Journal of
Renewable Energy Research and Applications (RERA)
Vol. 3, No. 2, 2022, 155-164 *DOI: 10.22044/rera.2022.11737.1106*

Estimating Solar Energy Potential in Eritrea: a GIS-based Approach

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Received Date 11 March 2022; Revised Date 15 April 2022; Accepted Date 16 May 2022
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Abstract
The remote sensing technology is suitable to analyze the potential of renewable energies such as solar energy, and play a great role to minimize global warming worldwide. However, in Eritrea, exploration of the potential of solar energy using such an advanced technique is so limited. In this work, a digital elevation model (DEM) is applied to estimate the potential of solar energy in Eritrea at a regional level for the photovoltaic system. The ArcGIS and ENVI softwares are used to compute the solar radiation from the DEM data. In addition, the global horizontal irradiation (GHI) is adopted to evaluate the suitability of the solar energy potential for the photovoltaics development. The results obtained reveal that the annual average maximum and minimum GHI of the three regions (Maekel, South, and Anseba) in the highlands and the three regions (Ghash Barka, Norther Red Sea, and Southern Red Sea) in the lowlands range between 2775 kWh/m^2 and 870 kWh/m^2, and between 2238 kWh/m^2 and 830 kWh/m^2, respectively. Thus the results show that Eritrea is suitable to develop the photovoltaics (PVs) electricity where the 69% and 31% part of the country is categorized as excellent suitable and highly suitable to generate the PVs power. Therefore, this research work might be significant for the decision-makers and to serve as a reference data for further studies in this area.

Keywords: *Regional; Digital elevation model; Radiation; Photovoltaic system.*

1. Introduction

The discovery of fossil fuel energy has caused a dramatic change in the world such as advancement in the industry, agriculture, economy, society, and politics. It was a great finding that solved enormous human issues including food security, transportation, electricity, infrastructure, etc. However, as the production and consumption of this energy increased, CO_2 emission into the atmosphere also enhanced. At the global energy scale, the highest level of greenhouse gases is estimated to emit from the urban centers [1, 2]. A high level of greenhouse gases into the atmosphere, particularly CO_2, caused global warming. Consequently, global warming began to alter the conditions of the climate, environment, economics, agriculture, and human health, just to mention some. In addition, it caused political, social, environmental, and economic stresses, which became a global concern. Today, all countries in the world have agreed to find an immediate solution. One of the best solutions to minimize the impact of global warming is to establish an alternative energy from wind, geothermal, solar, hydrology, and ocean wave and tide energies. Such renewable energies are free from pollution. Nevertheless, the solar energy technology is the most suitable alternative energy [1, 3-6].

Solar energy is generated from the sun's radiation. The sun radiates light constantly to the earth's surface through the atmosphere. However, the earth receives only about 30% of the incoming solar radiation [3], and the remaining radiation returns to space through several factors in the atmosphere such as cloud cover, aerosols, dust particles, and air moisture. Solar radiation that is received by the earth's surface is also influenced through different factors including topography, altitude, aspect, slope, latitude, and buildings [7]. Generally, solar radiation decreases from the equator toward the poles [3], and the flat top surface of highlands or mountains receive direct maximum sunlight. In the northern hemisphere, south and north facing slopes or aspects receive the highest and the lowest solar radiation, respectively, and the reverse is true in the southern hemisphere; however, solar radiation also varies greatly at the local scale. In order to estimate the suitability of solar radiation at the regional or national level, it is significant to determine the potential of solar energy at different time scales (daily, weekly, monthly, annually, and seasonally) [8]. The potential of solar energy can be assessed using several methods. The most suitable and accurate measurements are those from the ground stations; however, it is difficult to estimate the solar energy potential with limited ground stations at the regional, national or global scale [9]. Today, the satellite data plays a great role to evaluate the solar energy potential at different scales.

It is crucial to asses and estimate the variation in the solar radiation potential to generate efficient photovoltaic energy. Remote sensing images are a suitable technique for processing and analyzing the characteristics and patterns of the solar energy potential at different zones of the world. The satellite data is also helpful to make high resolution solar maps using weather models and local factors including atmosphere, seasons, and locations [10]. For instance, the Heliosat (Helios satellites) model describes that the superficial solar radiation can be estimated through analyzing the effect of clouds [11]. Recently, several researchers have applied the remote sensing data to evaluate and estimate the surface solar radiation such as Medium Resolution Imaging Spectro-radiometer (MODIS), Earth Observing System (EOS), Tropical Rainfall Measuring Mission (TRMM), and Digital Elevation Model (DEM) [9, 12]. Some researchers have also suggested different methodologies to evaluate the solar energy potential at different scales using remote sensing data and geographical information systems (GISs) [13].

GIS plays a great role to analyze the renewable source of energy including the energies generated from wind, water, geothermal, solar, etc. [14]. The GIS methods have been applied by several studies to estimate the solar energy potential [15, 16]. It is suitable to evaluate solar radiation at different scales. The integration of GIS and remote sensing also provides an appropriate estimation of the solar energy potential [8, 17]. Although several remote sensing data have been applied to evaluate solar radiation as mentioned above, DEM is most commonly used in the study of solar energy, where some researches have been adopted it using the ArcGIS tools [9, 12]. In ArcGIS, the solar radiation analytical tool supports for mapping, analysis, and modelling of the solar energy potential at different geographical scale, and in particular, period of time. However, some factors (such as altitude, slope, aspect, latitude, buildings, and seasonal or daily shift of the sun) need to be considered, which may have an effect on the spatial distribution of solar radiation. Thus GIS is suitable to evaluate photovoltaics (PVs) and concentrated solar power (CSP) at different geographical areas [8]. However, in Eritrea, the application of GIS to investigate solar energy is scientifically so limited.

In Eritrea, the major source of energy to generate electricity or other related purposes is petroleum. In addition, in the rural areas, biomass is the main source of energy for heating, cooking, and lightening due to lack of electricity access [18-20]. To import petroleum requires a huge amount of foreign currency; as Eritrea is a poor country, it will be difficult to afford. Moreover, the current electricity service is very poor in the country. In addition, the demand and consumption of electricity rises from time to time, particularly in the rural areas [18]. Thus shifting to renewable sources of energy is a method to minimize the consumption of much energy. Eritrea is estimated to have high a renewable energy potential such as wind, solar, and geothermal. For instance, it has a high wind energy potential along the Red Sea coastal regions [20, 21], and the geothermal energy potential is also expected in hot springs and fumaroles of the Red Sea coast [18, 22, 23]. The mitigating problems related to the fossil fuel energy, the government of Eritrea has taken some efforts to encourage the importance of alternative energies, particularly the solar energy [20]. Eritrea, being in the tropical region and long sunshine hours is profitable to develop the solar energy technology. According to [19], the solar panels have already been installed in some rural areas, schools, and clinics. In a small scale, solar energy has been used in household for light, heating, cooking, watching, television, etc. Moreover, it has also been applied in the industrial, agriculture and other sectors. However, poor countries like Eritrea are far from the application of these technologies or it is very limited. This circumstance might be due to the lack of access and poor education facilities; especially in Eritrea, as a new country, the introduction of this technology has been very slow. Particularly, monitoring and managing of renewable energies such as solar and wind with the help of remote-sensing technology and GIS applications are very limited.

The request to improve electric supply in Eritrea has motivated the country to look for alternative energy resources to enhance the existing power. Eritrea, being in the tropics, is well situated to harvest solar energy to improve its power supply status. Although several solar energy projects have been initiated, very small has been done in the country. Therefore, the main purpose of this research is to fill the gap of limitations of scientific research in solar energy in Eritrea and to map the spatial and temporal variations of solar energy potential and suitability to generate solar power in Eritrea using DEM. The spatial distribution temperature and precipitation of the country was highlighted to understand the climatic condition. Thus this paper will be a significant input in the country for developing solar energy by different sectors and it might also be a helpful input for the researchers who are interested in this region for further study**.**

2. Studied area

Eritrea is located in the Horn of Africa between 12º 22’ and 18º 02’ North and 36º 26’ and 43º 13’ East. It borders with Sudan in the west, Ethiopia in the south, Djibouti in SE, and Red Sea in the east (Figure 1). Eritrea is a young country, which got its independence in May 1991 from Ethiopia after a thirty-year war of liberation. Two years later, with the United Nation’s supervision, a referendum was conducted to ascertain the wish of the Eritrean people. Consequently, 99.8% of the people voted for independence, and the Sate of Eritrea was officially proclaimed. Today, Eritrea is divided into six administration regions. The total land area of the country is estimated about 121,434 square kilometers with about 1200 kilometers of coastline in the Red Sea. It has a marine exclusive economic zone of 121,000 square kilometers, of which about 56,000 square kilometers is territorial water, where the country exercises exclusive sovereignty. The country has also more than 356 small- and medium-sized islands [24].

Eritrea has diverse topographical features such as mountains, hills, plains, and escarpments. Geographically, it is divided into highlands and lowlands, where most of the lowlands are dominated by an arid and semi-arid climate; particularly, the eastern lowlands is desert and very hot throughout the year. The highlands are characterized by rugged topography, and stretch to north-south. Figure 1 explains the DEM variation of the country prepared in ArcGIS 9.3, where it ranges between 140 m below the sea level and 3000 m above the sea level. The climate condition of the country is also diverse, varying from extremely hot along the deserts to cold and favorable climate in the highlands. In Eritrea, topography plays a great role to regulate the climate condition; three seasons within two hours can be experienced as someone travels from the Massawa port to Asmara, the capital city in central highland.

Eritrea is expected to receive high solar radiation annually since it is located in the tropical region of eastern Africa, and along the Sahle and Danakil region, which is very hot throughout the year. According to [25], eastern Africa has the highest solar energy potential than any part of the world including Eritrea. In addition, Eritrea is located within tropics north of the equator, so it receives long sunshine hours. However, solar radiation varies spatially, seasonally, and regionally within the country due to its diverse topographical features, diverse climatic condition, and its location [24, 26].

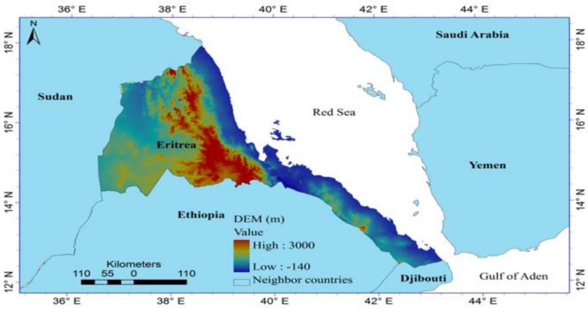

Figure 1. Geography and DEM of studied area.

3. Data collection and methods

3.1. Data collection

The remote sensing data is suitable for analysis to estimate the spatial and temporal solar energy potential at the local, regional, and global scale. In this work, remote sensing digital elevation model (DEM) was used to estimate the potential of solar energy in Eritrea. The images were downloaded at a spatial resolution of 90 m. DEM is collected from the Shuttle Radar Topography Mission (SRTM) at “http://gdem.ersdac.jspacesystems.or.jp/search.jsp”.

In this work, DEM was processed and analyzed in a software such as Geographical Information System (GIS) and Environment for Visualizing Images (ENVI**)**. Solar energy can be estimated from the DEM images using the GIS spatial analysis tool. Regional SEP was estimated in order to compare and contrast the spatial and temporal variations of solar energy at the regional scale [25]. The climate data, particularly temperature of the country, was adopted and extracted from the recent research article published by [24], which is significant to understand the variation of temperature in each administration region of the studied area.

3.2. Methods

3.2.1. Image pre-processing

The DEM images were imported to the ENVI software, where the atmospheric and geometric correction was completed, and the images were mosaicked to create a single file. All images were projected to Universal Transverse Mercator (UTM) 37'N at the World Geodetic System 1984 (WGS1984). In addition, a masking building method was applied to extract the size of the studied area. The DEM image was exported to ArcGIS for further processing.

3.2.2. Image processing

In ArcGIS 9.3, DEM of each region was extracted in order to have a regional analysis, and to compare and contrast the suitability of solar energy potential (SEP) among the regions. The spatial analysis tool is suitable for processing SEP when the size of the image is smaller. Thus it is difficult to process SEP for the whole country.

inn ArcGIS; several methods can be used to evaluate SEP including area solar radiation, point solar radiation and solar radiation graphics. In this work, SEP was processed using the area solar radiation method. In this tool, although it is optional, the characteristics of the image should be defined including latitude, sky size, time configuration (yearly, monthly or daily), date, and year should be selected. In this work, the yearly SEP was analysed (i.e. 2020), which started in January 1 and ended December 31. The latitude can be automatically determined by the spatial analysis too once the image is imported; the latitude is positive for the northern hemisphere and negative for the southern hemisphere here since Eritrea is located north of the equator indicated by positive latitudes. The central latitudes of all images are defined automatically, and thus it ranges between 13 degree north and 16 degree north. The sky resolution or sky-size for the view-shed, sky-map, and sun-map grids (unit cells) can also be optional and defined automatically. Here, 200 by 200 cells of resolution, and a 14 day interval and half an hour (0.5) interval are used, the annual SEP computed in a biweekly means. The raster output produced correspond to the global radiation or total amount of incoming solar insolation (direct + diffuse); it has a unit of watt hours per square meter (Wh/m^2/year).

3.2.3. Image post-processing

Image post-processing is one of the most significant methods in ArcGIS, particularly with remote sensing data. In this work, the area solar radiation of each image was further converted and reclassified. The images, therefore, the output (area solar radiation) (i.e. Wh/m^2/year) was altered into kilowatt hours per square meter (kWh/m^2/year), and reclassified into SEP suitability. There are two methods to estimate the solar energy potential: Global Horizontal Irradiation (GHI) and Direct Normal Irradiation (DNI), the GHI considers direct and diffuse radiation but DNI only takes the direct sunlight, which is a better proxy to analysis energy. GHI and DNI better approximate for the PVs and CSP cell output, respectively [16, 25]. In this work, GHI was applied to assess SEP for PVs production. In addition, solar energy suitability index was divided into four categories (i.e. unsuitable, suitable, highly suitable and excellent) [25]. The two extreme values below 1000 and between 2500 and 3000 considered as unsuitable and excellent, respectively (Table 1). Figure 2 illustrates a flow chart for this work.

Table 1. Suitability index of SEP.

Category	Energy (kWh/m2/year)
Unsuitable	< 1000
Suitable	1000–1500
Highly suitable	1500–2500
Excellent	2500–3000

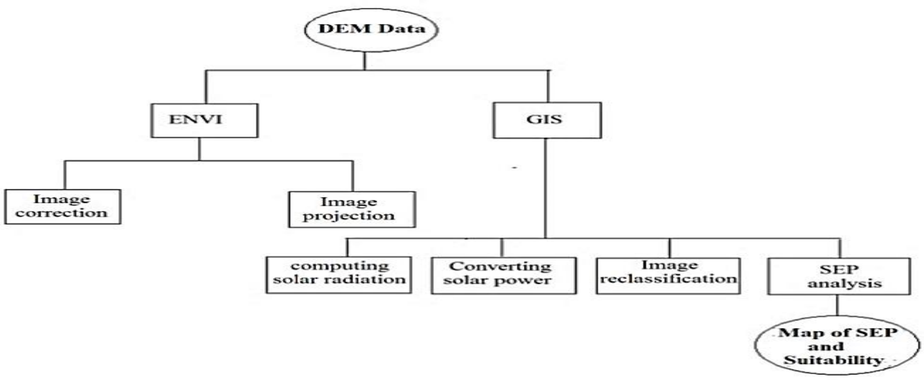

Figure 2. A flow chart for estimating solar energy potential in Eritrea.

4. Results

4.1. Assessment of regional elevation

Figure 3 shows the DEM values of each region. The regional elevation of the country is characterized by its diverse relief including highlands, lowlands, slopes, and escarpment, characterized by different topographic features such as mountains, plains, and depressions. Generally, elevation ranged from 140 m below the sea level to about 3000 m above the sea level. In addition, it is divided into highlands and lowlands. The highland occupies the central part of the country with north-south extension, while lowland covers the western and eastern parts, where its altitude ranges below 1,500 m above the sea level. Moreover, the western lowland extends from the foot of western escarpment to the border with Sudan, and covers most parts of Gash Barka and some parts of Anseba regions whereas the Eastern lowland stretches from the coast to the foot of the eastern escarpment. The result indicate that Maekel, Anseba, and South regions are located in the highlands with an elevation of 2,606, 2,640, and 3,000 m, respectively, whereas NRS, SRS, and Gash Barka regions are situated in lowlands with the lowest elevation of -140, -90, and 404 m, and with the highest elevation of 2858, 2177, and 2474 m, respectively. Therefore, in this work, the DEM variation was suitable to estimate the spatial distribution of SEP in Eritrea. According to the above results, it may be estimated that the amount of solar radiation varies from region to region, which encourages significantly studying the variation of solar energy in this area. In addition, to study the topographic variations in Eritrea using DEM is also an appropriate method to establish and select the regional solar energy development priorities.

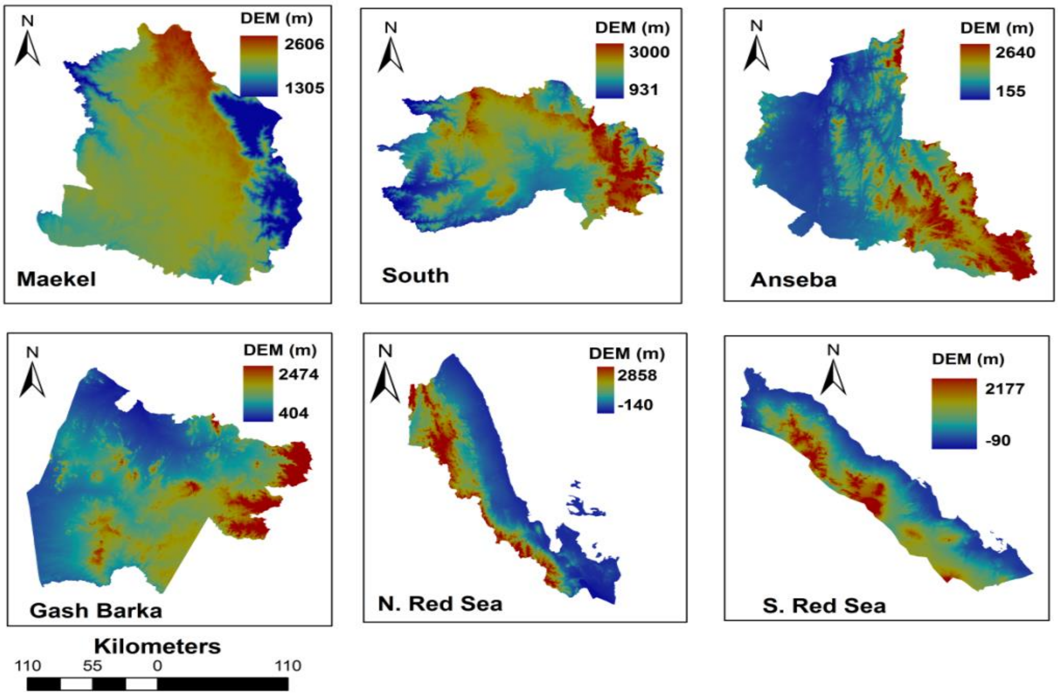

Figure 3. Regional elevation of country.

4.2. Spatial climate assessment

In Eritrea, topography plays a great role to regulate the climate condition. In addition, Eritrea is located within tropics, which has a significant role in the type of climate. Figure 4 displays the spatial distribution of precipitation and temperature in Eritrea. The results revealed that rainfall and temperature showed direct and indirect correlation with altitude, respectively. In this work, the mean annual rainfall and temperature ranged between 504.3 mm and 103.9 mm, and 30.12 and 18 ºC, respectively. However, rainfall varies between lowlands and highlands, and it varies within highlands or lowlands. Generally, it increases from northern highland toward south and from northwester lowland to southwestern lowland. However, the eastern lowland along the coast of Red Sea is characterized by low rainfall because it is the extension of Sahara Desert, which is the largest desert in the world, and has a great influence on the climate condition of the horn of Africa.

Annually, the highland receives the highest rainfall (average about 504 mm) and the eastern lowland around the coastal area receives the lowest rainfall (about 200 mm). Temperature also varies regionally where the lowlands and the highland are characterized by hot and cold temperatures, respectively. The highland has a comfort climate throughout the year. Although the highlands are of the country are considered as the coldest region but it is estimated as suitable area to generate solar energy because it receives direct solar radiation throughout the year. Therefore, both its location and climatic condition show that the country is suitable to develop the solar energy technology. A barrier of solar radiation in Eritrea is very low because it is dominated by lowlands and top flat surface highland. Based on its climate, Eritrea is expected to high potential to generate solar energy throughout the year. However, the escarpments and north facing slopes are expected to have low or moderate SEP because they are away from the direct solar radiation or they are under shadow most of the day.

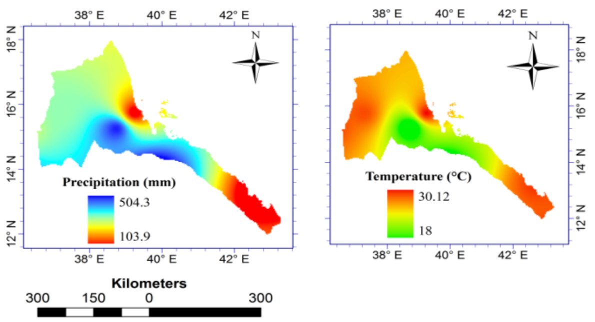

Figure 4. The spatial distribution of precipitation and temperature in Eritrea

4.3. Regional solar energy potential

Figure 5 illustrates the annual variation of solar radiation in each region. The result revealed that due to direct solar radiation, the highest annual solar radiation was recorded in the highland part of Maekel and South Regions, where the annual maximum and minimum GHI ranged (between 2737 kWh/m^2 and 1367 kWh/m^2), and (between 2862 kWh/m^2 and 826 kWh/m^2**)**, respectively. In these regions, a comparatively low GHI was observed in eastern and northern facing aspects and some part of western facing slopes in the South Region due to low angle sunlight and short sunshine hours. Relatively, the lowest solar radiation was detected in the Anseba region (between 2725 kWh/m^2 and 418 kWh/m^2), due to north facing aspects and low sunshine hours. Generally, due to flat surface and free from any sunlight obstacles, the regions located in arid and semi-arid climate (Gash Barka, NRS and SRS) have an adequate solar energy potential, where the annual maximum and minimum GHI fell between 2219 kWh/m^2 and 957 kWh/m^2, 2303 kWh/m^2 and 544 kWh/m^2, and 2192 kWh/m^2 and 991 kWh/m^2, respectively. Generally, the annual average maximum and annual average minimum of GHI ranges between 2506 kWh/m^2 and 850 kWh/m^2, respectively. Thus the above results demonstrate that Eritrea is potentially suitable to generate solar energy and to develop PVs system in any place with the exception of some few places in northern and western aspects, which remain under shadow most of the day.

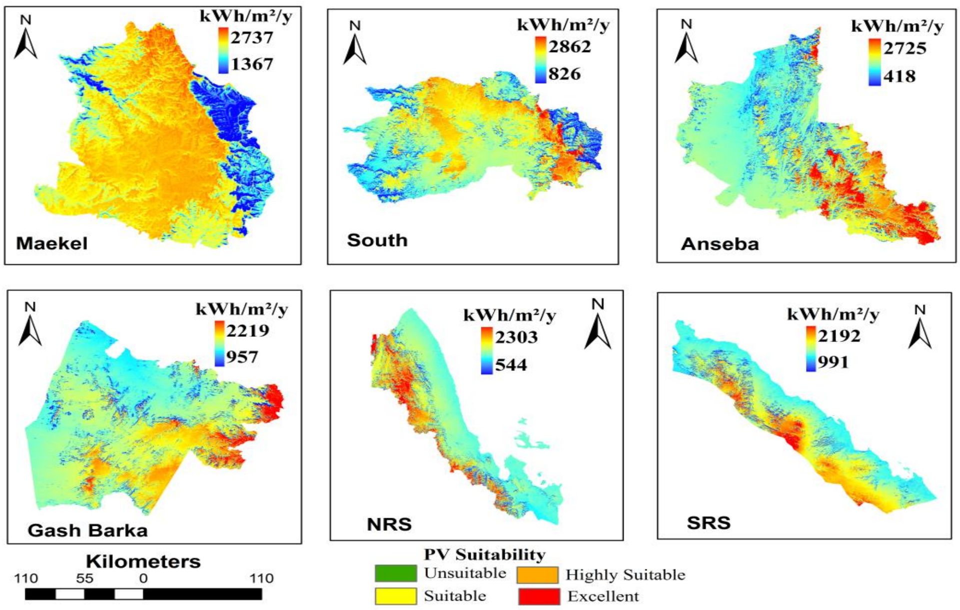

Figure 5. Spatial distribution of solar energy potential in different regions of Eritrea.

4.4. Regional solar energy potential

Figure 6 reveals the SEP suitability in each region. Generally, the results demonstrate that large portion of each region observed as excellent to harvest solar power. The flat highlands of the Maekal and South regions were dominated by excellent SEP. This is due to the solar radiation strikes, directly the flat top surface of the highland plateau. However, the regions away from direct sunshine such as the gentle and steep slopes especially north or west facing hills or mountains within the highland were considered as suitable and unsuitable SEP for developing PVs system, respectively. In addition, the flat lowland surface of the Gash Barka, NRS, and SRS regions, where solar radiation is free from any obstacles is considered as excellent SEP. Meanwhile, highly suitable SEP recorded in the South and Anseba regions due to their rugged topography, and the rough topography of the eastern and north-western facing cliffs of Maekel region was dominated by a suitable SEP. However, the results are insignificant for unsuitable and suitable categories for each region. For instance, the area for unsuitable SEP in Maekel, Gash Barka, NRS, and SRS is not noticeable without magnifying the image. This reveals that Eritrea is generally very suitable to establish the solar energy.

Table 2 explains the suitability index of each category in percentage. In each region, the highly suitable and excellent of SEP has the highest record, while unsuitable and suitable SEP cover a very small percentage. The unsuitable category was only noticed in the South and Ansaba regions, covering approximately 0.001% and 0.023%, respectively. An excellent suitability index was dominant in the Maekel, Gash Barka, NRS, and SRS regions, showing approximately 79.6%, 99.8%, 98.6%, and 99.7%, respectively. However, a highly suitable index was observed in the Anseba and South regions (about 65.56% and 98.08%, respectively). The unsuitable and suitable parts are very small and not significant in all regions. Generally, the average area of the unsuitable and suitable categories of all regions was about 0.005% and 0.007%, respectively, while the average area cover under the highly suitable and excellent categories was 37.2% and 82.8%, respectively.

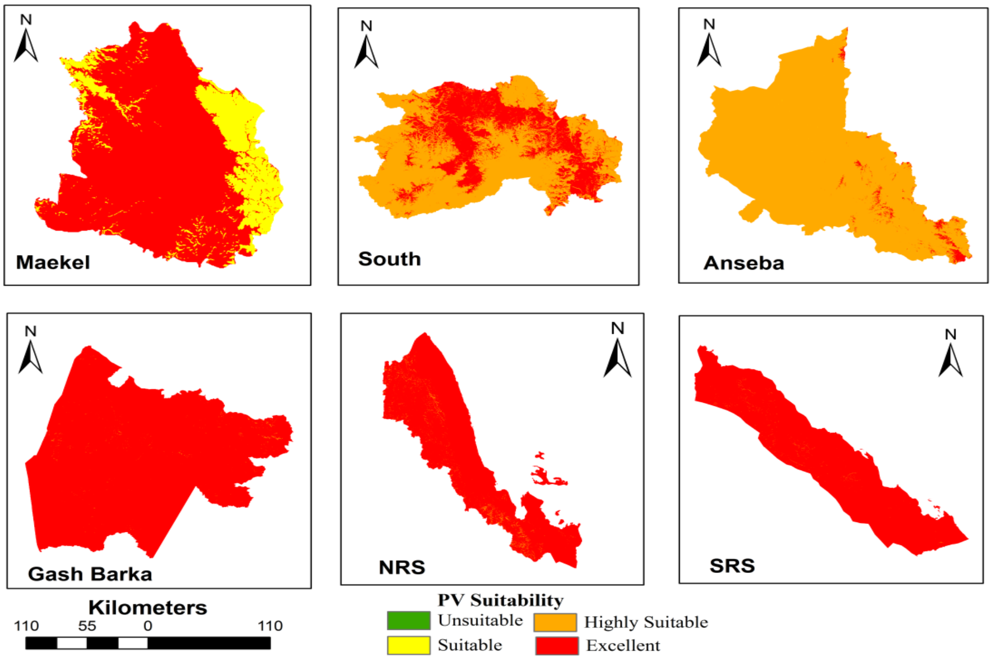

Figure 6. Regional suitability of solar energy potential in Eritrea.

Table 2. Solar energy suitability in percentage for each category.

Suitability	Maekel	South	Anseba	Gash Barka	NRS	SRS	Average
Unsuitable		0.001	0.0232				0.004
Suitable	0.007	0.012	0.014	0.0001	0.00332	0.0001	0.006
Highly suitable	20.34	65.562	98.0873	0.153	1.38	0.25	30.96
Excellent	79.653	34.43	1.8984	99.85	98.62	99.754	69.034

5. Discussion

The amount of solar radiation on the earth's surface varies spatially and temporally, reliant on duration of sunshine hours, angle of radiation that strike the ground, latitudinal location, altitude, topographical features, slope and aspect, and climate variations. This work is consistent with some researchers [7, 9], where Eritrea's physical diversity is significantly observable within a short distance. The highlands that stretch from north to south have various altitudinal variations, characterized by rugged topographical features [26]. According to [20], the highland of Eritrea is characterized by rough terrain and cooler climate than the lowlands. The population density in this area is high, where electricity demand is considerable. The escarpments are found in the eastern and western sides of the highlands. Despite the significant physical diversity observed, Eritrea is entirely found within the tropics and not far from an equatorial location. Thus variations in topography regulate the type of climate [8]. All these variations in location, topography, and climate lead to vary the solar radiation spatially and temporally. For example, [7] has studied the impact of topographic variation on the solar radiation distribution. The effect of topography on solar radiation variation is prominent at the local or regional scale [9, 12]. Since Eritrea is located north of the equator (or northern hemisphere), relatively low solar radiations are recorded along north facing aspects due to the shadowing effect, which correspond to the previous studies [16, 27]. For instance, [7] has stated that the north sloping mountains receive less solar radiation. In addition, the flat surface of highlands and lowland plains are characterized by an excellent amount of solar radiations [5], which is consistent with this work.

Remote sensing data integrating with GIS has a great significance to estimate the solar radiation variation from the local to the global scale [3, 5, 16]. The DEM data is suitable to analyse solar radiation variations in a complex topography [9, 12, 27], which correspond to this research work. In this work, solar radiation vary in Eritrea regionally. The highlands of the Maekel region and the lowlands of the NRS, SRS, and Gash Barka regions are experienced by extremely high solar radiation, while the south and Anseba regions are categorized as highly solar radiation. In addition, with a complex topography, low to medium solar radiation is observed in all regions, particularly in the south and Anseba regions. The DEM model is significant to estimate the amount of solar radiation at different topographical features. For example, [8] has stated the importance of DEM for analysing and estimating the spatial variation of solar radiation. DEM is also suitable to extract the surface slope and aspects [17], where the north facing aspects remain under shadow in most of the year, which is not suitable to generate solar energy, while the south facing slopes are excellent. [12] has stressed the role of DEM to analyse complex topographic variations such as altitude, slope, and aspect, which plays a great significance in the spatio-temporal distribution of solar radiation. [9] has stated similarly the significance of DEM to study the topographic variations and to estimate solar radiation at every topographic point.

Due to the contribution of fossil fuels in some global environmental issues such as environmental degradation and global warming, the solar energy source represents viable alternative to meet the increasing demand of energy in the future [5, 15, 28]. The use of solar energy is growing worldwide [29]. In this case, the solar energy potential (SEP) suitability assessment is significant to regulate the pertinence of the sites for the installation of solar PVs to generate more efficient, clear, and reliable electricity. Estimating the area of suitability index can be suitable for planning implementation in the installation of PVs projects [25]. In this respect, estimation of solar energy suitability for PVs electricity generation in Eritrea is very significant. Eritrea being in tropics has a high potential for PVs development, which is consistent with some previous studies in this region [5]. [16] has identified that the tropical regions have a considerable potential for PVs system such as southern India.

Quantification of the solar energy potential is significant for the PVs or CSP technology development [8]. The SEP suitability for PVs generating system is determined by the amount of solar irradiation and duration of sunshine and also land topography. The amount of solar radiation and duration of sunshine is high in the tropical region [3], and as Eritrea is located in this region, it is expected to have a high rate of solar radiation. In this respect, it has been reported that the local shadowing effects of the terrain due to land slope and aspect play a crucial role in modifying the solar energy potential suitability. Accordingly, the performance of solar PVs system increases generally in the case of flat or gentle slopes [7]; this paper is consistent with the previous studies [5]. In Eritrea, the regions that are located partly or exclusively within the highlands such as Maekel, South, and Anseba show an excellent amount of solar radiation, where the average maximum solar power of three regions is 2775 kWh/m^2/y. However, the regions situated within the lowlands (Ghash Barka, NRS, and SRS) are categorized under a high solar power, where the average maximum solar power of three regions is 2238 kWh/m^2/y. Therefore, the majority of highlands and lowlands are excellent and highly suitable for PV development, which is consistent with previous studies [3, 16].

6. Conclusion

Eritrea, its geographical location within the tropics, and the climatic condition that is characterized by long sunshine hours throughout the year makes it to be suitable for harvesting the solar power. The topographical feature of the country varies regionally including lowlands, highlands, slope and aspect, cliffs, hills, escarpments, and so on. In addition, most of the land surface of the country is dominated by an arid and semi-arid climate; particularly the lowlands are very hot throughout the year. The highlands of Eritrea are also characterized by a flat tope surface that receive direct sunlight. In Eritrea, solar radiation varies regionally due to the topographical and climate variations. The DEM image used in this work was suitable to estimate and map the solar energy potential in Eritrea, where the solar radiation variations were detected in all regions. Based on the suitability index for the PVs system development, approximately 99% of the regions are considered as suitable to generate solar energy. The south and Anseba regions are categorized as a highly suitable index for PVs establishment due to their rugged topographical features and north facing aspects. Moreover, the Maekel region in central highland due to its flat tope surface, and the Gash Barka, NRS, and SRS regions are dominated by lowlands and hot climate are considered as an excellent suitability index to create PVs power. Therefore, Eritrea as a whole receives an adequate insolation for small scale solar power, and most parts of the country are also suitable for a large scale energy establishment.

7. Acknowledgements

This research work was done at the senior project, Department of Geography, College of Business and Social Sciences. The authors also express their thanks for all colleagues for their fruitful efforts and comments to improve the quality, clarity, and structure of this research work.

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