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An Assessment of Wave Climate Variability Using Energy Flux Method: A Case Study in the Coastal Area of Negombo to Wadduwa

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Abstract: Wave climate can be described as the distribution of wave characteristics averaged over a period of time and for a particular location. Coastal erosion has significant impact from the change of wave climate. The West coast of Sri Lanka is identified as a severely eroding coastline according to the Master Plan for Coast Erosion Management in 2006. This study quantifies the wave climate variability in the West coast of Sri Lanka using ECMWF (European Centre for Medium-Range Weather Forecasts) wave data, in particular, ERA 5 collected over the years from 1979 – 2019. The occurrence of wave classes in the study area and the temporal changes in the wave parameters such as significant wave height, wave period, wind speed and sea surface temperature were analysed. Then significant change in long-term wave climate variability (1979-2019) and short-term wave climate variability (2010-2019), and the variation of wave energy in the study area were assessed. The significant increment has been happened in occurrences of wave classes and the wave parameters of the study area within the short term of period. Results of wave energy computations clearly indicate increase in the residual changes of wave energy flux in the short-term period during the Southwest monsoon. In addition, the occurrence of wave heights events which are greater than 2m have increased during the short-term of period than in long-term period. The changes in wave parameters and subsequently the coastal retreats in study area and possible measures are discussed in the paper.

Keywords: wave climate, wave parameters, energy flux, coastal erosion

Introduction

In recent years, coastal construction projects are rapidly arisen around the Sri Lankan coast line, especially in the Western coastal stretch. As examples, Colombo Port development with the extension of breakwaters, reclamation of 269 hectares of land from the ocean known as Colombo International Financial City, and upcoming construction of a beach reclamation called Beach Front project. Moreover, this coastline is the most invested coastline in Sri Lanka and the city of Colombo which is the country's front door, also located in this coastline.

Waves are the vital contributor that controls the where and how coastal structures are constructed and it is a sudden occurrence of or increase in a phenomenon that usually created by the wind with an undulation of the sea surface (Pinet, 2011). Wave height, wave period, and wave direction are the three different characteristics that necessary for coastal studies (Dodet, Bertin and Taborda, 2010). Wave climate is the distribution of wave characteristics averaged over a period of time and for a particular location (Kummu et al., 2016). The energy flux is known as rate of transfer of energy through a surface. The energy flux method is related to the longshore transport rate. It is based on the concept of wave energy flux, where the wave calculate the energy flux recorded for each wave in a wave time series (Galvin et al., 1973; Benedet et al., 2016).

Basically, the wave climate in Sri Lanka is mainly controlled by monsoon seasonality. Northeast monsoon (December to February) and Southwest monsoon (May to September) are the two main tropical monsoon periods that can be categorized according to the seasonal change of Sri Lankan weather (Gerritsen and Amarasinghe, 1976). When Compared with the Northwest monsoon, the Southwest monsoon is more probable to have higher wave events in the western coast of Sri Lanka (Jayathilaka and Fernando, 2019). Sri Lanka's Western coastline shows severe erosion under stormy conditions during the Southwest monsoon period (Lakmali et al., 2017).

The West coast of Sri Lanka is identified as erosion prone area during last decades (CCD plan, 2006,2004; Jayathilaka, 2015). Possible reasons for ongoing coastal erosion are coastal intervention, sea level rise, river sand mining and offshore dredging and wave climate change. The engineering aspects for coastal erosion were analysed by Amarasinghe (1971), Genitsen (1974) and Wickramaratne (1985). The effect of sand mining for coastal erosion were analyzed by CCD (2004, 2006). The impact of sea level rise with coastal erosion and inundation of West coast of Sri Lanka was discussed by Palamakumbure et al. (2020) and Wijayawardane et al. (2013). In the context of Sri Lanka, the studies of wave climate impact on the West coast of Sri Lanka indicated are hardly found. The proper assessment of wave climate is so indeed to control coastal erosion. (Gunarathna, Ranasinghe and Sugandika, 2011). Therefore, the influences of the probability of occurrence of wave events on the near-shore wave climate thus coastal erosion in the West coast have to be well studied.

As per the previous studies conducted by The National Aquatic Resources Research and Development Agency (NARA) have revealed that the land area along the coastline Pitipana and Wedikanda have experienced severe sea erosion every year during the Southwest monsoon. Coastal conservation department have expended millions of rupees to mitigate the coastal erosion problems in the area (CCD plan). Sand mining in the rivers and coastal areas, coastal construction and the wave climate change are identified as contributory factors that govern the coastal erosion (CCD plan 2006). Understanding the wave climate change in this coastline is vital for mitigating the ongoing coastal erosion problem. Consequently, this study would help to take required management decisions and mitigation strategies for such future constructions in the West coast of Sri Lanka.

Research Design

A. Data Collection

The ECMWF (European Centre for Medium-Range Weather Forecasts) wave data was used in this study. In particular, ERA 5, the most recent reanalysis of wave data was collected from 1979 to 2019.

B. Methodology

Data was collected from Negombo to Wadduwa based on the locations of Pitipana and Wedikanda. First, occurrence of wave classes were assessed. Then long term (1979-2019) and short term (2010-2019) wave climate variability was analysed with wave, wind, temperature parameters and the wave energy variation was evaluated considering the Southwest and Northeast monsoon periods through the energy flux method.

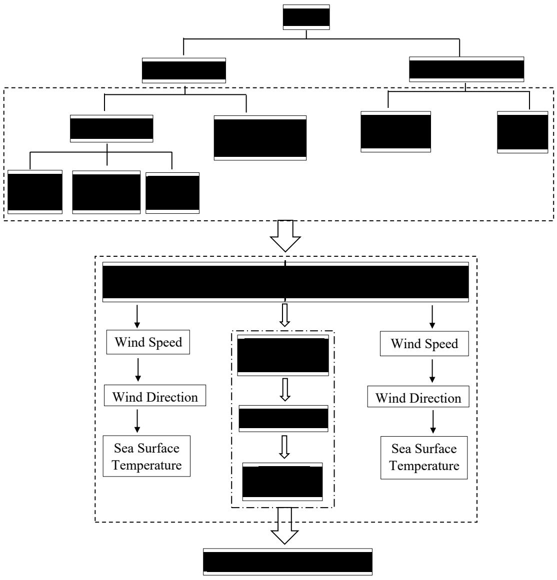

Figure 4: The overview of the research methodology used in the study

C. Energy Flux Method for wave climate

The method is based on the concept of wave energy flux, where the wave calculate the energy flux recorded by each wave in a wave time series and used the following equation;

$$Ef = (\rho\ g\ Hs2/8)\ Cg$$

Where ρ is the water density, g is the gravity acceleration, Hs is the significant wave height and Cg is the group wave celerity, in deep water (Benedet et al., 2016).

Results and Discussion

A. Analyse the wave classes

In prior, the occurrence of wave classes in the study area were analysed.

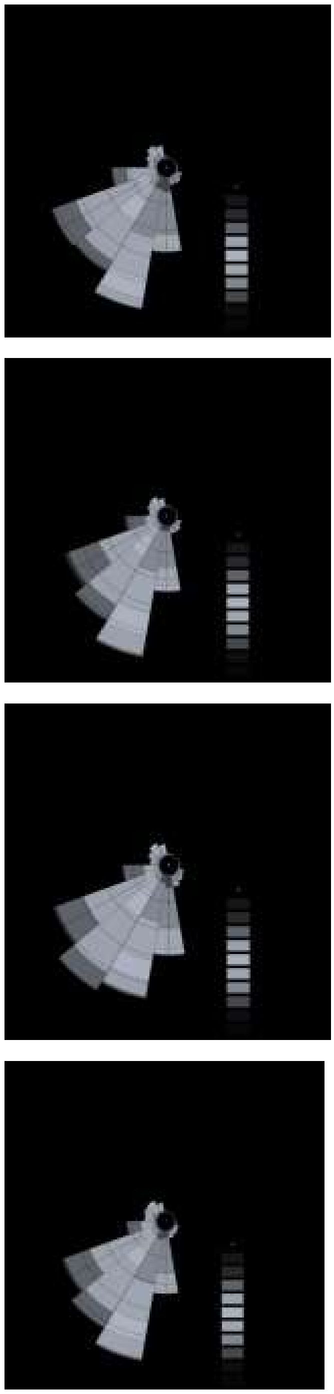

Figure 5: Comparison of Significant Wave Height(SWH) classes with wave roses in study area between 1979 – 2019

In here the colour of each cell represents the Significant wave height and the alignment of each the arm gives the direction that wave coming while the length of the arms of the wave roses represents the percentage of occurrence of the wave classes. According to the 40 years of wave data analysis with wave rose diagrams (Figure 2), the occurrence of Significant wave height classes was increased between 1989 to 1999 than 1979 to 1989. But within 1999 to 2009 the occurrence of Significant wave height classes was comparatively decreased. Again, within the nearest decade (2009 - 2019), the occurrence of Significant wave height classes were increased. But, when consider the overall occurance of Significant wave heights, it can be said that the significant increment has been happened in occurrence of wave classes within the short term (2009-2019) of period.

B. Analyse the wave climate variability

Wave climate analysis indicates Significant wave height varies from 0.5 m to 3 m. The most probable wave height is about 1.5 m. Wave direction distribution is mainly in 210^0–250^0 during the Southwest monsoon. According to the wind climate in the study area from May to September, the wind direction is Southwest and the wind direction distribution is between 220^0-240^0. During the Southwest monsoon, the wind speed varies between 7-11 m/s. (Jayathilaka and Fernando, 2019).

To analyze long-term wave climate variability and short-term wave climate variability, the yearly maximum, minimum and average of parameters from wave, wind and temperature data sets were analyzed in the study area from 1979 to 2019 and from 2010 to 2019 respectively. Wave height, wave period, wave direction and wind direction for Southwest monsoon season, wind speed, temperature, wave energy and erosion were taken as parameters to observe long-term (1979 – 2019) wave climate variability and short-term (2010 – 2019) wave climate variability.

Based on the below observations (Table 1);

- An increment can be seen in long term yearly maximum of significant wave height and a slightly improvement can be seen in yearly average of significant wave height within short term of period.
- Change the value in yearly maximum of wave period is not revealed, but yearly minimum and yearly average values are slightly increased within the short term.
- To the study area, the effect of Southwest monsoon is highly considered (Lakmali et al., 2017; Jayathilaka and Fernando, 2019). Therefore, the effect of Northeast monsoon is not considered for this study. The effect of yearly average of wave direction is slightly decreased and wind direction is slightly increased towards the study area within the short-term period.
- Within that short-term of period the yearly maximum wind speed and yearly average wind speed is increased. The yearly minimum value is not applicable.
- While the yearly maximum and average sea surface temperature is increased, the minimum value has decreased within short term of period.
- The yearly average of wave energy in short term is considerably increased than the yearly average of wave energy in long term.
- The yearly average of short-term erosion rate is higher than the yearly average of long-term erosion rate.

Table 2: Long term (1979-2019) and short term (2010-2019) wave climate variability

	1979-2019			2010-2019		
Parameter	Yearly maximum	Yearly minimum	Yearly average	Yearly maximum	Yearly minimum	Yearly average
Significant wave height(m)	3.8101	0.4788	1.3850	3.2712	0.4788	1.3925
Wave period(s)	15.1885	5.0131	8.8386	15.1885	5.3645	8.8581
Wave direction (SW monsoon) (⁰)	NA	NA	233.5	NA	NA	233.3
Wind speed (m/s)	10.90	NA	4.44	11.25	NA	4.50
Wind direction (SW monsoon) (⁰)	NA	NA	248.2	NA	NA	248.3
Sea surface temperature (C)	30.3080	26.6809	28.32222	30.5389	26.5597	28.4527
Wave Energy (Kw/m)	NA	NA	2.2778e+05	NA	NA	2.2992e+05
Erosion (m/year)	NA	NA	Low	NA	NA	High

Figure 4: Residual change between short term and long-term wave energy flux.

NA – Not Applicable

Accordingly, it was found that the significant increment in yearly average of wave parameters such as significant wave height, wave period, wind speed, wind direction changes, sea surface temperature and wave energy.

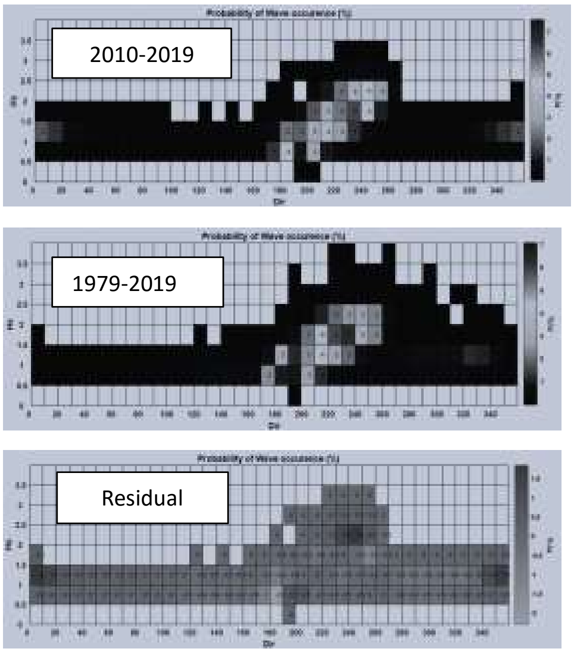

Figure 3: Residual change between short term and long-term wave occurrence probability

This complies the increased of coastal erosion rate during the short term (2010-2019) study conducted by NARA.

The residual change between short term and long-term wave occurrence probability (%) was analysed (Figure 3). It is clear that the short-term wave height bins which are more than 2m have increased their occurrence probability comparing with the long-term trend. Most of the higher probabilities occur in the Southwest monsoon period.

B. Evaluate the variation in Wave Energy

Figure 4 illustrates that as per the residual changes, it is clear that during the Southwest monsoon the wave heights which are greater than 2m have increased the wave energy within the short term of period and the wave heights which are less than 2m have reduced the wave energies. Also, some waves between the heights of 1-1.5m appear during the Northeast monsoon in the short term period though it was not experienced in long term period.

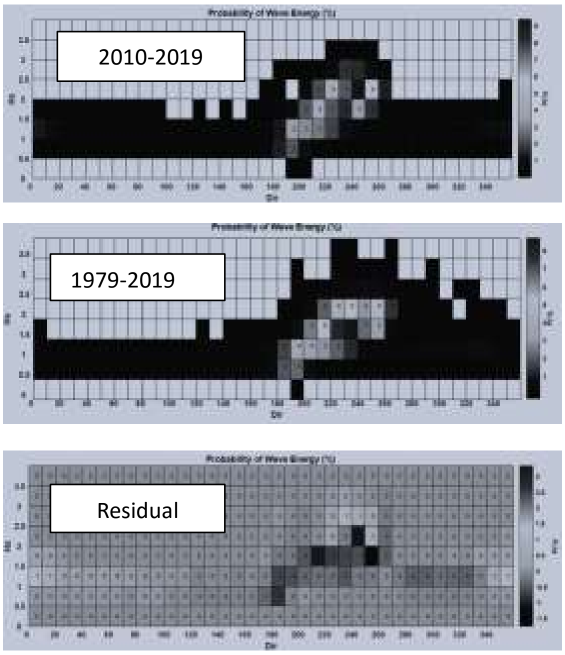

Figure 4: Residual change between short term and long-term wave energy flux.

Conclusion and Recommendation

In prior asses the occurance of Significant wave heights of the study area with fourty years wave data. Therefore, it can be said that the significant increment has been happened in occurrences of Significant wave height classes of the study area within the short term (2010-2019) of period. Furthermore, wave heights which are greater than 2m have been increased during the Southwest monsoon therefore the wave energy during short term period have been increaed. Also the wave heights less than 2m have reduced the wave energies and some waves between 1-1.5 m appears during the Northeast monsoon through the short term period which was not experienced within long term period. Hence, it can be concluded within the short term of period the wave energy fluxes have been comparatively increased. This will be another major reason that increases the wave power in the study area. In overall the short term (2010-2019) wave climate has been increased in the study area. Therefore, the influences to the probability of increment in short term (2010-2019) wave climate variability, triggered to the coastal erosion in the West coast of sri Lanka.

Coastal stretch of West, Sri Lanka was stabilized by introducing several hard-structural solutions. All of these major stabilization projects were implement prior to the Colombo South Port Development and Port City Development. The principal causes of erosion in West coast includes; natural process due to monsoon generated wave attacks, to evaluate the rate of erosion due to the change of wave climate, a comprehensive modelling studies are recommended through the long term and short term. Also it is recommended to maintain the coastline's natural appearance and preserves natural shoreline dynamics by preventing seafront development. Removes structures/people from the hazard zone, making it a highly effective method of minimizing property damage due to coastal erosion and tie the setback policy to exist land use and building regulations.

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