Research Article

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Exploring Physical and Human Induced Coastal Morphodynamics: A Study with Reference to Nintavur to Addalaichenai Coastal Areas of Ampara District, Sri Lanka

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Abstract

Observing and mapping the long-term coastal morphodynamics because of the human and physical induced factors using conventional methods could not give expected outcomes. State-of-the-art technology and tools are the best methods to do so. Thus, this study is to explore the long-term coastal morphodynamics of coastal strip from Nintavur to Addalaichenai area using the Landsat satellite images of the years 1991, 2001, 2011 and 2019, downloaded from the Earth Explorer website. Google Earth (GE) historical images were also used for the comparison of periodic coastal morphodynamics. Normalized Difference Water Index (NDWI) was processed for land and water separation. Direct observation, perspective of the respective officials and inhabitants, reports concerning the departments and authorities were also considered as the sources for this study. In conclusion, this study has found that the coastal morphological changes have been made because of the both human and physical induced factors of which waves and river flooding withing the study area are the physical factors and construction activities; port and breakwaters are the human activities which have modified the beach in the study area. In comparison, after the construction of the port, remarkable coastal morphodynamics have been recorded in the period from 2011 to 2019 in the study area.

Keywords: *morphodynamics, Nintavur, Addalaichenai, NDWI, land and water separation, wave, river flooding*

1. Introduction

The term morphodynamic is defined as the process by which morphology affects the hydrodynamics plus further evolution of the morphology itself. Grain size deviation, biological process, geological characteristics, human impact and long-term sea-level fluctuation, wave and tidal forcing, nature of waves, profile shape and slope are possibly determinant factors for coastal morphodynamics (Friedrichs, 2011). A single factor or combination of natural process and human activity have impacted on beaches over the world in short- and longer-term time scales (Chaibi and Sedrati, 2009).

Coastal erosion is the process of wearing materials away from a beach profile because of the imbalance in the supply and export of material from a certain section (Marchand, 2010) and the erosional and accretional process are the major means through which the coastal morphological changes happen. Thus, both physical and human induced phenomena influence for increasing coastal morphodynamics. The physical factors which affect the coastal erosion are strong wind, high waves, tidal fluctuation and storm surge conditions. Meanwhile, the human induced impacts are improper consumption of coastal resources, unplanned construction activities, removal of coastal vegetation, soil mining in river beds and beaches, construction of coastal structures and dam construction (Tai-Wen et al., 2007). The coastal erosion is a critical problem which have caused many ramifications to the coastal environment whole over the world.

As an island, coastal erosion in Sri Lanka is a severe problem which poses many threats to the coastal environment. Normally, the coast is the dynamic environment which physically, biologically and chemically also with the human activities, directly or indirectly is modified or disturbed (Mathiventhan and Jayasingam, 2018). Thus, this study is to explore the coastal morphodynamics by the physical and human factors in selected coastal Grama Niladhari Divisions (GND), located between Addalaichenai Divisional Secretariat Division (DSD) and Nintavur DSD of Ampara District, South Eastern Part of Sri Lanka.

The study area had a rich biodiversity while supporting the locals for their subsistence and socio-economic development. However, it is apparent that the present morphology has been changed; the vast beach has been consumed by the sea, extensive coconut cultivation has been vanished, biodiversity has been disrupted and anomalous sedimentation has also been induced leading to many implications. Due to the fact that, the protest of the public against the respective agencies which also highlights the severity of the consequences to their daily life.

2. Study area

Coastal strip of selected 12 GNDs from *Addalaichenai* and *Nintavur* DSDs have focused as the study area because of the severity and the seriousness of the coastal morphodyanmics. The figure 01 shows the study area which is the length of 11.5 Km and 100m range from the shoreline to inland within which 04 rivers are emptying into the Sea causing enormous coastal morphodynamics.

2.1 Addalaichenai DSD

Addalaichenai DSD is located in Ampara District consisting 32 GNDs. The boundaries of the Addalaichenai DSD are;

- North – *Kaliodai* river
- South – *Akkaraipattu* DSD
- East – Bay of Bengal
- West – paddy lands

2.2 Nintavur DSD

Nintavur DSD is located in the coastal region of Ampara District consisting 25 GNDs. The boundaries

of Nintavur DSD are;

- North – *Vettaru*
- South – *Kaliodai* River
- East – Bay of Bengal

Agriculture and fishery are a major subsistence of the inhabitants of *Nintavur*. Moreover, small-scale and rice mill industries are the other source of income of the people. Coastal erosion in *Nintavur* DSD is a major challenge to the coastal environment which cause many consequences for paddy & coconut cultivation and fishing activities. Riswan & Mustafa, (2017); Urban Development Authority, (2019).

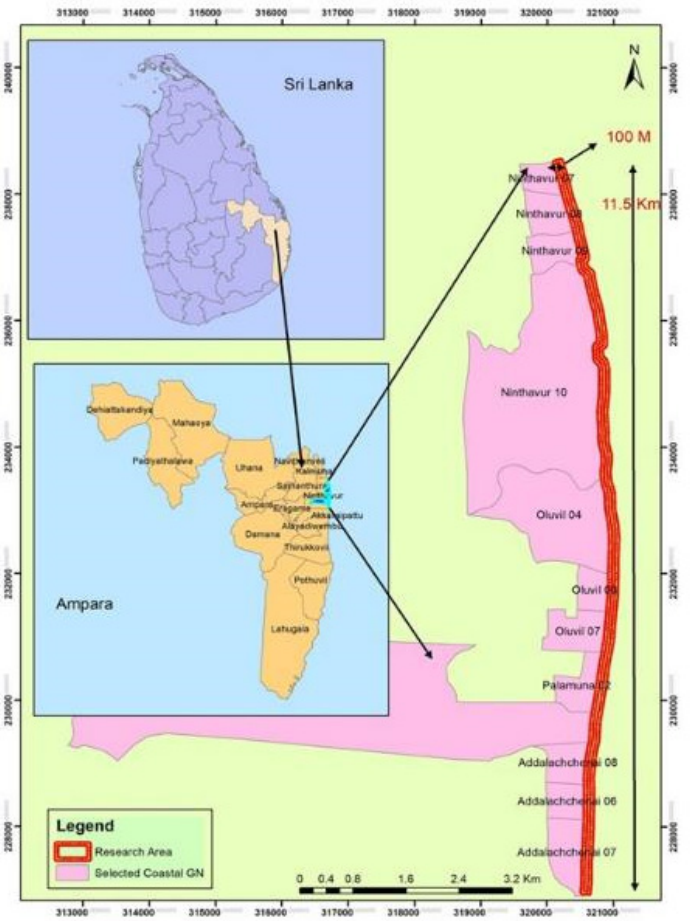

Figure 01: Study area
Source: Retrieved form Arc GIS 10.4

3. Methods and materials

Both primary and secondary data were collected to this study. As primary data, direct observation was done by the researcher frequently and photos as the real time data were collected for the comparison. Satellite images, previously published articles, topographical sheet, GE images, and other published sources were considered as the secondary data for this study.

3.1 Reception of satellite images

Landsat satellite images of the years 1991, 2001, 2011 and 2019 were accessed from the earth explorer website as given in the table 01.

Table 01: Satellite images used for this study

No.	Satellite imagery	Year	Row and path	Resolution (m)
01	Landsat 5 TM	1991	055:140	30 x 30
02	Landsat 7 TM	2001	055:140	30 x 30
03	Landsat 7 TM	2011	055:140	30 x 30
04	Landsat 08 OLI	2019	055:140	30 x 30

Source: https://earthexplorer.usgs.gov

3.2 GE historical images

GE historical images could provide an extensive coverage of the particular area in different years. Those georeferenced images were extracted from various years in order to identify the yearly or seasonal changes of the coastline particularly, in the estuarine areas where the rivers are emptying into the Sea within the range of the study area.

3.3 Data analysis

3.3.1 Generation of Normalized Difference Water Index (NDWI)

The NDWI was calculated using the following algorithm with Near-Infrared (NIR) and Green bands. This formula highlights the amount of water in water bodies.

$$\text{NDVI} = \frac{Green-NIR}{Green+NIR}$$

Water and land indices were separated using NDWI calculation (Sarker et al., 2013). NDWI was processed to separate the land and water properties from the satellite images. This process was performed to the all the satellite images of 1991, 2001, 2011 and 2019. Then, the shorelines where the land and water properties are interacting were distinguished. Shoreline of 1991 satellite image was considered as the baseline on which rest of the extracted shorelines were compared. Then, they were overlaid with the view to find the delineation of coastal morphology from the baseline according to the figure 02.

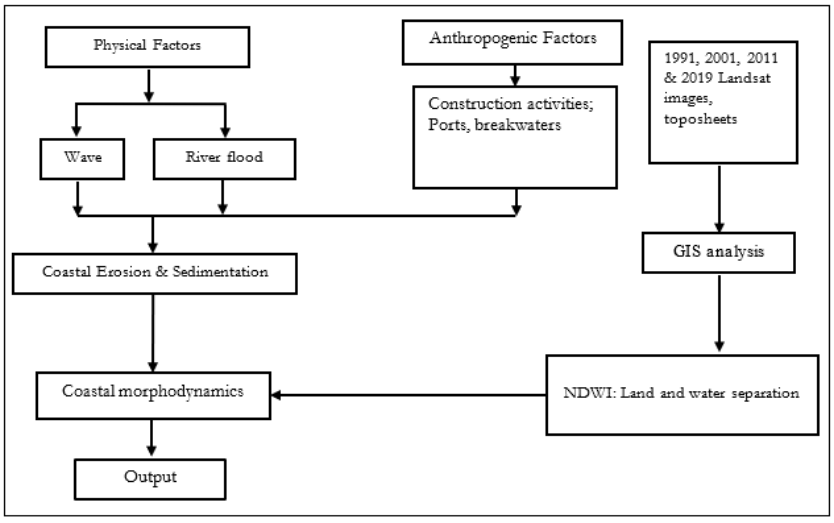

Figure 02: Methodology framework

4. Result and discussion

Coastal morphodynamics because of the physical and human induced impacts have been found following the analysis with the collected data. Result shows that the significant morphological changes in the study area have been recorded in the period of 1991 to 2001, 2001 to 2011. However, the anoumoulous changes have been observed in the period of 2011 to 2019 which is the period of post harbor construction.

4.1 Periodic coastal morphodynamics in the study area

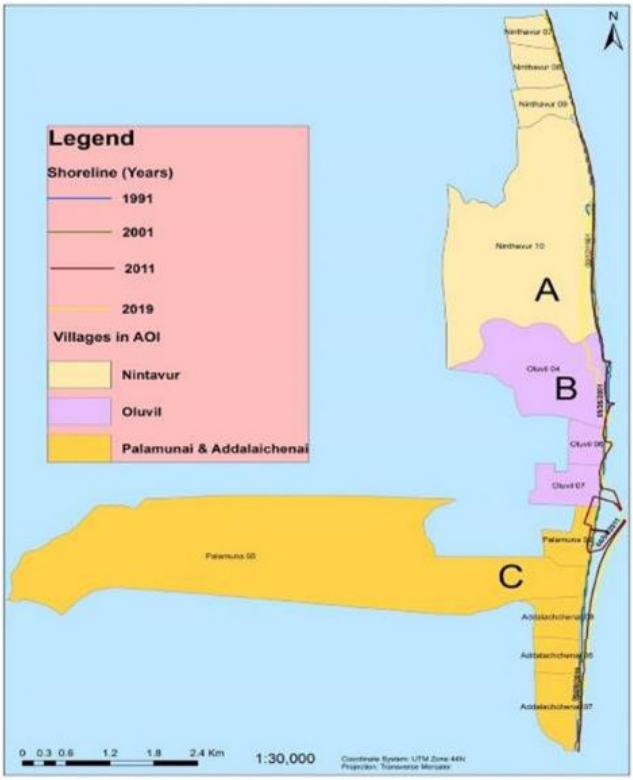

Figure 03: Periodic coastal morphodynamics in the years of 1991, 2001, 2011 and 2019 in the study area
Source: Retrieved from Arc GIS 10.4

Figure 03 shows the 03 divisions of the study area, divided as A, B and C with the view to clearly show the morphological changes. The coastlines of the years 1991, 2001, 2011 and 2019 were overlaid to show the periodic coastal morphological changes. Thus, coastal morphodynamics have been found in many locations of the study area because of the wave action and river flooding in the years of 2001 and 2011 but, mammoth change in the coastal morphology has been identified in the year of 2019, which is the period of post harbor construction in Oluvil area.

It was found that the sedimentation and erosion have been recorded South and North ward of the port respectively. Further, the rivers, emptying into the Sea during the flooding period, cause morphological modifications, in particular to the river mouths which tangent to the beach.

4.2 Periodic coastal morphodynamics in Nintavur area

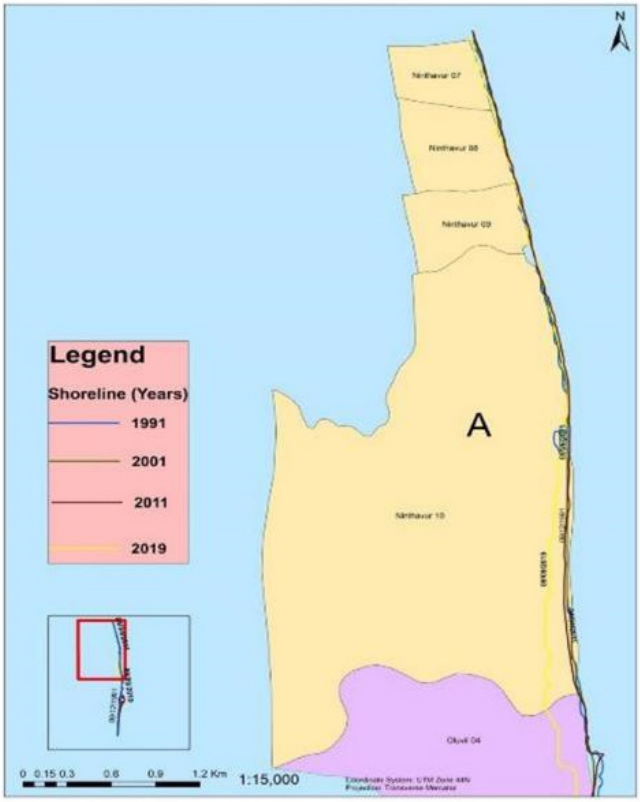

Figure 04: Periodic coastal morphodynamics of 1991, 2001, 2011 and 2019 in *Nintavur* area (A)
Source: Retrieved from Arc GIS 10.4

Figure 04 exhibits the enlarged view of the *Nintavur* coastal areas and periodic coastal morphodynamics in the years of 1991, 2001, 2011 and 2019. Accordingly, coastal morphological changes have normally been identified over the period from 1991 to 2001 because of influence of the waves and river flooding of *Nochcniyadi* and *Wavvalodai* rivers. Yet, the significant deviation has been normally identified from the year 2011 to 2019, the changes of the beach morphology has been increased losing huge extent of the land in the GND of *Nintavur-10* which is in *Addapallam* village. Also, major portion of the land has been eroded and disappeared because of the anomalous erosion in other GNDs such as *Nintavur-09*, *Nintavur-06* and *Nintavur-07*.

4.2.1 Periodic coastal morphodynamics in Wavvalodai river mouth, Nintavur village

The figure 05 shows the coastal morphological changes in *Wavvalodai* river mouth which is located in *Nintavur* village. When flooding of the river, the overflow through the *Wavvalodai* river out of the river breaks the sandbars, across the river. In this situation, the river mouth is getting modified because of the erosion and transportation of the sand and soil. It is apparent that in the years of 2006 and 2016, the river water flow broken the sandbar across the river mouth. In other years, the river flooding has widened the river mouth in multi-directions.

Figure 05: Periodic coastal morphodynamics in *Wavvalodai* river mouth, *Nintavur* Village

4.2.2 Periodic coastal morphological changes in Nochchiyadi river mouth in Nintavur area

Figure 06 shows the periodic coastal morphodynamics in *Nochchiyadi* river mouth, *Nintavur* area. Nochchiyadi river mouth is a widened estuary where two rivers converge and empty into the sea. This situation has created beach morphodynamics in the river mouth along the beach.

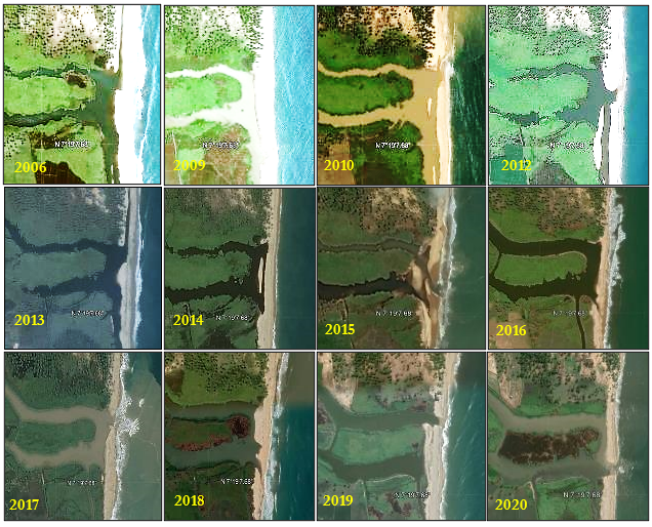

Figure 06: Periodic coastal morphodynamics in Nochchiyadi river mouth, Nintavur Village

According to the figure 06, the morphology of the river mouth has been changing in the years of 2010, 2012, 2015, 2017, 2019 and 2020. The rest of the years, the sedimentation has occurred in the river mouth. Due to the fact that, the coastal morphological changes have been induced by the river flooding in the particular area. The flooding broke sand bars across the river mouth. When the sand bars are broken down, the morphology is modified in a significant extent.

Wavvalodai and *Nochchiyadi* rivers are playing a vital role in changing the coastal morphology in *Nintavur* coastal area.

Figure 07: Coastal area of A; *Nintavur-07*, B; *Nintavur-08*, C; *Nintavur-09* & *Nintavur-10* GNDs

Figure 07 depicts the scenario of the *Nintavur* beach and how the shoreline has been modified because of the perennial wave action and periodical river flooding. A huge extent of the land has been eroded and transported from one place to another. This situation is leading the beach for getting shrinkage.

4.3 Periodic coastal morphodynamics in Oluvil coastal area

Figure 08 shows the coastal morphoynamics scenario of *Oluvil* area which is a hotspot, being affected because of the coastal erosion. Based on the comparison of the satellite images, it was found that the costal morphological changes in *Oluvil* area has been induced recently in the period from 2011 to 2019.

Despite the existence of the *Kaliodai* river within the coastal strip of *Oluvil* has made significant coastal morphological changes in previous period, large scale changes in *Kaliodai* river mouth could also be found in such period as a result of the induced wave action after the port and the offshore breakwater constructions.

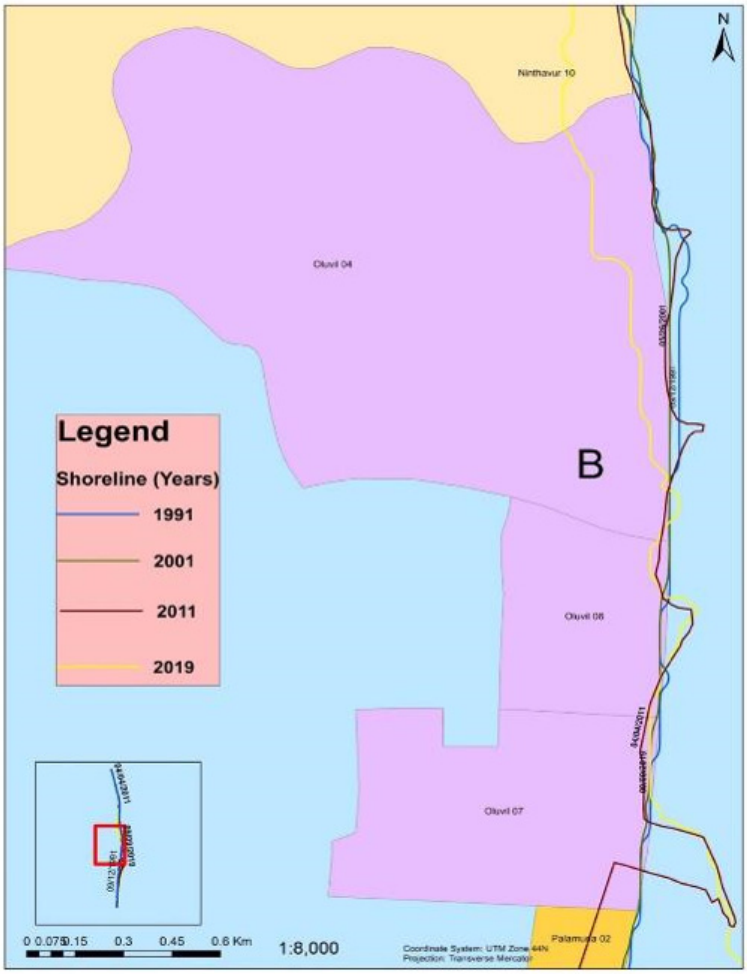

Figure 08: Periodic coastal morphodynamics of 1991, 2001, 2011 and 2019 in *Olvuil* area (B)
Source: Retrieved from Arc GIS 10.4

4.3.1 Periodic coastal morphodynamics in Kaliodai river mouth, Oluvil area

Kaliodai tributary of Kal-Oya river empties into the Sea through the *Oluvil* beach according to the figure 09. The flooding river has been changing and those changes are observable in the periodic satellite images of the figure 09. Enormous changes have exposed in the river mouth as a result of the river flooding and increased sediment loads. In order to control the erosion in the *Oluvil* coast, offshore breakwaters were constructed in the Sea. Subsequently, those breakwaters have created the tombolo landforms (2012) and small bays in embayment of the coast.

Considering the present scenario of the *Oluvil* beach, it displays the colossal changes compared to the 2011 scenario. Many hectares of the land in *Oluvil* have been eroded by wave action. The sandbars which are visible in 2006, 2009, 2010, 2015 and 2016 have vanished in the years of 2013, 2014, 2017, 2018, 2019 and 2020. This is a good example to indicate the severity of erosion in *Kaliodai* river mouth.

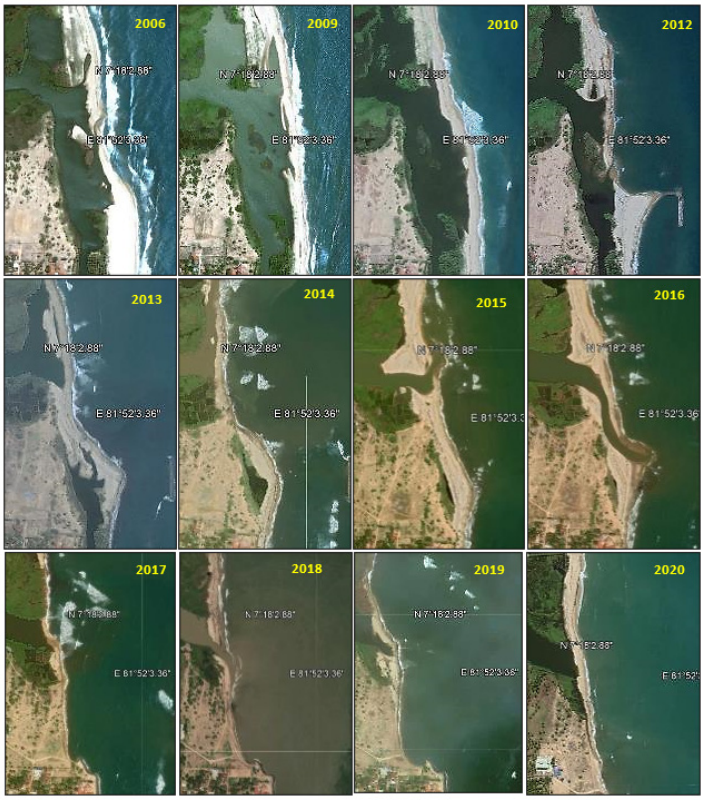

Figure 09: River mouth morphological changes of *Kaliodai* river

Figure 10: A; bay formation, B; Kaliodai river mouth, C; eroded beach and D; bay in embayment closed to the light house in *Oluvil* village

Figure 10 shows the real scenario of morphologically changed coast of *Oluvil* area. Because of the induced wave action and river flooding, the morphology has been changed. For an instance, according the images "A & B", the bays have formed which were not formed previously.

4.4 Periodic coastal morphodynamics in Palamunai and Addalaichenai area

According to the figure 11, the coastal morphological changes of *Palamunai* and *Addalaichenai* areas have been identified and shown in the period from 1991, 2001, 2011 and 2019. Accordingly, major changes have been recorded immediately to the Southward direction of *Oluvil* port because of the severe sediment effect. It should be highlighted that the period 2011 to 2019 shows higher rate of coastal morphological changes as a result of the increased sedimentation compared to other periods. The breakwaters at the entrance of the port are halting the longshore sediment transport leading the sedimentation in the port entrance and Southward direction of the port namely, *Palamunai* and *Addalaichenai* beaches.

This sedimentation effect has formed siltation between the mouth of the *Oluvil* port where the operation of vessels is standstill. This situation has turned the port futile without meeting the objective of the port construction. Presently, the operation of fishery and commercial port is not in a position to be proceeded. Inhabitants from *Oluvil* and *Palamunai* have protested demanding their affected subsistence to be reestablished.

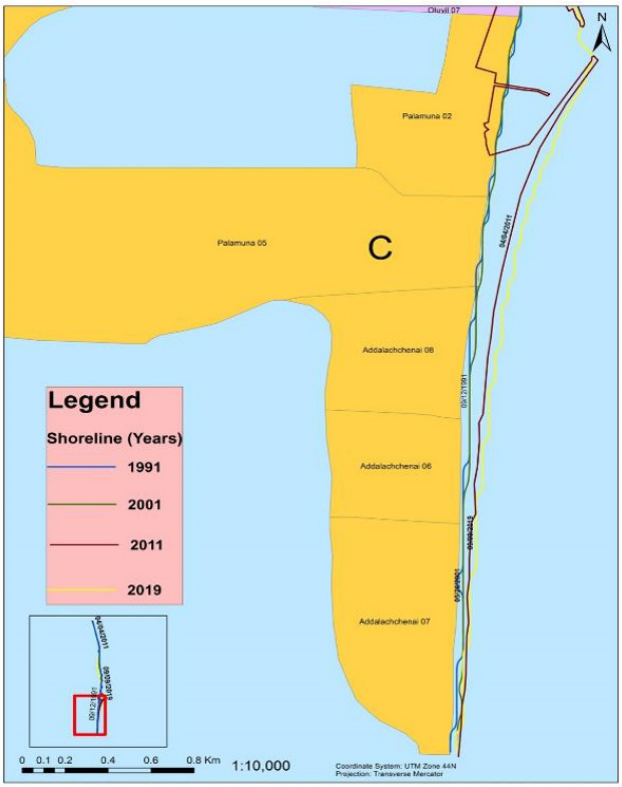

Figure 11: Periodic coastal morphodynamics of 1991, 2001, 2011 and 2019 in *Palamunai* and *Addalaichenai* area (C)
Source: Retrieved from Arc GIS 10.4

4.4.1 Periodic coastal morphodynamics in Konawatta river mouth, Addalaichenaio area

Figure 12 shows the coastal morphological changes in *Konawatta* river mouth, *Addalaichenai* area. The increased flow of water in *Konawatta* river breaks the sandbar across the river. This situation also makes changes in the coastal morphology of the river mouth inner and outer scales of the sandbars.

The encircled areas on the images are the places where the river water frequently breaks the sandbars and causing the morphological changes and, in some instances, the inhabitants widen the river mouth to drain the storm water to the Sea. Eroded river mouth and consequent changes of the beach have been shown in 2012, 2013 and 2018 GE images.

Figure 12: River mouth morphological changes of *Konawatta* river

Figure 13: A; *Palamuanai*-02 GND, B & C; *Konawatta* river mouth D; Southward of the port

The figure 13 exhibits the present situation of the *Palamunai* and *Addalaichenai* coasts where voluminous sedimentation formed. In particular, *Palamunai* area which is immediately closed to the port in Southward direction has experienced anomalous sedimentation effect.

4.5 Sedimentation effect in Oluvil port

The figure 14 shows the sedimentation effect within the harbor. The breakwaters, at the entrance of the port accumulate the longshore sediment transport within the port. It is evident that soon after the construction of the harbor in 2013, there is no sedimentation within the port. Then the sedimentation has been increasing from 2015, 2016, 2018, 2019 and 2020. However, in 2017, the sedimentation was removed using the excavator in order to operate the port. Due to the fact that the sedimentation has poorly been recorded in such year according to the figure.

This situation has led the *Oluvil* port standstill without being operated for any purpose. Both, the fishery and commercial harbors are not in a position to be operated. Inhabitants are protesting against the officials saying that the previous fishing activities also has been affected.

Figure 14: sedimentation effect in *Oluvil* port entrance

4.6 Influence of offshore breakwater construction in coastal morphodynamics because of the breakwater construction in Northward direction of the Oluvil port

In post harbor construction period, offshore breakwaters were located to control the wave force as the coastal protection measure according to the figure 15.

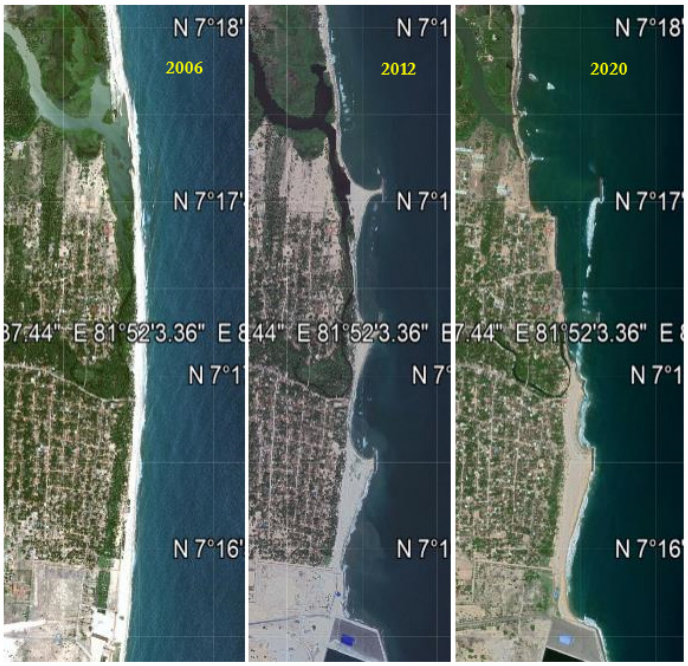

Figure 15: Role of offshore breakwaters in coastal morphodynamics

According to the figure 15, after the construction of breakwaters, tombolo shaped landforms have formed relative to the breakwaters. The 2012 image shows the tombolo shaped landforms, made relative to the offshore breakwaters. In 2020, the situation has become worser leading the vast landmass inundated by the Sea. According to the estimation of land loss, 8.7 hectares of sandy beach has been inundated and eroded because of the erosion. This situation highlights the seriousness of the coastal erosion and consequent morphological changes.

5. Conclusion and Recommendations

Waves and river flooding are the physical factors and the construction of *Oluvil* port and breakwaters are the human factors considered responsible for coastal morphological changes in the study area. The wave surge on the coast is a major constituent which caused critical morphological changes in the post harbor construction period. Thus, the physical and human factors are interdependent as the human intervenes in the natural system of the coastal environment, the wave action on the rise as a counter action against the beach.

This study has found that the wave and river flooding plus the port and breakwater construction in the study area have heavily changed the coastal morphology. Since 1991, the coastal morphodynamics have been occurring in the study area as a natural regularity. In 2019 scenario, because of the accelerated wave action, coastal morphological changes have severely occurred in the study area. Frigaard & Margheritini (2011) have explained this scenario in the 3rd party opinion report regarding the Oluvil port. It has been clearly explained that the present erosion in Northward direction of the port and the accretion in the Southward direction of the port are the consequence of the port construction. This is one of the major factors for the increased coastal morphodynamics in the period from 2011 to 2019.

Other hand, river flooding in the river mouths of *Wavvalodai*, *Nochchiyadi*, *Kaliodai* and

Konawatta also have significantly caused morphological changes in the study area over the period. During the rainy seasons, such changes could obviously be found in river mouths (estuaries). Construction of offshore breakwaters have also influenced for the beach morphological changes in the study area. This study finally suggests that to curb the adversarial impact of the coastal morphodynamics, the sustainable solutions with the long-term observation and numerical modelling should be proposed with the institutional assistance.

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