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BASIC REQUIREMENTS OF USING KRIGING INTERPOLATION METHOD FOR CONSTRUCTION OF CLEARNESS INDEX CONTOUR MAPS: A CASE STUDY OF SIX SELECTED TROPICAL STATIONS IN SOUTH-WESTERN, NIGERIA

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Abstract

Clearness index map can be described as a two dimensional representation of three dimensional data inform of contour. In this study, kriging Technique was adopted in the construction of clearness index maps for some selected tropical stations in the South western, Nigeria. Characterization of solar radiation was carried out to assess the feasibility of solar renewable energy utilization in the region. Clearness index, diffuse ratio and diffuse co-efficient are computed from the acquired data of global solar radiation, maximum and minimum temperature, and relative humidity obtained from the satellite-derived data from National Aeronautic and space Administration (NASA). A characterization of the sky conditions over the stations based on the calculated clearness index kT values for the eleven years (January, 1995 – December, 2005) were presented. All monthly irradiance data given as mean monthly radiation are transformed into monthly clearness index values through the application of kriging technique. Finally, the monthly mean clearness index contour maps were equally constructed for the stations for selected years using kriging interpolation method as presented by Beryer et al, 1997. The results revealed that the values of global solar radiation computed vary from 12.248 – 20.844 MJm-2day-1 in Abeokuta, 12.880 – 21.744 MJm-2day-1 in Ado Ekiti , 12.064 - 21.888 MJm-2day-1 in Akure, 12.600 – 19.224 MJm-2day-1 in Ikeja , 12.960 – 22.916 MJm-2day-1 in Ogbomoso and 12.420 – 21.276 MJm-2day-1 in Osogbo. The results revealed that the clearness index varies with the geographical location and period of the year. The implications of these results on the effective utilization of solar energy are discussed. The results in this study serve as very useful information for engineers and other renewable energy technologists in the process of designing and estimation of performance of solar application systems.

Key words: *kriging Technique, Solar radiation, Clearness index, Diffuse ratio, Diffuse co-efficient, clearness index maps..*

INTRODUCTION

Solar radiation received at the earth's surface under different atmospheric conditions may have great effects on the quality and amount of radiation obtained at the ground during the course of the day. Solar radiation at the earth's surface is essential for the development and utilization of solar energy. It is needed for designing collectors for the solar heater and other photovoltaic equipment that depend on solar energy. Knowledge of the global solar radiation is of fundamental importance for all solar energy conversion systems. The transparency of the atmosphere is indicated by fraction of Extraterrestrial radiation that reaches the earth's surface as global radiation. It is measure of the degree of clearness of the sky (Akhlaque et al. 2009.). in the quest for exploitation of the vast energy of the sun, basic technologies in design, development and application of solar energy collection and conversion systems are required. The performance evaluation of such energy conversion systems as claimed in above require relevant information on the periodic variation and distribution of the amount solar energy received at a particular location. The separation of solar irradiance into the various components is also necessary for a wide range of these solar engineering tasks (Iqbal, 1983). According to Okogbue et al. (2009), the knowledge of the distribution of the diffuse fraction of solar radiation (the ratio of the diffuse solar radiation to the global solar radiation) is particularly required in assessing the climatological potential of a locality for solar energy utilization and in estimating the expected values of the output of concentrating solar collectors (Iziomon and Aro (1998).

Kriging is a geostatistical gridding method that has proven useful and popular in many fields. This method produces visually appealing contour and surface plots

Figure 1: showing map of the selected locations.

from irregularly spaced data.

Kriging can be either an exact interpolator or a smoothing interpolator depending on the user specified parameters.

Therefore, a contour map is a two-dimensional representation of three dimensional data. Different gridding methods can have different results when interpreting data. Kriging technique is the best gridding method that produces the map that best represents the available data in this study because it interpolate into other locations with no data, but with similar climatic and geographic characteristics. Kriging. In general, this is the method that is most recommend due to its advantages over other available methods. Kriging is the default gridding method because it generates the best overall interpretation of most data sets.

Notable researchers that have carried out studies in generation of radiation contour maps using other methods for the purpose of mapping solar energy potentials and study sky conditions in Nigeria are Falayi and Rabiu, (2011); Oyedepo (2011); Okogbue et al (2002, 2009); Ojosu (1989); Augustine and Nnabuchi (2009); Ezekwe (1981) ; Dike et al (2011) and Abur and Duvuna (2014).

Therefore, evaluating the renewable energy resources in the locations through clearness index mapping is justifiable cause of this study. The aim of the study is to present and use kriging technique to construct clearness index maps for solar radiation with the objectives of determining the areas that have prospective solar energy potential that could be harnessed.

MATERIALS AND METHODS.

in this study , kriging technique was presented and adopted to construct clearness index contour maps for solar radiation for the elected locations. For generation of these maps, satellite-derived data was used in an interpolation/merging process to derive maps of long-term monthly global radiation that cover an area ranging from 03˚ 19′ E to 04˚ 42′ E and from 07˚ 03′ N to 08˚ 01′ N.

The materials required for this study are the Satellite-derived data on solar radiation, relative humidity, minimum and maximum temperature which are adopted from the Atmospheric center data of National Aeronautic and Space Administration and National Space and Development Agency, Abuja. The data obtained covered a period of eleven (11) years, from January 1995 to December, 2005 for six locations in South western Nigeria.

In the process of data treatment, the global solar radiation data measured in $KWm^{-2}day^{-1}$ was converted to $MJm^{-2}day^{-1}$ using a factor of 3.6 (according to Igbal 1983.).

Solar radiation data were presented in dimensionless form as the ratio of global irradiance (H) to extraterrestrial radiation (H_0) . Then the clearness index could be expressed as:

$$K_T = \frac{H}{H_0} \quad \text{.............................. 1}$$

Where K_T is the clearness index, which is a measure of the availability of solar radiation or the transmissivity of the atmosphere.

$$K_d^1 = \frac{H_d}{H} \quad \text{and} \quad K_d = \frac{H_d}{H_0} \quad \text{..................... 2 (a \& b)}$$

Where K_d^1 and K_d represent the diffuse ratio and diffuse co-efficient respectively, which are transmission characteristics of diffuse radiation and hence mirror the effectiveness of the sky in transmitting diffuse solar radiation.

In this study, simple model of the Supit and Van Kappel (1998) was adopted to estimate the monthly mean of daily total terrestrial solar radiation falling on horizontal surface at a particular location. According to Supit and Van Kappel (1998),

$$H = H_0\left[\sqrt[a]{(T_{max} - T_{min})} + \sqrt[b]{(1 - C_w/8)}\right] + c \text{........... 3}$$

Where C_w is the mean of the total cloud cover of the daytime observation in percents, tenths, or in eight of the sky covered by cloud, T_{max} and Tmin are maximum and minimum temperature. H_0 is the monthly mean of daily total extraterrestrial solar radiation on horizontal surface in the absence of atmosphere while a, b and c are empirical constants.

$$H_0 = \frac{24 \times 3600}{\pi} G_{sc}\left(1 + 0.033Cos\frac{360n}{365}\right)\left(Cos\emptyset Cos\delta Sin\,\omega_s + \frac{2\pi\omega_s}{360} Sin\emptyset Sin\delta\right) \quad \text{.... 4}$$

Where H_0 is the monthly mean daily extraterrestrial radiation in MJm^{-2} , G_{sc} is the solar constant with a value

Table 1: Geographical Co-ordinates of the selected Locations.

S/No	Location	Latitude	Longitude	Altitude (metres)
1	Abeokuta	07˚ 03′ N	03˚ 19′ E	104.1
2	Ado Ekiti	07˚ 38′ N	05˚ 12′ E	541.0
3	Akure	07˚ 15′ N	05˚ 05′ E	353.0
4	Lagos	06˚ 25′ N	03˚ 27′ E	34.0
5	Ogbomoso	08˚ 01′ N	04˚ 11′ E	341.0
6	Osogbo	07˚ 48′ N	04˚ 42′ E	318.0

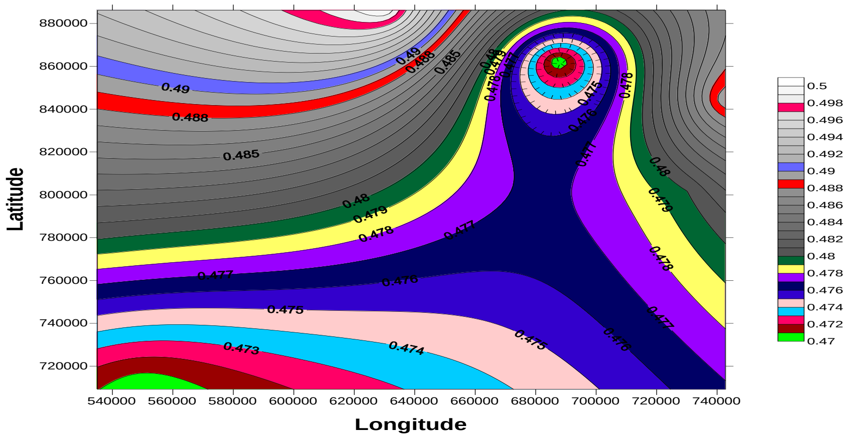

Figure 2: Monthly mean clearness index map for the selected locations (1997)

1367W/m^2 while w_s is the sunset hour angle for the typical day n for each month in degrees, then

$$\omega_s = Cos^{-1}(-tan\theta tan\delta) \text{ .... } 5$$

θ is the Latitude angle for the location in degrees

δ is the declination angle for the month in degree and n is the mean day of each month and

$$\delta = 23.45\, Sin\left[360\left(\frac{284+n}{365}\right)\right] \text{ .... } 6.$$

RESULTS AND DISCUSSION.

This aspect attempts to discuss the basic procedure required to generate contour maps in the selected locations based on the available solar radiation data and computed clearness index parameter of previous years. In the process of clearness index contour maps generation, the following relevant information are very pertinent for each location. These are;

- Geographical location of the place, in respect to its longitude and latitude,
- Altitude (the place height above the sea level),
- Associated data such as global, diffuse and direct solar radiation on the horizontal surface,
- Available clearness index for previous years.

There is need for generating the maps for concise and proper interpretation of the availability of solar radiation at the locations for solar energy utilization and efficiency. All monthly irradiance data given as mean monthly radiation sum are transformed into monthly clearness index values through the application of interpolation technique (Beryer et al, 1997, Goovaerts, 1999). Out of series of these techniques, Kriging method was adopted because in application, it uses trend in the map to extrapolate into areas without data. To adopt kriging method in generation of clearness index contour maps, some pre-treatment of the available data were necessary. Clearness index data sets were subjected to time-series analysis in order to identify the nature of the variability of the solar radiation over the locations under study. This serves as very useful information to study the potential applicability of solar energy utilization and optimal design for effective prediction of the system performance. The contour maps for monthly mean clearness index maps for the stations for specific years such as, 1999, 2001, and 2003 were displayed. According to Okogbue et al. (2009) claim that large clearness index means high global solar radiation, which is dominated by the direct component. The adopted software programme will not accept the units of Longitude and Latitude as degree and minutes, for conformity, the units were converted to Universal Transverse Mercator (UTM). The plotted monthly mean clearness index maps for selected years were displayed in figures 2 to 6 below.

Latitudinal variations of clearness index with high

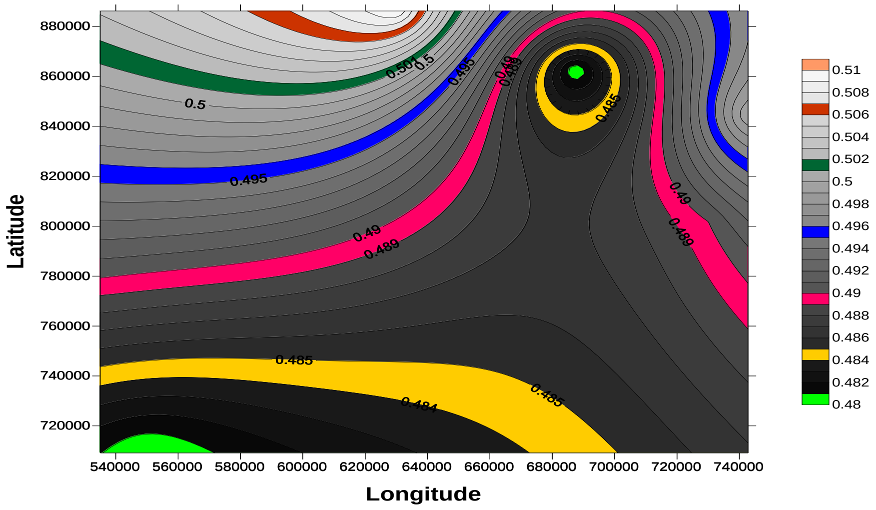

Figure 3: Monthly mean clearness index map for the selected locations (1999)

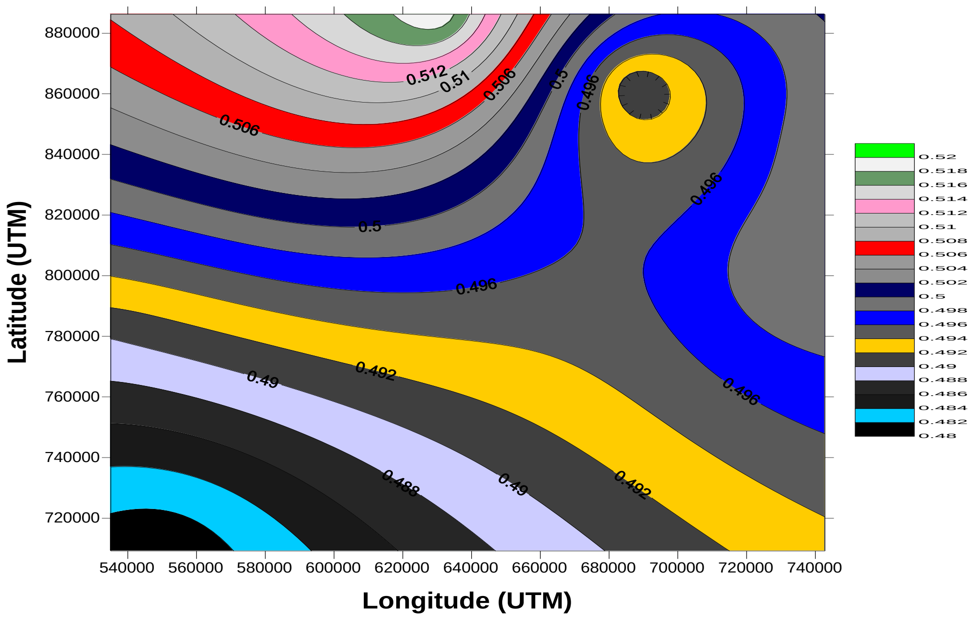

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Figure 4: Monthly mean clearness index map for the selected locations (2001)

values at Ogbomoso, Akure and Ado Ekiti. The trends of variation patterns are consistent with high values during the dry period and low values during the raining season except in Ikeja and Abeokuta with bimodal distribution in the clearness index, global and diffuse solar radiation values . The results were consistent with those found by Okogbue et al (2002); Beryer et al, (1997); Okogbue and Adedokun, (2009); Chukwuemeka and Nnabuchi, (2009) and Falayi and Rabiu, (2011).

It was generally observed that the global solar radiation increases with latitude. This implies that the locations near the coast are characterized by low values of solar radiation, these values declining with distance from the coast. Clearness index were consistent for the locations under study, the values range between 0.35 and 0.58 which was in good agreement as predicted by Falayi and Rabiu (2011). Clearness index increased to about 0.612 in the months of January and December for Ogbomoso, Akure and ado Ekiti. The information serves as useful hints for designers of solar energy devices. The results revealed that the values of global solar radiation computed vary from 12.248 – 20.844 $MJm^{-2}day^{-1}$ in Abeokuta, 12.880 – 21.744 $MJm^{-2}day^{-1}$ in Ado Ekiti , 12.064 - 21.888 $MJm^{-2}day^{-1}$ in Akure, 12.600 – 19.224 $MJm^{-2}day^{-1}$ in Ikeja , 12.960 – 22.916 $MJm^{-2}day^{-1}$ in Ogbomoso and 12.420 – 21.276 $MJm^{-2}day^{-1}$ in

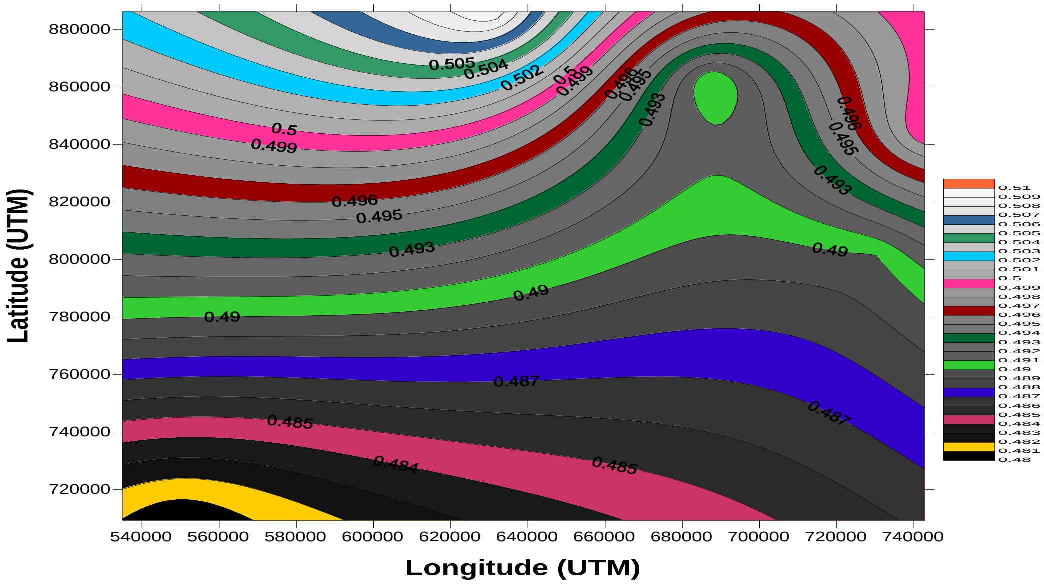

Figure 5: Monthly mean clearness index map for the selected locations (2003)

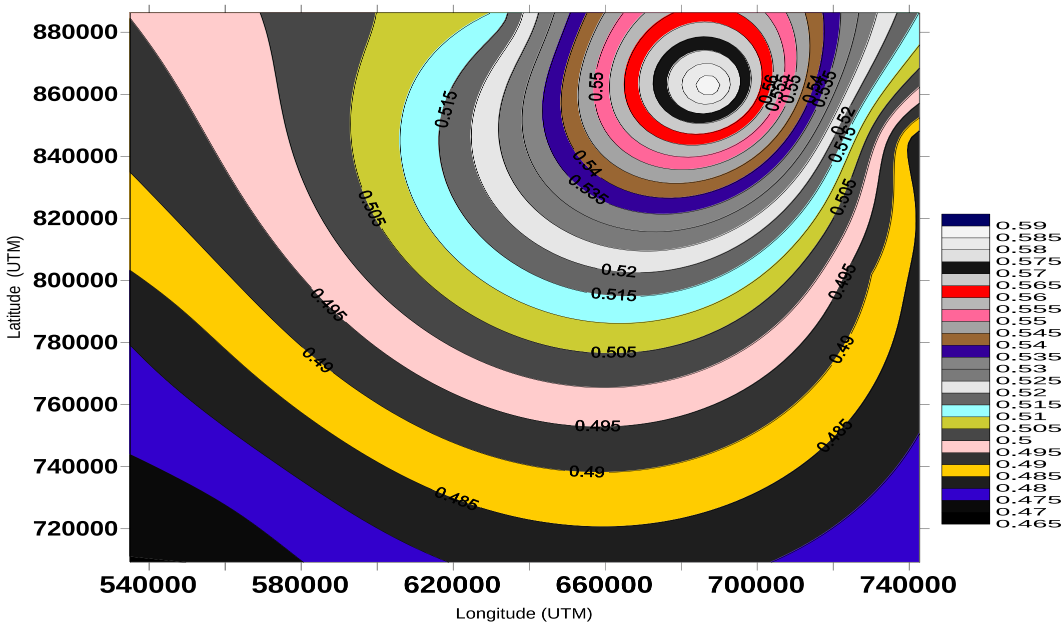

Figure 6: Monthly mean clearness index map for the selected stations (2004)

Osogbo. The results revealed that the clearness index varies with the geographical location and period of the year. The sky is very clear over Akure, Ado Ekiti, Ogbomoso and Osogbo throughout the year except in June to August.

CONCLUSION.

Kriging technique is the best gridding method that produces the map that best represents the available data because it interpolate into other locations with no data, but with similar climatic and geographic characteristics.

With the trends of the solar radiation available in these locations, solar energy utilization has a bright prospect in these locations but in Abeokuta and Ikeja, the available global solar radiation and its trends of variation may not support the solar energy devices throughout the year.

The results in this study serve as very useful information for engineers and other renewable energy technologists in the process of designing and estimation of performance of solar application systems.

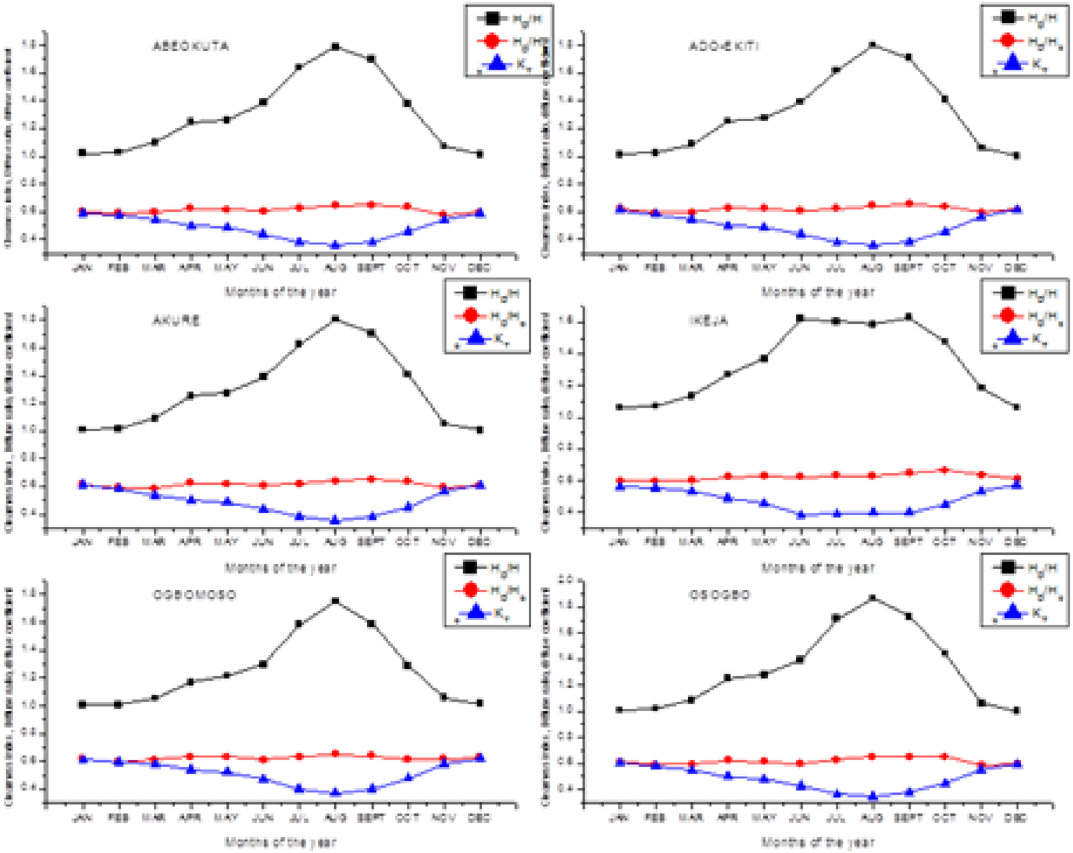

Figure 7: Plot of monthly averages of clearness index K_T, diffuse ratio H_D/H and diffuse co-efficient H_D/H_0 over the selected locations for the period 1995 – 2005.

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