Integrating WAsP and GIS Tools for Establishing Best Positions for Wind Turbines in South Iraq

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Abstract—**The correlation between WAsP (Wind Atlas Analysis and Application Program) and GIS (Geographic Information System) is presented. This correlation was undertaken to produce wind energies maps by data analysis for wind speeds and directions and benefit from management ability of the widely used WAsP model and utilizing Arc GIS program. The data involved in WAsP modeling were converted and integrated into GIS using spatial analyst tools. The Inverse Distance Weighted (IDW) was used in this project. So, the correlation determined the best location depending on WAsP model and utilizing the Arc GIS program to produce map of the distribution of wind energies for 6 stations in southern of Iraq represented the studied area.**

Key words- WAsP; GIS, IDW; mean speed, Power density.

I. INTRODUCTION

The WAsP is a standard tool typically used for sitting the appropriate locations for the construction of windmills of electric power turbines. The numerical model was first introduced in 1987 by the Department of Wind Energy at the Technical University of Denmark [1, 2]. It was developed to produce winds maps of the European Wind Atlas. The program employs a comprehensive list of models for projection of the horizontal and vertical extrapolation of wind climate statistics, the estimation of wind climate and wind resources [3]. The WAsP model is a linear numerical model which is based on the physical principles of flows in the atmospheric boundary layer. This model has been validated by a number of comparisons between measured and modeled wind statistics and wind farm production [4]. The program is capable of describing wind flow over different terrains, close to sheltering obstacles and at specific points. The method employed by WAsP is called the ***wind atlas methodology***. The wind atlas methodology requires that wind data should be collected for a period not less than one year [5]. The WAsP model extrapolates wind speed for turbines of heights starting from 10m (from the ground level at meteorological station upwards to the hub height of the turbine, as given by;

$$\frac{u_2}{u_1} = \frac{\ln(\frac{h}{z_{01}})}{\ln(\frac{h}{z_{02}})} \tag{1}$$

Where: u_1 and u_2 are the wind speeds at 10m and the hub height (h), respectively, and z_{01} and z_{02} are the upwind and the downwind roughness lengths.

The WAsP program enables an analysis of any time-series of wind speed and directional measurements. The output is a ***wind rose*** and wind speed distributions in different sectors of the study area. Weibull distribution function which is fitted to the measured histograms is implemented to provide scale and shape parameters A and k for each sector, as given by;

$$f(u) = \frac{k}{A}\left(\frac{u}{A}\right)^{(k-1)} e^{\left(-\left(\frac{u}{A}\right)^{k}\right)} \tag{2}$$

Where: *A* is a Scale Parameter (m/s), *k* is a Shape Parameter, and u is the wind Speed (m/s)

One of the functions of *GIS* is spatial analysis and spatial information processing to extract data and useful information from the original data. The *GIS* provides spatial analysis tools to calculate statistical features and geo data interpolation processing activities.In order to generate a wind's map for the speed and/or power intensity and is efficiently used in WAsP model, a suitable interpolation method has to be used to optimally estimate the values at locations where no recorded measurements were existed. The results of the interpolation analysis can then be used for analyses that cover the whole region of the study area [6]. *IDW* interpolation method explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, *IDW* uses the measured values surrounding the prediction location; the measured values closest to the prediction location given more influence on the predicted value than those farther away. Therefore, in the *IDW* interpolation the sample points are weighted during interpolation, the greater the distance the less influence on the predicted value [7], given by;

$$Z = \frac{\sum w_i z_i}{\sum w_i} \tag{3}$$

Where: $w = \frac{1}{d^k}$, z_i the location value of point *i*, *d* the distance to the known point *i*, and *k* is a constant that influence the distance weighting.

When WAsP creates a generalized wind climate for the study area, it uses the total energy content of the wind's mean that has calculated from the Metrological data. In our present project, the wind turbine adopted for this study was a ***V82 -1.65 MW-Vestas.*** It has a blade diameter 82m, cut-in wind speed of 3.5 m/s, and cut-out wind speed of 20 m/s. With the provided ***Vestas turbine power curve*** it can estimate the ***annual energy production*** (AEP) at each of the turbines in the wind farm layout [8], using;

$$AEP = T \int P(u)(\tfrac{k}{A})(\tfrac{u}{A})^{k-1} e^{(-\frac{u}{A})^k} du \tag{4}$$

P(u) represents the wind turbines power curve measured for a time period *T*.

II. THE STUDY AREA

The study area, as shown in Fig.1, represents the south-east regions of Iraq country, enclosed by the following Northern and Eastern geographical lines (N:32.601449° to N:29.816974°) and (E:48.518033° to E:44.613606°). The area contains six ground monitoring metrological stations namely; ***Al-Kut, Ali-Algharby, Emarah, Al-Hay, Basrah and Nasriyah***. The collected wind data were made up as time series and frequency statistics based on the available observations of wind speed and wind directions recorded for every 10 minutes intervals for the year 2011.

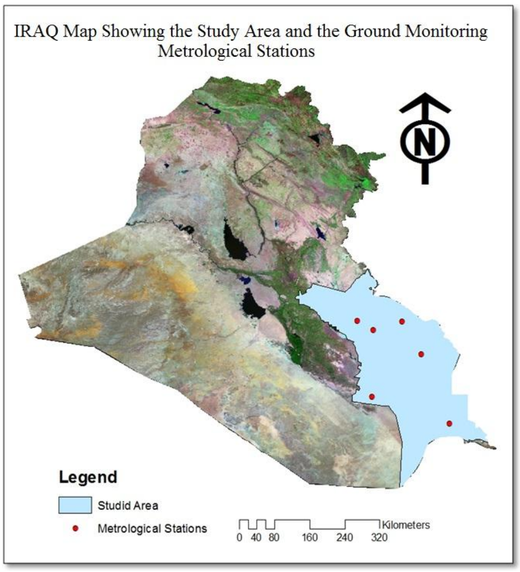

Figure 1 IRAQ country map shows the study area.

III. METHODOLOGY

In this project hourly wind speeds and directions have been collected from six observations metrological stations, recorded every 10 minutes time interval, for the year 2011. As it is known, the WAsP does not use the time-series of meteorological data but, instead, uses a tabular summary of the frequency of occurrence of wind speed versus wind direction. The ***Observed Wind Climate*** (OWC) is produced from the raw data files provided by the metrological ground station. The WAsP then removes the local topographic effects (e.g. roughness, shelter obstacles) to create regional wind climate suitable for wind resource mapping cover the turbine sites. The OWC then used as input data, utilizing the micro scale surface property descriptor of the WAsP.

The WAsP combines the topographic effects and the regional wind climate at the turbine site (the adopted turbine type in this project was *Vestas V82-1.65 MW* of hub height 70 m) to produce wind resource grid map for the study area, for the details see [9]. The produced regional wind climate map has resource grids (each of size 10Km ×10Km) cover the entire studied region, in which the metrological station lies at its center. The turbine locations can then identified as places having suitable wind resource. Within the provided *Vestas V82-1.65 MW* power curve, the annual energy production AEP can be estimated at turbine's position within the study area.

The resulted *mean wind speed*, the *power density*, and the *AEP* at hub height of 70m were utilized by the *GIS*

(*ArcGIS* tools) to produce geographic layers in as raster form. The raster formatted form facilitates the tasks of the addition or deletion of undesired raster values at the subsequent reclassification of the data layers. The data layers have been used to assess wind turbine sites depending on the wind speed resource, power density, and AEP. Because the current project covered large areas, a suitable spatial interpolation method (i.e. Inverse Distance Weighting "IDW") has been used to produce wind maps for whole studied areas.

IV. RESULTS and DISCUSSIONS

Taking into account the topographical factors, the following gathered annual data can be computed (i.e. wind speed and wind direction) at the meteorological tower (10m). It must be mentioned again that the meteorological data were collected every 10minutes on average. These results then projected on the map of the wind farm, using the defined locations on a topographic map of the study area and the characteristics of the used wind turbines. As the wind speed is predicted at hub height 70 m for each turbine site, the power production can be estimated. The measured mean speed, power density and AEP from the wind farm is presented in Table I

TABLE I The measured Mean speed, Power density and AEP from the wind farm

Stations	Turbine Site	Longitude (m)	Latitude (m)	Mean speed (m/s)	Power Density (W/m2)	AEP (GWh)
Al-Kut	Turbine site 1	564783.100	3600546.000	5.470	169	3.068
	Turbine site 2	563552.500	3582150.000	5.480	170	3.081
	Turbine site 3	580456.400	3581761.000	5.480	170	3.078
	Turbine site 4	572049.000	359242.000	5.480	170	3.072
Al-Hay	Turbine site 1	610306.600	3580370.000	5.480	170	3.087
	Turbine site 2	595585.400	3580566.000	5.480	170	3.075
	Turbine site 3	600399.600	3562460.000	5.480	169	3.067
	Turbine site 4	602013.000	3572355.000	5.480	170	3.072
Ali Al-Gharby	Turbine site 1	651764.700	3600441.000	7.140	342	5.568
	Turbine site 2	650586.600	3583762.000	7.110	338	5.524
	Turbine site 3	666024.800	3584444.000	7.110	338	5.522
	Turbine site 4	658038.000	3591936.000	7.130	341	5.554
Basrah	Turbine site 1	747272.100	3376963.000	7.100	337	5.511
	Turbine site 2	760237.400	3377093.000	7.100	338	5.513
	Turbine site 3	747402.000	3359633.000	5.090	336	5.501
	Turbine site 4	754369.100	3368104.000	7.100	338	5.518
Emarah	Turbine site 1	696319.400	3527910.000	11.000	1398	9.036
	Turbine site 2	686983.400	3512834.000	11.010	1402	9.030
	Turbine site 3	703045.900	3511906.000	11.010	1402	9.033
Nasriyah	Turbine site 4	695652.000	3520127.000	11.010	1400	9.031
	Turbine site 1	593322.900	3431994.000	6.220	290	4.300
	Turbine site 2	593831.500	341643.000	6.230	290	4.304
	Turbine site 3	607292.000	341487.000	6.230	290	4.306
	Turbine site 4	601887.000	3424539.000	6.230	291	4.306

One of the most useful features in WAsP wind resource network is the ability to produce a color image map over the study area. This feature can be used to determine the susceptibility of wind speed needed to run the turbines. Figs.(2, 3, 4, 5, 6, 7) represents color images of maps for wind farms, measured at a height of 70m. The red color represents the most appropriate sites while the blue color for the least suitability.

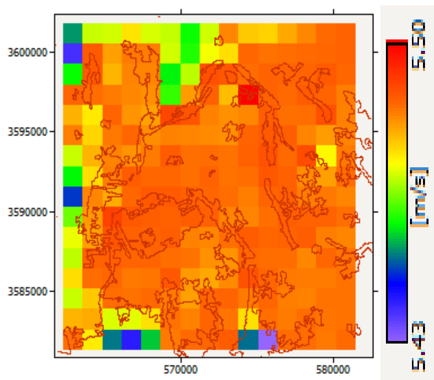

Fig.2 Al-Kut Site

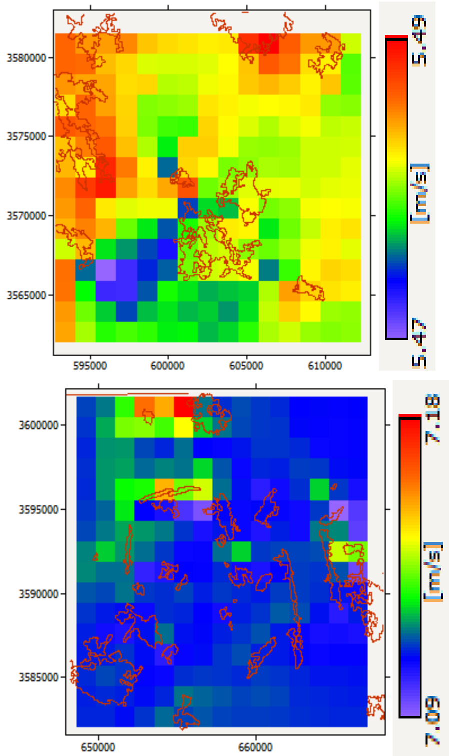

Fig.4 Ali Al-Gharby Site

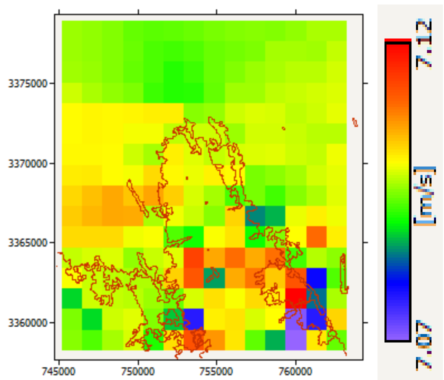

Fig.5 Basrah Site

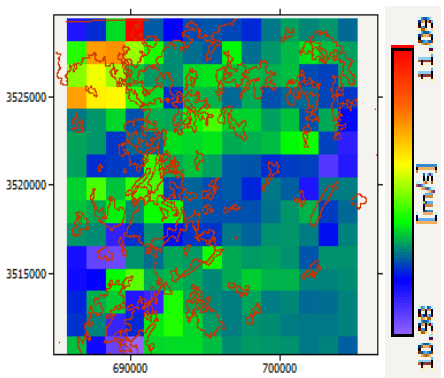

Fig.6 Emarah Site

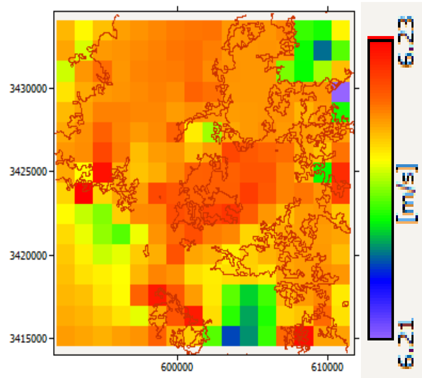

Fig.7 Nasriyah Site

Classification of the study areas in accordance with the rates of wind speed will facilitate the calculation of the amount of energy produced, especially in the most appropriated areas. Consequently, we can locate the positions of the wind turbines, as shown in figs. (8, 9, 10). The images represent maps of winds at a height of 70m above ground level. As is evident in these figures, the results were classified into (9) nine bands for wind speeds that can be exploited for the production of electrical energy.

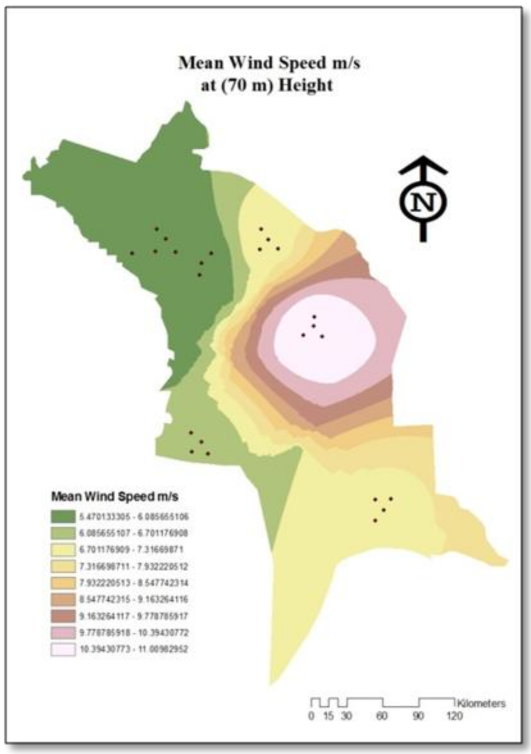

Fig.8 Mean Wind Speed (m/s)

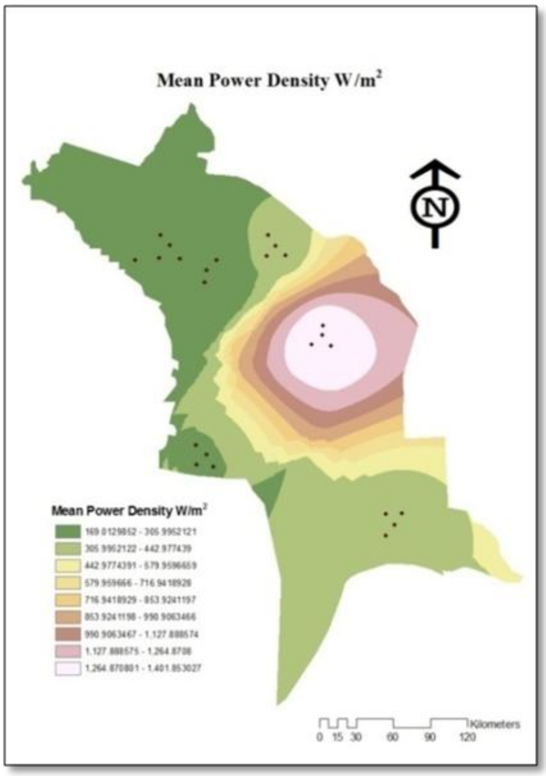

Fig.9 Wind Power Density (W/m^2)

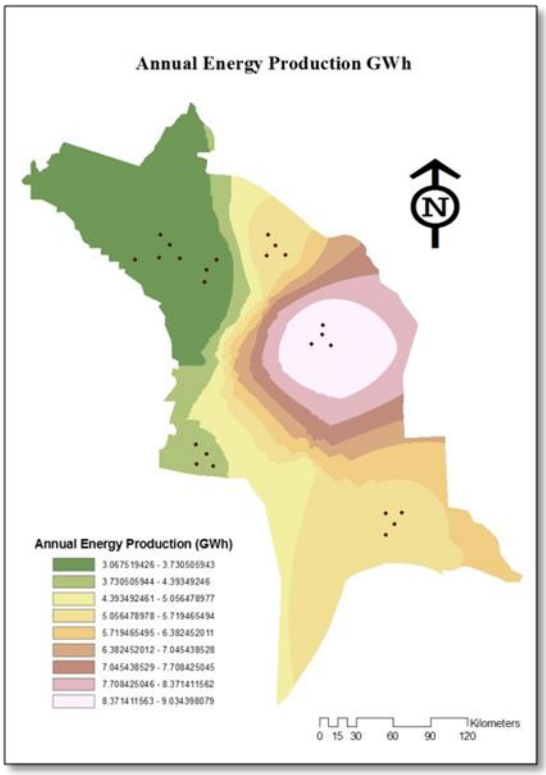

Fig.10 Annual Energy Production (GWh)

Statistics related to figures (7, 8, 9) are presented in Tables (2, 3, 4).

Table.2. Mean Wind Speed

Class	Range of Mean Wind Speed(m/s)	Area (m^2)
1	10.30 – 11.00	4713717232
2	9.77 - 10.30	4895783213
3	9.16 - 9.77	3205599075
4	8.54 - 9.16	2955082790
5	7.93 - 8.54	3080771309
6	7.31 - 7.93	6395667459
7	6.70 - 7.31	17091574209
8	6.08 - 6.70	8156726955
9	5.47 - 6.08	17649870213

Table.3. Power Density

Class	Range of Power Density (W/m^2)	Area (m^2)
1	1264.870801 - 1401.853027	3880089963
2	1127.888575 - 1264.8708	4509623230
3	990.9063467 - 1127.888574	3141993167
4	853.9241198 - 990.9063466	2772940505
5	716.9418929 - 853.9241197	2469592207
6	579.959666 - 716.9418928	2821146132
7	442.9774391 - 579.9596659	4843829715
8	305.9952122 - 442.977439	21601605762
9	169.0129852 - 305.9952121	22030873752

Table.4. Annual Energy Production (AEP)

class	Range of *AEP* (GWh)	Area (m^2)
1	8.371411563 - 9.034398079	5642193484
2	7.708425046 - 8.371411562	115923.2828
3	7.045438529 - 7.708425045	3516384776
4	6.382452012 - 7.045438528	3396772087
5	5.719465495 - 6.382452011	6546529511
6	5.056478978 - 5.719465494	15073400778
7	4.393492461 - 5.056478977	7721611335
8	3.730505944 - 4.39349246	4677848200
9	3.067519426 - 3.730505943	16523906873

CONCLUSIONS

The subject of our present study was to locate the appropriate sites for constructing wind turbines in selected areas of southern Iraq. The GIS tools were utilized together with WAsP model to perform the required operations. As it is well known, the WAsP model is used for ***strategic environmental assessments*** which are broader in scope than ***environmental impact assessments*** and, therefore, permit the decision maker to proactively determine the most suitable development type for a particular area before development proposals are formulated. It is suitable for areas of strong wind resources but, unfortunately, unusable for other cases. So, the GIS has been integrated with WAsP model to produce relevant assessment criteria for determining the best sites for erecting the wind turbines. In fact, the qualifications of the WAsP to estimate wind resources are perfect but for tiny areas. To overcome this shortage, the IDW interpolation method has been adopted, using the Arc GIS to superimpose the results obtained by the WAsP (i.e. mean wind speed, power density, and annual power density) over the whole study area. Four best locations of turbine sites have been defined for each study areas. The project can, easily, extended to locate more turbine sites as required to produce the desired power.

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