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Selection of Potential Sites for Solar Energy Farms in Ismailia Governorate, Egypt using SRTM and Multicriteria Analysis

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Abstract Egypt is known to be one of the most optimal locations in the world for solar energy production. Solar energy can provide a great opportunity for sustainable development and population redistribution in its vast deserts. Ismailia Governorate encompasses the Suez Canal which in turn possesses high development potentiality. The objective of this paper is to identify optimum sites for constructing solar energy plants in Ismailia Governorate. To achieve this objective, two interrelated steps have been applied in this research. First, remote sensing including satellite data from SPOT-4 was used to derive land use/land cover map of the study area. Also, Shuttle Radar Topography Mission (SRTM) and Digital Elevation Model (DEM) were used to model the aspect angles map and to model the global solar radiation map for the study area. The global insolation (direct and diffuse radiation, WH/m2) shows where the highest amounts of solar radiation are. Second, a Spatial Multicriteria Evaluation (SMCE) model was designed. Various criteria were used in this study, including meteorological (global insolation); terrestrial (the aspect); economic (distance from power lines, main roads and populated area). The Analytical Hierarchy Process (AHP) was used for calculation of the criteria weights. A weighted overlay was used to produce a suitability index map for solar energy power. Few sites were selected based on high suitability index values and area of a site. The methodology proves to be promising for creating zoning maps for developing solar energy infrastructures in the region.
Keywords *Egypt, Ismailia, Solar Radiation, Spatial Multicriteria Evaluation, Shuttle Radar Topography Mission, Site Selection*

1. Introduction

Selection of a suitable site is based on a set of criteria mainly depending on the local conditions of its surrounding environment. This fact applies on the problem of site selection for suitable solar farms. The varying atmospheric conditions (clouds, dust, pollutants) further modify the availability of solar irradiation within years and even days. Atmospheric conditions not only reduce the quantity of insolation reaching the Earth's surface but also affect the insolation quality by scattering and absorption of incoming light and altering its spectrum. While average insolation data offer an insight into solar energy potential on a regional scale, locally relevant conditions such as surrounding terrain may significantly influence the solar energy potential in a specific site (Hofierka and Cebecauer, 2008). In addition, some economic and social criteria participate in the evaluation of the lands. Example of such criteria is the proximity of the selected site to power transmission lines or converting stations and the proximity to main roads or populated areas.

Multicriteria Evaluation (MCE) is widely used as a spatial analysis tool in energy evaluation and environmental fields. Such methods are frequently integrated in GIS, to select the best site for a certain activity. It is thus possible to obtain continuous suitability maps, and thus provide an optimal framework for the integration of the environmental, economic, and social factors that affect land suitability for a certain use. Among the various MCE techniques that can be applied to the evaluation of land suitability, is the Analytical Hierarchy Process (AHP) method (Saaty, 1980) such method represents a specific problem by means of the hierarchical organization of criteria, and afterwards uses comparisons to establish weights for criteria and preference scores for classes of different criteria, based on user judgment. Recent developments in GIS have led to significant improvements in its capability for decision making processes in land allocation and environmental management, among which multi criteria evaluation (MCE) is one of the most important procedures (Janssen and Rietveld, 1990; Jankowski, 1995). (Arán-Carrión et al., 2007) used Multicriteria Evaluation (MCE) and geographic information system (GIS) to select the optimal location of grid connected photovoltaic power plants in North of the Granada Province. (Jiang, 2007) used the AHP and analyzed the suitable and low cost sites for industrial land using SMCE in Panzhihua, China. GIS and AHP were also used together for land suitability analysis for urban development in the studies conducted by (Aly et al., 2005; Mohammad et al., 2006; Cerreta and Toro, 2012). (Janke, 2010) used MCE and GIS to model solar and wind farms in Colorado. (Aydin et al., 2010) conducted a GIS-based environmental assessment of wind energy systems for spatial planning in Western Turkey.

2. Description of the Investigated Area

Ismailia Governorate is located between latitudes 30° 13´ and 31° 10´ North and longitudes 31° 48´ and 32° 50´ East, covering an area of 5067 square kilometers, equivalent to 0.5% of the total Egyptian territory (Figure 1). Population counts are 896,000 capita for 2006 which is equivalent to 1.2% of total population in Egypt (GOPP, 2007). The Governorate has five administrative divisions namely, Ismailia, Fayed, El Tell El Kebeir, El Kantara Shark and El Kantara Gharb. The main capital city is Ismailia city. Six towns in addition to a hierarchy of villages reaching a total of 30 units constitute the populated areas. The landcover are bare desert with some cultivated and newly reclaimed lands and established fish farms in addition to the lakes, the Suez Canal and urban areas. The climate and soil conditions promote the Governorate as Egypt’s significant fruits and vegetables producer. Its location as the hub-city for the Suez Canal region puts it at cross roads to Cairo, Suez, Port-said and Sinai. In addition, the Egyptian Government has plans for developing the Suez Canal Region as an international navigation and trade center. Such development potentials necessitated the evaluation and exploration of the region for renewable energy resources such as solar energy potentiality.

2.1. Geology

The land of Ismailia Governorate is mainly formed of gravelly plain extending northwards until reaching the Mediterranean coast. The area is drained by a large dry valley called Wadi Tumaylat, which forms an old arm of the Nile Delta ending near Ismailia. Such valley is a sandy depression located west of Ismailia and extends for 52 kilometers from west to east. The north of Wadi Tumaylat spread Plio Pleistocene deposits of gravel and sand forming the island of Tell El-Kebir.

2.2. Climatic Conditions

Ismailia Governorate enjoys an ideally moderate climate, with the sun shines most of the year an average of about 10 hours daily. Rainy days are few, and the north wind blowing from Europe cools of the weather in the study area even in summer (June to August). (Table 1) gives the monthly averages of some climate elements measured at Ismailia Meteorological station during the period 1961 to 1968 (Egyptian Meteorological Authority, 2005). This station is located at latitude 30° 35´ North and longitude 32° 14´ East.

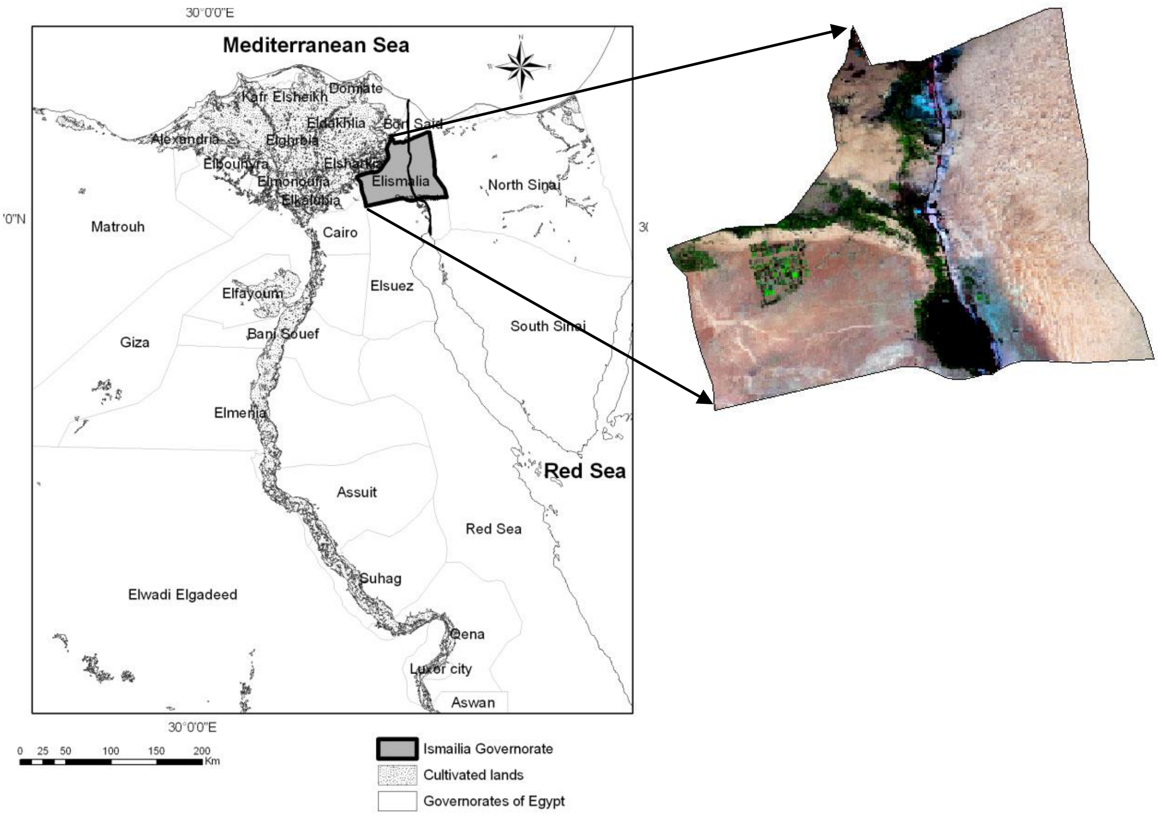


Figure 1: *Location of Ismailia Governorate*

Table 1: *Monthly Average of Some Climatic Elements at Ismailia Station*

Month	Max. Temp. ^oC	Min Temp.	Relative Humidity (%)	Rainfall mm/month	Sunshine Hrs.
January	19.6	7.9	66	7.2	9
February	20.9	8.5	61	6.2	8
March	23.5	10.3	59	6.8	9.5
April	28.3	13.6	53	1.7	10.5
May	31.8	16.5	50	1.3	11
June	34.6	19.5	53	0.0	12
July	35.9	21.9	57	0.0	12.5
August	35.7	22.1	59	0.0	11.5
September	33.5	20.3	61	0.0	10.5
October	30.3	17.4	63	1.5	9.5
November	25.8	13.3	65	3.9	8.5
December	21.1	9.4	67	4.7	7.5

2.3. Sunshine Duration

Sunshine duration is defined as the sum of sub-period for which the direct solar radiation is intense enough to cast distinct shadow, i.e. the direct solar irradiance exceeds 120 W/m3. Its unit is evidently time (hours) and it is measured to the nearest 0.1 hours. Sunshine duration at Ismailia, the monthly mean of the bright sunshine duration reaches up to 10 hours (Egyptian Meteorological Authority, 2005).

3. Data Sources

Two primary data sets were used to model the solar energy potential sites as follows:

A. **SRTM Data:** The Shuttle Radar Topography Mission (SRTM) data acquired by space shuttle Endeavour mission in 2001 by C-band SAR interferometry instrument were used in this study. The data was processed by NASA and the USGS SRTM data was used to model the area solar radiation map and the aspect angles map using ESRI ArcGIS 9.2 spatial analyst modules.

B. **SPOT-4 Data:** SPOT-4 is a French Earth Observation satellite that was launched in March 1998 at an altitude of 810 km. SPOT scenes are typically 60x60 km for vertical viewing, or 60 km by up to 80 km for oblique viewing. SPOT-4 is characterized by multispectral data represented by 4 bands covering green, red, near infrared and shortwave infrared portions spectrum, with 20 m spatial resolution, in addition to a single panchromatic band acquired in the wavelength region from 0.62 to 0.68 µm with 10 meter spatial resolution. SPOT-4 images acquired in 2010. The rectified images were mosaiced and classified in ERDAS Imagine software to derive the land-use / land-cover map. Such map was reclassified into a binary map to create the land cover constraints map.

C. **Maps:** The topographic map published by the Egyptian General Survey Authority (1989) scale 1:50,000 was scanned, geometrically corrected and used to extract the roads, power lines by on-screen digitizing. The roads were further updated from SPOT-4 imagery acquired in 2010. All data were projected to WGS-84 of the Universal Transverse Mercator System (UTM) of geographic coordinates, and were resample to 100 m resolution and used in the present study. A conceptual flow chart for the methodology is shown in (Figure 3).

4. Methods

Planning for solar energy usually entails the consideration of a number of interrelated factors. For studying such factors, the following materials have been acquired, collected, processed by adequate methods and a Spatial Multicriteria Evaluation model was designed.

4.1. Identification of the Criteria

Climate criteria are the most important for the decision rule since they define the electricity production capacity of the photovoltaic power plant. Next come Orography, whose importance mainly depends on the aspect angles (orientation) and land slope. The milder the slopes are, the greater the importance of this type of area since the most suitable sites are those where the ground is flat and oriented towards the south. For the investigated region, most lands are flat or mild slopes, thus only the aspect was considered. Accessibility factors were also considered in the site selection. Such factors are identified through the location criteria and help in identifying feasible sites for a solar farm. Factors such as proximity to power lines, main roads and populated areas are vital factors for the site selection. Land constraints were derived by masking out the water bodies, cultivated lands, urban areas, wetlands and sabkahs from the land use-land cover map. Criteria are described in the following section:

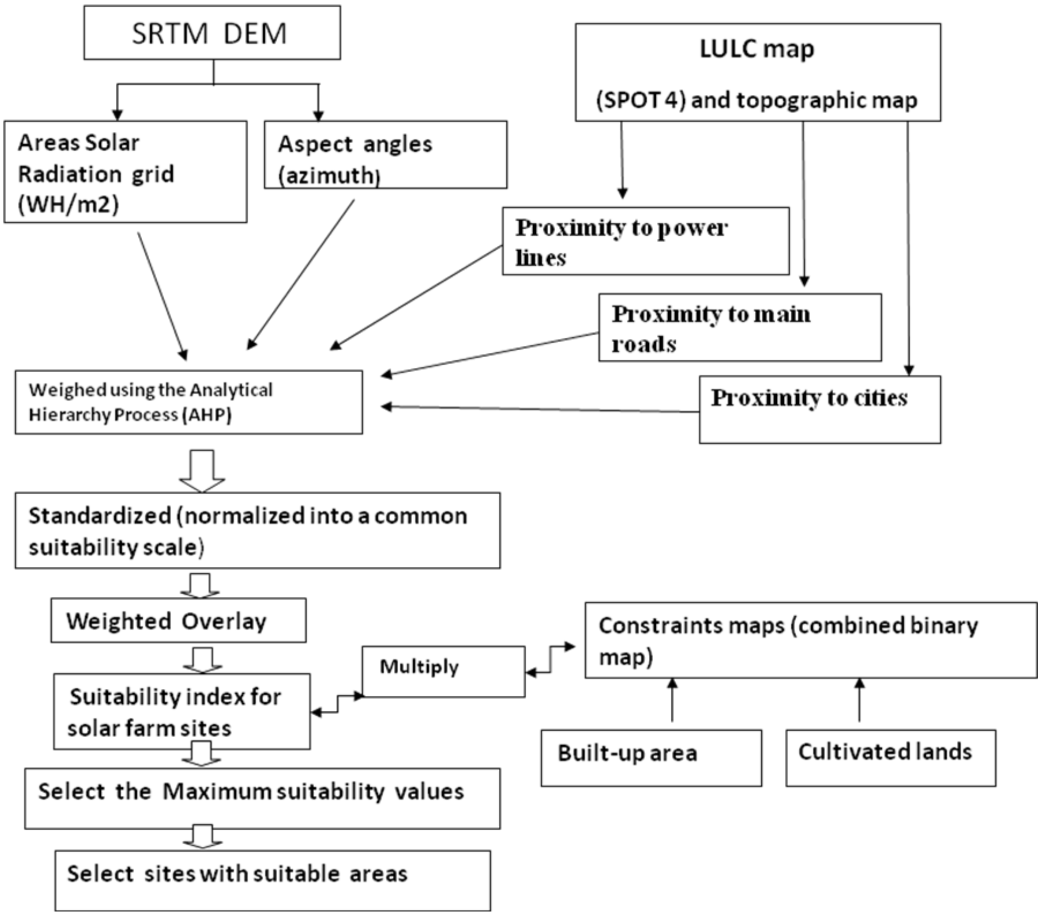


Figure 2: *Conceptual Chart for the Applied Methodology*

4.1.1. Solar Radiation Mapping

The solar radiation module in ESRI Spatial Analyst was used in this study to calculate the direct, diffuse and total global radiation map using SRTM digital elevation model. Topography is a major factor that determines the spatial variability of insolation (incoming solar radiation). Variation in elevation, orientation (slope and aspect), and shadows cast by topographic features all affect the amount of insolation received at different locations. Insolation originates from the sun, is modified as it travels through the atmosphere, is further modified by topography and surface features, and is intercepted at the earth's surface as direct, diffuse, and reflected components. Direct radiation is intercepted unimpeded, in a direct line from the sun. Diffuse radiation is scattered by atmospheric constituents, such as clouds and dust. Reflected radiation is reflected from surface features. The sum of the direct, diffuse, and reflected radiation is called total or global solar radiation. The solar radiation analysis tools, in the ESRI Spatial Analyst extension, were used to map and analyze the effects of the sun over a geographic area for specific time periods. It accounts for atmospheric effects, site latitude and elevation, steepness (slope) and compass direction (aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding topography. The solar radiation analysis tools calculate insolation across a landscape or for specific locations, based on methods from the hemispherical view shed algorithm developed by (Rich, 1990; Rich et al., 1994) as further developed by (Fu and Rich, 2000) The total radiation is calculated as the sum of the direct and diffuse radiation. The total amount of radiation calculated for a particular location or area is given as global radiation.

The calculation of direct, diffuse and global insolation is repeated for each feature location or every location on the topographic surface producing insolation maps for an entire geographic area. The solar insolation equations are described as follows (ESRI Spatial Analyst):

$Dir_{\theta,\alpha} = S_{Const} * \beta^{m(\theta)} * SunDur_{\theta,\alpha} * SunGap_{\theta,\alpha} * \cos(AngIn_{\theta,\alpha})$ .... (1)

Where

S_{cons} : Solar flux (constant) (1376 W/m2)

$\beta^{m(\theta)}$: The transmissivity of the atmosphere (av. Of all wavelength) for the shortest path in the direction of the zenith,

$SunDur_{\theta,\alpha}$: The time duration represented by the sky sector. For most sectors, it is equal to the day interval multiplied by the hour interval.

$SunGap_{\theta,\alpha}$: The gap fraction of the sun sector.

$AngIn_{\theta,\alpha}$: The angle of incidence between the centroid of the sky sector and the axis normal to the surface.

$Dif_{\theta,\alpha} = R_{glb} * P_{dif} * Dur * SkyGap_{\theta,\alpha} * Weight_{\theta,\alpha} * \cos(AngIn_{\theta,\alpha})$ .... (2)

Where

R_{glb} : The global normal radiation

P_{dif} : The proportion of global normal radiation flux that is diffused. Typically it is approximately 0.2 for very clear sky conditions and 0.7 for very cloudy sky conditions.

Dur : The time interval for analysis.

$SkyGap_{\theta,\alpha}$: The gap fraction (proportion of visible sky) for the sky sector.

$Weight_{\theta,\alpha}$: The proportion of diffuse radiation originating in a given sky sector relative to all sectors.

$AngIn_{\theta,\alpha}$: The angle of incidence between the centroid of the sky sector and the intercepting surface.

Global radiation (Globaltot) is calculated as the sum of direct (Dirtot) and diffuse (Diftot) radiation of all sunmap and skymap sectors, respectively.

$Global_{tot} = Dir_{tot} + Dif_{tot}$ .... (3)

The solar radiation maps are shown in Figure 3.

4.1.2. Aspect Angle

Shuttle Radar Topography Mission digital elevation model was used to derive the aspect angle in azimuth for the investigated area. The aspect is expressed in positive degrees from 0 to 359.9, measured clockwise from north. For the geographical location of the investigated region (in Northern Hemisphere), the southern direction is the best in receiving solar radiation, the south-west and south-east are the second and third best respectively (Figure 4).

4.1.3. Proximity to Power Lines

Proximity of a site for the solar plant to a power supply line is considered an economic factor. It reduces the cost of installation and creation of a new infra-structure. A distance function (multiple buffers) was used to calculate the distance from the power lines (Figure 5a).

4.1.4. Proximity to Main Roads

Proximity of a solar plant to a main road is considered an economic factor. A distance function (multiple buffers) was used to calculate the distance from the main roads after considering a road buffer area of 200 meters. (Figure 5b)

4.1.5. Proximity to Cities

Proximity of a site for the solar plant to a populated area is considered an economic factor. A buffer zone (2 kilometers) was used around the cities and towns as a constraint. A distance function (multiple buffers) was used to calculate the distance from the main cities (Figure 5c).

4.2. Constraints Criteria

The land use -land cover map was derived by supervised classification of SPOT-4 satellite image (Figure 6a). Constraints (unsuitable cells) are cultivated lands, built-up areas buffers, natural vegetation areas and road buffers. Such classes were excluded from the lands considered for developing a solar farm (Figure 6b).

4.3. Criteria Weighting

For suitability analysis it is necessary to give a relative weight for each of the participating criteria as per their relative importance in the desired development. Analytical Hierarchy Process (Saaty, 1997) was used to assign weights to each criterion, factor, and indicator, and thus determine their relative importance in the final decision adopted within the model. The method is based on pair-wise comparison within a reciprocal matrix, in which the number of rows and columns is defined by the number of criteria. Accordingly, it is necessary to establish a comparison matrix between pairs of criteria, contrasting the importance of each pair with all the others. Subsequently, a priority vector was computed to establish weights (wj). These weights are a quantitative measure of the consistency of the value judgments between pairs of factors (Saaty, 1992). Satty's scale of measurement is used as follows:

S = {1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/ 2, 1, 2, 3, 4, 5, 6, 7, 8, 9}

A pairwise comparison matrix was designed. The comparisons ratings are provided on a nine-point continuous scale, which was proposed by (Eastman, 1995). The comparisons ratings and factors were discussed with experts and the pairwise comparison matrix was constructed based on (Table 2a). If we call that weight aij, and use that scale of comparison and if the relative weighting is a23 = 3/1, then the relative importance of attribute 3 with regard to 2 is its reciprocal a 32 = 1/3. This process generated an auxiliary matrix in which the value in each cell is the result of the division of each value judgment (aij) by the sum of the corresponding column. Finally, the average of the normalized values of rows was obtained, which corresponds to the priority vector (wj). This was normalized by dividing each vector value by n (the number of vectors), thus obtaining the normalized overall priority vector, representing all factor weights (wj). For estimating consistency, it involves the following operations:

a. Determination of the weighted sum vector by multiplying matrix of comparisons on the right by the vector of priorities to get a new column vector. Then divide first component of new column vector by the first component of priorities vector, the second component of new column vector by the second component of priorities vector, and so on. Finally, sum these values over the rows.

b. Determination of consistency vector by dividing the weighted sum vector by the criterion weights. Once the consistency vector is calculated it is required to compute values for two more terms, lambda (λ) and the consistency index (CI). The value for lambda is simply the average value of the consistency vector.

The calculation of CI is based on the observation that λ is always greater than or equal to the number of criteria under consideration (n) for positive, reciprocal matrices and λ=n, if the pairwise comparison matrix is consistent matrix. Accordingly, λ-n can be considered as a measure of the degree of inconsistency. This measure can be normalized as follows:

CI = (λ-n) / (n-1) …………… (1)

The term CI, referred to as consistency index, provides a measure of departure from consistency. To determine the goodness of CI, AHP compares it by Random Index (RI), and the result is what we call CR, which can be defined as:

CR = CI/RI …………………. (2)

Random Index is the CI of a randomly generated pairwise comparison matrix of order 1 to 10 obtained by approximating random indices using a sample size of 500 (Saaty, 1980), Table 2b shows the value of RI sorted by the order of matrix.

Table 2a: *Saaty's Nine-Point Weighting Scale*

Intensity of Importance	Description	Suitability Class
1	Equal importance	Lowest suitability
2	Equal to moderate importance	Very low suitability
3	Moderate importance	Low suitability
4	Moderate to strong importance	Moderately low suitability
5	Strong importance	Moderate suitability
6	Strong to very strong importance	Moderate high suitability
7	Very strong importance	High suitability
8	Very to extremely strong importance	Very High suitability
9	Extremely importance	Highest suitability

The consistency ratio (CR) is designed in such a way that if CR < 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparisons; if, however, CR > 0.10, then the values of the ratio are indicative of inconsistent judgments. In such cases one should reconsider and revise the original values in the pairwise comparison matrix.

Table 2b: *Random Index*

Order Matrix	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4.4. Standardization of Criteria

In this step the criteria are placed in either minimization or maximization functions. Solar radiation indicators were classified using equal intervals between the maximum and minimum values and are distributed in homogenous intervals. For the Aspect criterion, the standardization was done by classifying the aspect map into the azimuth main directions (Table 6). The economic criteria of proximity to roads, power lines and populated areas data were minimization criteria (the less values the better). Such criteria maps were classified using equal intervals into ten classes using equal intervals between the maximum and minimum values (Table 7). All classified criteria attributes were recoded into a suitability scale ranging from 1-10.

4.5. Combining the Criteria Maps

The simple additive weight method was used to combine the criteria and constraints to yield the suitability map as follows:

$$\text{Suitability map} = \sum (\text{factor map} * \text{weight}) \prod (\text{constraint map})$$

The result was also normalized and reclassified. Figure 6 shows the suitability map that was obtained.

4.6. Selection of Potential Sites

A condition rule was used to select some potential sites for constructing solar energy farms. The sites should have a maximum suitability value from 7-9 and should have an area between 1-2 square kilometer.

5. Results and Discussion

Results obtained from each of the above described methodology are given in brief description in the following section.

5.1. The Solar Maps

The diffuse radiation, direct radiation and global Solar Radiation maps result of running ESRI Spatial Analyst solar module are depicted in Figures 3a, 3b and 3c respectively.

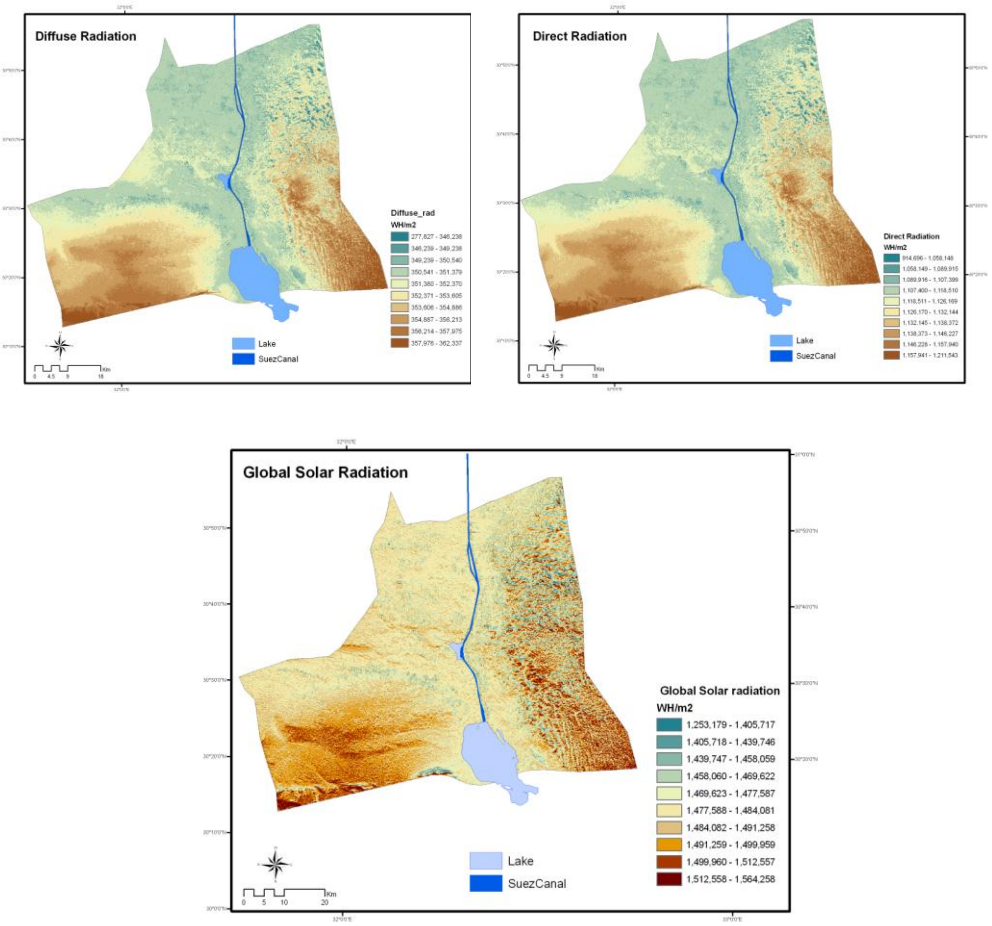


Figure 3: *a) Diffuse radiation b) Direct radiation. c) Global Solar Radiation*

5.2. Aspect Map

Aspect map describes the direction in azimuth for land slope angles. Aspect produced from SRTM digital elevation model is shown in Figure 4.

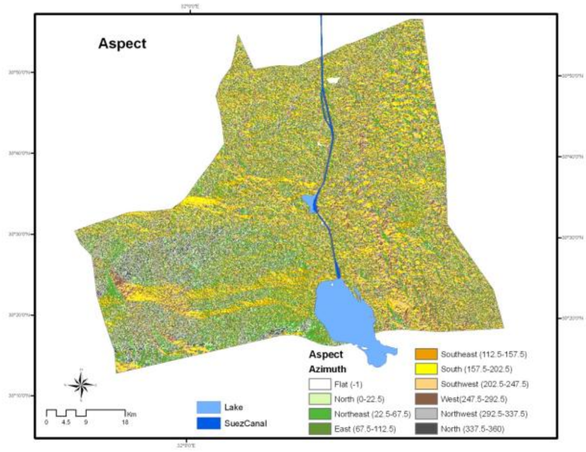
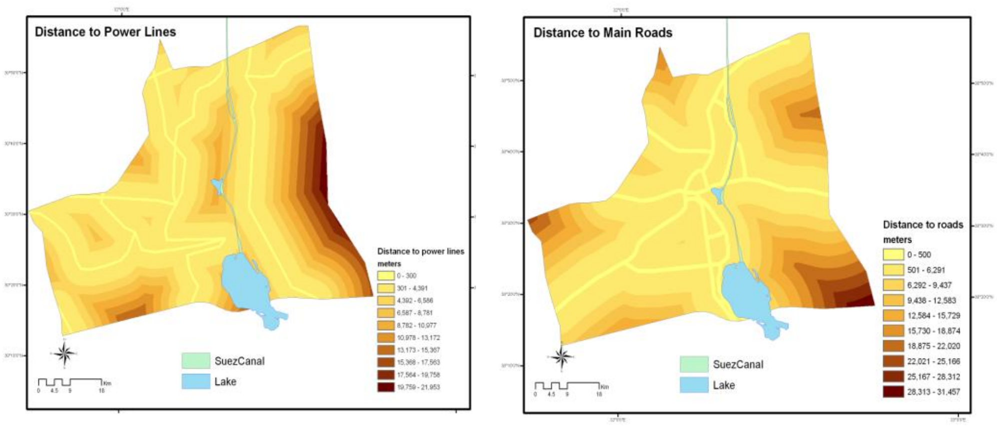


Figure 4: *Aspect Angles Map*

5.3. Proximity Maps

The proximity maps are the results of running the distance functions in ESRI Spatial Analyst Proximity to power lines, main roads and cities are shown in Figures 5a, 5b and 5c respectively.



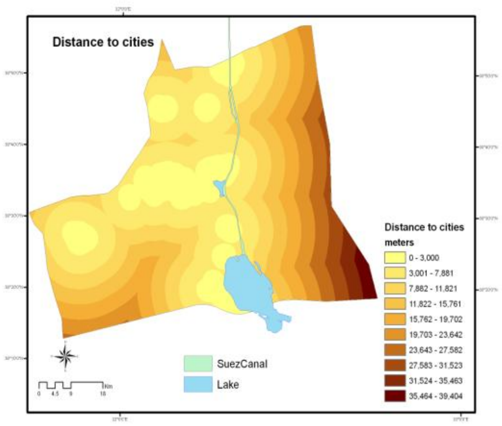


Figure 5: *Location criteria for suitability modeling for solar energy potential sites. (a) Proximity to power lines (b) Proximity to roads (c) Proximity to cities*

5.4. Constraints Map (Exclusion Zones)

The land cover map derived by classification of SPOT-4 image and the land cover constraints map are shown in Figures 6a and 6b respectively.

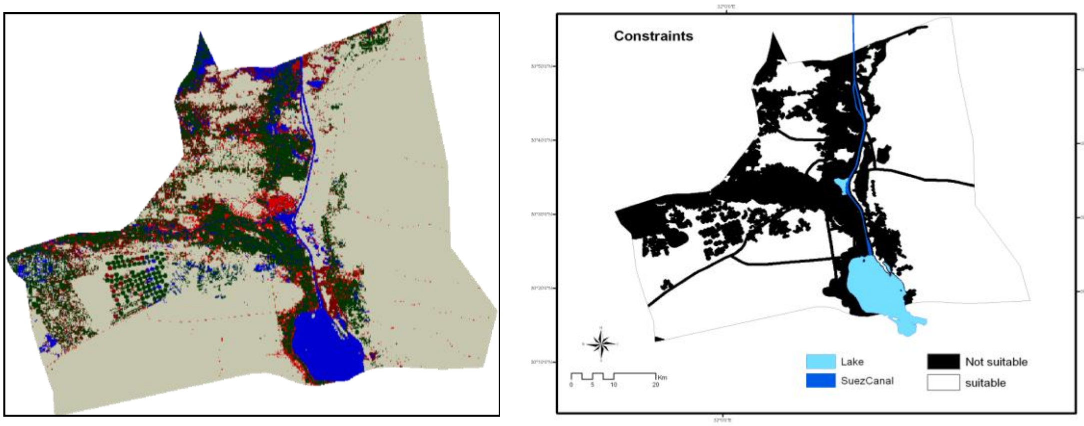


Figure 6: *(a) Land Use-Land Cover Result of Supervised Classification of Spot- 4*
(b) Constraints Map Derived From the Land Use-Land Cover

5.5. Pairwise Comparison Matrix and Calculation of Criteria Weights

Results of the pairwise comparison matrix are shown in Tables 3, 4 and 5.

Table 3: *Pairwise Comparison Matrix*

Pairwise Comparison Matrix					
	Solar Radiation	Aspect	Distance to Power Lines	Distance to Roads	Distance to Cities
Solar Radiation	1	2	4	5	6
Aspect	0.50	1	2	2.5	3
Distance to Power Lines	0.25	0.50	1	1.25	1.50
Distance to Roads	0.20	0.40	0.80	1	1.20
Distance to Cities	0.17	0.33	0.67	0.83	1
Total	**2.11**	**4.23**	**8.46**	**10.58**	**12.7**

Table 4: *Normalized Pairwise Comparison Matrix*

Normalized Pairwise Comparison Matrix						
	Solar Radiation	Aspect	Distance to Power Lines	Distance to Roads	Distance to Cities	Weight
Solar radiation	0.473	0.472	0.473	0.473	0.472	0.47
Aspect	0.237	0.237	0.236	0.237	0.236	0.24
Distance to power lines	0.118	0.118	0.118	0.118	0.118	0.12
Distance to roads	0.094	0.094	0.095	0.094	0.095	0.09
Distance to cities	0.078	0.079	0.079	0.078	0.079	0.08
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table 5: *Calculation of the Consistency Vector*

Criteria	Weight Sum Vector	Consistency Vector
Solar Radiation	[(1)(0.47)+(2)(0.24)+(4)(0.12)+(5)(0.09)+(6)(0.08)]	2.4 / 0.47 = 5.10
Aspect	[(0.5)(0.47)+(1)(0.24)+(2)(0.12)+(2.5)(0.09)+(3)(0.08)]	1.42/0.24 = 5.91
Distance to Power Lines	[(0.25)(0.47)+(0.50)(0.24)+(1)(0.12)+(1.25)(0.09)+(1.5)(0.08)]	0.589 / 0.12 = 4.9
Distance to Roads	[(0.2)(0.47)+(0.4)(0.24)+(0.8)(0.12)+(1)(0.09)+(1.2)(0.08)	0.478 / 0.09 = 11.28
Distance to Cities	[(0.17)(0.47)+(0.33)(0.24)+(0.67)(0.12)+(0.83)(0.09)+(1)(0.08)	0.392/ 0.08 = 4.9

5.6. Calculation of Lambda

(λ) (Average of Consistency vectors) = (total consistency vectors / n) ………………equation (3)
(λ) = (5.10 + 5.91 + 4.9 + 5.31 + 4.9) /5 = 5.22
λ should be equal or greater than the number of criteria under consideration. The value calculated above satisfies this condition.

b) Calculation of CI

CI = (λ-n) / n-1 ....equation (4)
CI = (5.22-5) / (5-1) = 0.22/4 = 0.055

Calculation of CR

CR = CI/RI ....equation (5)
RI = 1.12 for n =5
CR = 0.055 / 1.12 = 0.049

CR (= 0.049) <0.10 indicated a reasonable level of consistency in the pairwise

Comparison matrix used for the weight calculation.

5.7. Standardization of the Criteria Maps

Table 6: *Standardized Solar and Aspect Criteria Attributes*

Suitability Scale	Solar Radiation (WH/m2)	Aspect (Azimuth)
1	1,253,179 - 1,405,717	327.1 – 360 (North)
2	1,405,717 - 1,439,746	22.1 - 67 (North East)
3	1,439,746 - 1,458,059	67.1 – 112 (East)
4	1,458,059 - 1,469,622	292.1 – 337.5 (North West)
5	1,469,622 - 1,477,587	-
6	1,477,587 - 1,484,081	-
7	1,484,081 -1,491,258	247.1 – 292 (South West)
8	1,491,258 - 1,499,959	112.1 – 157 (South East)
9	1,499,959 - 1,512,557	247.1 - 292 (South West)
10	1,512,557 -1,564,258	157.1 - 202 (South)
10	-1 - 0	Flat lands

Table 7: *Standardized Economic Criteria Attributes*

Suitability Scale	Distance to Power lines (meters)	Distance to Main Roads (meters)	Distance to Urban Areas (meters)
0	0 - 300	0 - 500	0 - 3, 000
9	301 - 4,391	501 - 6,291	3001 - 7,881
8	4,392 - 6,586	6,292 - 9,437	7,882 - 11,821
7	6,587 - 8,781	9,438 – 12,583	11,822 -12,584
6	8,782 - 10,977	12,584 – 15,729	12,584 - 15,729
5	10,978 -13,172	15,730 – 18,874	15,730 – 18,874
4	13,173 -15,367	18,875 – 22,020	18,875 – 22,020
3	15,368 - 17,563	22,021 – 25,166	22,021 – 25,166
2	17,563 - 19,758	25,167 – 28,312	25,167 – 28,312
1	19,759 - 21,953	28,313 – 31,457	28,313 – 31,457

5.8. Weighted Overlay

The obtained spatial decision model is the result of crossing information from a series of layers regarding weather, environmental, topographic and location, as well as excluding some constraints (e.g. natural vegetation, cultivated land, urban areas), where a decision methodology (Multicriteria Evaluation and Analytical Hierarchy) has been followed. The suitability index map (of grid values ranging from 1-9) is shown in Figure 7. Large zones of high grid values 7, 8 and 9, mean that there are plenty of suitable areas to build photovoltaic power plants. The suitability map reflects the carrying capacity of the land for hosting solar energy farms. Excluded areas are not considered in this assessment as these are cultivated or urbanized lands. The result shows that large desert areas of highly suitable locations (8-9) are spatially distributed all over the image. Most suitable lands with large areas spread in the south-west bank of the Suez Canal. This is logic due to the nature of the flat desert lands which receives large numbers of sun hours and high level of global irradiation and its proximity to power lines, main roads and cities. In the Eastern bank of the Suez Canal, the same class exists in flat and gentle slopes lands with southern orientation (aspect) yet, with less areas due to low density of power transmission networks and main roads where most cities in the governorate are located in the western bank of the canal. The south eastern region of the study area receives high irradiation quantity. If the area is to be developed and the infrastructure improved in the future, the carrying capacity (suitability values) is expected to increase and more highly suitable areas would emerge in the eastern bank of the Suez Canal.

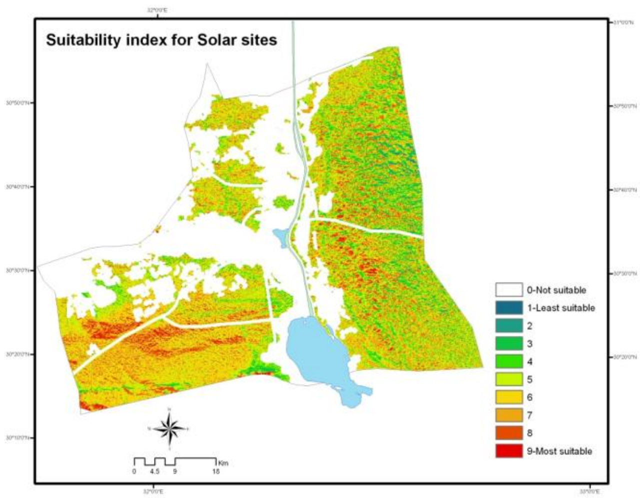


Figure 7: *Suitability Index Map Result of the Weighted Overlay Model*

5.9. Potential Sites for Solar Farms

Thirteen optimum locations for solar stations were selected from the suitability index (Figure 8). Details of such locations are shown in Table 8. Such locations fulfill the five model criteria in addition to the two selection criteria (the first is the suitability value and the second is the site area).

Table 8: *Areas of Potential Sites for Solar Farms*

Site Numbers	Suitability Values	Area in Square Meters
1	7	1,130,242
2	7	1,974,183
3	7	1,184,334
4	8	1,913,135
5	7	1,240,840
6	7	1,485,743
7	8	1,012,124
8	8	1,191,839

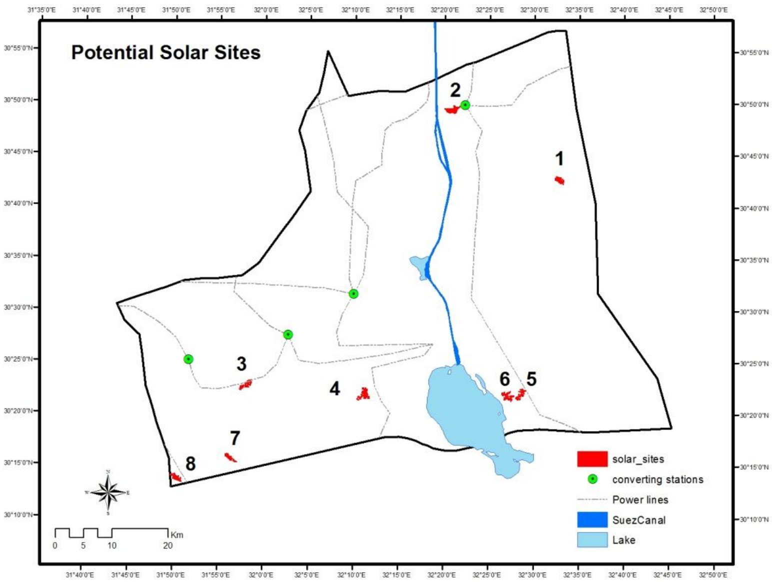


Figure 8: *Location of the Potential Sites for Solar Farms in Ismailia Governorate*

6. Model Validation

Model validation was done to guarantee if the model offers reliable representations of the system it represented (Arán-Carrión et al., 2008). Validation was done as follows:

a) The landcover classification image was verified by checking the accuracy of the pixels using a high resolution image.
b) Visual comparisons were performed between the resulting suitability index values and the highest values in the criteria images.
c) Selected optimum sites locations were overlaid on a high resolution image to verify the location has no constraints.

7. Conclusion

1) The selection of suitable sites for solar energy farms in Ismailia Governorate is based on a number of interrelated factors of geography, climate and land use-land cover. For studying such factors, remote sensing (SPOT-4 and SRTM) and GIS techniques were used and a Spatial Multicriteria Evaluation (SMCE) model was designed.

2) Integration of the interpreted data obtained from a series of layers regarding environmental and topographic features and land cover resulted in developing a spatial decision model. The study produced a suitability index map with plenty of suitable zones to construct grid-connected photovoltaic power plants. This is mainly because the Ismaila Governorate has almost flat and gentle slopes topography, and enjoys most sun radiation hours in a year period.

3) It is concluded that Spatial Multicriteria evaluation analysis managed to solve the site selection problem and fulfill the objective of the study. It considered the most effective criteria, i.e. climate and orography, and their relative importance in the decision making. Such decisions support tool studied need more attention from both researchers and decision makers.

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