wjert, 2018, Vol. 4, Issue 5, 07-17. *Original Article* ISSN 2454-695X

World Journal of Engineering Research and Technology

WJERT

www.wjert.org SJIF Impact Factor: 5.218

SURVEY OF THE MOST SUITABLE SITE FOR SOLAR STATION IN YOLA, NORTH EASTERN NIGERIA USING LANDSAT-7 ETM+ SATELLITE IMAGE

[1]Hayatu A. A. and [2]*Alkasim, A.

[1]Department of Physics, Adamawa State College of Education Hong, Nigeria.

[2]Department of Physics, Modibbo Adama University of Technology Yola, Nigeria.

Article Received on 21/06/2018 **Article Revised on 12/07/2018** **Article Accepted on 02/08/2018**

***Corresponding Author**
Alkasim, A.
Department of Physics,
Modibbo Adama University
of Technology Yola,
Nigeria.

ABSTRACT

Solar radiation is the key to the optimum performance of any solar/photovoltaic device. Identifying the best site to receive of the solar radiation has been the major difficulties for the users of such devices. This paper finds out the best site for optimal performance of solar devices in Yola metropolis, North eastern Nigeria using ENVI 4.5 software and thermal band 6.2 to estimate solar radiance, surface reflectance and surface temperature, from Landsat-7 Enhanced Thematic Mapper Plus (ETM+). Imagery sensors acquired as a digital number (DN) ranging from 0 – 255 in thermal band, were first converted to radiance values (wm^{-2}sr^{-1} μm^{-1}) using the bias and gain value specific to the individual pixel, then the radiance was converted to surface reflectance and eventually to surface temperature in (Kelvin). This study reveals the most suitable site for solar station in Yola and these areas are suggested based on the solar parameters during the dry and rainy seasons within the period of study, the areas identified with their locations are: Karewa GRA Extension (9^{o}14’39.93”N, 12^{o}27’3.44”E), Around the Yola International Hotel (9^{o}16’06.93”N, 12^{o}28’07.55”E), FCE Academic Area (9^{o}15’12.39”N, 12^{o}28’21.34”E), Jambutu Motor Pack (9^{o}17’5.19”N, 2^{o}25’25.43”E), Along Airport Road (9^{o}15’57.99”N, 12^{o}25’55.99”E), AUN Administrative Block (9^{o}11’57.71”N, 12^{o}30’05.46”E), Police Roundabout (9^{o}15’31.18”N, 12^{o}27’23.43”E) and Gate II Jimeta Modern Market (9^{o}14’54.78”N, 12^{o}26’58.28”E).

KEYWORDS: Solar Station, Satellite Images Radiance, Surface Reflectance and Temperature.

INTRODUCTION

The idea of solar energy available in a location not only by means of its personation but by the aggregate value, but also its worldly separation, spectral distribution, and nature (direct or diffuse). Most countries have put up networks for measuring solar radiation but investments and control costs for each site are somewhat high (Rigo and Parlow, 1994).

Every second the sun radiates more energy than people have used since the beginning of time. The amount of solar energy reaching earth is 1.76 x 1017 J/s; more than 10000 times the global energy consumption today. Still this enormous source of energy accounts for only 0.1% of the total consumption, whereas 77% comes from fossil fuels (Dagestad, 2005). The reasons for the low exploitation rate of solar energy are that it is difficult to collect since it is spread over the whole earth, and difficult to predict since it is fluctuating in time and space. To increase the efficiency of solar power plants a detailed knowledge of the spatial and temporal variation of solar irradiance is needed. Such climatology can be made by interpolating between measurement stations, as has been done in e.g. the European Solar Radiation Atlas, ESRA (Dagestad, 2005). However, low spatial and temporal resolution of such data has led to non-optimal site selection and incorrect system sizing, and thus unnecessary use of conventional energy source.

Satellite can be defined as a strong transmitter with transponders positioned streamline in the orbit. They amplify and separate signals. Unlike wireless ground repeaters which relay signals between two known positions; satellite interconnect many locations and positions, both stationary and dynamic over a wide range of area. It receives microwave signals from source on the earth in a given frequency band (uplink) and retransmits them at a different frequency to earth stations (downlink) (Nishida *et al.*, 2000).There are several satellite systems in operation today that collect imagery that is subsequently distributed to users. Several of the most common systems are; SPOT, LANDSAT and MODIS. Each type of satellite data offers specific characteristics that make it more or less appropriate for a particular application. And for this research Landsat was choose because of its multispectral sensors.

Satellite data are very useful in various applications like, astronomy, atmospheric studies, earth observation, communications, navigation, search and rescue (Prasad *et al.*, 2013). Land surface temperature is an important parameter in the field of atmospheric sciences as it combines the result of all surface-atmosphere interaction and energy fluxes between the ground and the atmosphere and is, therefore, a good indicator of the energy balance at the Earth's surface (Prasad *et al.,* 2013). Surface temperature controls the surface heat and water exchange with the atmosphere which affects climatic change in the region.

It is very important to know the site depended solar parameters available and the patterns of its seasonal availability, variability of irradiation, and surface temperature on site. Due to significant inter-annual variability of weather conditions across a year, such measurements must be generated over the two seasons within a year. The fact that the number of meteorological stations is insufficient in Nigeria particularly, Yola constitute limitation in obtaining solar parameters data from such regions. Thus, these limitations motivated researchers toward a tendency to develop alternative estimation methods to find more reliable data sources. In recent years, satellite-based techniques are widely used as an accurate method and as data source for solar parameters estimations. One of the most important advantages of satellite is that it is a reliable and fast for obtaining up-to-date and continuous information about large geographical areas. In addition to this, satellite provides opportunity to perform solar parameters estimations in rural, mountainous, cities and remote places where meteorological stations are insufficient or not available.

This study surveys the most suitable sites for solar station in Yola, northeastern Nigeria using Landsat-7 ETM+ satellite images for efficient performance of solar station. Knowledge of the solar parameters is needed for many environmental studies such as, radiative transfer studies, soil conditions and so on which are very important for agricultural activities (Khondokar *et al.,* 2010). It can also provide important information about the land surface physical properties and climate which play roles in many environmental processes. Many methods have been devised by researchers in estimating solar parameters for both urban and rural areas using data of ground based meteorological stations. These methods take a long processing time and need many meteorological parameters.

Determination of solar parameters using data of space based (satellite) sensors is expected to be a better alternative to the ground based methods. The advantages of using remotely sensed data are the availability of high resolution, consistent and repetitive coverage and capability of measurements of earth surface conditions (Khondokar *et al.*, 2010).

Landsat, Enhanced Thematic Mapper Plus (ETM+) data is composed in a unit of scene with a size of 200 by 200 Km. each scene is coded with path number and row number, based on what is called World Reference System (WRS). Image data are recorded with respect to each pixel with a numerical value (DN) of 8-bits (0-255) (Khondokar *et al*., 2010).

METHODOLOGY

Study area

The study area, Yola is the capital city and administrative center of Adamawa State, Nigeria. The city is made up of two parts the old and new Yola. Jimeta (new Yola) is about 5 km North West of the old Yola. Geographically Yola is located between latitudes $9^0$11'N to $9^0$20'N and longitudes $12^0$23'E to $12^0$33'E and covers an area of about 305 km^2. The area has a mean annual rainfall of 919 mm, monthly minimum temperature of 19^0C and maximum temperature of 37.9^0C. The mean monthly temperature is 28.5^0C. While the annual average relative humidity is 85%. The study area is characterized by broadly flat topography with gentle undulations and hill ranges (Ishaku, 2011), and is largely drained by the Benue River.

According to the 2010 National Population Commission, The population of the study area is about 336648. The area is in boundary internationally with republic of Cameroon due to East and within the country Gombe, Borno and Taraba States to the North, North East and West respectively.

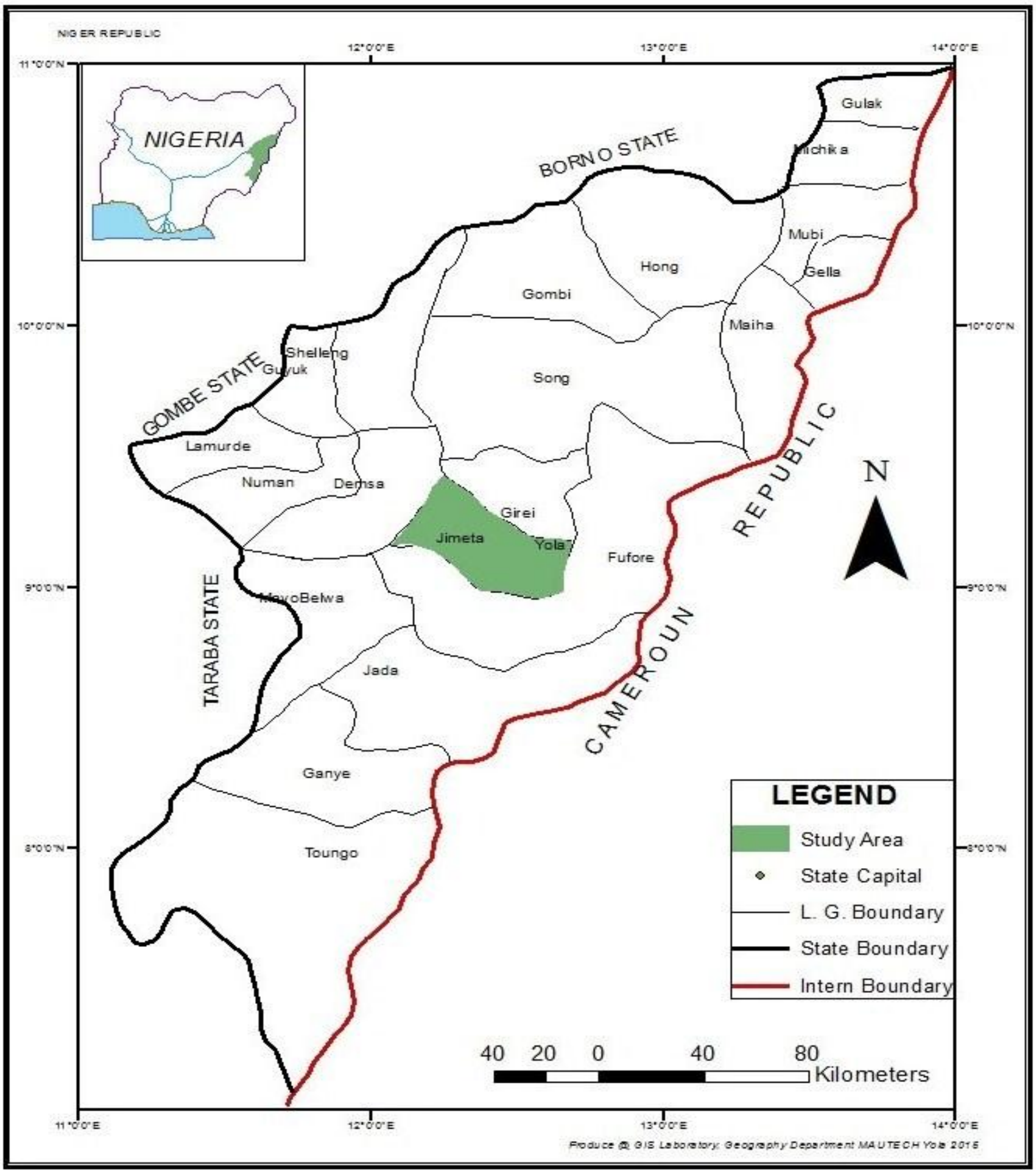

Figure 1: Map of Adamawa State Showing Geopolitical Boundaries of the Study Area.

Data Processing

The DNs were converted to radiance values using the bias and gain values specific to the individual pixel and radiance values to surface reflectance, and eventually to surface temperature in Kelvin the effective at-sensor brightness temperature is obtained from the spectral radiance using Plank's inverse function. The surface emissivity is used to retrieve the final Surface Temperature. The steps were processed using ENVI 4.5 software in a computer system.

Conversion of Digital Number (DN) to Spectral Radiance

The landsat-7 ETM+ thermal data was converted to spectral radiance using an equation

$L_\lambda = Gain \times DN + Bias$ (Arvidson, 2002). (1)

Where: L_λ = spectral radiance measured over spectral bandwidth of a channel, DN = digital number value recorded and

$Gain = \left(\frac{L_{Max} - L_{Min}}{255}\right)$ = Slope of response function (Javed *et al.*, 2008) (2)

L_{Max} = radiance measured at detector saturation in ($Wm^{-2}sr^{-1}\mu m$); L_{Min} = Bias = lowest radiance measured by detector in ($Wm^{-2}sr^{-1}\mu m$), it is determined as the intercept of the response function.

Table 1: L_{Max} and L_{Min} values of Landsat data.

Band No.	**Satellite/Sensor**	L_{Max} **($Wm^{-2}sr^{-1}\mu m$)**	L_{Min} **($Wm^{-2}sr^{-1}\mu m$)**
6.1	Landsat7 / ETM+ Low	17.04	00.00
6.2	Landsat7 / ETM+ High	12.65	03.20

(***Source***:NASA Landsat-7 Hand book, 2001)

Conversion of Radiance to Surface Temperature

The solar radiances (L_λ) will be converted into Effective satellite temperatures T(a) in Kelvin using equation (3) (Wukelic *et al.*, 1989).

$$T(a) = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (3)$$

Where K_1 is First calibration constant in $Wm^{-2}sr^{-1}\mu m^{-1}$, K_2 is the Second calibration constant in Kelvin, and L_λ the Spectral radiance $Wm^{-2}sr^{-1}\mu m^{-1}$.

For Landsat ETM+, NASA handbook gives the values for K_1 = 666.09 Wm^{-2} sr^{-1} μm^{-1} and K_2 = 1282.71 K respectively. The values were also given in the header information of the thermal bands. Then, corrections for emissivity (ε) were applied to the radiant temperatures according to the nature of land cover. The emissivity corrected surface temperature can be computed as follows (Qin *et al.*, 2001):

$$T_S = \frac{T(a)}{\left(L + \frac{T(a)}{b}\right)\ln\varepsilon} \quad (4)$$

Where L is the wavelength of emitted radiance (for which the peak response average of the limiting wavelengths of 11.5 mm) was used (Markham and Barker, 1985),

$$b = \frac{hc}{k_B} = 1.438 \times 10^{-2}\, mK \quad (5)$$

Where k_B is the Stefan Boltzmann's constant, h the Planck's constant and c is velocity of light.

RESULTS AND DISCUSSION

The results for the radiance, surface reflectance and surface temperature during the two different seasons in the study areas are as presented in Tables 2 – 4. The aero map of the identified locations is presented in figure 2.

Table 2: The mean Radiance for the locations for both dry and rainy seasons.

Place	Dry Season Radiance ($wm^{-2}sr^{-1}\,\mu m^{-1}$)	Rainy Season Radiance ($wm^{-2}sr^{-1}\,\mu m^{-1}$)	Coordinates
Karewa GRA Extension	10.5	9.8	9°14'39.93"N, 12°27'3.44"E
Near International Hotel	11.2	9.7	9°16'06.93"N, 12°28'07.55"E
FCE Academic Area	10.9	10.1	9°15'12.39"N, 12°28'21.34"E
Jambutu Motor Pack	11.9	9.2	9°17'5.19"N, 12°25'25.43"E
Along Airport Road	11.7	8.7	9°15'57.99"N, 12°25'55.99"E
AUN Administrative Block	12.1	9.5	9°11'57.71"N, 12°30'05.46"E
Police Roundabout	11.4	8.9	9°15'31.18"N, 12°27'23.43"E
Gate II Jimeta Modern Market	12.8	9.7	9°14'54.78"N, 12°26'58.28"E

Table 3: The mean Surface Reflectance for the locations for both dry and rainy seasons.

Place	Dry Season Surface Reflectance	Rainy Season Surface Reflectance	Coordinates
Karewa GRA Extension	0.41	0.39	9°14'39.93"N, 12°27'3.44"E
Yola International Hotel	0.46	0.42	9°16'06.93"N, 12°28'07.55"E
FCE Academic Area	0.49	0.45	9°15'12.39"N, 12°28'21.34"E
Jambutu Motor Pack	0.52	0.47	9°17'5.19"N, 12°25'25.43"E
Along Airport Road	0.48	0.45	9°15'57.99"N, 12°25'55.99"E
AUN Administrative Block	0.43	0.38	9°11'57.71"N, 12°30'05.46"E
Police Roundabout	0.47	0.44	9°15'31.18"N, 12°27'23.43"E
Gate II Jimeta Modern Market	0.53	0.48	9°14'54.78"N, 12°26'58.28"E

Table 4: The converted mean Temperature for the locations in both dry and rainy season.

Place	Dry season Temperature (K)	Rainy Season Temperature (K)	Coordinates
Karewa GRA Extension	300.4	294.6	9°14'39.93"N, 12°27'3.44"E
Yola International Hotel	309.1	299.0	9°16'06.93"N, 12°28'07.55"E
FCE Academic Area	310.8	301.2	9°15'12.39"N, 12°28'21.34"E
Jambutu Motor Pack	302.1	297.2	9°17'5.19"N, 12°25'25.43"E
Along Airport Road	307.5	301.7	9°15'57.99"N, 12°25'55.99"E
AUN Admin Block	311.8	303.0	9°11'57.71"N, 12°30'05.46"E
Police Roundabout	308.7	299.5	9°15'31.18"N, 12°27'23.43"E
Gate II Jimeta Modern Market	312.9	307.8	9°14'54.78"N, 12°26'58.28"E

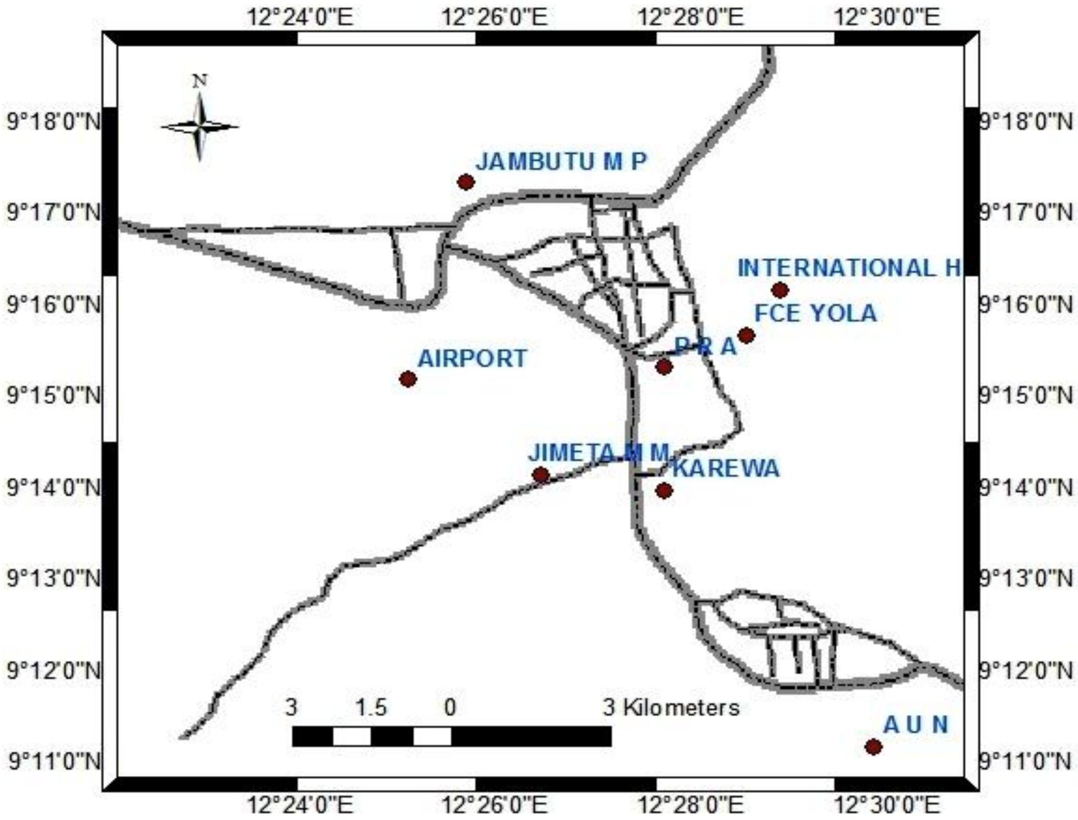

Figure 2: Arial map indicating the most suitable sites for citing solar station in Yola.

The mean Solar Radiance during the dry seasons was somewhat greater than that of the rainy seasons (Alkasim et al 2011), from table 2 it can be observed that the solar radiance for all locations ranges between (8.7 to 12.8) $Wm^{-2}sr^{-1}\mu m^{-1}$ for both Dry and Rainy seasons indicating that they all possesses the potentials for citing solar panels for any solar thermal appliance.

Surface reflectance values were presented in table 3. The range of values is 0.39 to 0.53 which according to Wukelie *et al*., 1989, is a good condition for citing solar photovoltaic station. The temperature range as presented in table 4 is 294K – 312.9K for both seasons which is quite above 200K, the average value required for any solar station (Nishida *et al*., 2000).

The map in fig.2 indicated the identified areas suitable for the citation of any solar station in and around Yola. It can be estimated that the area identified by this research are within the area covered by (9^o 11’0” N – 9^o18’0”N longitude) and (12^o24’0”E – 12^o30’0” Latitude).

CONCLUSION

It can be concluded that the best method to estimate solar radiance, surface reflectance and surface temperature is by using satellite images data. From this pattern of study, it is seen that the solar radiance, surface reflectance and surface temperature varies with the different season throughout the year. Maximum values are obtained in the dry season while minimum values in the rainy season. The methodology adopted by this study can be applied in any topographic and climatic conditions of an area, owing to the fact that this procedure is maintained by using landsat-7 ETM + satellite images.

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