GLOBAL ACADEMIC RESEARCH INSTITUTE

COLOMBO, SRI LANKA

GARI International Journal of Multidisciplinary Research

ISSN 2659-2193

Volume: 07 | Issue: 02

On 30th June 2021

http://www.research.lk

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GARI Publisher | GIS | Volume: 07 | Issue: 02

Article ID: IN/GARI/ICSD/2021/105 | Pages: 142-162 (20)

ISSN 2659-2193 | Edit: GARI Editorial Team

Received: 09.03.2021 | Publish: 30.06.2021

SOLAR POWER PLANT SITE SELECTION USING GIS TECHNIQUES IN HAMBANTOTA DISTRICT

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ABSTRACT

In the modern world, renewable energy resources are the newest trend in the field of energy generation. Establishing solar power plants is still young for Sri Lanka. Main aim of this study was to identify the most suitable sites for establishing solar farms in Hambantota district using GIS techniques. For that, seven criteria were considered including land use, slope, proximity criteria and solar radiation. A model was created in GIS environment to evaluate the criteria. Each criterion was further divided into sub categories using five scale where, very poor (rank=1) and Very good (rank=5). Seven criteria were overlaid using Weighted Overlay tool in Arc GIS spatial analyst extension. Total land area under each suitability level was calculated. The results show that approximately 3% of the total study area is highly recommended and about 62% of the area is not suitable for establishing solar farms. Most of the suitable sites were located within Sooriyawewa, Hambantota, Tissamaharama and Lunugamvehera DS Divisions. The largest seventeen sites for solar farms were suggested and approximate energy potential amounts were calculated. Finally, a model validation was conducted by visually comparing the existing and resulting solar farm sites. Land use was the major factor that influenced for the results. Although Hambantota district belongs to the semi-arid zone, has a flat topography and receives a plenty of sunlight throughout the year, the suitability does not appear equally for every location. Therefore, a site selection procedure is vital to avoid shortcomings and to have a successful energy project.

Key Words: Solar power, GIS, Land use, weighted overlay

INTRODUCTION

Background of the study

Energy resources are the fuels that are used for various purposes such as transportation, heating and electricity production. Mainly, they belong to two categories as renewable and non-renewable energy resources. Renewable energy is a source that its consumed amount is replaced by the nature. Sunlight, wind, water, waves and geothermal heat are the major types of renewable energy resources. Fossil fuel, coal, nuclear power, oil and natural gas are some non-renewable energy resources, which are limited in supply. Today, the world tends to consume renewable energy since it has less negative impacts rather than non-renewable energy resources (Sadeghi, Karimi and Engineering, 2017). Climatic changes and increasing energy demand have become issues in the present world. Therefore, renewable energy resources can be mentioned as a great solution for them. Many developed and developing countries are creating and maintaining policies to increase the renewable energy consumption (Tiwari, 2014).

In Sri Lanka, the electricity generation is done by using three primary sources. They are thermal power (which includes coal and fuel oil), hydropower, and other non-conventional renewable energy sources such as solar power and wind power. As a developing country, Sri Lankan government is aiming to have a self-sufficient nation of energy by 2030. Therefore, country is going to increase the power production capacity from the existing 4,043 MW to 6,900 MW by 2025 with maximum development in renewable energy.

Among various renewable energy resources, solar power is one of the completely renewable energy resources. It is the energy conversion of sunlight into the electricity. Mainly, there are three methods in solar power generation. They are directly using Photovoltaic (PV), indirectly using concentrated solar power or a combination of both. In the developed countries including UK, the newest trend of power generation is solar power (Ã and Neame, 2006). The study area considered in this research is Hambantota district in Sri Lanka. The electricity generation in this area is done by several ways. Already there are three solar power plants, an oil-fired power station and a wind farm in this area. Among three solar power plants, one plant belongs to the government and other two belong to private companies. According to the government, the wind farm is to be removed due to the high amount of rent to pay for the land and its less efficiency. Therefore, the electricity generation using renewable energy resources should be further developed in Hambantota district. Primary Objective of this study is selecting the optimum sites for solar power plants.

Problem Statement

Sri Lanka government is aiming to increase renewable power generation capacity. However, solar power plants are still young for the country. Therefore, determining suitable sites for a solar power plant is an issue. This study is conducted to identify the suitable areas for solar power plants within the Hambantota district using GIS techniques.

Importance of the Research

There are both renewable and non-renewable power plants established in Sri Lanka. Non-renewable power plants include coal-fired, oil-fired and Municipal Solid Waste (MSW)-fired power stations, while the renewable power plants include hydroelectric, solar and wind power plants. The main source that supplies the electricity to the national grid of Sri Lanka is the hydroelectric power. Although Sri Lanka has enough water to generate hydroelectricity, the electricity supply goes down at some occasions due to various reasons. However, with the population increment, the electricity demand has gone up. Therefore, this research will be heading a solution for that.

The solar panels produce electricity during the daytime when the sunlight is available. Since Sri Lanka is a country near to the equator, sunlight is available in huge amounts throughout the year. Therefore, establishing solar power plants are highly economical and suitable for a country like Sri Lanka to generate electricity. Since Hambantota is located in the dry zone, the efficiency will be higher. These solar power systems may become ideal for remote areas far from the distribution network, since solar panels convert sunlight directly into the electricity.

The present world is eager for establishing a healthy environment. Non-renewable sources are playing a major role in badly affecting the environment. Ozone depletion, environmental pollution and global warming are some of the results of them. Therefore, the trend is alternating renewable energy solutions. Solar energy is the cleanest and most accessible energy source. Solar power plants are very eco-friendly energy generating sources. Hence as a developing country, Sri Lanka should concentrate about these new renewable energy sources like solar power plants. Although the establishment cost of these power plants is high, it will be reasonable when considering the benefits of them. Some developed countries have also proven this fact. Site selection is not an easy task due to the rules and regulations that need to be followed on utilizing of lands for this purpose. Therefore, sites have to be selected so that they satisfy some spatial criteria. This research will be a great precaution for that.

Study Area

Hambantota district is located in Southern province of Sri Lanka. It is located within latitude 6'15" N and longitude 81'10" E and covers an area of 2,593 km². The population is about 647,000 in Hambantota district as counted in 2017 census data. It is the second level administrative division in the country. The district capital is Hambantota town and the other prominent towns include Tangalle, Beliatta, Ambalantota and Tissamaharama. Hambantota is in the dry zone of the country so it has a very dry climate. The government has planned to establish a Special Economic Zone (SEZ) in Hambantota district. Therefore, such development required a well-managed energy system. Renewable energy resources such as solar energy are great to fulfill that aim. Taking into account all these facts, Hambantota District was selected as the study area for this research. Figure 1 shows the map of Hambantota District with its DS divisions.

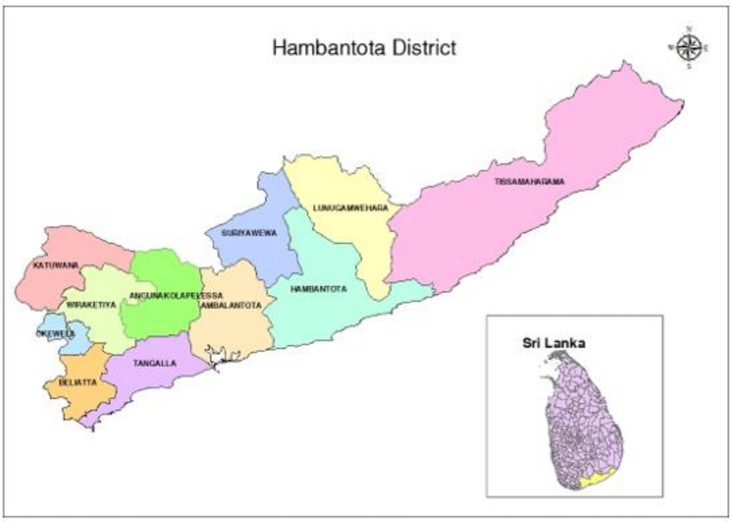


Figure 1 - Hambantota District Map

Research Objectives

Primary Objective

- Selecting the optimum sites for solar power plants

Sub Objectives

- Preparing solar radiation maps
- Preparing the slope map
- Creating proximity maps for roads, transmission lines and cities
- Obtaining the land use map
- Obtaining the suitability index map

LITERATURE REVIEW

In the reviewing of literature related to the study, 12 well-known researches were selected for the reference after a comprehensive review. The following sections describe and evaluate the facts including their criteria, methods, results, limitations and a comparison of each of them the current study.

The criteria considered were determined in the current study based on the research topic, objectives, existing literature and the available data. Table 1 represents a summary of the analysis criteria considered in the studies taken from the literature

Table 1 - Solar Farm Site Suitability Criteria Considered in Previous Studies

Criteria	**Sub Criteria**	**References**
Environmental	Land use	(Al Garni and Awasthi, 2017), (Khan and Rathi, 2014), (Uyan, 2013), (Zoghi *et al.*, 2017), (Nazari, Aslani and Ghasempour, 2018), (Charabi and Gastli, 2011), (Piyatadsananon, 2016), (Yousefi, Hafeznia and Yousefi-Sahzabi, 2018), (Effat, 2013), (Hott, Santini and Brownson, 2012), (Sadeghi, Karimi and Engineering, 2017)
Technical	Solar Radiation	(Zoghi *et al.*, 2017),(Akkas *et al.*, 2017), (Nazari, Aslani and Ghasempour, 2018), (Charabi and Gastli, 2011), (Piyatadsananon, 2016), (Effat, 2013), (Sadeghi, Karimi and Engineering, 2017)
	Sunshine Hours	(Zoghi *et al.*, 2017), (Akkas *et al.*, 2017), (Yousefi, Hafeznia and Yousefi-Sahzabi, 2018), (Sadeghi, Karimi and Engineering, 2017)
Geomorphologic	Slope	(Al Garni and Awasthi, 2017), (Khan and Rathi, 2014), (Uyan, 2013), (Zoghi *et al.*, 2017), (Akkas *et al.*, 2017), (Charabi and Gastli, 2011), (Piyatadsananon, 2016), (Yousefi, Hafeznia and Yousefi-Sahzabi, 2018), (Hott, Santini and Brownson, 2012), (Sadeghi, Karimi and Engineering, 2017)
	Aspect	(Al Garni and Awasthi, 2017), (Zoghi *et al.*, 2017), (Effat, 2013), (Hott, Santini and

		Brownson, 2012), (Sadeghi, Karimi and Engineering, 2017)
	Elevation	(Zoghi *et al.*, 2017), (Yousefi, Hafeznia and Yousefi-Sahzabi, 2018), (Sadeghi, Karimi and Engineering, 2017)
Economic	Proximity to Cities	(Al Garni and Awasthi, 2017), (Uyan, 2013), (Zoghi *et al.*, 2017), (Yousefi, Hafeznia and Yousefi-Sahzabi, 2018), (Effat, 2013), (Sadeghi, Karimi and Engineering, 2017)
	Proximity to Roads	(Al Garni and Awasthi, 2017), (Khan and Rathi, 2014), (Uyan, 2013), (Zoghi *et al.*, 2017), (Charabi and Gastli, 2011), (Piyatadsananon, 2016), (Yousefi, Hafeznia and Yousefi-Sahzabi, 2018), (Effat, 2013), (Sadeghi, Karimi and Engineering, 2017)
	Proximity to Utility Lines	(Al Garni and Awasthi, 2017), (Khan and Rathi, 2014), (Uyan, 2013), (Zoghi *et al.*, 2017), (Nazari, Aslani and Ghasempour, 2018), (Charabi and Gastli, 2011), (Piyatadsananon, 2016), (Effat, 2013), (Hott, Santini and Brownson, 2012), (Sadeghi, Karimi and Engineering, 2017)
	Proximity to Water Features	(Charabi and Gastli, 2011), (Piyatadsananon, 2016), (Yousefi, Hafeznia and Yousefi-Sahzabi, 2018)
	Population	(Hott, Santini and Brownson, 2012)
Climatic	Air Temperature	(Al Garni and Awasthi, 2017), (Khan and Rathi, 2014), (Nazari, Aslani and Ghasempour, 2018)
	Cloudy Days	(Zoghi *et al.*, 2017)
	Dusty days	(Zoghi *et al.*, 2017), (Charabi and Gastli, 2011)
	Rainy & Snowy Days	(Zoghi *et al.*, 2017), (Akkas *et al.*, 2017)
	Humidity	(Zoghi *et al.*, 2017), (Sadeghi, Karimi and Engineering, 2017)
	Wind Potential	(Akkas *et al.*, 2017)

According to the review of literature, land use has become a criterion in eleven studies out of twelve. Therefore, it can be considered as the most popular criterion among these studies. Both the slope and proximity to utility lines were considered in ten studies therefore, they have become the second most important criteria according to the literature. In nine studies out of twelve, proximity to roads fact was considered and in seven studies, solar radiation was taken in to account. Proximity to cities was used in six studies while the aspect was used in five researches.

In the work of Al Garni and Awasthi, 2017 a site selection was conducted for a PV power plant using a GIS and MCDM approach. GIS model maker has been used to evaluate the criteria while using AHP methods to assign weights. The analysis performed there included four steps. In the first stage, the constraints and restrictions were considered and the areas, which are not suitable, were removed. Next, the AHP technique was applied to define the weights for different criteria according to their relative importance to the analysis. As the third step, the weighted sum tool was applied for the overall evaluation of the site. In the final stage, unsuitable sites were excluded. A land Suitability Index (LSI) was determined to visualize the spatial distribution of the suitable sites. The assumption made was that a PV system of 18000 m2 would generate nearly one MW of electricity. Therefore, only the areas, which were larger enough to produce electricity in a utility scale, were considered as the suitable areas. However, a limitation was that, depending on the type of PV technology the area, which is needed to produce one MW, could vary. According to the study, the suitable areas have the pattern with the range of proximity criteria. Air temperature was considered using data taken from real atmospheric sensors in this study, which is not included in the current study. However, they did not have considered solar radiation factor, which has been used for many other studies as well as in the current study. Solar analyst tool, which is used in both studies, is very powerful and important due to the flexibility of it.

Khan and Rathi, 2014 have conducted a study to find the optimal sites for solar PV power plant using GIS techniques. Ten factors were considered in the study after classifying them as analysis criteria and exclusion criteria. First, the suitable sites were determined using the Analysis criteria. Then the exclusion criteria were used to remove the unsuitable areas from the selected sites. When comparing with the present research, some of the exclusion factors considered in this research is different. The variation in local climate was taken into account as an exclusion criterion in this study. However, that is not much important for the present study since the climate does not vary largely within the current study area. Here the geotechnical issues were considered. They included soil PH levels, groundwater resistivity, seismic risk and load bearing properties. Although those facts are important, it was unable to use them for the current study due to the lack of data. Module soiling is also an uncommon criterion that has been used in this study. It means the pollution of PV modules due to various particles such as dust and bird excreta. This factor is also very important since it can reduce the efficiency of the power plant. Although this factor is not considered in the present study, a solution was given in a different way. In the present study, the proximity to water features was taken in to account to make sure that water features are located near the power plant. Therefore, the dirt can be removed from modules since they can be cleaned with water without taking much effort. After selecting the most suitable area, the potential yearly amount of solar energy has been calculated in this study according to their assumption.

Another study was carried out by Uyan, 2013 to determine the suitable solar farm sites using GIS and AHP technique. Only five criteria were used in this study including land use, proximity criteria and aspect while the present study considered seven criteria. Here, before considering the analysis criteria, the unsuitable sites were removed. Then the suitable sites were determined using GIS and the weights were assigned according to the AHP technique. Four grades were considered in Land Suitability Index (LSI) as "low suitable", "moderate", "suitable" and "best suitable". Although the solar radiation was considered as a criterion in the present study, it has been neglected here since it was slightly varying throughout the study area. After creating the suitability index map, only the public lands were selected as the suitable size to overcome the issues related to the property. However, in the current study, private lands were also selected because the property rights can be taken under the owners' willingness.

In the study of Zoghi et al., 2017 an optimization site selection was conducted using fuzzy logic, Multi Criteria Decision Making (MCDM) technique and Weighted Linear Combination (WLC). Among the twelve researches that could be found related to the current study, this is the one, which considered the largest amount of criteria. Twelve different criteria were taken into account including solar radiation, land use, slope, proximity criteria and climatic criteria such as humidity, cloudy, dusty, rainy and snowy days. They have taken climatic criteria as one of the most important categories, which were not considered in the current study. There were three steps to determine the best suitable sites. In the first step, fuzzy method was used to prepare the layers and value them. Under that, r.sun rule, which is a location model for solar energy, was used to determine the solar radiation in this study while the solar radiation tool in ESRI spatial analyst was used in the present study. The topography's shadowing effect was also considered here which is not used in present study. The second step was conducted in order to assign the weights for criteria using AHP, which is the most popular type of MCDM techniques. The third step was done to combine the different criteria using WLC. In the fourth step, the restricted areas were removed from the suitability map.

Akkas et al., 2017 have selected five cities and carried out a study to determine the city, which is the most appropriate one for solar power plant establishment. When comparing with the current study, this is somewhat different. Here, four MCDM methods were used for the city selection process with the aim of maximizing the output and minimizing the cost. Unlike the current study, mainly three criteria were used in the study. They were slope, feeder capacity of the distribution centre and the solar energy potential. However, they have not considered land use and proximity criteria, which were considered as important in the present study. Feeder capacity that was included in this study is an important factor. It contains the number of utility lines, transformer capacities, cable sections, etc. The four sub methods of MCDM used in this study were TOPSIS, AHP, ELECTRE and VIKOR. Here, MATLAB program was used to conduct the simulation for solar power plant location establishment. Although GIS was used in the methodology of present study, Akkas et al., 2017 has not used it.

Another research was conducted by Nazari, Aslani and Ghasempour, 2018 to determine the suitable sites for a solar power plant in four different regions. Those regions were selected based on their land availability and power demand. Here, TOPSIS method, which is a sub method of MCDM was used. In the first step of the methodology, the criteria were defined as solar radiation, air temperature, land use and proximity to utility lines. However, proximity to cities, road and water bodies were not considered as the current study. In the second step, a questionnaire was prepared and the expert opinions were gathered in this study to determine the relative importance of the defined criteria. In current study, such a method was not conducted to determine the final weights. In the present study, the opinion of an expert was gathered and the expert knowledge in the existing literature was used to determine the weights. Not only that but also a model validation, which can be used to justify the weights was done for the current study.

Charabi and Gastli, 2011 has carried out a study to determine the PV site suitability using GIS. There, fuzzy multi criteria evaluation and FLOWA module was used as the method of the study. The used tool for the analysis applied fuzzy quantifiers. In the implementation, different PV technologies were taken into account unlike the current study. Here, dusty days were concerned as a criterion which wasn't included in the current study. Piyatadsananon, 2016 has conducted a different method to identify the spatial factors required for a solar power plant site selection. Although the study does not involve with a site selection process, it was important for the current study to determine the criteria. Six criteria were analyzed in the study using GIS. The result of the study showed the structured spatial database which was acquired in a PV construction system.

In the work of Hott, Santini and Brownson, 2012 a spatial analysis based on GIS was carried out for large scale solar energy and utility line issues. Here, a decision support tool was developed to determine the locations for a large-scale solar power plant by focusing on the state level utility line issues. The site suitability analysis was conducted using GIS and MCDM technique. An analysis was conducted on the resulting suitable locations by focusing on the population and existing utility lines. The difference between the current study and this study is that, they have not considered the distance from the cities.

The optimum sites for establishing a solar power plant were determined by the study of Effat, 2013 using GIS and Multi Criteria Analysis. They have used six different criteria including terrain aspect, which was not taken into account in the present study. However, they have not considered the proximity to water features. AHP was the technique used to determine the weights for the criteria. A weighted overlay was carried out to create the final suitability map. Here, the created model was validated as in the current study.

Sadeghi, Karimi and Engineering, (2017) also used GIS and AHP technique for selecting the suitable sites for a solar power plant. First, the restricted areas were removed. Then ten factors were taken into account in the research analysis. However, they have not considered proximity to water features, which was used in the current study. Elevation, humidity, air temperature aspect and sunshine hours were used in this study, which were not considered in the current study.

A fuzzy logic model, which was based on GIS was used by Yousefi, Hafeznia and Yousefi-Sahzabi, 2018 for a spatial solar site determination. Here, the Boolean and fuzzy logic raster layers were combined to determine the solar suitability areas. Seven factors were considered in the research analysis. However, they have not considered solar radiation and proximity to utility lines, which were used in the current study, but used elevation and sunshine hours.

METHODOLOGY

Criteria Identification and Data Acquisition

Seven different criteria were considered in the study to analyze the site suitability. They were land use, proximity to utility lines, proximity to roads, slope, solar radiation, proximity to water features and proximity to cities. Each criterion is described below.

Land use

This is one of the most important environmental criteria in the study. Land use decides the land availability for construction. By analyzing the land use types, an idea can be taken whether a land parcel is available for construction or not. One of the aims of the study was to reduce the damage to the natural environment. Therefore, the environmental sensitive areas such as dense forests, forest plantation and wet lands were excluded. Other restricted areas included major cultivations, salt producing land parcels, built-up areas, rocky areas, clay pits and water features. According to the expert knowledge, scrublands were selected as the most suitable land use type for establishing a solar power plant. The private lands such as Chena were considered as suitable since the property rights could be possessed under the owners' will after buying the land or offering compensation.

Proximity to utility lines

The power transmission grid plays a major role in selecting the optimal sites for a solar power plant. This is an economic criterion, which saves the cost of power transmission by recommending the nearest areas for establishing a power plant. Not only the cost for transmission and infrastructure but also the loss of energy can be reduced by considering this factor. Buffer zones were created from utility lines for the study area. The first 500 meters buffer zone was considered as the most suitable area for the study.

Proximity to roads

This is the factor, which is related to the accessibility of the power plant. For every workplace, there should be a proper access. The existing road network data were collected from the Survey Department. Here, only the footpaths were neglected while other roads including, major roads, minor roads and jeep/cart tracks were taken into account.

Proximity to water features

Although the water features were excluded from the land use layer, the distance to them from the solar farm is important. The efficiency of the power plant would reduce due to the dust particles that lie on the solar panels. Since Hambantota is located in the dry zone, dust percentage may be high. Therefore, frequent panel cleaning is an essential thing. For that, the nearby locations of the water features should be considered. Otherwise supplying water to the plant would be difficult and costly. The water features were extracted from the land use layer and Euclidean distance was considered.

Slope

For a ground mounted solar farm, a large area with a flat terrain is required. When considering the topography of the area, slope plays an important role. For a large-scale solar power plant, flat or a very small slope is suitable. Therefore, areas with a slope less than five degrees were considered as the most suitable ones. Since the topography of Hambantota does not vary in a higher scale, this criterion was not taken as important as land use criteria.

Solar radiation

Solar radiation is the amount of solar energy that incidents to the ground. Generally, the main factor that should be considered when selecting the suitable sites for a solar farm is solar radiation. However, in the present study, solar radiation was not considered as a major factor. It is because Sri Lanka is near to the equator and Hambantota area receives a good amount of solar radiation throughout the year. Further, within the study area solar radiation is most probably constant. Solar radiation maps were prepared using SRTM DEM data.

Proximity to cities

Since a large area is required for the ground mounted solar farm establishment, 2km buffer distance from each city were excluded in the analysis. This was taken only as an exclusion criterion.

DATA ANALYSIS

Steps of the working process are described in the flow chart shown in figure 2

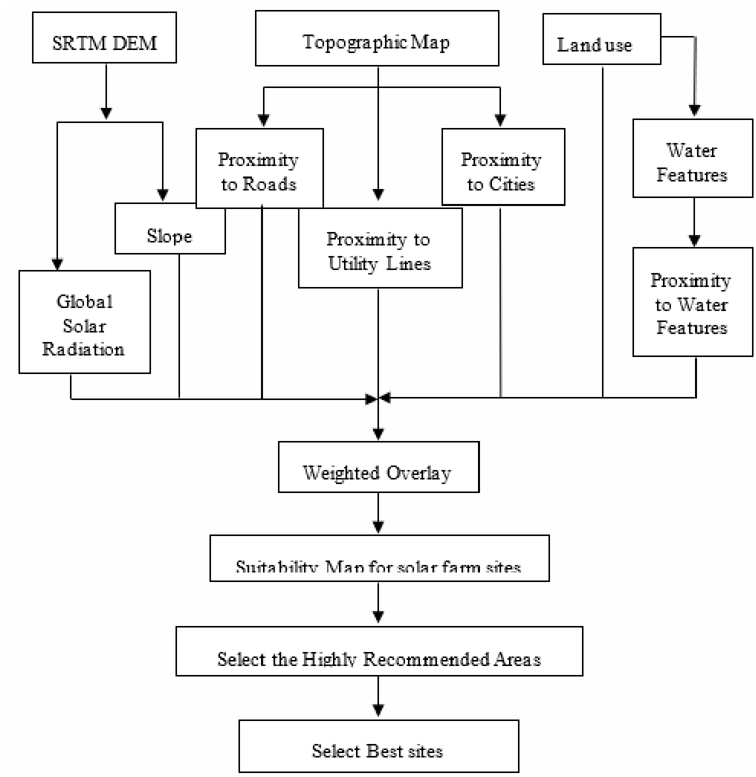


Figure 2 - Methodology Workflow

First, the data collected were converted into the required data layers. All the input layers were transformed into the projected coordinate system WGS_1984_UTM_Zone_44N with a cell resolution equal to the resolution in SRTM DEM layer. SRTM DEM data for the study area were acquired as a collection of three separate tiles. Therefore, they were combined into a single layer. DEM was filled to remove its small imperfections.

Global solar radiation and slope layers were created using the above-mentioned SRTM DEM data layer. "Area solar radiation" tool was used to acquire the global solar radiation map while "slope" tool was used to create the slope map. Then, the global solar radiation layer was reclassified into five sub categories. When creating the slope map, output measurement parameter was given as degrees since the criteria condition was considered with degrees. The slope map was categorized only into two types. Cities, road network and utility grid data were used to create proximity maps using Euclidean distance tool in Esri spatial analyst. The distances were measured in meters. Then those distances were reclassified according to the requirement. All the water features were extracted from the land use layer. Then a new vector layer was formed to create the proximity to water features layer.

The land use layer was classified into five different categories by adding a new field to the attribute table. There, the restricted layer was created by including the areas of built up, abandoned paddy, coconut, tea, rubber, paddy, dense forest, forest plantation, wetland, water bodies, rocky areas and clay pits. The created five categories were given ranks according to their importance by adding another field. Then polygon to raster tool was used to convert the "land use" vector layer into a raster file for further analysis.

Finally, all the created criteria layers were overlaid using weighted overlay tool to create a suitability map. Criteria were given weights according to their importance to the evaluation based on the expert knowledge and the existing literature. There, sub categories of the criteria were ranked on their importance according to one to five scale where, Very poor (rank=1), Poor (rank=2), Moderate (rank=3), Good (rank=4), Very good (rank=5). Table 3 indicates the considered criteria and their weights.

Table 3 - Weights and Ranks for Criteria Considered in Solar Farm Site Suitability Analysis

Criteria	Weight	Sub criteria	Rank
Land use	0.4	Scrub Land Barren Land Sandy Area Other Plantation Restricted	5 4 3 1 Restricted
Proximity to utility lines	0.2	0-500 500-1000 1000-5000 5000-10000 >10000	5 4 3 2 1
Proximity to roads	0.15	0-500 500-1000 1000-5000 >5000	5 4 2 1
Proximity to water features	0.1	0-500 500-1000 1000-2000 >2000	5 4 2 1
Slope	0.08	0-5º >5º	5 Restricted
Solar Radiation	0.04	< 750000 750000-760000 760000-770000 770000-780000 > 780000	1 2 3 4 5
Proximity to Cities	0.03	0-1000 >1000	Restricted 5

RESULTS AND DISCUSSION

This chapter describes the results obtained from analysis of this study. The method used in the present study provides the benefit that it has the ability to apply the resulting model for selecting suitable sites at any location. Using GIS for the data analysis was ideal because of its capability of handling various spatial and topological models properly.

Solar Radiation Maps

After running the area solar radiation tool in Esri spatial analyst extension, three maps could be obtained. They were direct, diffuse and global solar radiation maps and they were shown in figure 3, 4 and 5 respectively. Global solar radiation was the layer used in weighted overlay process in this study while other two were the optional outputs.

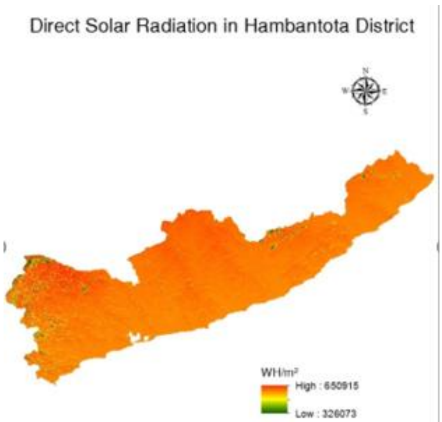


Figure 3 - Direct Solar Radiation Map of Hambantota District

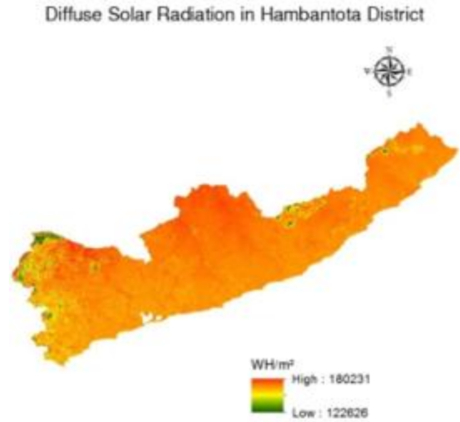


Figure 4 - Diffuse solar Radiation Map of Hambantota District

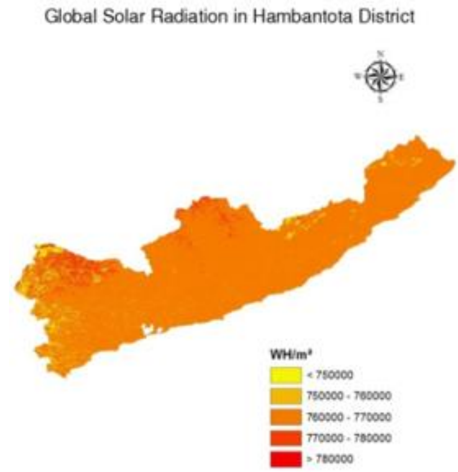


Figure 5 - Global solar Radiation Map of Hambantota District

Direct, diffuse and global solar radiation maps indicate that solar radiation is almost constant throughout the study area. This is the reason for assigning lower weight for solar radiation factor in suitable site selection analysis of this study.

Slope Map

According to the literature and expert knowledge, slope more than five degrees were considered as steep slopes. Therefore, the areas with a slope from zero to five degrees were considered as the suitable areas. Other areas were assigned as restricted areas. Figure 6 indicates the slope map of the district.

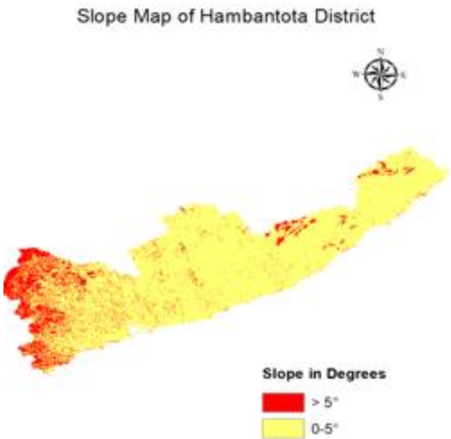
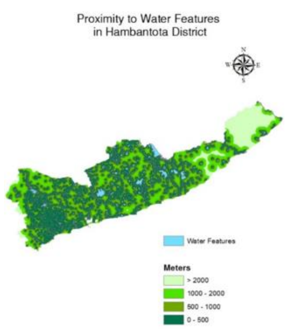


Figure 6 - Slope Map in Hambantota District

Slope map highlighted that there is no considerable slope variation all over the district. Therefore, this criterion was also given a lower weight (8) during the analysis.

Proximity Maps

Four different proximity criteria were considered in the study. Out of them, three were used to minimize the losses from power transmission, water supply, travel and transportation. The main aim of considering proximity to cities was to exclude the urban areas from the suitability site map. Resulted maps were shown in figure 7, 8, 9 and 10.



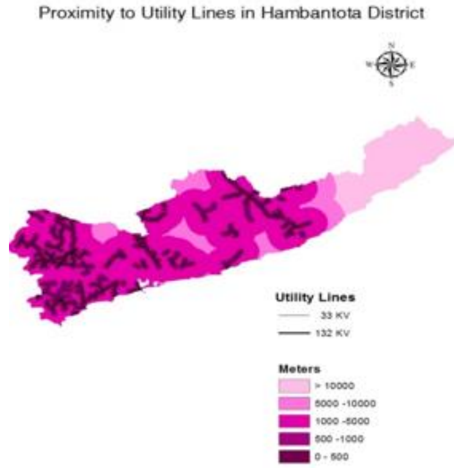


Figure 7 - Proximity to Utility Lines Map in Hambantota District

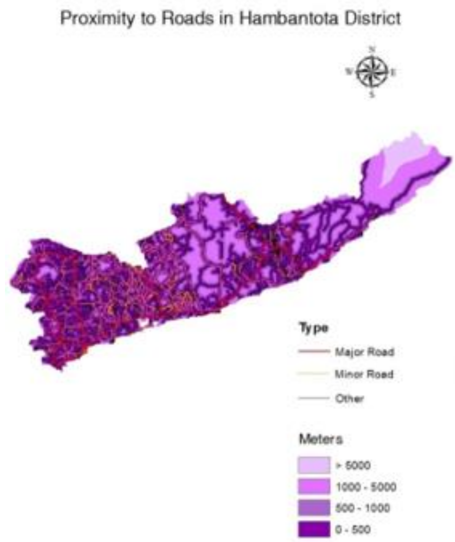


Figure 8 - Proximity to Roads Map in Hambantota District

Figure 9 - Proximity to Water Features Map in Hambantota District

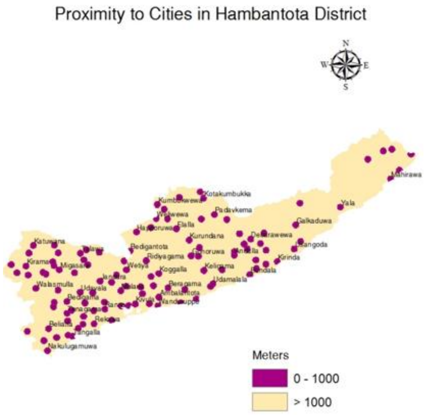


Figure 10 - Proximity to Cities Map in Hambantota District

Availability of utility lines was the second major factor that influences the analysis of the land suitability for establishing a solar farm. Otherwise, new transmission lines have to be decided and cost will be increased for establishment and maintenance. Power loss while transmitting increases with the distance. Therefore, the areas near to the utility lines were considered as the most suitable for solar power plant establishment. Same way areas near the roads and water features were considered as the most suitable.

Land Use Map

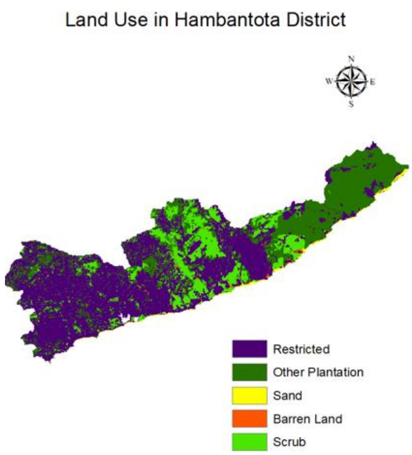


Figure 11 - Landuse Map in Hambantota District

Figure 11 shows the land use type of the Hambantota district. Here, the private lands such as Chena were also considered as suitable because the property rights could be transformed from one person to another. According to the expert opinions and related literature, scrublands were selected as the most suitable land use type available within the study area for this analysis. Land availability is the most prominent factor for establishing a large-scale solar power plant. Therefore, this criterion was assigned the largest weight (40). By excluding the protected and unsuitable areas from the analysis, the negative impacts from establishing a power plant for the society, environment and infrastructure are reduced. When considering the land use criteria, only the present land use types were considered. However, accuracy of the results can be increased by considering the proposed land use types for future projects. There is a modern trend of establishing solar farms on water features such as lakes and reservoirs. However, this model was created by categorizing all the water features as restricted areas due to the inability to determine exactly which water features are suitable to establish solar farms.

Final Suitability Map

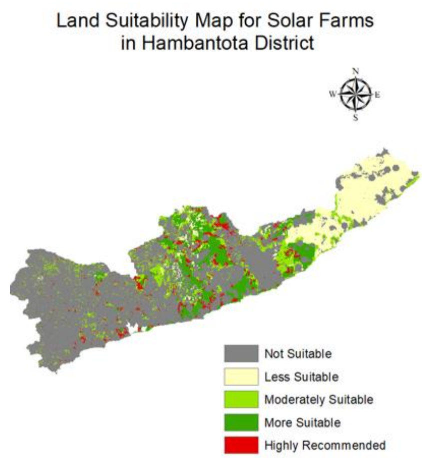


Figure 12 - Final Suitability Map for Solar Farms in Hambantota District

Map shown in figure 12 demonstrates reaching the main objective of this study by displaying suitable lands for establishing solar power plant within Hambantota district. This map indicates that area within Hambantota district, have been classified into five classes based on the suitability levels for setting up the solar power plant. Table 4.1 indicates the total area represented by each suitability level in the final map. The area was calculated using following equation.

Total Area = Area of a pixel * Number of Pixels (6)

Table 0 - Total Area Represented by each Suitability Level

Suitability Value	Suitability Level	Area (Hectares)
0	Not Suitable	158981.3
1	Less Suitable	40137.9
3	Moderately Suitable	24447.1
4	More Suitable	25290.1
5	Highly Recommended	8230.3

Table 4 indicates that about 3% of the area in Hambantota district is highly recommended for setting up the solar power plant. Further, table 4 stresses that about 62% of the area is not suitable, about 22% of area is suitable to establish the solar power plant. Those site locations are displayed in figure 13. Figure 13 also shows that most of the suitable sites locate within Sooriyawewa, Hambantota, Tissamaharamaya and Lunugamvehera DS Divisions of district. Within these DS Divisions transportation network was well developed due to the airport and international cricket playground etc. presently. This may further give the positive impact to establish power plant.

Potential Capacities of the predicted Sites

Before extracting the solar farm suitable sites, the suitability map was converted into a polygon layer using raster to polygon tool. Here, both simplify polygons and create multipart features parameters were kept unchecked in order to gain individual polygons in the resulting map.

When comparing with other power plants, solar power plants require a significantly larger area. According to the literature, the minimum area required to produce 1MW is 10000 square meters (Imhan, 2014). So in this study possible energy amounts were calculated only for the area falls under highly recommended suitability category. In this calculation it could be identified a large number of sites with the best suitability and the capacity over 10 MW. Only 17 sites were selected as the best sites, which have the capacity more than 100 MW as indicated by Figure 13. Table 5 indicates these sites and their energy capacities.

Table 5 - Best 17 Sites and Predicted Energy Capacities

Site Number	Area (square meters)	Capacity (MW)
1	5281465.20	528.15
2	3409804.64	340.98
3	1544757.71	154.48
4	1515468.73	151.55
5	1422877.75	142.29
6	1383195.90	138.32
7	1350127.69	135.01
8	1338790.02	133.88
9	1244309.42	124.43
10	1174393.78	117.44
11	1118650.23	111.87

12	1115815.81	111.58
13	1112981.40	111.30
14	1087471.64	108.75
15	1078023.58	107.80
16	1066685.91	106.67
17	1052513.82	105.25

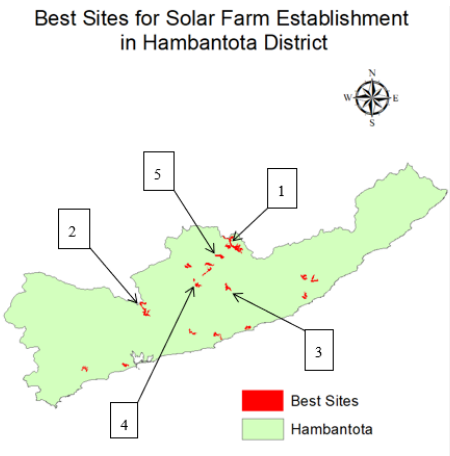


Figure 13 - Map including Best 17 Sites for Solar Farm Establishment in Hambantota District

Table 5 highlighted that site No.1 has the capacity around 500 MW, which can be suggested, as the best site for solar power plant within the study area. Site 2 with capacity around 300MW is another best location for setting up solar power plant within the Hambantota district. Sites 3, 4, and 5 also can be considered to establish the power plant since they have capacity around 150 MW.

VALIDATION OF ANALYSIS RESULTS

A model validation was conducted to ensure that the results of the model were accurate and reliable. Here, the suitable sites from the model result and the existing solar sites were compared. The most suitable areas were overlaid on a high-resolution image taken from Google Earth Pro software to ensure that there are not any constraints in those areas. Those four sites were equivalent to the built up areas in the land use layer in the study. This is because the land use data considered in this study were captured in 2016 and the existing sites were already there when collecting the land use data. Therefore, those existing sites were appeared in the model result as not suitable areas. Images shown in figure 14, 15 and 16 indicate how the land use of those four sites appeared before and after the year of 2016.

Figure 14 - Land use on 23_07_2009

Figure 14 represents the above-mentioned four sites in 2009. It shows the land use of the area before extracting land use data by the Land Use Policy Planning Department in 2016. At that time, there cannot be seen any construction work. Only some bare lands and plantations are there.

Figure 15 - Land use on 18_01_2017

In Figure 15, four sites can be seen in 2017. It indicates that some construction work is ongoing when it becomes to 2017. According to the literature, construction of "Hambantota Solar Power Station" was begun in 2012 and construction of "Sagasolar Power Station" was started in 2016. Therefore, the construction that can be seen in Figure 16 can be mentioned as construction of these solar farms. It can be more justified using Figure 16, which represents the land use in 2019.

Figure 16 - Land use on 23_02_2019

However, the adjoining areas to these four sites appear as highly recommended in analysis results. That can be used to justify the results of the current study.

This study shows that the sites next to the existing sites fall under the highly recommended suitability level and it is clearly indicated in figure 17. Therefore, by using the output of this study, the most suitable sites can be identified to establish new large-scale solar power plants.

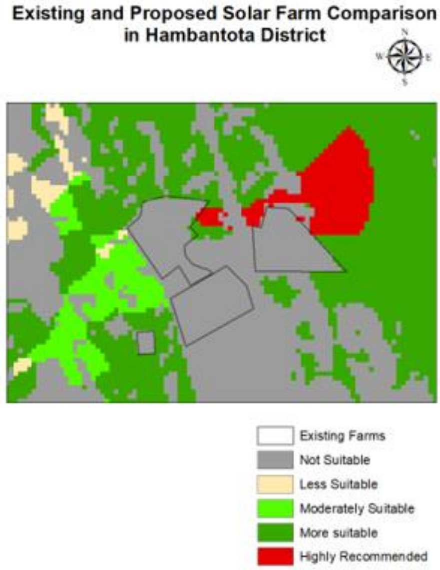


Figure 17 - Comparison of Existing and Proposed Solar Farms in Hambantota District

CONCLUSION

Site selection is suggesting appropriate lands for a particular purpose through the consideration of various criteria. This research was conducted in order to select the optimum sites for establishing solar power plants in Hambantota district. Seven criteria were considered including land use, global solar radiation and slope. To reach the sub objectives of the study, GIS layer maps were created for these seven criteria. The technique used to combine the criteria used in the study was important because it separated a huge amount of area as not-suitable areas. The most important finding in the study was the final suitability index map, which fulfil one of the sub objectives of this study. About 2677591 m2 (about 3% of the study area) was recognized as highly recommended for establishing the solar farms. The site which has the potential energy about 528MW was recognized as the best site. In addition to that, another 16 sites were suggested as the sites which have the energy potential above 100 MW. These information shows that the achievement of the primary objective of the study. The weighting process and the exclusion criteria had the highest influence on the results of the study. The sites next to the existing solar farms represent the highly recommended category in the final map from the model. Therefore, by using the output of this study, the most suitable sites can be identified to establish new large-scale solar power plants. One of the major advantages of this study is that, the result can be used for a better power supply within the study area by utilizing the existing resources and infrastructure.

The results of the current study have the ability to provide a guideline for establishing the solar power plants in Hambantota district. The proposed sites are related with the existing sites within the study area. A large number of new sites can be identified for the solar developers by referring the results of this study. The most suitable sites with the highest capacities have been found near the areas such as Kotakumbukka, Wetiya, Landajulana and Kurundana. Although Hambantota district is located in the dry zone, receives a plenty of sunlight throughout the year and owns many none built up areas, study indicates that very few sites are suitable for establishing a solar farm. Therefore, this site selection study is essential for the government and other interested organizations as the initial step to establish a solar power plant. Since the environmental sensitive areas were excluded in the study, the land clearance can be done without damaging such areas. When calculating the site capacities, the whole area of the site was assumed as equal to the surface area of the solar panels. All the data obtained from various sources depend on the capability of the data collectors and software. Therefore, the result of the study also depends on the accuracy of considered datasets. The model can be developed to provide the ability of identifying solar farm suitability sites for any location. In addition, it can be utilized as template to find suitable sites for other renewable energy power plants.

Limitations of the Study

According to the literature review, there can be seen a lot of criteria that can be considered in solar power plant site selection. However, here only several criteria were considered. In this study, some criteria such as sunshine hours, air temperature, wind potential, dust and humidity were not considered due some reasons such as the unavailability of data, time limitation and the less importance to the objective of the study. Among them, sunshine hours were available only for one station therefore; interpolation was unable to create a data layer. Aspect criteria was not taken into account since Sri Lanka is located near to the equator and the direction of slope does not influence much for receiving the solar energy. However, this will not be same for other regions in the world since it depends on the location. In addition, population and elevation data of the study area could not be considered as criteria for the study. By adding above discussed criteria in to the model, a more accurate result would be able to obtain.

The study was conducted only for the area of Hambantota District. It would be more important if this study was conducted for the whole area extent of Sri Lanka.

RECOMMENDATIONS AND FUTURE WORK

At the completion of this study, many opportunities are able to open up new studies for future workers. Here only solar radiation has been considered as the energy source for the power plant. However, hybrid systems can be created by combining renewable energy sources such as wind-solar or solar-biomass. Site selection for such a power plant would be a cost effective way to increase the renewable energy production in future. Another direction for future work is considering the establishment of solar panels on the rooftops. It will be a more advanced and important filed since the effort of locating the power plant would be less than in large-scale solar farms. Conducting the same study with different methods would be ideal to compare the results and gain an accurate final decision. Rather than obtaining the solar radiation maps using DEM data, establishing solar sensors and using that data for the study would be reliable. Converting the suitability model into a tool in ArcGIS by setting the inputs as parameters will be another future direction. Researchers will be able to use it for other regions in the world too. The model results can be used as a guidance to set up new utility lines for the regions that are lack of them but full of solar potential. Future works can be focused on conducting a more detailed survey for the study area in order to obtain data that are more accurate. There are several Photovoltaic technologies available. After selecting the suitable sites, selecting the best PV technology for the sites is a future direction of work.

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