A Geospatial Database for Wind and Solar Energy Applications: The Kingdom of Bahrain Study Case

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ABSTRACT

This research is aimed at designing, implementing, and testing a geospatial database for wind and solar energy applications in the Kingdom of Bahrain. All decision making needed to determine economic feasibility and establish site location for wind turbines or solar panels depends primarily on geospatial feature theme information and non-spatial (attribute) data for wind, solar, rainfall, temperature and weather characteristics of a particular region. Spatial data includes, but is not limited to, digital elevation, slopes, land use, zonings, parks, population density, road utility maps, and other related information. Digital elevations for over 450,000 spot at 50 m spatial horizontal resolution plus field surveying and GPS (at selected locations) was obtained from the Surveying and Land Registration Bureau (SLRB). Road, utilities, and population density are obtained from the Central Information Organization (CIO). Land use zoning, recreational parks, and other data are obtained from the Ministry of Municipalities and Agricultural Affairs. Wind, solar, humidity, rainfall, and temperature data are obtained from the Ministry of Transportation, Civil Aviation Section. LandSat Satellite and others images are obtained from NASA and online sources respectively. The collected geospatial data was geo-referenced to Ain el-Abd UTM Zone 39 North. 3D Digital Elevation Model (DEM)-50 m spatial resolutions was created using SLRB spot elevations. Slope and aspect maps were generate based on the DEM. Supervised image classification to identify open spaces was performed utilizing satellite images. Other geospatial data was converted to raster format with the same cell resolution. Non-spatial data are entered as an attribute to spatial features. To eliminate ambiguous solution, multi-criteria GIS model is developed based on, vector (discrete point, line, and polygon representations) as well as raster model (continuous representation). The model was tested at the Al-Areen proposed project, a relatively small area (15 km^2). Optimum site spatial location for the location of wind turbines and solar panels was determined and initial results indicates that the combination of wind and solar energy would be sufficient for the project to meet the energy demand at the present per capita consummation rate..

Keywords; Bahrain, GIS, renewable energy, Multi criteria modeling,

INTRODUCTION

Providing secure and sustainable energy represents a major challenge to every country worldwide. Energy demand is continuously increasing due to population growth and urbanization. Electricity brings social and economic benefits to rural communities which represent 52% of the human population [1]. More than 2 billion rural residents in developing countries currently lack reliable electricity service [2], providing a plausible prognostication for a significant threat to

livelihoods if the problem is not addressed. This problem and its ramification was articulated by The Millennium Goals adopted by the 2002 World Summit on Sustainable Development. [3].Coal and fossil fuel has been the mainstay of the world's energy for over 6 decades and has effected the phenomina of global warming and myriad environmental issues which weighed in on the urgency of finding an alternative. Renewable energy sources such as solar, wind, biomass, and others present the alternative sources. Nearly every country has established policies within their borders that address the need of and demand for renewable energy sources and began running pilot projects to explore such sources and ascertain ways and means of promoting its exploitation. The development of renewable energy in the Arab States of the Gulf has been relatively slow despite its many conducive elements and tremendous potential. This market has been stifled by a combination of constraints, such as the absence of relative legal and policy framework, the high initial capital costs and the lack of commercial skills and information [4].

THE KINGDOM OF BAHRAIN: OVERVIEW

The Kingdom of Bahrain is an archipelago of around 33 islands; the largest is the main island of Bahrain, all are low-lying islands between latitudes 26.10º and 25.22º North and longitudes 51.070º and 50.160º East [5]. They lay in an arm of the Arabian Gulf, known as the Gulf of Salwa, which separates the Qatar peninsula and Saudi Arabia.

The Kingdom's total land area was about 620 km^2 in 1965 [5]. Due to significant land reclamation activities since 1965, the estimated total area is 756 km^2 [5]. This represents an increase of 22% in total square area, making the Kingdom the most dynamic country in the world in terms of land reclamation.

The Climate of Bahrain

Bahrain's climate is characterized by a high average temperature and relative humidity during the summer. The minimum recorded temperature for the recorded years between 2003 and 2012 is 10.2 C, maximum is 39.7 C, the average 27.3, the mode 35.1 C, and the standard deviation is 6.8 C. The minimum relative humidity was 16%, maximum of 92%, average of 59%, mode of 59%, and standard deviation of 12.4% for the same period. Maximum rain for the same period is 34.7mm, and the numbers of days of rain are 222, the average is 0.2mm. On the other hand, the mean daily hours of sunshine range from a minimum of 7.3h in January, to a maximum of 11.3h in June [6]. The average annual wind speed is nearly 5m/s and it's mainly North to North West. Since Bahrain is an island, the

sea and land breezes assure the availability of wind most of the year. June is the windiest month throughout the year and noon is the windiest time during the day [6]. The solar radiation intensity in Bahrain is very high, ranging from a minimum of 3.25 kWh/m^2 in December, to a maximum of 7.19kWh/m^2 in July [6].

Energy Consummation

Bahrain is among the highest energy consumption rates in the world. The country uses nearly 10 times more energy than Japan on a per capita consumption basis. Bahrain's estimated energy consumption is about 695 million Btu's, compared that of Japan of only 178 million [7].

Renewable Energy

Bahrain has developed some renewable energy sources and achieved some progress during the last decade. Specifically, the adoption of solar technology was very advantageous in Bahrain in the small capacity projects that were inaugurated [4]. However, high temperatures and the mixture of dust and humidity tend to reduce photovoltaic and solar cell efficiency [8]. Due to relatively low wind speed, only small and limited wind turbine may be utilized According to the study of W.E. Alnaser, a good solution that is under construction is a mobile RES (hybrid) system consisting of wind generators and solar panels to produce 1.5 kW of (alternating current) electricity for rural areas. This system utilizes solar power (which is abundant in Bahrain) and wind power and is suitable for many applications, such as mini mobile clinics, small schools, libraries, and camping sites [9].Oceans and seas hold enormous and never-ending energy resources, which could be harnessed to produce sufficient energy by using the forces generated by the waves, currents and coastal water displacement between high and low tides. This source of energy is not cost effective in Bahrain due in part to a minimal tidal range the height of which does not exceed 3m. Investment in such projects is not recommended unless a location with a tidal height larger than 6m is found, [9].
The average family doweling energy consumption in Bahrain is very high; a number of studies has been conducted regarding building energy conservation and illustrating the electricity savings potentials in the residential sector [10].
The ECC is planning to formulate policies and regulations that would enable the government to establish a long-term and comprehensive energy program, the ECC would conduct a comprehensive study on the energy efficiency of various sectors in the kingdom. It would be carried out with the assistance of a Japanese consulting firm and the Japan International Co-operation Agency (JICA). The ECC had also initiated a project in co-operation with Japanese company InterDomain to install a

wind power measurement system for 12 months. This would enable assessment of the feasibility of utilizing the wind as a renewable energy source in Bahrain [7]. NOGA has embarked on an ambitious plan to secure more sustainable supply of energy for Bahrain.

Topography and Land Use
DEM analysis shows that Bahrain's elevation above sea level ranges from 1.00 to 134m, with 51.70% being above 5m. However, most urban areas are located between 0 to 2.0m. The Kingdom is mostly flat or near level, with 79% of Kingdom being nearly level (0–1%).

Renewable Energy Site selection
Geospatial data and Geographic Information systems (GIS) have been used in renewable energy research in three ways:

1. Decision support system [10-12]. GIS-based analyses are used to characterize spatially-related variables within a digital environment and help produce informative visualizations.
2. Model design for identifying renewable energy sources. GIS-based assessments have been used to evaluate renewable energy sources in the USA [12], developing Latin America countries, China, and Taiwan [13-15], solar radiation potential in rural India and Greece [16,17], community scale solar potential in the UK and California [18,19], and also to characterize site locations for wind farms [20] and manage community water resources [21,22].
3. Site selection [23], which is the focus of this research.

The literature suggests many different criteria for selecting the most suitable site for both solar and wind sites. The most common criteria categories are: environmental and economic. Site topography is of special importance, because of its impact of slope, aspect, and height. It also impacts directly wind speed and turbulence. Mountains result in increased wind speed; this is partly a result of altitude. Equally, topography may produce areas of reduced wind speed, such as sheltered valleys, areas in the lee of a mountain ridge or where the flow patterns result in stagnation points [24]. Wind regimes in different geographical locations can vary widely. At a given location, temporal variability on a large scale means that the amount of wind may vary from one year to the next, with even longer scale variations on a scale of decades or more [24].These long-term variations are not well understood and may make it difficult to make accurate predictions of the

economic viability of particular wind farm projects, for instance. On timescales shorter than a year, seasonal variations are much more predictable, although there remain large variations on shorter timescales [24].

STUDY AREA

A 3.5km^2 study area is located in the south-west of the Kingdom of Bahrain. Although wind speed is moderate according to obtained data, the area has a large moderate slope terrain, which is preferable considering the slope criteria constraints of wind farm locations. Additionally, the area also has adequate highlands for air inflow. Thus, it can be stated that the city may have sufficient wind energy potential. Figure 1

DATA COLLECTION AND PREPARATION

A base map for the Kingdom of Bahrain, DEM for over 450,000 spot elevation points at 50m spatial horizontal resolution plus field surveying and GPS -at selected locations- are obtained from SLRB. Road, utilities, and population density are obtained from the CIO. Land use zoning and recreational parks are obtained from the Ministry of Municipalities and Agricultural Affairs. Wind, solar, humidity, rainfall, and temperature data are obtained from the Ministry of Transportation, Civil Aviation Section. LandSat Satellite images are obtained from NASA, others images are obtained from online sources. The collected geospatial data were geo-referenced to Ain el-Abd UTM Zone 39 North.

Data Analysis

ArcGIS 10.2 and extension are used for data processing and analysis. A 3D surface is generated based on the DEM at 50m spatial resolutions. Slope and Aspect maps are generated from the created 3D surface (figures 2 and 3). Supervised image classification to identify open space areas was performed utilizing satellite images. Other geospatial data is converted to raster format with the same cell resolution. A 100 meter buffer zone is created around all POI, roads, and national parks. A multi-criteria GIS model is developed based on vector (discrete point, line, and polygon representations) and raster model (continuous representation) to eliminate ambiguous solutions.
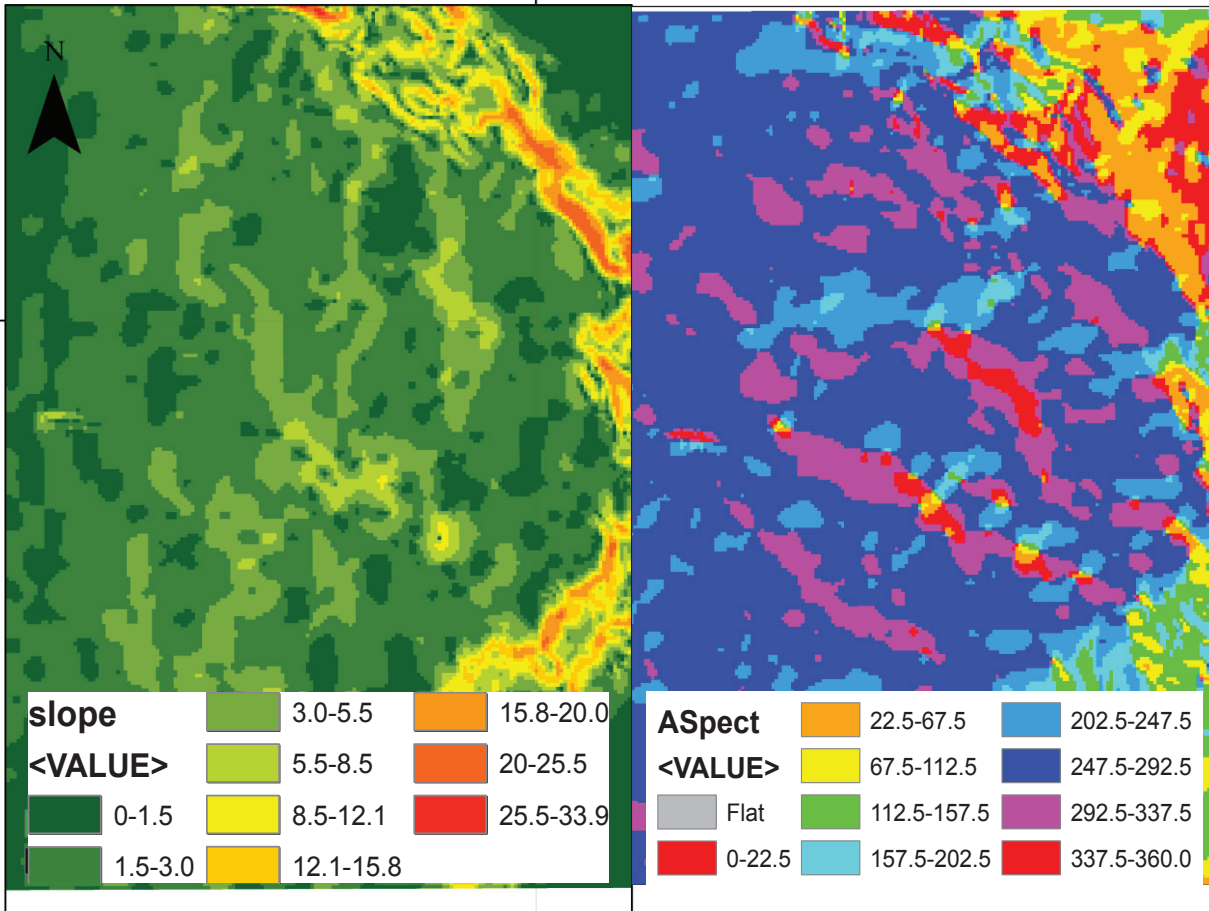
Figure 24 the Study Area

Figure 2 Slope Distribution

Figure 3 Aspect Distribution

RESULTS

Using the obtained DEM raster surface, slope, aspect maps, and multi-selection criteria listed in table 1, the most suitable sites map is created (figure 4). The map shows that there are broad field for suitable wind farms, however, the size of these sites differ significantly, between 500- 27,000m^2. All sites are to the west and north-west, this area is an open area with very little restrictions. The area toward the east side is mostly rough and with steep slope terrain.

Table 1 Site selection Criteria

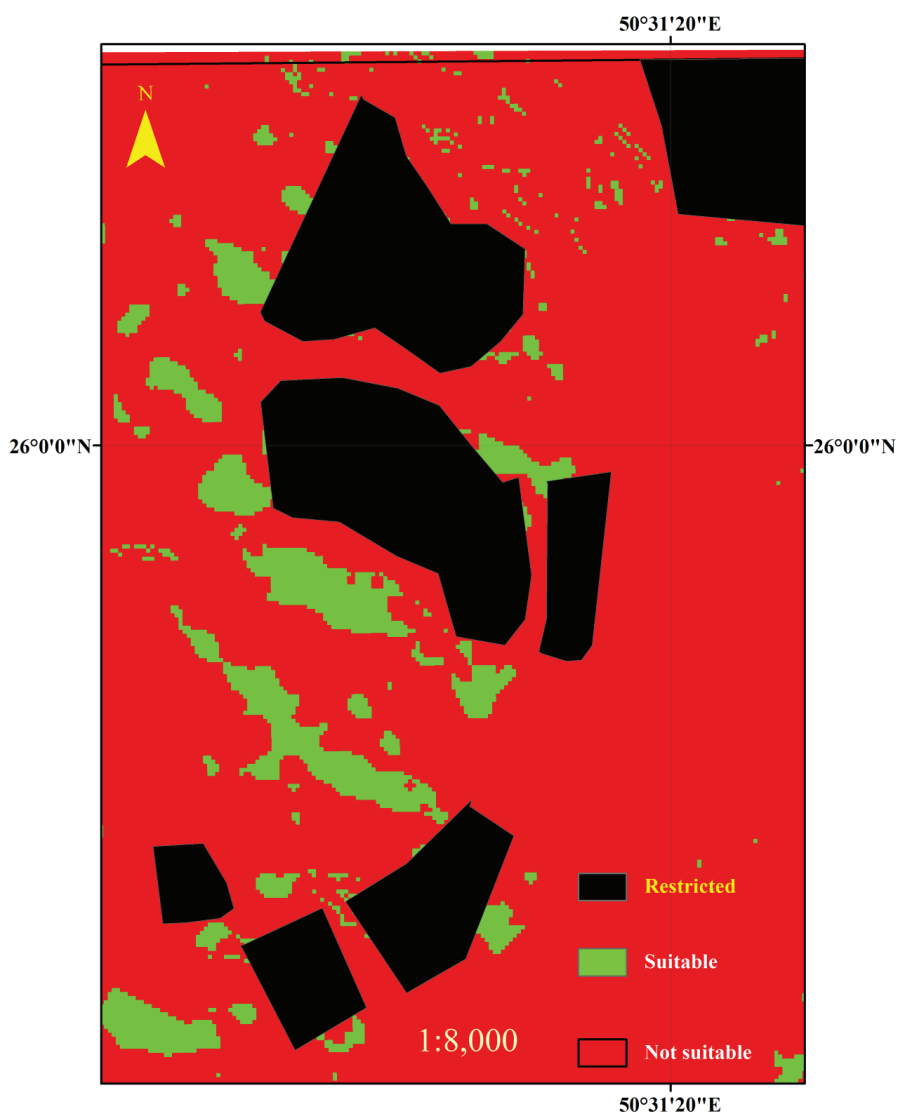| Class	Score	Class	Score	Class	Score
Roads		**Slope**		**Aspect**	
0-100 m	0	0-5%	100	0-180 ^{0}	0
> 100 m	100	5 -10%	50	180-270^0	50
POI		>10	0	270-300	75
0-100 m	0	**Elevation**		300- 360^0	100
> 100 m	100	0-10	0		
		> 10	100		

Figure 4 Obtained Suitable Sites

CONCLUSION

Renewable energy is no longer a choice, it is a must. Traditional fossil energy sources are depleting rapidly and cause environmental degradation. Countries around the globe are searching for new energy sources and planning an effective decision making-system that can facilitate renewable energy management. Identifying, locating, and implementing wind and solar projects depends primarily on the spatial location and terrain properties. A geospatial database is at the heart of any decision making systems. It encompasses an array of multidimensional thematic spatial and non-spatial information. Examples of which are digital elevation, road centerlines, utilities, wind speed, wind direction, etc. A geospatial database for the Kingdom of Bahrain was created. It includes all necessary information needed to plan and implement a renewable energy project. The created geospatial database was tested for identifying the most suitable site for installing a wind turbine and solar farm. A $3.5km^2$ area was selected in the Southern province of the Kingdom of Bahrain. A GIS based on a multi-criteria site selection was implemented to decide the most suitable wind and solar farm locations. Despite some limitations and constraints the study has portrayed both the effectiveness of GIS as a research tool and the importance's of having a geospatial database. The study established that that the Kingdom of Bahrain is capable of implementing wind power as a sustainable and renewable energy source.

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