Monitoring Beach Profile Changes and Modelling Nourishment Scenarios for Ratmalana Beach

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Abstract
Sri Lanka is an island nation endowed with a wide range of coastal resources, greatly contributing to the Gross Domestic Product. Coastal erosion is a major issue related to the beaches in Sri Lanka. In this regard, Ratmalana beach is critically important as a potential tourism destination due to its proximity to the capital city and the accessibility to a coastal railway station. To develop a beach as a tourist destination, it is importance to monitor the beach profile changes and find out the remedial measures for erosion prevention. For such a management plan, either hard or soft engineering solutions can be utilized. Out of the soft engineering solutions, the most reliable solution is beach nourishment. In this research, Ratmalana beach was regularly monitored and a numerical model was built by utilizing the public domain of XBeach to model the hydrodynamics in the area. Finally, two nourishment scenarios were modelled, and the optimum nourishment scenario is determined. Beach profile monitoring and calculated sand budget indicates that there is significant erosion during the stormy weather season. Based on grain size analysis, Ratmalana beach has a broad grain size distribution. According to the modelled nourishment scenarios, profile nourishment has shown better performance.

Keywords: Numerical Modelling, Sand Budget, Tourist Destination, XBeach

1. Introduction

The Gross Domestic Product (GDP) of the coastal regions in Sri Lanka in 2004 was 44% of the National GDP [5]. Coastal erosion remains a major issue in coastal zone in Sri Lanka. To prevent coastal erosion, it is important to monitor the beach and find out the practicable remedial measures.

Coastal erosion is the removal of sediments or rocks in the coastal belt due to wave actions driven by currents, tides, and winds. It is caused by many different processes, such as changes in the prevailing wind direction, coastal currents, reestablishment of a new equilibrium profile, sea level rise and fall, exceptional storms, hurricanes/cyclones, man-made structures and tsunami events [11].

It is necessary to implement a proper system to manage the coastal zone by reducing the erosion and increasing the accumulation of sediments without harming ecological aspects. For such a management plan, either hard or soft engineering solutions can be utilized. As hard engineering solutions, man-made structures, such as groins, breakwaters, sea walls, revetments, etc. are constructed to protect coastal zones. As soft engineering solutions, beach nourishment, beach dewatering and dune regeneration can be considered. However, in general terms, soft engineering solutions are less expensive to implement and maintain than hard engineering solutions.

1.1 Study Area

Ratmalana beach in Sri Lanka is considered as the study area of the research which is bounded by the coordinates (374625.00m E, 753865.00m N), (374926.88m E, 752914.97m N), (373640.21m E, 753625.22m N) and (373943.72m E, 752636.53m N) [UTM 44N]. The study area is a 1 km wide strip of the beach. It is a critically important location for tourism due to its closeness to Colombo (the capital city) and the accessibility to a coastal railway station (like Mount Lavinia)

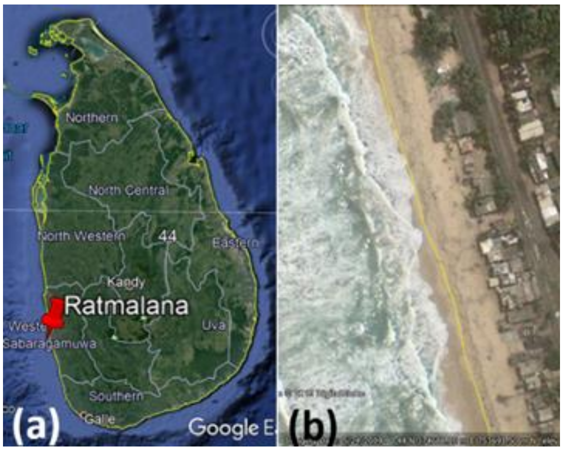

Figure 1:(a) The location of Ratmalana beach in Google map; (b)A zoomed satellite image

1.2 Research Problem

Coastal erosion in Ratmalana beach of Sri Lanka has been a significant issue over a long period, as it is a potential beach front that can meet the requirements of a tourism destination [3]. Furthermore, beach erosion can badly affect the day to day life of the people, and thus, it is required to apply engineering solutions to overcome this issue. Considering the aforementioned facts, applying hard engineering solutions is not favourable as it reduces the scenic view of the beach. Out of the soft engineering solutions, the most reliable solution is beach nourishment [2], [8] & [9]. Whilst nourishment is also carried out in different ways; for example, with (1) Different nourishment locations and (2) Different grain sizes [6], the optimum nourishment scenario must be determined using scientific manner. However, up to the present, no such study was carried out to find out the potential of this beach. Furthermore, it cannot be seen any investments made for developing infrastructure in this venue.

Therefore, the research problem is "What is the optimum nourishment scenario for Ratmalana beach?". In this research, the public domain of XBeach was utilized to numerically model the beach [1], [4] & [10].

1.3 Scope of the Project

Since Sri Lanka is an island nation, providing engineering solutions to beach erosion is a national relevance. By defining an optimum engineering solution to a beach, ultimately that solution turns into a basis for the investors to make investment decisions. Hence, this research was divided to achieve below mentioned objectives.

1. Determine the erosion / development rate of Ratmalana Beach.
2. Identify the seasonal changes of the beach due to monsoons.
3. To build an XBeach model for the study area.

4. To assess the response of the beach by applying various nourishment scenarios and find out the most reliable scenario.

2. Methodology

2.1 Data Collection

The research study area was divided into 11 beach profiles. Therefore, the captured data was related to a particular beach profile.

Figure 2: The beach profiles

Table 1: Beach Profile Start Locations

Beach Profile	Easting (m)	Northing (m)
R	399739.0536	479492.3440
RR1	399720.1878	479582.7424
RR2	399688.6261	479685.5760
RR3	399654.4663	479784.9114
RR4	399637.8628	479883.7901
RR5	399598.3595	479971.6619
RL1	399767.2123	479417.5003
RL2	399799.7712	479313.5478
RL3	399845.0241	479177.7655
RL4	399873.5023	479096.0606
RL5	399904.4838	479022.4567

The coordinates of starting points are shown in Table 1. All coordinates are in SLD99 datum.

The research study can be divided into two parts: (1) Monitoring beach profile changes and (2) Modelling nourishment scenarios. Monitoring beach profiles is an important part of the study which should be carried out continuously to monitor the profiles for identification of changes taken place during the period.

Study of the incidence of tidal wave cycles was an important factor to be considered when organizing the field visits. According to tide terminology, tidal variation is highest at spring tide and lowest at neap tide. For capturing a longer profile, the field visits were arranged during the neap tide time, as it allows walking along the whole profile length to measure the heights along the beach profiles.

Therefore, the field visits were carried out on the following dates:

- 31st December 2018
- 24th February 2019 } North Eastern monsoon
- 24th March 2019 – Inter monsoon period
- 26th May 2019
- 18th August 2019 } South western monsoon
- 5th January 2020 - North Eastern monsoon

2.1.1 Data obtained during field visits

- Beach profiles were obtained using a Real Time Kinematic (RTK) GPS with a millimetre level accuracy. For measuring the profiles, the GPS and the 3D coordinates at the starting point of a beach profile (e.g. start location of RR5) were recorded. Next, coordinate was recorded walking approximately 2 meters perpendicular to the beach. Likewise, points along the beach profile were recorded at 2m intervals until the low water level.

- Generally, the grain sizes are different at each location along the profile. During the field visit on March 2019, sediment samples were obtained from both the dry beach (berm level), Mean Sea Level (MSL) and the breaker zone. During the other field visits, samples were obtained only from MSL.

2.1.2 Data obtained from other sources

This data was basically for numerical modelling purposes.

- As **bathymetric data** mandatory for creating a numerical model, it was obtained from the Coast Conservation Department. The origin of data was a survey carried out by Lanka Hydraulic Institute Ltd. (LHI) on October 2017 (Datum SLD99)
- The **tidal data** was obtained from Sea Level Monitoring website [7] with the required parameters being the time and water level.
- The **wave data** was obtained from a wave gauge placed outside the Colombo harbour.
- The **wind data** was obtained from the Meteorological Department of Sri Lanka.

2.2 Laboratory work and Data Preparation

2.2.1 Laboratory Work

Laboratory work mainly consists of particle size analysis by sieving the samples. Obtained sand samples were transferred to trays for air drying for two days in the laboratory. This was followed by samples drying in the oven at 105 ^{0}C for 24 hours. By cone and quartering, the size of the dried samples was reduced to 500 g. Each sample was sieved for 15 minutes. Weight of retaining sand on each sieve was recorded. Total recovery, cumulative weight percentage and the percentage passing through each sieve were calculated and the Particle size distribution curves were plotted. Since it requires D50 and D90 for XBeach, they were obtained by plotting the curves with DPlot software.

In addition to sieve analysis, the beach profiles were plotted. During each field visit, sand volume of the visible beach area was calculated at that time. It was calculated for the visible beach area, bounded by the coordinates (374625.00m E, 753865.00m N), (374926.88m E, 752914.97m N), (374601.63 m E, 753858.28 m N) and (374900.27 m E, 752907.43 m N) [UTM 44N] which is a 20m wide strip of the beach.

2.2.2 Data Preparation for XBeach Model

The planned XBeach model type was a 1-Dimensional (1D) model. Therefore, **bathymetric dataset (**1D beach profiles of approximately 1 km length) was prepared by combining both the bathymetric data obtained from the Coast Conservation Department and GPS profiles. The data was saved in two separate files where; (1) File *x.grd* containing the distance from the offshore boundary of the profile to the landward boundary of the beach, and (2) File *bed.dep* containing the depth at each distance w.r.t. the Mean Sea Level.

- Tide dataset obtained was averaged to each hour. In case of missing tidal data, graphs were plotted with the available data and the missing data was determined from the graphs. Finally, the tide was saved in two files: (1) File tide_time.txt containing the time of each tide value and (2) The file, tide_value.txt containing the tide value/water level.
- The required **wave data** parameters were Significant Wave Height (Hm0), Wave Period (Tp), Wave Angle (*mainang*) and the time of the tide. As the dataset did not contain Hm0, it was calculated from Hs (Average height of the highest one-third of the individual waves in record) in the dataset.
- The required **wind data** were wind speed and the wind direction. The data was saved in two separate text files.

- **D50 and D90** values at the MSL required for the model were obtained by plotting particle size distribution curves.

2.3 Modelling with XBeach

Modelling with XBeach involves building an XBeach model, running the model and visualizing the outputs. Models were entirely run for the time periods between the field visits from the available precise beach heights on those dates. Therefore, comparison of model results with the beach profiles could be done.

2.3.1 Model Calibration

The model was run for RL3 beach profile. For the calibration, model was run form 24th March 2019 to 26th May 2019. The outputs were obtained at 5 days, 10 days, 30 days, 40 days, 50 days and 63 days intervals. Finally, the model output made on 26th May (output after 63 days) was compared with the actual beach profile obtained by the GPS.

2.4 Nourishment Modelling

Nourishment modelling was also carried out for the RL3 beach profile. Model time period was from 24th March to 26th May. Bathymetry data sets were modified for,
(1) Profile nourishment
(2) Nearshore Bar nourishment, on equal volume basis. (Figure 3)

In both the nourishment scenarios, the additional area under the nourishment curves were equal (Figure 3) and the value was 57 square meters. If the complete beach stretch was nourished in the same way, 57,000 cubic meters of additional sand is needed for the nourishment for both scenarios as the interested area is 1000 m long strip of beach.
The response of the beach after 5 days, 10 days, 30 days, 40 days and 63 days periods was modelled, and the results were compared.

3. Results

The results are of 2 types: The Actual and the XBeach model results.

3.1 Actual Results

Actual results include the results obtained during the field visits. Analysis of beach profile variation, sand budget and grain size distribution helped to assess the potential of a beach as a tourism destination.

3.1.1 Beach Profile Variation throughout the time period

Beach profile monitoring was continuously carried out during the field visits. As Ratmalana is situated in the western coast, south western monsoon highly affects the beach.

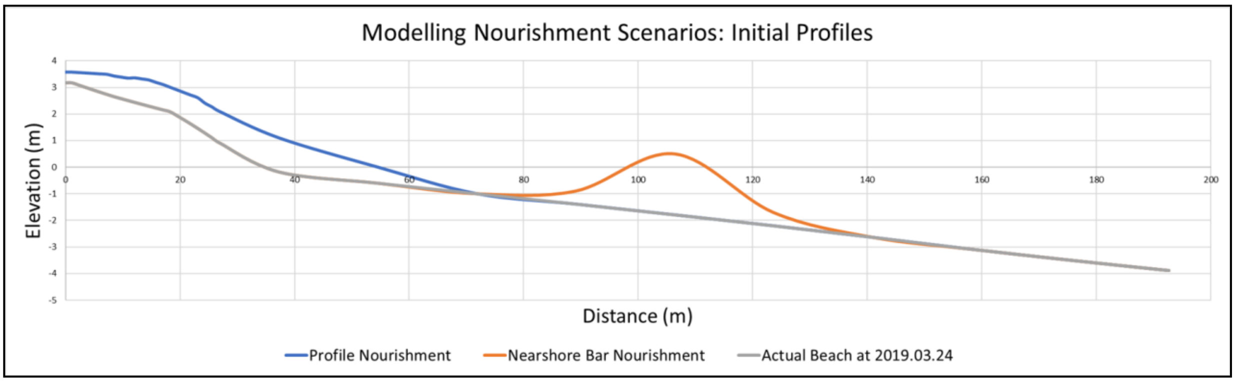

Figure 3: Nourishment Scenarios – Initial Profiles

According to the conducted beach profile monitoring, a significant erosion of the beach profiles was observed during the South Western Monsoon. Figure 4 shows the beach profile variation of Profile RR1. After the monsoon, the beach profile obtained in January shows a significant development.

3.1.2 Sand Budget/Volume

The sand volume was calculated after each field visit.

Table 2: Sand Volume at beach

Date	Sand volume of the beach (cubic meters)
2018.12.31	3015.10
2019.02.24	3086.18
2019.03.24	3073.22
2019.05.26	2537.55
2019.08.18	1870.67
2020.01.05	3167.43

A significant reduction in sand volume in August is shown.

According to Figure 5, there is a significant reduction of sand volume in the months of May and August, which is within the south western monsoon season. Table 3 also provides an evidence to the above point.

Table 3: Sand Budget

Time Period	Sand Budget (Cubic meters)
2018.12.31 to 2019.02.24	+ 71.08
2019.02.24 to 2019.03.24	- 12.96
2019.03.24 to 2019.05.26	- 535.67
2019.05.26 to 2019.08.18	- 666.88
2019.08.18 to 2020.01.05	+ 1296.76

3.1.3 Grain Size Analysis

A comparison of the grain size variation of the Dry beach, Mean Sea Level and the Surf zone as at 24th March 2019 is made.
With regard to grain size distributions, the grain size variation at dry beach and MSL, beach profiles R, RR1, RR4, RL1, RL3, RL4, RL5 shows a similar pattern.

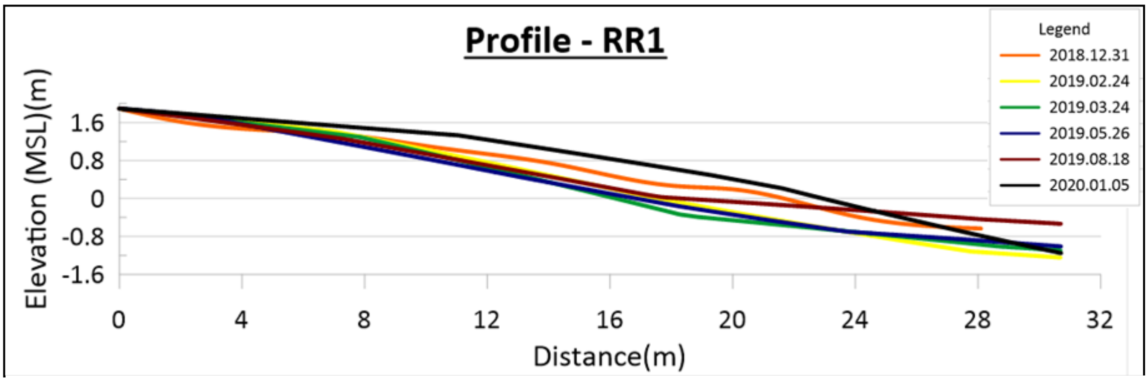

Figure 4: Beach Profile Monitoring at Profile RR1

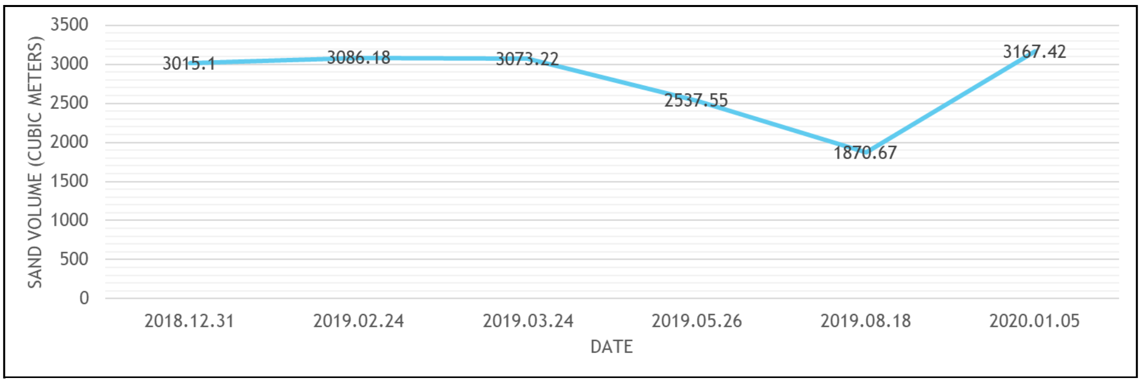

Figure 5: Sand Volume Variation

Table 4: Behaviour of D values among the profiles

All the Profiles	Behaviour (X=D50 and D90 values)
Except RL5	X dry beach< X MSL & surf zone
Except RL2 & RL5	X values are highest at the surf zone
Except RL2 & RL5	X values are intermediate & MSL

The grain size distribution curves (Figure 6) of the dry beach tend to rise before the MSL and surf zone curves for all the profiles except that of RR2, RR3 and RR5. In RR2, both curves coincide whereas, in RR3 and RR5, only dry beach and MSL curves coincide.

All the cases except the profile RR2, the surf zone curve is below the other two curves.
Since the aforementioned patterns can be observed in 8 beach profiles out of the eleven profiles, the conclusion that the grain size distribution of an arbitrary cross section of the Ratmalana beach will follow the same pattern can be made.

When D value is increasing, grain size also increasing. So, it is difficult to erode. Furthermore, an average value for D50 and D90 for the Dry beach, MSL and Surf zone of the Ratmalana Beach can be calculated. The averaged values are as follows,

1. For the Dry Beach: D50 = 0.458 mm, D90 = 1.011 mm
2. For the MSL: D50 = 0.596 mm, D90 = 1.211 mm
3. For the Surf Zone: D50 = 0.822 mm, D90 = 1.590 mm

Based on the percentage passing at 5% and 95%, the d/d' was calculated for all the profiles. Since d/d'>4, it can be concluded that the sand in Ratmalana beach has a broad size distribution.

3.2 XBeach Model Results

This includes model calibration results as well as nourishment modelling results.

3.2.1 Model Calibration Results

Model was calibrated for the time period between March 24th and May 26th (63 days).
According to Figure 7, the model shows an acceptable variation until 2019.05.03 (until 40 days). However, it starts to deviate from the reality afterwards. To ensure that the model is perfectly calibrated, the modelled output should vary within the two actual profiles obtained with GPS on 2019.03.24 and 2019.05.26.

3.2.2 Nourishment Modelling

Results of the nourishment scenarios are shown in Figure 8.

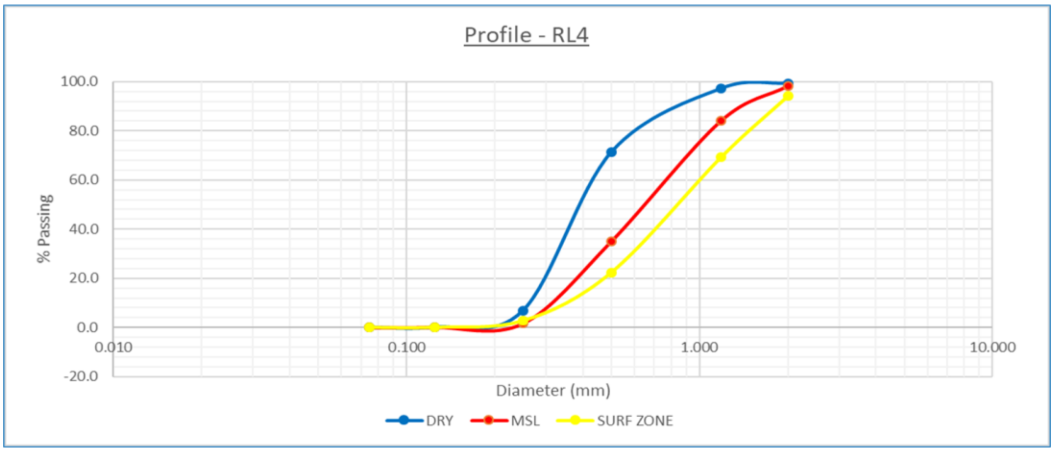

Figure 6: Grain size distribution curves for the RL4 profile

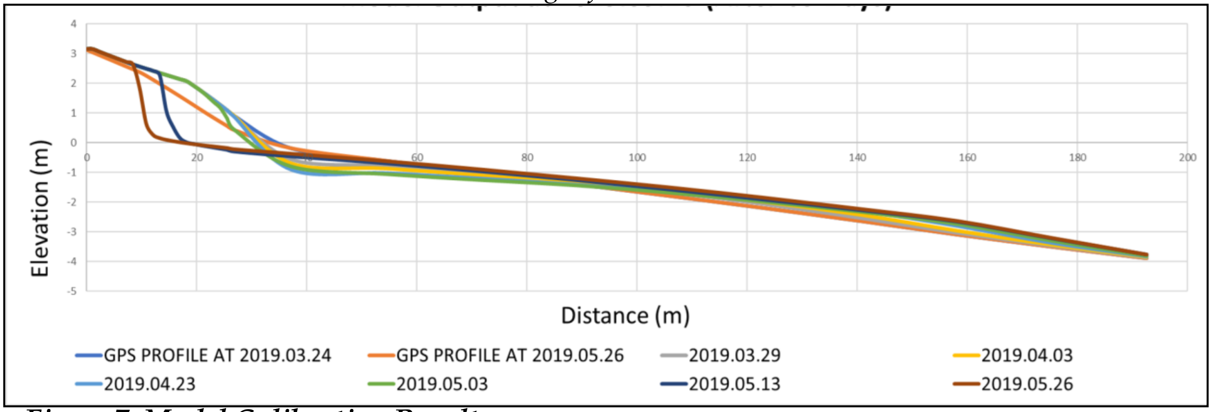

Figure 7: Model Calibration Results

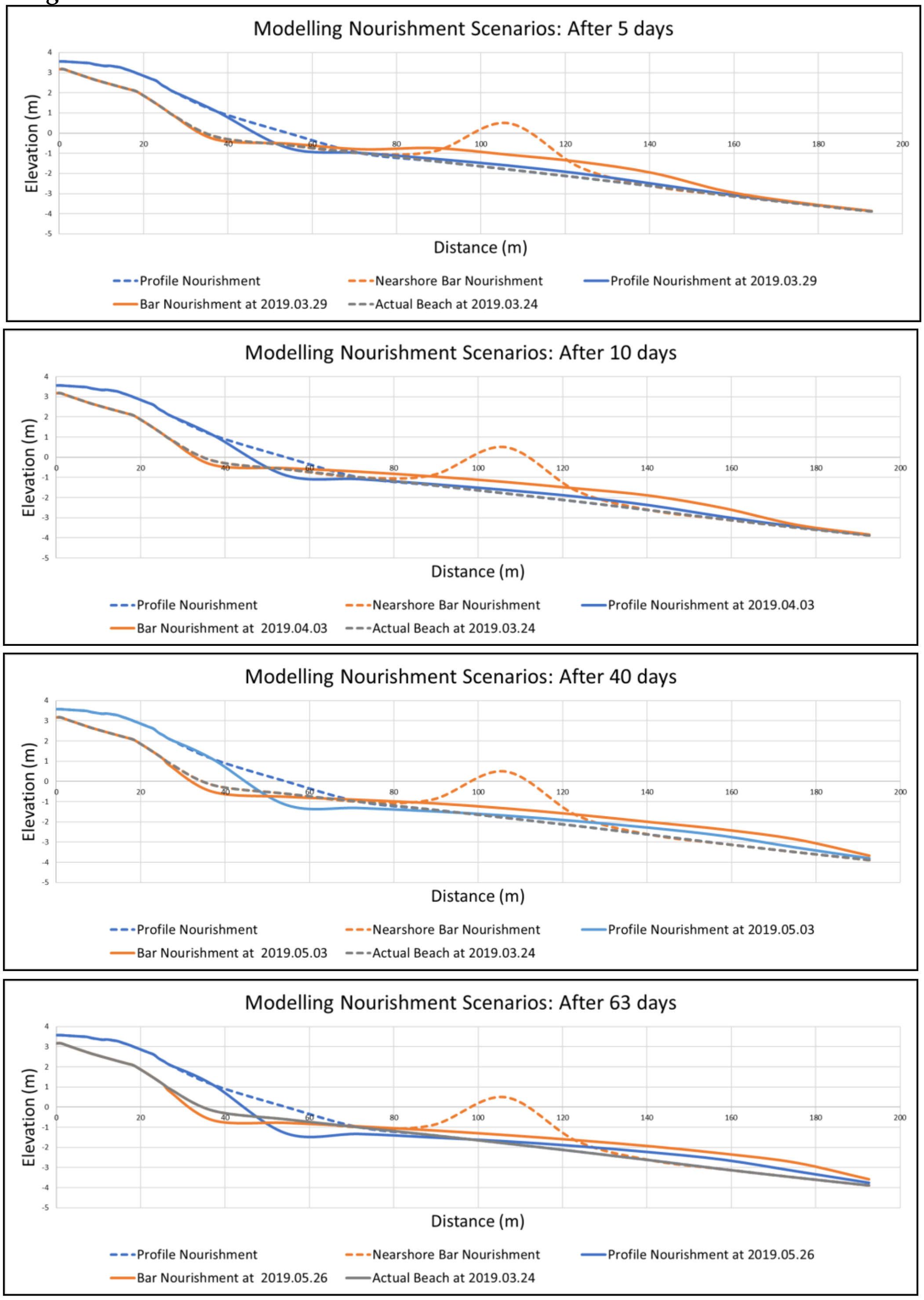

Figure 8: Nourishment Modelling Results

4. Discussion

According to Beach profile monitoring, significant erosion is observed during May and August. This is due to the South Western Monsoon continuing from May to September.
After the Monsoon, the beach profiles significantly developed up to the same extent, as was in the previous year. A significant reduction in the sand volume is observed during the South Western monsoon season.
According to the model calibration results, created XBeach model shows an acceptable variation until 40 days (from 24.03.2019 to 03.05.2019). However, it starts to deviate from the actual scenario afterwards.
Based on the results of the nourishment scenarios, flattening of the artificially created sand bar is observed with time. The profile nourishment is also showing some erosion. When compared with the actual GPS beach profile at the end of the modelling date, the nourished beach has not eroded up to the extent expected. Therefore, both nourishment scenarios preserve the beach for the modelled time period. However, it is recommended to run the model for a longer period. This study was carried out for a period of 63 days using a 1-dimensional (1D) XBeach model. At this stage the XBeach model was built and run with the main parameters such as bathymetry, waves, tides, wind and grain sizes and it is better to run the model with all the model parameters to obtain more realistic outputs.

5. Conclusions

The beach shows a significant erosion during the South Western monsoon season and it develops after the monsoon. During the nourishment modelling, carried out in early monsoon period, both nourishment scenarios preserved the beach from erosion. However, when consider the bed level variation up to 650 m towards the sea, the added sand for Near-Shore Bar nourishment was moved to offshore. Therefore, in terms of sand preservation, Profile nourishment is preferred for this location.

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