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Solar Farm Suitability Analysis Model Using GIS

Case Study of As-Salamiyeh District, Syria

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Abstract

Syria is a country which has an area 185,180 km^2. Since the outbreak of the crises in 2011, Syria has suffered a massive power blackout across the country: the transmission network and power stations have been destroyed both tactically and accidentally, leaving Syrians predominantly reliant on heavily polluting and expensive diesel generators to keep the lights on. On the other hand, this country, in general, has rich solar energy resources and the average global horizontal solar radiant flux in Syria is approximately 5 $kWh/m^2/day$ or 18 $MWh/m^2/year$.

In order to help in finding a solution for the power shortage problem and also solve one of the environment-related challenges in producing clean power and the opportunities once the conflict has moved to a recovery phase, sustainable energy supplies such as solar energy power stations would be as an ideal solution.

As-Salamiyeh District is a part of Hama Governorate and has a large territory which receives intensive sunshine. This would be an ideal place for solar energy production which can solve the power shortage problem in the main city and other places within the district. It can also solve one of the environment-related challenges in producing clean power and using the opportunities once the conflict has moved to a recovery phase.

The results of this study will create a new model for screening possible optimal locations for solar power farms which can contribute to finding a solution due to the enormous distribution potential of solar energy farms. The importance of this study came from the possibility that that model can be implemented as a part of a larger model into a decision-making infrastructure of future planning sites for solar stations for different parts in Syria.

1. Research area description

The study area is represented by the administrative boundaries of As-Salamiyeh District, which is a part of Hama Governorate (Figure 1). As-Salamiyeh District contains the main city and 202 villages with a total population of 351,437 (according to 2011 census), of which As-Salamiyeh City alone has a population of 105,538 people (Source: Civil Registration Office, As-Salamiyeh City, 2011). There were many factors behind choosing to work on this area:

- The familiarity of the researcher with the study area supported by many data sources.
- The area located within two climatic zones (arid and semi-arid) which receive a big amount of sunshine during the year.
- This area is considered as one of the safe areas during the Syrian crises which allow implementing long term projects.
- Many NGO's are currently working there and they are showing interest in implementing renewable energy projects (Aga Khan Foundation[1] started to make solar and wind turbine street lights within the city as shown in the photo, Figure 2).
- The need for electricity and power supplies greatly increased in this area, because it has received a huge number of internally displaced people, which puts pressure on the local resources that is already considered as vulnerable.

The district of As-Salamiyeh is divided into five sub-districts as shown on the map, Figure3:

- As-Salamiyeh Sub-district
- Barri Sharqi Sub-district
- Al-Saan Sub-district
- Sabburah Sub-district
- Uqayribat Sub-district

[1] Aga Khan Foundation is part of the Aga Khan Development Network (AKDN) and it is a group of private, international, non-denominational agencies working to improve living conditions and opportunities for people in specific regions of the developing world.

The point of showing the sub-districts division is that later in this research the model will be also applied within the sub-districts of As-Salamiyeh District and also I would like to mention that I didn't use the national transcription of the geographic names on the maps instead, I used the English one since it is more popular and most of the research resources are in English.

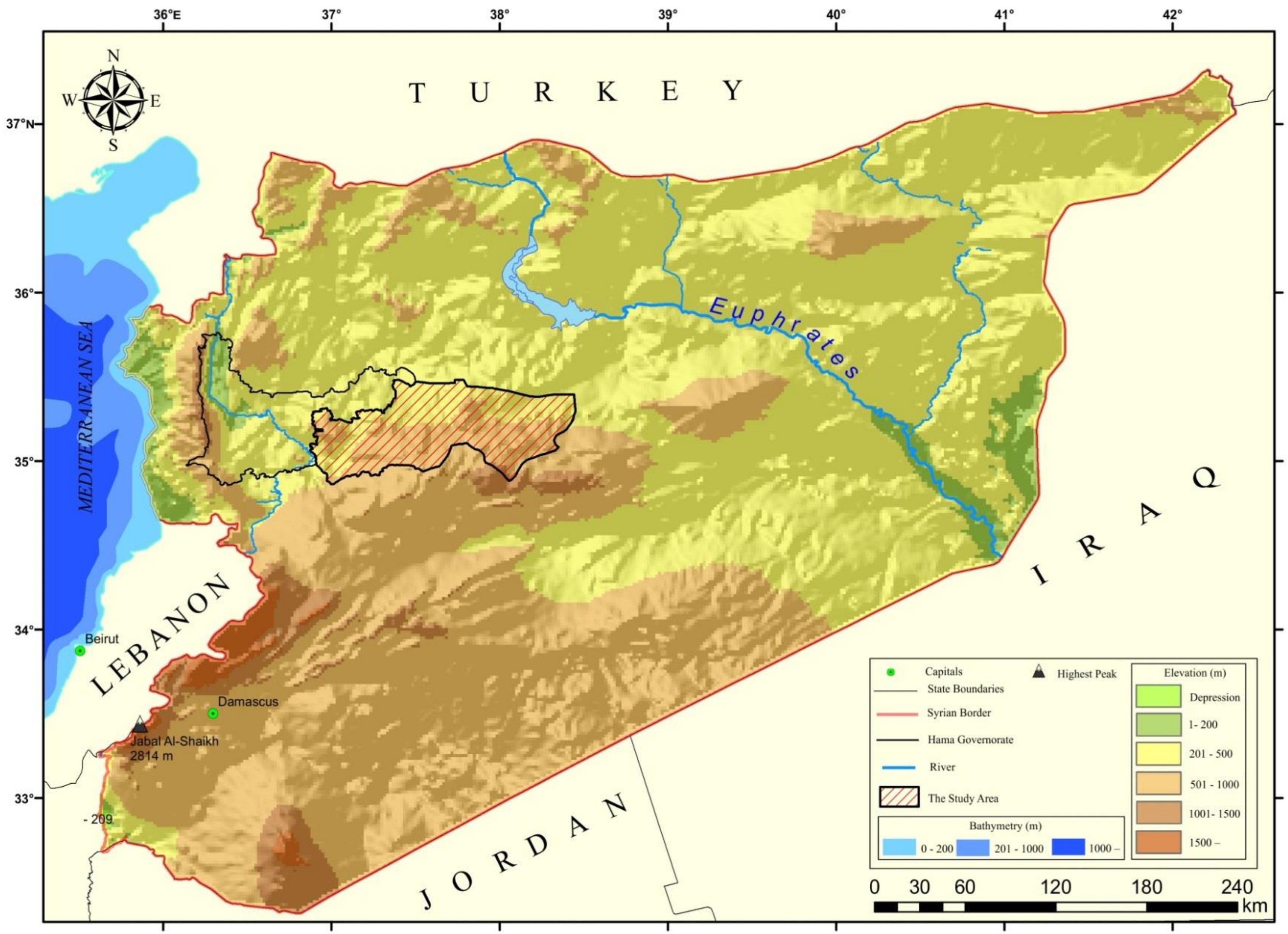

Figure 1: The location of the study area in Syria (Derived from Open Street Maps, USGC)

Figure 2. Solar and wind turbine street lights in As-Salamiyeh City (photo taken by a friend)

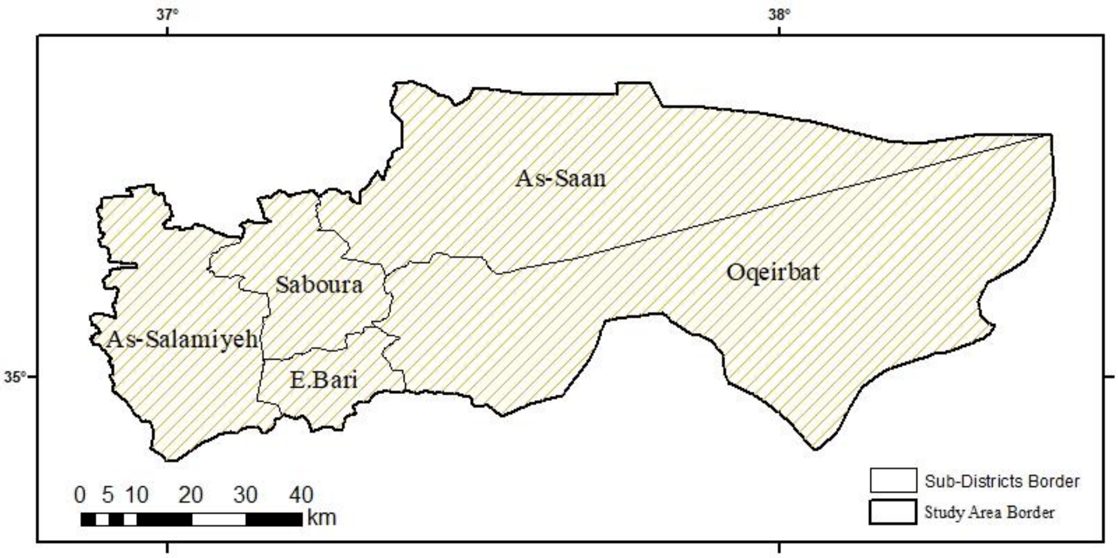

Figure 3: The sub-districts of As-Salamiyeh District (Derived from Open Street Maps)

1.1 **Climate conditions of the study area**

As-Salamiyeh District has a surface area of 5,500 km^2, which is located on a low plateau region. The surface-water network ends up in the basin of the Asi River on the west and arid and semi-arid climates are shaping the main climate characteristics of the As-Salamiyeh area. (Source: Mousa Ali and Harba Mouhammed, Hama Governorate, 1985, in Arabic). Although the current climate conditions seem to fit perfectly this project, we have to keep in mind that Syria, in general, is opened to many of climate anomalies. If we could turn back in time one hundred years, we could see that the climate was not the same as the current days. For example, it is hard to expect that this area would receive a continuous 40 days of snow (in a row), which happened in 1910[1]. This kind of event would make some restrictions to implement solar energy projects perfectly. And if we compare 15 years in a row of rainfall data between the years 1900 and 1915 and the same climate series for the same months between 2000 and 2015, we can see clearly the difference in the amount of rainfall between these two periods. (Derived from rainfall data of the World Bank group website: https://climateknowledgeportal.worldbank.org). This is shown in Figure 4:

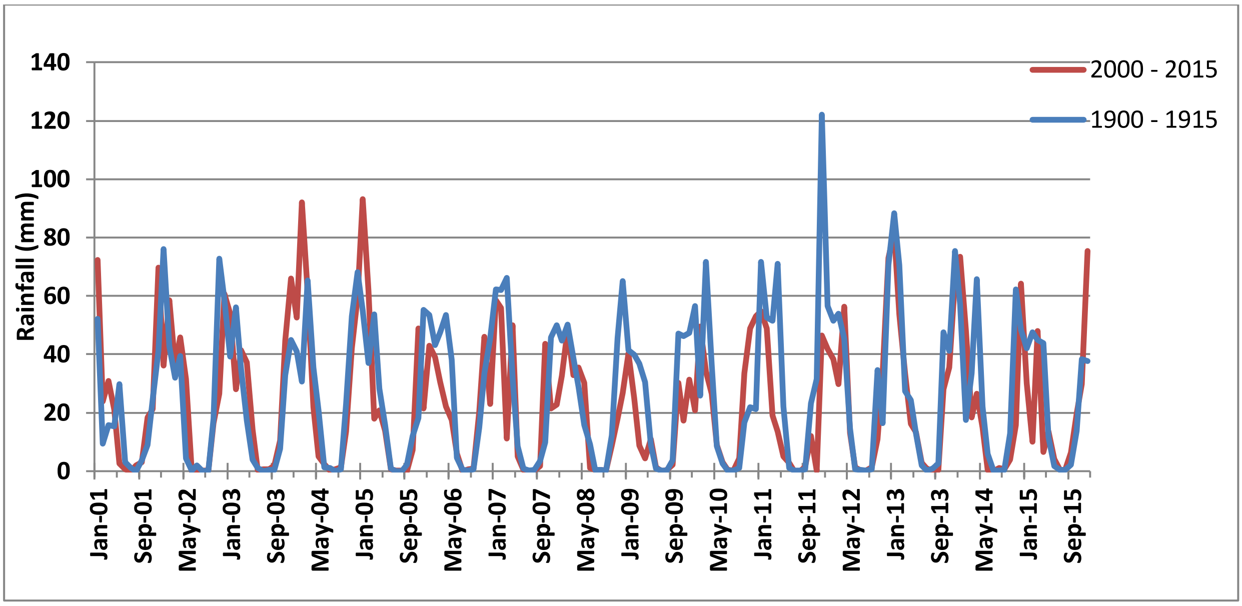

Figure 4: Average rainfall graph for 15-year series of Syria (Derived on World Bank group historical data)

[1] According to Dr. Ibrahim Fadel, manuscript, another sources claimed that the 40-day snow happened in Aleppo between 20 January and 1 March 1911.

As presented in the graph, the climate anomalies are visible in the amount of rainfall especially between Jan 1911 and March 1913 (the blue peak). As a result of the climate condition at that time, a lot of water flows out of the ground as springs (more than 300 water streams) and some of them with more than 20 km length (Source: Manuscript provided by Dr. Ibrahem Fadel, in Arabic).

We can also use place name as indicators of manifestations of recent landscape and climate changes, and if we make a quick overview of the place names of As-Salamyieh we will find the following. (I used many resources in Arabic to make the table, such as Ameen Kudaha, Dr. Abdullah Al-Helo and others).

Table 1. Overview of the place names of As-Salamyieh City

The proper name	Derivation structure	The meaning	The reason
Σαλαμίς (ancient Greek)	Salamis→ Salamiyah	Salamis is island is known for the Battle of Salamis	Memorizing name by Alexander the Great (Alexander III of Macedonia) 330 BC As memory of the Battle of Salamis
𐡔𐡋𐡌 (Old Aramic)	Shalm→ Shalmia→ Salamiyeh	Shalm = peace	Meaning of Peace
ΕΙΡΗΝΟΠΟΛΕΙΤΩΝ (Roman times)		ΙΡΗΝΟΠΟΛΙΙΩΝ = Irenopolis = The city of peace	The city of peace
ܫ ܘܠ ܡܬ (The Syrrian Christian time)	Shelomoto		The city of peace
سلمية (in Arabic) Salamyieh (in English)	Salamiyeh Sail(stream) + miyeh(water)	(the water stream)	(Folk etymology)
سلمية (in Arabic) Salamyieh (in English)	Salamiyeh Salm(survive) + miyeh(one hundred)	one hundred survivors	Memorizing name (Folk etymology)

One of the place names that was given to this area, *the water stream*, is an indicator of the environmental situation during a considerable period of time, although the fact that this name is considered as a folk etymology and the derivation structure is weak for the place name. However, this explanation would not be reasonable if the environmental situation was not the same.

Another proof of the environmental changes can be seen in the old canal (Al Ashiq Canal), which still remains in use until these days. This canal was established to transfer drinkable water from As-Salamiyeh to the ancient Afamia City for almost 150 km and used also for irrigating the farms on its way. Afamia (Apameia) is located about 150 km on the northwest of Hama city and the remains of its old citadel known as Almadi'q Citadel – which was destroyed by the wars and earthquakes – are still there to this day.

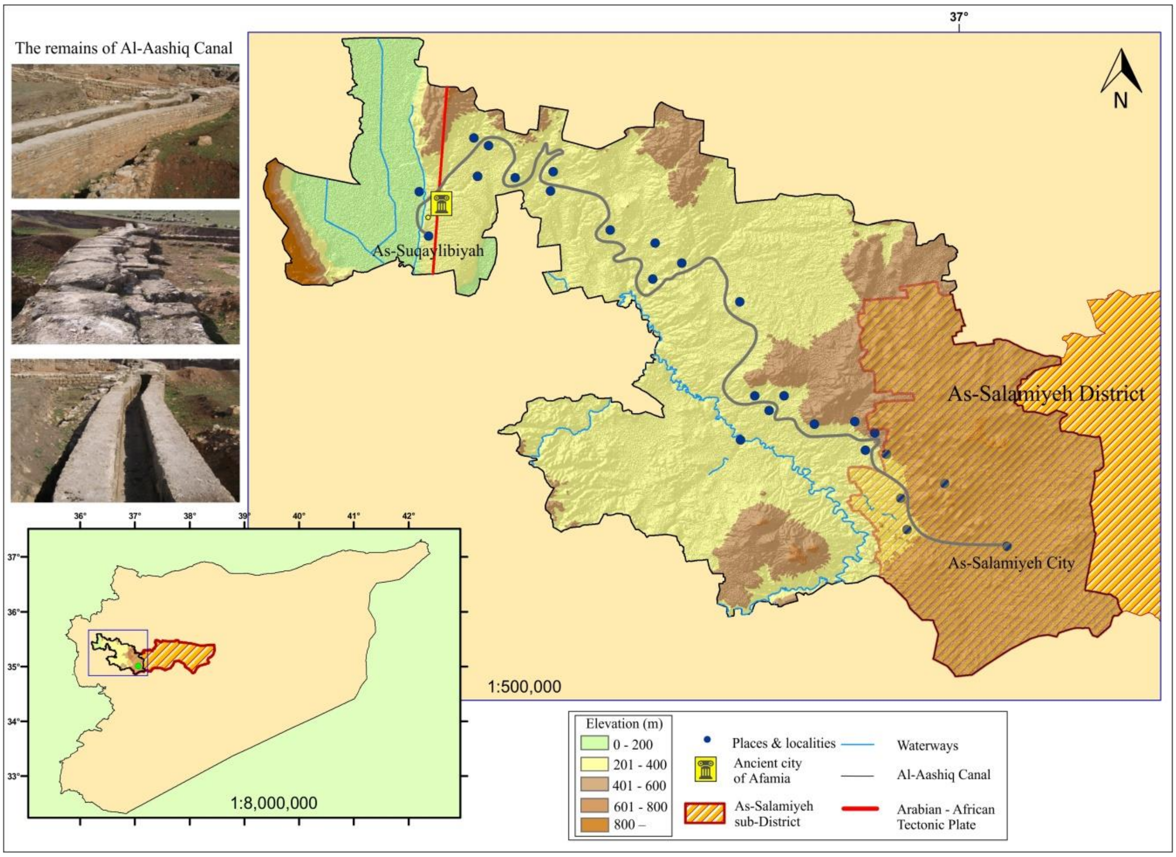

Figure 5: Map of the ancient Al-Aashiq Canal (Derived from Open Street Maps, USGC and UCLA).(The three photos of the Canal are downloaded from http://www.esyria.sy/)

One of the legends about the name of the canal which means *the lover* in Arabic came from the story that the king of Afamia during the Roman time has a very beautiful daughter and the prince of As-Salamyieh (Shmimis Citadel) wanted to propose for her and she put a dowry to the marriage: bring the water to her thirsty city first because at that time As-Salamiyeh was very rich in water resources (Source: The archaeology and tradition of As-Salamyieh City, al-Adiyat committee, in Arabic).

The Shmimis Citadel, which destroyed and rebuilt many times during the history, is located on the northwest part of As-Salamiyeh City dating back to 1200–1600 BC (Source: Nezar Kahla, the archeology within As-Salamiyeh City). Its remains can be seen in the following photo (Figure 6).

Figure 6: Photo of the remains of the Shmimis Citadel (downloaded from http://sy.geoview.info)

Some studies supported the claim that the date of building the Al-Aashiq Canal was in the first century and the water flow stopped going to Afamia after the Hama earthquake in 1157 due to tectonic reasons. As we can see from the Al-Aashiq Canal map, Afamia is located very close to the border of the African–Arabic plate (the red line), which is considered a dangerous and unstable location.

As it can be seen from the map, the ancient Al-Aashiq Canal ends up in a city called As-Suqaylibiyah, which is an Aramaic word meaning *the opposite, the resistant*, and derived its name from its geographic nature and location on the south of Afamia and its factuality as a defender of all attacks coming from the south. The intensity of the Hama earthquake can be seen clearly in the map. The source of the earthquake map is The historical earthquakes of Syria: an analysis of large and moderate earthquakes from 1365 BC to 1900 AD, Ryad Darawcheh and Mohamed Reda Sbeinati, which was a part of research on the historical earthquakes of Syria. Shmimis and Apamea were within the places which recorded the 1157 earthquake and that had an effect on the history of the area.

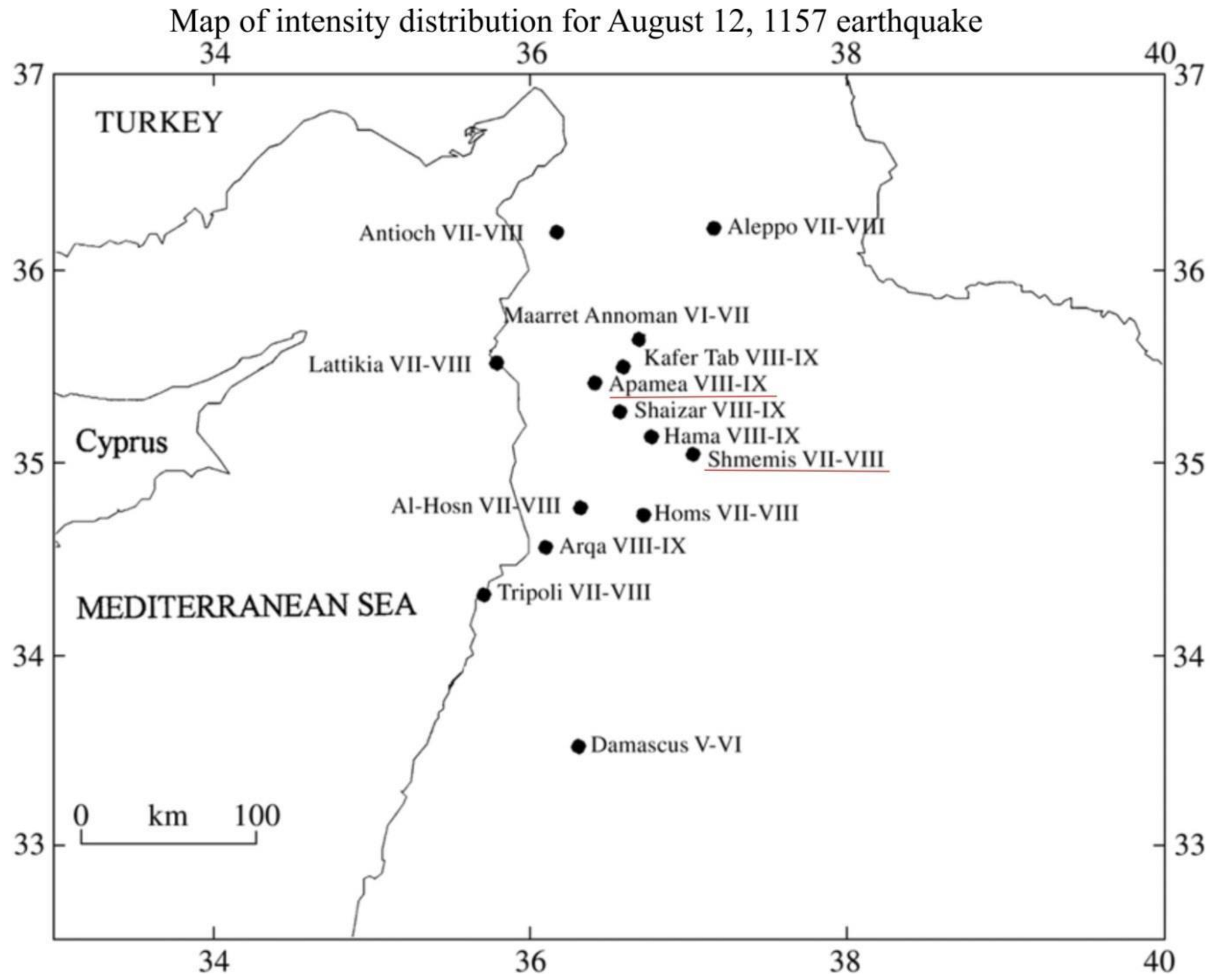

Figure 7: Map of intensity distribution for the 1157 earthquake (Source: The historical earthquakes of Syria research)

As a conclusion of shedding light on the climate conditions of the study area, we can define the possibility of receiving climatic anomalies. However, it would be considered as a temporary constrain only as it is not going to affect the fact that this area is highly suitable for solar power energy long term investment. Although the environmental situation has changed and if the environmental situation is still the same, we may find the area is available for another alternative energy such as water energy, for example.

2. **Methodology**

The optimization model is based on six raster datasets that are integrated through overlay analysis using the geographic information science field methods which were applied to select the desired location within the study area. The quantitative approach will be used as the main methodology for spatial analysis. Using the global data, the Aspects (the directions of the slope) and the direct normal sun irradiation are the more important factors for selecting the sites for the solar stations and the Digital Elevation Model (DEM) will be used to derive the Aspects, Slope and the Hill Shading. Other factors that will be taken into consideration are the distance from roads, the cloud cover, the land cover, and the slope (Figure 8).

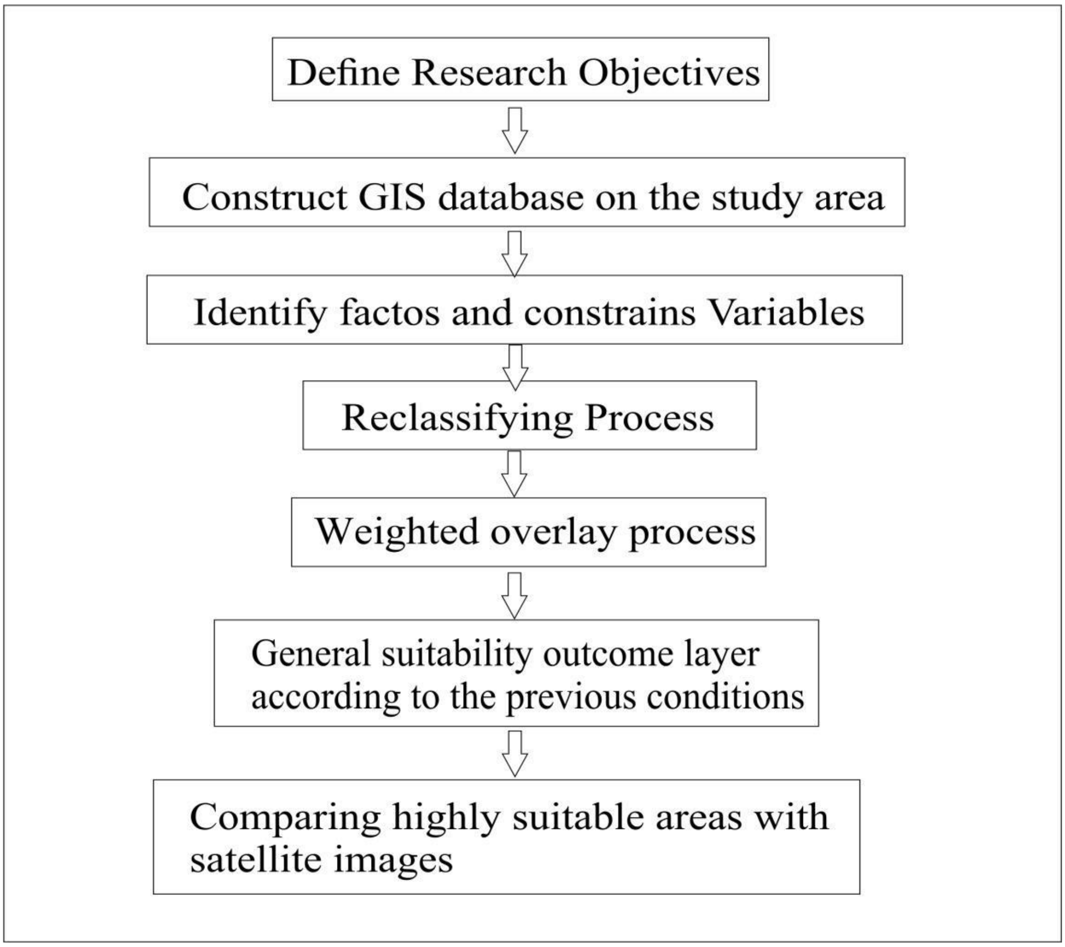

Figure 8: Flow chart of the solar farm site suitability analysis model designed

The first step was to define the research objects that is to find the suitable areas for solar power stations farms within the study area and to foresee what kind of results are expected to achieve. This step would not be done without making a literature review on this topic and identifying the steps needed to get the desired results. Then, I started to collect data and work mostly on collecting global data and constructing the different layers needed for the GIS database and getting the required data to start the analysis process.

Before starting the analysis process we need to review the factors and also to see what kind of constraints we would face which can be handled during the analysis (make a model of constrains, buffering, erase…) or handle these constraints separately through different analysis methods. When our GIS database is ready with the required data, I can start working on different tools and create the model which helps to organize the data on a sequence of geoprocessing tools that will be described later in this research. The end result of the model is to have a general outcome suitability layer which contains the different suitability category. The researcher's mission is to highlight the highly suitable area and compare it with satellite images to give a clear, concise and accurate representation of how the results are shown in reality.

Data preparation

The data set is downloaded from different resources and prepared and conducted using different software and they were mostly in raster format and combined and processed to be ready for the analysis.

Digital elevation model

The question has come to our mind which SRTM data is better for making this kind of suitability analysis? The Shuttle Radar Topography Mission (SRTM) data had previously only been available worldwide at a 90-meter resolution. The National Geospatial-Intelligence Agency (NGA), NASA, and USGS have released a newly processed, global SRTM 30-meter dataset (Source: Esri website, http://hub.arcgis.com) which provides open distribution of this high-resolution global data set and we used it in this research (Source: USGS EROS Archive - Digital Elevation - Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global).

The data downloaded from the USGS website and after getting the preliminary raster data and we applied many raster analysis tools in order to fit this data to the study area and we can be seen in the map Figure 9.

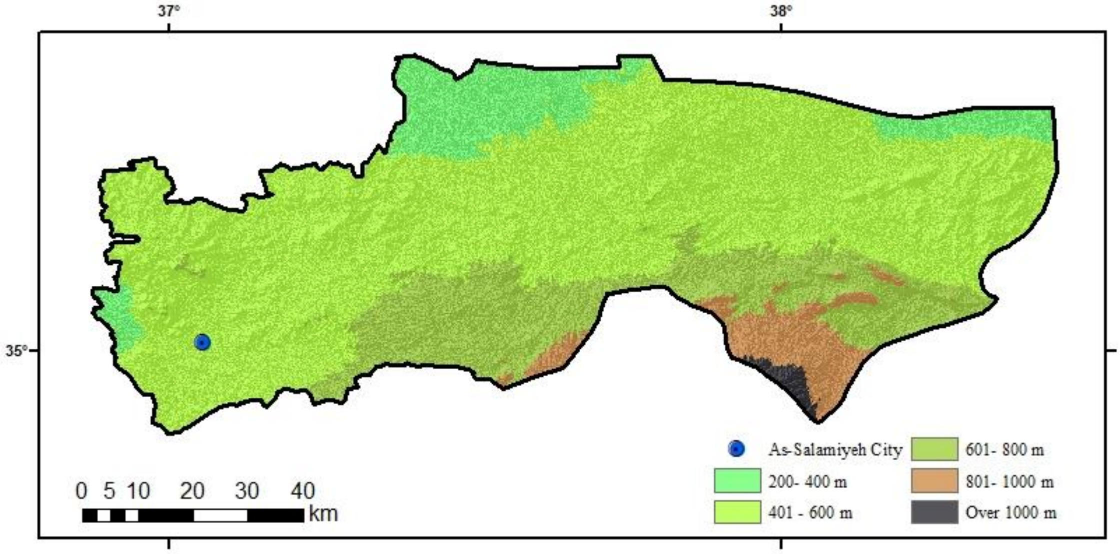

Figure 9: The digital elevation model of As-Salamiyeh Area (Derived from Open Street Maps, USGC)

Favourable aspects

The Aspects (direction of the slope) calculated using DEM and considered as a dominant factor variable for this study and the aspect is favourable when the terrain is either flat or oriented towards southeast, south, or southwest and lately we are going to reclassify the values of the aspects by giving the high values to the favourable aspects.

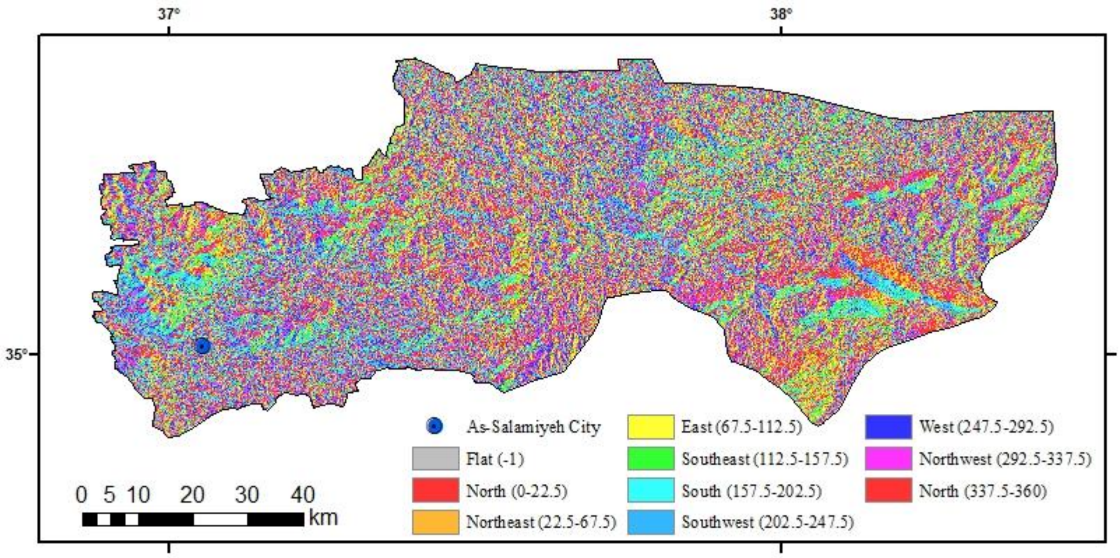

Figure 10: The Aspects (direction of the slope) of As-Salamiyeh Area (Derived from Open Street Maps, USGC)

The slope

The slope was derived from DEM data using the surface analysis module and the range of values in the output depends on the type of measurement units. For degrees, the range of slope values is 0 to 90 and we got only two values which are under one degree so it can be omitted and we will give it a low weight when we make the overlay analysis.

Euclidian distance

The distance to the main roads will be one of the factors that we have to consider when selecting the optimal places for solar power farms. The Euclidean distance output raster contains the measured distance from every cell to the nearest source (Source: Understanding Euclidean distance analysis—Help | ArcGIS for Desktop).

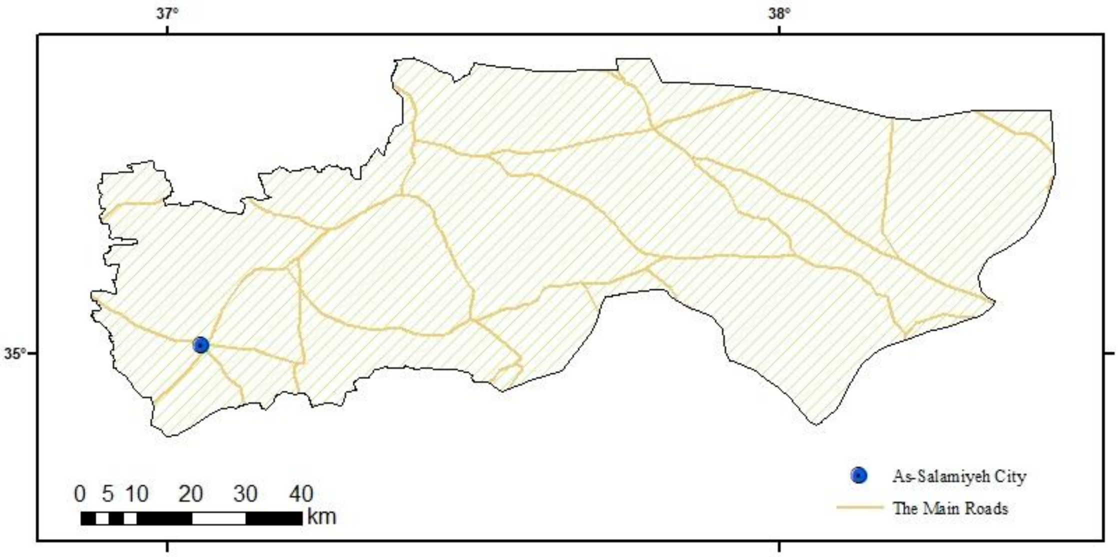

Figure 11: The main roads within As-Salamiyeh Area (Derived from Open Street Maps)

Lately, we will reclassify the values of this layer and give high values to the places which close to the main roads and lower values to the locations which are far away from the main roads (reverse the values).

The land cover

The land cover is also one of the factors that considered Land cover data documents how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types (Source: https://oceanservice.noaa.gov/welcome.html). As the area is located in the arid and semi-arid zones most of the lands are covered with a grassy land cover or bare lands. The land cover categories within the study area downloaded using the Global Land Cover project[1].

The annual cloud cover

The datasets integrate 15 years of twice-daily remote sensing-derived cloud observations at 1-km resolution and representing the Mean annual cloud frequency (%) over 2000-2014 (Source: "Wilson AM, Jetz W (2016) Remotely Sensed High-Resolution Global Cloud Dynamics for Predicting Ecosystem and Biodiversity Distributions. PLoS Biol 14(3): e1002415. doi:10.1371/journal. pbio.1002415" Data available on-line at http://www.earthenv.org/.) Figure 12 represents the annual cloud cover frequency of the study area:

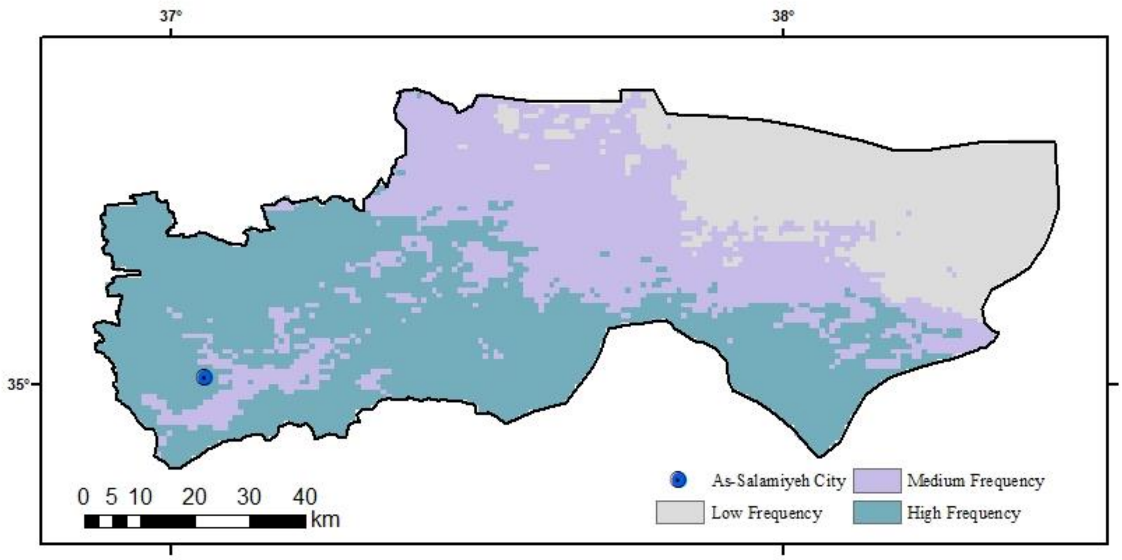

Figure 12: The Mean Annual Cloud Cover Map of As-Salamiyeh Area (Derived from Open Street Maps, Earth Env)

[1] The GLC2000 project uses the FAO Land Cover Classification System (LCCS). This is a hierarchical classification, which allowed each regional partner to describe the land cover classes at the thematic detail best suited to the land cover in their region of expertise, whilst following a standardized classification approach.

The direct normal irradiation

Solar radiation component that directly reaches the surface [kWh/m2]. It is relevant for concentrating solar thermal power plants (CSP) and photovoltaic concentrating technologies (CPV) (Source: Global Solar Atlas https://globalsolaratlas.info/about/data-description).

The data downloaded from the Global Solar Atlas website which is a long term data represent a time period from January 1999 till December 2015.

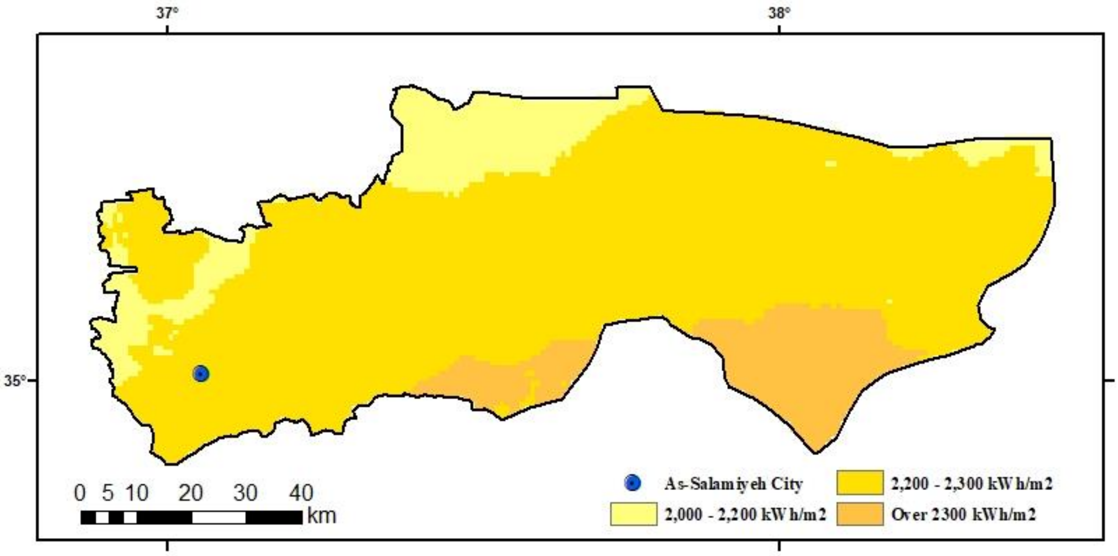

Figure 2: The Direct Normal Irradiation Map of As-Salamiyeh Area (Derived from Open Street Maps, Global Solar Atlas).

Environmental constrains (wind, dust waves)

Generally, solar panels are highly resistant to damage from windy conditions. In addition, when the wind blows across a roof with solar panels, it passes through the small space that typically exists between the panels and the roof (Source: Energy sage website: www.energysage.com). But for the study area if we review the daily wind data between 17/11/2011 and 29/08/2012 the mean of the highest wind speed as we can see from the wind rose is the Southeast (2.215851809 m/s) which can be classified as a Light breeze (Source: According to Beaufort-values of Wind force classification).

Table 2. The mean of the daily wind data of As-Salamiyeh Area

Wind Direction	**Wind Speed(m/s) mean**	**Duration (Min) max**
N	0.826752458	495
NNE	0.908665714	375
NE	1.107895700	210
ENE	0.863048687	360
SE	**2.215851809**	**330**
SSE	1.498898294	450
S	1.104848875	465
SSW	1.365880970	540
SW	1.737183476	1125
WSW	1.134690100	480
WNW	0.927192694	150
NW	0.735409846	225
NNW	0.707201881	345

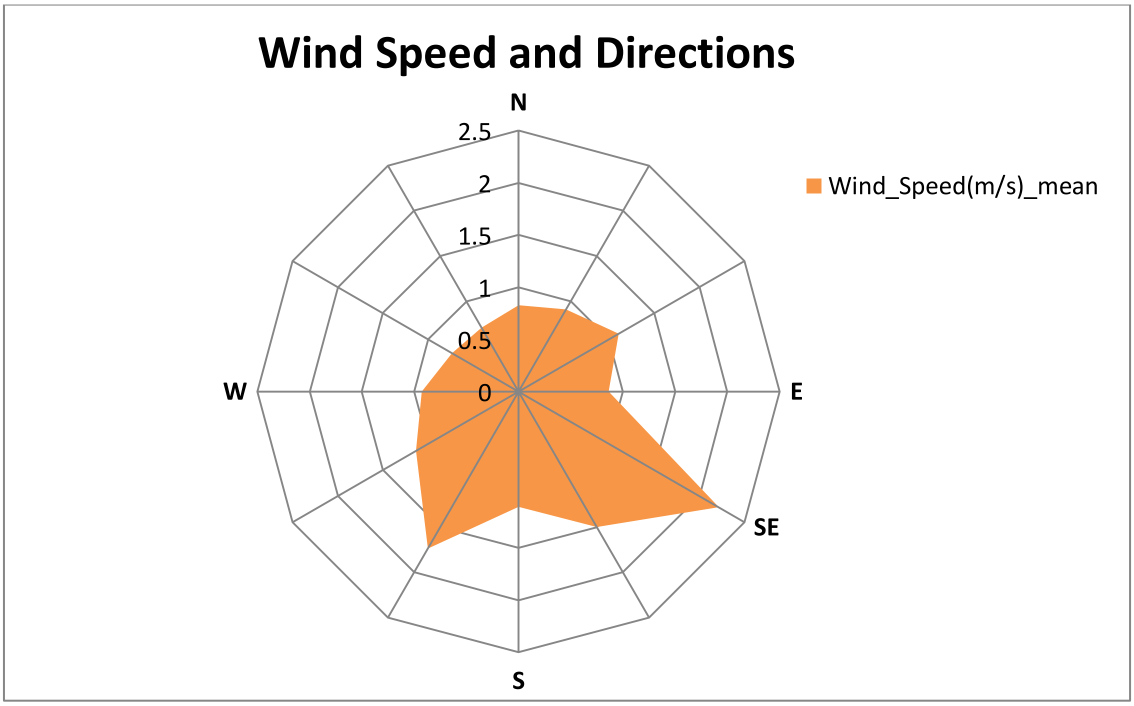

Figure 3: The mean of the wind speed within As-Salamiyeh Area (Derived from climatic data provided by the Aga Khan Foundation, Syria)

As we can notice that the bigger wind values are coming from Southeast direction and we have to take into consideration that the wind may contain dust which is one of the drawbacks of the development of solar energy in arid regions and It affects the performance of the solar PV panel by soiling the mirrors and receivers, which can be solved by regularly cleaning the panels which may affect the costs of operation only (Source: Shaharin A. Sulaiman, Haizatul H. Hussain, Nik Siti H. Nik Leh, and Mohd S. I. Razali, Effects of Dust on the Performance of PV Panels).

3. Suitability analysis model

The general purpose of this model is to rank potential sites according to suitability for a proposed type of activity and for our model (Source: Suitability Analysis in Raster GIS, Combining Multiple Maps, www.esri.com)

Reclassifying the input layers

After having all the required data we have to reclassify the values according to its importance and we have to mention that most of the time the reclassification is not objective which need to be done according to the importance that the experts may give to each factor and according to the purpose and what type of suitability analysis model we are dealing with. In addition "Weighting and rating" is also considered as a key opportunity for public deliberation (According to the same previous reference) and they can make their own contribution to see what can be a priority or importance for them.

Weighting overlay

The goal of this step is to create an attractiveness model with the ability to "Weight" factors. We applied the weighting overlay two times the first one for the study area in general and the second was applied only within As-Salamiyeh Sub-district but we took the same previous values for both models. We give the following Weight for each parameter:

Table 3.The Weight for each suitability factor

Factor	**Weight**
DNI	40%
Aspect	40%
Cloud Cover	5%
Slope	5%
Land Cover	5%
Roads Euclidian Distance	5%
Total	**100%**

The model

Model logic can be recorded in a diagram within we can organize the data better and see every step we have made. The following model contains 6 datasets:

- The mean annual cloud cover
- The direct normal irradiation
- The slope
- The land cover
- The aspects
- The main roads

All the previous datasets reclassified then we brought it all together to the weighted overly process and give a weight for each factor and then we get the weighted result as a layer with different categories according to evaluation scale (we used **1 to 5 by 1** in our model). The next step was to concentrate our result only on one category to be shown in our model which is the highly suitable areas so we used the (Set Null) for the rest of the values. After having our desired result, we changed the raster to polygon and then we used the tool (layer to KML) to be able to check the results by satellite images. The following figure contains the model and the main steps that we did in the analysis:

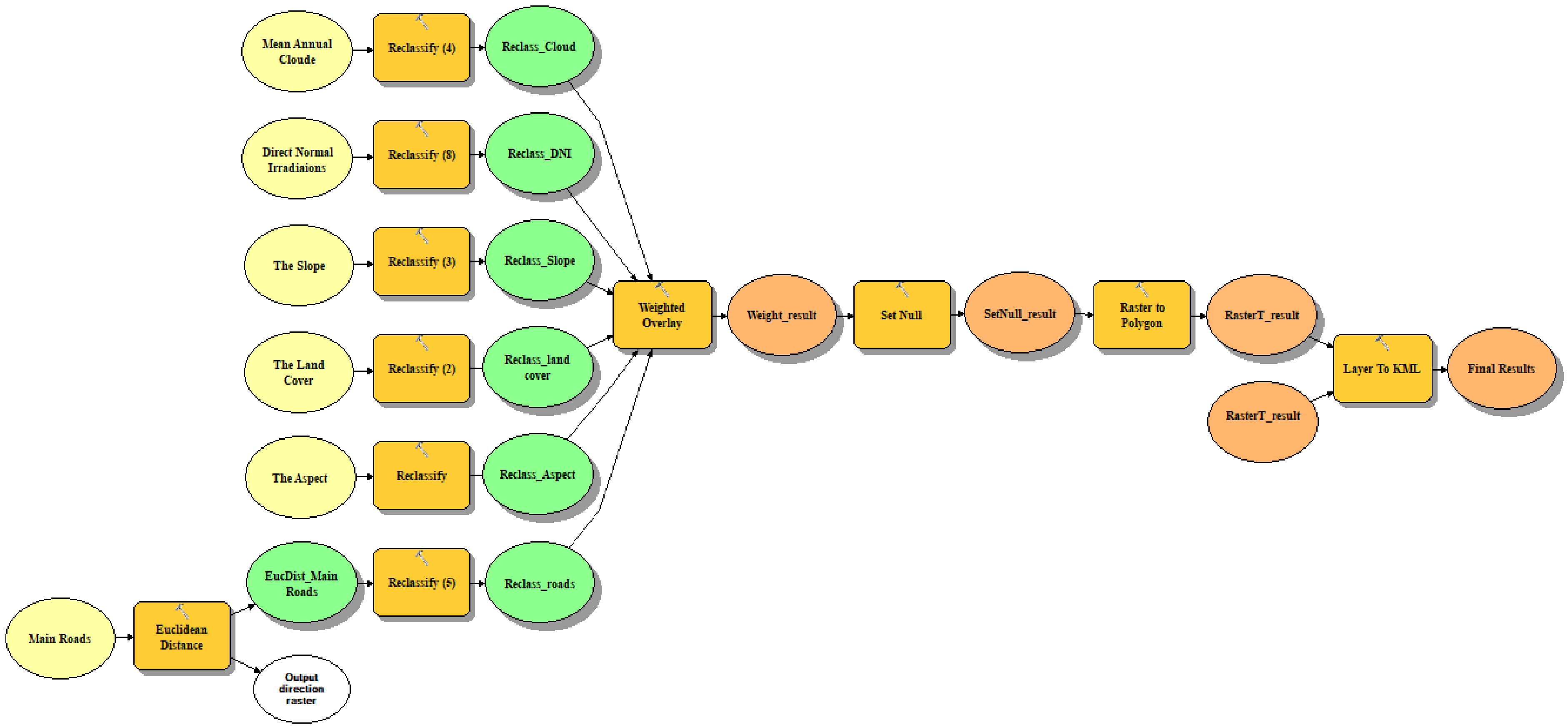

Figure 4: Suitability analysis model logic

The results

Suitable areas suggestions within the study area

When we apply the weighted overlay tool we got the results and according to that we got the layer with 5 categories with different colours which are dark red for unsuitable areas and light red for the less suitable ones and the light yellow for the moderately suitable and actually what really matters for us is the light and dark green areas which are representing the normal and highly suitable areas which would be our areas of interest in this research. The first model was applied for the study area with the Weight for each factor as was shown in Table 3.

Table 3.Wights of factors in the model

Factor	Weight
DNI	40%
Aspect	40%
Cloud Cover	5%
Slope	5%
Land Cover	5%
Roads Euclidian Distance	5%
Total	**100%**

Output maps from the location optimization model

In the first map (Figure 16) the model shows that as we go south the suitability index increases.

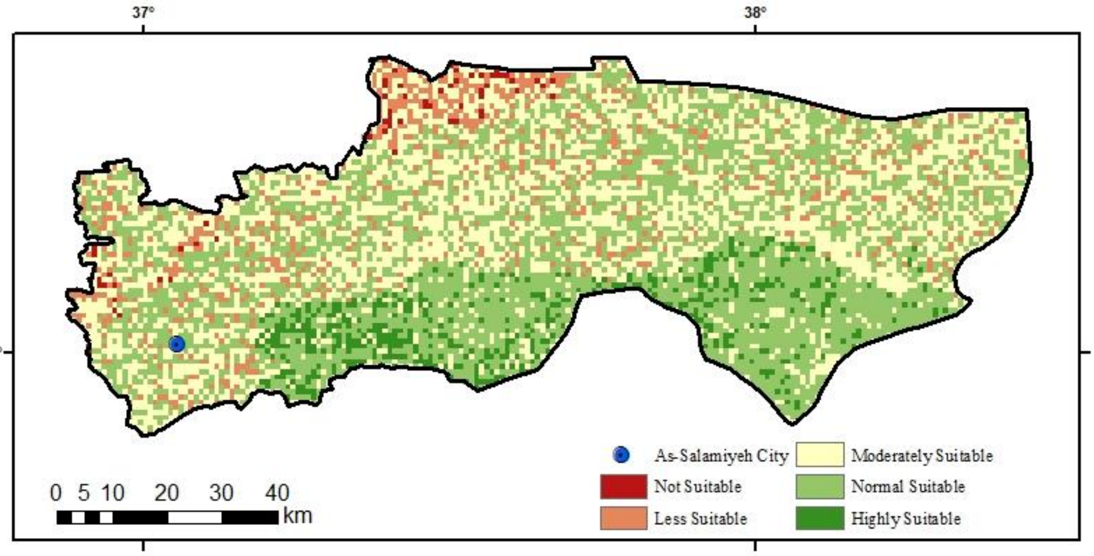

Figure 5: The Site suitability Analysis Map of As-Salamiyeh Area (Derived from Open Street Maps)

If we focus on Normal and Highly suitable areas we will see that these two categories lie on most of the places within the study area but the high suitability index is increasing toward the south (Figure 17).

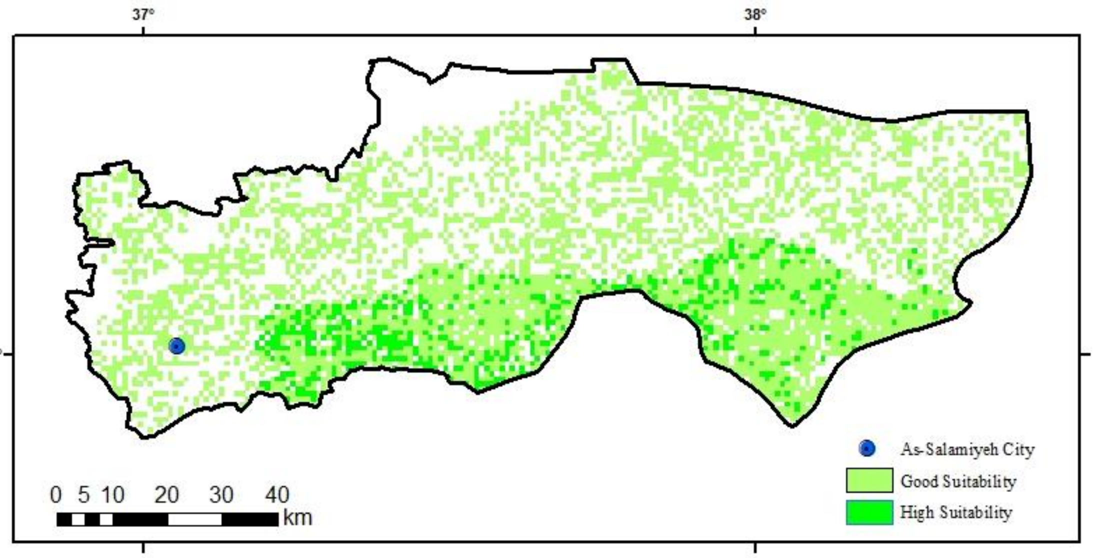

Figure 6: Good and High Suitability Places Map of As-Salamiyeh Area (Derived from Open Street Maps)

The previous results it was according to the dominant factors when we distribute the 100% weight with focusing mainly on the Aspects and the DNI and it would be an inserting thing if we apply almost the same weight for each factor to see what would the final results be and if we change the weight overlay values in order to give almost the same weight for each factor as can be seen from the following table:

Table 4. The same weight for each factor

Factor	Weight
DNI	17%
Aspect	17%
Cloud Cover	17%
Slope	16%
Land Cover	16%
Roads Euclidian Distance	17%
Total	**100%**

The output map contains three categories and the moderately suitable areas are the representing most of the places within the study area and as we can see the suitable areas are very limited but still intersected and contained within the highly suitable areas of the previous model.

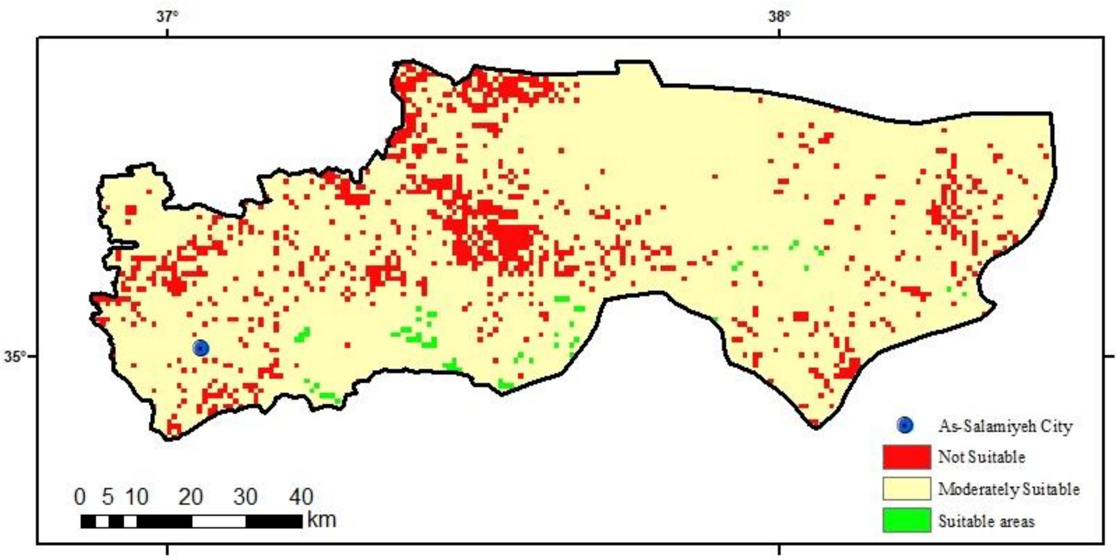

Figure 7: The map showing the results after giving the same weight for each factor (Derived from Open Street Maps)

Suitable areas suggestions within As-Salamyieh Sub-district

If we apply the same criteria within As-Salamiyeh Sub-district so we will get specific results which can be suitable for As-Salamiyeh City alone. We can notice that the results within the As-Salamiyeh Sub-district are following the same trend which can be located in the south and after use another method of creating a buffer zone around some localities within the area and erase it from the model with increasing the tolerance a bit we get three optimal sites which can be seen in the following map.

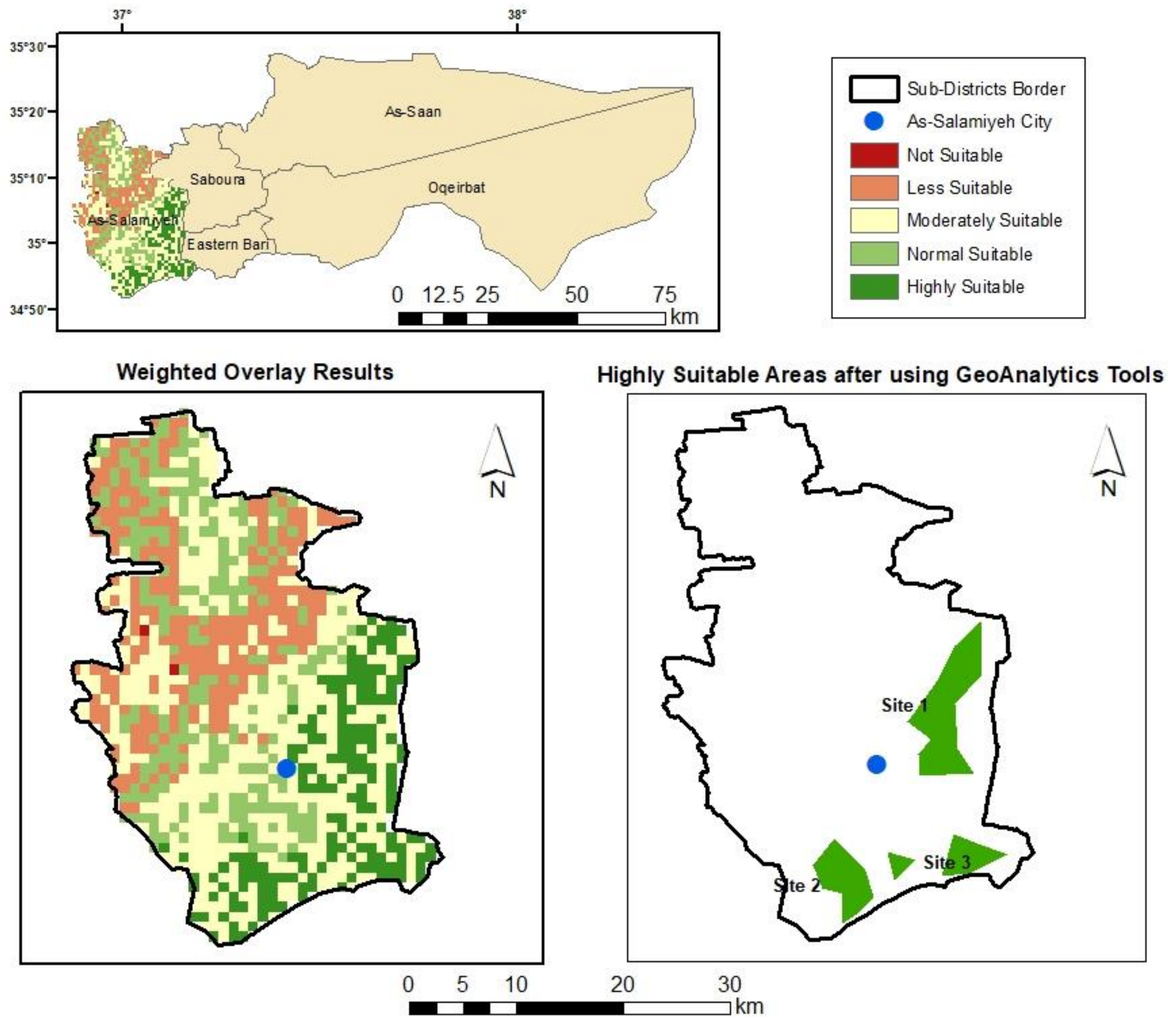

Figure 8: The suitability analysis map of As-Salamiyeh Sub-district (Derived from Open Street Maps using ArcGIS 10.1)

The highly suitable places as seen in the satellite images

The validation for the resulting map is required to determine whether the three sites selected are the most suitable sites in reality or not. From the satellite images, it can be seen that most of the areas in the three sites consist of grassland or agricultural areas. This indicates that the three sites on the resulting maps can be used as solar farms in the real world. The site 1 can be divided into two sites because there is a street cut the middle of the place and in site 2 the part of the northeast area should be removed as one of the highly suitable places. The corresponding Google Earth satellite images are shown in the following images.

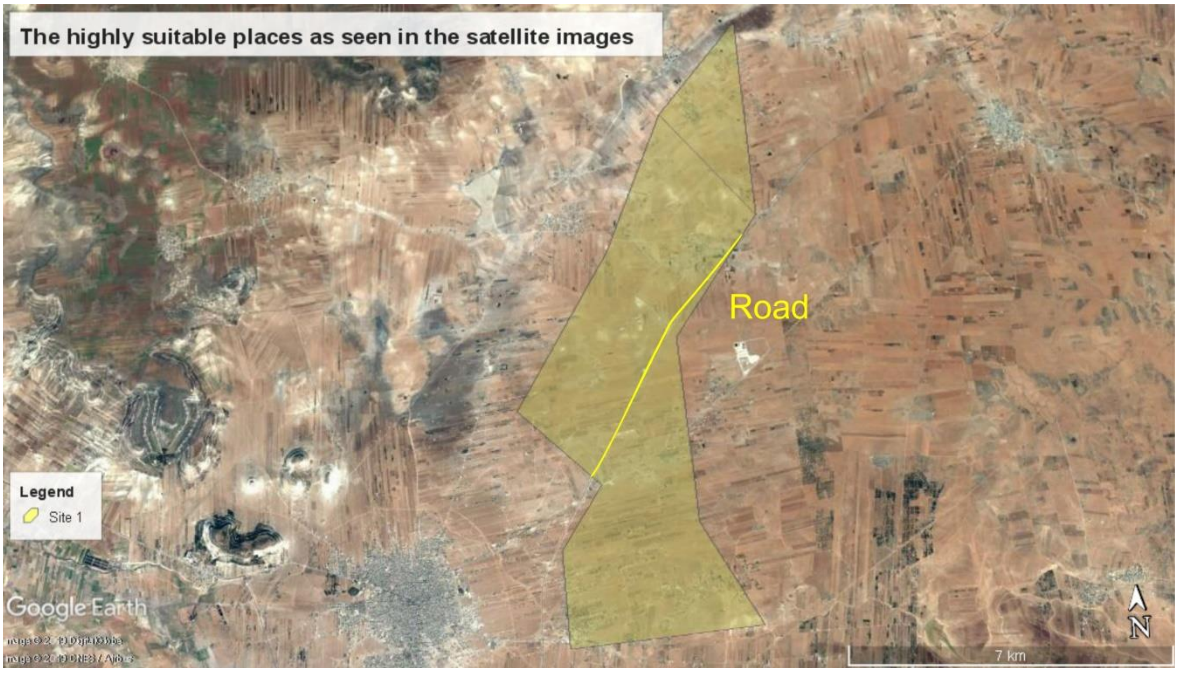

Figure 20: Satellite image of the Site 1 from the highly suitable areas (Derived from Google Earth satellite images)

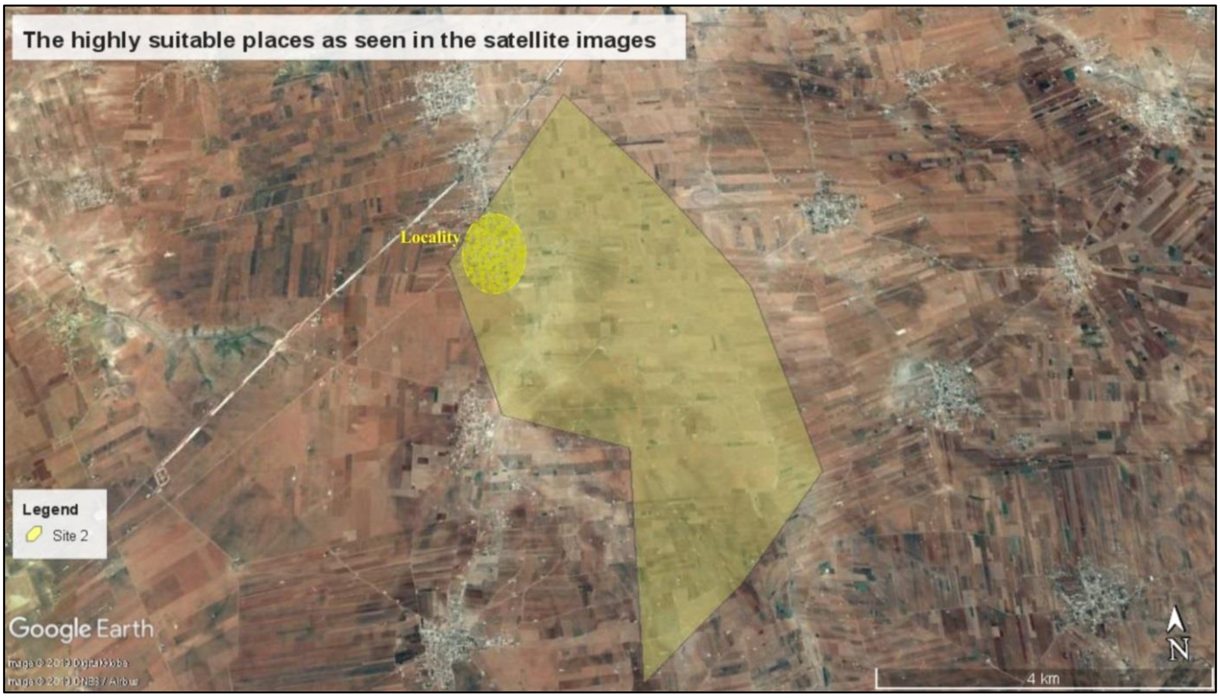

Figure 21: Satellite image of the Site 2 from the highly suitable areas (Derived from Google Earth satellite images)

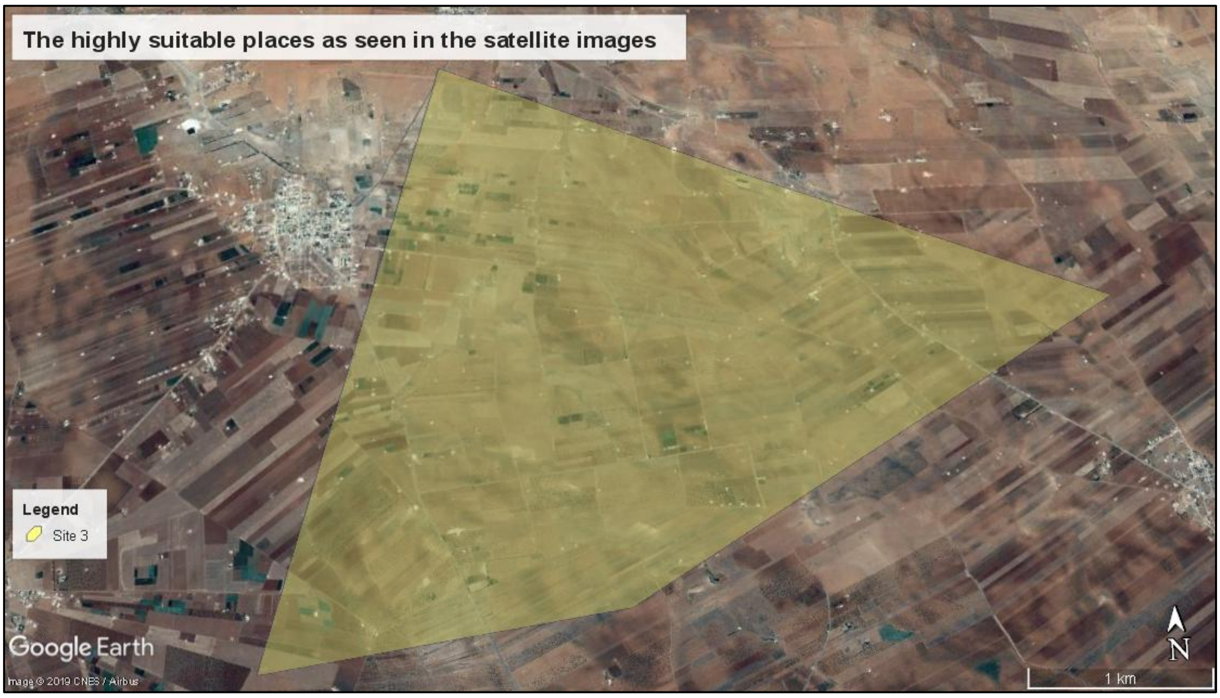

Figure 22: Satellite image of the Site 3 from the highly suitable areas (Derived from Google Earth satellite images)

Limitation and future development

- Having such a solar project during the crises in Syria we may find problems with material access, with logistics, with the capacities we needed in order to actually deploy the system.
- As we have monthly climate data for Syria for more than one hundred years we can predict the scenario for the past times and also how would the situation be in the future climate using different analysis techniques for climate time series decomposition.
- Although most of the data used in this research are global data the challenges of some metrological data gathering from Syria it may consider to be a hard mission.
- The study of the place names would be done in a large scale supporting by time series analysis for long climate data to cover every place name in Syria which reflect geographic features or climate condition on a specific period of time within a trend of better understand the climate changes pattern within the country.

Conclusion

The research generated a holistic view of places that fit the criteria set at the beginning of the study for different areas that could be suitable for solar energy farms within As-Salamiyeh area and different criteria were tested in the suitability model.

And we shed the light of the environmental conditions related to climate in general and especially the climate anomalies that could be causing some constraints (could potentially reduce the electricity outcomes) when we apply such a project.

For this research, it is important to take into consideration again that most of the time the reclassification and the weight that we give to each factor is done according to the importance to each factor and according to the purpose and what type of suitability analysis model we are dealing with and during the research we tested different values for each factor when we give different values and the situation when we give the same values and showing the corresponded results.

The research showed also that most the areas within As-Salamiyeh area are good for solar power energy production with identify the highly suitable areas within As-Salamiyeh District and as well as the sub-district and decision makers and organizations who are working within As-Salamiyeh have the possibility with the model focus their future investigations to the most interesting areas where to locate new solar power farms.

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DECLARATION

I, undersigned Nour Naaouf (NEPTUN CODE: *MNQG3A*), declare that the present master's thesis is my original intellectual product in full and that I have not submitted any part or the whole of this work to any other institution. Permissions related to the use of copyrighted sources in this work are attached.

I AGREE to the publication of the accepted master's thesis in pdf form on the website of the Department of Cartography and Geoinformatics.

Budapest, *15 May 2019*

(signature of the student)