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Assessment of the quality of satellite derived irradiance data for Rwanda by comparison with data from a fleet of automated ground stations

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Abstract

Satellite data is a worldwide available data source, quality in regions with dense networks (eg. Europe, North America) well known as less data for comparison for central Africa.
Here, analysis of Satellite data source enhanced ground data now offered by Rwanda Environment Management authority (REMA) network.
REMA has installed around 22 Automatic Weather Stations (AWS) in Rwanda (surface area of Rwanda ~26000 km^2). Solar irradiance data are available since end 2013 with a time resolution of 5min. After passing through a quality check, a first analysis of this data base is done by the investigation of the applicability of standard models of both, their probability distribution and autocorrelation characteristics performed for temporal resolutions of 1day, 1h and 15min. As currently time synchronous ground and satellite derived data sets are missing these data are used here for but a first qualitative comparison to the Satellite derived data available
Keywords: Solar *irradiance, Satellite derived data, Automatic Weather station*

1. Introduction

To support planning concerning solar energy application in Rwanda, the quality of local solar resources is on important decisive. The spatial and temporal distribution of solar radiation resources are needed to be analyzed. Due to the limitation of available local measurement data of global solar irradiance in some regions of Rwanda, this problem is sort out by exploitation of the empirical model tools (Museruka and Mutabazi, 2007; Safari and Gasore, 2009) with daily means monthly results, and indirect measurement data sets from meteorological satellites (PVGIS, 2015) which covering 20 years with a temporal resolution of 15min. Currently, radiation data from several web services which offer irradiance information for Africa and Rwanda (PVGIS, 2015; GeoModel, 2013; NASA, 2015). However, each has its own limitation in space-time and accuracy level for the inspected region is no well-known. In this study, satellite derived irradiance from Photovoltaic Geographical Information System (PVGIS) has been used. PVGIS gives the hourly pattern of the average day of the month from the HelioClim-3 database with a temporal resolution of up to every15min and spatial (approx. 5 km) observations. Due to its excellent help and its integration of geographical database of solar radiation model, PVGIS has been exploited as interactive web for estimating the potential for solar energy in Rwanda and offers a long time series with daily monthly means of global horizontal irradiance values that cover the period 1985-2004. As complement, the daily global solar energy with 15-time resolution data supplied by GeoModel solar, Slovakia (GeoModel, 2013) is available from 2007 to 2012 for Kigali location and was also analyzed here. Currently, the new data set of solar irradiance at some particular location in wide variety of real operating environmental condition in Rwanda has been given by Rwanda Environment Management Authority (REMA), the global solar irradiance data with a high temporal resolution of 5min (Meteo Rwanda, 2014) in 17 districts of Rwanda where 22 automatic weather stations has been installed and operated since end of 2013. As the ground data measurement tool, these new automated weather station data has been analyzed for being a new source for technical assessment of solar energy potential in Rwanda and its

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quality is been investigated by a qualitative comparison with the existing satellite derived irradiance data model. Due to this problem we have propose to explore the similarity between the available global solar data from AWS and satellite derived irradiance data for Rwanda.

The objective of this paper is thus to give a first comparison of local irradiance provided by automated ground station data (AWS) versus satellite derived irradiance data for Rwanda

2. Solar radiation components at the ground level

The presented analysis of satellite derived data is based upon the global horizontal irradiance estimated at inclination of 15^{o} degrees as tilted angle of inclination, fixed at azimuth 0^{0}(north) for both PVGIS and GeoModel**.** This global solar irradiance (G) received at ground level is taken as a sum of direct irradiance G_b, diffuse irradiance G_d and ground reflected irradiance G_r.
The ground measured data of global tilted radiation used, has been offered by the automatic weather station installed across the country and they are received from Meteo Rwanda. Due to the incoherent space and time resolution for these 3 sources data (PVGIS, GeoModel and AWS), the conversion for common resolution has been done, especially from 5 minutes (AWS data) to 15 minutes (Satellite derived data). In this study, the correlation for both set data (ground measurement and satellite derived data) was statistically tested by mean percentage error (MPE %), mean bias error (MBE) and root mean bias error (RMSE) as it is defined by Indira et al. (2012).

3. Data acquisition of global solar radiation in Rwanda

3.1 Satellite information

Global solar irradiance can be derived from weather satellites measurements. There are many sources of the global solar irradiance for Africa and including Rwanda such as NASA, NREL/SWERA, PVGIS/HelioClim and Solar GIS for free or by payment (PV magazine, 2014). The data sources here apply different versions of the Heliosat method (Hammer et al., 2003; PVGIS, 2015; GeoModel, 2013).

Figure 1 illustrates a map for annual irradiance sum over Rwanda, as given by PVGIS. This map refers to the average for the years 1994 to 2010.

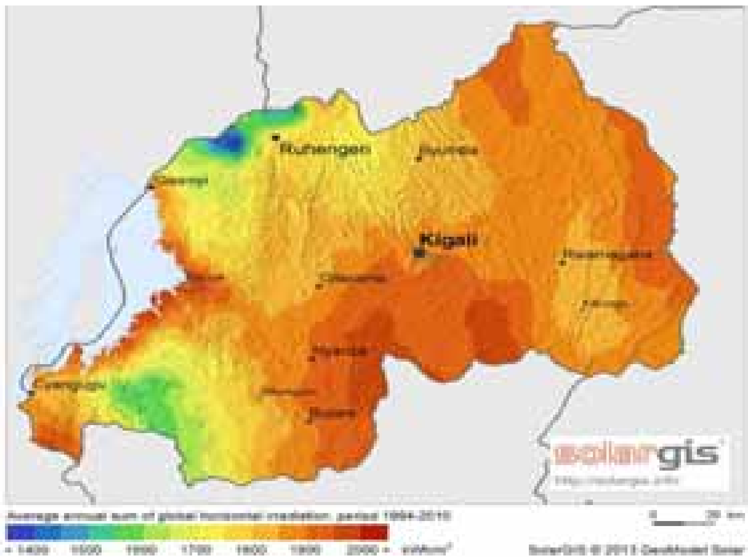

Fig.1: Average annual sum of global horizontal irradiation in Rwanda (GeoModel, 2013).

3.2 Surface observation

In 2013, Rwanda Environment Management Authority (REMA) has installed 22 automatic weather stations with 7 Automatic Weather Station for Hydro-meteorological (AWS-H) Observation located close to water bodies and 15 Automatic Weather Station (AWS-S) for synoptic observation installed on land (Meteo Rwanda, 2014). As an advantage, some of them are web-based and can be accessed online through Meteo Rwanda`s authorization. Nowadays, in Rwanda, meteorological data are manually and automatically collected from weather countywide. The figure 2 represents some positioning of automatic weather station in Rwanda.

Fig. 2: Automatic weather station (AWS) in Rwanda (Meteo Rwanda, 2014).

The AWS offers local weather data (global solar irradiance) with 5 minutes of temporal resolution. These parameters are often needed for prediction of performance of solar system application. Additionally, each station for AWS is equipped the weather sensors, for monitoring data that can be used in assessment of current climate. The some AWS data bases are already containing the information monitored data from October 2013 until today, but some data are missing or incomplete for some AWS.

4. Checking the similarity of satellite derived datan and automated ground station data

4.1 Comparison of annual and monthly means

At country wide scale, due to the small extension of the country, here should be distinctive latitudinal gradient of global solar radiation on the territorial surface of Rwanda as represented on figure 1 from PVGIS. But as at local scale, terrain is the major factor characterizing the spatial distribution of global solar radiation. The trend of spatial distribution of solar irradiation is characterized by its continuous positive gradient from West to East region and from North to South region of Rwanda which is corresponding to the negative gradient of relief in Rwanda. The annual average of global solar radiation has been estimated for some locations from PVGIS and AWS; the results are represented on the figure 3.

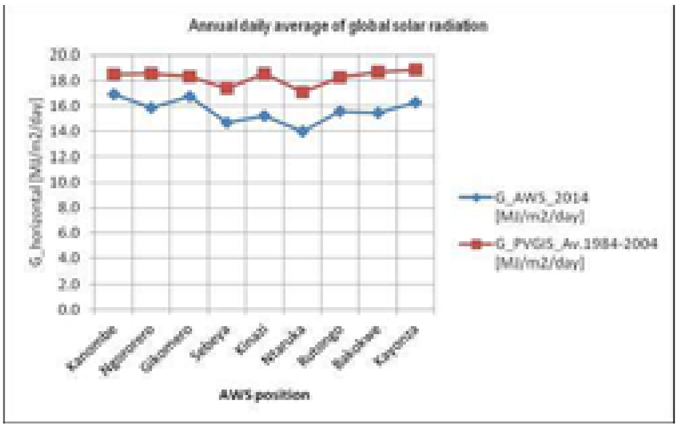

Fig.3: Annual daily average of global solar radiation from PVGIS (several years) and AWS (2014)

The annual average of the daily global solar radiation sum shows but small differences from station to station from both sets. It is remarkable that – by showing a similar station to station pattern – the satellite data give higher values throughout. This difference has to be traced back to be either a result from year to year variations or from an overestimation error in the satellite data. Table 1 gives the mean absolute MBE and percentage MPE deviation for various sites.

Table 1: Spatial variation of MPE, MBE and RMSE for data derived satellite (average 1984-2004) and automated ground station data 2014

Location	MBE[MJ/m2/day]	MPE[%]	RMSE [MJ/m2/day]
Kanombe	1.7	-10.2	2.8
Ngororero	2.6	-17.2	3.7
Gikomero	1.6	-9.9	2.7
Sebeya	2.7	-19.1	3.2
Kinazi	3.4	-23.8	4.4
Ntaruka	3.2	-23.8	3.9
Rutongo	2.7	-18.1	3.6
Bakokwe	3.2	-21.3	3.8
Kayonza	2.6	-15.9	3.2
Average	2.6	-17.7	3.5

Looking at the month-to month deviations of ground and satellite derived data (table 2, fig.4) it can be remarked, that the deviations are mostly pronounced in the May to August period. This may give an indication for a problem in the satellite derived data due to faulty assumptions on the monthly atmospheric turbidity.

Table 2: Monthly values of MPE, MBE and RMSE for satellite derived (multi year average) and automated ground station data (single year)

Month	MBE [MJ/m2/day]	MPE [%]	RMSE [MJ/m2/Day]
Jan	0.7	-4.9	0.3
Feb	3.0	-21.0	2.7
Mar	2.1	-14.4	1.7
Apr	2.6	-17.0	2.2
May	3.4	-23.7	3.4
Jun	5.3	-36.5	8.1
Jul	5.3	-32.4	8.1
Aug	5.9	-40.8	10.0
Sep	3.4	-22.0	3.4
Oct	0.0	-0.5	0.3
Nov	1.2	-8.4	0.5
Dec	-0.9	5.1	0.6

Looking at the analysis of results of table 2 shows that one only month of December the MPE is 5.1 (greater than 0), means that the data monitored from AWS is greater than data estimated from PVGIS. October presents a good agreement data for both set of data.

Analyzing the other satellite derived set, which allows for looking at year to year variations gives the same qualitative result of a positive Bias of the satellite data, being highest in the Mai to September period. The general overestimation for the satellite derived data again indicates a necessary adjustment of the assumptions of atmospheric turbidity used by the models.

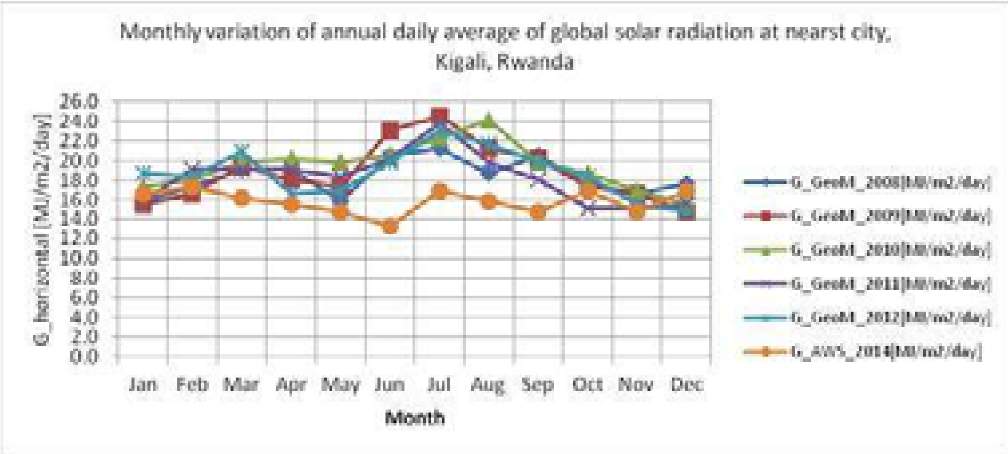

Fig. 4: Comparison of GeoModel and AWS global horizontal irradiance data on a monthly basis.

4.2. Comparison of cumulative distribution functions.

Based on 15 minutes of resolution available in the GeoModel and the ground station sets the similarity of the distribution functions of the 15min irradiances can be analyzed

The annual cumulative distributions for one site - Rutongo - is given in figure 11, shown here in the higher than presentation. The distributions refer to the 2014 ground data set and GeoModel sets for individual days.

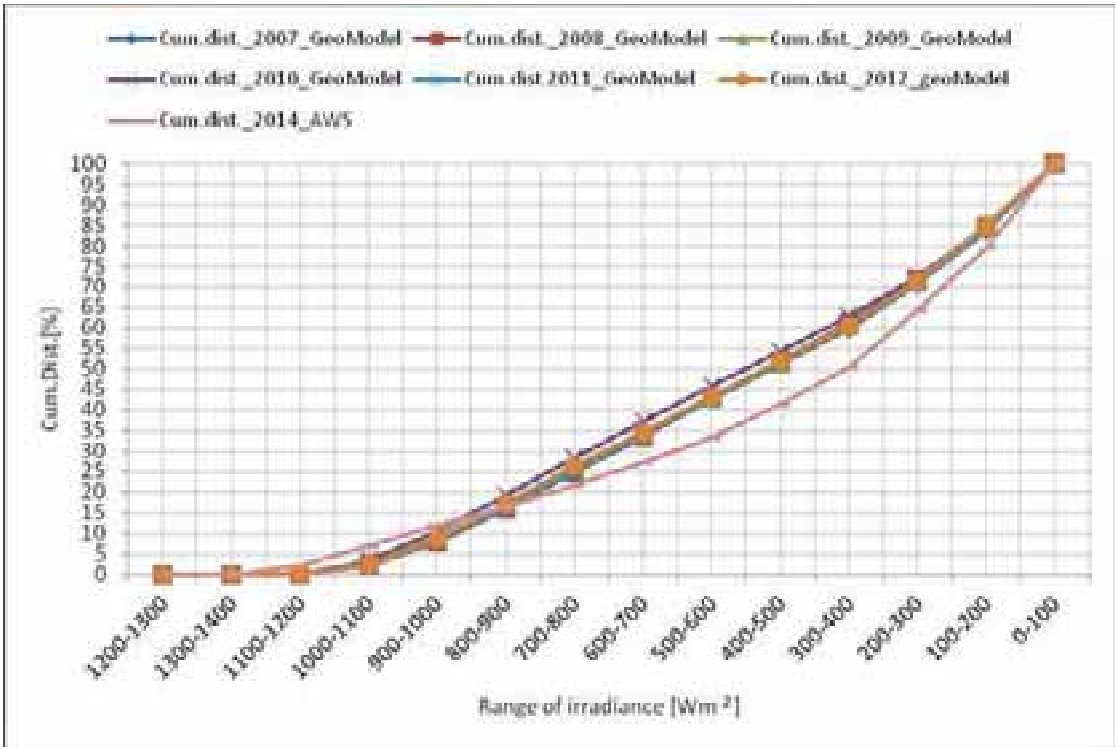

Fig.5: Cumulative distribution of global solar irradiance from multiple years GeoModel and 2014 AWS sets (shown here in the higher-than presentation.

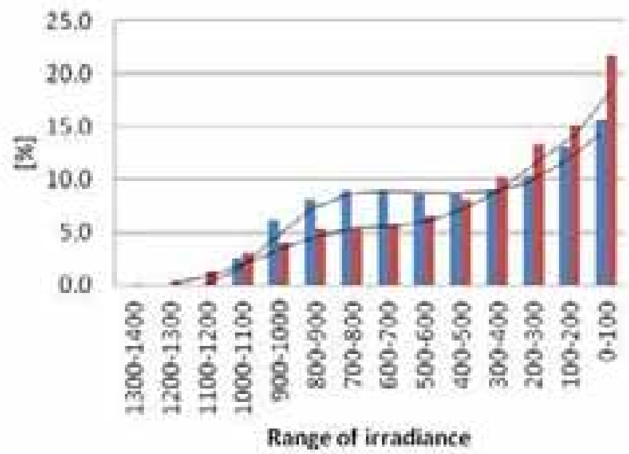

Fig.13: Histrgram of the 15min irradiances fo the 2014 ground data set (red) and the 2008-2014 satellite derived set (blue).

4.1 Conclusions on data similarity

Whereas the data confirm, that the basic spatial and temporal distribution of the ground measured irradiance can be reflected by the satellite derived sets, even from this problematic case of not time parallel data sets it has to be stated, that the quality of the satellite derived data needs improvement. From the error pattern it may be stated, that that a better representation of the atmospheric turbidity can lead to substantial improvements here.

5. Conclusions

In this paper a preliminary analysis of the quality of satellite derived irradiance data by using a set of newly installed ground stations in Rwanda is performed. Within the limitations enforced by the missing of time parallel data sets a need for the improvement of schemes for the derivation could be pointed out. However, this proves the value that should be given to this kind of in-situ measurements of the solar resource.

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