ESTIMATION OF VARIOUS TIDAL PARAMETERS AND POSSIBILITY FOR HARNESSING TIDAL ENERGY ALONG THE SOUTHEAST COASTAL AREA OF KARACHI, PAKISTAN

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ABSTRACT: *The understanding of the sea tides and related phenomena are essential for estimating general oceanography parameters for any coast and also to calculate and plan harnessing of tidal energy for electricity generation. Energy consumption and demand in Pakistan, especially in the coastal city of Karachi has increased drastically over past decade and this situation particularly becomes worst in summer. This leads to a situation of increase in unit price of electricity for domestic and commercial users. To overcome this problem, a study is conducted with the help of Pakistan Navy hydrography department, in which first time real time tide related data along the Karachi coast (24^o 48'N 66^o 58'E) located on the southeastern coastline of Pakistan has been acquired for the period of three months during summer of 2014. In this research study an attempt has been made to estimate various essential tidal energy harnessing factors using tide related data.*

Key words: Tidal energy, Tidal parameters, type of tides, spring tide, neap tide, Pakistan.

1. INTRODUCTION

Tides play a very important role in the formation of global climate as well as the ecosystems for ocean habitants. At the same time, tides are substantial potential source of clean renewable energy for future human generations [1]. The analysis of tidal behavior has been developed by many notable mathematicians and applied physicists, including Newton, Laplace, Airy, George Darwin and Kelvin [2].

Tidal power, sometimes called tidal energy, is the energy dissipated by tidal movements which directly derives from the interaction of the gravitational forces between the seas and the primary astronomical bodies of our system [3]. This is generated from the combination of gravity among the earth, the sun, and the moon. Newton's law of gravitation can be mathematically expressed as:

$$F_G = G\frac{m_1\, m_2}{r^2}$$

where,

F_G = Tide generating force

G = universal gravitational constant

m_1, m_2 = respective masses of the object (earth, sun, or moon)

r = distance between the center of the objects

Tide is affected by the near shore hydrography, bottom friction, Coriolis acceleration, and resonant effect [4]. Tidal range is influenced by the relative distance and position of the earth, the sun, and the moon. There are many factors that influenced the tide and each of these variables can be represented mathematically by one or more sine wave function and are called harmonic constituents of the tides. Another factor that influenced the tide is called surge, caused by meteorological effects including wind, atmosphere pressure changes etc.

1.1. Pakistan and Tidal Renewable Energy

Energy crisis seems to be a global problem and every country is now looking for alternative and sustainable way to generate electricity to meet its ever growing energy demand and to minimize the environmental hazards. Similar dramatic situation arises in case of Pakistan, where energy crises threating the country socio-economically, as the power demand has drastically increased during the past decades than its supply. The energy demand versus supply scenario in the country becomes worse during summer season [5]. This lead to a situation of increase in electricity cost for domestic and commercial/industrial users. Solution to this energy crisis in Pakistan is to explore and exploit sustainable/renewable sources for electricity generation. Potential for generating electricity from almost all type of renewable energy sources exist in Pakistan comprising of solar, wind, geothermal and tidal/oceanic energies [5].

Energy sources in Pakistan's current energy mix include hydro, thermal (coal, natural gas and furnace oil), and nuclear for electricity generation and gasoline, diesel and compressed natural gas (CNG) for transport sector. In addition, electricity generation using renewable energy resources has just started in the country, as reported by Pakistan Energy Crisis-Recommended Solutions, prepared by Pakistan Academy of Sciences (PAS, 2013).

Pakistan has about 1000 km long coastline, but as there is no data collection and rational thinking to utilize the available tidal energy [6]. Although, [7] studied feasibility of electricity generation at creek areas of Pakistan. But this study was based on personal communication and there was no tidal related data investigated to calculate the amount of power generated. All the calculations by [7] were based on the assumption of 10 m tidal range, whereas according to the personal communication tidal heights vary from 2-5 m in same article. However, the tidal range of 10 m was never observed in study area (Karachi), according to our research study.

Another study carried by [8] was done without analyzing any tidal data which was mentioned by authors in result and discussion section of the article.

Aforesaid in view, first time research study is carried out with real time tidal data which is acquired from automatic tidal gauge with the help of Pakistan Navy hydrography department for analyzing different parameters of tides for electric generation at study area.

1.2. Study Area

Tide propagations were studied at Karachi (24^o 48'N 66^o 58'E), located on the coast of Pakistan as shown in Figure 1 and contains two major ports of the country, namely Kemari and Port Muhammad Bin Qasim. It is located in the province of Sindh and is surrounded by the islands, namely Manora, Churna and Bundal. The Karachi coast constitutes a coastal belt of about 100 km situated between the Indus Delta on the southeast and Hub River on the west. Area of Karachi city is approximately 3527 km^2 holding 9.856318 million people, making it the largest cosmopolitan city of Pakistan [9]. Increasing population has also increased energy consumption within the city where power generation is mainly dependent on fossil fuels.

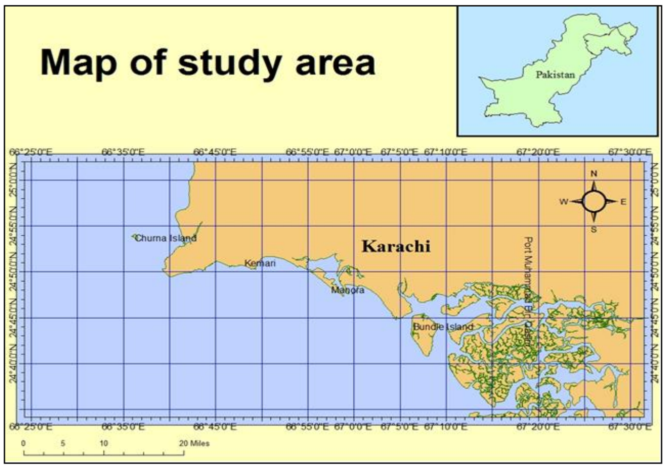

Figure 1 A map of study area

2. MATERIALS AND METHODS

2.1. Data Processing and Collection

The tidal data pertaining to this research study was collected from June 2014 to August 2014. The automatic tide gauges and tide poles were used to collect tidal observations on sea level with a resolution of one minute. These permanent automatic tide gauges are maintained by Hydrographic department, Pakistan Navy. Detailed analyses are made on the observed sea level to understand tidal and non-tidal variations. The tide level in Karachi is Chart Datum, which is 4.392 meters below a Bench Mark close to tidal observatory.

Harmonic analysis of observed sea level provides the basis for predictions of tides [10].

The harmonic tidal constituents which enable us to recognize characteristic features of tides at our study area include main lunar diurnal constituent (O_1); Luni-solar constituent (K_1); main lunar semidiurnal constituent (M_2) and main solar semidiurnal constituent (S_2) [11]. Four major constituents and relative strength compare to M_2 for the coastal city Karachi have been determined and listed in Table 1. Each constituent combines in different ways at specific location to produce the local tide.

Table 1 Tidal Constituent and relative strength parameters at Karachi coast.

Symbol	Relative strength
M_2	100.00
S_2	37.80
K_1	50.00
O_1	24.39

The classification of different types of tide is presented in table 2. The relative importance of diurnal and semi-diurnal harmonics can be determined from following ratio (∂):

$$\partial = \frac{O_1 + K_1}{M_2 + S_2}$$

Table 2 Types of tides.

Ratio	Tide Type
0.0 to 0.25	Semidiurnal
0.25 to 1.5	Mixed (predominantly semidiurnal)
1.5 to 3.0	Mixed (predominantly diurnal)
> 3.0	Diurnal

The ratio ∂ between (O_1 + K_1) and (M_2 and S_2) have been calculated as 0.540 for the study area declaring the tide type as mixed with semidiurnal predominantly. Close examination of the predicted tidal pattern at study area in figure 2 also shows that semidiurnal tides are dominant. Figure 2 shows predicted sea level for June 2014, July 2014 and August 2014.

Observed hourly tidal data is extracted from the tidal data per minute to compare it with the predicted model using software. Daily high and low water is also extracted from the observed tidal data per minute for three months to calculate different tidal parameters for harnessing tidal energy and are shown in table 3.

2.2. Generating Methods and Power density Calculations

The energy extracted from the tides can be obtained from both, the vertical water movements associated with the rise and fall of the tides, potential energy or the kinetic energy, which is a result of the roughly horizontal water motions termed as tidal currents. For these reason, tidal power facilities can be categorized into two main types: tidal current turbines shown in figure 3 [12] and tidal barrages [13] shown in figure 4. Tidal current turbines extract the kinetic energy from the moving unconstrained tidal streams to generate0 electricity. Conventional tidal current turbines are classified by the position of rotor axis, i.e. mounted vertically or horizontally. Alternatively, the energy in tidal currents can be extracted by hydroplanes or harnessed indirectly, by venture devices that convert water flow into air flow, which is then used to drive the generator. The tidal barrage is a model which essentially involves a structure with gated sluices and low-head hydro turbines. Bridging two sides of an estuary, the principle of operation is to allow water to flow into the area behind the barrage with the flood tide and out during the ebb tide. As water flows out, the collected head of water turns the turbines to generate power [14].

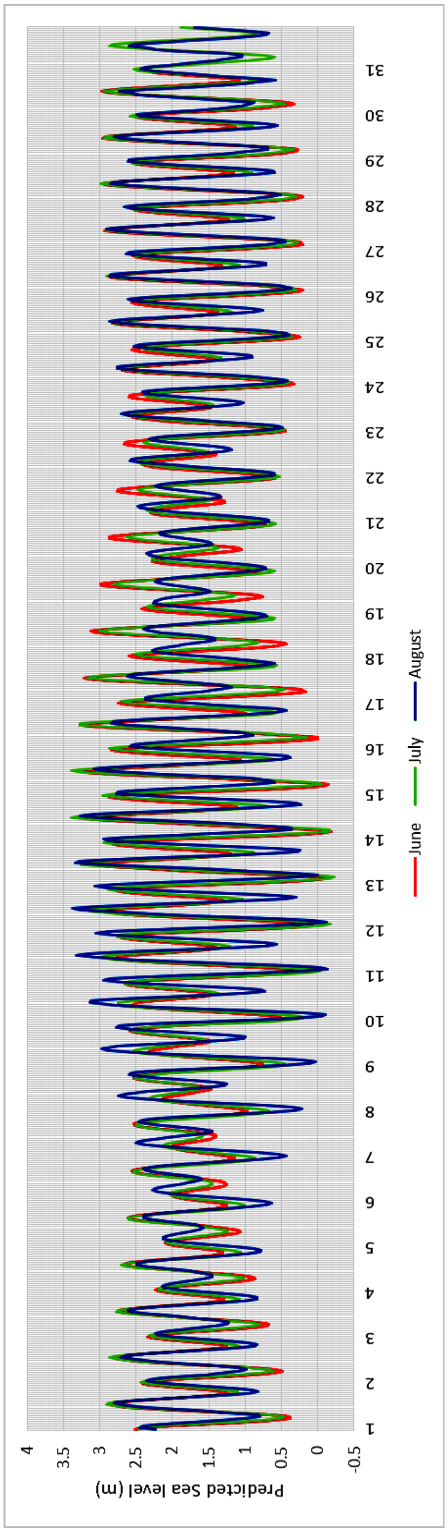

Figure 2 Predicted Sea Level, Karachi coast, June 2014, July 2014 and August 2014

Table 3 Tidal parameters for June 2014, July 2014 and August 2014 at Karachi coast.

Tidal Parameters	June 2014	July 2014	August 2014
Highest tide (m)	3.416	3.366	3.542
Lowest tide (m)	0.586	-0.18	0.118
Largest Tidal Range (m)	2.391	3.083	3.074
Smallest Tidal Range (m)	0.359	0.54	0.501
Mean spring tidal range (m)	1.937	2.328	2.481
Mean Tidal Range (m)	1.278	1.821	1.875

Figure 3 Gorlov Helical Turbine

This research mainly focuses on tidal barrage model based on tidal range technology because of the availability of data and have not discussed tidal current turbine because of the non-availably of the tidal current data. Figure 6 describes complete flow of methodology adopted.

2.2.1 Tidal range technology

This technology harvest the potential energy generated from tidal energy through flood generation, ebb generation and combination of both flood and ebb generation [15].

2.2.2. Generation at ebb tide

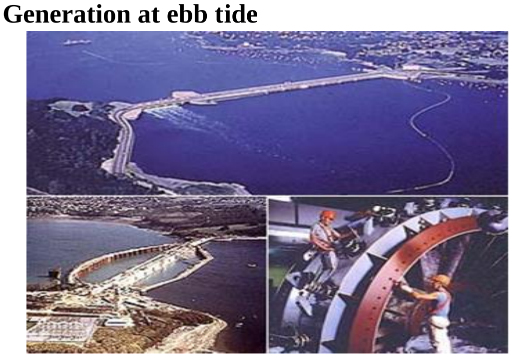

Figure 4 The La Rance Tidal Power Station in France

The reservoir is filled at flood tide through sluices gate or valves that are closed once the tide had reached its highest level. At ebb tide, the water in the reservoir is released through the turbines and power is generated [15].

2.2.3. Generation at flood tide

At flood tide the sluice gates kept closed to isolate the reservoir while at its lowest level. When the tide is high, the water from sea side flows into the reservoir via turbines, thus generating power [15].

2.2.4. Generation by combination of both flood and ebb tide

Both incoming and outgoing tides generate power through turbines [15].

Methods of extracting tidal energy

There are several methods for exploiting energy of tides through tidal range technology: Tidal barrages, Tidal reef and Tidal lagoon.

2.2.5. Tidal barrages

Tidal barrages allow tidal water to fill an estuary via sluices and empty through turbine and requires 5-10m head of water to operate successfully. A tidal barrage commonly consists of bulb turbines to harness tidal energy. A variety of turbine are available in the form of rim turbine and tubular turbine[16].

2.2.6. Tidal lagoons

Work on same principle as a tidal barrage but by capturing an area of water rather than being a complete barrier across an estuary but could sit with in the ocean [15-16]. The tidal barrage project in the Grevelingen lakes in Netherlands would be the first ultra-low-head barrage, as the tidal difference would only be between 50cm to 1m [15].

2.2.7. Tidal reef

A number of new innovations are being considered. The design of the turbines would allow them to work off a lower head of water (2-3m) and to be more actively controlled [15-16].

2.3. Power Calculations

Potential energy component of the tide can be calculated as [2]:

$E = 0.5A\rho gh^2$ (Energy per tide) -------(1)

where,

h is the mean tidal range

A is the horizontal area of the barrage basin

ρ is the density of water = 1025 kg per cubic meter (seawater density varies between 1021 and 1030 kg per cubic meter)

g is the acceleration due to the Earth's gravity = 9.81 m/s^2

The potential mean power for one tidal period t, equation (1) becomes:

$P\ (mean) = A\rho gh^2/2t$ -------(2)

The value of t for semi-diurnal tides is 12 hours 25 minutes = 44700 seconds

Now we have 2 high tides and 2 low tides every day. At low tide the potential energy is zero.

Therefore the total potential mean power in a day = $(A\rho gh^2/2t) \times 2$

$= A\rho gh^2/t$ -------(3)

Therefore, the potential mean power density = $\rho gh^2/t$

$= 1025 \times 9.81 \times h^2 / 44700$ s

$= 0.225 \times h^2$ W/m² --------(4) Power density per tide is expressed as:

$= \rho gh^2/6$ hours -------(5)

Using the above mathematical model, the potential mean power density for the three months at the study area is given in table 4.

Table 4 Power computed from the tides for three months

Months	Potential mean power density (W/m²)	Potential mean power density spring (W/m²)	Highest power density (W/m²)
June 2014	0.367	0.844	2.658
July 2014	0.746	1.219	4.42
August 2014	0.791	1.385	4.394

3. RESULT AND DISCUSSION

3.1. Tidal Variations

In this section we describe the observed sea-level variations at Karachi for three months and relate it to the astronomy and other affects.

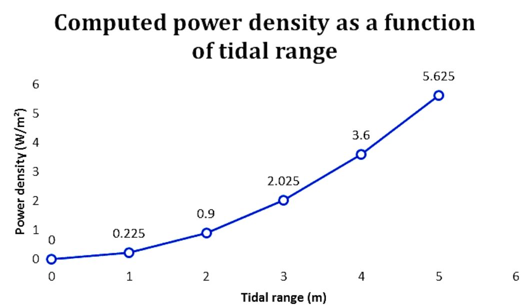

Figure 5 Computed power density as a function of tidal range

Because power density computed from above mathematical model varies with the square of tidal range, it increases rapidly with tidal ranges as shown in figure 5.

The regular and predicted pattern of tides is modified by irregular factors, the principle one being the atmospheric pressure and the winds acting on the sea surface [17]. Figure 7 shows how the predicted pattern of sea level at Karachi was modified by the meteorological affects in June 2014, July 2014 and August 2014. Under normal meteorological conditions it was observed that predicted sea level variations are well matched with observed sea level and differences up to 0.35 meter were observed due to seasonal variation but significant differences up to 0.8 meters were observed for the period of June 10, 2014 to June 13, 2014.

Significant difference in the predicted and observed sea level during June are caused by meteorological affect (called surges) and these irregularities are shown in Figure 8. These variations observed in the sea level for the month of June are comparatively high due to the tropical cyclone Nanauk in June 2014.

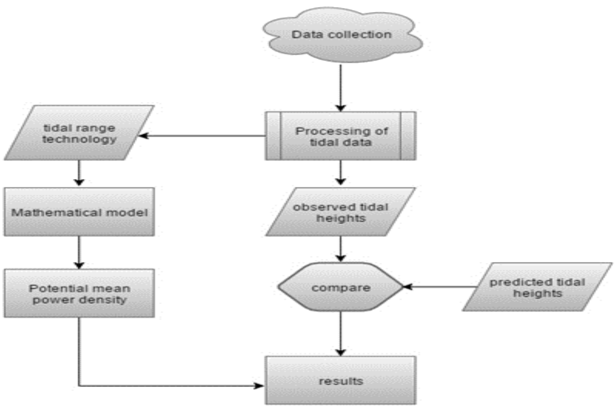

Figure 6 Flow chart of methodology used

Tropical cyclone Nanauk formed west of India on June 10, 2014 and since then had been moving toward the northwest over the open waters of the Arabian Sea, shown in figure 9 [18]. Nanauk contained powerful storms dropping rain at a rate of over 247.3 mm or 9.7 inches per hour when viewed on June 11, 2014. On June 13, 2014 the storm's last official position was at 21.3 north latitude and 64.3 east longitude, about 285 nautical miles (328 miles/528 km) southwest of Karachi, Pakistan. At that time the dissipating storm was moving to the north at 9 knot [19].

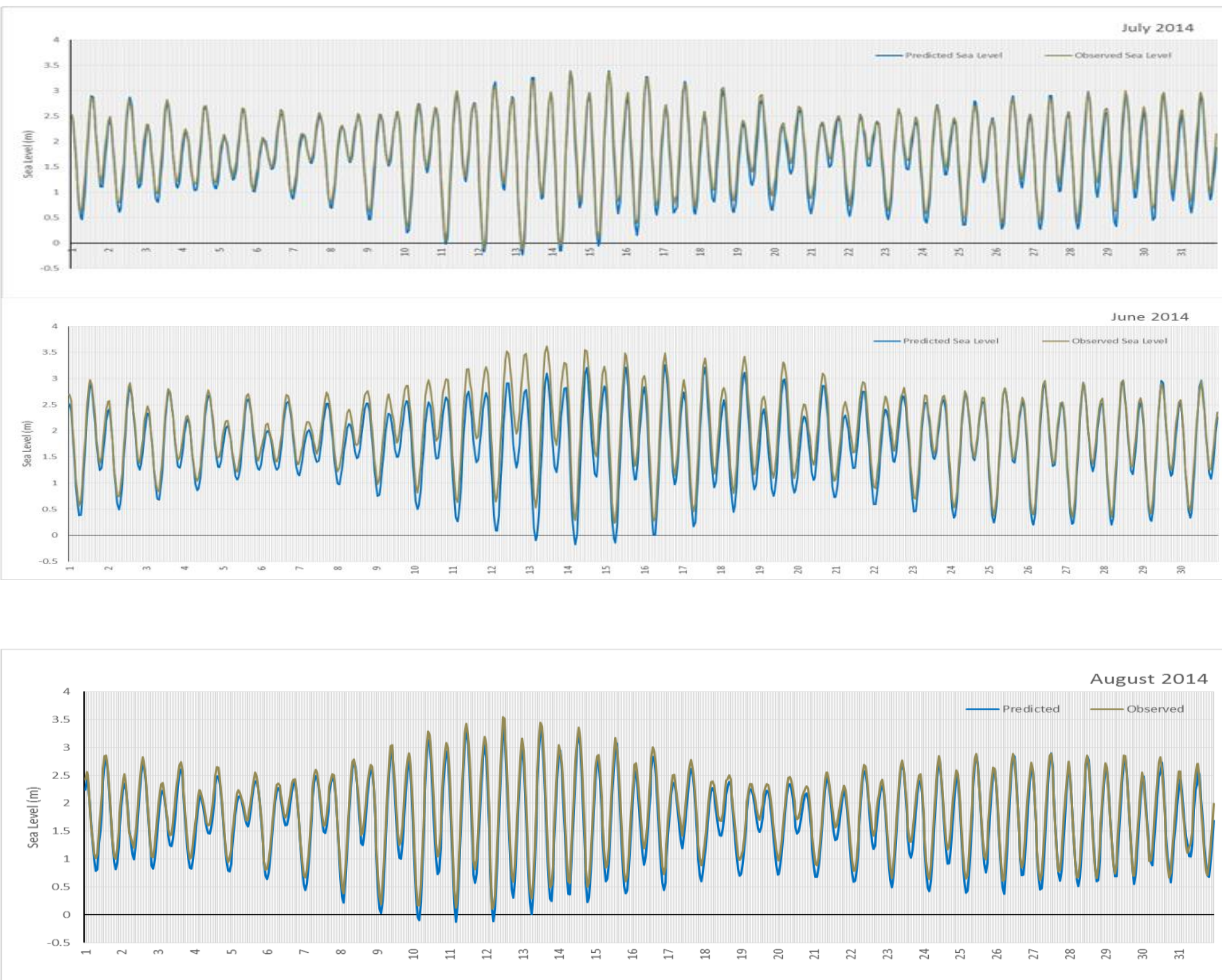

Figure 7 Predicted and observed variations in sea level, Karachi coast, June 2014, July 2014 and August 2014

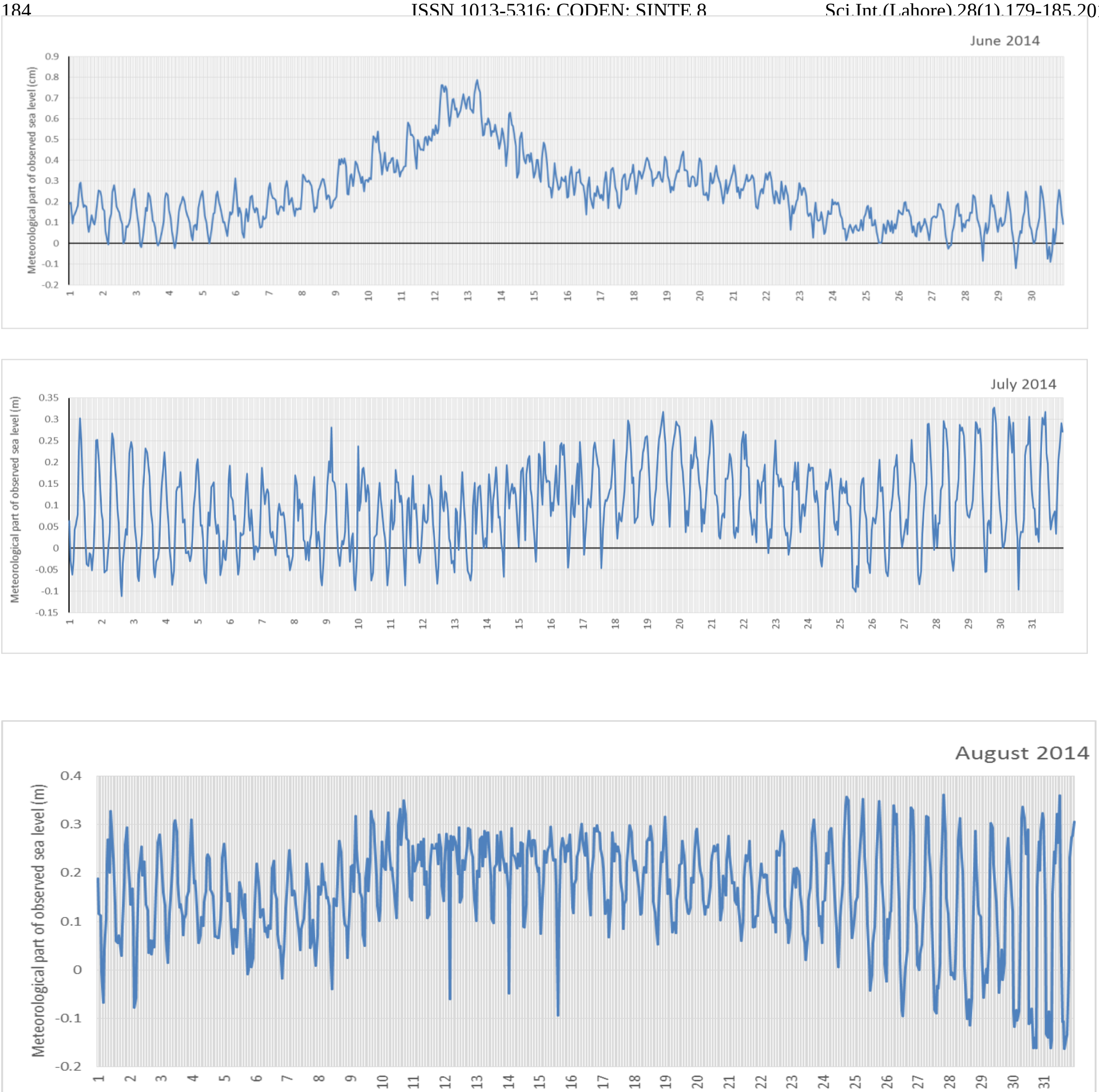

Figure 8 Meteorological irregularities in observed sea level, Karachi, June 2014, July 2014 and August 2014

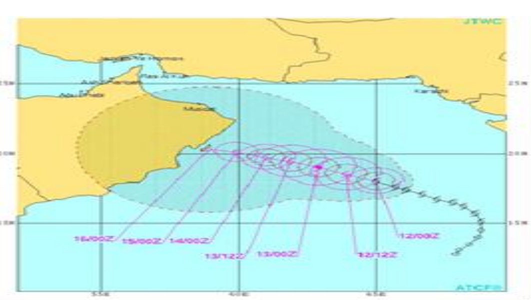

Figure 9 Tropical cyclone Nanauk forecasted track

As a result of this cyclone, total high level caused by the coincidence of a spring tide and increase in sea level due to storm occurred during 10-13 June 2014, is represented in figure 7.

Large surges, causing flood occurred during the tropical storm Nanauk. These dramatic rises and resulting coastal flooding are rare events in Karachi. Beach huts in Hawk's Bay, Sand's Pit and Paradise Point areas have effected by the rise in sea level. The water reached the roads in these area and villagers living along the Karachi coastline had to flee their homes [20].

3.2. Practical implications of the findings

All the tidal parameters presented in Table 3 shows good indication for practically implantation of tidal plants for harnessing tidal energy especially during spring tide when significant tidal range was found. The tide variation of 2.0m to 3.5m was observed at study area, which is comparable to the tidal heights of The Kislaya Guba Power Plant, Russia [21] and BaiShakou Power Station, China [2], which also supports the practical implantation of tidal power plants. Tidal reef technology discussed in section 2.2.7. and ultra-low-head barrage technique, is also viable option for harnessing tidal energy at study area. Table 4 shows the computed potential mean power densities for three months extracted from the mathematical model discussed under section 2.3 In view of above, further studies are required for the selection of basin area. Some sites are proposed which includes Ghizri Creek, Korangi Creek and Boat Basin.

4. CONCLUSION

In this study an effort has been made to acquire the available tidal data from hydrographic department of Pakistan Navy and processed it to extract and calculate some useful information that are important for harnessing tidal energy at study area; including tide type, difference in predicted and observed tides, storm surges, spring-neap variations, tides heights and range. After analyzing all the available data and calculating results, a view is establish that may leads in future a complete system of power generation through tidal energy at study area. It is concluded that type of the tide found at study area are mixed with semidiurnal predominantly means there are two high and two low tides per day for a duration of 6 hours 14 minutes each. Predicted sea level variations were compared with the observed sea level variations for three months and as a consequence predicted sea level variations well matched with the observed sea level variations except for the month of June 2014 because of the occurrence of tropical cyclone Nanauk. During spring tide, significant tidal range was observed as compared to neap tide. After examination of different tidal parameters at study area and comparing it with the other tidal power plants, it is also concluded that coastal belt of Pakistan has significant potential for harnessing tidal energy to overcome the energy crisis of the country and improve the socio-economic and environmental conditions.

5. ACKNOWLEDGMENT

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