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Technical note

Monthly average daily global solar irradiation maps for Uganda: A location in the equatorial region

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ABSTRACT

Proper sizing of solar energy systems is necessary in order to optimize their output. This requires a database of solar irradiation for locations for which the systems are being assessed. Solar irradiation data is also required in modeling a building's thermal performance, as input into ecological and crop models and evaluation of long-term effects of climatological changes. Solar irradiation data can be provided through measurements. In Uganda, measurements of global solar irradiation have been carried out for a few locations because the measuring instruments are expensive to purchase and install. An alternative to obtaining solar irradiation data is to estimate it either by use of an appropriate solar irradiation model or interpolation of the few existing records. The present study attempted to draw global solar irradiation maps for Uganda. Global solar irradiation values were estimated for eight out of twelve stations using an artificial neural networks model proposed for Uganda. Measured values of monthly average daily global solar irradiation were used for the remaining four stations. The values for the twelve stations were then utilized for the interpolation using moving average method. The result is a set of twelve global solar irradiation maps for Uganda with relative errors in the range of 8%–16%.

1. Introduction

Solar irradiation data is required in assessing performance of solar energy systems. This data may not be readily available in places where the assessment is to be carried out. The obvious and more accurate method for providing the solar irradiation data would be to measure it by installing measuring equipment in places of interest. However the equipment is expensive to buy and maintain and can only be installed in a few places. In the absence of measured data, estimates can be made using solar irradiation models appropriate for the location. Estimated solar irradiation values for some locations together with the existing measured data can be used to interpolate, to obtain solar irradiation maps. Interpolation exploits the spatial feature of solar irradiation. Solar irradiation maps have been drawn for many regions in the World and some examples can be found in references [1–4].

Suckling [5] interpolated global solar radiation values over distances of 100 km for locations where no data existed. He reported relative errors of 33% and 48% during summer and winter, respectively. Zelenka et al. [6] interpolated global solar radiation values for Switzerland and north-eastern USA using kriging and inverse-distance-squared weighting techniques. They reported similar error values from both techniques. Other evaluations of interpolations in solar irradiation networks have been carried out by other authors [7–9].

Mubiru et al. [10] investigated the performance of five interpolation methods in Uganda which included: Nearest Point, Moving Average, Moving Surface, Trend Surface and Ordinary Kriging. Results showed that the Moving Average linear decrease was the most appropriate for interpolating global solar irradiation in Uganda. The corresponding normalized mean bias error and root mean square error were 0.035 and 0.078, respectively. In a Moving Average operation, output values are weighted averages of input point values. Output values are calculated using Eq. (1.1) [11]

$$\hat{z}_0 = \sum_{i=1}^{n} w_i z_i / \sum_{i=1}^{n} w_i \quad (1.1)$$

where w_i is the weight, z_i is the actual value at an ith station and n is the number of surrounding stations.

Linear decrease and inverse distance are two forms of the weight function. We used the linear decrease function which is represented by Eq. (1.2).

$$w_i = 1 - \left(D_{(0,i)}\right)^p \quad (1.2)$$

where p is an integer weight exponent and $1 \le p \le 6$.

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Table 1
Meteorological stations in Uganda.

	Station	Latitude	Longitude (deg. East)	Altitude (m)
1	[a]Mbarara	−0.62	30.65	1413
2	[a]Lira	2.28	32.93	1189
3	[a]Tororo	0.68	34.17	1170
4	[a]Kampala	0.32	32.58	1220
5	Arua	3.05	30.92	1280
6	Masindi	1.68	31.72	1147
7	Kasese	0.18	30.10	959
8	Entebbe	0.05	32.45	1155
9	Jinja	0.45	33.18	1175
10	Gulu	2.78	32.28	1105
11	Soroti	1.72	33.62	1132
12	Kabale	−1.25	29.98	1869

[a] Measurement study site.

The relative distance, $D_{(0,i)}$ is defined by Eq. (1.3).

$$D_{(0,i)} = (D_i/D_0) \tag{1.3}$$

where D_i is an Euclidean distance of the ith station to an interpolated point and D_0 is a limiting distance.

The inverse distance function is represented by Eq. (1.4).

$$w_i = 1/\left(D_{(0,i)}\right)^p - 1 \tag{1.4}$$

The pool of data containing both measured and estimated values were used with the purpose of drawing a complete set of monthly solar irradiation maps for Uganda, a country located in the Equatorial zone.

2. Data and experimental procedure

Uganda lies between latitudes 01°30′S and 04°00′N, and longitudes 29°30′E and 35°00′E. It covers an area of 241,500 km^2, 15.3%

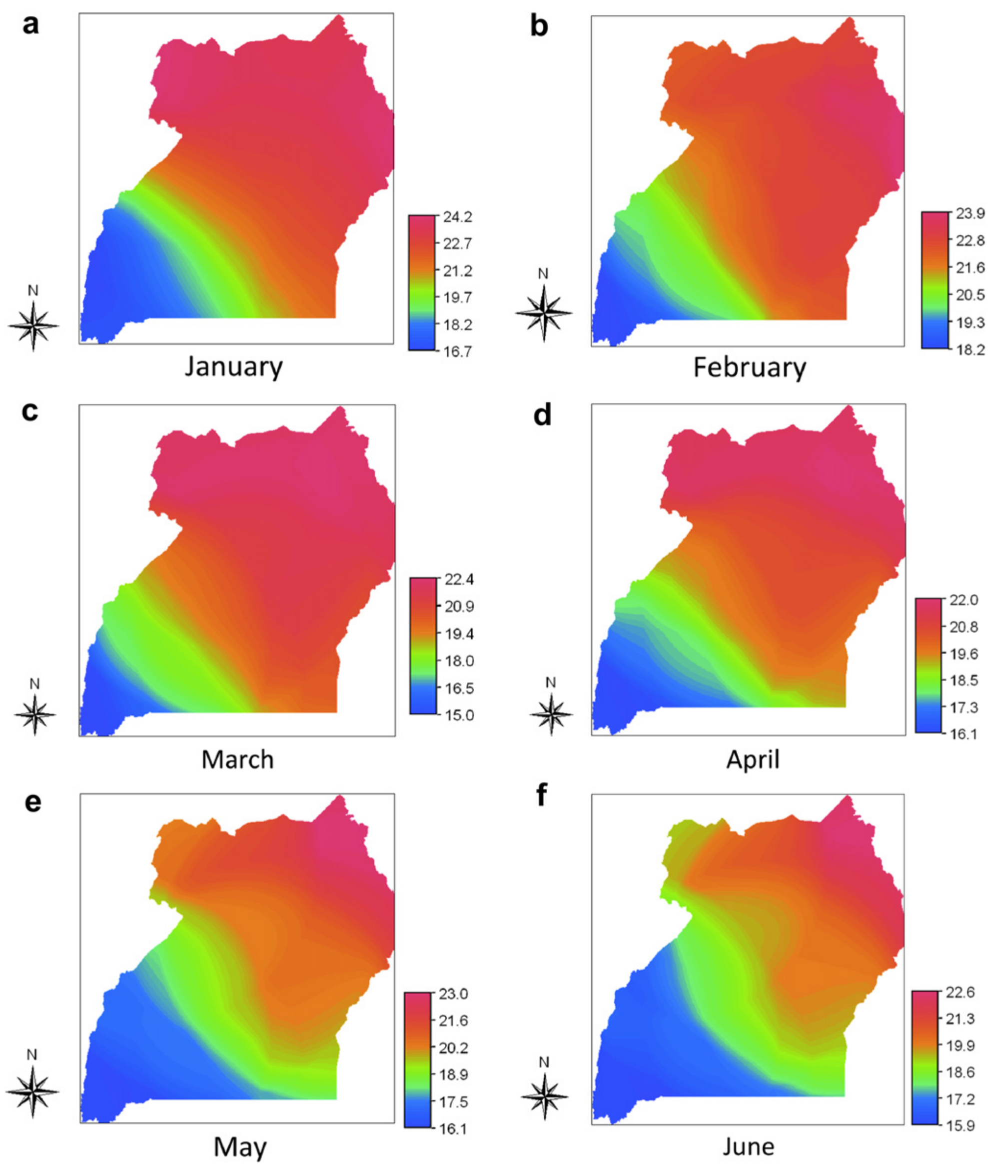

Fig. 1. Global solar irradiation (MJ/m^2) maps for Uganda.

of which is open water, 3.0% permanent wetlands and 9.4% seasonal wetlands. The perimeter of Uganda is 16,630 km. Its topology is characterized by plateaus, highlands, mountains, rolling hills, flat lands, rivers, lakes and wetlands [12].

The global solar irradiation data was measured from four sites spread out in the country: Kampala in central, Mbarara in the west, Lira in the north and Tororo in the east. Table 1 shows their location parameters. A Kipp & Zonen Pyranometer CM6B of sensitivity $(11.52\mu V/W)/m^2$ was used for the measurement (2003–2005) and the data corrected for errors.

Table 1 shows all twelve Uganda meteorological stations including the four stations where measurements of solar irradiation were taken. The global solar irradiation values were estimated for the eight stations where measurements of solar irradiation were not made. The ANN model proposed by Mubiru and Banda [13] was utilized in the estimation task with the following inputs: latitude, longitude, altitude, sunshine hours, maximum temperature and cloud cover.

A pool of both measured and estimated values of solar irradiation was then used for the interpolation task. The present study has used the moving average interpolation method, proposed by Mubiru et al. [10], for interpolating global solar irradiation. In this interpolation a linear decrease was used as the weight function with a weight exponent of five [10] and a limiting distance of 304,026 m [10]. The limiting distance was determined based on the number and spread of the data points used in the study. ILWIS 3.2 Academic and ArcView 3.2a programs were used for interpolation. The procedure used with these programs, is included in the Appendix.

The computation of relative errors involved exclusion of the fourth measurement site (Kampala) from the interpolation process. We obtained the interpolated solar irradiation values of this site, and together with its actual values, we computed the relative errors.

3. Results and discussions

Fig. 1(a) to (l) show global solar irradiation maps for Uganda, from January to December. The maps are a representation of monthly average daily values of the global solar irradiation. The

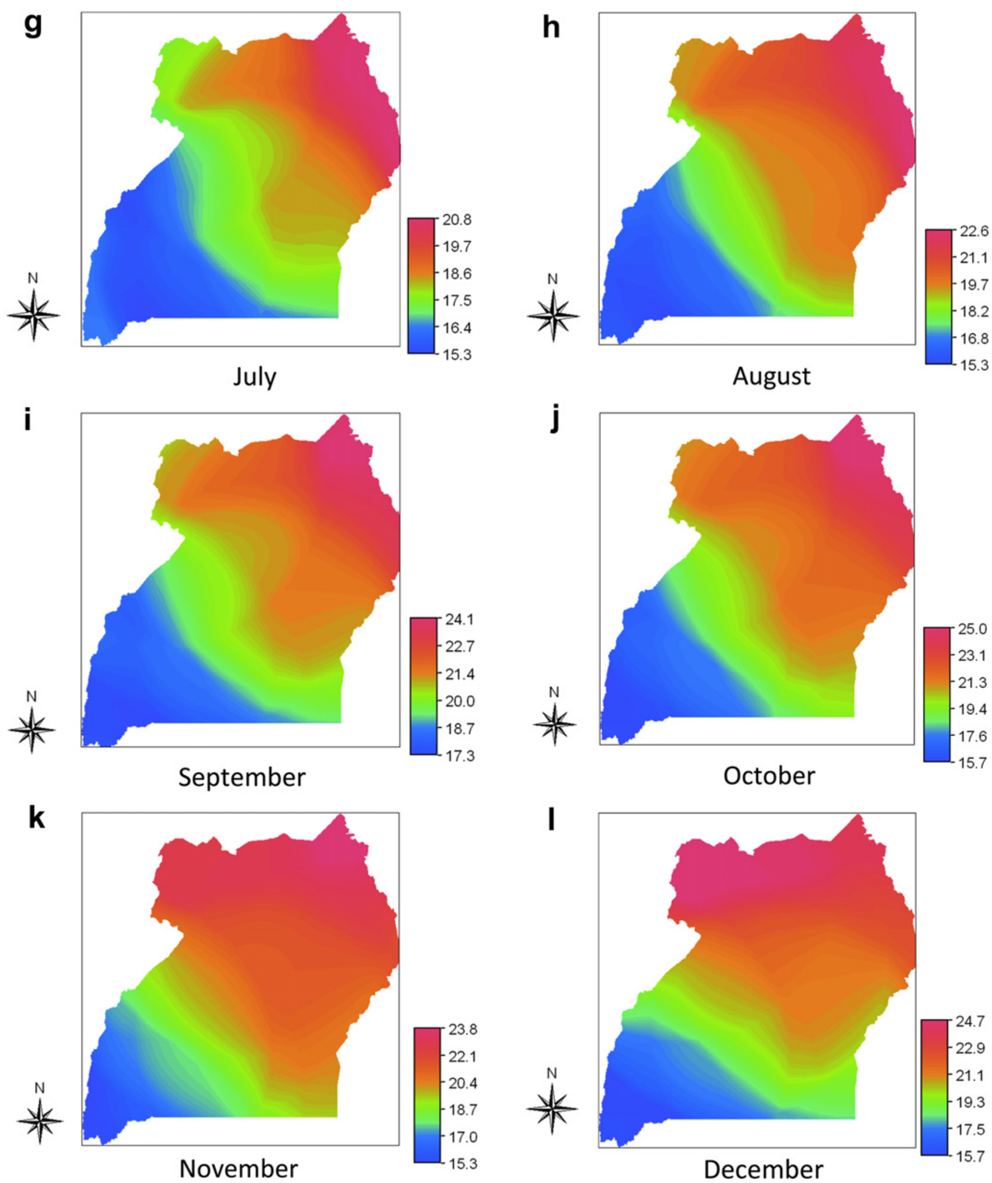

Fig. 1. (*continued*).

south-western part of the country exhibits less global solar irradiation. This region is characterized by fewer sunshine hours and more cloud cover. The global solar irradiation increases progressively toward the north-eastern part of the country during the year. This region has more sunshine hours than other regions of the country. These results are further supported by two separate studies [14,15], which showed the Lira site (north) to exhibit more solar irradiation than the Mbarara site (south-west).

Results have shown that the monthly average daily global solar irradiation varies between 15.0 and 25.0 MJ/m^2. The northern region of the country receives the greatest amount of global solar irradiation from January to April and the last two months of the year. The north-eastern region of the country receives the greatest amount of global solar irradiation during the rest of the months, that is, from May to October.

The month of February (Fig. 1b) exhibits the greatest amount of global solar irradiation followed by September (Fig. 1i). The sunshine hours are more during these months due to a lower cloud cover. The least amount of global solar irradiation is realized in July (Fig. 1g). Results have shown relative errors of 8% and 16% in February and July, respectively, as representative months for the two seasons of the year.

4. Conclusions

A pool of measured and estimated values of global solar irradiation was interpolated, successfully, to generate solar irradiation maps for Uganda. Results have shown relative errors of 8% and 16% in February and July, respectively, as representative months for the two seasons of the year. These solar maps indicate that global solar irradiation is higher in the northern region than the rest of the country. Global solar irradiation is higher in February which is also characterized by higher sunshine hours. The present study provides resource data on global solar irradiation on a horizontal surface, in any location in Uganda. The data can enable proper selection, design and assessment of solar energy systems.

Appendix. Interpolating procedure using ILWIS 3.2 Academic and ArcView 3.2a programs

The following are steps used for interpolating, using ILWIS and ArcView programs:

1. While in ILWIS, create a table with appropriate columns.
2. Import data into this table (copy from Excel and paste in table, say).
3. Create a Point map from this table with the following particulars: x-column as longitude, y-column as latitude, coordinate system as “unknown”, select: “use column of table” and specify column with the solar data.
4. Convert units of the Point map to meters by:
   (a) Exporting the Point map in SHP format
   (b) Opening the ArcView program and creating/opening a project and then creating a new view
   (c) While in ArcView, add “Theme” for the .SHP Point map
   (d) Move to the “View” menu and select “Properties”
   (e) Change map and distance units to meters
   (f) While still in View Properties, click the “Projection” button and select “Custom”
   (g) Set the following parameters: projection as Mercator, spheroid as Clark 1880, central meridian as 33, latitude of true scale as 0, false easting as 500,000, false northing as 10,000,000
   (h) Click OK, all through
   (i) Move to the “Theme” menu then select: “Convert to shapefile”.
5. Return to ILWIS and import the projected map.
6. Attribute this imported Point map to the associated Table.
7. Interpolate with the ‘moving average’ method, using the attributed Point map and set the following parameters: weight function as linear decrease, weight exponent as 5, limiting distance as 304,026 m (default) and an appropriate georeference. A raster map is created in the process.
8. Cross this raster map with the Ugandan raster map. Ensure the Output map box is ticked, to create the map.
9. Attribute the crossed map to its corresponding table. A final raster map is created in the process.

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