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Feasibility study on wind farm construction in Gorgan Bay using GIS

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Abstract

One of the latest advances in renewable energy is wind turbines located in aquatic areas such as lakes, estuaries and gulfs. Determining the best location for these turbines is very important in terms of energy production and its final price. This research investigates geographic analytical data available for water-based wind turbines using GIS, which is used to determine the best location for building wind turbines in the Gorgan Bay. The data used in this analysis include depth of water, annual wind speed, distance from the coastline and shipping lines. The efficiency of water-based wind power plants depends on three major factors: water depth, wind speed, and distance from the coastline in order to access power transmission networks. The distance from the coastline is determined using the GIS system. In addition to the depth of water, the wind speed and the distance from the coastline, which are the main factors in determining the proper location of the site, it is necessary that other elements are well considered. Then, regarding the appropriateness of the Gorgan Bay region for the construction of a field of wind turbines based on water is discussed.

Keywords: Wind turbine; Renewable energy; Gorgan Bay.

1. Introduction

Today, most of our electrical energy comes from non-renewable sources such as fossil fuels. Currently, with the rise in fossil fuels prices and the growth and development of industrialized

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countries in the context of reducing greenhouse gas emissions, the search for other energy sources around the world has been increased. The International Energy Agency (IEA) report on November 12, 2008 stated that if demand for oil continues to increase with current trends, by 2030, the world needs new sources of oil production, equivalent to four times the production of Saudi Arabia which is only possible by evacuation of existing oilfields (Gies, 2008). According to the American Wind Energy Association report on 2009, electricity generation using fossil fuels is one of the largest industrial air pollutants in the world. Wind energy is clean, renewable, and has a decent production price compared to other renewable energy sources and reduces greenhouse gas emissions. The energy potential of wind in the world is estimated about 94112 MV and each megawatt production causes one million dollars growth in economic (Uelmen, 2010). Using Geographic Information System (GIS) can analyze the power of wind turbines located in water. Furthermore, some information such as average wind speed, depth of water and distance from the coastline are simultaneously studied. The purpose of this research is to determine the potential of Gorgan Bay region for the construction of a wind power plant in the water.

1.1. Study area

Bay is a creep due to seaward advancement in a land that is important in many aspects. Gorgan Bay is the most important landform of southern coast of Caspian Sea. The crustal stretch along the Caspian Sea caused a new plumage, followed by the advent of the sea, causing the widest sedimentary zone in the southeast of the Caspian Sea. After the sea recaptured in the Neo-Caspian, many gulfs have appeared on the margin of the Caspian Sea, including the Gorgan Bay. The existence of dispersed wetlands and marshes between the Bay and Neka-rood and the decline in depth toward the west, shows its greater extent at the time of its appearance. Gorgan Bay with an approximate length of 50 km, a maximum width of 12 km and an area of more than 400 km^2 is in the form of a triangle which its head placed in the western part. Its maximum depth at center of the Bay is reported 6.5-7 m.

The transmitted s ediments from the sub

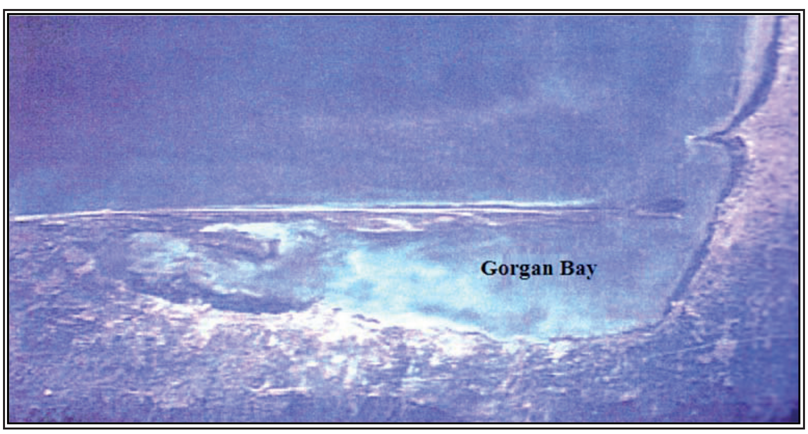

Figure 1. Satellite Image of the Gorgan Bay

branches of Neka-rood, several sub-waterways from the south of Bay, the Ghareh-Sou River, and Gorgan River, are the most important factors in reducing the useful life of the Bay. Gorgan Bay is a semi-enclosed sedimentary environment, where sediments and suspended loads of the rivers are deposited, and during a flood or storm, coarse sediments from sea can also be found inside it. The bottom sediments are mostly mud or mud-sand combined with shellfish. Figure 1 shows the satellite image of the Gorgan Bay.

2. Materials and methods

In order to feasibility of using wind energy potential in the region, a lot of information are needed that the most notable are as follow:

- Topography and depth of water in the Gorgan Bay
- Wind speed in the area
- The conditions of the coastlines of Gorgan Bay
- Shipping lines and transportation in Gorgan Bay

Further, topographic and wind speeds in the region are studied extensively. But regarding the importance of the two last ones, the condition of the coastal lines, as well as the shipping lines, it should be noted that since the power generated by each power plant should be able to be easily transmitted to the transmission and distribution networks, it seems that easy access to these networks is necessary. Therefore, the distance between the wind farm and the coastlines and transmission networks is very important. In addition, the wind turbines in the Bay should not create bottlenecks in transportation and shipping lines, which is another important point. Of course, regarding the importance of the location of wind farms relative to the coastlines, the importance of the turbines' perspective can be noted in establishing tourist areas, as well as the ease of their maintenance (Uelmen, 2010).

2.1. Topography and water depth

In the Gorgan Bay, based on the maps and the results of some studies in the region, there are no complicated topographical gaps such as deep gullies and significant prominences. Since the southeast part of the Caspian Sea leads to flat and plain areas and there are no special

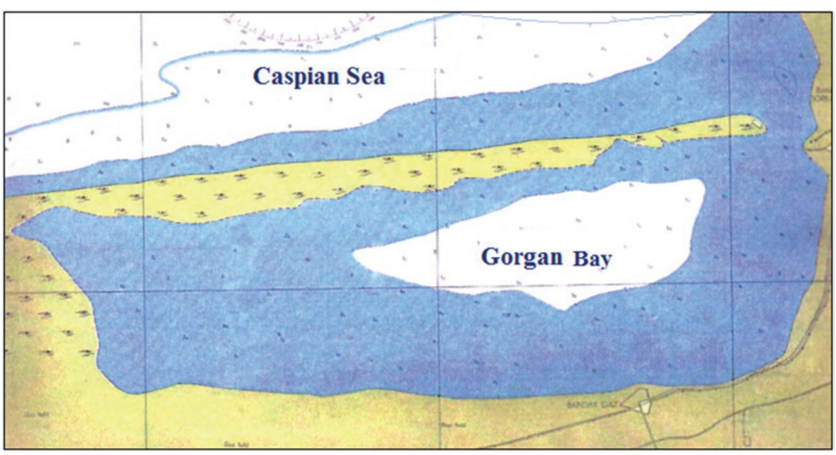

Figure 2. Topography of the Gorgan Bay

complications and roughness in this region, the slope of the earth is mild both in the land and in the sea and is topographically without complexity. The bay is an almost rectangular blue mass that is linked to the Caspian Sea through a canal in its northeast. The dimensions of this region are approximately 50 and 12 kilometers. In terms of topography, a bed with a mild slope from the sides leads to a maximum depth of 6 m. This slope is higher in the northern and eastern parts of the country, and it is lower in the western and southern parts. Figure 2 shows the topography of Gorgan Bay (Pourmandi *et al*., 2003).

Almost more than 60% of the area has a depth of less than 5 meters and only one part in the middle section has a depth of 5 to 6 meters. This deeper part is located on the northeast of the Bay, and the southern and western parts have a depth of less than 2.5 m.

2.2. Wind conditions in the Gorgan Bay

In general, the meteorological information and statistics provided by the stations indicate the information of the entire region at that station in radial. Therefore, the geographic coordinates of each station, that is their length, width and height, are very important in the models that are used for meteorological research. For this purpose, it has been tried to use the meteorological stations located in the Gorgan Bay basin and have more detailed statistics and information to study the wind data. Therefore, Turkmen port station located at the end of east of the Gorgan Bay with the coordinates of 36° 52' N and 54° 6' E, and Tirtash station located in 10 km of southern and middle of the Bay in the 36° 45' N and 53° 44' E. The Tirtash station is also considered to be a reference station due to the fact that it is located in the middle of the basin (Gorgan Bay). Unfortunately, this station has no wind statistics. Babolsar station is located in140 km of the west of Gorgan Bay in 36° 43' N and 52° 39' E and has long term statistics, especially for wind speed and wind direction.

Another considerable point is that the wind plays an important role in the movement of moist air masses and is one of the essential factors in the development of rainfall and evaporation. When the thermal equilibrium in air is disturbed, the air flow starts and the wind is generated. The wind causes the water molecules to evaporate faster than in the stationary surface, thereby increasing the evaporation rate. Isobars and their geographical distribution determine the air flow direction and wind speed. Due to the fact that local winds and daily changes cannot be detected on isobar maps, it is necessary to use synoptic stations to study the winds and their changes. At these stations, the wind speed and wind direction are measured in octagonal directions and in three turns. Also, wind study is very important in analyzing the hydrodynamic characteristics of the sea. In order to study the wind in the Gorgan Bay, it is necessary to use the data from the stations near to the Bay. For this reason, the wind data of Gorgan stations are used because their availability in the long-term (about 30 years) and being close to the Gorgan Bay and coastal nature of Babolsar area.

2.2.1 Wind speed and wind direction in Gorgan station

In order to study the wind at Gorgan station, considering available statistics, the 30-year period is assumed as the index period. Drawing wind rose plot, the frequency of wind in eight directions shows that 21.3% of the wind speed is between 4 to 6 knots in spring and summer and the dominant wind direction in the four seasons and yearly (Figure 3). As it is seen, the highest wind speed was recorded in autumn with 84% and the lowest was in spring and summer with 66.7% in Gorgan station. Also, the highest percentage was for the west wind. Considering the average of annual rate, 73.9% of the winds in this station were slow and 17.4% of the observations had the speed between 4 and 6 knots. The dominant wind direction in a year is from the west.

2.2.2 Wind speed and wind direction at Babolsar station

Babolsar station is located in 36° 43' northern latitudes and 52° 39' eastern longitudes at 140 kilometers west of Gorgan Bay, and since 1951 the 3-hourly record of wind speed and wind direction are available. In this study, wind speed data has been processed during a 40-year period. Because the statistics of the Babolsar station are measured at 10 meters, they do not need to be adjusted. On the other hand, comparing the statistics of two stations in Gorgan and Babolsar and considering that the statistics of these two stations do not differ significantly, Babolsar statistics are used for further calculations.

The annual and seasonal Wind-rose diagrams for the Babolsar station are shown in Figure 4. The monthly average of highest values of wind speed (Babolsar and Gorgan) is presented in Table 1. As shown in Figure 4, the autumn season has the highest percentage of calm wind (66.3%) and the spring has the lowest percentage of calm wind (51%). The highest probability of wind incidence was 25.7% in the summer between 4 and 6 knots. The dominant wind direction in the spring and summer is from the northwest and in the fall and winter is from the east. On average, 56.6%of the winds in this station were slow and 22.4% were between 4 and 6 knots. Also, 1.2% of which were recorded at the speeds between 11 and 16 knots, and the yearly dominant wind direction was from the west.

Table 1. The monthly average of the fastest wind speeds (m/s) in Babolsar and Gorgan stations (1951-2005)

Month	Station	
	Babolsar	Gorgan
January	21.5	19.3
February	20.3	27
March	20.3	23.7
April	22	33
May	20.3	22
June	16.5	22.6
July	11.5	21.5
August	16.5	16.5
September	24.2	16
October	21.5	16
November	50.1	22.6
December	21.5	16

2.3. Converting wind data on land to wind data on water

As it is seen, wind data is not available on the water, but data on adjacent land is available. Figure 5 can be used to convert wind data on land to wind data on water. Of course, this is

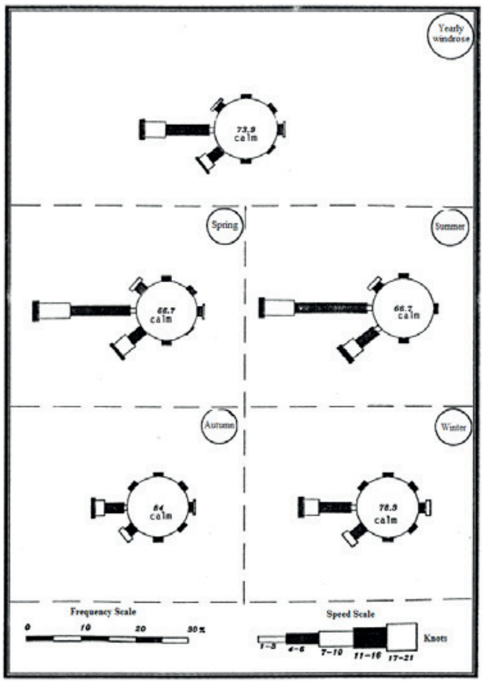

Figure 3. Annual and seasonal wind rose charts at Gorgan Station

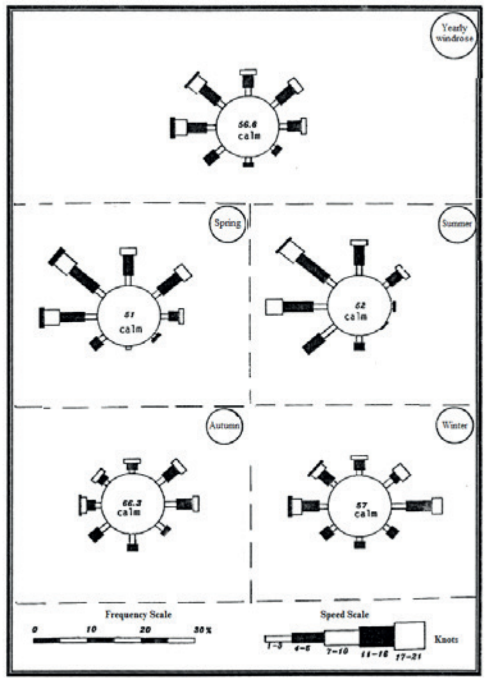

Figure 4. Annual and seasonal wind rose charts at Babolsar Station

used in the same pressure gradient conditions, and when the only major difference is surface roughness.

In fact, R_L is the same correction factor for spatial effects which has particular importance to the stations used above, because all these stations are located on the land. In addition to the R_L, there is another important coefficient as a correction factor. This coefficient is due to the temperature difference between air and sea. If the difference in temperature ($\Delta T = T_{air} - T_{sea}$) is zero, the boundary layer is stable, and correction of wind speed is not necessary. Regarding Figure 6, if the ΔT is negative or positive, the boundary layer is unstable and the wind data needs to be corrected. The amplification factor of wind speed, R_T, which

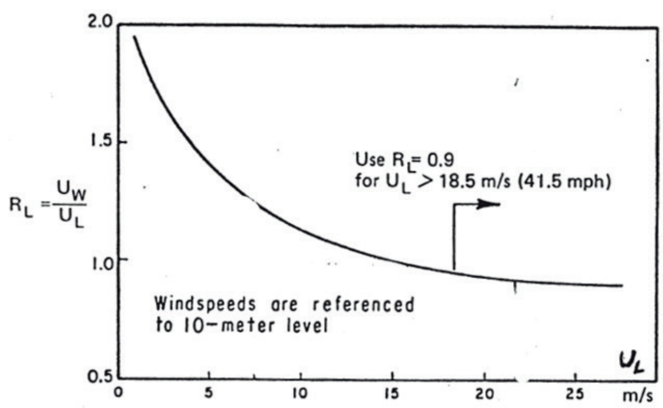

Figure 5. The wind speed ratio on the water (U_W) to the wind speed on land (U_L) (SPM, 1984)

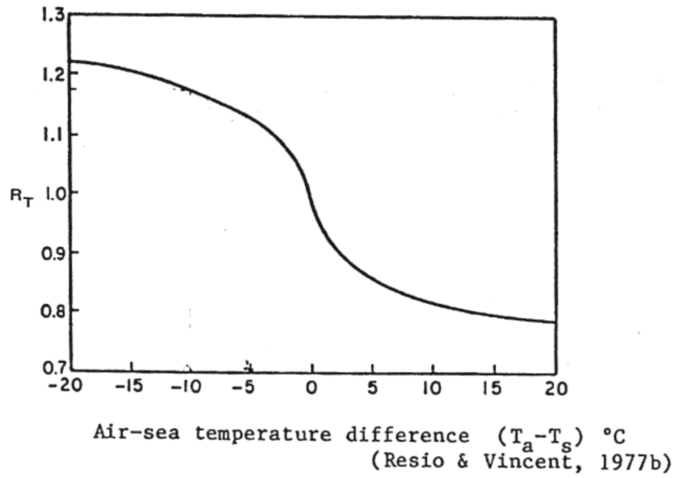

Figure 6. Amplification factor for taking the difference between the temperature of air and sea (SPM, 1984)

Table 2. Monthly average of the fastest wind speed in Gorgan during 2005

Month	Wind speed in 10-m (U_{10}) m/s
January	9.3
February	14.8
March	13.7
April	16
May	10.5
June	12.7
July	11.5
August	8.5
September	8
October	17
November	15
December	21.5

results from the temperature difference of the air and sea, is presented in Figure 6 (Chegini, 2006). Because the statistics of Babolsar station are measured at 10-m level, there is no need to correct the elevation. On the other hand, comparing the statistics of two stations in Gorgan and Babolsar and because there no significantly difference between the stations, wind speed data from Babolsar station are used for further calculations. Now, applying the location and stability correction factors on the wind data of the stations in the Gorgan Bay area, as well as local observations and the climatic conditions prevailing in the area, show the presence of strong winds in the area. The Table 2 shows the average monthly wind speed (m/s) in 2005.

According to the monthly average of wind speed in Gorgan Bay as well as the wind rose diagrams of the Bablosar station and the analyzes presented therein, it can be concluded that over one year, almost more than 21% of cases has the wind speeds higher than 8 knots, so, applying the location and stability correction factors (Mehrfar *et al.*, 2007):

$$\left.\begin{array}{l} U_L = 8 \ \ knot \\ R_L = 1.3 \end{array}\right\} \Rightarrow U_W = R_L U_L = 10.4 \ \ knot$$

$$\left.\begin{array}{l} U_W = 10.4 \ \ knot \\ R_T = 1.15 \end{array}\right\} \Rightarrow \overline{U}_{10} = R_T U_W = 11.96 \ \ knot$$

By converting the speed unit to m/s:

$$\overline{U}_{10} = 11.96 \times 0.551 \approx 6.59\, m/s$$

2.4. Wind power density

Due to the random nature of the wind, long measurements at different times, the Weibull density function is used to calculate the wind energy.

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(\frac{V}{c}\right)^{k}}$$

where, V is the wind speed, c and k are the scale and shape parameters, respectively. These parameters can be obtained using the Maximum Likelihood method with a repetitive method. The wind energy that passes through the area of the turbine blade rotation (A) has a direct relation to the third order of wind speed:

$$P(V) = \frac{1}{3}\rho A V^{3}$$

where, ρ is the air density in the area. Given these relationships, the wind power density in a site can be calculated based on the Weibull distribution as follows (Gandmkar and Kiarzi, 2006; Sharifi and Shirzad Sibbani, 2006; Parvin, 2010).

$$\frac{P}{A} = \int_{0}^{\infty} P(V) f(V) dV \propto \rho V^{3}$$

So, according to the estimated average wind speed, the wind power density can be calculated. For this purpose, the surface air density of Gorgan Bay in the average annual temperature of 17.4 °C in the area is estimated about 1.2 kg/m^3. In addition, the average annual wind speed in 21% of cases for offshore areas on the Gorgan

Table 3. Standard classes of wind power density for different heights (Parvin, 2010)

Level	10-m		30-m		50-m	
Parameter	Wind speed (m/s)	Power density (W/m^2)	Wind speed (m/s)	Power density (W/m^2)	Wind speed (m/s)	Power density (W/m^2)
Class						
1	0-4.4	0-100	0-5.1	0-160	0-5.6	0-200
2	4.4-5.1	100-150	5.1-5.9	160-240	5.6-6.4	200-300
3	5.1-5.6	150-200	5.9-6.5	240-320	6.4-7	300-400
4	5.6-6	200-250	6.5-7	320-400	7-7.5	400-500
5	6-6.4	250-300	7-7.4	400-480	7.5-8	500-600
6	6.4-7	300-400	7.4-8.2	480-640	8-8.8	600-800
7	7-9.4	400-1000	8.2-11	640-1600	8.8-11.9	800-2000

Bay and at an elevation of 10-m was obtained about 6.59 m/s. So, the wind power density is estimated to be approximately 345 W/m^2 which is considered as class 6 in accordance with the standard classes (Table 3).

It should be noted that in the United States Wind Power Atlas, the wind power density for different heights from the ground is defined in a table like Table 3 to range from 1 to 7. There is no possibility of generating power with the average wind speed of the first class with today's wind turbine technology. Classes 2 and 3 will also be operational in the coming years with the advancement of technology. The Gorgan Bay, with its wind power density, is offered in class 6, which is one of the best classes for wind power utilization with today's technology.

3. Analysis of research findings

According to the standards, the wind speed and its continuity must be such that at least 65 to 80 percent of the time can rotate the turbines and generate energy. It has been shown that a site is an economically viable wind energy source, when 20% of wind speed values over a year are higher than 7 m/s (Parvin 2010).

The calculations carried out in the various sections of this study and the results show that over one year in more than 21% of the wind speeds, recorded at land-based stations in the vicinity of the area are about 8 knot. Now, by affecting the spatial and sustainability correction coefficients on this speed, and then converting the unit into m/s, the wind speed at10 meters above sea level is equal to 6.59 m/s. Given the estimated speed, the wind power density can be calculated. As the surface air density of the Gorgan bay is about 1.2 kg/m^3, the wind power density was estimated to be approximately 345 W/m^2 which in accordance with Table 3 is considered as sixth industrial class.

Since wind turbine technology currently has the potential to produce power with an average wind speed in the sixth and seventh classes, it is technically feasible, as well as considering that most of the water-based wind power plants are all deployed in the depths lower than 20m. Thus, the Gorgan Bay with the wind power density represented in class 6, is one of the best places to exploit wind energy with today's technology.

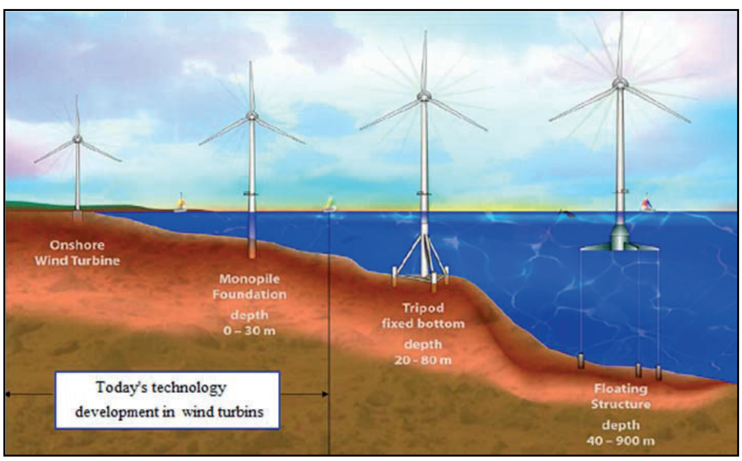

Figure 7. The growth process of marine turbines in the present and future (Pryor *et al.*, 2005)

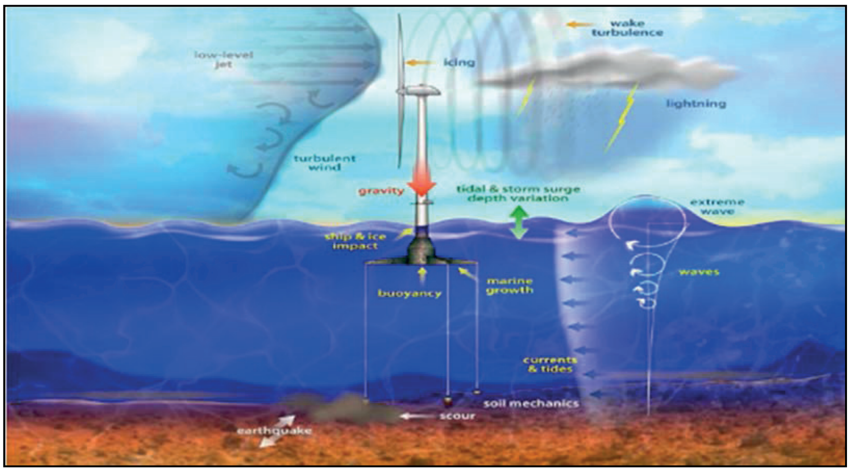

Figure 8. Factors affecting the construction of water turbines farm in water (Pryor *et al.*, 2005)

4. Discussion and Conclusion

Water-based wind turbines, which are in the early stages of designing, are more expensive than dump turbines and harder to install and maintain. Marine turbines must be resistant to waves and weather changes, and resistant to marine erosion. Marine power plants have two major advantages, one that can make turbines used in water larger than turbines used on land, so the amount of electricity produced by each turbine increases, and second more powerful winds blow over sea surface. Today, the electricity produced by marine wind power plants around the world is 600 MW. These power plants are all located in the water depths of less than 20 m (Figure 7). With a research and development program, it is possible to install wind turbines in deeper waters by building similar platforms to those used for marine drilling rigs.

In this article, the selection and initial approval of a site for the construction of a wind turbine plant in Iran and in the Gorgan Bay is was investigated. According to the research, the efficiency of the farm of wind turbines in water depends on several key factors:

- The highest wind speed that is most desirable to generate energy.
- The number of turbines, their location and depth of water.

Wind speed is also depended to other key factors such as distance to the coast and depth of water. For example, the furthest marine turbine has the highest wind speed for more energy. But it should be kept in mind that the furthest turbines from the coast will have problems with the energy transfer issue. In short, the purpose of determining the appropriate location for such plants is really complex and requires a lot of information for a comprehensive analysis, as schematically illustrated in Figure 8.

In this regard, considering the importance of marine and meteorological parameters and other factors such as sea currents, wind speed, water temperature, air temperature, etc., as shown in Figure 8, more studies are essential. The first step is to construct active synoptic stations on the coasts that cover the whole area under study. In addition, using new tools such as meteorological buoys in the Gorgan Bay seems to be necessary and inevitable.

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