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Research Article

# The Parametric Estimation of Tidal Potential Power Density using Modeling Strategies at Hajambro Creek of Indus Delta, Pakistan

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**Abstract:** There are many accessible resources for electricity generation using renewable energy, like, solar, wind, tidal and wave etc. The output of all these resources depend on weather conditions, force of gravity or rotation of the Earth, but tidal energy has a major advantage over many other forms of renewable generation as it is predictable over a long period of time. Pakistan has about 1000 km long coastline with complex network of creeks in the Indus delta region which include 17 major creeks and further divide into a number of estuaries with considerable tidal ranges and tidal current. This research study is carried out at one of these major creeks namely Hajambro (Hajambro river) and extends from Hajambro 24$^o$ 08'N 67$^o$ 22'E (sea mouth) to Keti Bander 24$^o$ 09'N 67$^o$ 27'E (mouth of river Indus). Study area is targeted within creek region where there is a large shortfall of electricity observed and this situation has threaten the community socioeconomically. In this research study, available tidal energy resources of Hajambro creek are assessed, tidal power density models and bathymetry model are developed in Arc-GIS (geographical information system) environment, for the first time. A comprehensive tidal turbine technology review is conducted and based on up-to-date tidal turbine technology review and results achieved from assessment of tidal energy resources, deployment of a turbine at Hajambro creek is proposed. With effective area of 9.46 km$^2$ mean spring estimated power (seasonally) is observed as 14 MW in winter, 12.9 MW in Pre-Monsoon, 13.6 MW in Monsoon and 13.1 MW in Post-Monsoon

**Keywords:** Tidal Energy Resources, Hajambro, Keti-bander, GIS, Power Density.

## 1. INTRODUCTION

Currently, the worldwide energy requirement is predominantly being met by exhaustible resources of fossil fuels (oil, gas, coal, etc.). A decreasing resource and increasing need have resulted in variation of fuels prices. Variation in these prices in conjunction with the adverse environmental effects of fossil fuel combustion results in emission of harmful gasses. Similar problem arises in Pakistan and is encountering a serious issue of energy shortage and environmental pollution. This energy shortfall will rise in upcoming days and a significant supply-requirement gap in energy scheme is projected. On average, the supply-demand gap was experienced around 5000 MW, while it touched the peak of over 7000 MW, resulting in load shedding of 12-16 hours across the country, as reported by [1-2]. The elucidation of these difficulties is the usage of Renewable Energy (RE) resources in the energy mix of the country.

The RE resource provides several eco-friendly and economical profits in comparison to traditional energy sources [3-4]. There are many accessible resources for electricity generation using renewable energy, like, solar, wind, tidal and wave etc. Output of all these resources depend on weather conditions, force of gravity or rotation of the Earth. For example, solar energy extraction linked with the intensity of sunlight and wind energy is dependent on wind speed [5]. Tidal energy has a major advantage of being predictable over long periods of time, whereas electricity generation is not predictable to some extent using other forms of renewable energies [6-7].

Several studies show that there is enormous

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potential for production of electric power from wind energy in Pakistan in the form of development of wind energy plants at Gharo and Jhimpir [8-10]. Some studies also shows the exploitation of solar energy for the generation of electric power in Pakistan in the form of the development of Quaid-e-Azam solar park [11, 12]. Published literature also indicates that sugarcane bagasse can possibly be used to produce 2000 MW of electricity in Pakistan, by utilizing biomass energy [13]. A comprehensive literature review was carried out at different platforms to find pertinent studies concerning the evaluation of tidal energy resources globally, it was published that in current years tidal energy is broadly exploited to generate electric power in various countries, including France, United Kingdom, China, Canada, India, India etc. [14].

The coastal belt in Pakistan is around 1000 km long which includes a complex system of creeks in the Indus Delta. The area of Indus delta is about 1900 $Km^2$ [15]. The exploration of tidal energy within the Indus Delta region (that is so far ignored) is considered to be a great asset for future energy resources in Sindh province of Pakistan and needed to be estimated and exploited.

In this research study, an effort is made for the first time to assess available tidal energy resources of Hajambro-Keti Bander region using GIS tools and techniques. Study area is targeted within the creek region where there is a large shortfall of electricity observed and this situation has threatened the community socio-economically. Therefore an attempted is made to overcome this problem by harnessing tidal energy for generation of electric power.

### 1.1 Study Area

This research study was carried out at Hajambro creek of Indus Delta, which lies in the Thatta District, Sindh province, Pakistan, situated southeast of Karachi. Figure 1 shows the map of Area Of Interest (AOI) and its geographical location. AOI extends from Hajambro 24$^{o}$ 08'N 67$^{o}$ 22'E (sea mouth) to Keti Bander 24$^{o}$ 09'N 67$^{o}$ 27'E (mouth of river Indus) with channel length of about 10 Km and channel width narrower towards land.

The community around AOI consists of approximately 2,000 households covering an area of 610 $Km^2$, it includes 42 Dehs (settlements) out of which 28 have been flooded due to the sea intrusion, over the last 40 years. Besides sea intrusion, the major problems facing by community are drinking water, health, unemployment and electricity. Only 20 % households have access to electricity out of 91 % of the inhabitants who live in thatched huts. Due to these reasons, the population is continuously shifted towards the urban areas of Sindh province of Pakistan. (Source: [16]).

The main source of livelihood of people living around AOI is fishing (around 90% of people are fishermen) and the remaining are associated with small-scale business and agriculture. According to the villagers' perception of poverty, those people who are dependent only the natural resources are poor. Those people who have other resources along with the natural resources and can earn enough are middleclass. Those people who have more than one business or other kinds of resources are rich. According to this analysis of poverty, 85 % of the people living around AOI are considered poor, 12 % belong to middle class and only 8% are rich (source: [17]).

## 2. MATERIALS AND METHODS

### 2.1 Data Acquisition

Data is classified into two types: Tidal data and satellite images. Tidal observations of one-hour resolution (tidal heights recoreded per hour) were acquired using tidal gauge and tidal pole for the period of January 2013 to December 2013 from Hydrography department Pakistan Navy.

Beside the tidal related data, satellite images have also been considered necessary for the development of models for AOI. In this connection, satellite imagery from Environmental Systems Research Institute (ESRI) was also utilized (last accessed: September 2018).

### 2.2 Data Processing

Hourly tidal heights were analyzed to extract daily high/low levels of water. Based on these levels of water, different important parameters were

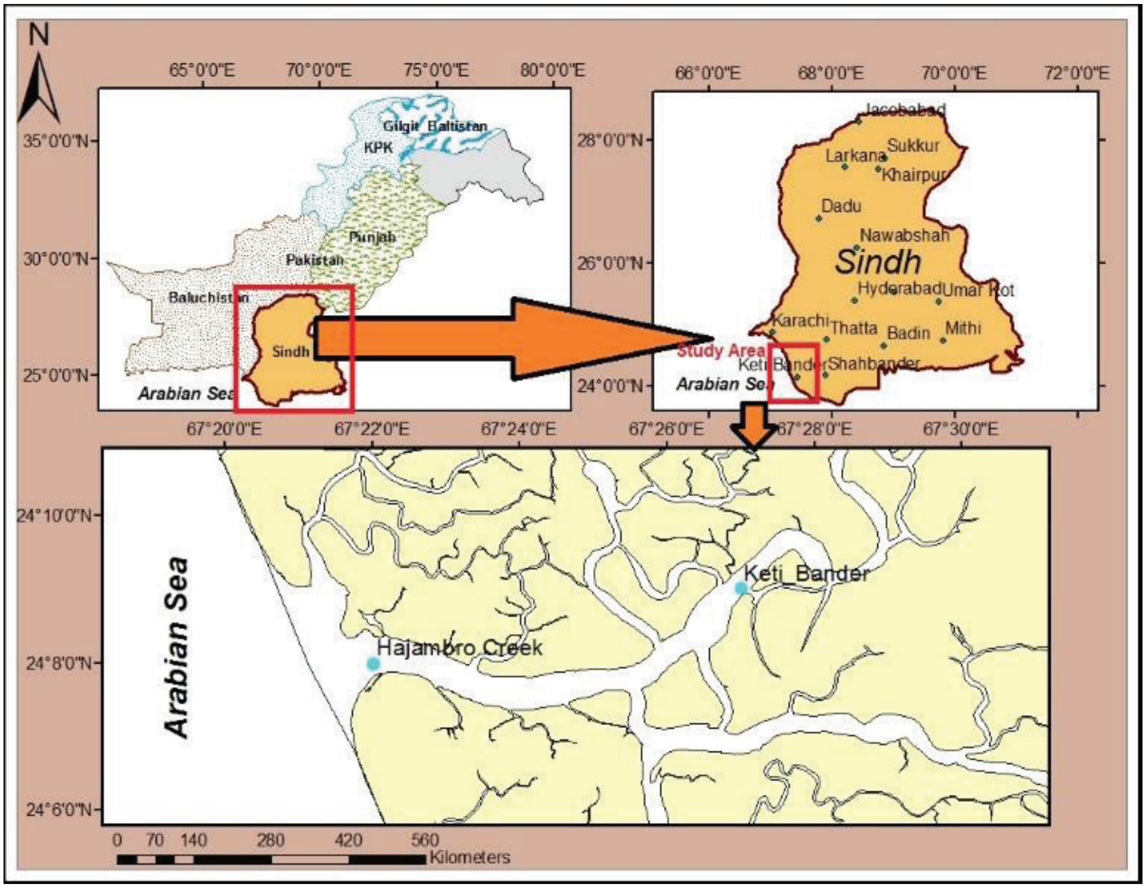


**Fig. 1.** Map of study area

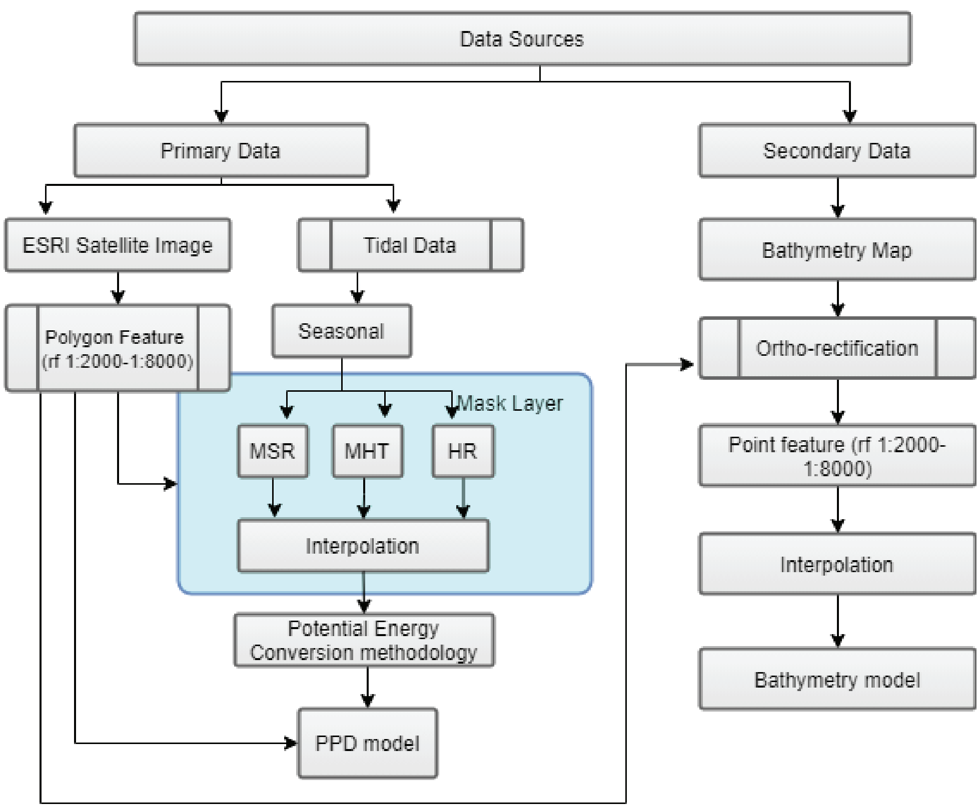


**Fig. 2.** Block diagram of methodology adopted

calculated, which includes Mean High Tide (MHT), Highest Range (HR) and Mean Spring Range (MSR). MHT represented mean of high levels of water observed during the all four seasons. HR represented highest range (difference of high level water and low level water) observed during all four seasons. MSR is calculated by taking difference between highest levels of water during the new and full moon (occurred bimonthly) to produce larger than average tides, called spring tides.

MSRs were used for the evaluation of Potential Mean Spring Power Density (PMSPD). All these parameters were seasonally averaged except HR (HR was seasonally highest value), for the period of January 2013 to December 2013.

Satellite data: Satellite imagery used in this research work was acquired from ESRI and was used for digitizing the region of AOI using Geographical Coordinate System (GCS) WGS-1984 with the resolution factor (rf) of 1:2000 to 1:8000. The resultant data have been used to develop the power density models and modelling of different important tidal parameters in ArcGIS environment. Figure 2 shows the block diagram of the methodology adopted.

## 3. RESULTS AND DISCUSSIONS

Power available from the potential energy of the water movements associated with the rise and fall of the tides in a day, is given by [18]

$$PPE = \rho A g h^2/t \quad (1)$$

where ρ is the water density, A is the area of the barrage basin, g is the acceleration due to the Earth's gravity, h is the mean tidal range and t is the tidal period ( for semi-diurnal tides value of t is 12 hours and 25 minutes). The average tidal potential power density is then given by [18]

$$PPD = \rho g h^2/t \quad (2)$$

### 3.1 Assessment of Tidal Energy Resources at AOI

Mean spring range layer for four different seasons (seasons are defined according to Pakistan

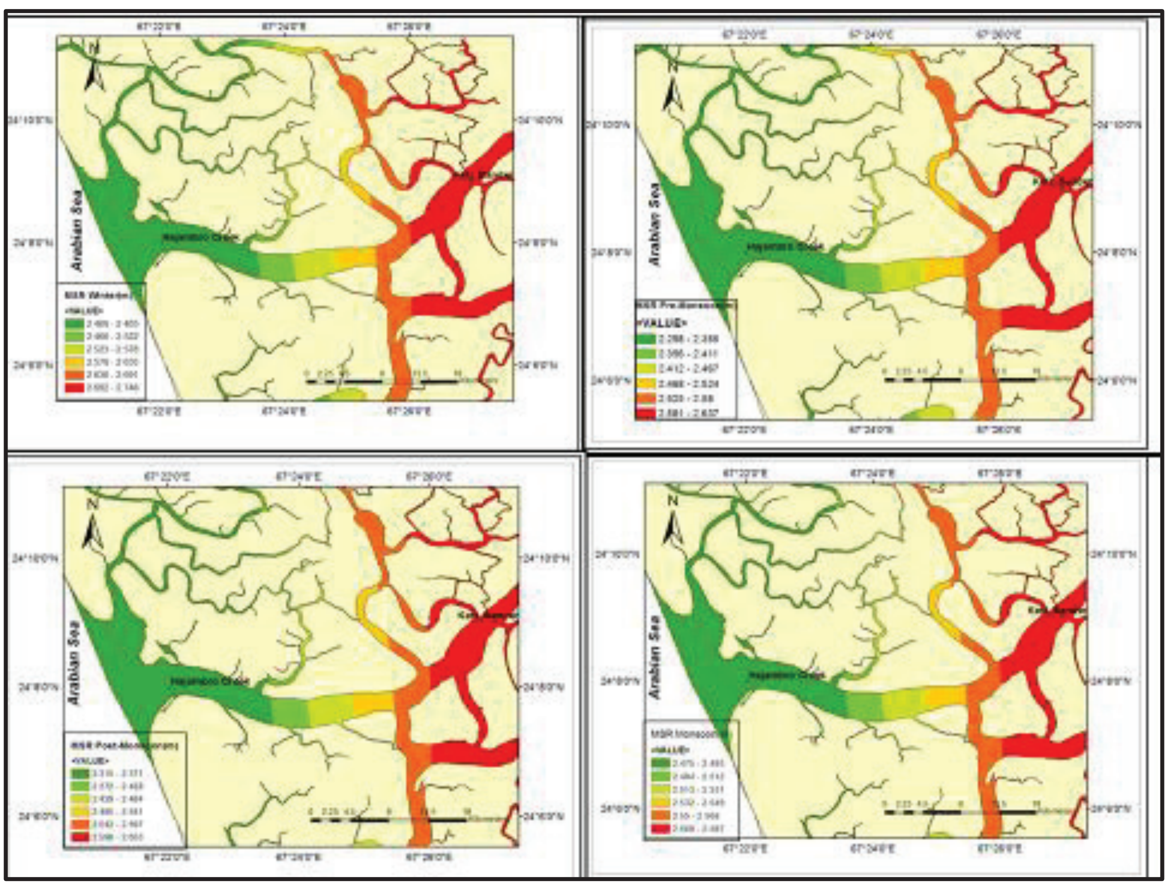


**Fig. 3.** MSR model for four seasons (in meter)

Meteorological Department [19]; namely: winter, pre-monsoon, monsoon and post-monsoon) was generated by implementing spatial interpolation technique using spline formula, proposed by [20] and [21]:

$$\boldsymbol{S(x,y) = T(x,y) + \sum_{j=1}^{N} \lambda_j R(r_j)} \quad (3)$$

Where N is the number of data point, λj are coefficients found by the solution of a system of linear equations, $r_j$ is the distance from the point (x, y) to the jth point. For regularized spline interpolation $T(x, y) = a_1 + a_2 x + a_3 y$ and

$$R(r) = \frac{1}{2\pi}\left\{\frac{r^2}{4}\left[\ln\left(\frac{r}{2\tau}\right) + c - 1\right] + \tau^2\left[k_o\left(\frac{r}{\tau}\right) + c + \ln\left(\frac{r}{2\pi}\right)\right]\right\}$$

Where, $a_i$ are coefficients found by the solution of a system of linear equations, r is the distance between the point and the sample, $\tau^2$ is the weight parameter, $k_o$ is the modified Bessel function and c is a constant equal to 0.577215. The modified Bessel function of the second kind diverges for all orders at x = 0.

The initial value of *r* was set equal to 1.39-m, τ was set 0.1 and n equals to 12, for the regularized spline interpolation technique. Figure 3 shows the layer of seasonally averaged spring ranges over the AOI. Same interpolation techniques were used for seasonally averaged high tide and seasonally highest range. Figures 4 and 5 represent the GIS layers for MHT and HR respectively.

It may be noted from layers developed in Arc-GIS domain represented in Figures 3, 4, and 5, that all the values of MSR, MHT and HR are increasing from Hajambro towards Keti Bander, as the landward portion of a creek is narrower than that of its mouth. Moreover, these creeks are further divided into number of estuaries, resulting in significant values that be seen from Figures. 3, 4 and 5.

It was necessary to match digitized land layer of AOI with bathymetric chart to prevent any possible distortion. The image was ortho-rectified in Arc-GIS environment and presents contour map of water depth in AOI. Thus, point bathymetry data layer was generated and combined with digitized land layer to produce bathymetry model for AOI as represented in Figure 7. The unit for coordinates are degree decimal and water depth is in meters. From this Figure, the water depth of AOI is variable and varies between 0.2038m to 10.5m

### 3.2 Results of Resource Estimation

The potential power density (PPD) model for AOI is generated for four seasons by utilizing the GIS layer of land digitization, MSR and by using Eq. (2). Final PPD model masked over the water surface for AOI is presented in Figure 6. PPD model for different seasons represents potential mean spring power density (PMSPD) in W/m$^2$.

After generating GIS layer of MSR, PPD model has been developed for AOI. PPD model reveals that there is significant potential for producing power from potential energy associated with tides due to the following reasons:

- The complete range of MSR and PMSPD for AOI is estimated in Table 1 and it is clear from Figure 3 and 6 that these values are increasing when moving towards the land region (as the land region is narrower than that of its mouth).
- A comparison between MSR (MSR shown in Table 1 for AOI) and the mean ranges of the Kislaya Guba Power Plant, Russia [22] and BaiShakou Power Station, China [23] supports the installation of tidal power plant for producing power from potential energy associated with tides. However, tidal reef technology (working range 2-3m) [24, 25] is more feasible option than traditional barrage scheme for harnessing tidal energy at AOI.

As discussed earlier in section 1.1, community around AOI is suffering from huge shortage of electricity which further effects their basic necessities of life. Effective area for tidal barrage is estimated as 9.46 km$^2$ and power estimated for different seasons is around 14 MW in winter, 12.9 MW in Pre-Monsoon, 13.6 MW in Monsoon and 13.1 MW in Post-Monsoon (shown in table 2). This estimated electric power can resolve the major issue of AOI, i.e. electricity and can also improve livelihood and socioeconomic conditions. There are 2000 households around AOI, if around 1000 W electric power will be provided to each household, total power required will be 2 MW, whereas the remaining power could be used for hospitals, small

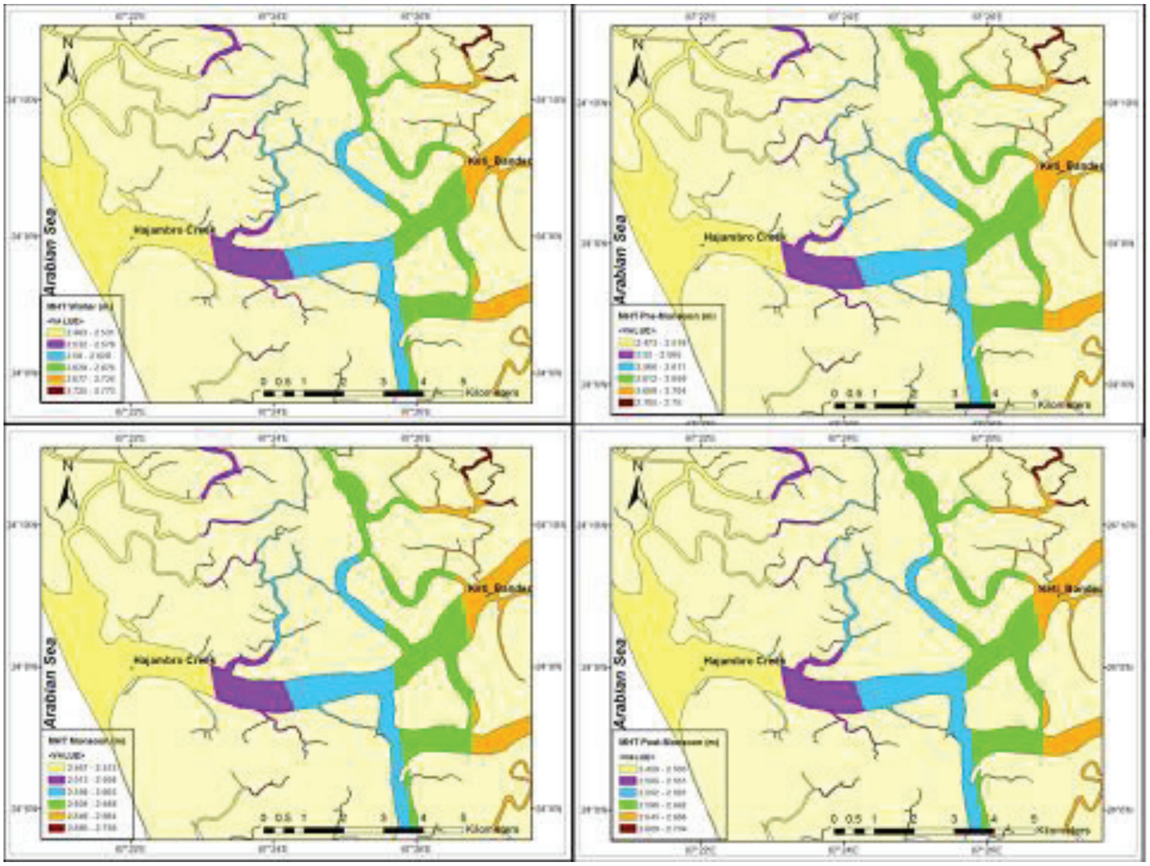


**Fig. 4.** MHT model for four seasons (in meter)

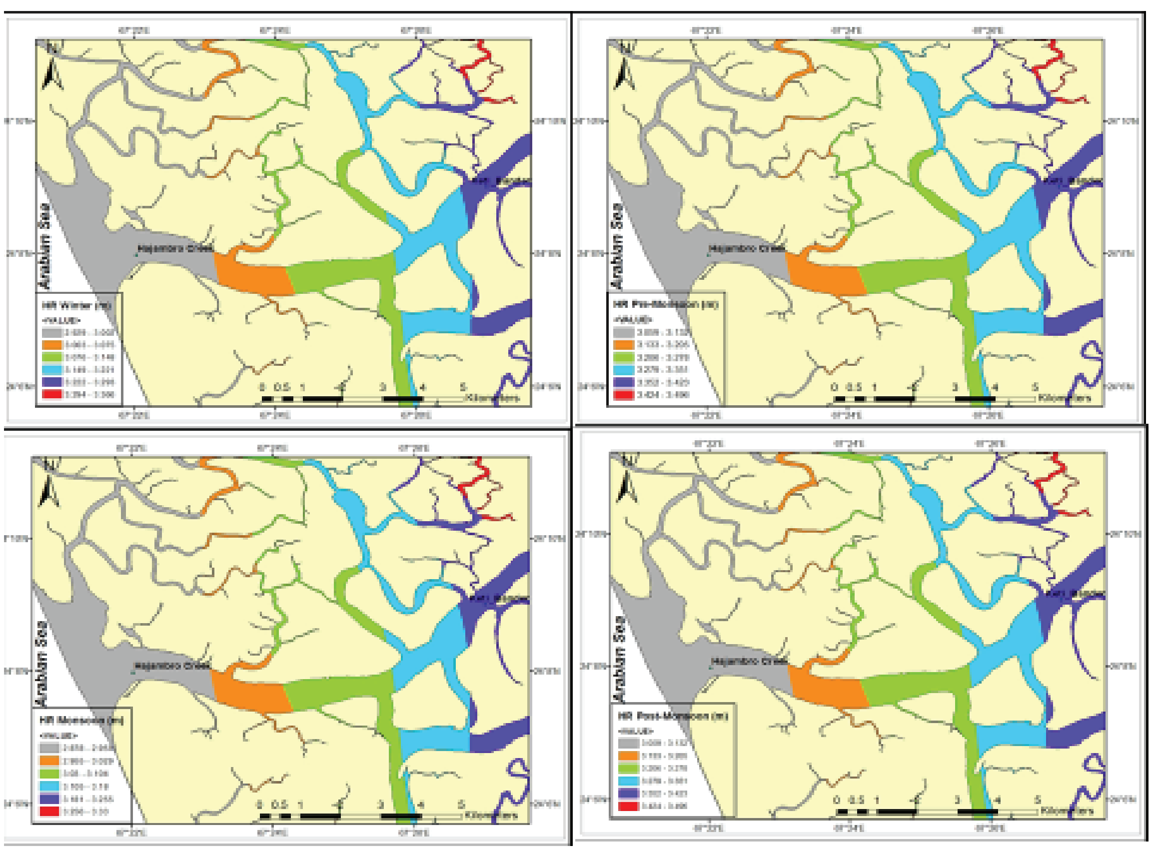


**Fig. 5.** HR layer for four seasons (in meter)

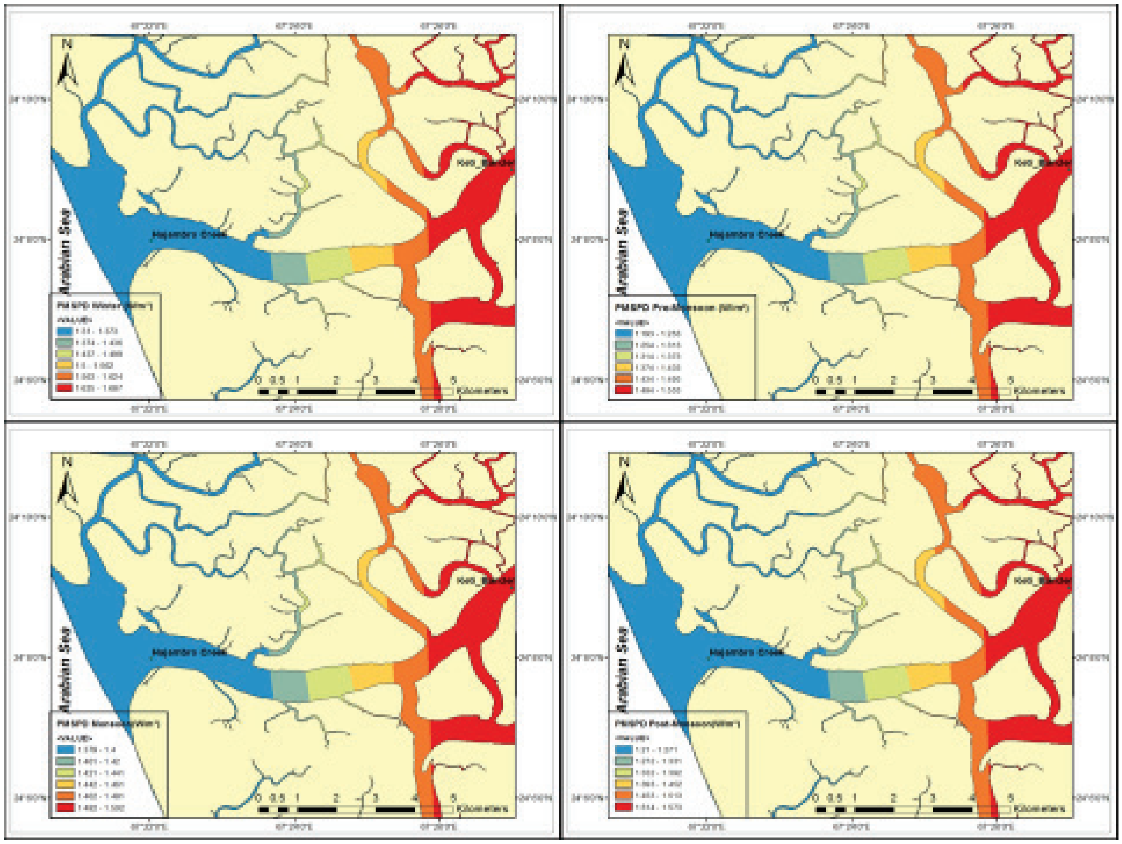


**Fig. 6.** PPD model for four seasons representing potential mean spring power density (*in W/m²*)

**Table 1.** Seasonally estimated MSR and PMSPD

| S.No. | Seasons | MSR (m) | PMSPD (W/m²) |
|---|---|---|---|
| **1** | Winter | 2.409-2.748 | 1.31-1.687 |
| **2** | Pre-Monsoon | 2.298-2.637 | 1.193-1.553 |
| **3** | Monsoon | 2.475-2.587 | 1.379-1.502 |
| **4** | Post-Monsoon | 2.315-2.653 | 1.21-1.573 |

**Table 2.** Seasonally estimated power (in MW)

| S.No. | Seasons | Estimated Power (MW) |
|---|---|---|
| **1** | Winter | 14 |
| **2** | Pre-Monsoon | 12.9 |
| **3** | Monsoon | 13.6 |
| **4** | Post-Monsoon | 13.1 |

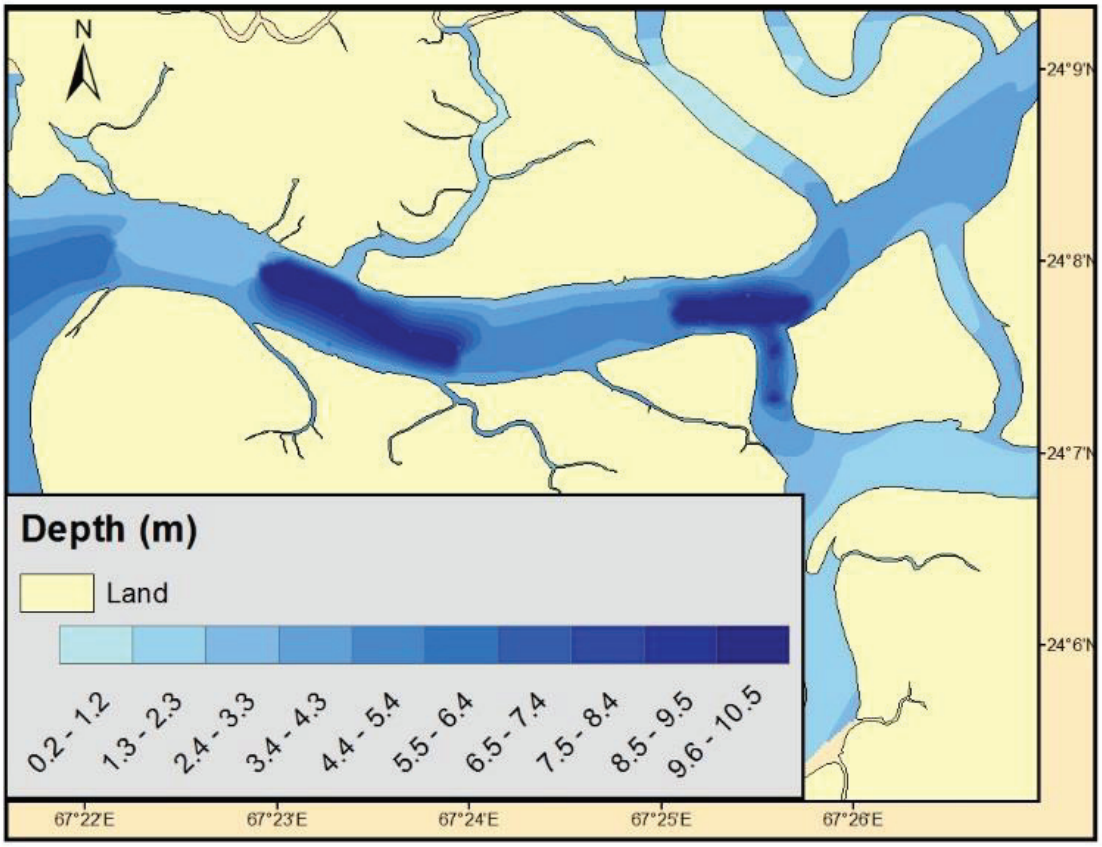


**Fig. 7.** Bathymetry map of AOI

industries, schools and desalination for providing fresh water.

## 4. CONCLUSIONS

The main purpose of the study is to assess tidal energy resources to overcome the problem of non-availability of electricity at AOI without causing pollution. Therefore, GIS based power density models are developed and discussed in this research work for AOI:

First, PPD model (Figure 6) shows significant values of power densities for all four seasons. By comparing the model results with installed power plants' parameters as discussed in section 3.2, it is concluded that there is significant potential for the power generation from potential energy associated with tides. With effective area of 9.46 km$^2$ mean spring estimated power (seasonally) is observed as shown in table 2. 2 MW power is estimated for households and remaining power could be utilized for other purposes.

## 5. ACKNOWLEDGMENT

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## 6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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