Mapping Suitable Solar Farm Sites in Suez Governorate via Remote Sensing and GIS Techniques

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Mapping suitable Solar Farm Sites in Suez Governorate via Remote Sensing and GIS Techniques

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Abstract:
Egypt has a great potential for using renewable energy sources, particularly solar energy. Various regions, including the Suez Governorate, have the ability to generate electricity from solar energy through the selection of suitable sites. Therefore, this study aims to identify suitable sites for solar farms in the Suez Governorate, Egypt, using Geographic Information Systems (GIS), remote sensing, and Boolean overlay operations. Key factors considered include global solar radiation, aspect, slope, and land use land cover. The analysis revealed that 35.3% of the region is suitable for solar farm development, with aspect being the most significant factor affecting suitability. Specifically, unsuitable areas account for 37.5% of the total area due to aspect. The efficacy of GIS in spatial decision-making processes is demonstrated by this method, which guarantees sustainable and effective site selection for renewable energy projects. This product will help decision-makers and urban planners identify the governorate's primary suitable sites for the installation of solar infrastructure.

Keywords: Suez Governorate, Solar Energy, Suitable areas, GIS, Boolean overlay operation.

1. INTRODUCTION:

Over 50% of people on Earth currently live in cities, and by 2050, that number will rise to 70%[1]. As a result, it is predicted that by 2030, urban energy consumption will account for 75% of the world's energy consumption [1, 2]. In parallel, developing nations are working to combat the severe effects of climate change by switching from conventional to renewable energy [3] As a result, the potential for renewable energy has emerged as a crucial consideration in the formulation of energy regulations and policies [1, 4]. Because solar energy is plentiful, cost-free, and environmentally friendly [2], it is regarded as one of the best options for renewable energy [3, 5].

Furthermore, solar power has a promising future, particularly in light of the aging and deteriorating energy grid and the rising cost of fuel [5]. Egypt's rapidly increasing population makes the development of the energy sector a pressing issue [6]. Egypt is one of the sunbelt countries, so there is a lot of potential for installing PV panels throughout the country. The Red Sea coast and Upper Egypt cities like Luxor, Aswan, and Asyut are the highest potential locations[7]. Consequently, in order to meet the country's energy target for 2035, the Egyptian government announced a plan to promote the production of solar energy, which is anticipated to account for 22% of total energy production [8]. Determining the best locations for solar energy infrastructure is recognized as the crucial step for utilizing solar energy sources[3]. The place with the most solar resources is not always the best option since several criteria are taken into consideration when choosing a site for a solar farm [9]. These parameters include the following: distance to roads, distance to transmission lines, aspect, slope, climate, land use, land cover, and distance to fault lines[8, 10, 11]. To get around the lack of measured data, many researchers are using satellite imagery to evaluate solar radiation and other aspects affecting the suitability of solar energy[8]. Remote sensing and GIS technology have become an indispensable tool in identifying and evaluating areas suitable for solar energy installation. as it is utilized in the assessment of solar radiation, allowing for the mapping and analysis of the sun's impact over a given geographic area over specific periods [10], Topographic mapping and land use land cover analysis are some of the primary components in determining the appropriate locations for the installation of solar energy farms. In addition, remote sensing uses satellite data, which is preferable to measurement stations due to the better spatial coverage and higher degree of resolution[16]. Many researchers combined multicriteria decision-making models with GIS-remote sensing to determine the best location for solar farms [3, 8–11, 13, 14, 17] The boolean overlay operation is used to produce the final suitability map. It is considered a powerful tool in multicriteria decision-making to identify suitable sites for specific reasons; it depends on creating a 0 and 1 map where 0 is not suitable, and one is ideal for allocating the targeted project. Global solar radiation, aspect, slope, and land use land cover were used to define the suitable and non-suitable areas for allocating solar energy farms. The main target of this paper is to present a methodology to select the primary suitable sites of solar farms in the Suez governorate, which is one of the most promising areas in solar energy development, depending on the available remote sensing imagery. This research aims to help urban planners and policymakers integrate solar development into regional and local urban plans.

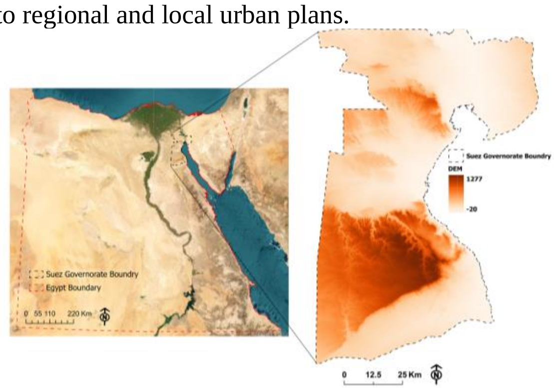

Fig. 1. Suez Governorate location within Egypt.

2. STUDY AREA

Suez Governorate is strategically positioned at the southern entrance of the Suez Canal in Egypt. Suez's unique location makes it an essential hub for international trade and shipping. The governorate of Suez is home to a number of industrial zones that attract both domestic and foreign investment. At 0.76 million residents in 2020, it constituted 0.8% of Egypt's total population and is regarded as one of the country's principal urban governorates. The location of the Suez Governorate in Egypt is shown in Fig. 1.

3. DATA

The main data used in this research were the digital raster land use and land cover maps for 2023, which were derived from ESA Sentinel-2 imagery at 10 m resolution. It contains water bodies, trees, vegetation, built-up barren land, and range lands. The digital elevation model (DEM) was derived from the United States Geological Survey (https://earthexplorer.usgs.gov/). Slope, global solar radiation, and aspect were produced using slope, aspect, and area solar radiation modules in Arc GIS Pro 3.2, depending on the DEM raster image. Crops, trees, built and water bodies were excluded from the LUCC map using the extract by attribute module. Additionally, the Suez Governorate database from the General Organization of Physical Planning (GOPP) in Egypt was used to create a shape file of the administrative boundary (see Table 1).

By maximizing sun exposure, topographical suitability, and land availability, the combination of solar radiation, slope, aspect, and land use/land cover aids in the identification of places that are ideal for solar farms. The features of the factors are highlighted by the following:

3.1 Solar radiation: In this land suitability analysis, solar radiation is thought to be the primary and deciding factor. Data on solar radiation aids in identifying areas that receive a lot of sunlight. Higher solar irradiance sites generate more electricity; therefore, higher solar radiation makes a place more suitable [10]. Areas with less than 1300 $kW/m^2/year$ were masked and excluded from this study [8]

3.2 Aspect: Aspect refers to the site's orientation in which solar panels are oriented. It is crucial in determining the best location for PV solar farms. When installing PV panels in Egypt, the south-facing aspect (180°) is usually the best choice because it receives the maximum amount of solar irradiance, which increases the panels' efficiency and energy output. The study area was masked, and the North, Northwest, and Northeast-facing aspects were excluded [11]

3.3 Slope: it is a major factor in determining the suitable locations for solar farms. High slopes have a significant impact on how much PV installation costs because installing PV panels on a steep slope often requires more extensive grading and excavation. Moreover, moving materials and equipment to and from steep sites can be expensive, time-consuming, and complex. As a result, regions with slopes of more than 5% were concealed and disregarded[3, 10, 11].

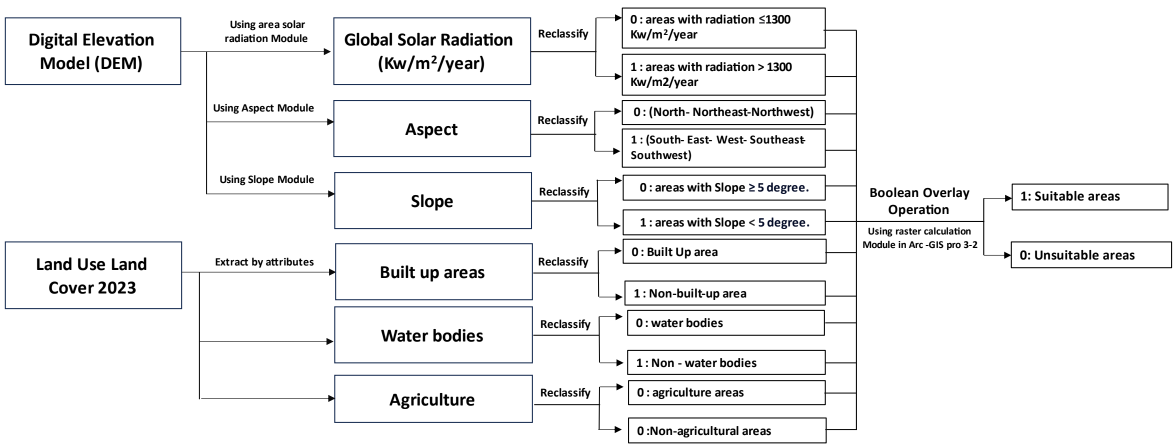

Fig.2. Research Methodology

Table 1. Data Resources

Factors	Source	Resolution	Date of acquisition
DEM	U.S. Geological Survey portal	30	August 2015
Slope	Rasterized from Dem	30	
Global solar radiation		30	
Aspect		30	
LUCC	Sentinel 2 Satellite	10m, then resampled to 30m Resample module in GIS	2023

3.4Land use Land Cover: According to[3] there are strict geographic land restrictions for the construction of solar farms. Thus, land and use land cover (LULC) play a major role in choosing appropriate sites for PV farms. LULC favors empty spaces like barren land because they have fewer competing interests and are more straightforward to transform into solar farms. In general, data on land use and cover help to identify areas with low environmental impact and available suitable land. Five land use patterns, including wetlands, lakes, rivers, protected areas, and construction, are not appropriate for the installation of solar panels, according to[11, 17]. Water bodies, agriculture, and urban areas were not included in this study.

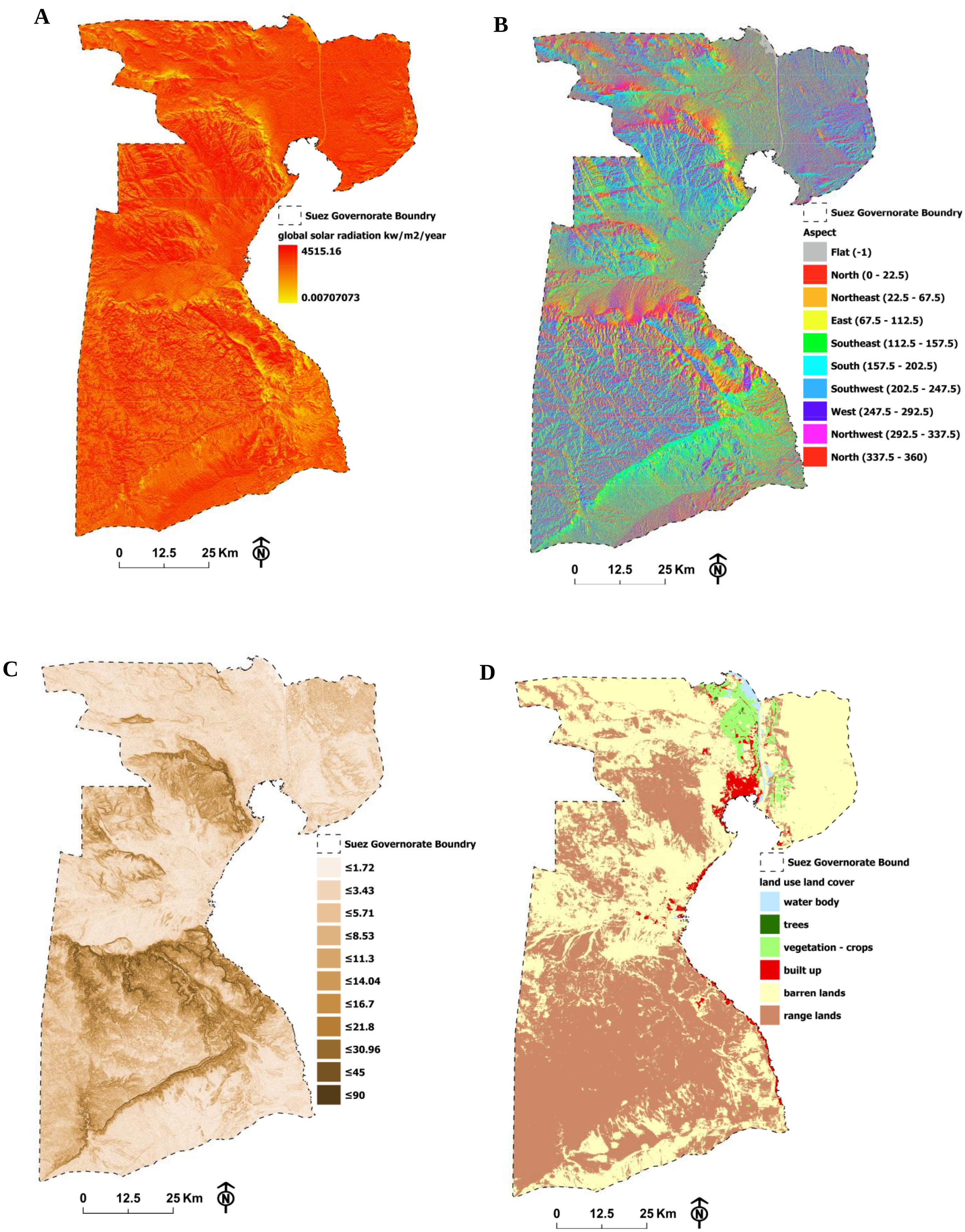

Fig. 3. The main factors to produce the suitability map: A) Global solar radiation, B) Aspect, C) Slope, and D) land use land cover (LULC)

4. Modeling:

In this study, a boolean overlay operation is used to produce suitable areas for solar energy installation. It depends on the number of boolean raster images, which are 0 and 1. These images are multiplied to produce the final 0 and 1 image, where 1 is suitable and 1 is not suitable. Firstly, global solar radiation factor: areas with more than 1300 kW/m^2 per year are considered suitable, and non-suitable areas have less. Secondly, regions that have north, northwest, and northeast-facing aspects are considered non-suitable, other than considered suitable. Thirdly, areas with a slope greater than 5 degrees will be excluded and considered unsuitable. Lastly, land use land cover, built-up areas, water bodies, and agriculture areas were masked and given a value of 0, whereas the other land uses were given a value of 1, which means that they are suitable. These factors were rasterized as boolean images using the reclassify tool. After reclassifying the factors into 0 and 1, they were multiplied using the raster calculation module to produce the suitability map, where 1 is a suitable area and 0 is not a suitable area for allocating solar farms. Raster analyses were performed using Arc GIS Pro-3.2. Fig. 2 shows the research methodology.

5. RESULTS

The final suitability map is derived from the spatial distr ibution of the factor characteristics and the constraint layers that display the areas that could not be used for so lar energy.

5.1 Spatial Distribution:

As can be seen in Fig. 3A, the Suez global solar radiation is generally high in the north area on both sides of the Suez Canal and low in the scattered areas in the west, south, and northwest. Areas around the Suez Canal have the strongest global solar radiation, receiving 4515 kW/m^2/year, and areas in the southeast have poorer global solar radiation, receiving less than 10 kW/m^2/year. Fig. Fig. 3B shows the aspect factor, which considers the site orientation. It was noticed that north, northeast, and northwest-facing aspects spread largely in the north of the Suez Canal and in the middle, south, east, and northwest of the region. These areas receive less direct sunlight compared to the south-facing aspect, and the solar panels here will produce less energy because they are not optimally oriented to capture the maximum amount of solar radiation. Fig. 3C shows the slope degree within the governorate borders, where the areas in the east of Suez City are built-up areas, and the governorate south part has the highest slope value, with more than 5 degrees reaching more than 90 degrees. The rest of the governorate is considered an almost flat area with a slope of less than 5 degrees. Fig. 3D depicts the land use land cover map where urban areas, crops, and trees are distributed around the Suez Gulf and the Suez Canal; the rest of the governorate is barren land and range land (desert and mountainous lands).

5.2 Constraint analysis:

The results of the constraint analysis can be explained as follows:

The southeast part, the finger part western of the Suez Canal, and scattered areas in the south, northeast, and far east parts of the governorate were excluded as having global solar radiation less than 1300 kW/m2/ear (see Fig. 4A), finding that 70.4% of the region is suitable for installing solar energy in terms of global solar radiation characteristics. In addition, many scattered areas, especially south and west of Alain Sokhna Port, as well as the areas east of Suez City and north of the Suez Canal, were excluded from the suitability analysis as they are facing north (see Fig. 4B). Aspect was considered the most influential factor in selecting the solar infrastructure site as it excludes 37.5% of the region because of its north-facing aspect, as could be seen in Table 2. Areas in the south and west of Suez City and scattered areas in the east of Suez Canal, in addition to the majority of the southern part of the governorate, were excluded as they have more than 5% slope (see Fig. 4C). These 65.1% of the governorate is available for solar project installation due to its flatness and low steepness. The swaths beside the Suez Canal and the Suez Gulf coastline were excluded because of the land use and land cover constraints (see Fig. 4D). These places constitute 4.4% of the regions, which means that 95.6% of the governorate is suitable due to land availability. The constraint map was overlaid and multiplied to produce the suitability map, where 1 is suitable and 0 is not.

Table 2. Share of suitable and not suitable areas according to the constraining effect

Constrain	% Suitable	% Not suitable
Global solar radiation	70.4	29.6
Aspect	62.5	37.5
slope	65.1	34.9
land use land cover	95.6	4.4

5.3 Suitable sites:

The suitability map for establishing solar farm projects is displayed in Fig. 5. 0.3 million hectares, or 35.3% of the governorate overall, are suitable lands. 64.7% of the governorate's total land, or 0.55 million hectares, are considered unsuitable environments. It generally spread all over the governorate, in the east of the Suez Canal, west of the agriculture areas, and the middle areas, starting from Alain Sokhna port and continuing to Aladabia port and the far south part of the region. However, it could be mainly utilized in the areas north, east, and west of Suez City, in addition to the areas close to Alain Sokhna Port. The unsuitable areas include waterbodies in addition to the vegetation and built-up area surrounding the canal and the Suez Gulf. Besides, there are the sporadic north-facing locations and the high-slope, steep sections in the region's midsection and south.

6. CONCLUSION

This research demonstrates the application of Geographic Information Systems (GIS), Remote Sensing and Boolean overlay operations in identifying suitable sites for solar farms in the Suez Governorate, Egypt. The study effectively integrated significant variables, such as, slope, global solar radiation, and land use land cover, to identify the suitable places to produce solar energy. According to the research, 35.3% of the territory is appropriate for the establishment of solar farms. The most crucial restriction was found to be an aspect that made 37.5% of the land unsuitable. Slope came in second at 34.9%, global solar radiation at 29.6%, and land use land cover at 4.4%. This study's approach and conclusions can be used as a model for similar assessments in other areas.

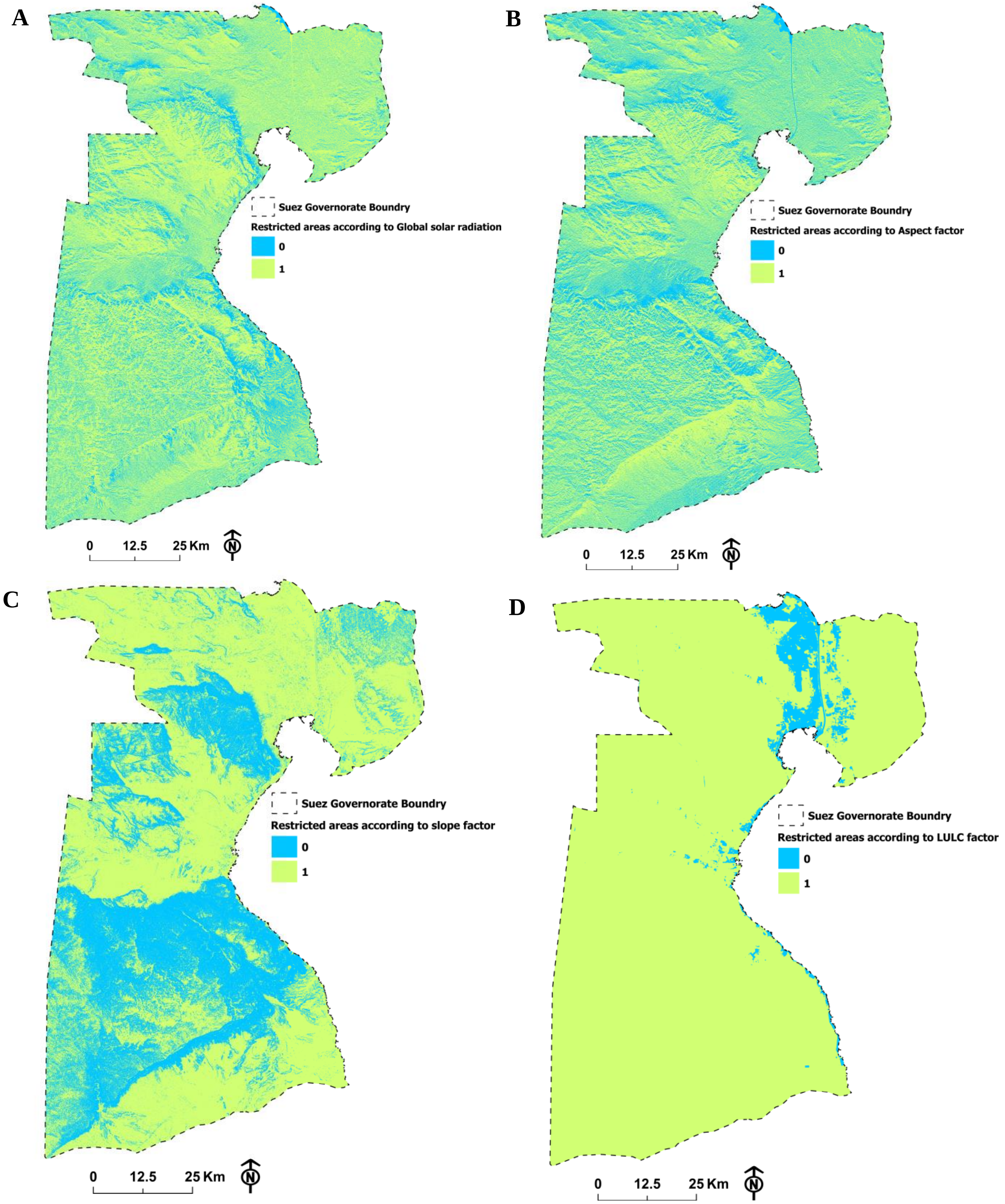

Fig. 4. Constrain factors layers.

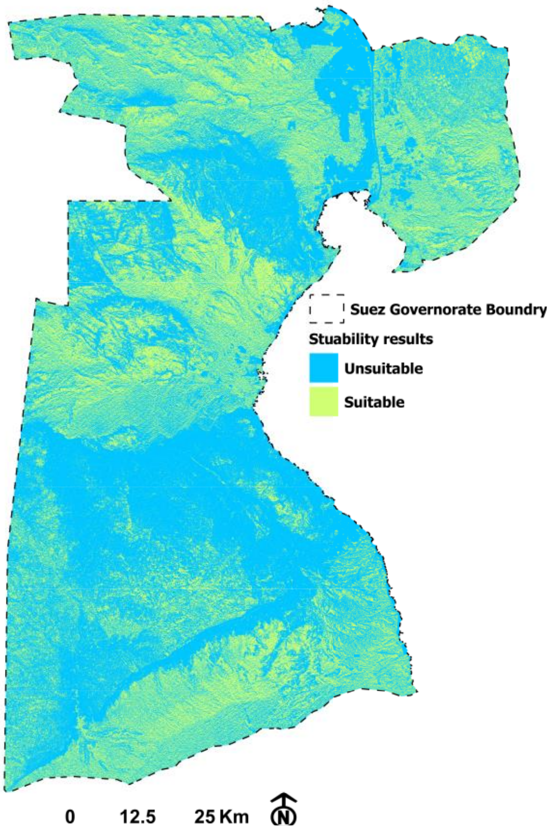

Fig. 5. Suitable areas for allocating solar farms.

7. FUTURE STUDY:

GIS-AHP will be used in the next study to identify the best location for solar energy infrastructure allocation. A multitude of other variables will also be included, such as soil, temperature, and the distance to residential areas, transmission lines, and roadways. In addition, the technical estimation of the solar energy output potential.

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