GIS for Wind Energy: A Case of UAE

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Abstract
In this study, the mean monthly wind speed complemented by remote sensing and GIS spatial and statistical analysis are utilized to identify suitable areas for wind energy generation in UAE. The suitable areas are found along the north-western coastal areas of Abu Dhabi. The areas are weighted based on the wind energy generation capacity and proximity to the demand centers (urban, agriculture, ports, refineries, airports, etc.), roads, and transmission lines. The wind energy locations identified can be utilized to meet the increasing demands arise from population increase and the rapid development. The study demonstrates unique combination of physical (topography, land use, etc.), climatic (wind), and socio-economic variables.

1. Introduction: GIS and Remote Sensing for Renewable Energy Assessment

Efforts have been conducted around the globe to investigate the use of remote sensing and GIS for renewable energy. A study carried by the University of California (Berkeley) demonstrated the usefulness of GIS for renewable energy analysis (Lian, 2005). In France, a wind atlas was created using GIS to help in identifying suitable windmill locations and possible future impact of wind farm (Durand, 2007 and Philippe and Julian, 2006). Similar studies were carried out in India (Jayakumar et al., 2002 and Kanagavel, 2004), the Netherlands (Johan, 2003), South Africa (Diab, 1995), US (Swisher, 1995), and Europe (Troen and Petersen, 1989). However, to this date there is no utilization of remote sensing and GIS technology in UAE for renewable energy, although the potential has been identified by Nasser (1998). It is recommended to use satellites to complement ground stations data, especially in offshore areas (Nielsen et al., 2004 and Denegre, 1994). The strength of satellite-borne remote sensing is in its richness of data, repetitive coverage, accessibility to hazardous and unreachable areas, good temporal, spatial and spectral resolutions, and the availability of data in digital format that can be integrated directly with GIS. GIS has the ability to integrate heterogeneous data (weather data, land use, facilities, topography, etc.), perform spatial analysis, has the capability to interact with external models, and allows visualization of the results in a vivid way.

2. Objectives

The objective of this study is to identify suitable areas for wind energy generation in UAE using remote sensing and GIS multi-criteria decision analysis. The analysis is based on building GIS databases for meteorological stations and factors influencing on suitable wind energy site. These include proximity to urban centers, power lines, airports as well as type of land uses and slope.

3. The United Arab Emirates (UAE)

Established on 2 December 1971, the United Arab Emirates (UAE) is a federation of seven emirates comprising an area of 83,600 square kilometres. The country lies between latitudes 22°-26.5° North and longitude 51° -56.5° East, bordering the Arabian Gulf and Gulf of Oman. The population of the UAE is estimated to be approximately 5 millions with a growth rate of 6.5 per cent per year (UAE, 2006). Although oil presents the economic mainstay of the country, recently business, financial services and tourism have emerged as important sectors in the economy. There is a need in the country to diversify its energy sources and renewable energy is among the viable alternatives. Masdar Initiatives in UAE is established to help develop and commercialize renewable-energy technologies. Recently (2009), UAE also host the International Renewable Energy Agency (IRENA). The UAE experience a tropical hot desert climate with high temperature range between 35°C during summer (April-November) and 18° C during winter (December-March) and low average annual rainfall of 36mm (UAE Atlas, 1993). The principal influences on the atmospheric pressure patterns of the UAE are the Siberian anticyclone (area of high pressure) in winter, and in summer the Asiatic low centred over central and southern Asia, extending in abroad belt across the continent at approximately 30° N.

The secondary influence comes from Azores high pressure cell in summer and from the African low pressure cell in winter. Latitude also influences the atmospheric pressure. Lying near 30º N the UAE is directly under the sub-tropical (Jet stream convergence zone) anticyclone, known as a low-altitude or Hadley cell. There is a tendency for wind to be stronger between March and August and the prevailing wind direction is from north-west (Shamal) (UAE Atlas, 1993).

4. Data Sources

The data were gathered from various governmental departments. The time series (2004-2007) wind data were obtained from the UAE National Center of Meteorology and Seismology. Although there are many other meteorological stations in the UAE operated by different departments such as the military, agriculture, and transportation, some of these data are restricted or unavailable and others are questionable in terms of the accuracy, maintenance and calibration of the equipment used to collect them. Therefore, data from the main 6 UAE airports (manned stations) in addition to 27 automatic stations newly installed in 2003 were used, as they were considered more reliable due to regular maintenance and update. The automatic stations used speed sensors with a measuring range of 0.5 to 60m/s, resolution of 0.5 m/s, and accuracy of $\pm$ 0.1 m/s. The data for the period 2004-2007 were considered the most available complete set (no missing data). The wind speed in UAE is measured at stations with various altitudes varying from 4 to 345 m above Mean Sea Level (MSL). All the wind data is normalized to 10 m above ground using the one-seventh power law (Diab, 1995). Elevations vary from flat near northern coastal areas to moderate in the inner sand dunes to steep and high along the northern-eastern coastal mountains. It should be pointed out that long-term historical data, minimum of 5 years observations for a potential site should be used for reliable site evaluation (Cheremisinoff, 1979). The data used in this study have originally gathered for meteorological purposes. In general, meteorological data provides initial assessment of wind power, but is inadequate to carry out detailed planning for installation of wind turbines for power generation (Ganesan and Ahmed, 2008). The existing electricity grid network and substation data were obtained from Abu Dhabi Water and Electricity Authority (ADWEA). Petroleum and oil facilities were scanned from the UAE Atlas (UAE Atlas, 1993) due to the difficulty in obtaining recent data. High resolution land observation and remote sensing images (QuickBird) were bought from private companies and other low resolution images such as IRS were obtained from the Space Reconnaissance Center, UAE Air Force and TM images were downloaded from US Geological Survey web site. The UAE Digital Elevation Model (DEM) data were also obtained from the US Geological Survey web site (ftp://edcsgs9.cr.usgs.gov/pub/data/srtm).

5. Methodology

A database that contains remotely sensed images, monthly meteorological data, elevation, land use maps, and energy-demand centers (towns, villages) was established. Other data included roads, airports, electricity network, farms, ports, refineries, protected natural and cultural sites. A series of criteria was used for locating the most suitable wind energy location. The criteria were compiled from various sources such as the American Wind Energy Association (AWEA) (AWEA, 2008), Kovarik and Hurst (1979) analysis, and the International Energy Group (IEG, 2008). Following these studies, this analysis used wind speed as the main selection factor, because the basic equation of wind power depends on the third power of the wind velocity in addition to density of air and cross-sectional area. This can be expressed as (AWEA, 2008 and Hunt, 1981):

$$P = 0.5 \times \rho \times A \times V^3$$

Equation 1

where: P = power in watts, ρ = air density (about 1.225 kg/m^3 at sea level with temperature of 15° C), A = rotor swept area exposed to the wind (m^2); V = wind speed in meter/second (m/s), The power density (W/m^2) available in a unit cross-sectional area normal to the wind is given by (Justus, 1978) as:

$$P = 0.5 \times \rho \times V^3$$

Equation 2

Since air density $\rho = 1.225$ kg/m^3 then:

$$P = 0.5 \times 1.225 \times V^3$$

Equation 3

For the most accurate characterization of wind power, equation [1] with average hourly wind speeds rather than mean statistics should be used (Diab, 1995). However, for this preliminary study data at the required resolution was not available, so Equation [3] successfully applied by Johannessen and Korsbakken (1998) was used. In general, average annual wind speeds of greater than 3.5 m/s are required for users who are connected to the electric power grid. Large wind power plants (wind farms/utility-scale) require a minimum average speeds of 5m/s and upward for cost-effective operations (IEG, 2008; Mathew, 2006; Sorensen, 2005). In this study, areas with wind speed greater than 4 m/s are considered possible potential sites. This is because such wind speed can be utilized for small scale activities and because the developments in turbines are directed towards increasing hub height, increasing surface area, and starting at lower speeds (Chompoo-inwai et al., 2008). The wind data were converted from Excel Spread Sheets database, and exported to the GIS environment. In the GIS, the mean monthly wind data were averaged over 4 years (2004-2007) and the attribute data were linked to their spatial locations. Satellite images were processed to extract land use maps using supervised method of classification. Spatial analysis functions within the GIS (Spatial Analyst-Grid format) were utilized for identifying suitable areas for wind energy generation using multi-criteria analysis. The criteria took into account wind speed, topography, slope, seasonal changes, land uses, proximity to urban and agricultural areas, ports, refineries, and airports. Maps showing potential locations of wind energy were generated. The wind speed and wind power were interpolated using the Inverse Distance Weighted (IDW) interpolation method. IDW is used because it explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. In this study and due to the small size of UAE, other meteorological conditions were kept constant. Wind speed is considered a decisive factor in determining a site for wind energy (Mathew, 2006). Therefore, its analysis is set as the first priority. Tables 1 and 2 show a summary of wind speed and power at all stations. Out of the 34 meteorological stations, 9 stations had average monthly wind speed for the period 2004-2007 that exceeded 4 m/s. Out of this, seven stations (78%) are in the western region of Abu Dhabi, one at Ghantuat (between Abu Dhabi-Dubai), and one at Al Ain. This indicates that more detailed analysis would be needed in the western region of Abu Dhabi. The average January power (winter) at these stations was found to be 64 W/m^2 and for July was 61 W/m^2. This implies that the seasonal change in wind energy in UAE is not that significant.

6. Results and Analysis

The results provide detailed analysis on the impact of elevation, the regional variation in wind speed and power, and the western region of Abu Dhabi.

6.1 Elevation, Wind Speed and Power

Wind speed was expected to be high along the Eastern coastal areas facing the Gulf of Oman such as in Fujariah and Kalba because of the higher elevation. A previous study published in the UAE Atlas (1993) noted that the strongest winds were experienced along the coast of the Gulf of Oman, followed by mountain regions, the Arabian Gulf Coast, and the desert foreland, with the lightest wind in the interior. However, results in this study showed low wind speed values along the Eastern coastal areas facing the Gulf of Oman. This may be due to a problem with data, because data are strongly influenced by land-based measuring stations that are placed in sheltered locations, valleys, or along run ways, and the wind measurement may not represent the true average wind speeds. This has implications for the use of meteorological data to assess and forecast production for wind turbines. Another factor is that the 1993 study was based on limited meteorological stations mainly at the six airports while this study is based on 34 stations (6 airports in addition to 27 new automatic stations installed in 2003). Therefore, the availability of more data provides better analysis of wind speed and wind energy. Although variations in elevation above MSL cause variations in wind speed (wind shear) and consequently wind power, in general, in the UAE the relationship is not particularly significant, with correlation coefficient of only 0.167 for the best fit trend lines. This may be due to the fact that the heat flux at the surface in UAE is generally large and directed from ground to atmosphere. Therefore, the transport of heat and matter is likely to be highly convective and unstable. This results in rapid mixing and therefore less variation of wind speed with height.

6.2 Regional Classification of Wind Speed and Power

To have a closer look at the distribution of wind speed and power, the UAE is classified into three main areas: Offshore, coastal, and inland areas. The classification was based on the assumption that each of these areas has different surface roughness and therefore different wind regimes.

6.2.1 Offshore areas

Offshore areas are addressed separately because they have low surface roughness (no buildings or topography). Selection by location function in GIS was used to screen all offshore stations within the Arabian Gulf. There are more than 200 UAE islands in the Arabian Gulf. Some of these islands contribute significantly to the oil production such as in Zakum Oil field. Other islands play an important role in environmental and conservation efforts such as Sir Bin Yas Island. The island contains unique species of plant, animal, birds, and sea life. Abu

Alabyad is considered the biggest island and Dalma is known as the pearl center in the past. With the economic and real estate market boom, islands are becoming more attractive/potential sites for development due to their characteristics as water fronts e.g. Saddiyat, Reem, Palm, and world islands. Therefore, there is an energy need at these islands for diverse uses. The study showed the availability of potential wind energy around islands, especially along the western coast of Abu Dhabi. The wind speed (Figure 1) varies between 3.89 m/s and 4.44 m/s with mean of 4.07 m/s. Maximum wind speed (gust) ranges between 8 and 14 m/s. This speed can be accounted for in turbine design (cut-in and cut-out speed). The wind power varies between 36 and 53 W/m^2 with the mean of 42 W/m^2 (Table 1, Figure 2). Therefore, wind energy can serve as an alternate or backup source of electricity for the islands. In fact, a US$ 2.5 million power plant wind turbine has already been established in Sir Bin Yas Island,. The wind turbine, which stands 65 metres high has three rotor blades each with a 52 metre wing span, with a production capacity of 850 KW per hour. The energy it is currently producing is being used to power the island's facilities alongside conventional supply from the national grid (UAE Interact, 2008). This study proved as an independent one the suitability of Sir Bin Yas area for wind energy generation.

6.2.2 Coastal areas

The UAE coastal areas are the most highly populated areas. Almost 70% of the UAE population and consequently the majority of economical and social activities are along the coast, meaning it is an area with highest energy demand. The UAE coast extends 644 km along the Arabian Gulf and 90 km along the Gulf of Oman. Studies, at the University of Virginia, of winds in the coastal zones between 5 km inland and 5 km offshore, indicate that maximum wind power is usually found in areas about 5 km offshore and at altitude about 50 meters above the sea surface (Eldridge, 1980). Annual availability of wind energy in different parts of the world also showed coastal zones as among the top three areas that have higher wind energy (Eldridge, 1980). Coastal areas in this study are defined as those within 30 km inland and offshore from the shoreline. This is because the majority urban areas along the UAE coast fall within the 30 km zone. A buffer function in GIS was used to delineate this zone. The larger cities such as Abu Dhabi, Dubai, Sharjah, Ras Al Khaimah, Ajman, and Fujairah, are within this buffer zone. The highest wind speed (5 m/s) and consequently the highest wind power are identified mainly in the north-western coastal areas of Abu Dhabi (Tables 1, 2 and Figure 1). The main causes of this may be:

- The sea-side facing the coastal areas of the Arabian Gulf has low surface roughness. Coastal areas of western Abu Dhabi have low vegetation cover, buildings, and topography/elevation, therefore, the chances of wind movement inland is higher than in areas that have high surface roughness such as Abu Dhabi, Dubai, and Sharjah.
- Since the prevailing wind direction in UAE is from north (Shamal), it is expected that areas in the north and north-west of UAE will have higher wind speed. The wind speed will reduce as it moves inland due to surface roughness and to low kinetic energy.
- The large surface area of the Arabian Gulf facing western Abu Dhabi in comparison to the small surface area facing Dubai and Sharjah along the Strait of Harmoz. A study by Sorensen (2005) concluded that the best sites for wind energy conversion will usually be coastal sites with large fetch regions over water.

Table 1: Summary of wind speed (m/s) at all stations

	Offshore Stations	Coastal Stations	Inland Stations
Number of Stations	3	14	17
Mean speed	4.07	3.39	3.36
Max speed	4.44	5.28	4.40
Min speed	3.89	1.67	2.2
Standard deviation	0.26	1.02	0.5

Table 2: Summary of wind power (W/m^2) at all stations

	Offshore Stations	Coastal Stations	Inland Stations
Number of Stations	3	14	17
Mean power	42	30	25
Max power	53	90	53
Min power	36	3	7
Standard deviation	8	23	13

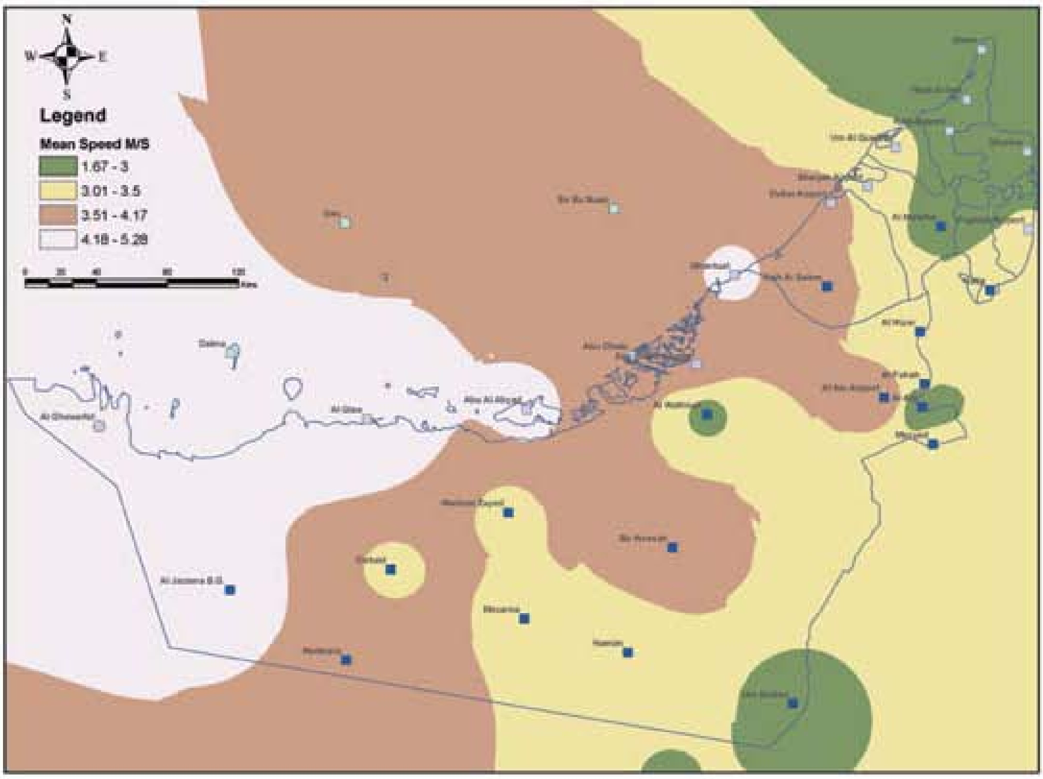

Figure 1: Distribution of mean-monthly wind speed in UAE

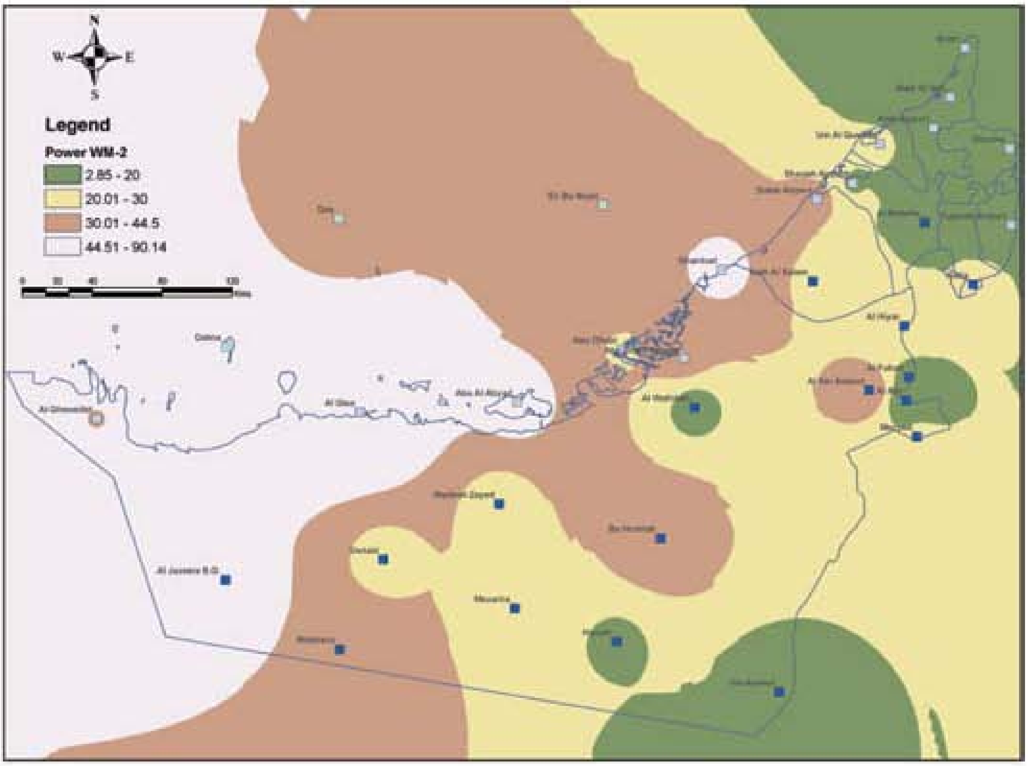

Figure 2: Distribution of mean-monthly wind energy in UAE

- The height or altitude of the Iranian Plate may affect also on the wind speed. The elevation of the Plate is found higher and steeper than the part facing Dubai and Sharjah. This indicates that the wind as passes from the high pressure zone (Latitude 30° North, Siberia) over the Plate will be compressed and consequently it is speed will increase.
- Other local factors include ocean-land interaction. Because of the difference in temperature between the Arabian Gulf and inland desert during the day and night, sea-land breeze generates local wind circulation that may reach speed of up to 5-8 m/s for sea breeze. The wind speed generated by Gulf breeze reaches its maximum during the middle of the day due to the high difference between sea and land temperature and consequent differences in pressure. This is to the advantage of wind energy because most of electricity consumption is during the day due to human activities (business, industry, schools, etc.) and mainly in air conditioning. Therefore, the link between the sun-solar radiation temperature, pressure, and wind movement and speed should be dealt with as integrated atmospheric system that influences wind energy.

6.2.3 Inland areas

The inland areas are those at a distance of 30 km away from the shoreline inland. There are 17 inland stations. The wind speed in these stations varies between 2.2 m/s as minimum and 4.4 m/s as maximum with the mean of 3.36 m/s and standard deviation of 0.5. Four inland stations had speeds exceeding 4 m/s, with mean power of 25, and maximum of 53 W/m^2 (Table 2). Generally speaking, all inland stations had low wind speeds. This is expected because as wind moves from the Gulf inland it loses power and faces more surface roughness due to sand dunes, trees, and urban areas. The exception for Al Ain is the due to the relatively high elevation. The elevation varies from 200 m in the city up to 1000 m above Mean sea Level at Hafeet Mountain.

6.3 Western Region of Abu Dhabi

The north-western coastal areas of Abu Dhabi had high potential for wind energy; the wind speed at the area exceeds 4 m/s. Therefore, more details are given. The details focused on the association of the wind potential with population centers, elevation, and other infrastructure in the area.

Population centers: Urban centers in the north-western coastal areas of Abu Dhabi include Tarif, Al Mirfa, Ruwais, Jabel Dhanna, and Shuwaihat. In general, the area is marked by agricultural activities and dominated by oil production, refineries, and petrochemical industries. Buffers with different radii (20, 30, 40 km) were made around the three potential meteorological stations (Al Qlaa, Abu Al Abyadh, Dalma) (Figure 3). The majority of the villages including Ruwais petroleum industrial area were found around Al Qlaa station (Figure 3). Moreover, Al Qlaa station is located along the coast which provides easy accessibility to roads, lower cost for setting wind turbine, ample area for wind farm and substation, while the other stations (Abu Al Abyadh and Dalma) are offshore. Therefore, the area around Al Qlaa station can be further explored for wind energy generation.

Elevation: The areas in western Abu Dhabi is relatively flat with elevation various between 10 to 100 m above Mean Sea Level. Therefore, screening is not largely affected by elevation.

Electricity network: One station (Al Qlaa) is found within a distance of 6 km and the other two stations are at distances of 45 km (Dalma) and 25 km (Abu Al Abyadh). Therefore, the area surrounded Al Qlaa meteorological station is considered appropriate for future link to the power network (Figure 3).

Road accessibility: Al Qlaa area is found at a distance of 8 km from the main roads and Abu Al Abyadh at 1 km while Dalma at distance of 58 km. Therefore, both Al Qlaa and Abu Al Abyadh areas are considered appropriate in terms of road accessibility with Abu Al Abyadh having higher weight.

Oil and Gas Infrastructure: The three stations are found at distances of 16 km, 28 km, and 15 km, respectively, from the oil infrastructure (pipelines, oilfields). The nearest biggest petroleum industrial area at Ruwais is at a distance of 15 km from the stations (Figure 3). Therefore, areas around the stations can be utilized for wind energy generation.

Water sources: Almost 80% of UAE drinking water comes from desalination plants. The nearest plant is at Al Mirfa at a distance of 47 Km from Al Qlaa, 35 km from Abu Al Abyadh, and 125 km from Dalma (Figure 3). Therefore, all the areas around the stations are suitable for wind energy generation.

Water Bodies: All sites screened were within the specified buffer zone of 1000 m from coastal areas (Figure 3).

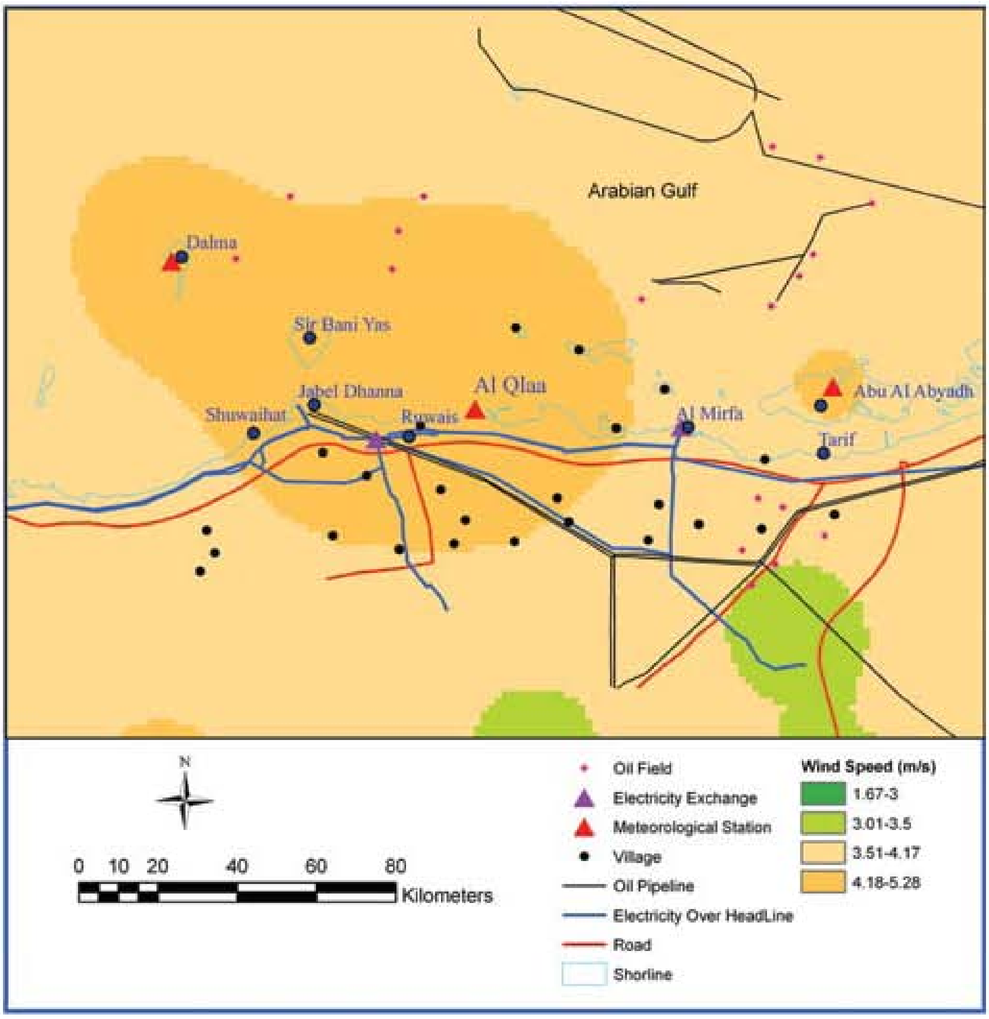

Figure 3: Areas with high potential wind energy (Western Abu Dhabi)

Airports: All UAE international airports were not within the selected sites, the nearest one is at Abu Dhabi at 80 Km away. The nearest local airport is at Al Mirfa at a distance of 50 Km.

Reserved and Recreational Areas: The suitable site for wind energy should be away from reserved and recreational areas by at least 1000 m in order to avoid threatening of endangered species, wildlife, and habitat. The nearest reserved area (Sir Bin Yas island) is located far away from any of the stations by at least of 40 km (Figure 3).

Historical Sites and Cultural Resources: At 10,000 m away from historical sites. The majority of historical sites in UAE are fortunately away from the selected sites, the nearest is at Liwa at a distance of 141 km away. From the above analysis it is clear that the area around Al Qlaa meteorological station is considered of high potential, therefore, more site specific analysis for the wind regime around the station is needed (Figure 3). A study carried out in Thailand showed the possibility of harvesting wind power for a country with low-medium wind speed profile by optimization in the design of turbine (Chompoo-inwai et al., 2008).

7. Conclusion

Four years (2004-2007) mean monthly wind speed data collected over 34 meteorological stations in UAE were used to assess the available wind power potential using GIS analysis. The average monthly wind speed at the top stations is found varies between 4.17 and 5.28 m/s. The estimated wind power varies between 44 and 90 W/m^2. Temporal/seasonal analysis shows that wind power varies between 28 and 127 W/m^2 during winter (Dec-March) and between 42 and 91 W/m^2 during summer (April-Nov) without major difference. Maximum wind speed (gusts) ranges between 8 and 14 m/s. This speed together with the minimum speed can be accounted for in turbine design (cut-in and cut-out speed). With the advent of new wind turbines that can start at wind speed of 4-5 m/s, the study showed possibility of establishing wind farms along the north-western coastal areas of Abu Dhabi. This compares with international findings. Available wind in western coastal areas in UAE can be utilized for diverse uses such as water pumping, lighting up highway signboards, and GSM Stations. Integration of the wind power data with power grid needs further investigation. Spatial and seasonal trends in mean wind as well as energy density are provided for whole UAE. The lesson learned from this work is that remote sensing images and GIS functions provide good management and screening tools for the initial wind energy assessment. However, for detailed analysis other tools such as Wind Atlas Analysis and Application Program (WAsP) may be required. The methodology adopted here can be extended to other parts of the world to assess wind energy potential. A wind Atlas for UAE is recommended. Public awareness is needed to promote and encourage renewable energy (Karl, 2006; UN-ESCWA, 2000).

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