Application of Hydrodynamics to Assess Coastal Morphology to the North of Kelani River, Sri Lanka

Ishankha[1] W.C.A., Kahawala[1] K.K.H.B., Sandushan[1] J.A.C., Hewavidana[2] S.M., Silva[3] K.B.A. and *Ratnayake[1] N.P.

[1]Deprtment of Earth Resources Engineering, University of Moratuwa, Sri Lanka
[2] Lanka Hydraulic Institute Pvt Ltd, Sri Lanka
[3] Department of Civil Engineering, Osaka University, Japan

*Corresponding author – nalinratna2010@gmail.com

Abstract
Studies on hydrodynamics are important since the hydrodynamic processes highly contribute to sediment transportation in the coastal regions. Erosion in Uswetakeiyawa coastal region of Sri Lanka has been a significant environmental issue since 2000. The Coast Conservation & Coastal Resources Management Department of Sri Lanka carried out artificial beach nourishment in 2012, and then a set of offshore breakwaters was constructed in 2013 to protect the nourished stretch of the beach. However, the beach was not developed to the desired extent. This research was carried out to assess hydrodynamics to forecast the noted coastal morphology in the Uswetakeiyawa coastal region. Wave data were gathered and analyzed using "SWELLBEAT" software for 12 months, covering both the monsoons. Further, "Delft3D" open source software was used to simulate the hydrodynamics in the study area, and seasonal changes of coastal morphology were analyzed for the study area using GoogleEarth images. The findings of this research indicated that due to the strong wave action perpendicular to the coast during the southwest monsoon, the beach was more vulnerable to erosion and there was no sediment transportation to the beach from longshore drift during inter-monsoon periods because sediments contributed from Kelani River were directly transported to the ocean. Also, the predominant sediment transportation to the study area was during the northeast monsoon.

Keywords: Beach nourishment, Breakwaters, Coastal morphology, Longshore drift, Numerical modelling

1 Introduction

Sri Lanka consists of approximately 1,600 km long coastline, being an island in the Indian Ocean [1]. Coastal zones of Sri Lanka play a major role in the economy of the country as more than 44% of the National Gross Domestic Production (NGDP) has been generated within the coastal regions [2]. Coastal erosion has become a long-term problem in many coastal zones of Sri Lanka, and it directly affects the economic development of the country.

The assessment of coastal morphology is utmost important for the identification of coastal erosion and accretion processes and, thus proper coastal management [3,4]. The changes in coastal morphology are mainly governed by hydrodynamics in the offshore and nearshore areas. The longshore drift is the main process that leads to the longshore movement of sediment in the beach zone by waves, and it affects the coastal morphology along the beach. Also, cross-shore currents which transport the sediments perpendicular to the shore affect for the morphology changes over time. The strength of the current depends on the energy flux (W/m), and higher the energy flux of currents higher the transport rate [5].

Coastal erosion in Uswetakeiyawa coastal region of Sri Lanka has been a significant environmental issue since 2000 [6,7]. As a solution for this, the Coast Conservation & Coastal Resources Management Department (CC&CRMD) decided to artificially nourish the Uswetakeiyawa Coastal region, and Sri Lanka's first major beach nourishment project was carried out over a 1.8 km stretch in the Uswetakeiyawa - Palliyawatta area. The nourishment project was conducted in January 2012, and 300,000 m^3 of offshore sand was used to nourish the stretch of eroded beach, and in 2013 after the nourishment, a set of breakwaters were constructed to protect the nourished stretch [6,7].

The long term beach width evolution indicated that the beach has a gradual increase in width after the nourishment program [6]. Although the CC&CRMD implemented the above remedies to prevent beach erosion in the area, the beach was not developed to the desired extent. However, after the breakwaters were constructed, the beach widths have shown irregular changes over time, with some locations drastically eroding and some other locations accreting [6,7]. Coastal hydrodynamics are the main reasons for these changes.

The main objective of this project is to assess hydrodynamics to forecast the coastal morphology that has been noted in the coastal region from the Kelani river mouth to Uswetakeiyawa area. Previous researches assessed the coastal morphology with field measurements in this area [6]. In the present study, the authors assessed the coastal morphology in Uswetakeiyawa coastal zone by observing the hydrodynamics over 12 months from June 2014 to May 2015.

2 Methodology

2.1 Study Area

Figure 1: Study Area from Kelani River Mouth to Uswetakeiyawa.

The study area, Uswetakeiyawa is located about 10 km north of Colombo on the western coast of Sri Lanka, and it was selected along a 10-km stretch of the coast from Kelani river mouth to Uswetakeiyawa that consists of different coastal structures such as groins, fishery harbours and offshore breakwaters.

2.2 Collection of Data

Wind data for the Uswetakeiyawa area for 2014 and 2015 years were collected from the Meteorological Department, Sri Lanka and bathymetric data for the area were collected from Sri Lanka Navy Hydrographic Unit of National Aquatic Resources Research and Development Agency (NARA).

During the preliminary field visit, water samples were collected from eight locations to determine the water density. Global Positioning System (GPS) was used to determine the co-ordinates of the sample locations. Multiple wave parameters such as average wave height, peak wave period and wave direction on the western coast of Sri Lanka were measured using the Inter Ocean S4DW electromagnetic current meter [8].

2.3 Wave Data Analysis

SWELLBEAT wave data analysis software [5] was used to compute the fundamental wave parameters such as average wavelength, wave celerity, maximum horizontal and vertical velocities, and energy flux. The software used the linear wave theory to compute above wave parameters.

2.4 Laboratory Works

The water samples collected during the field visit were tested for conductivity using a HQ 14D conductivity meter (HACH). The conductivity (mS/cm) and the temperature of each water sample were measured. The results were used to determine the densities of the samples.

2.5 Numerical Modelling With Delft3D Flow Model

2.5.1 Bathymetry Preparation

The land boundary and the other boundaries of the model area were demarcated using GoogleEarth Pro, and the coordinates along the boundaries were obtained using ArcGIS software.

The grid preparation for the model area was carried out by Delft3D RGFGRID with a grid size of 16 m × 16 m. Delft3D QUICKIN pre-processing tool was used to prepare bathymetry using the prepared grid and bathymetry data. Since the model area had high sample density grid cell averaging interpolation method was used for the interpolation [9].

2.5.2 Model Setup

For the Delft3D flow model, there are specific file formats for each and every input.
Curvilinear grid, bathymetry, wind data and astronomic flow conditions at boundaries are the main input files for the flow model. The input files were prepared using the required format using Delft3D (Graphical User Interface) GUI and QUICKIN pre-processing tool.

2.5.3 Model Simulation and Extraction of Results

The Delft3D flow model was used to simulate the depth average velocity in the study area and at the Kelani River mouth for a 12-month period and the simulated results at the Kelani River mouth were extracted using QUIKPLOT post-processing tool.

The resultant depth averaged current velocity at Kelani River mouth was used in the standard curve representing the relationship between average current speed and average grain size [10] to find what has happened to the sediments contributed through Kelani River at the river mouth.

2.5.4 Morphological Analysis for the Study Area

Morphological changes in the study area from 2014 to 2018 were analysed using available Google images obtained from the "Google Image Pro" software. Images were obtained with the special features in the study area, which can clearly represent the morphological changes over monsoon periods.

3 Results and Discussion

3.1 Wave Data Analysis

Table 1 contains the wave parameters obtained from SWELLBEAT software.

Mean wavelength is an important parameter to determine the wave base. Wave base is the maximum depth at which waves cause for significant water motion. For the water depth deeper than the wave base, bottom sediments are not stirred by the wave motion above, and the wave base is half of the wavelength [10].

According to the results presented in Table 1, the maximum mean wavelength was in June during the south-west monsoon, and was 43.2 m. Therefore, the maximum wave base should be 21.6 m for the period from June 2014 to May 2015. The wave base should be considered when making policies for sand mining in the offshore areas. The sand mining should be done beyond the depth of maximum wave base to avoid the impact from sand mining to the natural sediment dynamic process in the sea.

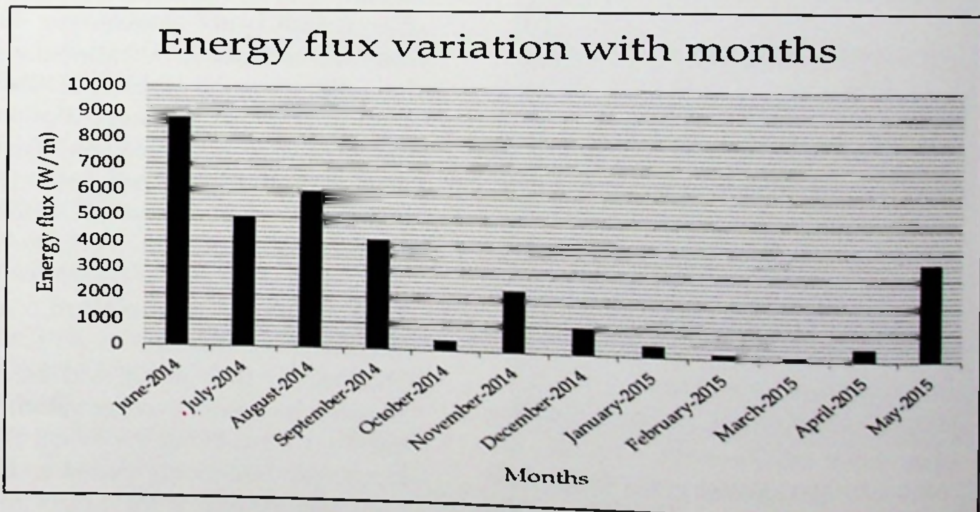

Figure 2: Energy Flux Variation with Months.

Table 1: Results of Wave Data Analysis.

	2014							2015				
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Mean wave length (m)	43.24	38.67	41.48	37.68	36.53	36.71	32.19	27.45	27.71	32.86	40.23	35.10
Wave celerity (m/s)	7.14	6.96	7.07	6.91	6.85	6.86	6.60	6.26	6.28	6.64	7.02	6.78
Maximum horizontal velocity (m/s)	0.77	0.62	0.65	0.57	0.18	0.44	0.32	0.23	0.15	0.12	0.19	0.56
Maximum vertical velocity (m/s)	0.58	0.49	0.50	0.47	0.15	0.36	0.28	0.21	0.14	0.10	0.15	0.47
Mass flux (kg/ms)	221.05	138.13	156.78	119.20	11.92	68.06	34.98	18.01	7.39	4.69	12.69	110.70
Energy flux (W/m)	8796.5	4987.9	6021.4	4198.2	407.76	2338.2	1050.1	451.1	187.1	144.0	474.6	3640.5
Hs (m)	1.587	1.238	1.330	1.146	0.361	0.863	0.607	0.424	0.273	0.220	0.377	1.094
Average Tp (s)	7.039	6.465	6.820	6.344	6.201	6.223	5.669	5.100	5.131	5.750	6.662	6.023
Monsoon period	SW	SW	SW	SW	IM 2	IM 2	NE	NE	NE	IM 1	IM 1	SW

Hs- Significant wave height, Tp- Peak wave period

Higher the energy flux higher the coastal erosion. According to Figure 2, there were significantly higher energy fluxes during June, July, August and September, and lower energy fluxes during January February, March and April. Therefore, higher beach erosion was experienced in southwest monsoon in the study area than the other monsoon periods.

Based on the average peak wave period, the wave type in the study area for the considered time period was chop waves because all average peak wave periods were below 10 seconds.

3.2 Wave Rose Diagrams

Waves act perpendicular to the coast during southwest monsoon and sediment transportation due to longshore currents cannot be observed during this monsoon. The significant wave heights are also higher than other monsoons. In addition, since the energy fluxes were higher in southwest monsoon according to Table 1 and Figure 2, the beach is more vulnerable for erosion in the southwest monsoon.

The prominent wave direction during second inter-monsoon is from the southwest direction is southwest according to drawn rose diagrams, and therefore there should be a longshore drift along the beach from south to north direction.

Waves act at the coast from northwest direction during December, January and February (Figure 4). Hence, sediments should transport from the north to south direction and sediments should accumulate on the beach.

The first inter-monsoon is the same as the second inter-monsoon. The prominent wave direction is from northwest direction, and hence the sediments should transport from south to north direction along the beach due to the longshore drift.

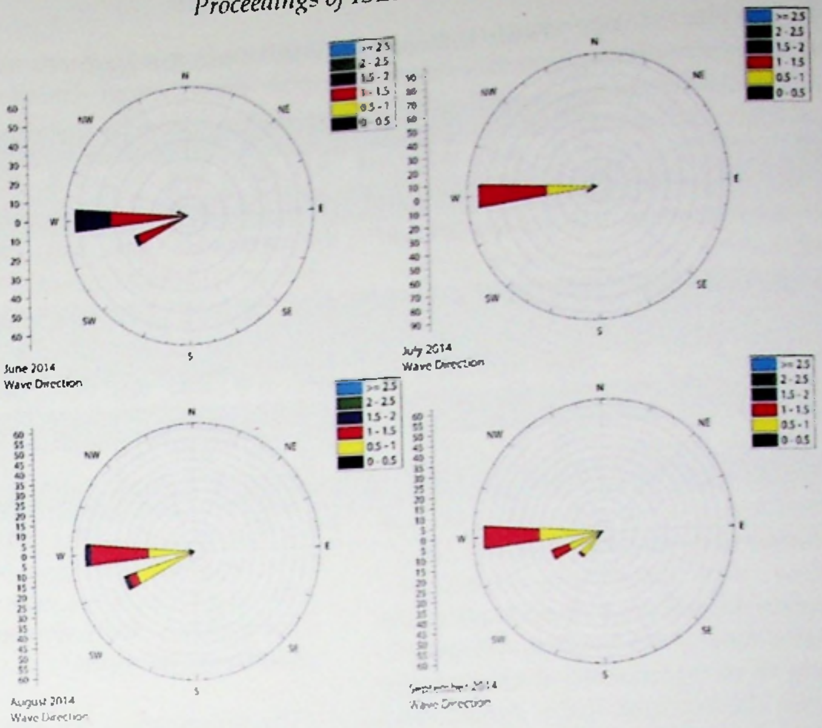

Figure 3: South-West Monsoon (June 2014 – September 2014).

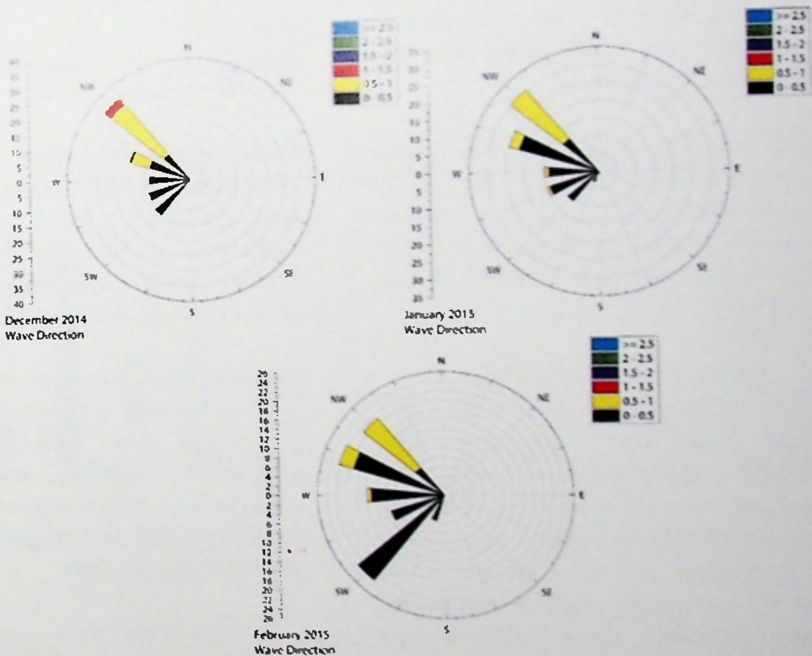

Figure 4: North-East Monsoon (December 2014 – February 2015).

3.3 Numerical Modelling With Delft3D Flow Model

The resultant velocity at the Kelani River mouth was calculated as 0.82 m/s after simulating the flow model. According to the the standard curve representing the relationship between average current speed and average grain size [10], the sediments range between 0.004 mm to 1.1 mm grain size (Silt, Fine/medium/coarse sands and gravels) should be subjected to the erosion at river mouth or transportation to the ocean based on the depth-averaged velocity which can exist at the river mouth. The average density of water was determined as 1019.2 kg/m^3, and it was used in the flow model setup.

3.4 Morphological Analysis for the Study Area

According to the Figure 5 and Figure 6, it is clear that though there should be a sediment supply from the longshore currents during inter monsoon periods and southwest monsoon, it has not happened. It implies that there is no sediment transportation from the Kelani River sediment budget to the north direction along the beach, and it confirms the results from the flow model.

The only sediment supply for the area is in northeast monsoon from north to south, and during the southwest monsoon, the coast is affected by the cross-shore currents with higher energy flux which leads for excessive beach erosion.

Figure 5: South-West Monsoon (August) 2014.

Figure 6: North-East Monsoon (January) 2015.

Further, morphological analysis was carried out to confirm the consistency of the morphological changes of the coastal region in the study area from 2015 to 2018, and the results were confirmed that there is a consistency in the morphological changes.

4 Conclusions

Waves having higher energy fluxes leads to erosion at the coast and change the morphology.

Sediment dynamics is controlled by wave direction, and though there should be a sediment supply from the longshore currents during inter monsoon periods and southwest monsoon, it has not happened. It concludes that there is no sediment transportation from the Kelani River sediment budget to the north direction along the beach.

The only sediment supply for the area is during the northeast monsoon from north to south, and during the southwest monsoon, the coast is affected by the cross-shore currents with higher energy flux which leads for excessive beach erosion.

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