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A Novel Geographic Information System –Decision Supporting System Siting Model for Wind Farms Industry in Egypt*

M. N. Abelwhab[1], Basem E. Elnaghi[1], Tamer M. Ismail [2+] and Khaled Ramzy[2+]
[1] *Department of Electrical Power and Machines, Suez Canal University, Ismailia, Egypt*
[2] *Department of Mechanical Engineering, Suez Canal University, Ismailia, Egypt*

Abstract: *This study introduces a new model of (GIS) linked to a (DSS) for wind site selection in order to support the wind energy industry investors in Egypt. Sixteen conflicting constraints are involved in the siting model and solved based on the powerful ArcGIS tools. The output results are successfully ranked (0 to 5) by implementing the overlay weighted approach with reference to a consistency ratio of 0.031 which is far below the threshold of (0.1). For economic analysis, the output optimal GIS sites of the new model have been interlinked to the international package WAsP to determine the wind turbines configuration at the site, and the long term energy production including the uncertainty and sensitivity variation in the economical results. Different wind large wind farms capacities are investigated at different scenarios of wind turbine technology to support the client final decision. These results are hybrid to the DSS to determine the final wind farms siting in Egypt and act as a "Siting Atlas" covering the country with enough information.*
Keywords: *GIS Geographic information system; DSS decision supporting system; Wind siting; Wind Atlas; WAsp data.*

I. INTRODUCTION

They Egyptian supreme council for energy (ESCE) have established strategic plans of both short and long terms for the country energy portfolio. The council [1-2] was aware of the efficiency of the wind energy production, that was proved to be better than the other alternatives because Egypt has a high potential of wind speed that reaches in some good areas about 10.5m/s. Currently, there is a short term plan that aims at increasing the already installed capacity of a wind site to about 1100 MW. It had been forecasted that the estimated growth of the installed capacity required by 2030 from sources of renewable energies should be about 15000 MW including wind farms energy. 1.5 million Feddans have been assigned for upcoming projects of wind energy. In Egypt, the wind farms industry is not only concerned with the wind speed or wind potential. There are some other factors that should be regarded when determining the most appropriate sites in the country for establishing wind sites. Suitability and siting of wind farm locations is a great challenge and a complex task, and includes different criteria investigation for the suitable choices to get over any challenges of the private sectors. In Egypt, the areas of wind potential will be remapped using high accuracy including several layers sub-maps overlaid and linked together with all terms, objects, and constraints that meet both the international and national needs. Until now, no definite process or mechanism has been determined in Egypt concerning the locations of wind sites that regard all hardships and analysis sets that offer options concerning the selection of the site before constructing or installing any wind energy farm system at any place.

This paper main goal is to present a new GIS-DSS model with analysis built on an intelligent hybrid technique that applies the Analytical Hierarchy Process (AHP) and the economic analysis. The model will represent a process of national site screening which supports both the private sectors and the governmental ones to choose the supreme economical wind sites in Egypt.

II. EGYPTIAN POTENTIAL AND PROBLEMS OF WIND FARMS.

In top notch wind technology, a dependent dbase is important as a first phase that determines the probability of selecting a suitable area for wind sites in any place around the world. The Wind Atlas is considered as a great wind data-base in Egypt, it covers more than one million km^2 [3]. The resulted data were built on measurements that took eight years, of at thirty metrological stations as shown in Fig.1. Furthermore, numerical methods were used to manipulate the registered data to scan the whole state with dbase of reliable good wind as explained in Fig. 2. Collecting these databases together with raising maps extracted from the task of space shuttle topography and land maps built on images captured by satellites, the power production and resource of a specific wind farm can assist in making decision concerning choosing the most suitable siting for establishing a factory depends mainly on wind energy.

In Egypt, it was observed that the potential of the wind energy is outstanding and providing a chance for producing wind energy. Egypt Wind Atlas approves that there is boundary resources of wind energy in the following areas:

i) Gulf of Suez

ii) The Nile River Banks, especially next to Governorates of Menia and Beni-Sweif

iii) New Valley Governorate, especially El-Kharga Oasis.

The last mentioned areas are probably regarded as the best locations owing to stable and high wind speeds. The first stage of investigation proves that the Suez Gulf West Zone can be a high productive location to build huge farms because of the following reasons:

- It has an average of high wind speeds that range from (8-10) m/s.
- It is surrounded with large desert area.

For example, built on the estimated data explained in Fig. 2, a commercial standard of 2.5MW, in case of installing a rating wind turbine at the most suitable location in the Suez Gulf southern area, it would produce about: 10500 MWh/y. The other places are still predicted to be high-productive locations that have wind velocity average of 8-9 m/s.

There are different international and national limitations that may stop installation of wind farms at wind locations. These limitations include [4-8]:

i) The accessibility and capacity of electrical transmission

ii) The accessibility, orientation, capacity, and complexity of a site

iii) Some protected areas by the governmental law near the location

iv) The location is close to urban and/or cities

v) The location is close to vegetation and/or National parks,

vi) The location is close to the immigration bird,

vii) The awareness on both social and cultural levels about wind energy

viii) The conditions of the location's soil

xi) Telecommunications/Aviation permission

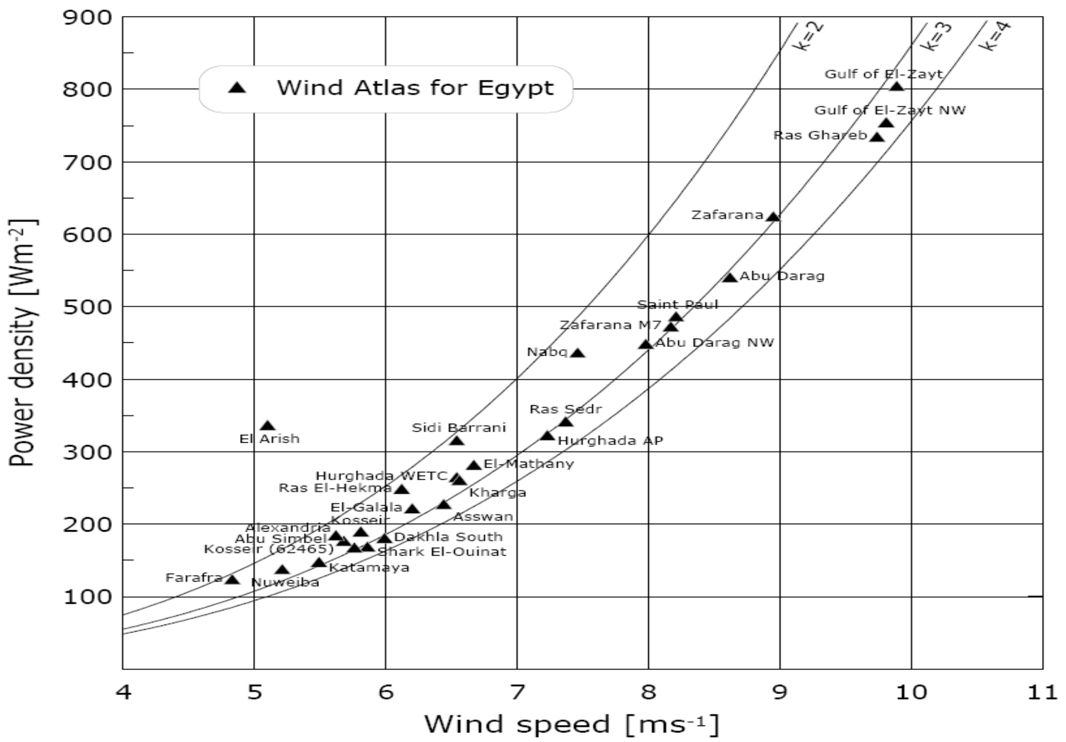

Figure (1) *The Measurement of Egyptian Wind Locations*

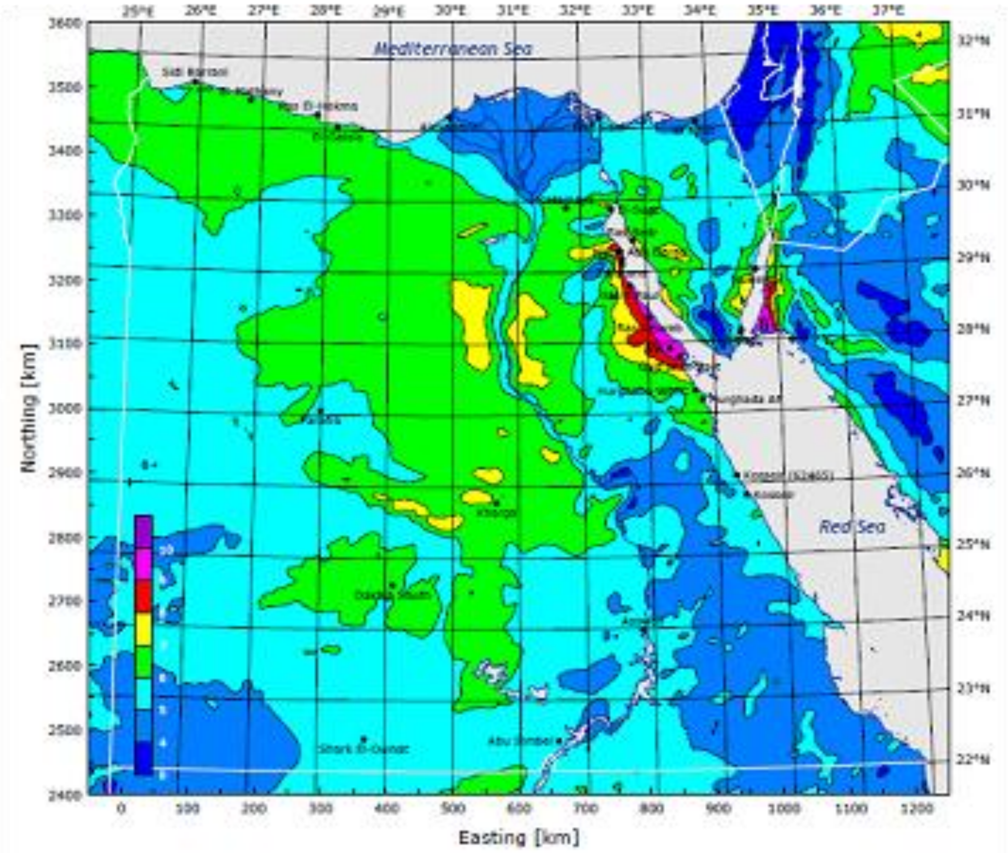

Figure (2) *Egypt Wind Resources Layer Chart*

Based on the international reference conditions [4-12], the economical doorway is comparable to the locations that have a dense wind power of more than 400 W/m^2. It depends on the ability of wind at least 6m/s to establish an economical wind farms.

The wind energy development in Egypt depends on three issues:

i) Appropriate locations of the wind sites.

ii) Technology of wind farm.

iii) Production of electric energy for maximum investments in systems of wind energy.

The study is to set up a smart model to offer the appropriate answers for decision makers and make them able to have well-informed decisions. The study also deals with the problems connected to the wind energy farm scales united into systems of the electrical power including: wind turbines technology, optimal site selection, and effective economical cost investments.

III. METHODOLOGY OF THE NEW GIS-MCDS MODEL

In Egypt, no definite mechanism or decision, concerning the construction of wind energy farm, would take into consideration the conflicts to improve the suitability of location; this project presents a solution model for the locations for the industry wind farms. To achieve this goal, the research activities are concentrating on the following:

i) To identify the main limitations of development the wind energy farms.

ii) To introduce a screening mechanism, estimating and arranging resources wind site locations.

iv) To establish a GIS-DSS system to perform as “Egyptian Wind Atlas” that provides any investor with the sufficient information with high accuracy to support the defining and the selection of the supreme convenient locations for wind farms depending on:

a) The availability of ideal wind energy in the whole country.

b) The ability of effective wind energy is in accordance with the location features and the environmental fitness.

c) The systems of technological ability of wind industry.

d) The economic ability of the output energy from the wind site.

Due to the connected elements drawing from the location conditions including: nature, demography, economy, politics, and environment, the paper in hand gives treatment for such problems by embracing two complementary phases:

(A): This phase is based on four processing stages that deal with:

i) Evaluation of the Egyptian wind potentials and rejection the improper locations of wind sites selection,
ii) Land suitable evaluation,
iii) Economic Approach
iv) Introductory of prioritizing, weighing and ranking of the location

Stage (B): This stage depends on two processing steps:
i) Connecting the Geographic Information System (GIS) with final scanning
ii) Developing combined GIS-DSS system.

IV. THE GIS-DSS DEVELOPMENT

The developed GIS-DSS system will be depend to:
i) D-base environment of extensive GIS based on this study.
ii) A significant index developed to make interaction with the GIS data-base.

The perfect quality is estimated for the valuable resources of the wind energy, the integrated platform of GIS-DSS should replace all data into objects sets of the same reference conditions and interacting according to their relation basis.These objects interaction tools are supplied by the GIS, however the procedures of object sets design and their behavior characteristics were developed in this project.The accuracy of the accessible data and objects has a significant effect on the over-all results of the quality of the location of wind farm. Fig.3 shows the complications layers of the approach which results in the suitable selection of the wind farm in the country. The methodology presented in this paper and interlinked to the GIS-DSS is generalized, flexible and gives a well-known outline to any renewable energy sources. Furthermore, the proposed system develops the wind technology potential that reflects the optimum energy resource resulted from the wind site, including:
a) The computation of energy produced cost for each farm having suitable available potential.
b) The economic analysis provides a significant for the utilities and the private sectors may be needed.

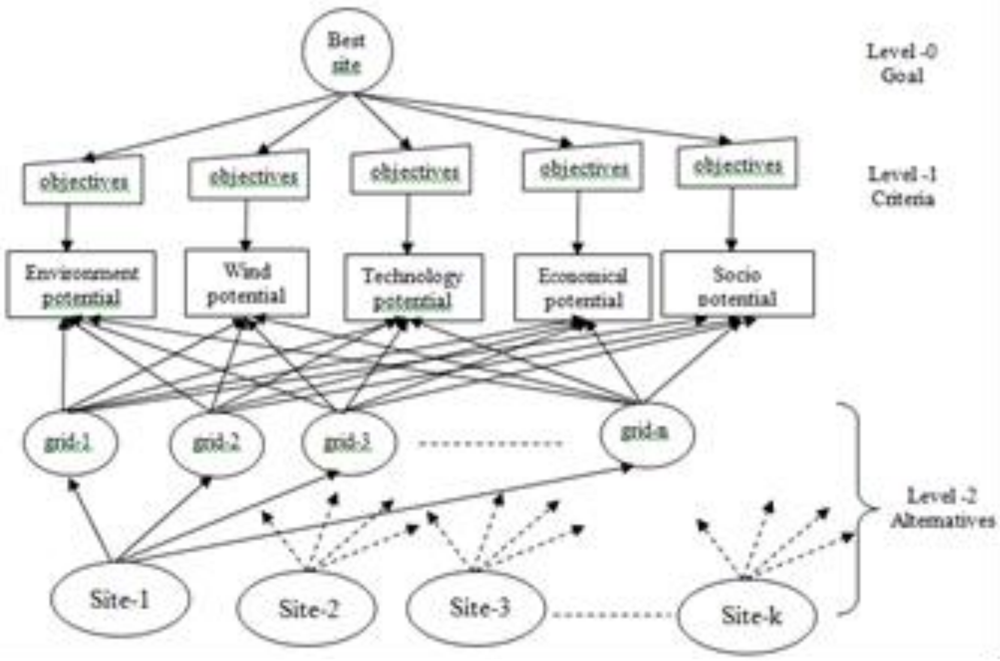

Fig. 3 Layers of the GIS-DSS Complications Combined Approach

4.1 Developing the criteria of wind farm sites

Specific siting standards were first developed to be accordance with the national and international regulations and standards as follows:
i) The mean wind speed for Egyptian selected locations should provide energy with economic feasibility.
ii) Environmental considerations: taking into account the social hardships of any wind site project, which include health, safety, and noise pollution. These require that wind farms should be established outside main cities and urban areas.

iii) Hydrology: water bodies, ecological lands value, or special scientific interest value are secured through some restrictions offered in this project.
iv) The protective culture of heritage: other restrictions can be considered to keep the cultural heritage, the protected areas and historic places.
v) Elevation: physically, the wind farms should be located on suitably developed areas, avoiding summits, and facing the prevailing conditions of wind in the selected locations.
vi) Birds migration: It's very useful for national and international communities
vii) Airports locations and their borders
viii) Economic cost: once choosing the appropriate site for a wind site, it should be as near as possible to the high voltage transmission lines and main roads network. However, it should be determined at a convenient distance from electrical networks and roads.

Table (1) presents the concept of the restrictions which have been adopted in the proposed study.

Table (1) *Definition of Map Layers Used in This Project*

Layer name	**Type**	**Description and constraint (D=distance, E=Elevation)**
Wind potential layers	Polygon	> 5 m/s
Urban map layers	Polygon	Boarders of civilized areas in Egypt D >= 500 m
Main cities in the country	Points	Locations of main cities in Egypt D >= 2000 m
Boarders of Governorates	Lines	Belts of Governorates boarders in Egypt D >= 2000 m
Protected areas layer	Polygon	Boarders of areas protected by law in Egypt >= 500 m
Birds paths in the country	Lines	Connected lines of birds paths in Egypt >= 500 m
All ports (Air ports and others)	Points	Locations of main ports (air and sea), Egypt D >= 2500 m
Hydrology map layer	Raster	Colored areas of hydrology sources D>= 1000 m
Geology map layer	Raster	Geological colored areas in Egypt D>= 2000 m
Soil map layer	Raster	Colored regions of soil in the country >= 500 m
Gazetteer map layer	Points	Locations of important species >= 500 m
The Elevation and contour map layer	Lines	Layers of elevation levels and contours >= 500 m
Earthquake map layers	Points	Locations of Earthquake in Egypt over 20Y >= 500 m
Main and branches roads in Egypt	Lines	Highways all over Egypt connecting main cities and governorates D >= 2000 m
Transmission lines map layer	Lines	Electrical grid connections in Egypt >= 500 m
Wind turbine	points	Importance of weight for wind turbines technology
The future investment map layer	Polygon	Importance areas of expected future investments

V. GIS APPROACH OF WIND SITE LOCATION

The mentioned established models in this section are built on the Geo-processing tools and powerful ArcGIS software. Such attitudes enable to define, manage, and analyze the data required to make the proper decisions. There are two models combined together then have been developed to utilize the raster and vector obtainable data. The models as follows:
Model-A: Arc-GIS vector model for Egyptian wind siting leads to a main contribution of an environmental appropriate complicated map layer for the best proper locations for establishing industries of wind farm that achieve the least restrictions.
Model-B: Arc-GIS raster model wind siting leads to define the suitability of a final location for a wind farm ranking map layer for all proper areas covered by the last model.
These two models are developed for the following reasons: the model of vector data handles the estimation of all Egyptian restricted locations easily; however it is still useless concerning ranking and weighting the wind farm siting. This is due to the disability to control weighting and overlaying more than two map layers in the same time. In Egypt, there are 16 overlaying data layers maps. On the other hand, raster model proved high level of efficiency in deciding the right ranking depending on how much each involved layer is important. During the processes of planning and designing these models, only the map layers can significantly affect the decision making of determining the land suitability for a wind farm. They can be summarized as:
i) Initial wind potential;
ii) The accessibility to near-by the lines of electrical transmission network.
iii) The accessibility to near-by main transportation roads.
iv) Classes of land gradient
v) Effect of the protective places.
vi) Effect of birds migration.
In other words, the two key outcomes have been interlinked with the recent necessities to determine the appropriateness of the areas to establish wind farms.

The developed models were built according structural theory as follows:
1) Combined sensitivity analysis that covers estimation and management for better siting.
2) Applying suitable index that includes screening, weighting and scoring to all restrictions (as shown in Table 1) and the importance of all model layers.
3) Combining the scored and the constraint maps to remove unacceptable locations for final ranking. This leads to an output ranking map generation that is able to identify the proper areas to establish the industry of wind technology and well-scaled in a final format of the raster (shaded gray or colored at an appropriate scale).
The concept of GIS model operations and the general flow chart presented in this paper are developed to provide data about the supreme convenient locations for wind sites are shown in Fig. 4.

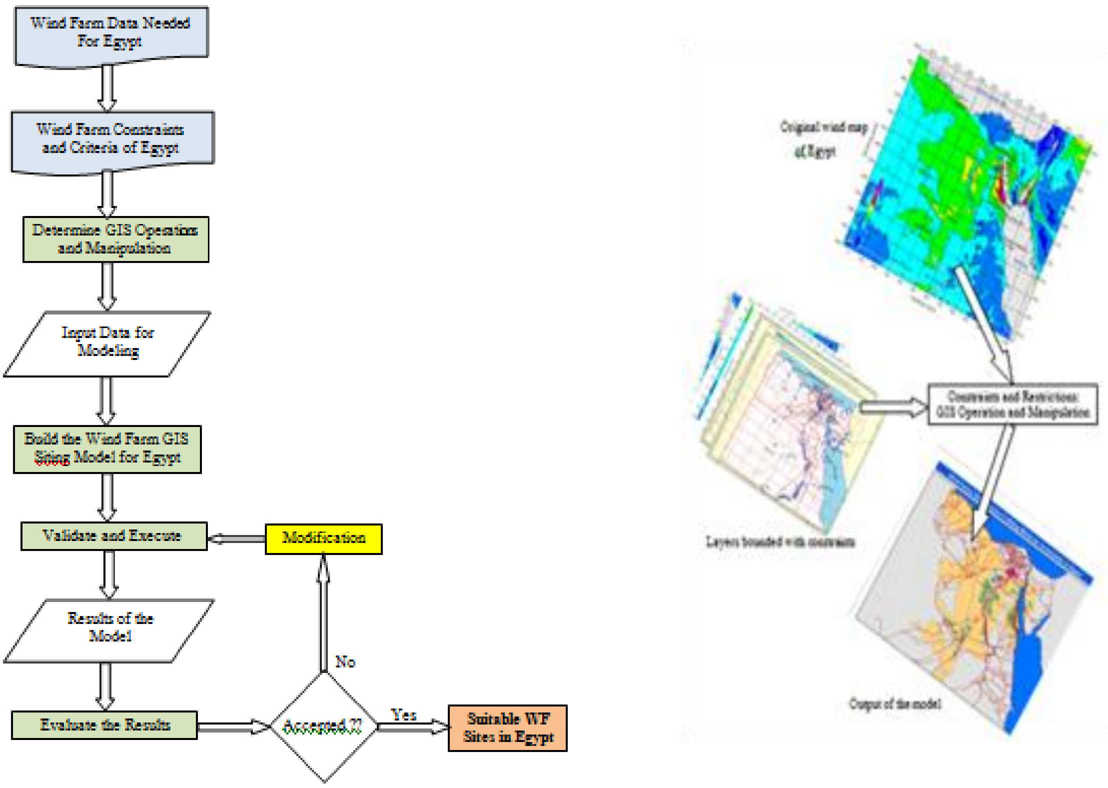

***Fig.4** The Developed Models Instruction Flow*

5.1 Construction of GIS vector model-A

Depending on the predetermined concept and information, the analysis was performed using several tools; like: “selection”, Structure Query Language (SQL) set, “buffer”, “erase”, and so on. It has been a difficult task till it was determined the specific contribution needed from the approach and the model. concerning the developed vector model in this study, the produced output after the procedure of the model should be a net layer of wind resources map which achieve the least limitations mentioned in Table(1) and relevant to the project main goal. The entire ArcGIS model has been illustrated and explained in Figure (5) and typical outcomes have been presented in Figure (6). Figure (5) shows the building of GIS Model for developing the proposed GIS vector model-A for the industry of wind sites. The properties of the involved vector map layers and the restrictions stated by both the international and national terms are shown by the input to this model. Fig.6 shows the vector model-A final results clarifying all suitable regions for establishing the industry of Egyptian wind farms. These outcomes also achieve the optimum limitations the national or international terms have imposed. It was mentioned in details in Table 1. Some other features are also explained, such as: protected areas, main cities, main roads, and sand dunes, to approve that these locations are left out from any suitable location for wind farms. Fig.7 presents a clear picture of the supreme convenient locations for the industry of wind sites in the Suez Gulf.

5.2 Constructing GIS raster model-B

The features are represented as a matrix of data model cells (pixels) continuously. Every single feature is represented in each layer (although there is an ability to attach other attributed to a cell) and the proposed analysis unites the layers to construct new layers with corresponding cell ones. Although the sequence of raster gives all-time coverage of an area geographies and the analysis is very effective, it is hard to apply only the raster –model approach due to wind farm complexity problem to achieve all the goals the analysis. That's why this study tries to present a development for the vector model-A and then hybrid to the raster model. In the model-B raster, the input raster have been identified at first, and the derived raster were established, including the layers input raster mentioned previously in Table 1. The vector model- A output needed to get changed to raster and then developed as the raster model-B first input characteristic. After that; all other layers of the vector were changed to the raster model and then supplied to model-B.

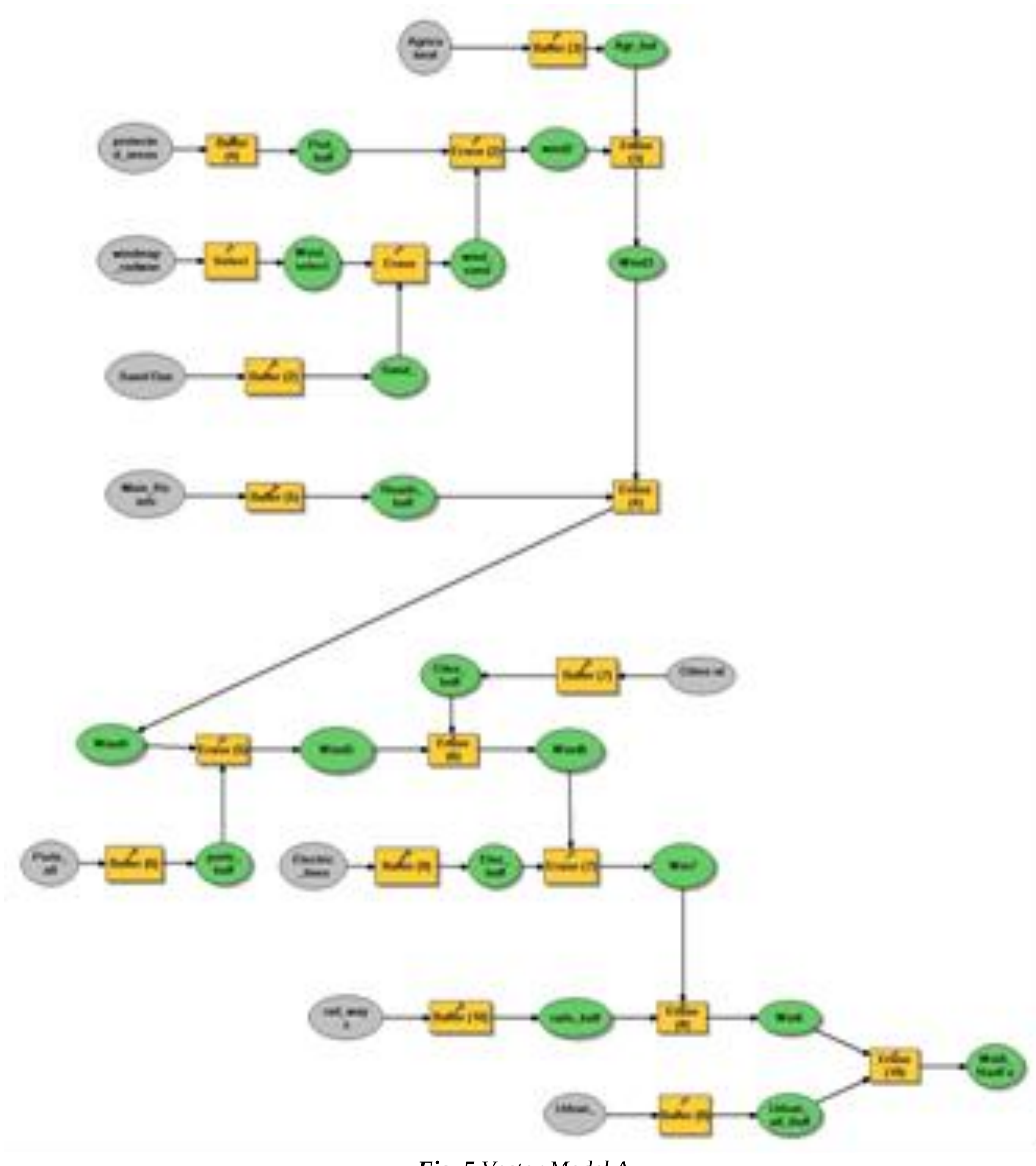

Fig. 5 *Vector Model A*

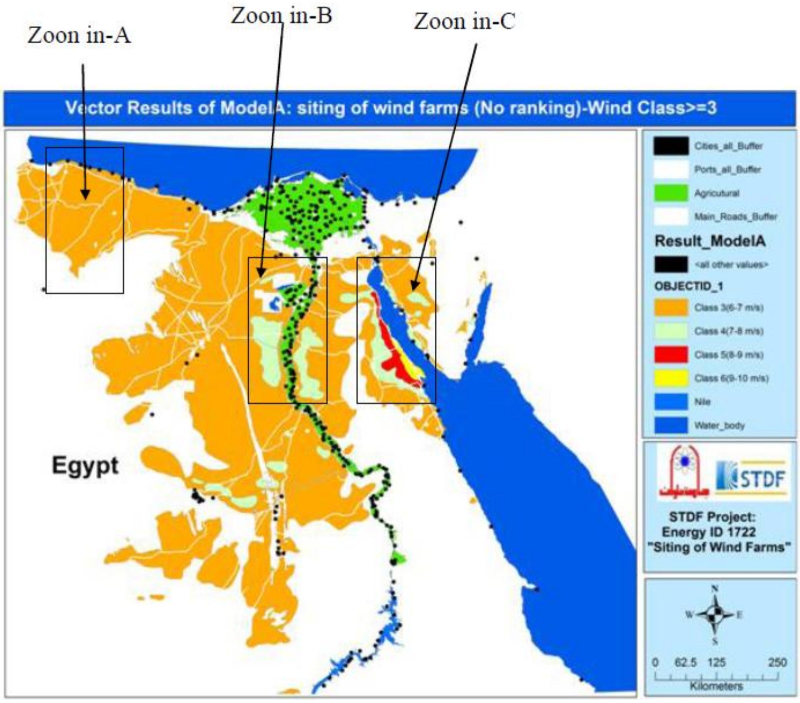

Fig.6 *Vector Model-A Final Results for Wind Sites Technology.*

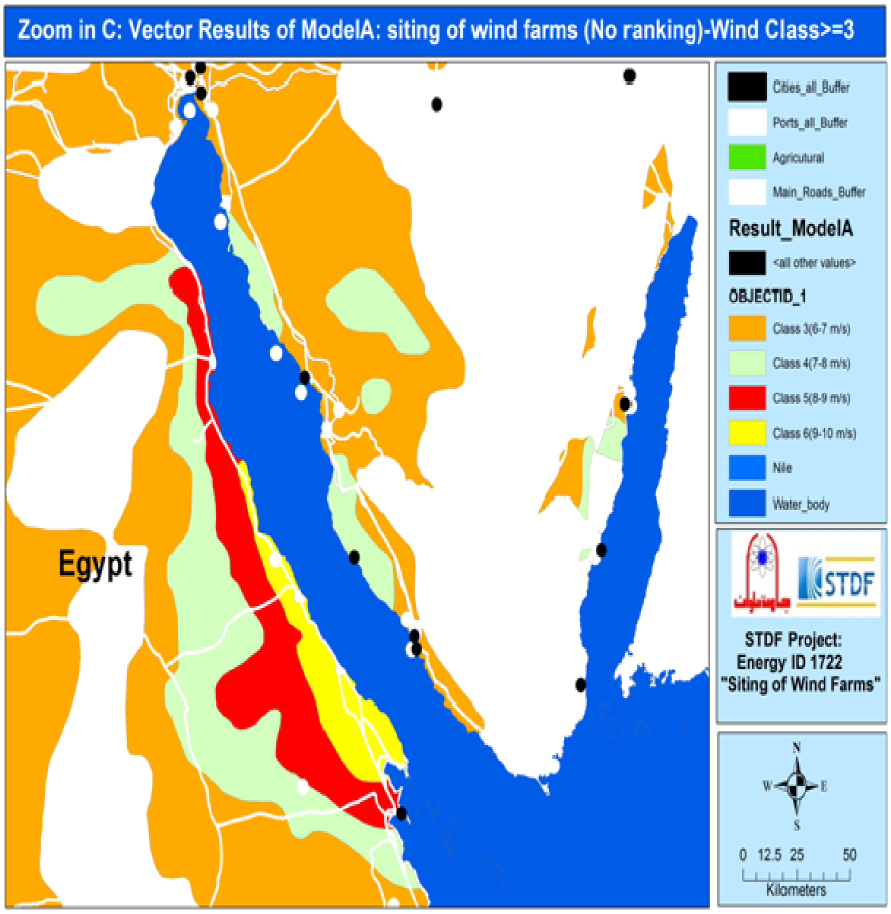

Fig.7 *Vector Model-A Final Results (Zoom-in for Suez Gulf area).*

Wind farms index-overlay model

It means building a model that is able to decide the ranking of the most suitable areas of wind potential for wind sites based on the vector model-A output. The valuable Geo-processing tools available in Arc-GIS were developed for controlling the data sets, conducting weighted overlay process, and performing all data transformation. For developing the raster model, there are some instruction steps performed, which are:

i) Setting up a scale for evaluation (Reclassification): in the current developed model; there is a common evaluation scale that ranges between (0 to 5) was adopted with (0) scale to refer to the least possibility, and (5) that refers to the highest suitability.

ii) Involving all input raster attributes. The current model includes: model-A wind resources after conversion, protected areas, the slope, and the accessibility to H.V.

iii) According to the common scale (score) developed, the cell values of each analyzed input raster are determined. In GIS terms, it helps the model performing operations of various arithmetic on the features of rasters input to the model. Table 2 shows sample of the reclassified values.

iv) Setting up the relative weight of significance to the 6 involved input rasters. Although this process has several techniques, the current model develops the pair-wise comparison based on the Analytical Hierarchy Process (AHP). The total importance weight for all rasters must be 100%. The relative importance weights of the involved rasters in the current model are given in Table 3.

v) Calculate the overall ranking of the most proper wind farms areas using the importance of relative weights and the score determined till now according to the following formula of suitability:

$$Suitability\ Function = \sum_{i=0}^{i=N} W_i \times M_i \qquad (1)$$

Where W refers to the ranking weight and M refers to the involved layer.

***Table 2:** Transmission Lines Reclassification*

Standard	Score	Classification
>= 40 km	0	Excluded area
(20 – 40) km	1	Poor
(10 – 20 km)	2	Less proper
(5 – 10 km)	3	Proper
(1- 5 km)	4	very proper
< 1 km	5	The most proper

***Table 3:** The Used Weights for Ranking the Locations of Wind Farms*

Layer	slope	Wind	T.L.	PA	Roads	BH	Weight
Slope of Land area (slope)	1	0.2	0.25	0.333	0.25	0.333	0.0436
Wind Potential (WP)	5	1	4	4	4	4	0.4300
Proximity of T.L. (T.l.)	4	0.25	1	2	1	2	0.1644
Protected Areas (PA)	3	0.25	0.5	1	0.5	1	0.0987
Proximity of Roads (Roads)	4	0.25	1	2	1	2	0.1644
Bird's Habitat (BH)	3	0.25	0.5	1	0.5	1	0.0987
						Sum	1.00

Based on the chart presented in Fig. 8, the ArcGIS Model Builder was developed with the appropriate tool boxes. All the features derived of this models relay mainly on the feature of the raster during the analysis process. The full raster model is shown in Fig. 9.

VI. OUTPUT RESULTS OF WIND FARM SITES RANKING IN EGYPT:

After completing all the requirements of the established raster model, the model was compiled and run to produce the final results of optimal wind farm sites ranking in Egypt. The output results were recoded to cover many cases and variances. Sample of these results are typically shown in Figs. (10-11).

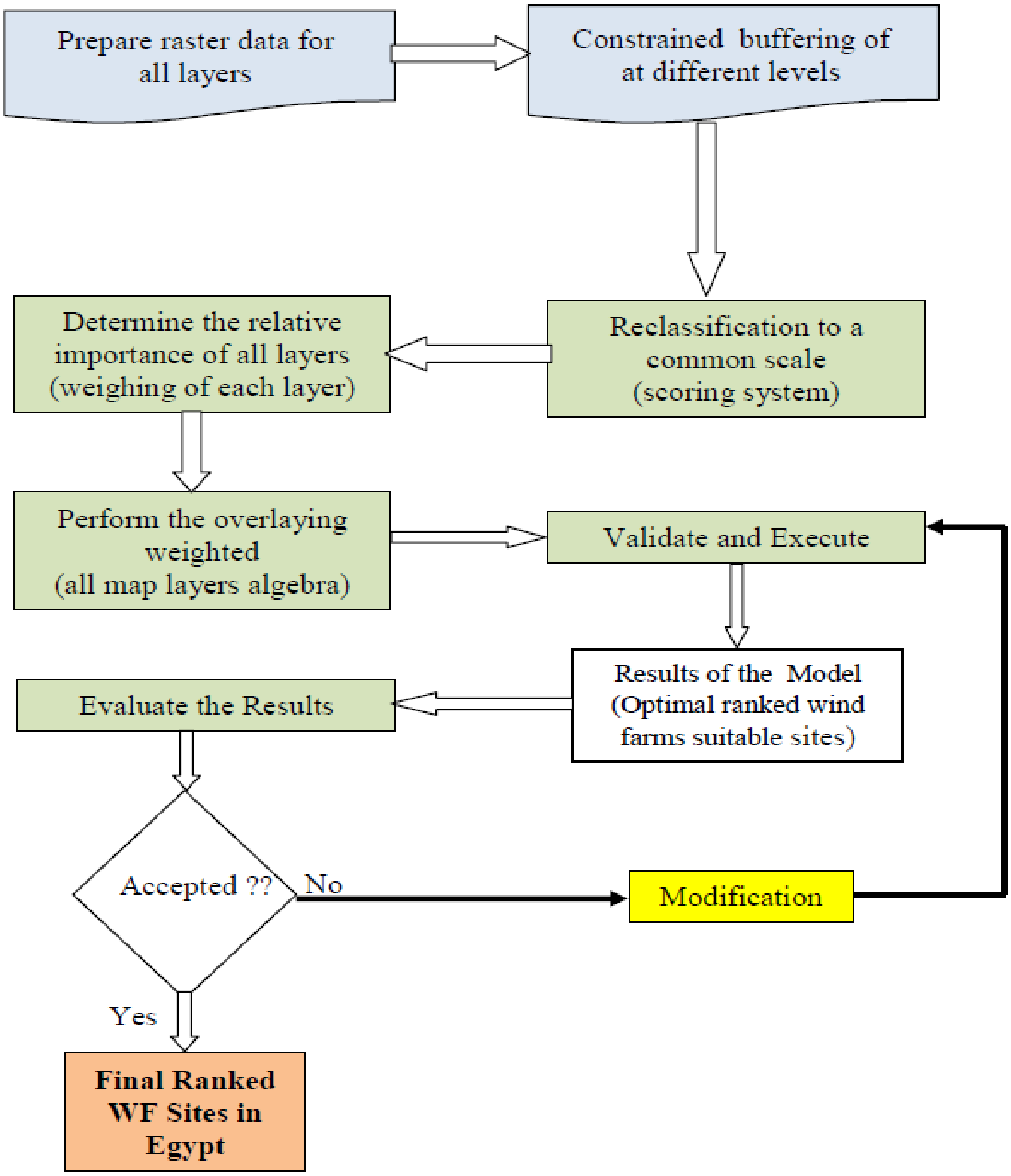

Fig. 8 *Raster Model Process for Ranking and Indexing*

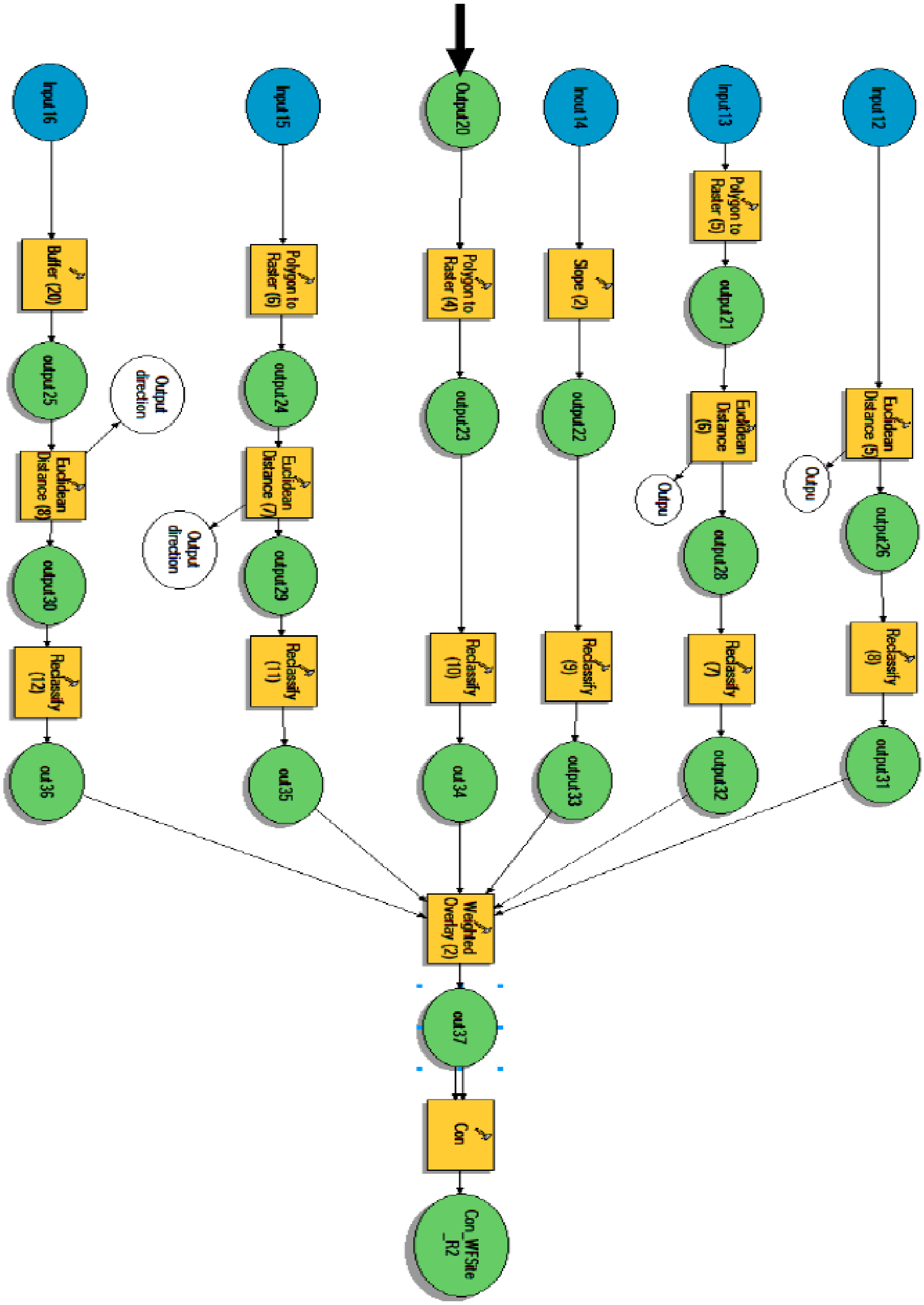

Fig.9 *The Current Study Development for Raster Model-B*

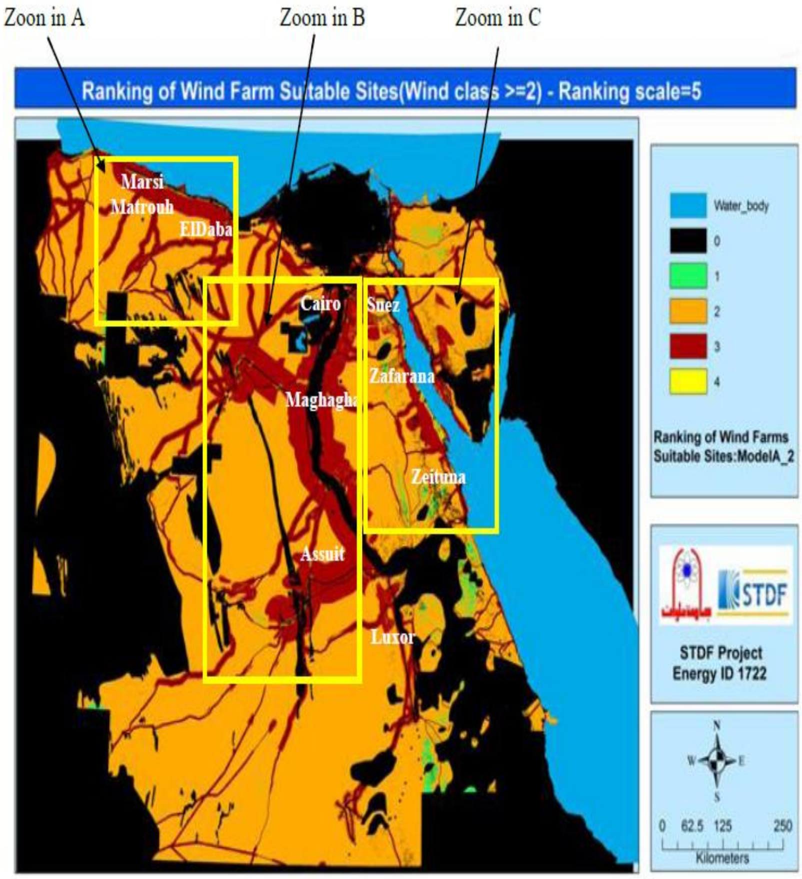

Fig. 10 *Final optimal site locations for WF industry in Egypt. (Raster results-Model B, Wind Class >= 2) Input results of Model A*

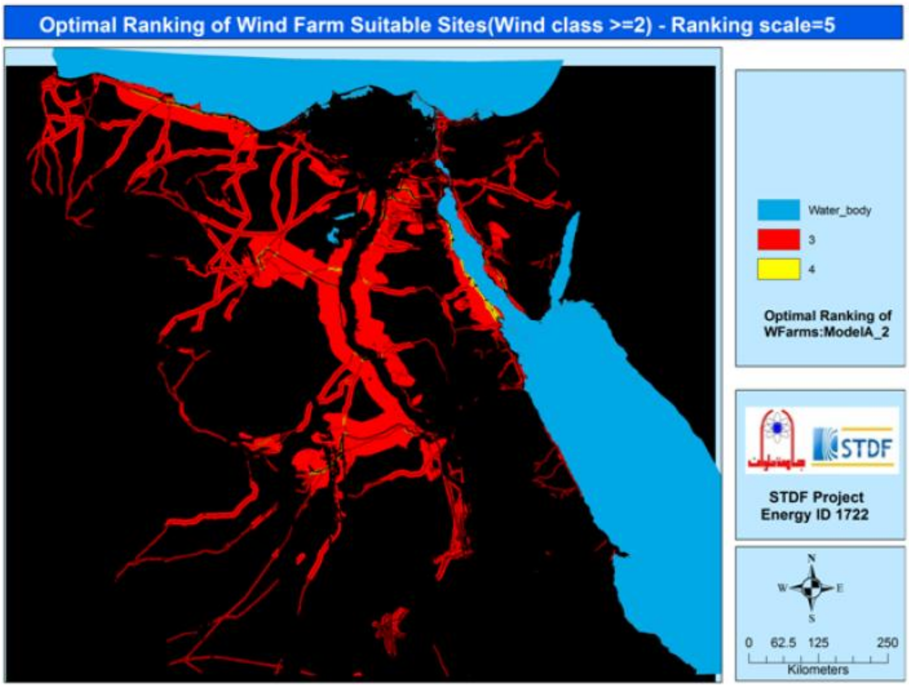

Fig. 11 *Final Optimal Site Locations for WF Industry in Egypt. (Raster results-Model B)*

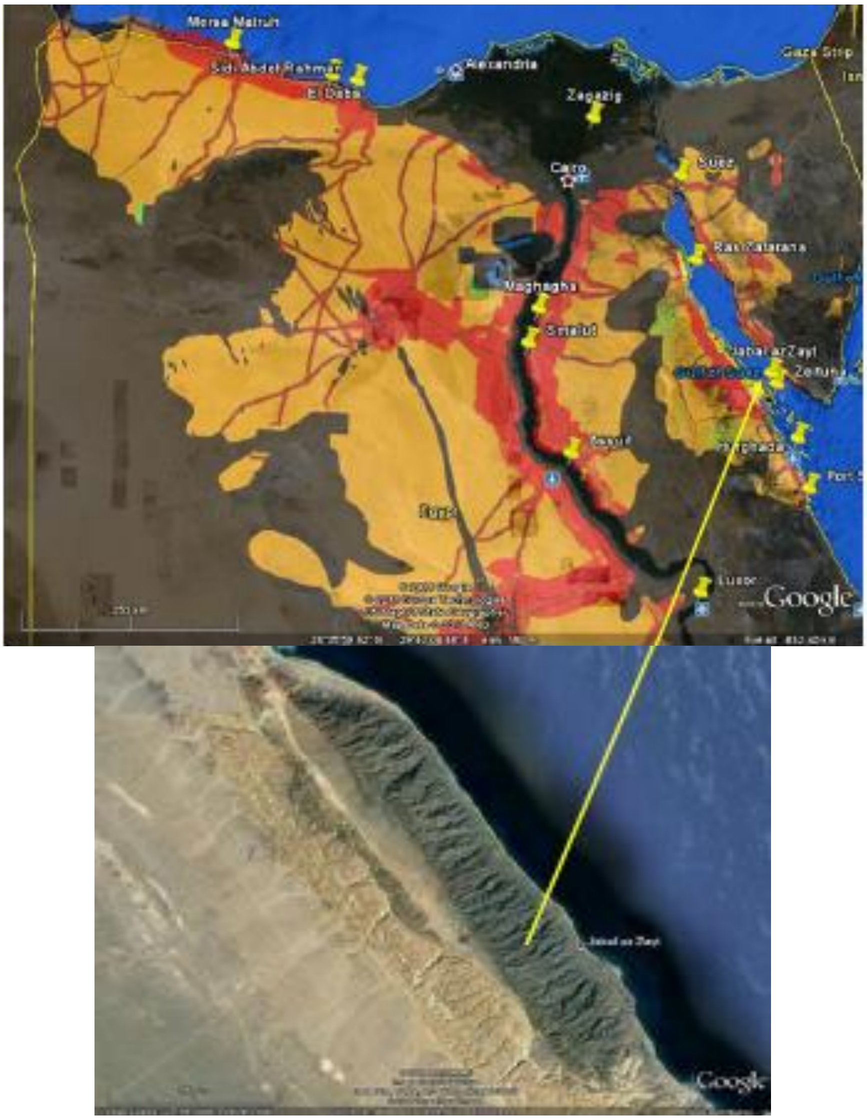

Fig.12 *Validation of Ranked Wind Farms Sites*

VII. SENSITIVITY AND UNCERTAINTY ANALYSIS

Sensitivity analysis is used for examining how much sensitive the wind farms site selections are to the weights criteria changes. If the rankings are not effective as the weights are different, insignificant errors concerning the attribute weights estimation can occur. If the ranking of alternatives are sensitive to one or more weights, the estimating weights accuracy has to be carefully examined. The approach in this study for the sensitivity analysis is to change the criteria weights for sensitivity by ±10% while maintaining the 100% sum of the weight factors. Based on the AHP process, the change in the attribute of the criterion set (± 10) were re-implemented in the new ArcGIS model. Typical results of the model under the sensitivity analysis are given in Figs. (13) for (-10%) change in the criterion set respectively. Examining these figures, in comparison with the original results of the optimal siting ranks given before in Fig. (11) confirms that the changes in pixels ranking were (-4%) in rank 3 and (0.46%) in rank 4 respectively. This final results support the robustness of the GIS model developed here.

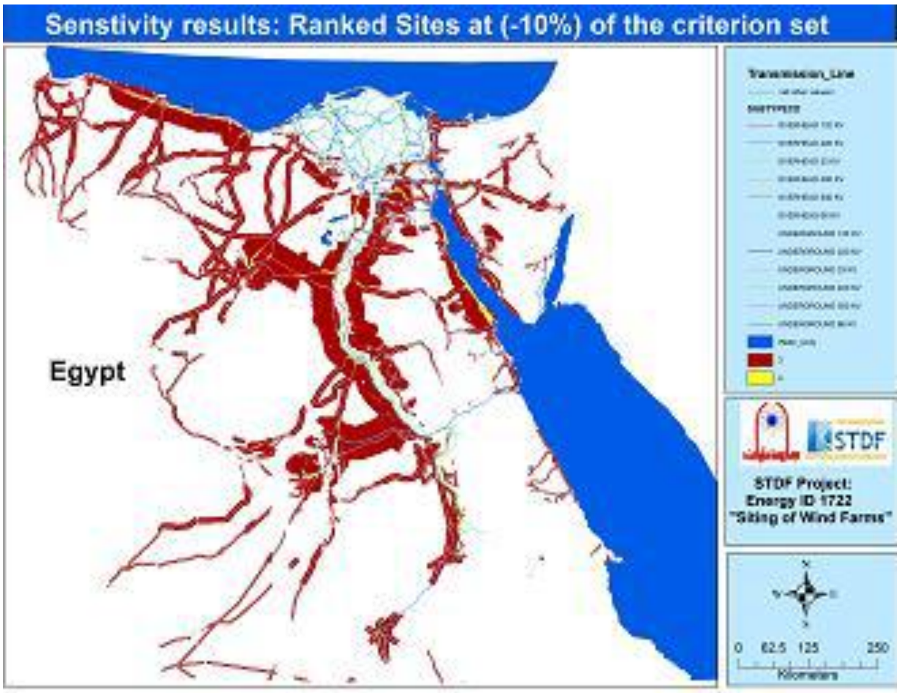

Fig.(13) *Sensitivity Results for (-10%) Weights Variation*

VIII. LINKED MODEL TO WASP

As an entry to economic analysis to complement the decision making support for the industry investors of wind farms in Egypt, we adopted the international WAsP package to determine the energy production of a specific wind farm based on the new model results of GIS optimal siting locations for the industry of wind farms. To generalize the cases, these GIS optimal siting of wind farms were divided into equal areas based on two different ratings namely 100 km^2 and 200 MW respectively as illustrated in Fig.(14) that show all possible GIS subareas for (25 km^2) capacities. For any sub area (25 km^2) or more of the optimal wind farm siting map, the information of this area is linked to WAsP in conjunction with the contour map of the country. The examined subarea is first overlayed on the contour map layer of Egypt and then passed to WAsP to start the computation of the model. The flow of the computational process in link with WAsP is summarized as:

a) Determine the wind Atlas data including the roughness level, the height level, and Weibull distribution.
b) Select the technology potential (wind turbine data and performance characteristics) for the selected scenario
c) Design the wind turbine array at the selected area (columns by rows)
d) Compute the total output energy (MWh/y) harvested from the selected wind farm area.
e) Data collection for the report

Full analysis was conducted based on the developed model including:

i) The Weibull distribution (wind roses),
ii) The related Weibull parameters.
iii) The configuration of wind turbine generators in the farm,
iv) The wind potential at each wind turbine,
v) The power density at turbine site,
vi) The annual energy production of each turbine generator.

These results were obtained to provide as much information as possible to all energy sectors in Egypt as given in Table (4).

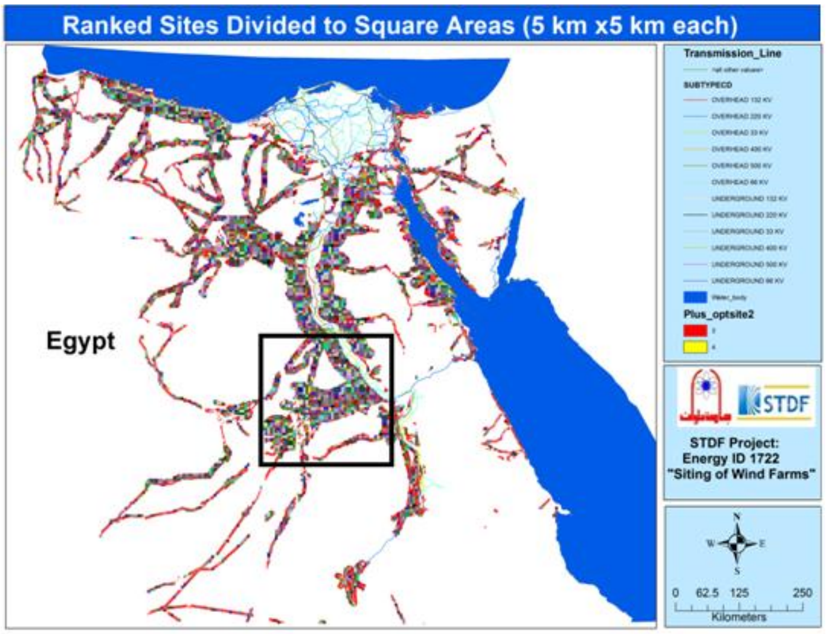

Fig.(14) Optimal GIS Sub-Areas for WAsP Analysis

8.1 Wind Resource Mapping

Wind resource grid allows managing a rectangular set of points for which summary forecasted wind climate data have been evaluated. The points have been regularly spaced and arranged into rows and columns. This enables to observe a pattern of wind climate or wind potentials for a site. It doesn't need to create each point in the grid individually. Instead specification of the grid location, the number of rows, columns and the distance between the points.

8.2 Evaluation of Wind Energy Production

The global energy potential of the average wind has been evaluated by WAsP. moreover, an evaluation of wind turbine average annual energy production (AEP) can be determined by applying WAsP with the wind turbine power curve [13].

Gamesa 1-MW wind turbine has been installed at Zafarana farm in (Suez Gulf –Egypt), the following outcomes are readily obtained:

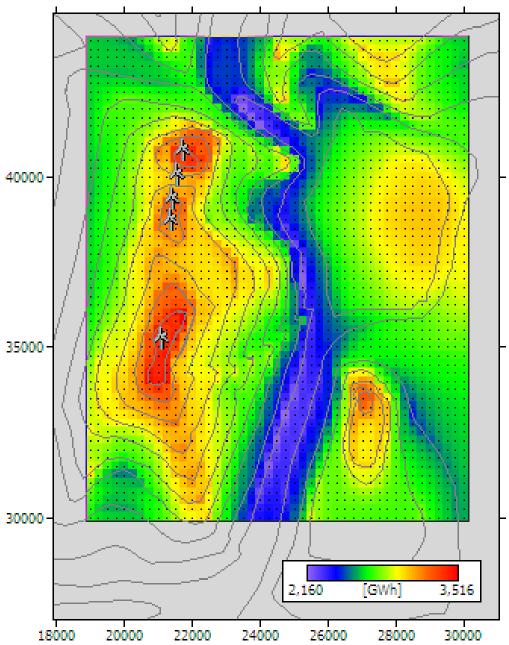

***Fig. (15)** Wasp Results: Wind Resource Mapping*

Sector		Wind climate				Power		
#	a [°]	f [%]	W-A	Weib-k	U	P [W/m²]	AEP	I [%]
1	0	2,1	5,9	2,42	5,19	138	0,024	-
2	30	4,3	7,8	2,44	6,95	331	0,107	-
3	60	5,7	6,5	2,36	5,75	192	0,090	-
4	90	7,8	6,5	3,12	5,83	167	0,113	-
5	120	6,4	7,3	3,01	6,49	234	0,127	-
6	150	5,5	7,4	2,78	6,59	258	0,117	-
7	180	7,2	7,5	2,63	6,66	276	0,160	-
8	210	8,0	9,9	2,55	8,75	637	0,314	-
9	240	12,5	11,6	2,88	10,37	982	0,640	-
10	270	16,5	10,5	2,54	9,34	780	0,721	-
11	300	16,7	10,7	2,66	9,51	795	0,752	-
12	330	7,4	8,5	2,33	7,49	429	0,220	-
All			(9,2)	(2,28)	8,12	556	3,384	-

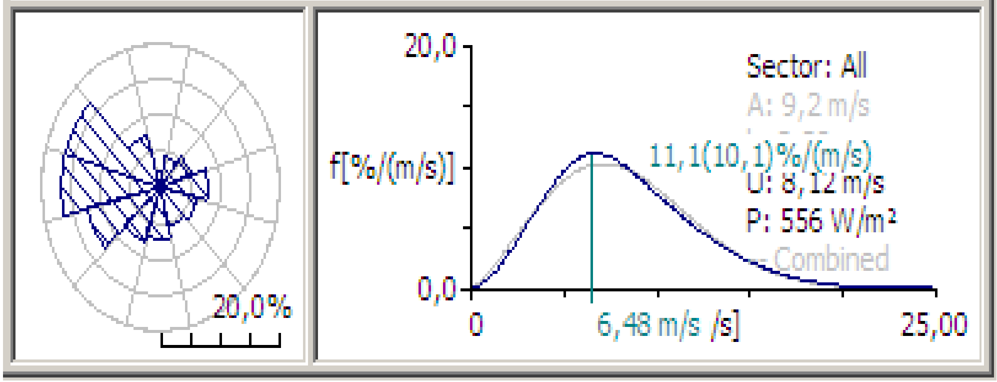

Fig. (16) *Zafarana Turbine Site (3390 GWh)*

8.3 Wind Turbine Siting

Once certain regional wind climate and a digital map have been provided to the Wasp program, hence the wind meteorological data at any site and height in this map can be assessed in few seconds. A 'visual' wind turbine site could be transferred from place to place, either by setting its coordinates or by hovering the mouse. In addition to the wind meteorological data and predicted energy production can be evaluated. A case study for Zafarana wind turbine siting in a digital map has been illustrated in Fig. (17):

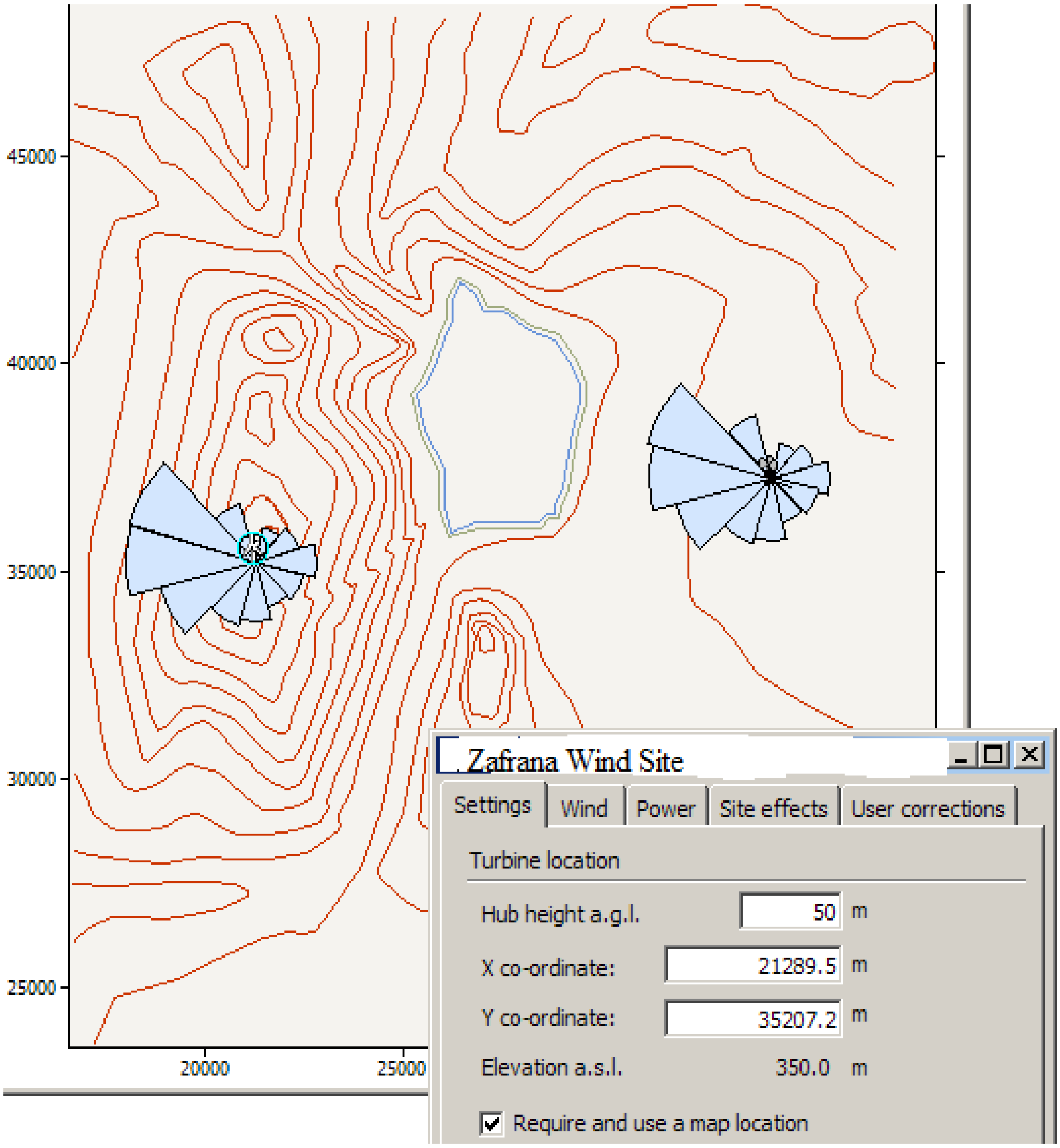

***Fig.(17)** Zafarana Wind Turbine Siting*

8.4 Wind Atlas Assessment

By identifying the wind climate observations and by demonstrating site description, hence the Wind Atlas data sets can be evaluated which reflect regional wind meteorological and climate data [13]. The Wind Atlas window in WAsP displays the average wind speed and average power density for twenty miscellaneous standard classes, defined by the roughness coefficient and the height above ground level as illustrated in Zafarana Wind Farm in Fig. (18).

		R-class 0 (0,000 m)	R-class 1 (0,030 m)	R-class 2 (0,100 m)	R-class 3 (0,400 m)
Height 1 (z = 10 m)	U [m/s] P [W/m²]	7,48 438	5,26 172	4,59 114	3,62 55
Height 2 (z = 25 m)	U [m/s] P [W/m²]	8,18 563	6,26 274	5,63 201	4,74 119
Height 3 (z = 50 m)	U [m/s] P [W/m²]	8,76 679	7,18 385	6,56 297	5,69 196
Height 4 (z = 100 m)	U [m/s] P [W/m²]	9,46 866	8,41 585	7,73 453	6,81 309
Height 5 (z = 200 m)	U [m/s] P [W/m²]	10,38 1172	10,24 1065	9,36 814	8,21 544

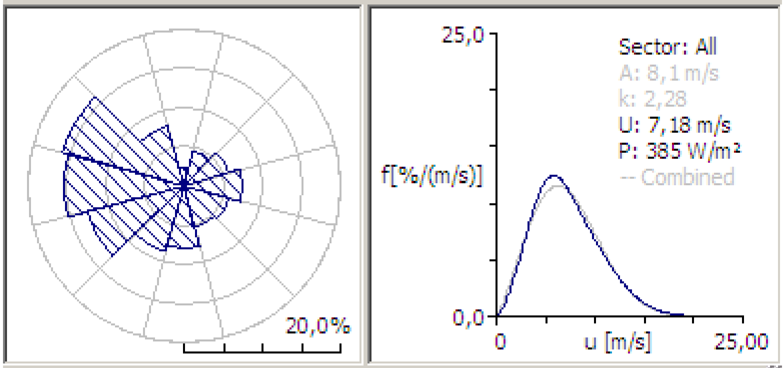

Fig. (18) *Zafarana Wind Atlas Generation*

8.5 Estimation of wind farm Capacity

The Wasp program is capable of estimating the wake losses by studying wind farm profile and thrust coefficient profile for each turbine and by adding annual wind farm energy production hence, the net annual energy production of entire wind farm can obtained.

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	12,858	3,215	3,079	3,346
Total net AEP [GWh]	12,813	3,203	3,065	3,332
Proportional wake loss [%]	0,35	-	0,09	0,47
Mean speed [m/s]	-	7,89	7,72	8,06
Power density [W/m2]	-	514	484	542
RIX	-	-	0,0	0,0

Fig. (19) *Calculation of Wind farm Production*

IX. CONCLUSIONS

- Despite the complexity, and the data dealt with in this research, the analysis and the developed model resulted in effective results of the proper areas for the industry of Egyptian wind sites. Outcomes showed which about 13% of the complete area in Egypt is optimal for wind farms at a rank of 3 and 4 out of 5.
- The ranked results of the new model are helpful and supportive for all utilities in Egypt, the Ministry of state of Environment and investors as well.
- The study also introduced more supporting information by linking the GIS results to the international WAsP to determine the configuration of WT and the annual energy report from any wind farm in Egypt.
- The research is planned and supported with STDF-fund project to present economic resources and development for GIS-DSS system.
- The approach with help of Wasp program proposes a method of how to select the optimal wind turbine according to the site wind information so that the output energy can be optimized while maximizing the utilization of the wind power available at the location.

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