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GIS-based suitability analysis for Solar Homestead Sites (Case Study: Sheikh Zayed Area, 6th Of October City in Egypt)

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Abstract: The climate change problem refers to long-term shifts in temperatures and weather patterns. Human activities have been the main driver of climate change, primarily due to the burning of fossil fuels (like coal, oil, and gas) increasing heat-trapping greenhouse gas levels in the Earth's atmosphere. The world is shifting towards renewable energy resources to mitigate environmental problems Renewable energy sources are preferable as they are usually free, and widely available with limited or no environmental impacts. Egypt is renowned for being among the best places in the world to produce solar energy.This study aims to provide a GIS-based model for multi-criteria suitability analysis to identify optimum sites for constructing large-scale solar farms in the Sheikh Zayed area, 6th Of October City in Egypt, where solar radiation from different Digital Elevation Models (DEM) sources was calculated and compared to each other. Data obtained from Solar-Med-Atlas using Heliosat Method. The results identified 47 sites in Sheikh Zayed and neighboring areas as suitable for solar energy utilization.

Keywords: Smart City, Solar Farm, Shuttle Radar Topography Mission (STRM), Site Selection models builder, and GIS Suitability Analysis

1. Introduction

Our cities must grow smarter as our globe becomes more urbanized. When 66% of the world's population lives in urban areas by 2050, it will be impossible to provide these populations with basic supplies. A smart city can use technology, data, and political vision to create a comprehensive strategy for urban and service improvements. The primary six characteristics of smart urban environments are clever people, smart living, smart mobility, smart environment, and smart government. Renewable energy sources represent a viable alternative to meet the increasing demand for energy in the future [1] and attain sustainable development [2]. Solar energy is one of the clean, free, and abundant sources of energy that could meet the growing demand for electric power in many countries [3].

The development of solar power technologies has a strong case for being the next development in the generation of renewable energy.

On a national scale, the Egyptian Cabinet approved, in 2012, an ambitious plan to increase the percentage of renewable energy to 50% by 2050. Some current solar energy projects include the solar water heaters project for hotels in the Red Sea and the south Sinai governorate. However, selecting appropriate sites for harvesting solar energy is not a single-criteria task. Basically, it is based on several sets of topographic, physical, environmental, and socio-economic criteria to decide optimum geographical locations. Geographic Information System (GIS) has been utilized comprehensively in the last eras for sighting optimum locations for a variety of objects such as groundwater, touristic infrastructures, urban development, and wind turbine. The selection of an appropriate location for solar energy development has an impact on the cost of the system, the effectiveness of the solar panels, and the environment. GIS solutions-based multi-criteria approach has proven to be an efficient decision support tool for locating optimum spatial sites, particularly for solar energy harvesting. For example, a study suggested a GIS-based multi-criteria evaluation for a sitting solar farm in South Central England [4].

This broadside objective is to localize applicable sites for solar energy collecting in Sheikh Zayed Area 6th of October City in Egypt utilizing the GIS solutions based on multi-criteria solving. A GIS-based multi-criteria methodology has proven to be an efficient decision support tool for locating optimum spatial sites, particularly for solar energy farms.

Methodology

1.1 Data Used

Data collected from open and free sources as below:

- A 30m x 30m Digital Elevation Model (DEM) from the following website: https://earthexplorer.usgs.gov/ ,
- A DEM of 90m x 90m From the following website: http://www.solar-med-atlas.org/solarmed-atlas/download.htm
- City boundaries shape file From Google Earth Pro as a file. KMZ for boundaries area,
- Land use shape file and road shape file are obtained from Open Street Map (OSM) from the following website: https://extract.bbbike.org which provides data of (OSM) in many extant.

- Electrical Network as a shape file (EN) from the following website: http://www.solar-med-atlas.org/solarmed-atlas/download.htm.
- Solar Radiation data has been calculated by using DLR Heliosat Method From the following website: http://www.solar-med-atlas.org/solarmed-atlas/download.htm
- A 3m x 3m Digital Elevation Model (DEM) generated from land surveying observation using Total Station and Global Positioning System (GPS).

1.2 Developed Different Criteria and weights for Site Suitability Analysis

Based on several trials, investigations, and literature, [5] [6] concerning solar energy criteria, Table (1) presents the most commonly utilized criteria types, or elements (parameters) and the diverse weights recommended from altered previous hearings. The site suitability analysis was conducted using ArcGIS 10.6 software which is a Geographic Information System (GIS) worldwide package with the addition of the above-mentioned data. Digital Elevation Model (DEM) for the study area was created from the observed data to create a solar radiation raster using ArcGIS Spatial Analyst and Area Solar Radiation tools. The needed area's average annual solar radiation was used to calculate the solar radiation raster, which was then classed into ten distinct classes utilizing natural breaks on a 0 to 100 scale using the ArcGIS Spatial Analyst tool (Reclassify), [7] as shown in Table (2).

Note that, the highest solar radiation is valued as (100) but the lowest one is valued as (0). Since higher solar radiation is more desirable for a solar farm location. DEM for the study area was subsequently used to create a slope raster using the Spatial Analyst, and Slope tools. Reclassified once more done but here into five separate classes from values (0) until (100) and scaled as clarified in Table (3).

Because a lower slope is more advantageous for a solar farm location, the lowest slope is valued at (100) and vice versa. This is because the solar panels must be stationary and on a flat surface to maximize solar energy absorption. [8].

Digital Elevation Model (DEM) for the study area afterward was used to create a hill shade raster and an aspect raster using the respective Spatial Analyst tools. The hill shade raster was then reclassified using five natural break values from (0) to (100) scale, realize in Table (4).

Note that, the lower hill shade is valued at (100) and vice versa, since lower hill- shade means higher solar radiation.

Following that, the aspect raster was classed using five distinct classes on the same scale, as shown in Table (5). Due to the sun's position in relation to the geographical area, which permits increased solar radiation on south-facing facing slopes, a south-facing aspect is preferable. The land cover raster was then classed using five distinct classes on a scale of (0) to (100), as shown in Table. (6).

TABLE (1): The Most Common Utilized Criteria and Weights

Criteria Type	Criterion	Weight
Technical	Solar Radiation	0.25
	Slope (degree)	0.15
	hill shade	0.025
	aspect	0.025
	Distance from Electrical Network	0.15
Economical	Distance from Roads (km)	0.15
Constraints	Land Use	0.25
	Lakes	
	Valleys	

TABLE (2): Solar Radiation Reclassification Values

Solar Radiation (WH/m2)	Re-classified Value (%)
1484397 - 1583347	100
1457101 - 1484397	90
1433216 - 1457101	80
1409332 - 1433216	70
1382036 - 1409332	60
1347915 - 1382036	50
1300146 - 1347915	40
1225081 - 1300146	30
1081775 - 1225081	20
709862 - 1081775	10

TABLE (3): Slope Reclassification Values

Slope (Degrees)	Re-classified Value (%)
0 - 2.6	100
2.6 - 4.7	75
4.7 - 7.4	50
7.5 - 12.4	25
12.4 - 51.9	0

TABLE (4): Hill Shade Reclassification Values

Hill shade (Illumination Value)	Reclassified Value (%)
0-156	100
156-170	75
170 - 180	50
180-190	25
190 - 253	0

TABLE (5): Aspect Reclassification values

Aspect	Reclassified Value (%)
North	0
Northeast	25
East	25
Southeast	50
South	100
Southwest	75
West	75
Northwest	25
Flat	100

The study area Road shape files were used to create a buffer zone around roads. Using the Euclidean Distance tool from Arc Toolbox Calculates, for each cell, the required Euclidean distances were found to the closest source. The Euclidean distance raster was reclassified using five separate classes varying from (0) to (100) which scaled as well, as it's clear in Tables (7), and (8).

TABLE (6): Land Cover Reclassification Values

Land use	Reclassified Value (%)
village green	0
military	0
farmland	0
grass	0
residential	0
retail	100
cemetery	50
construction	0
commercial	50
industrial	0
recreation _ ground	25
orchard	0
quarry	100

TABLE (7): Buffer Zone around Roads and Reclassified Values

Roads Buffer (m)	Reclassified Value (%)
0 - 359.5	100
359.5 - 1018.7	75
1018.7 - 1837.6	50
1837.6 - 2836.3	25
2836.3 - 5093.4	0

TABLE (8): Buffer Zone around Electrical Network and Reclassified Values

Electrical Network Buffer (m)	Reclassified Value (%)
0 - 150	100
150 - 272.8	75
272.8 - 502.9	50
502.9 - 656.9	25
656.9 - 731.9	0

1.3 Methodology

The Area Sun Radiation tool adds direct solar radiation and diffuse solar radiation to determine an area's total solar radiation., as in Equation (1).

$$Global_{tot} = Dir_{tot} + Dif_{tot} \quad (1)$$

$Global_{tot}$ is the total solar radiation of the area and calculated in units of watt hours per square meter (WH/m2).

Dir_{tot} is the total direct solar radiation of the area, which is calculated by ArcGIS using Equation (2).

Dif_{tot} is the total diffuse solar radiation of the area which is calculated by ArcGIS using Equation (4).

$$Dir_{tot} = \sum Dir_{\theta, \alpha} \quad (2)$$

Dir_{tot} is the total direct insolation and the sum of $Dir_{\theta, \alpha}$ is the direct insolation from all sun map sectors which is calculated using Equation (3).

$$Dir_{\theta, \alpha} = S_{Const} \cdot \beta^{m(\theta)} \cdot SunDur_{\theta, \alpha} \cdot SunGap_{\theta,\alpha} \cdot \cos(AngIn_{\theta,\alpha}) \quad (3)$$

β is the transmissivity of the atmosphere for the shortest path in the direction of the zenith.

$m(\theta)$ is the relative optical path length.

$SunDur_{\theta, \alpha}$ is the time duration represented by the sky sector of the sun.

$SunGap_{\theta,\alpha}$ is the gap fraction for the sun map sector.

$AngIn_{\theta,\alpha}$ is the angle of in- cadence between the centroid of the sky sector and the axis normal to the surface. Equation (3) allows the total direct solar radiation of the area to be determined. The total diffuse solar radiation is determined by using Equation (4).

$$Dif_{tot} = \sum Dif_{\theta, \alpha} \quad (4)$$

Dif_{tot} is the total diffuse insolation and is the sum of $Dif_{\theta, \alpha}$ which is the diffuse insolation from all sun map sectors calculated using Equation (5).

$$Dif_{\theta, \alpha} = R_{glb} \cdot P_{dif} \cdot Dur \cdot SkyGap_{\theta,\alpha} \cdot Weight_{\theta,\alpha} \cdot \cos(AngIn_{\theta,\alpha}) \quad (5)$$

$Dif_{\theta, \alpha}$ is the diffuse insolation from each sun map sector.

R_{glb} is the global normal radiation.

P_{dif} is the proportion of global normal radiation flux that is diffused.

Dur is the time interval for analysis in this study 365 days. $SkyGap_{\theta,\alpha}$ is the gap fraction for the sky sector. $Weight_{\theta,\alpha}$ is the proportion of diffuse radiation originating in a sky sector relative to all sectors. **AngInθ,α** is the angle of incidence between the centroid of the sky sector and the axis normal to the surface, again used as it was previously in determining the direct insolation. This angle of incidence is the factor that takes into account the effect of surface orientation and is calculated using the equation below, Equation (6).

$$AngIn_{\theta,\alpha} = \cos^{-1}(\cos(\theta)\cos(G_z)+\sin(\theta)\sin(G_z)\cos(\alpha-G_a)) \quad (6)$$

(θ) is the solar zenith angle and (α) the azimuth angle. (Gz) is the surface zenith angle and (Ga) the surface azimuth angle. This allows the effects of surface orientation in relation to the angle of the sun to be factored into the total solar radiation of an area. The site suitability of areas was calculated using Equation (7) in Raster Calculator.

$$Site\ Suitability = (Re\ Solar\ Radiation \cdot v1) + (Re\ Land\ cover \cdot v2) + (Re\ Slope \cdot v3) + (Re\ Aspect \cdot v4) + (Re\ Hill\ shade \cdot v5) + (Re\ Rds \cdot v7) + (Re\ Electrical\ Network \cdot v8) \quad (7)$$

Noting that values are all arbitrarily selected based on the desired priority assigned to each, weights are all utilized to reflect the relevance of the various reclassified rasters. However, the numbers were chosen to be a sequence of decimals to equal 1, making each factor a different percentage of 100. This was done in order to establish values of site appropriateness using a scale of 0% to 100%. The equation following provides an illustration of this that was utilized in the experiment. (8). [9]

Site Suitability = (Re Solar Radiation • 0.25) + (Re Land cover • 0.25) + (Re Slope • 0.15) + (Re Aspect • 0.025) + (Re Hill shade • 0.025) + (Re Roads • 0.15) + (Re Electrical Network • 0.15) (8)

The site suitability analysis determined that 47 suitable sites achieved (%95: %98) criteria for locating a solar farm in the study area as shown in figure (1A – 1B).

Table (9), shows some Samples of Suitable Coordinates sites in UTM zone 36 N, Site with coordinates (313242.65 E, 3308496.12 N) and (314202.65 E, 3308496.12 N) is already located within a built-up area so they will be excluded. These sites are provided to help decision-makers to take the right decision for the most suitable place to labor on a solar farm. There are several sites close to each other so they may be the most suitable, in early payment it is possible for the decision-makers to put a buffer zone around sites area to prevent urban crawl.

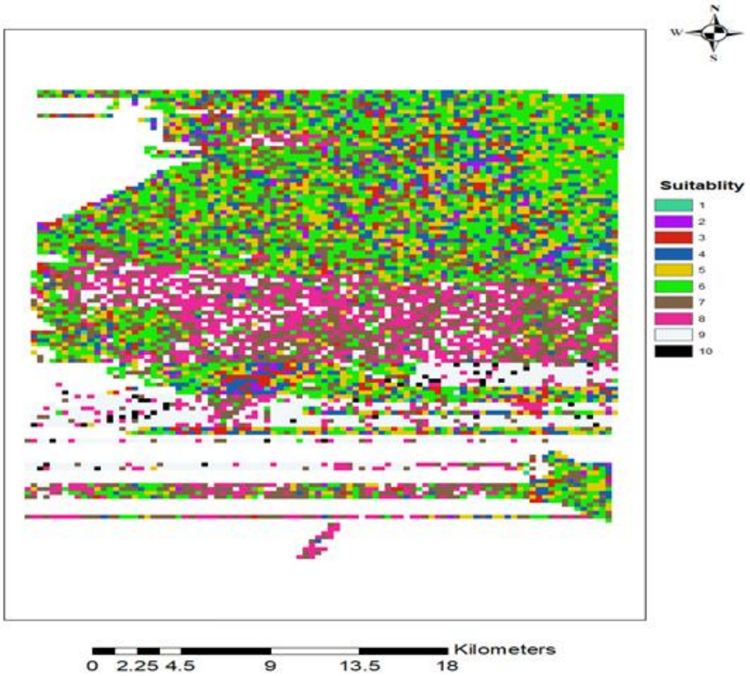

Fig 1A: Most suitable sites for a solar farm in the Study area

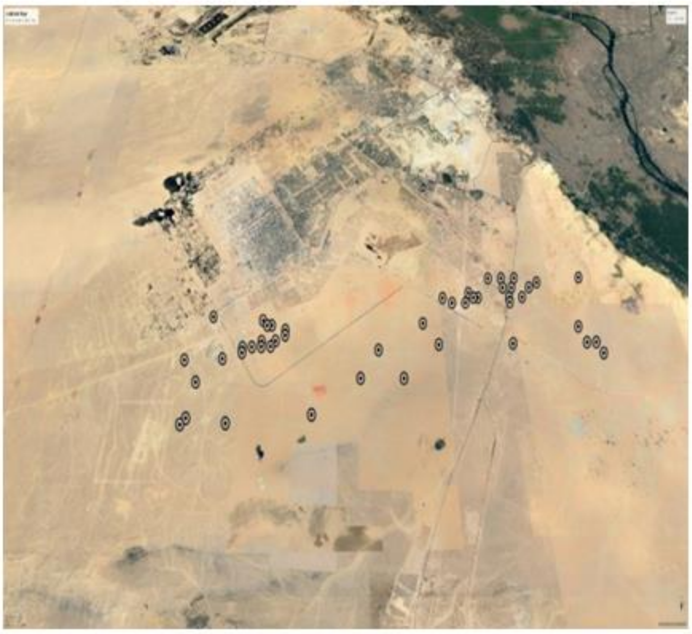

Fig 1B: location of suitable sites.

TABLE (9): Samples of Suitable Coordinates sites in UTM zone 36 N

Location	E (m)	N (m)
L1	313242	3308496
L2	314202	3308496
L3	315162	3308496
L4	319962	3308496
L5	316762	3308176
L6	314202	3307856
L7	314842	3307856
L8	316122	3307856
L9	311642	3307536
L10	309722	3307536
L11	311962	3307216
L12	312282	3307216
L13	314522	3307216
L14	315482	3307216
L15	310362	3306896
L16	311322	3306896

2. Building a Full Automated Model for Identifying Solar Site Suitability Analysis for any Area

An internal application of ArcGIS software called Model Builder is used to develop, edit, and manage geographic models. Wide-ranging models are well-known as workflows that connect a series of geoprocessing tools, using the result of one tool as the input for another. Another way to think of Model Builder is as a visual programming language for creating workflows. A program called Model Builder makes it simple to create and execute workflows composed of a series of tools. A specific tool can be created by users using Model Builder. Model Builder tools can be utilized with Python scripting, together with other models and scripting, to combine ArcGIS with other applications., [9]. A model has been built to perform all steps to identify the suitable location automatically, model examines to input the projected DEM and the boundary of the study area, then the model automatically extracts the study area from the DEM, calculates and reclassifies Aspect, Hill shade, Slope and Area Solar Radiation. Subsequent the model inquires to input the projected Land use shape file, converts it to raster, and asks to input the boundary of the study area formerly. The model automatically extracts the study area from the Land use and reclassifies it. The model asks to input the projected Electric network shape file to input the boundary of the study area. The model automatically clips the study area from the Electric network, calculates Euclidian distance, and reclassifies it. The model asks to input the projected road shape file to input the boundary of the study area then the model automatically clips the study area from the road, calculates Euclidian distance, and reclassifies it. The model calculates all reclassified criteria with their own weights then reclassifies raster calculated values and converts them to polygons as realized in Figure (2) and detailed model in Figures (2A) and (2B).

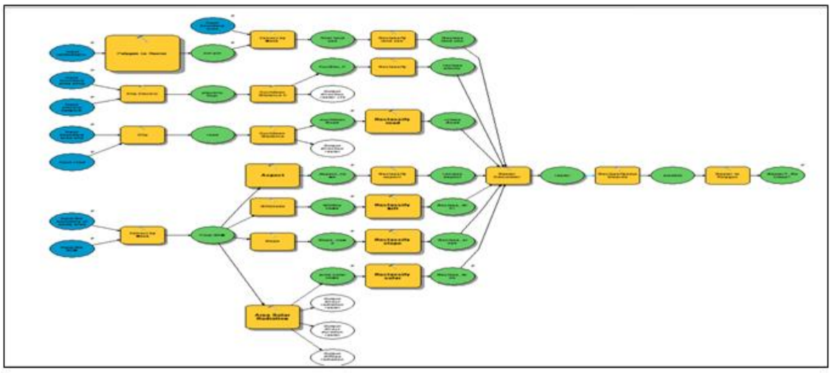

Fig (2): The Full Automated Model for Identifying Solar Site Suitability Analysis.

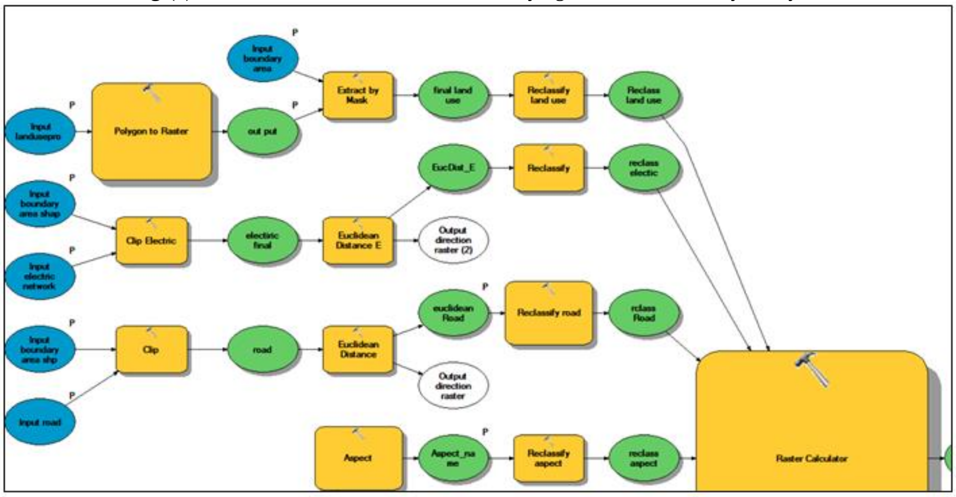

Fig (2A) part one

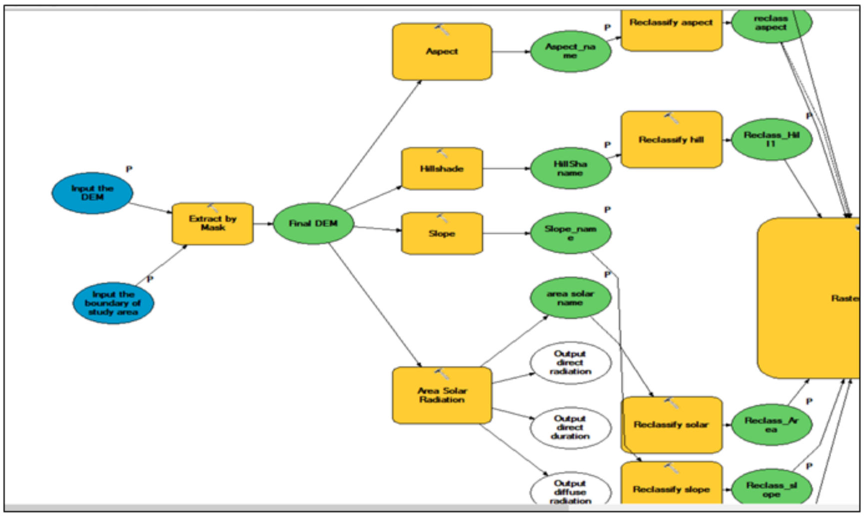

Fig (2B) part two

3. Analysis of Elevation Interpolation Methods for Creating Digital Elevation Models

We discuss interpolation techniques for generating Digital Elevation Models (DEM) from geoinformation system data. The most popular approaches, including Inverse Distance Weighting (IDW), Kriging, Natural Neighbor (NN), and the approach based on building a Triangular Irregular Network (TIN) model, are examined for this purpose. The accuracy of the model is estimated for the study area. Analysis of the results of estimating the accuracy of a digital relief model created using the ArcGIS software. Topographic data were collected by a total station of 3000 points which allowed the creation of a DEM in a vector format of the spatial data, containing information about ground elevations above the mean sea level, water levels, and other topographic objects. Separating the points acquired by the total station to 1000 points as checkpoints and 2000 points to liability points using 2000 points to create (DEMs) by different interpretation methods. Using checkpoints to evaluate the different methods.

The Inverse Distance Weighting (IDW) method is the simplest. In this method, the elevation of a point is calculated by averaging the Z-coordinates of points located in some neighborhoods. The averaging is performed considering the weight coefficients, for which a certain inverse function of the distance from the reference point to the center of the raster cell is determined.

The kriging Method is a local geostatic interpolator and is a powerful tool for modeling various phenomena. TIN Method in this method a DEM is constructed using a set of elevation marks at the nodes of a Triangular Irregular Network. The net of triangles corresponds to the Delaunay triangulation on a set of discrete points connected with each other by disjoint straight-line segments. In this case, the circle circumscribed around each triangle does not contain the reference points of the original set. This method is a local, exact, and deterministic interpolator.

Natural Neighbor (NN) in this method the z-coordinate of a reference point in some study area is determined as the average weighted value of this variable at the nearest reference points.

The accuracy estimates show that the TIN and NN methods provide DEMs with minimum errors and SD for different terrain conditions flat and slope areas and floodplains

4. Estimating Solar Radiation using Different DEM's after a Comparative Analysis between them

Topography is obtained by land surveying observation using the Total Station instrument and Global Positioning System (GPS) techniques The most crucial element in determining how solar radiation is distributed at the surface is methods. [10] When stations are unavailable, interpolation techniques are typically used to estimate solar resources, but they frequently have limited utility[11]. especially where topography land surveying observation is an important source of variability that carries the use of very dense radiometric networks, with the high cost and difficult maintenance [12]. A novel and distinctive method for calculating solar radiation have just been put forth, even in places with complex topography [13]. This method provided quick, affordable, and reliable estimates of solar radiation across vast areas by utilizing data from Digital Elevation Models (DEM), such as slope and aspect, which were integrated into Geographical Information Systems (GIS). Arc Info GIS is one of many software programs available today that offer many approaches. [14] [15]

Using experimental data, the accuracy of these strategies for calculating solar radiation in various locations is tested. To estimate the daily global radiation statistics in the research area, in particular, the Arc Info Solar Analyst software package is employed. Solar radiation estimates are tested against measured values collected from Solar-Med-Atlas. The solar analyses were conducted using ArcGIS (ArcGIS 10.6.1, ESRI, and Redlands, CA).

The different DEMs for the study area were used to create a solar radiation raster using the ArcGIS Spatial Analyst tool and Area Solar Radiation. The solar radiation raster was determined using the yearly average solar radiation for the area, then extract the values of solar radiation which calculated from DEMs and the values data which from Solar-Med-Atlas by 2870 stations that have (E, N) in UTM zone 36 N, and a comparison between different solar radiation values for different DEMs done, as described in Table (11) sample of different solar values in KW*H/ m2 and the coordinates in projected UTM zone 36 N.

The difference in spatial resolution results is a difference in the value of solar radiation as see in table (12).

The differences between the estimated solar radiation from DEMs by area solar radiation tools in ARC Map and data from Solar-Med-Atlas calculated DLR Heliosat Method seen in table (13).

TABLE (10): The Accuracy Estimates and SD for different Methods.

Method	Minimum	Maximum	Mean	SD
TIN	-6.269771	4.517139	-0.228391	0.950902
IDW	-6.280376	4.124605	-0.213209	1.170126
NN	-6.2364	4.161243	-0.257068	0.960115
Kriging	-6.22282	4.061222	-0.258707	1.036249

TABLE (11): Sample of Different Solar Values and its Corresponding coordinates

ID	E (m)	N (m)	Generated DEM	SRTM (30m)	SRTM (90m)	Solar-Med-Atlas data
1	305005.2	3329629	1480.86	1430.25	1461.46	2090.5
2	304998.6	3329626	1478.83	1430.59	1461.47	2090.5
100	304835.9	3329575	1467.62	1415.86	1461.48	2090.5
182	304701.9	3329648	1457.07	1467.37	1461.47	2120.5
184	304670	3329628	1371.33	1484.62	1469.31	2120.5
212	304793.6	3329654	1473.3	1486.59	1461.47	2090.5
284	304813.4	3329690	1455.72	1401.68	1461.48	2090.5
865	304703	3329401	1410.61	1465.37	1461.48	2120.5
1000	304699.7	3329592	1438.51	1446.48	1461.48	2120.5
1274	304516	3329595	1445.69	1421.65	1469.31	2120.5
1309	304462.6	3329634	1446	1458.63	1469.31	2120.50
1325	304265.5	3330145	1472.83	1487.27	1463.43	2105
2341	304246.2	3330055	1444.92	1373.49	1463.43	2105
2417	304499.7	3330030	1452.60	1499.57	1463.43	2120.5
2870	305127.7	3329534	1445.10	1438.74	1461.48	2090.50

TABLE (12): Different between Created DEM and other DEM'S

Diff.	Minimum	Maximum	Mean	SD
Diff in SRTM 30	-119.26	274.12	0.74	40.05
Diff in SRTM 90	-72.87	272.81	15.12	31.32

TABLE (13) Diff. between Solar-Med-Atlas and other DEMs

Diff.	Minimum	Maximum	Mean	SD
Created DEM	-924.004272	-558.772949	-657.226154	35.330749
Diff in SRTM 30	-778.452393	-572.007202	-656.48411	32.300817
Diff in SRTM 90	-660	-629	-642.086649	12.419212

Conclusions

- Using more renewable energy resources can be considered one of the most powerful solutions to discourse pollution, global warming climate change problems. Egypt is notorious to be one of the most ideal locations in the world in place of solar energy fabrication.
- solar radiation from different Digital Elevation Models (DEM) sources was calculated and compared to each other. Data obtained from Solar-Med-Atlas using Heliosat Method. Digital Elevation Model (DEM) for the study area was created from the observed data to create a solar radiation raster, which was then classed into ten distinct classes utilizing the natural breaks method using different criteria.
- A GIS-based model for multi-criteria suitability

analysis identified the optimum sites for constructing large-scale solar farms in the Sheikh Zayed area, 6th Of October City in Egypt.

- The results identified 47 sites in Sheikh Zayed and neighboring areas as suitable for solar energy utilization. The accuracy estimates show that the TIN and NN methods provide DEMs with minimum errors and SD for different terrain conditions which are flat and slope areas and floodplains. At that moment solar radiation from different Digital Elevation Models sources was calculated and compared to each other.

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