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Clear and Real Sky Global Horizontal Irradiance (GHI) Determination in the Province of Bukidnon, Philippines

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ABSTRACT

The radiation reaching the earth's surface can be represented in a number of different ways and one of the ways is through GHI determination. This study determined the Global Horizontal Irradiance (GHI) in the Province of Bukidnon. GHI is the maximum concurrency of solar radiation at specific time and location on the surface of the earth. It was determined monthly from January to December 2014 using the R.sun model that runs in an open source Grass Geographical Information System (GIS) software which can compute direct (beam), diffuse and reflected solar irradiation raster maps for a given day, latitude, surface and atmospheric conditions. Inputs such as topography, location, Linke Turbidity and ground albedo, slope and aspect and sun's declination were also taken into account in the calculation. The results suggest that the values of GHI in a clear sky condition differ by almost 90% greater than the real sky condition. The highest GHI values were recorded in the month of January and May for clear and real sky, respectively. Thus, the output of this study recognized and may utilize further to assess the solar energy potential of the Province in terms of GHIs.

Keywords: *Solar Radiation, Solar Variation, Solstice, Equinox*

INTRODUCTION

The solar radiation reaching the earth's surface can be represented in a number of different ways. One representation is through Global Horizontal Irridiance (GHI) which corresponds to the total amount of shortwave radiation received from above by a surface horizontal to the ground. GHI can be determined into two aspects: clear and real sky. This value is of particular interest to photovoltaic installations and includes both Direct Normal Irridiance (DNI) and Diffuse Horizontal Irridiance (DIF) (Vaisala, 2016).

The definition of a clear sky is very loosely used in solar radiation modeling. Often clear-sky conditions are defined by the absence of visible clouds (Reno, J.M. et al., 2012). However, the absence of clouds does not imply non-varying GHI, because atmospheric turbidity can also vary in time and space. Clear sky is also defined as a condition without any visible clouds while real sky considers all time and events that the solar radiation occurs.

In acquiring GHI clear-sky values, many conditions, inputs and variations need to be taken into account such as topography, location, linke turbidity and ground albedo, slope and aspect and sun's declination. Those inputs as a result also, could be used to calculate a cloudiness index or clearness index which is an input for the real sky GHI computation. In order to accurately calculate these indices, a well-calibrated clear sky model must be used for the location (Reno, J.M. et al., 2012). R.sun is a solar irradiance and irradiation model that computes direct (beam), diffuse and reflected solar irradiation raster maps for a given day, latitude, surface and atmospheric conditions. It is also a useful tool for determining the values of GHI clear-sky accounting all of the above listed as an input to this model. However, studies concerning the GHI values in the Province of Bukidnon are not yet carried out.

In this study, the clear-sky and real sky GHI values in the province of Bukidnon was determined. The GHI values were determined monthly from January to December 2014 based on Synthetic Aperture Radar (SAR) data with 10 m resolution. The results of this study could then provide updated information for the determination of optimal location of photovoltaic systems for energy generation in the province.

Study Area

Observations by PAG-ASA from 2006-2011 showed that Bukidnon has two prevailing types of climatic variations in the rainfall pattern existing between the northern and southern sections. The northern part falls under the third or intermediate A type, i.e, no very pronounced maximum rain period with a short

dry season lasting only for one to three months. The southern part, beginning from Malaybalay, falls under the fourth type of intermediate B type, i.e, no very pronounced maximum rain period and no dry seasons. Rains are very frequent, almost daily for the rest of the year. Though the province is nearer the equator than Luzon Island, the climate is pleasant due to its altitude and the usual extreme heat of the tropical region is lacking. Moreover, the province is outside the path of typhoons.

The annual average monthly rainfall distribution from 2006-2011 is 241.68 mm. The rainy seasons last from March to October when monthly fall are generally somewhat in excess of 200.00 mm. The drier season has mean monthly falls of generally 7.1 to 150 mm. Records indicate that the months of January, February, November and December show a reasonable regularity or no effective rainfall.

As this characteristic of the province is well presented, there's still no studies has ever done before concerning the GHI values in the Province of Bukidnon. Thus, it leads into an idea of evaluating the GHI value of the province. Description of clear and real sky GHI using r.sun model in the province of Bukidnon is the very focused of this study. Any complex computation of GHI or comparison thereof in the field using solar sensor is beyond its limitation.

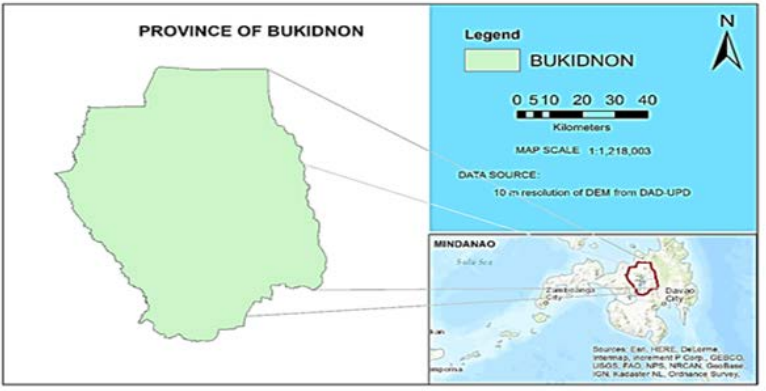

Figure 1. Map of the study area

METHODOLOGY

In producing an average monthly clear-sky GHIs of the year, Synthetic Aperture Radar-Digital Elevation Model (SAR DEM) with 10 meters in resolution was used with respect to its area coverage. SAR is a form of radar that is used

to create images of objects, such as landscapes which can either be two or three dimensional representations of the object. The said input was processed using r.sun software. This software is considered as the centralized process in computing clear-sky GHI. It is a topography-based solar radiation model, based on ESRA and implemented in Grass GIS. Grass GIS is free and open source software used for data management, image processing, graphics production, spatial modelling, and visualization of many types of data.

Figure 2 shows the work flow for clear sky GHI processing. Slope, aspect, horizon and normalized Linke Turbidity values were extracted initially from the SAR DEM. Slope and aspect (r.slope.aspect) of the province were formulated first for the GHI input. Horizon (r.horizon) was standardized at 3.75 angle step and the time step at 0.08333 in order to come up with their shadow effect, slope and aspect. The Linke Turbidity was then projected and used to determine all the normalized values of the turbidity each month. Every average day and declination of each month was considered for the determination of monthly average clear-sky GHI. Here, Julian day and declination of each month was recommended as an input in the r.sun process (Duffie & Beckman, 1991).

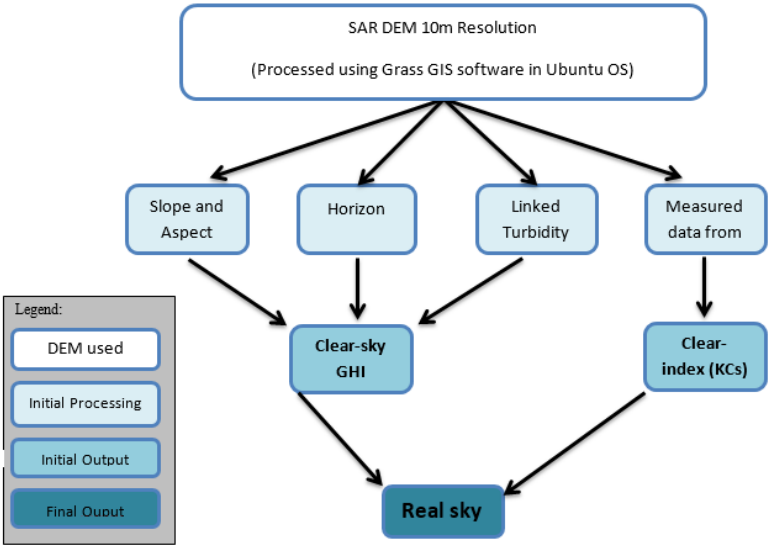

Figure 2. Flow of processing.

On the other hand, clear-sky index (KC) raster was processed from the monthly measured GHI value taken from BSWM sensors located all over the Philippines. The real sky GHI which is the true surface radiation of the study area was generated as the product of KC values and clear sky GHI.

Table 2
Alubijid Basin Model Performance Rating

Month	Average Day of the Month			
	Day	Julian Day	Declination (Degrees)	Declination (Radians)
January	17	17	-20.92	-0.3651228795
February	16	47	-12.95	-0.2260201381
March	16	75	-2.42	-0.0422369679
April	15	105	9.41	0.1642354826
May	15	135	18.79	0.3279473664
June	11	162	23.09	0.4029965243
July	17	198	21.18	0.3696607356
August	16	228	13.45	0.2347467844
September	15	258	2.22	0.0387463094
October	15	288	-9.60	-0.1675516082
November	14	318	-18.91	-0.3300417616
December	10	344	-23.05	-0.4022983926

Source: (Duffie & Beckman, 1991)

RESULTS AND DISCUSSION

GHI Values of the Study Area

Figure 3(a) and 3(b) below shows the highest and lowest value of clear and real sky GHI of Bukidnon province in a year. The highest and lowest calculated values of clear sky were 8,724.37 Wh/m2 and 840.17 Wh/m2, respectively. The real sky values were slightly lower compared to clear sky with highest and lowest values of 6,218.38 Wh/m2 and 508.55 Wh/m2, respectively. The lowest value of GHI for both clear and real condition was observed in the month of January. This result could be attributed to the shadow effect caused by earth's inclination, topography and geographic location of the study area. The tilt of the earth with respect to its pole produces variation of the sun's radiation and declination (Pidwinry, 2006). The

intensity of the GHI also depends on the angle of the surface towards the sun. Tilted angle is the vertical angle between the horizon and the array surface according to the study of Lu and Yang, 2007. In accordance of the result, the maximum available radiation can be captured when the tilted surface is perpendicular to the rays of the sun. In the case of Bukidnon (Figure 4), most of the tilted areas are facing directly to the sun and thus, have the highest GHI value compared to other areas.

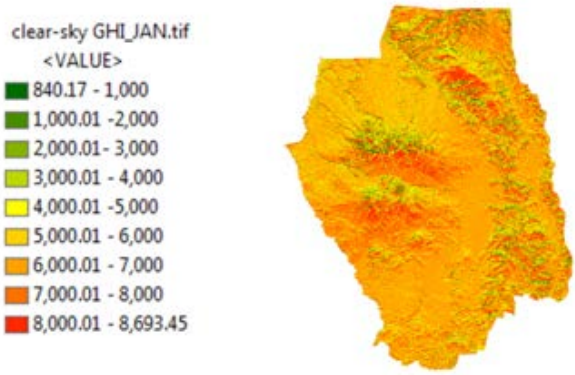

Figure 3a. Clear sky GHI of the province of Bukidnon with its highest and Lowest values

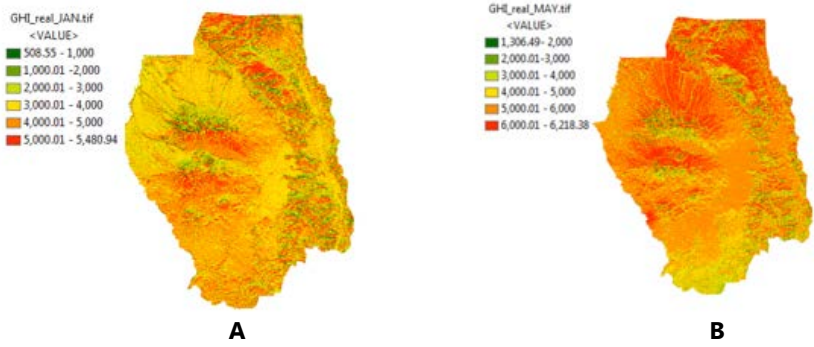

Figure 3b. Real sky GHI of the province of Bukidnon with its highest (A) and Lowest (B) values

On the other hand, the results also showed that low elevated areas have high GHI values compared to higher elevation. This is probably due to albedo and turbidity effect since these parameters can be affected by atmospheric composition such as gaseous water vapour and aerosols (Chaabane, M. et al., 2004). Moreover, GHI variability is also affected by the geographical location of the area since GHI intensity is highly dependent on the position of the sun relative to the earth's surface. Since Bukidnon lies between the parallels 7°25′ and 8°38′ north latitude and meridians 124°16′ east longitude which is located in the equatorial region, the area can receive the maximum exposure from the sun (Qiang, 2003). This could explain the reason why the Philippines, specifically the province of Bukidnon can acquire the radiation of the sun in every time.

Seasonal Variation of GHI

GHI values also vary greatly with seasonal variation. Solstices are events where the highest and the lowest attainment of the sun occur. This happens at every month of June and December. During equinoxes, the sun's path is located almost align with the equator, that is, 0 degree declination. This happens at every month of March and September. In connection to the GHI output, Figure 4 illustrates how these solstices and equinoxes connected to the output. By putting a sun (assumption) on each selected month, it definitely explains how the distribution of radiation happens. As the declination of the sun reached the equatorial axis, that is 0 degree latitude (September and March), the intensity of the sun focused nearly at the center place of the province. When the sun is at the highest and lowest attainment (June and December), the intensity focused at the upper and lower part of the province.

Taking into account all the possible considerations mentioned above, the result simply shows that there are areas of the province which are capable for gathering solar radiation which also are potential for solar energy production. Those areas were mostly located in the central part and lower-left of the province (See Figure 4).

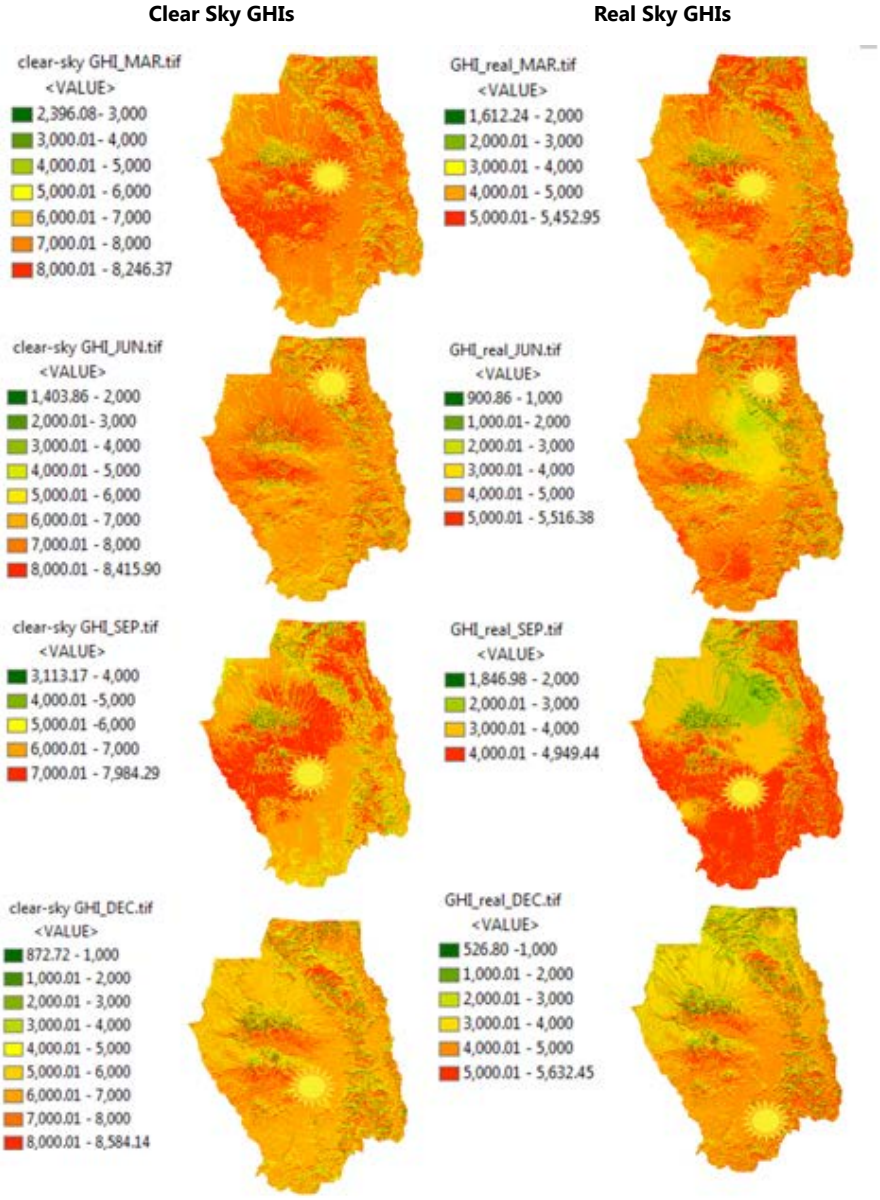

Figure 4. Illustrations of Seasonal Variation in GHI

CONCLUSION

Bukidnon province is located along the yearly path of the sun which signifies that every radiation of the sun will always be available on each part of the area. But in terms of getting the available energy through sun's radiation or GHI determination, no study has been carried out yet for the said province.

This study determined the Global Horizontal Irradiance (GHI) in the Province of Bukidnon in terms of clear and real sky condition. GHI is the maximum concurrency of solar radiation at specific time and location on the surface of the earth. It was done through the help of an R.sun model that runs in an open source software (Grass GIS).

According to the result of this study, most of the highest and lowest results of clear sky GHI occur on the month of January with GHI values of 8,703.35 and 867.785, respectively. In terms of the final determination of solar radiation or the real sky determination, the lowest and the highest value occurs in the month of January 508.554 and May 6,218.384, respectively. Also, the result of clear and real sky GHI differs greatly into almost 90% in favor of clear sky. The highest GHI values were recorded in the month of January and May for clear and real sky, respectively and those areas were mostly located in the central part and lower-left of the province.

Description of clear and real sky GHI using r.sun model in the province of Bukidnon is the very focused of this study. Any complex computation of GHI or comparison thereof in the field using solar sensor is beyond its limitation and can also be looked into for the future study.

RECOMMENDATION

Power shortage was a serious and alarming problem that the Province of Bukidnon has encountered these past succeeding years. Renewable Energy (RE) is a helpful alternative source of energy to lessen this problem. One of the RE that is the accessible and free to acquire is the Solar Energy (sun's radiation). Solar energy is very abundant. It can meet much of home energy as needs as well as other sectors via electricity.

Based from the result of the study, it has found out that the province is potential to put up some apparatus to absorb energy from the sun. This may help agencies, stakeholders or any concerned authorities or corporation as an input in making decision to their planning for putting up solar panels or any solar absorption processes. Also, it is a much more help for them that it will be followed-up using a solar sensor.

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