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Assessment of Wave Energy Potential at Ullal, Karnataka, A Numerical Modeling Approach

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ABSTRACT- Mounting concern over the risk of global climate change has led to an increased interest in research and development of renewable energy technologies. Renewable energy has the potential to fulfill demand with a smaller environmental outline and may help to ease other demanding problems. So, wave energy assessment is crucial. The ocean provides a huge source of energy resources, yet to be explored fully. With the advancement of technology in the assessment and conversion of wave energy, the feasibility of harnessing wave energy has increased. In the southern Australia, Denmark, Portugal, Scotland and many parts of the world the wave energy conversion projects are commissioned. In India, in the wave energy rich coastal regions, wave energy conversion may be feasible, which will significantly improve the economics, livelihood and environment scenario there. To identify such suitable regions assessment of assessment of wave energy potential is essential. In the present work the wave energy potential at Ullal, Karnataka is assessed using Mathematical modeling. This study analyses the wave energy resources using 3rd generation Spectral Wave Model (Mike21 SW) for year 2013 by using wind and wave data obtained from Indian National Centre for Ocean Information (ESSO-INCOIS) at two buoys Agatti and Kozhikode. In this study, the spectral wave model is used for the assessment of wave climates in offshore and coastal areas- in hindcast and forecast mode. The outcomes were calibratedusing SW model,and from the calibrated model wave energy potential is assessed. The results showed that, there exist wave energy hot spots along the Ullal coast.It is concluded that at the 3 location (Ullal, Someshwar, Dwarkanagar) the wave power is significant and wave energy extraction is possible.

Keywords: Renewable Energy, Wave Energy estimation, Spectral Wave Model, ESSO-INCOIS, MIKE 21SW, Numerical modeling.

I. INTRODUCTION

The sun is the source of all energy, and ocean waves are no exception. As the sun heats the earth unevenly, the wind rises. The Ocean waves are created as the wind blows across vast stretches of ocean. Wind, solar, and ocean energy technologies have advanced in recent decades and are being implemented at an increasing rate around the world. While ocean wave energy conversion is yet unproven on a commercial scale, major breakthroughs in research, design, and testing are continuously being achieved.The world's increasing demand for energy, along with dwindling non-renewable resources such as fossil fuels and coal, has prompted mankind to place a greater emphasis on renewable energy sources. Although wave energy comes from solar energy, it has some advantages in comparison with other renewable energy sources such as solar and wind energies. The development of the wave power generation project needs a detailed analysis of the wave energy potential at the site over the year, in every season. Numerous attempts were made to analyze global wave energy potential.As a result, the current research focuses on the use of wave energy for long-term development.

Vikas Mendi [1] had attempted to identify the feasible locations for extraction of potential tidal energy along the Indian Coast and he has recognized 213 total locations for potential tidal energy extraction, one of the locations is Ullal Karnataka, hence, in this study authors have used this location for analysis. Justin Thomas [2] used MIKE 21 SW model for assessment of wave energy potential along Ratnagiri coast on the west coast of India, considering power assessment the feasibility of installation of wave energy converters may be fruitfully explored. Annual average wave energy potential of the study location, using measured waves and from the numerical model is estimated to be 7 kW/m and 6kW/m respectively. Burak Aydogan [3] used 3rd generation Spectral Wave Model for years 1996-2009 to calculate wave properties by using wind data from European Center for Medium-Range Weather Forecasts (ECMWF). The biggest average wave power is about 7 kW/m at the South Western part of the Black Sea[4]. The main task of the present research was to analyze wave climate and evaluate energy resources in the Lithuanian territorial waters of the Baltic Sea. Waves upcoming from western directions conquer with mean wave height of 0.9 m.These waves are the peak and have the greatest energy potential. The toughest winds and the highest waves are characteristic for the winter and autumn seasons. The calculated wave height ranges from 0.68 to 0.98m, while the estimated mean energy flux reaches from 0.69 to 1.90 kW m-1 during a year of different wave intensity in the Baltic Sea Lithuanian nearshore. In this research the transformation of the offshore wave field as it propagates into this area is computed by means of a nearshore wave model (SWAN) in order to select the ideal locations for a wave farm[5]. Two zones appear as those with the highest potential for wave energy utilization. It was found that, while the average wave power is 70 kW/m in most of the area, this number increases to 135 kW/m in two zones and falls below 40 kW/m in others. Mork et al. [6] assessed global wave energy resource from the dataset used in the default calibrated wave database contained in the standard World Waves package. Due to the Coriolis force, it has been found that the major power levels occur off the western coasts of the continents and seasonality is much higher in the northern hemisphere is confirmed by the ratio of the minimum monthly to annual average power levels. Authors implement a nested computational grid along the major Hawaiian Islands in the global WaveWatch3 (WW3) model and utilize the Weather Research and Forecast (WRF) model to provide high-resolution mesoscale wind forcing over the Hawaii region[7]. This study has placed the foundation for a long-term wave climate study to provide data for planning and operation of wave energy devices in Hawaii. In Thailand, ocean wave energy has been created on both coasts because Thailand has the Gulf of Thailand (GOT) to the east and the Andaman Sea located to the west[8]. In this study the numerical model used is the Simulated Waves Nearshore (SWAN) model. The highest average significant wave height is found in the southwest monsoon season. In this research the maximum average significant wave height and wave power are found at station P12 while stations P13 and P14 show the second highest average significant wave height and power. Station P12 specifies wave power at 2.97 kW/m, 5.12 kW/m, and 3.25 kW/m during the pre-monsoon, SW monsoon, and NE monsoon seasons, respectively. The adjacent mainland shore from this station is the nature recreation area in the Mueang Ranong District, Ranong Province. This area includes national parks and mangrove forests. Ayat, B. [9] assessed and characterized wave energy potential of the Eastern Mediterranean Sea Basin in this study. By using wind data from European Center for Medium-Range Weather Forecasts ECMWF and wave fields found from 3rd generation spectral wave model for years 1994-2009 wave power estimated. Along the coasts of the whole model area calculated wave power to be below 2 kW/m. The supreme energetic coast of the Southern Mediterranean Basin is Egyptian coast lying between Nile Delta and the Libya border over a potential of above 4 kW/m. Raju and Ravindran [10] studied wave energy potential along the Indian coast using the GEOSAT altimeter data.The study concluded that the average wave power on west coast of India is more than that of east coast of India and also it is less cyclones prone compared to east coast. G. Iglesias [11] evaluated the wave energy resource along the Death Coast, the rough stretch from Cape Finisterre to the Sisarga Isles by using newly accessible SIMAR-44 data set, covering a 44-year period, together with wave buoy data. A coastal wave propagation model (SWAN) is then applied, validated based on wave buoy measurements, and used to examine the nearshore energetic patterns.

The current study examines the possibilities for wave energy in Ullal, Karnataka. The wave energy potential along Ullal was calculated using a third-generation spectral wave model, MIKE21 SW, using data from 2014 waves. The deep sea approximation of the wave energy equation was used

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to calculate wave energy from measured waves.Wave parameters and wave energy were calculated using the calibrated numerical model during simulation. In this study, the regional and temporal fluctuation of the wave energy potential for the year 2015 is shown. The data is analyzed to determine the wave energy potential distribution for various sea states.

II. DESCRIPTION OF STUDY AREA

There are areas on India's west coast that are more prone to erosion. These are the locations where a lot of wave energy is available, but it is not being used properly. Moreover, Wave energy converters will be able to convert the plentiful wave energy at these places. Ullal (12.8147° N, 74.8585° E), Karnataka, India, is one of the site who fulfills the above cited criteria, as a result, authors have chosen this place for present research. Fig. (1) Shows location map of study area.

Fig. 1: Location map of research area (courtesy- Google Earth)

III. MATERIALS AND METHODS

3.1 Data used

In this work, wind data was collected from Earth System Science Organization – Indian National Centre for Ocean Information Services, Hyderabad (ESSO-INCOIS). The wind is measured using moored buoy located at CB02 (Latitude: 10.877 N Longitude: 72.208E) in the – 10 m depth. The wind data obtained were in non-equidistant calendar axis format, which were converted into equidistant calendar axis format by interpolating using MIKE Zero toolbox. The time series of wind speed and wind direction were used for forcing the fully spectral model to obtain the required wave climate.

The near shore wave data is measured using moored data well directional wave rider buoy deployed by National Institute of Ocean Technology (NIOT) at the location, Karwar (Latitude: 14.82355N Longitude: 74.08268E) in the –10m depth. The measured wave data reports wave parameterslike significant waveheight, wave mean period, peak wave direction etc., the measured wave data has been analyzed to get a detailed idea about the nearshore wave climate prevailing in the region and the missing data were filled by linearly interpolating the wave data.

The availability of measured wave and wind data near Indian coast is limited. The available data isused judiciously.

3.2 Methodology

Waves are generated by the wind blowing over a large area and for long duration. Hence, in presentwork, authors have generated waves using the wind forcing. The measured wind speed and wind direction was used for wind forcing in the numerical modeling.

The waves are generated throughout the domain, the model area. To interpret any results, it is necessary to calibrate the outcomes. It is required to calibrate the simulated results with the measured wave data. Simulated time series of wave heights is calibrated with the measured time series of wave heights.

As the simulated data shows good agreement to observed data, it indicates the acceptance of model. Moreover, the authors obtained calibrated wave model using which wave climate in the model domain and in particular near Ullal is simulated. From these results wave energy is calculated. [12]

In India, on the west coast there are locations which are prone to erosion. These are the areas with high wave activity. It will be possible to convert the abundant wave energy at these locations, using wave energy converters. One of the locations is Ullal, Karnataka. So, authors have selected this location for simulation study. The wave energy converters can act as a barrier reducing the wave attack reaching the shore, thereby reducing the erosion. Ullal in Karnataka is affected by severe erosion. Ullal beach is a prominent tourist attraction, in Karnataka. If the conditions near Ullal are conductive to install wave energy devices it will serve dual purpose of Wave energy extraction and shore protection.

3.3 Model Setup

In order to study wave energy potential along Ullal, a large domain including the wind data measurement location is selected. The selected stretch for calculation of wave energy potential extends from 12.799768°N to 12.805066°N latitude and in the southern side it starts from 74.849269° E to 74.868881° E longitude as shown in fig 1. The model area for SW is in hundreds of Kms of coastal area. It covers approximately a distance of 425 km.
An unstructured triangulated mesh is generated with fluctuating sizes of triangles (elements) with finer triangles on the nearshore area and coarser triangles on offshore area. The mesh file generated in the present study has 6871 nodes and 13399 elements as shown in fig. 2. Input is wind forcing.

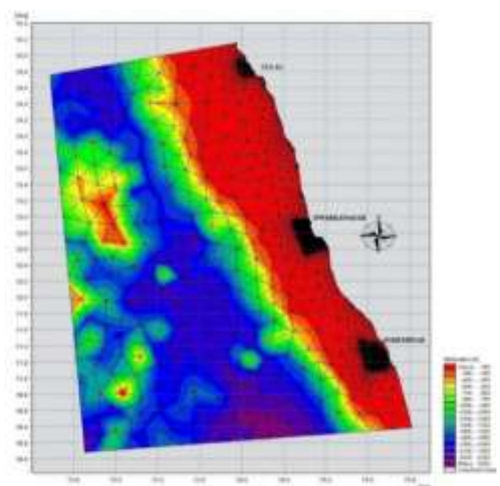

Fig. 2: Mesh Generated for entire bathymetry

A time period of a year 2013 was selected to calibrate the model results. Since monsoon waves contain almost 85% of the wave energy, calibrating the model in monsoon period will yield more accurate results compared to calibrating in any other time period. The model was calibrated with respect to bottom friction, white capping coefficient and boundary condition (Fig. 3).

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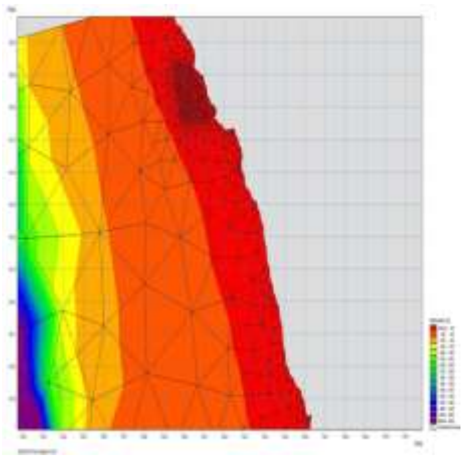

Fig. 3 Mesh Generated Bathymetry near Ullal

White capping is used as the calibration parameter. For white capping parameter 2, the comparison of simulated and the measured wave height time series is shown in figure 4. The correlation in the measured and simulated wave height time series is considered to be 0.9.

3.4 Performance of Numerical model

The present study describes the model set up using MIKE 21 modeling system developed by DHI. MIKE 21 SW is a third-generation spectral wind-wave model build on unstructured mesh. The model simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas. In this study fully spectral formulation was used as it is more reliable even though, it consumes more time for running the model. In the present model a formulation in terms of the wave direction, θ and the relative angular frequency σ has been chosen. The action density, N (σ, θ), is related to energy density E (σ, θ) by

$$N = \frac{E}{\sigma} \qquad \text{……. [1]}$$

This is a state of art wave model which simulates waves using wind forcing and transforms the wave climate over the model domain.

IV. RESULTS AND DISCUSSION

4.1 Numerical Model Results

The wave vector plot showing the spatial distribution of wave height and wave direction at 15/07/2013 at 0:50:30 for the region near Ullal is shown in figure 4. For wave power calculations a total of 3 locations were selected. The locations selected are having the geographical coordinates as mentioned in table 1. Average wave height and maximum wave height measured in the location of the study area are mentioned the table 2.

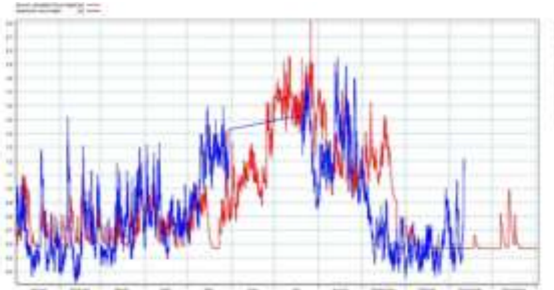

Fig.4: Comparison of measured and simulated significant wave height

However, average wave heights in monsoon (June-sept) and post monsoon (feb-may) are also stated in the table 2.

International Journal of Advances in Engineering and Management (IJAEM)
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Table 1: Geographical Co-ordinated for selected sites

Sr. no.	Location	Co-ordinates In decimal degree	
		Latitude	Longitude
1	Someshwar	12.805066°	74.868881°
2	Ullal	12.8076°	74.8423°
3	Dwarkanagar	12.799768°	74.849269°

Table. 2: Average Wave height, Maximum wave height and wave height during monsoon and postmonsoon

Location	Average wave Height	Maximum wave Height	Wave height occurred in Monsoon	Wave Height occurred Post monsoon
Ullal	1.0128	2.1978	1.5772	0.7344
Someshwar	1.0798	2.8226	1.8559	0.6966
Dwarkanagar	1.0252	2.4079	1.6512	0.7163

Table 3: Estimated annual average wave power

Locations near Ullal	Average Annual Wave Power (kW/m) at 5m depth
Ullal	4.755177
Someshwar	5.927013
Dwarkanagar	5.139744

The most prominent wind direction is west having wind speed less than 20.3 knots (10.4 m/s) for more than 90% of the time. Waves were observed to be up to 3m at study location with predominant wave directions to be West and WSW.

The simulated and the measured wave heights for the entire year were compared to validate the model it is seen that they match exceedingly well. It should be noted that for the time interval May 15 to July 1st measured wave data was not available.

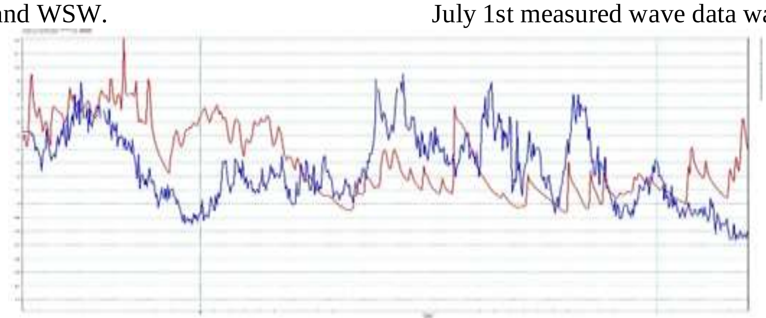

Fig 5: Comparison of measured and simulated significant wave height

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However, the trend of the simulation and the measurement is the same considering that it is in monsoon period and for that August's calibration is shown in fig 5.

Using the wind time series and wave as input model was run for the entire year. Fig. 6 shows a typical wave height plot with direction vectors in the region near Ullal at a certain time. To calculate the wave power potential of the Karnataka coast model results were used. The changes in the wave power potential at different locations are accurately depicted. Wave power values are extracted for the selected points from the simulated model. Wave power values of measured waves are calculated. The obtained wave power was analysed and the annual average values of wave power were estimated as given in table 3.

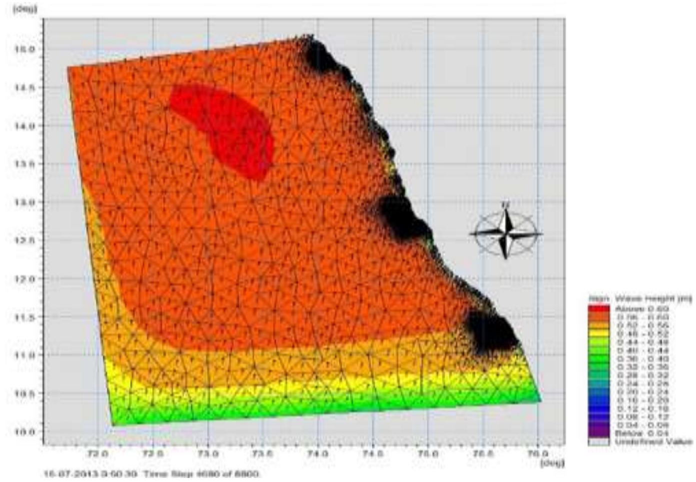

Fig. 6 Wave height and direction vectors in the region near Ullal

4.2 Additional Discussion

The model results were used to calculate the wave power potential of the Ullal coast, Karnataka. Spatial variation of the wave power is calculated for the predominant three season pre monsoon, southwest monsoon and post monsoon respectively. At the selected points results were extracted. From the simulation results, it can be observed that Someshwar has the highest wave energy potential among the selected points followed by Ullal and Dwarkanagar.

Most of the wave energy along the west coast of India occurs during the southwest monsoon only. Seasonal variation of wave energy of the study area is estimated by calculating the average wave power values for each month, which is plotted to understand the difference between monsoon months and non-monsoon months as shown in the figure 7. From the fig 7 it can be identified that the maximum wave energy occurs during the month of July followed by August and September respectively. From these results, it can be concluded that the seasonal variation of wave power is higher around the Ullal coast.

The most of the wave energy occurs during south west monsoon season i.e., June to September months. The total contribution of these months to the yearly average wave power values is estimated in table and the value is almost 84%. Annual total wave power occurred throughout the year, total wave power occurred in monsoon and percentage of wave power occurred during southwest monsoon is given in the table 4. Average annual wave power and average wave power occurred during monsoon is calculated and given in table 5. However, the wave power is having high seasonal variation along Ullal coast, which will affect the efficiency of wave power plant during non-monsoon season.

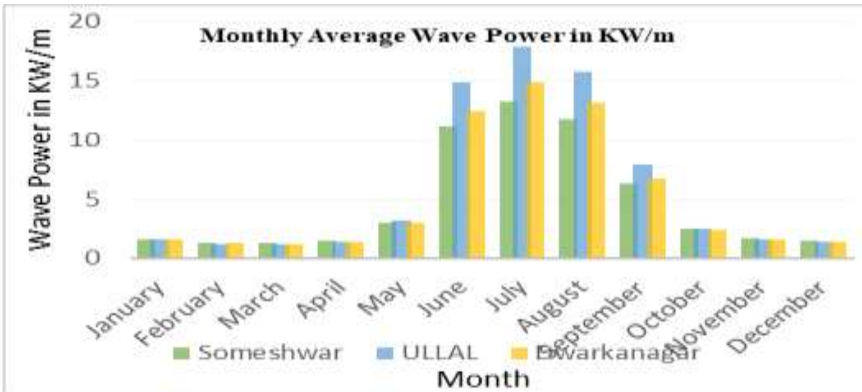

Fig. 7: Variation of monthly average wave power for the selected locations

Table. 4: Percentage of wave power occurred during southwest monsoon

Location	Total wave power occurred in kW/m	Wave power occurred in June to September in kW/m	Percentage of wave power occurred during June to September
Ullal	57.06212	42.55644	74.57
Someshwar	71.12416	56.58406	79.55
Dwarkanagar	61.67693	47.40231	76.86

Table. 5: Comparison of average wave power values during monsoon and complete year

Location	Average value of wave power occurred during monsoon 2013 in kW/m	Annual average wave power in kW/m
Ullal	10.63911	4.75517
Someshwar	14.14602	5.92701
Dwarkanagar	11.85058	5.13974

Attempt to extract wave energy near Ullal coast should also consider the high seasonal variation of wave energy prevalent in the area. Incorporating two energy devices like solar energy device along with the wave energy converters may produce stable energy source throughout the year. The results found were analysed for seasonal variation of wave power potential. From the simulation results, three locations which are high in wave energy potential were identified and wave energy potential was extracted from the simulated model in the time intervals of 60 minutes interval spanning the entire year 2013. The wave energy potential values indicated that the average annual wave energy occurring along Ullal coast is in the range of 4.76 to 5.93 kW/m and average wave energy during south west monsoon was around 10.64 to 14.15 kW/m.

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When the authors have consider the feasibility of the wave energy conversion at Ullal, it should be noted that, wave energy converter will act as a permeable breakwater. When wave energy converter is installed, it reduces the wave energy in the lee side of the WEC. Thus, the wave impact on the coast will be reduced, thus erosion could be controlled.

V. CONCLUSIONS

In present investigation, the wave transformation to obtain wave climate considering the wind forcing was carried out using third generation spectral model MIKE 21 SW. The model was calibrated successfully with correlation coefficient of 0.9.

From the simulated wave parameters, wave energy is calculated. Average wave energy during southwest monsoon was around 16.83 to 17.85 kW/m and annual average wave energy was found to be varying from 4.5 to 6 kW/m. Most of the wave energy occurred during southwest monsoon (June-September and seasonal variation is high along the coast. Around 84% of the total annual wave energy, occurred during southwest monsoon. Average wave power during southwest monsoon is almost 2 to 2.5 times of the annual average wave power hence it will help in reducing the erosion of coast.

Considering the wave power assessment, wave power extraction is feasible at all these locations. The conditions near Ullal are conductive to install wave energy converters. The dual purpose of wave energy extraction and coastal protection will be served.

It is concluded that at the 3 location (Ullal, Someshwar, Dwarkanagar) the wave power is significant and wave energy extraction is possible. The outcomes of present work will be useful to researchers and policy makers to plan and design sustainable energy system, and this approach will strengthen the nation’s economy.

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