 18: Images A, B, C and D show the submersion because of the tidal fluctuation in different ranges in Palamunai 02 GND

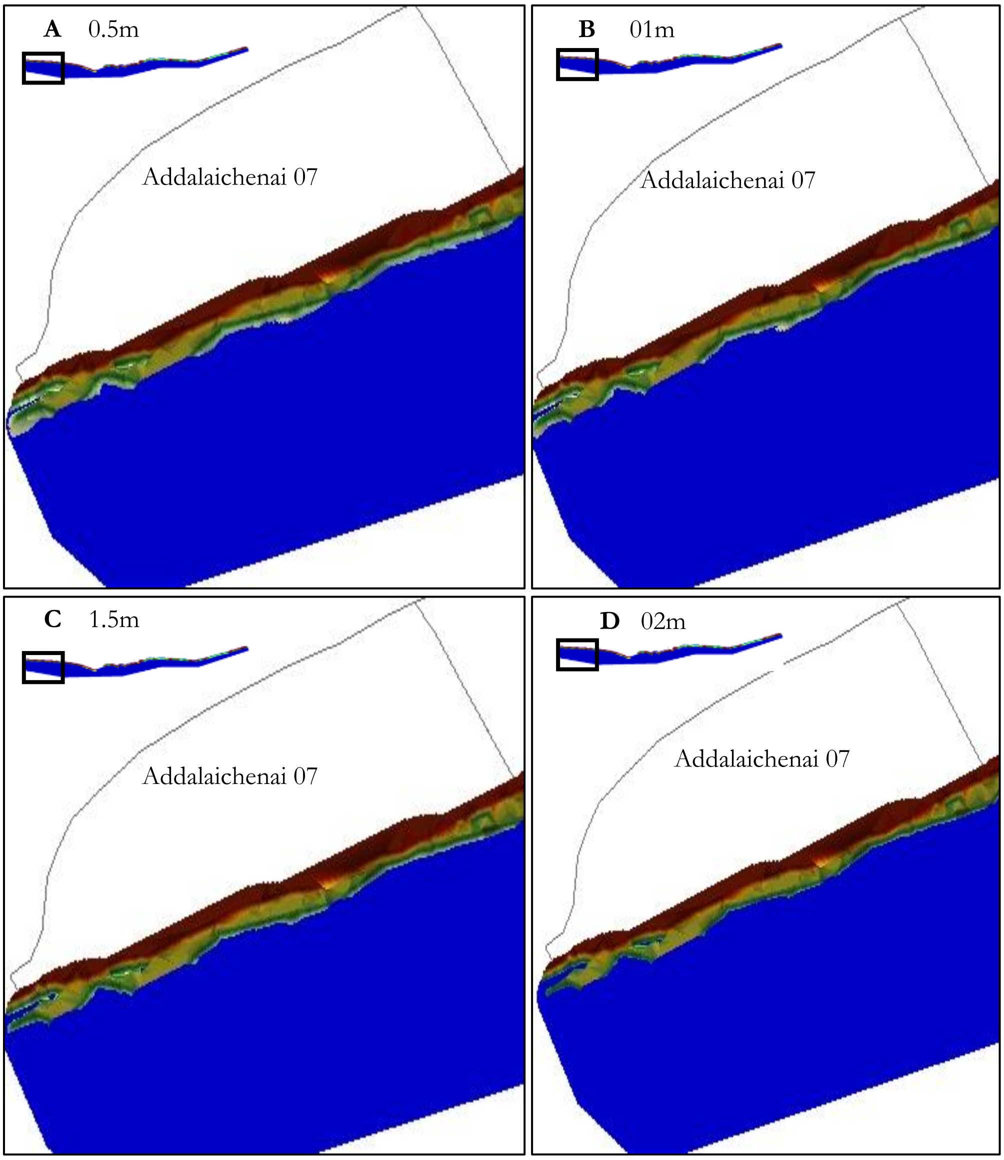


Source: Retrieved from Arc GIS 10.4

The figure 18 shows the inundation because of the tidal fluctuation in Palamunai 02 GND in different ranges; 0.5m, 01m, 1.5m and 02m. The vast sandy beach can be seen in the image "A" for 0.5m range. But, in the image "B", seaward sandy beach has been overwhelmed. And yet, in the image "C" the huge portion of the beach has been inundated. The image, "D" shows severe inundation of the beach because of sea water rise for 02m range. More than 50m shore in the specified 100m range appear to be inundated once the sea water level increase in 02m range.

Inundation because of the sea water rise in Addalaichenai 07 GND

Figure 19: Images A, B, C and D shows the tidal inundation map in the Addalichenai 07 GND

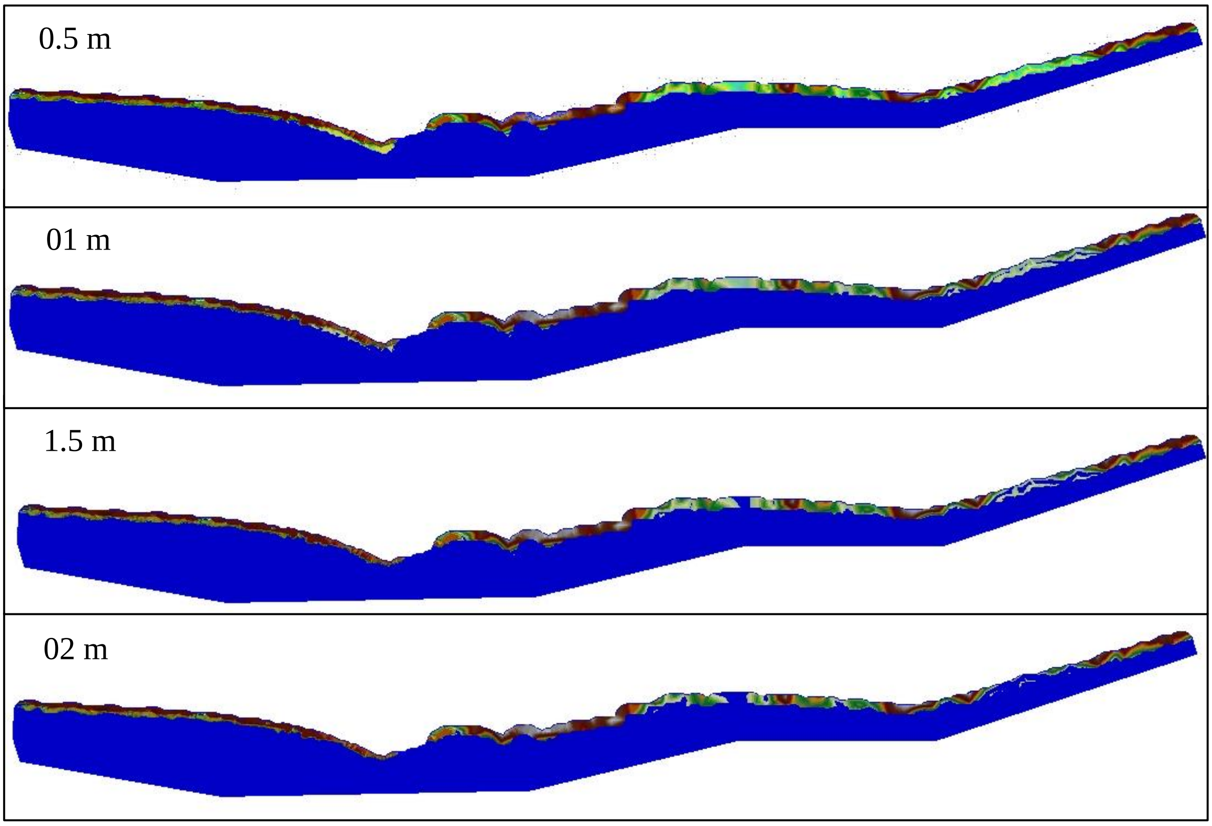


Source: Retrieved from Arc GIS 10.4

The figure 19 shows the submersion map because of the tidal fluctuation in Addalaichenai 07 GND for 0.5m, 01m, 1.5m and 02m ranges. According to the figure, variable inundation can be seen in different ranges when the Sea water rises relative to such ranges. Addalaichenai area is located in the southward direction of the Oluvil harbor and the sedimentation effect is significant in the area. Thus, mere lowlands in Addalaichenai 07 GND beach have overwhelmed because of the tidal fluctuation.

According to the figure 20, the TFMs for 0.5 m, 01 m, 1.5 m and 02 have been created in order to find the impacts caused by beach morphological changes. The tidal fluctuation model for 0.5 m range has the potential to inundate the low lands very closed to the sea approximately in the extend of 3m from the shorelines. Particularly, the sedimentation in Palamuanai area and the river mouths are vulnerable for the inundation.

Figure 20: Comparative observation of tidal fluctuation in 0.5m, 01m, 1.5m, and 02m ranges



Source: Retrieved from Arc GIS 10.4

In 01m range, it was quantified that in low lands, around 09m range from the shoreline area are vulnerable for inundation. The tidal fluctuation model for 1.5m and 02m could inundate the area around 30m – 70m respectively in the coastal region. If the tides occur in such ranges the inundation and impacts would be very high yet it would definitely cause socio-economic impacts eroding much extent of the land. Thus, this tidal fluctuation model advises and predicts that the maritime infrastructure development should be done considering the sea water rise due to the tides or perhaps other factors in future.

7. Conclusion

The study has found that as the Sea water increases in the ranges viz. 0.5m, 01m, 1.5m and 02m at what extent the coastal land inundation will take place in the study area. Accordingly, the models have been created and illustrated. The UGV application is the initial step to collect the GPS points for the TFM in the study. The UGV can be modified capable to collect the data for a long time using automatic embedding system. In future, using the high accuracy GPS and UGV with robotic autonomous system, the prediction of tidal fluctuation can efficiently be done.

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