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ASSESSMENT OF WAVE ENERGY POTENTIAL ALONG THE WEST COAST OF INDIA USING REGIONAL CALIBRATED SPECTRAL WAVE MODEL

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Abstract :

The current situation of energy demand around the world is highly unbalanced. Due to the diminution of conventional energy sources such as coal, fossil fuels, nuclear energy sources, it is essential to employ renewable and pollution free green energy resources as replacement to the conventional ones. The wave energy (ocean energy) is a promising renewable and green energy resource. Energy is concentrated in the waves and waves are more predictable which makes the wave energy an attractive resource. Ocean Wave Energy can be the future of energy generation in India as it is the most economic green process with less carbon emission. The power consumption and power generation of India is lagging behind the share of renewable energy because of growing power requirement. The wave energy technology is not much popular if current status of energy production in India is taken in to the account. If we consider Indian scenario, there is huge scope for the energy from the ocean as India has a large coastline. In this paper, calculation of wave energy along the West coast of India at Kudal town located in Sindhudurg district in Maharashtra state using numerical modelling has been performed, which is helpful to identify the spatial variation of wave energy. The major reason behind choosing the study area is that west coast is having more wave energy compared to east coast of India. Also, waves on the west coast are comparatively constant in nature and is least prone to cyclones and other natural calamities than east coast. East coast provides numerous challenges for the successful operation and maintenance of wave power plants. Since the safety of wave generating equipment is a major concern, west coast was opted for the estimation of detailed wave energy resource assessment.

***Index Terms* – Wave Energy, coastal engineering, mathematical modelling, renewable energy.**

I. INTRODUCTION

Energy resource, its production and consumption is incredibly crucial for the global economy. All economic, manufacturing, public utility, services and household activities are pivoted on use of energy. The power sector plays a key role in the economic growth and human development of any country. It indisputably improves the quality of life of human beings. One of the most significant indices for measuring the development level of any nation is its per capita consumption of electricity. Energy production has undergone several major evolutions throughout the history as it transforms from wood to coal, coal to petroleum, petroleum to nuclear.

India is one in all the fastest growing economy within the world. The total installed power capacity of India is around 329 GW. The power sector of India comprises of mostly the thermal resources i.e., natural gas and coal which contribute around 67% (220 GW) to the total installed capacity followed by hydro power 14% (44 GW), renewable energy resources 17% (57 GW) and nuclear sources 2% (6 GW). In the earlier days India relied heavily upon the low-cost thermal generation sources. Over the last five years, renewable energy has been the fastest-growing segment, but still contributes only around 17% to the total power capacity in India. There has also been a sharp rise in the demand for Power due to economic growth, demographic changes and lifestyle improvements. However, if we compare the current scenario of demand and supply, the required energy demand has yet to meet the energy production. To achieve the energy demand in the future, not only growth of power sector is required but optimum utilization of present resources in the energy sector is more important.

This objective of increasing the share of renewable energy to the total energy can only be achieved by developing different renewable energies in accordance with the resources or each region. Wind and solar energy conversion technologies have matured over recent decades, while ocean wave energy conversion, its design and testing are yet to be explored on commercial scale.

II. WAVE ENERGY

Waves approach the coast continuously and as they travel; they carry energy to the shore. The surface of the sea is continuously interacting with the wind, thereby waves are generated. The winds blowing over large area and long durations result in waves. So, in the waves, energy is concentrated. Sea waves are a very promising energy carrier among renewable power sources, enormous amount of energy resources in the form of waves is available in almost all geographical regions. The global theoretical energy from waves corresponds to 8x106 TW h/year, which is about 100 times the total hydroelectricity generation of the whole planet. (Leão Rodrigues, 2008). The characteristics and advantages of Wave energy extraction are summarised in the report, 'Study on Tidal & Waves Energy in India: Survey on the Potential & Proposition of a Roadmap: Final Report' by IREDA, published in 2014. It states "During the process of wave power extraction, wave energy does not create any waste or emit CO2: it leads to no noise pollution and is also environment friendly. Unlike most renewable energy resources, wave energy can produce power throughout the year. Wave energy is highly concentrated near the ocean's surface in oceans worldwide. Out of the abundant energy stored in waves, only a small part of it is used for commercial electricity generation today. This largely untapped resource could play an important role not only in compensating for depleting energy sources but provide an answer to the ever-increasing demand for electricity. It is clean and more predictable than other renewable energy resources such as wind and solar."

These observations denote that utilisation of wave energy could reduce of pollutant gases in the atmosphere, as desired by the Kyoto Protocol and lead stress upon by Paris convention achieved over the last decade. The efforts are incessant and commercial use of wave energy does not seem farfetched. Wave energy is more predictable daily or seasonally than the others. Since it is available 24 hours on 365 days, producing much steadier power from waves is possible. It is also environment friendly kind of energy since it does not require land area, access roads and smaller energy gathering devices than wind energy devices. As with other renewable energy sources, a thorough resource assessment is necessary for the significant spatial variations of wave climate.

2.1 Wave Energy Scenario in India

The power consumption and power generation of India lagging behind share of renewable energy because of growing power requirement. The wave energy concept is not much popular in our country if we see the current status of energy production. We know that in India, there is great scope for the energy from the ocean as India has a long coastline of about 7,516 km. The extraction of wave energy can be a feasible solution to the massive power requirements. Primary estimate of wave energy potential along the coastline is approximately 5-15 MW/m. So, the theoretical estimated wave energy potential is around 40-60 GW (T.V.S. Narasimha Rao and V. Sundar, 1982). The wave energy research in India started in 1983 at the Indian Institute of Technology, Madras on funding provided by Department of Ocean Development, Government of India. This led to the commissioning of a pilot plant of 150 kW capacity installed on a caisson in Vizhanjam, near Thiruvananthapuramin 1991. National Institute of Ocean Technology was also an Institute engaged in the experiments and investigations for this pilot plant.

Many researchers have done studies for the wave energy assessment in past years. Prerna Goswami and Dr. S.P. Deshmukh (2017) described the potential of wave energy along western coast of India. Authors have done an assessment of wave energy from data obtained through wave rider buoys and moored buoys containing significant wave height and mean wave period installed along various locations of western coast of India. Rupesh Kumar et al. (2018) estimated the wave energy potential near Ratnagiri. The inshore wave climate was obtained considering offshore wind and wave data from INCOIS as the input. Simulations done for the calibrated model used for the preparation of average wave energy potential maps of the Ratnagiri coast. R. P. Patel et al. (2019) hindcasted 17 years of wind-wave data using wind wave spectral model WAVEWATCH III for Indian coastal region. On the basis of total average and seasonal average values, wind power density and wave power flux were plotted on 50 m water depth contour line along the Indian coast. S.A. Sannasiraj and V. Sundar (2016) assessed the possible potential sites along the Indian coastline for establishing systems to convert energy in the ocean waves to electricity. V. Sanil Kumar (2013) examined the Variations in nearshore wave power at four shallow water locations along the east and west coast of India based on the measured wave data for one-year period. The study shows the comparison of annual wave power along the west coast and east coast of India. V. S. Raju and M. Ravindran (1997) assessed the wave energy potential along the Indian coast covering data for the period from 1985 to 1987. The wave power calculations were performed on the basis of GEOSAT altimeter data. According to this study, the average wave power available along the western coast of India was found to be greater than the eastern coast of India. Deshpande and Joshi (2015) analysed the wave energy potential by the interpolating statistical wave data available at Ratnagiri, Maharashtra taking 5 years measured by wave-rider buoy data.

In ocean engineering, wind induced waves is one of the most important subjects and the random state of sea waves makes it one of the most complex phenomena. Characteristics of the wave are mainly determined through field observations, physical model numerical simulations. Nowadays, numerical models are one of the most powerful tools for studying the characteristics of wave. These models provide valuable insight into the important physical processes. Over the past years, numerical models have reached a very good level of accuracy and detailing capacity that most dominant processes in the coastal environment can be quantified. The major advantage of numerical modelling approach is its economic efficiency and less time consumption, in comparison with the physical modelling approach. The models are also flexible enough to do experiments in high temporal and spatial scale in marine environment management.

The first step to harness wave energy is to identify the locations where the wave energy is in abundance. In this paper, the assessment of the wave energy potential during south west monsoon by using numerical modelling is done which is helpful in identifying the monthly variation of wave energy Potential near Kudal at South Maharashtra region along the west coast of India.

III. STUDY AREA

IREDA (2014) has identified number of hotspots for the wave energy extraction along the 9 coastal states of India. In the report, they have recognized 8 locations along the coast of Maharashtra State with Kudal location showing promising results. Hence for the wave energy assessment using MIKE 21 Spectral Wave model, Kudal location is selected.

Kudal is a town in Sindhudurg district located in Maharashtra along the Western Coast of India. Geographical Coordinates of Kudal is 16.008°N 73.687°E as shown in Fig. 1. It is situated on Karli River in southwest Maharashtra which empties into the Arabian Sea. After Sawantwadi, Malvan and Kankavli; Kudal is the fourth largest town in Sindhudurg district in Maharashtra.

Bathymetry is the measurement of the depth of water in ocean. In simple term, it is the underwater equivalent to topography. For the simulation of Spectral Wave model, bathymetry is one of the important input parameters. Using MIKE Zero – Mesh Generator tool, the bathymetry encompassing the area of 350 km X 380 km is prepared and shown in the Fig. 2. For preparation of bathymetry, two data viz., land file data and water file data are required. The land file is made from google earth software and water file data obtained from MIKE – CMAP software. Using this data, bathymetry consisting of 4338 nodes and 8278 elements is prepared using mesh generator tool.

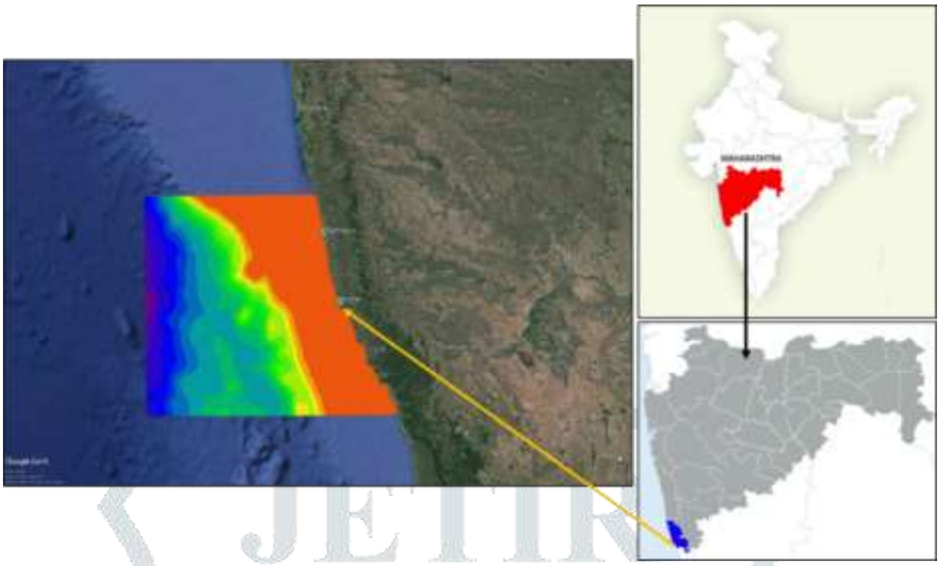

Fig. 1: Bathymetry showing Kudal location superimposed on Google Earth

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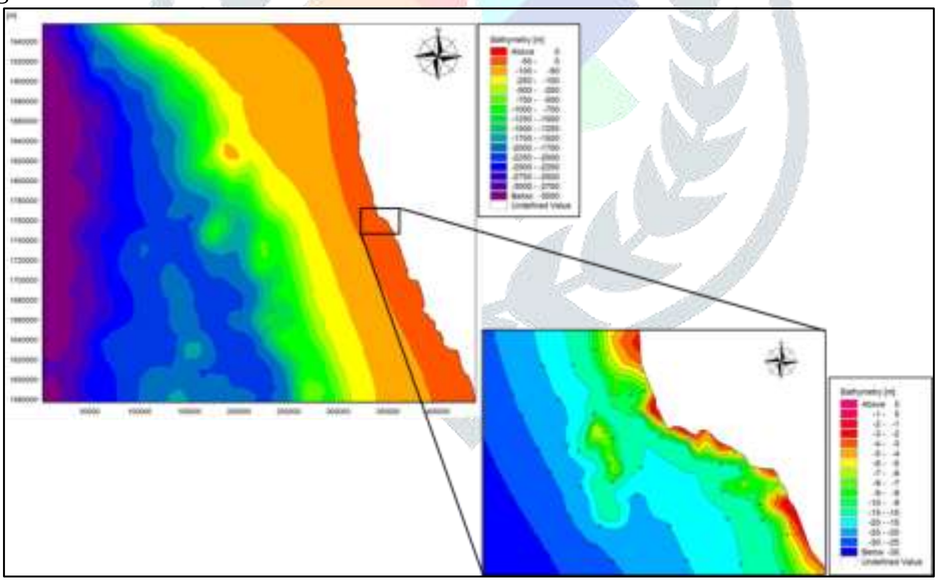

Fig. 2: Bathymetry near Kudal location

3.1 Data Collection and Analysis

For the assessment of wave energy, nearshore wave data is essential. Instrumentally observed wave data at the site over a period of several years, if available, is best suited for this purpose. However, if such data is not available, the nearshore wave climate can be obtained by transforming the offshore wave data to the nearshore location by using mathematical modelling technique. For this purpose, the wave data observed by ships plying in the offshore region of between Latitude 15-20 deg. N and Longitude 70-75 deg. E, reported by India Meteorological Department (IMD) during past 10 years were considered. This wave data was analysed for each month (January to December) and percentage occurrence of wave heights and wave direction are obtained. Wave data analysis for the month of July is shown in Table 1.

Table 1: Data analysis for the month of July

Wave Dir.	Wave Height									Total
	0.-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	
22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
67.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

112.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
135	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
157.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
180	0.00	0.00	0.00	0.00	0.65	0.00	0.65	0.00	0.00	1.30
202.5	0.00	0.00	0.00	0.00	1.95	0.65	0.00	0.00	0.00	2.60
225	0.00	0.00	0.65	1.95	1.30	0.65	2.60	0.00	1.30	8.44
247.5	0.00	2.60	0.00	2.60	11.04	5.19	8.44	3.90	6.49	40.26
270	0.00	0.00	2.60	3.25	5.19	5.19	12.99	5.19	5.84	40.26
292.5	0.00	0.00	0.65	1.95	0.65	0.65	0.00	0.00	0.00	3.90
315	0.00	0.00	0.00	0.00	1.95	0.65	0.65	0.00	0.00	3.25
337.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
360	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.0	2.6	3.9	9.7	22.7	13.0	25.3	9.1	13.6	100.0

3.2 Model Setup and Calibration

Setting up of the model is transforming real world events and data into a format, which can be understood by the numerical model. Model set up consists of selection of model domain, data processing, generation of flexible mesh and bathymetry, consideration of wave parameters and initial/boundary conditions. MIKE 21 SW Model is used for simulation for all the seasons considering each month i.e., January to December with wave heights and all the predominant wave directions obtained from analysing the IMD data.

For the first run, model is setup by considering all the boundaries as per the required wave directions. Initial run results showed a lot of discrepancies which showed the necessity for calibration. For this, calibration parameters have been identified from the previous literatures and MIKE 21 scientific documents. Calibration is done to ensure the accuracy of the model. Once the model is calibrated with measured results, it gives adequate security to do the simulation and to extract data from the simulated models. Calibration is done by comparing the simulated model results with the measured wave data. Since in the estimation of wave energy; wave height, which is in the order of two, is more important than any other parameter; so, in this study, importance is given to calibration of significant wave height only. For the calibration purpose, data obtained from wave rider buoy of INCOIS at nearshore location 314745.36 E, 1878164.21 N. At this same location, wave parameters obtained from MIKE 21 SW simulation are extracted and the comparison between observed and simulated significant wave height are shown in Table 2 which represents the model is well calibrated. It is observed that monsoon waves contribute more to the wave energy, so, calibrating the model in monsoon period will yield more accurate results compared to calibrating in other time period. Coast of Maharashtra receives southwest monsoon during the months of June to September; so, wave parameters are extracted for the monsoon season and compared with the observed wave rider buoy data shown in Table 2.

Table 2: Simulated and observed data near Ratnagiri

Month	**Direction**	**Simulated Hs**		**Observed Hs**
		Sig Wave Ht	**Average**	
June	157.5	0.483498	2.133061	2.01184
	180	1.60882		
	202.5	2.5995		
	225	2.93213		
	247.5	3.06954		
	270	3.09253		
	292.5	3.05342		
	315	2.74292		
	337.5	1.13526		
	360	0.612991		
July	180	1.40624	2.490699	2.62504
	202.5	2.04316		
	225	2.93213		
	247.5	3.06954		
	270	3.09253		
	292.5	2.46535		
	315	2.42594		
August	180	1.21375	2.042823	1.7303
	202.5	1.71802		
	225	2.89369		
	247.5	3.02944		
	270	3.06136		
	292.5	2.79756		
	315	2.42594		
	337.5	0.915944		
	360	0.329705		
September	157.5	0.19887	1.784558	1.156
	180	0.62344		
	202.5	1.38517		
	225	2.67225		
	247.5	2.81088		

	270	3.06136		
	292.5	2.79756		
	315	2.11722		
	337.5	1.56584		
	360	0.612991		

3.3 Simulation of Wave Climate along the West Coast for Annual Period

To examine the existing wave energy potential near Kudal location along the Maharashtra coast, MIKE 21 SW model is used and the wave climate along west coast of India is simulated. The model was calibrated against the measured wave data near Ratnagiri.

Wave heights vary depending on the season. Significant wave heights of higher orders occur in the monsoon season (June to September) as compared to the other period of the year. Typical wave vector plot for the month of July obtained from simulation is shown in the Fig. 3.

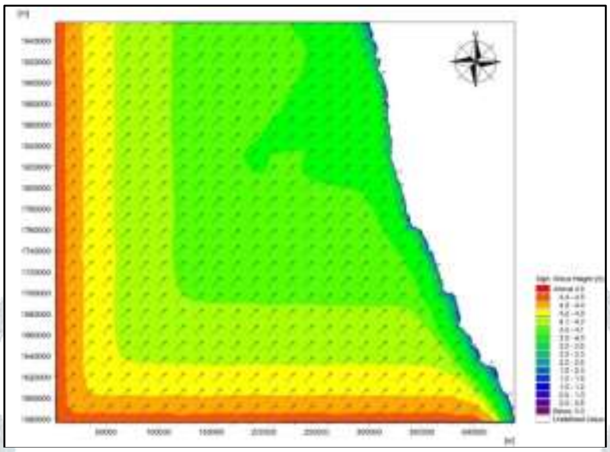

Fig. 3: Simulation of significant wave height in the model domain in July

3.4 Simulation of Wave Power

The wave power is then calculated for annual period near the Kudal location along the coast of Maharashtra using the MIKE 21 SW model. The results of the wave power potential near Kudal location are of interest, so the plots of distribution of wave energy potential in the nearshore region for the month of July are shown below in Fig. 4, which shows the monthly variation of wave power in the model domain area.

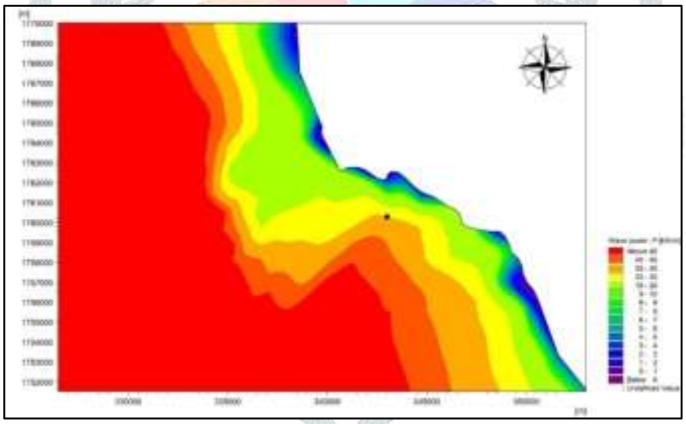

Fig. 4: Simulation of wave power in model domain near Kudal in July

3.5 Variation of Wave Energy Potential

In this paper, only the plots for wave energy variation for the month of July has been shown. Similarly simulations were carried out for entire annual period and shown in the Table 3. From the results, it is observed that the wave energy is highly concentrated in the South West monsoon, so much so that more than 75% of the available annual wave energy occurs in the South West monsoon. Hence the further studies can be focused on the monsoon months. By simulations for the month of January to December, it is clear that in the month of June, July, August and September, the wave heights and thus the wave energy is significantly higher than the other period of year. Comparison of wave energy potential at the Kudal location for the monthly period is important. As such we know the variation of average monthly wave power potential at the measured location. Wave parameters at location 342999.49 E, 1760268.7 N are extracted for the compilation of all the results i.e., significant wave heights and average wave power near the Kudal location.

Table 3: Simulated data near Kudal

Predominant Directions	Sig Wave Height	Hs Avg	Wave Power	P Avg
January				
270	1.01204	0.6889214	3.344	1.77196398
292.5	0.842192		2.20869	
315	0.941949		2.56454	
337.5	0.484686		0.659787	
360	0.16374		0.0828029	
February				

135	0.198038	0.629677667	0.140691	1.6332851
157.5	0.434457		0.662175	
180	1.0126		3.65364	
202.5	0.812114		2.45188	
270	0.684709		1.563	
292.5	1.10918		3.75602	
315	0.767575		1.72957	
337.5	0.484686		0.659787	
360	0.16374		0.0828029	
March				
135	0.0857245	0.877485227	0.0278997	3.242717427
157.5	0.301999		0.331433	
180	1.0126		3.65364	
202.5	1.20369		5.33285	
225	1.24295		5.67036	
247.5	1.06999		4.00282	
270	1.33238		5.69767	
292.5	1.35993		5.56329	
315	1.20143		4.11356	
337.5	0.656114		1.17213	
360	0.18553		0.104239	
April				
180	1.0126	0.9118292	3.65364	3.4584393
202.5	1.58947		9.22335	
225	1.64117		9.80296	
247.5	1.74005		10.3726	
270	1.6316		8.44168	
292.5	1.35993		5.56329	
315	0.941949		2.56454	
337.5	0.484686		0.659787	
360	0.140981		0.0628995	
May				
180	1.33708	1.240622	6.31053	6.429866944
202.5	1.58947		9.22335	
225	2.0283		14.8793	
247.5	1.74005		10.3726	
270	1.6316		8.44168	
292.5	1.35993		5.56329	
315	0.941949		2.56454	
337.5	0.396238		0.450613	
360	0.140981		0.0628995	
June				
135	0.267026	2.564004	0.249131	23.1542
157.5	1.13778		4.31274	
180	2.57298		22.7555	
202.5	2.87175		29.592	
225	2.88141		29.8682	
247.5	2.4107		19.8206	
270	2.08318		13.7347	
292.5	1.76338		9.25367	
315	1.27777		4.6466	
337.5	0.484686		0.659787	
360	0.16374		0.0828029	
July				
180	2.27345	2.45843	17.8609	21.14116667
202.5	2.33006		19.5826	
225	2.88141		29.8682	
247.5	2.4107		19.8206	
270	2.08318		13.7347	
292.5	1.5609		7.27199	
315	1.20143		4.11356	
August				
180	1.97145	2.438976667	13.5135	20.78823333
202.5	1.96754		14.0386	
225	2.85268		29.2726	
247.5	2.39126		19.4964	

270	2.07299		13.5957	
292.5	1.69489		8.54994	
315	1.20143		4.11356	
337.5	0.396238		0.450613	
360	0.0923575		0.028882	
September				
157.5	0.434457	1.964886	0.662175	13.851656
180	1.0126		3.65364	
202.5	1.58947		9.22335	
225	2.69407		26.1022	
247.5	2.27348		17.6157	
270	2.07299		13.5957	
292.5	1.69489		8.54994	
315	1.089		3.39474	
337.5	0.656114		1.17213	
360	0.16374		0.0828029	
October				
180	0.683668	0.9584292	1.68645	3.9643033
225	2.0283		14.8793	
247.5	1.74005		10.3726	
270	1.8646		10.971	
292.5	1.35993		5.56329	
315	0.941949		2.56454	
337.5	0.484686		0.659787	
360	0.140981		0.0628995	
November				
180	1.0126	0.954172	3.65364	3.484711843
202.5	1.58947		9.22335	
225	1.24295		5.67036	
247.5	1.06999		4.00282	
270	1.33238		5.69767	
292.5	1.35993		5.56329	
315	1.20143		4.11356	
337.5	0.656114		1.17213	
360	0.16374		0.0828029	
December				
180	1.0126	0.773831429	3.65364	2.271844071
202.5	1.20369		5.33285	
225	0.838307		2.60574	
247.5	1.06999		4.00282	
270	1.01204		3.344	
292.5	0.842192		2.20869	
315	0.767575		1.72957	
337.5	0.571442		0.901289	
360	0.140981		0.0628995	

Variation of Wave energy at the Kudal location, is estimated by calculating the average wave power values for each month. The monthly variation of wave power comparison is plotted as Bar Diagram in Fig. 5. It is observed that the monthly average wave energy values in the south west monsoon contributes to the majority of wave energy potential.

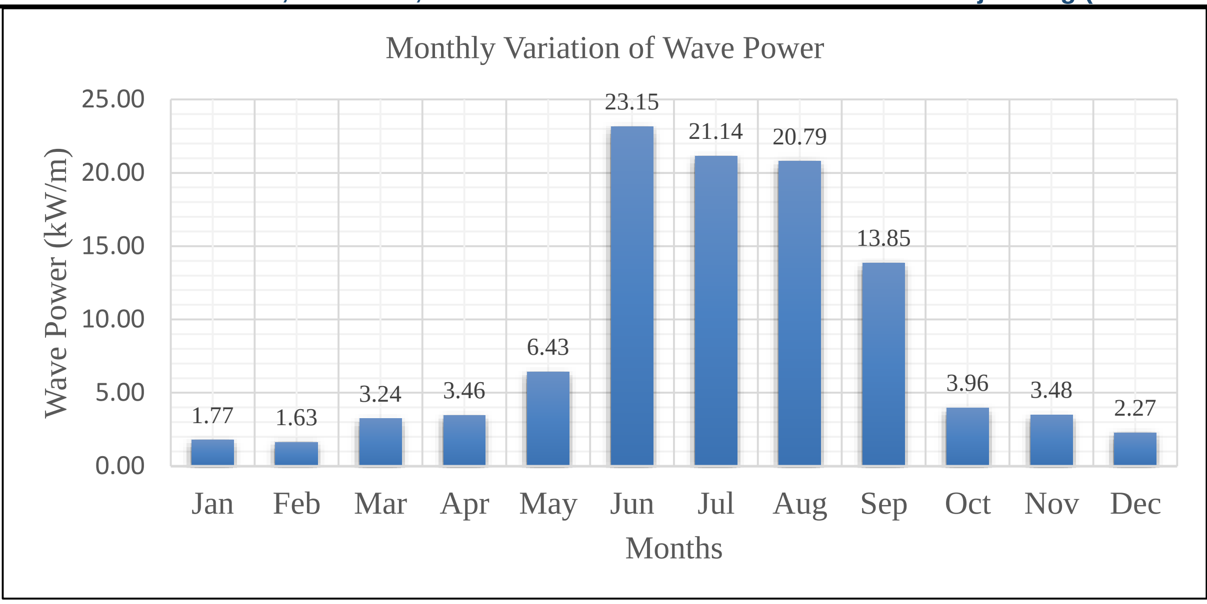

Fig. 5: Monthly variation of wave power

Table 4: Summary of results

Total Wave Power Occurred	105.19 Kw/m
Total Wave Power Occurred in SW Monsoon (Jun-Sep)	78.94 kW/m
% Occurrence of Wave Power in SW Monsoon	75.04 %
Average Annual Wave Power Occurred	8.77 kW/m
Average Wave Power Occurred in SW Monsoon (Jun-Sep)	19.73 kW/m

IV. Conclusion

1. The existing sources of energy (fossil fuel) will exhaust one day, hence there is a need of renewable energy resource, which will preserve the environment as well. If we consider the renewable energy sources like solar energy, wind energy and hydro power; wave power is the one which is least studied among all and also the most promising renewable energy resource having great future potential. Wave energy is predictable, concentrated, requires minimal land use. It can be used for multiple purposes such as energy production as well as shore protection.
2. Many successful commercial operations of converting wave energy in to electricity have commenced around the world. The world's first commercial wave power station on the Hebridean island of Islay was installed in 2000 which fed electricity into the UK's national grid till 2012. In 2012 wave farms, arrays of multiple wave energy converters were installed on the Western Australia coast which generate 5 MW. Thus, extraction of wave energy is a dream come true.
3. In India, pilot wave energy conversion unit was installed at Vizingham near Thiruvananthapuram, Kerala. It was decommissioned after extracting vital, useful information about the wave energy conversion caisson efficiency.
4. In this study, wave energy potential along the Maharashtra coast near Kudal is estimated with the help of a third-generation spectral wave model MIKE 21 SW with IMD ship plying data as input. Measured wave data near Ratnagiri at -15 m depth was available. The measured wave data and the simulated wave data were compared which matched very well. In the south west monsoon, wave disturbance is very high and hence the wave energy is abundant and concentrated. The calibrated wave transformation model was used to get the wave power in kW/m over the entire region. The results obtained were analysed for monthly variation of wave power potential. The major conclusions drawn from the study are listed below.
   - Average annual wave energy value calculated using measured wave data was found to be 8.77 kW/m.
   - Average wave energy during south west monsoon was around 19.73 kW/m. Average wave energy during southwest monsoon is almost twice the average annual wave energy.
   - The total wave energy potential at the Kudal in the South West monsoon is 78.94 kW/m and total wave energy potential in a year was found to be 105.19 kW/m. It is observed that Around 75% of the total annual wave energy, occurred during the southwest monsoon.
5. Considering the results obtained from wave energy assessment, we can conclude that wave energy extraction near Kudal town in Sindhudurg District, Maharashtra is feasible. Findings of this study can be useful for identifying the location of wave energy converter installation which can serve the dual purpose of wave energy extraction and shoreline protection.

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