PRELIMINARY ASSESSMENT OF WAVE ENERGY IN SRI LANKA

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Preliminary results of a numerical model developed to detail spatial and temporal assessment of theoretically available near shore wave energy, and potential wave energy extracting sites, along the Sri Lankan coast is presented in this paper. Wave energy is estimated applying *Danish Hydraulic Institute*'s *Mike 21 Spectral Wave (SW)* module. The model is developed and applied covering an area along the coast line of entire country extending from 315000 to 640000 mE, and 602000 to 1164000 mN. Model was run with boundary inputs of wind and wave, based on long term measured, and long term hindcast directional wave data available at seven locations, which are well distributed around the country. Model calibration and validation are carried out based on long term measured directional wave data at Colombo, Sri Lanka. Based on the estimated wave energy density maps, and spatial and temporal energy variations, Hambantota, in South East coast is identified as the most feasible location for wave energy harnessing. Annual and seasonal availability of the wave energy, for Hambantota area, at 25 m depth, were looked into in detail. In the above area, mean annual energy potential was estimated as 10 kW/m at 25 m depth, whereas maximum annual potential energy was estimated as 36 kW/m. During South West monsoon, where high waves are present, the mean energy potential is estimated as 15 kW/m.

Keywords: potential wave energy; numerical modeling

INTRODUCTION

Investigating additional energy resources is needed with continuous population growth, and resulting increase of energy demand. Wave energy is a clean form of renewable energy from oceans and seas around the globe. Sri Lanka, being an island, has a coast of about 1340 km in length, hence ocean wave energy has a high potential to become an economical energy source. However proper assessment of the energy potential in the ocean is yet to be exploited. Based on Cornett (2008), estimated available wave energy for Sri Lanka is about 10 kW/m. In present time, there are some positive developments towards wave energy locally and worldwide. The present study looked into available wave energy along the Sri Lankan coast. Estimate of potential wave energy is based on a numerical model, and measured and hindcast long term directional wave data at seven locations, which are well distributed around the country.

METHODOLOGY

A commercial numerical suite, *MIKE 21 SW* module is used for energy resource assessment. During the model development and model set up, due attention is paid in sourcing and assembling bathymetry data, mesh element size selection for different zones of the model, boundary type, input boundary data, calibration and verification of the model. Model is developed based on long term measured and hindcast wave data. *MIKE 21 SW* includes a new generation spectral wind-wave model based on unstructured meshes. The model simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas. *MIKE 21 SW* includes most of the physical phenomena, including, wave growth by action of wind, non-linear wave-wave interaction, dissipation due to white capping, dissipation due to bottom friction, dissipation due to depth induced wave breaking, refraction and shoaling due to depth variations, wave current interaction, effect of time varying water depth and flooding and drying. A cell centered finite volume method is used in discretization of the governing equations and a multi sequence explicit method is used for wave propagation with time integration carried out using a fractional step approach. *MIKE 21 SW* is used for the assessment of wave climates in offshore and coastal areas. However *MIKE 21 SW* module cannot handle diffraction and reflection.

The model includes two methods of wave simulation; directional decoupled parametric formulation and fully spectral formulation. Considering the extent of the model bathymetry and computational time, directional decoupled parametric formulation is used in this study.

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In the standard way, the energy flux or power (P) transmitted by a regular wave per unit crest width can be estimated as:

$$P = \frac{1}{8}\rho g H^2 C_g \tag{1}$$

Where, ρ is fluid density (1025 kg/m^3 for sea water), g is gravity, H is the wave height, and C_g is the group velocity, defined as:

$$C_g = \frac{1}{2}\left(1+\frac{2kh}{\sinh(2kh)}\right)\frac{L}{T} \tag{2}$$

Where, h is local water depth, L is wave length, T is wave period, k is wave number ($=2\pi/L$)

However, real sea is generally assumed as a combination of a large number of regular waves having different frequencies (wave periods), amplitudes (wave heights) and wave directions. Hence the real sea is generally described using wave spectrum, $S(f, \theta)$. In the standard way, the power transmitted per unit width for real sea, can be estimated as:

$$P = \rho g \int_0^{2\pi}\int_0^{\infty} C_g(f,h) S(f,\theta)\, df\, d\theta \tag{3}$$

Where,

$$C_g(f,h) = \frac{1}{2}\left[1+\frac{2kh}{\sinh(2kh)}\right]\sqrt{\frac{g}{k}\tanh(kh)} \tag{4}$$

Where, $k(f)$ is frequency dependent wave number, and h is local water depth.

Providing *MIKE 21 SW* with a suitable mesh and bathymetry is essential for obtaining reliable results. Bathymetry was prepared based on all available surveyed data under projects carried out at our institute, *Lanka Hydraulic Institute*. In addition *Global Multi-Resolution Topography*, *GMTR*, (freely available bathymetry data at *https://www.gmrt.org/*, viewed in June 2019) is used. Bathymetry is prepared extending from 315000 to 640000 mE, and 602000 to 1164000 mN. An unstructured triangular computational mesh model is developed, with total number of elements of 48190 with resolution that varies between approximately $3*10^7$ m^2 (8 km linear scale) near ocean boundary and $3*10^5$ m^2 (1 km linear scale) near coastline.

Boundary condition consists of wave, wind and land boundaries. Wave boundary of the model consists of directional wave data (wave height, peak wave period and wave direction) provided at seven locations around the country. Based on the collected long term measured and hindcast directional wave data (collected from United Kingdom Meteorology Office, *UKMO*), at each location, a representative directional wave data set (wave height, peak wave period and wave direction) with frequency of three hours for one year is calculated considering the mathematical average. Model is set up in such a way that, during the simulation, for each time step, based on the calculated yearly data at seven locations, relevant wave data for each element along the offshore boundary line is estimated using linear interpolation. The wave boundary is taken as varying in time and varying along the boundary line.

(a) (b)

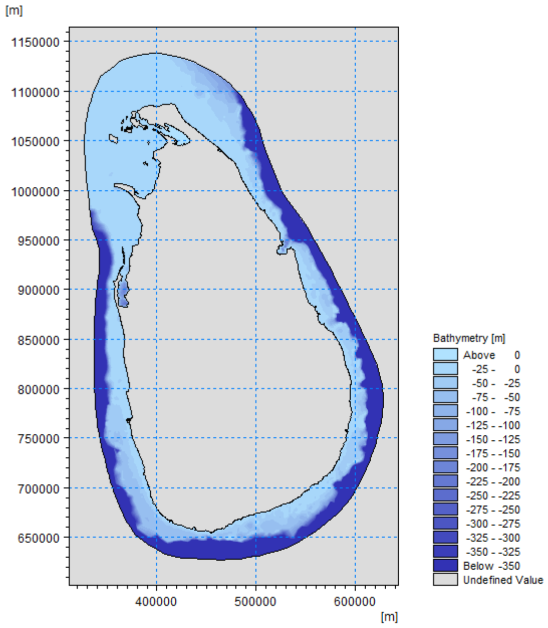

Figure 1. Developed bathymetry and computational mesh, (a) Bathymetry, (b) Mesh.

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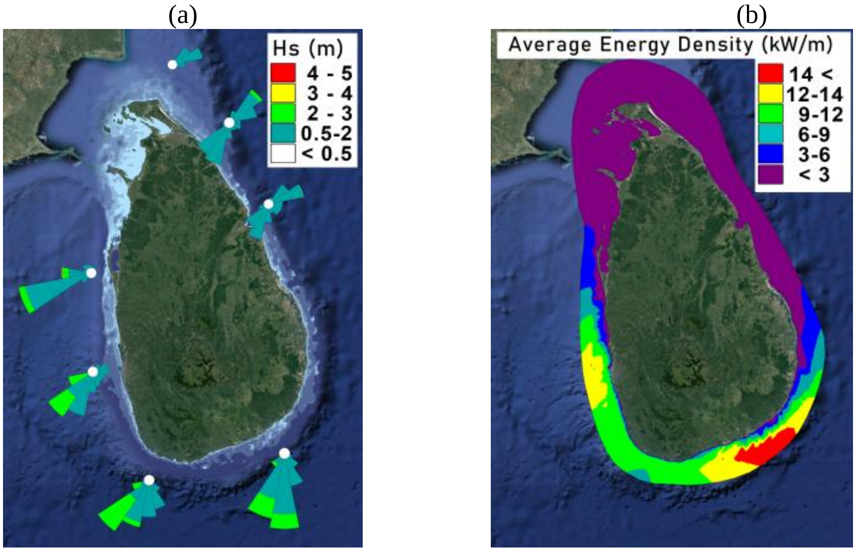

Figure 2. Wave boundary (wave roses are shown) used in the *MIKE 21 SW* module and Model simulated annual average Energy Density (kW/m),

Based on the calculated yearly average wave data at seven locations, wind speed is calculated based on Beaufort scale. Wind direction is assumed to be as same as wave direction. Based on representative yearly wind data at seven locations, the wind boundary is calculated over the space using ‘Thiessen Polygon’ (uses values available at nearest station) spatial interpolation method. Wind boundary (Wind speed and direction) is applied as varying in time and domain in the numerical simulation.

Island land boundary is assigned as land boundary, impermeable, zero normal velocity boundary.

The bottom friction is specified as Nikuradse roughness parameter, as 0.04 m. As stated in the *MIKE 21 SW User Manual*, Nikuradse value of 0.04 m is proved to be compatible with flow conditions for a range of swell and wind sea spectra.

White capping is included. Depth limited wave breaking is included and breaker parameter, gamma is set to 0.8. Selected time step for simulations is three hours, and *MIKE 21 SW* model simulations are carried out for one year.

MIKE 21 SW calculates, wave power

$$P = \rho g \int_0^{2\pi} \int_0^{\infty} C_g(f,\theta) E(f,\theta) df d\theta \qquad (5)$$

Where, ρ is the density of water, g is the acceleration of gravity, C_g is the group velocity, E is the energy density.

Model calibration/verification is carried out based on long term measured directional wave data at Colombo. The measured data is available from 1998 – 2015, at every three hour, and measured at 16 m depth. Based on the measured wave data, a representative directional wave data set, comprising significant wave height, peak wave period, and mean wave direction, for one year is calculated, considering mathematical average. The above time series, was compared with the model extracted wave data at the measured wave data location. See Figure 3 for the comparison. As Figure 3 indicates the model predicts the trend of significant wave height variation throughout the year comparatively to the measured data. However, there is a deviation in the magnitude of the significant wave height. This could be due to the process of estimating one year representative wave data set considering the mathematical average. The other reason could be due to the fact that in the calibration process, the time periods the data that is comparing is different. In the *MIKE 21 SW* Model boundary, the one year wave data set is calculated based on the available wave data in the time range of 1996 – 2018, and the measured wave data in Colombo is available for the time period of 1998 – 2015.

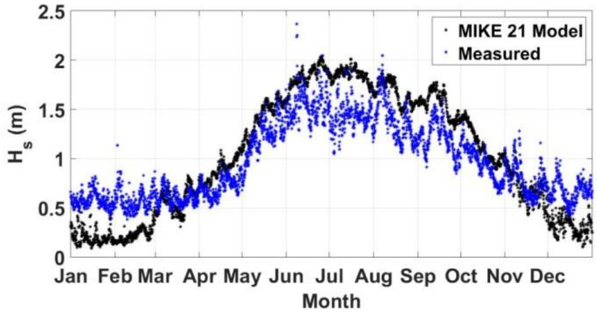

Figure 3. Calibration/Verification of the model, considering measured directional wave data at Colombo

RESULTS AND DISCUSSION

After model calibration and verification processes, numerical model results were looked into in detail. Numerical results consists of wave power, P (kW/m), significant wave height Hs (m), peak wave period Tp (sec), mean wave direction θ (degrees from North) and other important wave parameters, available for three hour interval for one year. The estimated wave power is looked into and analyzed in detail both spatially and temporally. Spatial variation of yearly average, maximum, and minimum wave power are calculated. Spatial variation of yearly average wave power is shown in Figure 2. Based on Figure 2, there exist yearly average high power in West coast (near Colombo area) and South – East coast (near Hambantota area). However it is observed that in west coast high power exist at deeper depths where as in South East coast similar high power exists at comparatively shallower depths. Hence energy in South East coast is looked into in detail. Average wave power is about 10 kW/m for South East coast. Due to practical difficulties in developing a wave energy extracting plant in deep depths, the energy density at 25 m depth is looked into in detail, See Figure 4 for a typical variation. Accordingly, for South East coast the maximum wave energy density is about 36 kW/m at 25 m depth.

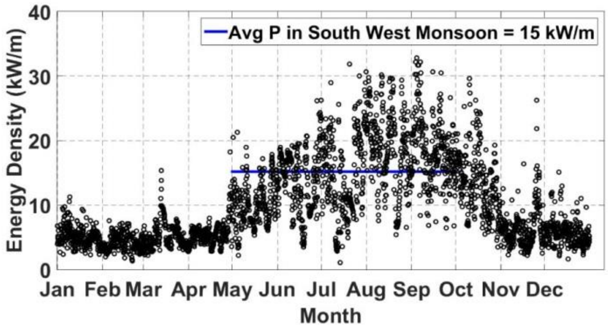

Figure 4. Typical temporal Energy Density (kW/m) variation within a year at 25 m depth in South East coast. Average over the South West monsoon is 15 kW/m,

Based on the annual mean wave power temporal variations, it is clear that high seasonal variation prevails in South East coast. Sri Lanka experiences four main seasons throughout a year. They are May to September - South West monsoon, October to November – Inter Monsoon 1, December to February – North East Monsoon, and March to April – Inter Monsoon 2. Out of the four main seasons, the South - West Monsoon and the North - East Monsoon are the critical monsoons in the country, where the dominant wind directions are South - West and North - East respectively. For South - East part of the country, the South - West Monsoon is more critical, since during the South - West monsoon, the wind blows across vast areas of the Indian Ocean. Due to the above wind characteristics, the South - East, coast is characterized by long period swell waves and local wind generated sea waves. Most violent wave climates are observed during South - West Monsoon, during which both swell and sea waves present with maximum strength. As shown in Figure 4, around 63 % of the wave energy presents during South West Monsoon. Average wave power during the South West monsoon is about 15 kW/m and is 50% increase from that of for a year.

Present assessment of wave energy potential in Sri Lanka confirms considerable wave energy potential exists in South East coast due to the presence of most energetic waves located in South East coast, near Hambantota, which is influenced by large ocean swells propagating from Southern Indian Ocean. Hence South East Coast is more suitable for future developments in energy harnessing.

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