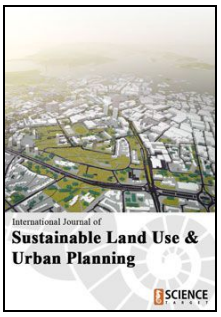
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Mapping Solar Energy Potential Zones, using SRTM and Spatial Analysis, Application in Lake Nasser Region, Egypt

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Abstract. The geographic location of Egypt gave it an enormous potential for solar radiation all through the year. Solar energy can provide a great opportunity for sustainable development and population redistribution in the vast deserts. One problem facing the development of desert zones is the lack of data. Deficiency of meteorological stations is one example. The spatial mapping of potential resources of renewable energy would help in the integrated regional energy planning. This article defines the structure and the principal phases of an environmental decision-support system that integrates multicriteria analysis, the analytic hierarchy process (AHP) with geographical information systems (GIS) technology to facilitate identifying potential zones for solar energy around Lake Nasser, in Aswan, Egypt. Global area-solar radiation was modeled using Shuttle Radar Topography Mission (SRTM) digital elevation. Landsat-7 ETM was used to derive the land use-land/land-cover map. The solar radiation, orography, infrastructure, and land-cover were combined in a multicriteria analysis model to arrive to the optimum zones for locating solar energy stations. Annual total area-solar global radiation reached 1,730,423 Wh/m^2 and a mean radiation equivalent to 1,606,410 watt hour per square meter. The result reveals zones having the highest potentiality for solar energy crop covering an area equivalent to 20% of the region and having ideal conditions for siting solar energy stations.

Keywords. *solar energy, insolation, area-solar radiation, remote sensing, spatial decision support system, SRTM, Aswan.*

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1. Introduction

1.1 Solar Energy and Spatial Models

Energy systems presently in use across the world can be classified into three main areas: fossil fuels, nuclear power and renewables. Renewable energy resources are easily accessible to mankind around the world. They are not only available in a wide range, i.e. solar, wind, biomass and wave energies but are also abundant in nature. Solar power is one of the most promising renewable energy. It is more predictable than wind energy and less vulnerable to changes in seasonal weather patterns (Muneer et al., 2005). Solar Irradiance is measured in W/m^2. When integrating the irradiance over a certain time period it becomes solar irradiation. Irradiation is measured in either J/m^2 or Wh/m^2. The best sites on earth, in extreme desert areas, receive an annual solar irradiation which can be more than 2500 kWh/m^2. On the other hand, there are cloudy sites at high latitudes with an annual irradiation far below 1000 kWh/m^2. On-site measurements and different types of sensors exist to measure the solar irradiance (Quaschning, 2003).

Topography is a major factor that determines the spatial variability of insolation. Variation in elevation, orientation (slope and aspect) and shadows cast by topographic features all affect the amount of insolation received at different locations. This variability also changes with time of day and time of year and in turn contributes to variability of microclimate. Pescador et al. (2006) explain that there are two types of models for estimating solar radiation at

the surface: point-specific models and area-based models. The point-specific models compute insolation for a location based upon the geometry of the surface, the visible sky from the specific point and the actual position of the sun. The local effect of topography is incorporated into the model by empirical or visual estimation. Such models can be highly accurate for a given location (Fu and Rich, 2000) but not for an entire landscape. In contrast, area-based models compute insolation for a geographic area, computing surface orientation and shadow effects from a digital elevation model (Dubayah and Rich, 1995; Kumar et al., 1997). As a consequence, whereas point-specific models can be highly accurate for a specific location, area-based models can calculate insolation for every location over a landscape. Digital Elevation Models (DEM) provide useful information for analyzing the topography of a terrain while the use of geographic information system (GIS) has contributed to solve the problem (Pescador et al., 2006). Different interpretation techniques have been used for analysis of the spatial distribution of solar radiation in a region. The solar radiation analysis tool in ESRI Spatial Analyst extension enables mapping and analyzing 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 resultant outputs can be easily integrated with other GIS data and can help model physical and biological processes as they are affected by the sun (ESRI, 2009).

A GIS as a system of hardware, software, and procedures to facilitate the acquisition, management, manipulation, analysis, modeling, representation, and output of spatially referenced data to solve complex planning and management problems (NCGIA, 1990). In recent years, GIS have become increasingly popular as a tool for territorial planning and for the selection of optimal sites for different types of activities and installations (Carrion et al., 2008; Ramachandra and Shruthi, 2005). Spatial multicriteria decision analysis is a process that combines and transforms geographical data (the input) into a decision (the output). This process consists of procedures that involve the utilization of geographical data, the decision maker's preferences, and the manipulation of the data and preferences according to specified decision rules. Suitability mapping involves using a variety of data sources in which weights are assigned to geographical criteria. Data are often imported into a Geographic Information System (GIS), which combines potentially unrelated data in a meaningful manner. Weights that emphasize the relative importance of one criterion to another are often determined by managers, research specialists, stakeholders, or interest groups to enhance decision-making. It is thus possible to obtain continuous suitability maps and to thus provide an optimal framework for the integration of the environmental, economic, and social factors that affect land suitability for a certain use (Janke, 2010; Malczewski 2004; 2006; Effat, 2013; 2014). Among the various multi criteria evaluation MCE techniques, the weighted linear sum is the simplest and most commonly used. Another technique is the Analytic Hierarchy Process AHP (Saaty, 1997; Carrion et al., 2008; Jun, 2000; Weerakon, 2002; Effat, 2013; 2014) method, which 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 / decision maker judgment.

This article defines the structure and the principal phases of an environmental decision-support system that integrates multicriteria analysis as well as the analytic hierarchy process (AHP) with geographical information systems (GIS) technology to facilitate potential zones for harvesting solar energy around Lake Nasser Region.

1.2 Description of the Decision Support Analysis

The analysis follows the phases of the elaboration of the spatial model:

(i) Identification of the objectives.

(ii) Specification of criteria and decision rules.

(iii) Calculation of weight consistency.

(iv) Determination of the land suitability for solar energy plants.

1.2.1 Identification of the Objectives

A specific goal and clear goal and objectives are the first phase of a decision support system. Achieving the goal has to be clarified by the objectives, which have to be comprehensible, consistent, and measurable.

1.2.2 Specification of the Criteria and Establishment of the Decision Rules

A criterion is a measurable aspect of a judgment, which makes it possible to characterize and quantify alternatives in a decision-making process (Carrion et al., 2008; Voogd 1983, Saaty, 1997). These criteria represent conditions possible to be quantified and contribute for the decision-making (Eastman et al., 1993). Selection of a proper set of evaluation criteria can be done by means of literature study, analytical studies, or survey of expert knowledge opinions (Voogd, 1983). Criteria are divided into factors and constraints. Each of these factors is determined by indicators defined as magnitudes that measure or rate a factor. Indicators can be classified in two groups: (i) positive indicators and (ii) negative indicators or restrictions. Positive indicators are those that enhance the suitability of an alternative. On the contrary, negative indicators restrict or limit the alternative's suitability while a constraint rejects the suitability of an alternative.

1.2.3 Calculation of Weights and Consistency

The process of converting data to a numeric scale is most commonly called standardization (Voogd, 1983). ArcGIS10.1 spatial analyst extension was used to classify the criteria attributes based on their favorability / unfavorability using the maximization and minimization functions to reclassify them into Saaty's scale of measurement (Figure 1).

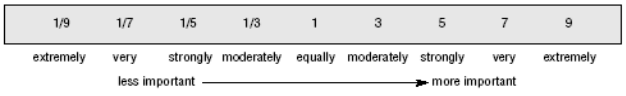


Figure 1: Saaty's 9-points rating scale (after Saaty, 1997)

The Analytic Hierarchy Process (AHP) technique is used to assign weights to the factors and determine their relative importance in the final decision. The method is based on pair-wise comparison between pairs of criteria, contrasting the importance of each pair with all the others. Subsequently, a priority vector is computed to establish weights (wj). These weights are a quantitative measure of the consistency of the value judgments between pairs of criteria (factors) (Saaty, 1980; 1990; Eastman and Jiang, 1996).

Determination of consistency vector by dividing the weighted sum vector by the criterion weight. Once the consistency vector is calculated, computing values for two more terms, lambda (λ) and the consistency index (CI), is required. 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 pair-wise comparison matrix is consistent. Accordingly, λ-n can be considered as a measure of the degree of inconsistency. This measure can be normalized as follows:

$$CI = (\lambda - n) / (n-1) \quad [1]$$

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:

$$CR = CI/RI \quad [2]$$

Random Index is the CI of a randomly generated pair-wise comparison matrix of order 1 to 10, which is obtained by approximating random indices using a sample size of 500 (Saaty, 1980). The RI sorted by the order of matrix is shown in Table 1. 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 pair-wise comparisons.

1.2.4 Determination of the Land Suitability Index

Traditionally, standardized factors are combined by means of weighted linear combination.

That is, each factor is multiplied by a weight, with results being summed to arrive at a multi-criteria solution. In addition, the result may be multiplied by the combined binary constraints map based on equation 3 (Eastman et al., 1995).

$$\text{Suitability} = \sum W_i X_i * \Pi C_j \quad [3]$$

where W_i = weight assigned to factor $_i$

X_i = criterion score of factor $_i$

C_j = constraint j

Table 1

Random index (Saaty, 1980)

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

2. Description of the Study Area

The study area is part of Aswan Governorate located between 24° 28' 0" N, 32° 27' 00" E and 22° 44' 30"N, 33° 22' 30" E. Aswan Governorate is bordered in the North by Qena governorate, in the East by the Red Sea Governorate, in the west by the New Valley Governorate, and in the south by Egypt-Sudan borders. The area has a rugged topography with an average elevation 194 meters above sea level. Lake Nasser is a reservoir on the River Nile. It was created by the impounding of the Nile's waters by the Aswan High Dam, which was built in the 1960s and dedicated in 1971. Agriculture is the main activity in the governorate, which is famous for growing sugar-cane, hibiscus, wheat, dates, and henna (Egyptian State Information Services, 2013). It is one of the most important tourist sites and contributes tremendously to the tourism sector and the national economy. Having a great heritage of temples and archae-ological sites, the governorate contributes to the world's historical and cultural tourism.

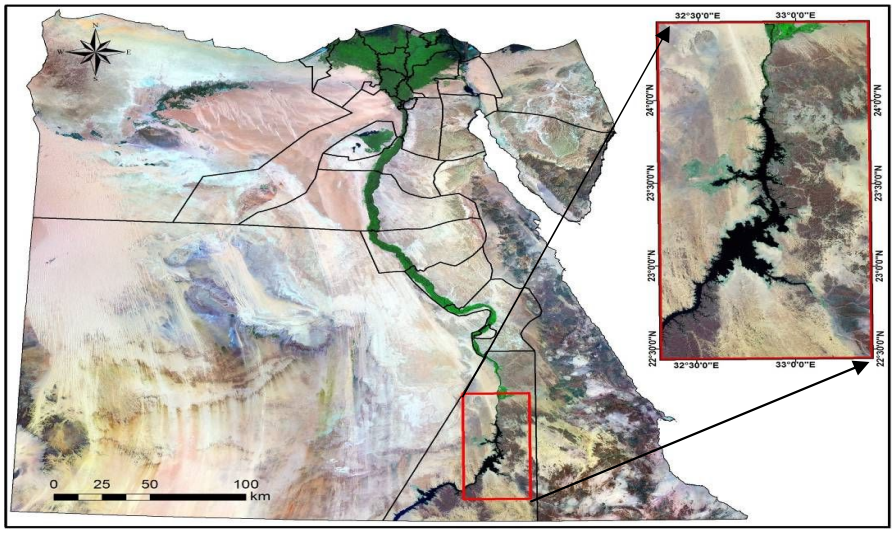


Figure 2: Location of the study area

Table 2

Monthly average rates of some climatic elements in Aswan (after CAPMAS, 2014)

Aswan	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum temperature (°C)	22.8	25.2	29.6	34.9	38.9	41.3	41.2	40.9	39.4	35.8	29.2	24.3
Minimum temperature (°C)	8.7	10.2	13.9	19.0	23.0	25.2	26.1	25.9	24.1	20.6	15.1	10.5
Rainfall (mm)	0	0	0	0	0	0	0	0.6	0	0.6	0	0
% Humidity	39	30	23	18	15	15	18	20	22	26	35	40
Sunshine hour/month	298	281	321	316	346	363	374	359	298	314	299	289

Source 1: Monthly average rates of some climatic elements in Aswan (after CAPMAS, 2014),
Source 2: NOAA (2015) Aswan Climate Normals 1961-1990 for mean temperature, humidity and sunshine hours.

Being part of Egypt, the climatic conditions of Aswan is hot and dry desert climate, according to Köppen climate classification is BWh (Peel et al., 2007). Average high temperatures are consistently above 40 °C (104.0 °F) during summer (June, July, August, and also September) while average low temperatures remain above 25 °C (77.0 °F). Summers are long and extremely hot. Average high temperatures remain above 23 °C (73.4 °F) during the coldest month of the year while average low temperatures remain above 8 °C (46.4 °F). The climate of Aswan is extremely clear, bright, and sunny all year-round with a low seasonal variation with about 4,000 hours of annual sunshine, very close to the maximum theoretical sunshine duration.

3. Description of the Data

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 10 spatial analyst modules.

Landsat ETM+: The data set was created by the U.S. Geological Survey and was obtained in geographic Tagged Image-File format (GeoTIFF) for 18 August 2013. The data type is level 1, which provides systematic radiometric and geometric accuracy derived from data collected by the sensor and spacecraft. Atmospheric correction was conducted using ENVI quick atmospheric correction module prior to the image classification. Supervised classification was used to produce the land-use / land-cover maps.

Maps: The topographic map published by the Egyptian General Survey Authority (1994) scale 1:50,000 was scanned, geometrically corrected, and used to extract the roads and power lines by on-screen digitizing. The roads were further updated from Landsat ETM imagery acquired in 2013. All data were projected to WGS-84 of the Universal Transverse Mercator (UTM) System of geographic coordinates and were resampled to 90 m resolution and used in the present study.

4. Applying the Decision Support Analysis on Lake Nasser Area

The results of applying the methodology on the Lake Nasser area are explained in the following section:

4.1 Definition of the Objectives

There is one goal and three objectives for this study. The goal is to identify a set of potential sites for solar power plants in Aswan. Because the region is characterized by a desert environment, the sites have to satisfy three objectives:

- To fulfill the maximum solar radiation crop as the main natural resource.
- To minimize the costs of establishment based on terrain characteristics.
- To avoid the environmental sensitive areas and constraints in the region.

The objectives are translated into a set of criteria and decision rules.

4.2 Specification of the Criteria and Establishment of the Decision rules

Climate criteria are the most important for the decision rule since global solar radiation defines the power production capacity as its main resource. 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. 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. 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 area-solar radiation map was given the highest relative importance among the criteria set. It was created using the areasolar radiation module in ESRI Spatial Analyst using SRTM digital elevation model. For the configuration option, the whole year with monthly intervals was chosen for year 2015. In such option, the model performs calculations for an entire year using monthly intervals. The latitude was automatically calculated as the input raster was projected to WGS1984 UTM zone 36N. For the sky size the default was used. The solar radiation analysis tools analyzes 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. The tool is developed by Rich (1990) and by (Rich et al., 1994) and further developed by (Fu and Rich, 2000). 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 results of the model are radiation raster grids, which have floating-point type and have units of watt hours per square meter (WH/m^2). Practitioners in the business of solar energy may use the unit watt hour per square meter (Wh/m^2). If this energy is divided by the recording time in hours, it is then a density of power called irradiance expressed in watts per square meter (W/m^2). The raster grid was classified using the standard deviation method and rated according to the quantity of solar radiation (Table 3.a)

Table 3.a

Climatic and Environmental Criteria standardization

Criteria	Factors	Attribute values	Rating
Climate	Global irradiance (Wh/m2/yr)	927,047 - 1,533,370	3
		1,533,371 - 1,562,586	4
		1,562,587 - 1,591,802	5
		1,591,803 - 1,621,018	6
		1,621,019 - 1,650,236	7
		1,650,237 - 1,679,451	8
		1,679,452 - 1,730,423	9
Environment	Land-use / land-cover	Cultivated land	0
		Bare land-desert-sand sheets	9
		Natural vegetation	3
		Urban area	0
		Water	0

The land use-land cover was derived from Landsat7 ETM+ acquired in 2013 using supervised classification. Five land-cover categories were rated based on their legibility to provide a suitable zone for solar farms. The desert bare lands were given the highest category, while zero was given to water, urban areas and cultivated lands (Table 3.a) Aspect angles (orientation) and slope degrees were category-

ized, the milder slopes being highly suitable since the most suitable sites are those where the ground is flat and with aspect angle oriented towards the south. Location criteria such as proximity to conversion stations and inhibited areas, roads were considered in the site selection (Table 3.b).

Table 3.b

Topography and Location Criteria standardization

Criteria	Factors (unit of measure)	Attribute Values	Rating
Topography	Slope (in degrees)	0- 2	9
		2- 5	8
		5 -10	7
		10 -15	5
		> 15	1
	Aspect (azimuth angle)	0 (flat)	9
		0 - 22.5 (North)	1
		22.5 - 67.5 (Northeast)	2
		67.5 -112.5 (East)	4
		112.5- 157.5 (Southeast)	7
		157.5 - 202.5 (South)	9
		202.5 - 247.5 (Southwest)	8
		247.5 - 292.5 (West)	6
		337.5 - 360 (Northwest)	2
Location	Distance to main roads (meter)	0 - 6,757	9
		6,757 - 13,513	8
		13,514 - 20,513	7
		20,514 - 27,027	6
		27,028 - 33,783	5
		33,784 - 40,540	4
		40,541 - 47,296	3
		47,297 - 54,053	2
		54,054 - 60,810	1
	Distance to conversion stations (meter)	0 - 18,831	9
		18,832 - 35,645	8
		35,646 - 54,477	7
		54,478 - 73,308	6
		73,309 - 90,796	5
		90,797 - 106,936	4
		106,937 - 123,750	3
		123,751 - 143,254	2
		143,255 - 171,501	1
	Distance to cities	0 - 10,435	9
		10,436 - 20,870	8
		20,871 - 31,305	7
		31,306 - 41,740	6
		41,741 - 52,176	5
		52,177 - 62,610	4
		62,610 - 73,045	3
		73,046 - 83,480	2
		83,481 - 93,915	1

4.3 Creating the Combined Constraint Map

A constraint map was created for the developed, protected, and vulnerable lands. Such maps include the lake body, cultural values and nature protected sites, urban areas, cultivated lands, and faults. The buffer zone of 500 meters was created around Lake Nasser to protect the gulls and the shoreline ecology. A similar zone was created around the protectorate. A buffer zone of 200 meters was created around the faults. In addition, the slope constraint rule was set such that lands with slope more than 15 degrees were masked out. Similarly, the aspect rule was set such that only the southerly-oriented lands lying outside the range of 112.5 and 247.5 were considered a constraint. Such maps were converted into binary maps giving a value of zero to the constraint lands and a value of one to the developable lands. The combined map was created by multiplication of all binary maps.

4.4 Calculation of Criteria Weights and Consistency Ratio

The climate factor was considered moderately more important than the location criteria as it is usually possible to build new urban areas, stations, and roads. It was considered very much more important than the topography because most of the lands were flat or with mild slopes. It was considered extremely more important than the environmental criteria (land-cover) because most of the lands are desert areas in addition to preserving the vulnerable lands (such as the cultivated lands and water bodies and the archaeology sites) was considered in separate constraints criteria. The criteria weights are calculated using a pair-wise comparison matrix (Table 4).

$\lambda = \sum Cv / n = 4.01$

$CI = \lambda - n / n-1 = 0.0033$

$CR = CI / RI = 0.0033 / 0.9 = 0.0037$

$CR < 0.01$ indicates that the weights are consistent.

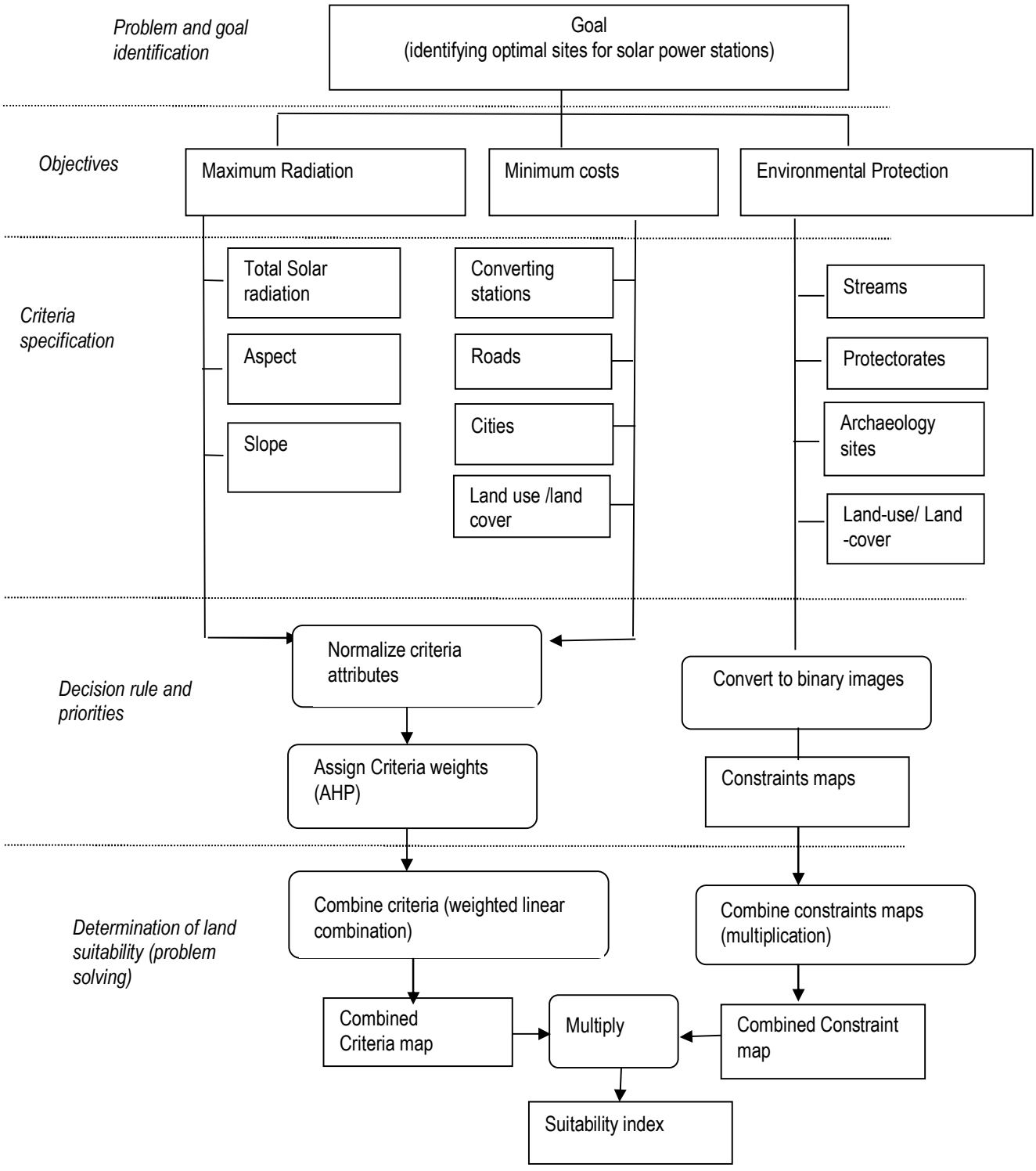


Figure 3: Conceptual Model for Location of Solar Power Stations

Table 4

Pairwise Comparison Matrix

	Climate	Topography	Location	Environment	Calculated weight
Climate	1	7	3	9	0.628
Topography	1/7	1	3/7	9/7	0.089
Location	1/3	7/3	1	9/3	0.208
Environment	1/9	7/9	3/9	1	0.069
Criteria	**Weight sum vector**				**Consistency vector C*v***
Climate	1(0.629) +7(0.089) +3(0.209) + 9(0.070) = 2.509				3.99
Topography	1/7 (0.629) +1(0.089) +3/7 (0.209) + 9/7 (0.070) = 0.359				4.033
Location	1/3 (0.629) +7/3(0.089) + 1 (0.209) +3(0.070) = 0.839				4.01
Environment	1/9 (0.629) + 7/9(0.089) + 1/3(0.209) + 1(0.070) = 0.277				4.01

5. Results

5.1. Determination of the Land Suitability Index for Solar Energy Plants

The total study area covers 25,139 sq.km in southern Egypt. Large areas of flat and gentle slopes extend both east and west of Lake Nasser and vast areas having southward orientations (south, south-east, and south-west orientation (Figure 4-a, 4-b). The total annual areasolar radiation (global radiation) recorded for the study area for the year 2015 reaches maximum 1,730,423 Wh/m^2 in the highest radiation areas, a minimum of 929,047 wh/m^2 and a mean equal to 1,606,410 wh/m^2 (Figure 4-c). The land-cover map reveals the area of the desert zones and sand sheets amounts to 16,928.7 sq.km equivalent to 67.3 % of the study area. Such class is favored for siting solar power stations because cultivated lands and natural vegetation classes should be protected from change. Cultivated lands are equivalent to 403.9 sq.km equivalent to 1.6% of the study area. The various land-cover classes and related areas are shown in Figure 5a and areas are mentioned in Table (5)

Location factors such as distance to conversion stations point out the proximity of the power infrastructure in the region (Figure 5a). Distance to cities and roads show the development pattern extending along the Nile River and Lake Nasser (Figures 5a, 5b, 5c, and 5d).

Applying equation 3, using ArcGIS10.1 spatial analyst, the suitability index was calculated and rescaled to eight suitability categories. Despite masking out the constraints lands, the result revealed that most of the lands around Lake Nasser are highly suitable for locating solar energy stations. The total area of highest-category (class 8) covers about 2,673 sq.km. This is equivalent to 20.1 % of the developable lands. Areas for zones of different suitability classes are graphed in Figures 6a, and 6c and 7. The area of the constraint lands (excluded lands) covers10,590 Km2 equivalent to 42.1 % of the study area. Such constraint lands include the national park, city buffer zones, faults buffer zones, and water bodies (Figure 6b).

Table 5

Land-use /Land-cover classes and related areas

Land use-land cover class	Area in sq.km.	Percentage of total study area
water	2,648	10.5
urban	61.9	0.24
agriculture	403.9	1.6
Bareland and sand sheets	16,928.7	67.3
Basement rocks	5,138.6	20.4

5.2 Model Validation

The final phase in the construction of a model should be its validation in order to guarantee that it offers a reliable representation of the systems represented.

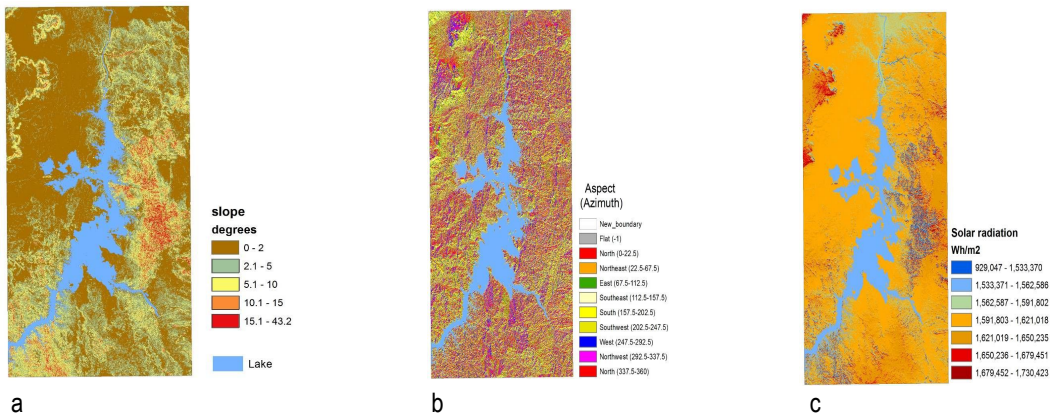


Figure 4: a- land slope angles; b- aspect angles in azimuth; c- annual global solar radiation

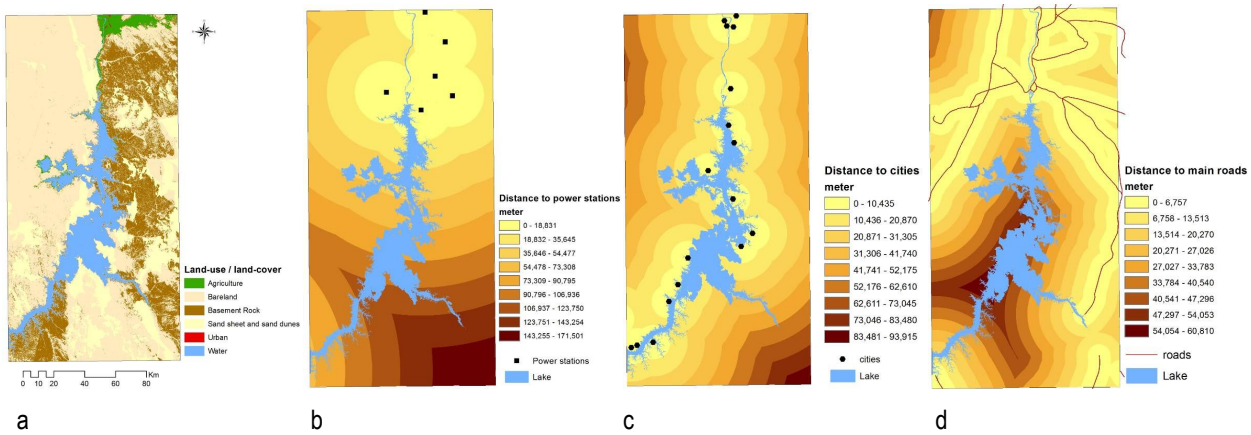


Figure 5: criteria maps: a- land-use/ land-cover map. b- distance to power stations. c- distance to cities. d- distance to main roads

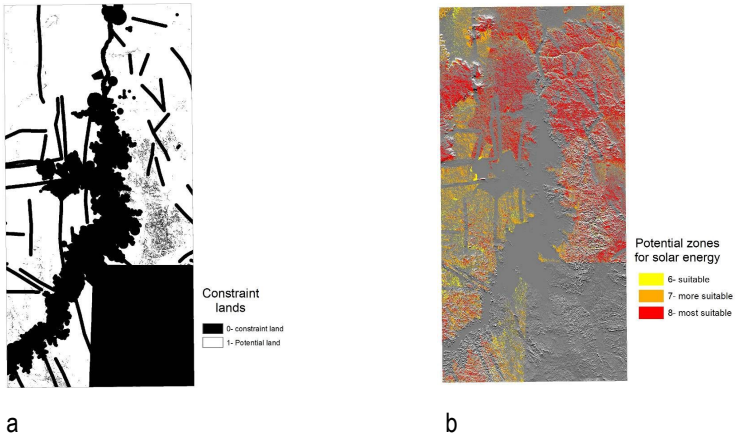


Figure 6: a- constraint lands. b- zones with highest potentiality for solar energy overlaid with hill-shade

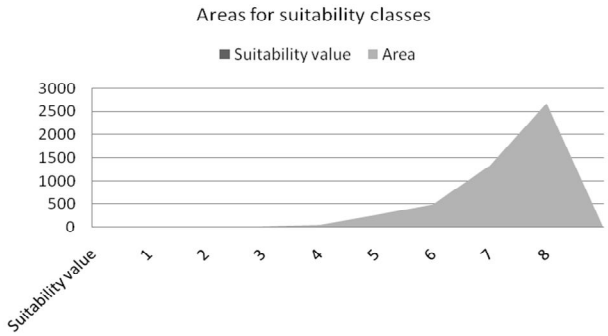
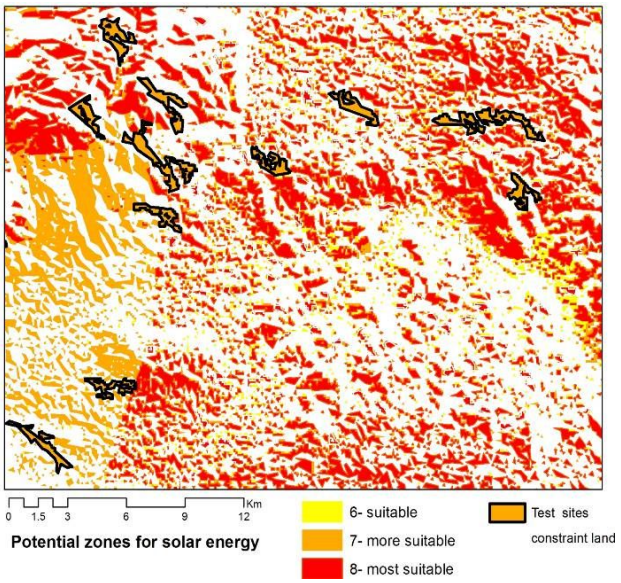


Figure 7: Land areas for solar energy potential categories

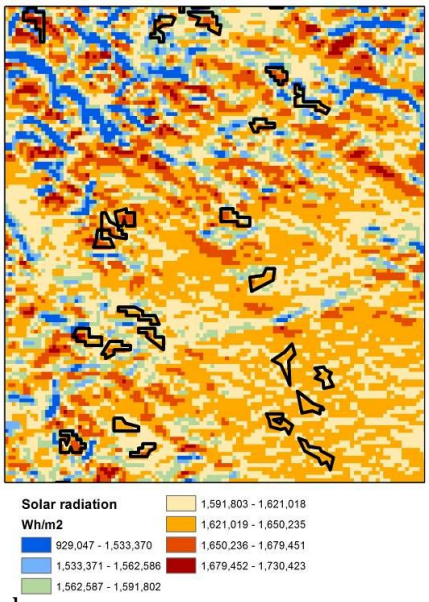
Table 6

Classification statistics of the result of areasolar model

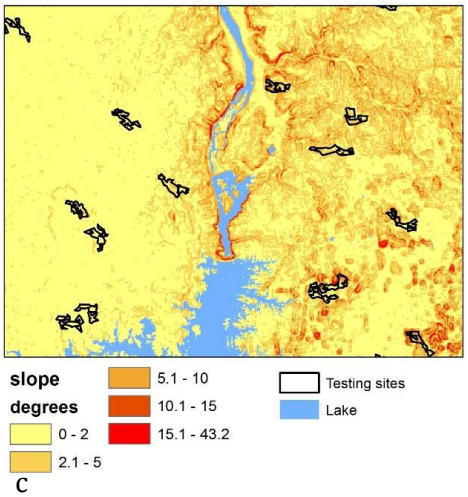
Awan Total Areasolar Radiation (Wh/m2) for year 2015		
Minimum radiation	Mean radiation	Maximum radiation
967,668	1,603,458	1,745,634



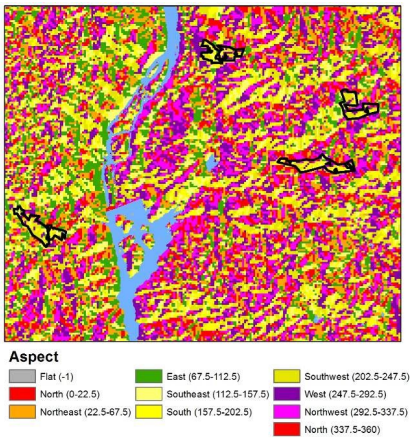
a



b



c



d

Figure 8: A snapshot of the randomly selected potential sites used for the model validation: a- suitability index. b- solar radiation map. c- slope. d- aspect

Table 7

Statistics for the 264 model validation sites

No of testing sites	Model validation parameter	Testing sites statistics Minimum	Maximum	Mean
264	Solar radiation (Wh/m2)	1,625,022	1,668,626	1,640,525
	Slope (degrees)	0.62 (flat)	13.5	5.6
	Aspect (azimuth angle)	132 (south-east)	259 (south-west)	185 (south)

The verification of a model means checking to see if the results fulfill the entry requirements. In other words, verifying if the model has been correctly designed by making sure that the criteria followed in the decision rule are correct (Carrion et al, 2008). For the present study, the validation was based on selection of 264 sites from the highest suitability value of land (classes 6, 7, and 8) within areas ranging between 1-2 square kilometers. First, the selected sites were displayed with the constraints map to ensure it complies with the no-constraints condition. Second, such sites were examined to verify they comply with the topographic factors decision rules (slopes less than 15 degrees and southerly oriented). Third, the area-solar radiation grid was used to check the radiation values in the selected sites. ESRI zonal statistics as table module were used. The tool summarizes the values of a raster within the zones of another datasets (in this case the zones are the 264 selected sites and the raster datasets are the slope, aspect, and area-solar grids). All sites were found to confirm with the decision rules. A summary of the area zonal statistics are displayed in Table 6.

6. Conclusion

The present study used Shuttle Radar Topography Mission (SRTM) digital elevation model to model the area solar radiation in the Aswan Region. The study area is equivalent to 25,139 sq.km Findings reveal that most of the lands surrounding Lake Nasser are highly suitable for locating solar energy stations. The total annual areasolar radiation reaches maximum 1,745,634 Wh/m^2 in the highest radiation areas and a mean equal to 1,603,458 wh/m^2. The percentage of high potential zones reaches 33% of the total study area. This result revealed a great and remarkable potential for harvesting solar energy.

The geographical location and topography of the Aswan Region are the main factors for such high potentiality. The vast bare rock-lands with mild slopes and southern orientation provided suitable conditions for harvesting solar radiation.

The results highlight the capability of combining digital elevation data and spatial models in providing initial, quantitative, and low cost analysis. Such results and maps are quite useful for land-use decision makers and energy planners in such a regional scale. Further local studies need to be conducted in more detail, such as field measurements, and use of high resolution elevation models. Yet such studies should focus on more limited areas. Generally speaking, it is believed that the results of the present study can be used as an indicator and guide map, a tool for decision support in land-use and energy planning.

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