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Estimation of daily global solar radiation using MODIS data for a clear sky day (case study: northwest of Iran)

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A B S T R A C T

Using renewable energy, particularly solar radiation is considered today as one of the most important energy resources all over the world. So that, the ratio of received solar radiation at a certain flat surface has been considered as one of important factors in crop-climate models, plant water requirement, and renewable energy systems. Analyzing solar resources, satellite images are fundamental tools for deriving solar radiation values. The goal of this study is to estimate the instantaneous and daily global solar radiation using MODIS data in the northwest of Iran (West Azerbaijan and East Azerbaijan province). At first, to separate Water, Land and Snow covers from each other, NDSI index was used. Then, instantaneous global solar radiation was estimated. After that, diurnal cycle of global solar radiation has been achieved using the sinusoidal model and outputs of previous step. Finally, to verify the daily global solar radiation that were estimated from MODIS data, the results were compared to measurements of meteorological data that were obtained in Tabriz and Uromia stations. Acquired results indicate that the RMSE error is less than 41.25 W/m^2. Finally, comparing these results to the values that were estimated using other references, an associated error coefficient results approximately 21 W/m^2 were achieved.

1. Introduction

Evaluating the renewable energy resources, solar energy is considered as the most actual and usable in the world. This energy can be obtained from any resources that the heat and rays from the sun are the important ones. It is well understood that global solar radiation (GSR) is an essential and important parameter for several purposes such as agricultural, environmental, hydrological and ecological modeling and generating electricity using photovoltaic solar cells. Therefore, the knowledge of the solar resource at the earth surface, with enough accuracy, is essential for planning any solar energy system at a given location [18]. Despite the great importance of GSR, the number of radiation stations is dramatically limited temperature, humidity, sunshine duration, and cloud coverage due to the cost and difficult maintenance of measuring equipment [17]. In this regard, employing satellite data, in conjunction with quality solar ground data sets and other meteorological data as well, has become an effective method in developing site-time specific solar resource assessment over the large areas [18]. Up to now, several algorithms and models for estimating the global solar radiation have been proposed. For instance, Tarpley processed GOES satellite images in 1979 and obtained a solar radiation model represented by three regression equations for clear, partly covered and overcast skies respectively [15]. In 1980, Gautier et al. analyzed the solar radiation balance in the Earth atmosphere system and estimated the solar radiation intensity using GOES images [4]. In 1986, Cano et al. built HELIOSAT, a statistical model consisting of an empirical relation between the ground measurements of global solar radiation and the GSR computed from METEOSAT images [2]. In 1987, Delorme et al. set up their GISTEL model by processing METEOSAT images [3]. In 2011, Saberi et al. using remote sensing statistical approach, estimated global solar radiation from NOAA-AVHRR satellite in southeast of Tehran.

Numerous methods, however, mainly focused on broadband satellite data such as Earth Radiation Budget Experiment (ERBE) wide-field of- view planetary albedo [6; 8]. It is well known that the spatial resolution of ERBE satellite data having nadir footprints larger than 30 km is too coarse for some applications. Most of current satellite data are narrowband spectra with higher spatial resolution. It is essential to estimate Net Surface Shortwave Radiation (NSSR) and GSR using multispectral narrowband satellite data with adequate spatial resolution. For example, in 2011, Jun Qin et al. estimated the monthly-mean daily global solar radiation based on MODIS and TRMM products [12]. Following these researches, the aim of present study is to estimate global solar radiation by using MODIS products in northwest of Iran.

2. Materials and Methods

2.1. Study Area

The study area is located at the northwest of Iran, including West Azerbaijan and East Azerbaijan provinces. This region covers an area of approximately 86111.149 km². The highest peak of study area is Mountain Sahand With a height of 3,722 meters, lying south of Tabriz. The climate of the study area is largely influenced by the rainy winds of the Atlantic Ocean and Mediterranean. Cold northern winds affect the region during winter and cause heavy snow. Average annual precipitation is 870 millimeters and maximum and minimum temperature is 34°C, and -16°C respectively. The location map of the study area is showed in Figure. 1.

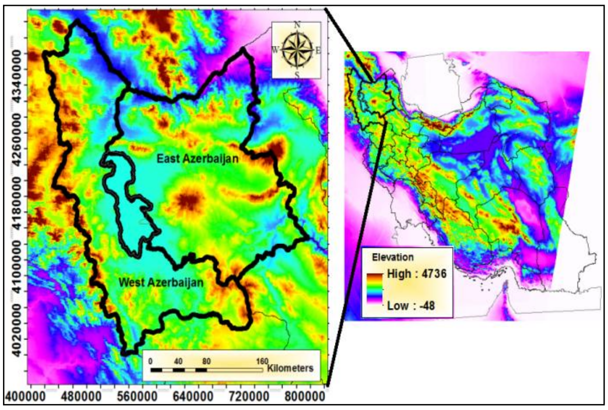

Figure 1:Location map of the study area

2.2. Data

Moderate Resolution Imaging Spectroradiometer (MODIS) is a passive imaging spectroradiometer, which covers the visible and infrared regions of electromagnetic radiation. Terra platform launched in 1999 and Aqua platform launched in 2002, provides comprehensive and frequent global earth imaging in 36 spectral bands between 0.41 and 14.39 mm and at variable spatial resolution with nadir footprints no more than 1 km. Furthermore, MODIS supplies a series of products for various land/ocean applications [14]. The data that have been used in this paper are the MOD021KM, MOD03 and MOD05_L2 products.

MOD03

The MODIS geolocation dataset, called MOD03, comprises the latitude, longitude, ground elevation, solar zenith angle, satellite zenith angle and azimuth angle for each MODIS 1 km pixel. The solar zenith angle is used to compute downward shortwave radiation [14].

MOD021K

The MOD021KM products, calibrated Earth View data at 1KM resolution by the MODIS Characterization and Support Team (MCST), including the 250 m and 500 m resolution bands aggregated to appear at 1 km resolution, are TOA radiances and reflectances [14].

MOD05

TheMOD05_L2 products are the near-infrared total perceptible water data consisting of column water vapor amounts over clear land areas of the globe, and above clouds over both land and ocean. Water vapor estimates are also derived in MOD05_L2 products over clear ocean areas [14].

The overall framework of the study area and used dara are showed in Figure. 2.

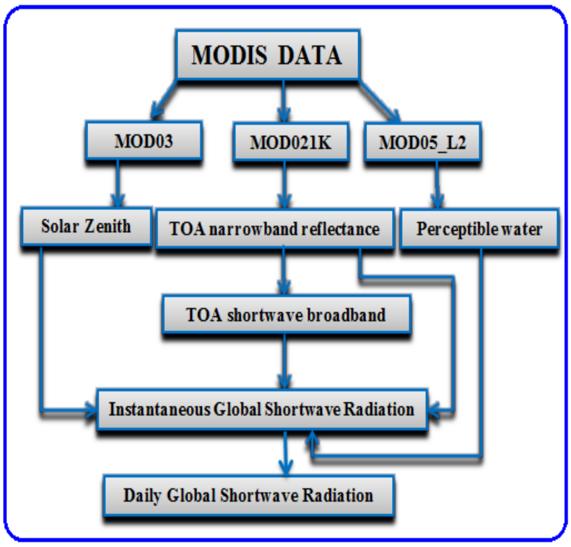

Figure 2:Schematic flowchart for estimating daily global solar radiation

2.2. Retrieval instantaneous global solar radiation from MODIS data

Tang et al. (2006) proposed a methodology for estimating Net Surface Shortwave Radiation (NSSR) and also, Tasumi et al. (2000) suggested a methodology for estimating surface albedo. We used both models and the model proposed by Bisht et al. (2005) for calculating upward shortwave radiation in order to estimate global solar radiation that can be expressed in terms of its components as:

$$R_s^{\downarrow} = \frac{a_s E_0 \cos(\theta_s)}{(1-a)d} \quad (1)$$

$R_s^{\downarrow}$: Global solar radiation (w/m^2)

E_0: is the solar constant at the atmospheric top, which is about 1367 w/m^2

θ_s: The solar zenith angle

d: the Earth–Sun distance in astronomical units is defined by:

$$\mathrm{d} = 1 + 0.033\cos(\mathrm{J}\frac{2\pi}{365}) \quad (2)$$

Where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

α_s : The flux absorbed at the surface expressed as a fraction of the flux incident at the TOA, is defined by:

$$\mathrm{a_s(m, w, r) = a\text{-}' b'r} \quad (3)$$

The interception α and slope β in (3) were expressed by

$$a = 1 - a_1\mu^{-1} - a_2\mu^{-x} - (1' - \exp(-\mu))(a_3 + a_4 w^y)\mu^{-1}$$
(4)

$$\beta = (1 +' a_s + a_6 \ln\mu + a_7 w^z) \quad (5)$$

In which μ is the cosine of the solar zenith angle, *w* the precipitable water, $a_1 - a_7$ are constants for various surfaces.

In Li et al. parameterization X, μ ,Z took the value 0.5, but they were free parameters in Masuda et al. parameterization (table 1)

Table 1:Coefficients for estimating the global solar radiation(14)

Surface type	land	water	Snow/ice
a_1	-0.011	0.003	-0.011
a_2	0.179	0.166	0.163
a_3	-0.980	-0.774	-0.648
a_4	0.929	0.733	0.631
a_5	-0.701	-0.511	-0.867
a_6	0.090	0.059	-0.013
a_7	0.846	0.637	0.927
x	0.478	0.342	0.510
y	0.052	0.067	0.060
z	-0.020	-0.034	0.018

r: TOA shortwave broadband albedo and calculated by using:

$$r = \sum_{b=1}^{7}\left[C_{band} \, . \, \mathrm{R}_{band}\right]. \quad (6)$$

Where

R_{band}: The TOA narrowband reflectance of MODIS band i is defined by:

R_{band_i}=Reflectance Scale (DN-Reflectance Offset.(7)

Table 2:Coefficients for estimating the TOA albedo (16)

band	Cb
Band1	0.262
Band2	0.397
Band3	0.679
Band4	0.343
Band5	0.68
Band6	0.639
Band7	-.0462

Land surface albedo data (α):

In the present study land surface albedo calculated by means (8) [16]

$$a = \frac{r - a_a}{\tau_{bb}^2} \quad (8)$$

r: at-satellite broadband bidirectional albedo (TOA albedo)

α_a: Atmospheric path induced albedo (this parameter is change between 0.025 to 0.04)

τ_{bb}^2: Two-way broadband atmospheric transmittance that assumes equal transmissivity for incoming and outgoing radiation

$$\tau_{bb} = 0.75 + 2\times10^{-5}\times z \quad (9)$$

Where:

Z: elevation at sea level

2.2. Daily average of global solar radiation

Daily radiation maps certainly have more applications than instantaneous radiation maps, especially for models trying to estimate evapotranspiration [5; 9;10].

$$DGSR = \frac{2IGSR}{\pi \sin\left[\left(\frac{T-2\alpha}{2T}\right)\pi\right]} \quad (10)$$

Where T is day length (i.e. the difference between tset and trise) and a is the difference in time between when solar radiation is the maximum and when MODIS overpasses.

It can be seen from Equation (10) that the ratio of DGSR and IGSR is dependent on two factors, namely T and a. The day length for solar radiation varied from 13 h in summer to 8 h during the winter. It was noted that the radiation_max generally occurred at 12:30 local time, when the ground observation data was aggregated over 15-min interval and MODIS overpass for Iran ranged from 9:00 local time to 13:00 local time for the study period, and because the time of our image MODIS is 11:00 thereby the value of α is 90 minute.

$$T = 7.64\tau \qquad (11)$$

τ :the hour angle of sun is given by:

$$\tau = \arccos\left[-(\tan\varnothing)(\tan\delta)\right] \qquad (12)$$

$\emptyset$: latitude

δ: Inclination angle of sun

$$\delta = 0.409\sin(0.0172J - 1.39) \qquad (13)$$

Where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

3. Results & Discussion

It is already elucidated that, the goal of the present work is estimating the global shortwave radiation flux merely using MODIS data. To achieve this, below processes were followed:

3.1. Geometric and radiation corrections

In the first step, we have removed stripe noise from MOD05 and band5 of MOD021km, so that, we have used the replace bad line algorithm in the Envi4.8 software. Then, the MOD03 has been utilized for geometrical correction and calculation the solar zenith angle that there is directly in the MOD03.

3.2. Determination of land cover types

In order to estimation α and β we should separate snow, land and water covers from each other. To this end, we used Normalized Difference Snow Index (NDSI) [7]

$$NDSI = \frac{band\,4 - band\,6}{band\,4 + band\,6} \qquad (14)$$

And following conditions:

$$\begin{cases} Snow : NDSI > 0.4 \quad and \quad band\,2 > 0.11 \\ \text{Water} : NDSI > 0.4 \quad and \quad band\,2 < 0.11 \\ \text{Land} : NDSI < 0.4 \end{cases}$$

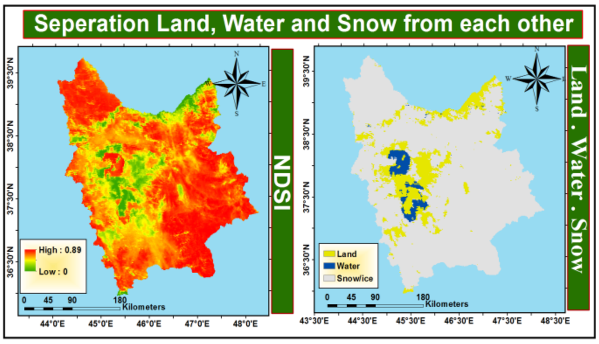

Figure 3: NDSI map(left side) and land ,water and snow land covers(right side)

Noticing the results (Figure 3), it is obvious that the most of the study area is covered by snow, because our MODIS data is in winter and as previously mentioned, and cold northern winds affect the region during winter and cause heavy snow.

3.3. Top of atmosphere Albedo and Land surface albedo

After separating snow, land and water from each other, in order to calculate land surface albedo and absorbed flux at the surface, we should compute TOA shortwave broadband albedo (r). Therefore, to measure this parameter we used Eq. (6) and the result are shown in Figure (4). Calculating TOA shortwave broadband albedo(r), next, we estimated land surface albedo by using Eq. (8) that corresponding results are exhibited in Figure 4.

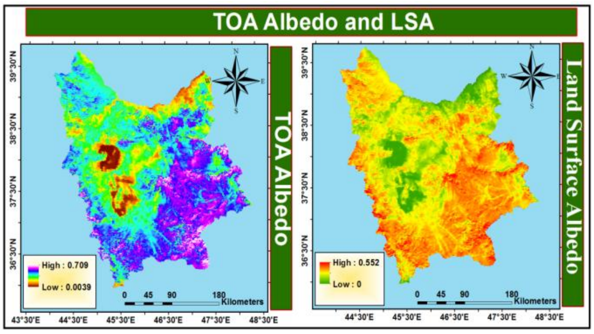

Figure 4: TOA albedo(left side) and land surface albedo(right side)

3.4. Daily global solar radiation

After obtaining each component by (1), $R_S^{\downarrow}$ can be ultimately calculated over the study area that map of this estimation is shown in Figure 5.

As previously mentioned, since instantaneous global shortwave radiation estimation has limited usage compared to daily average values or diurnal cycle and also because filed measurements are daily, we should compute the daily average global solar radiation. Therefore, we have employed the sinusoidal model that is illustrated in (10) and the results are demonstrated in Figure 5.

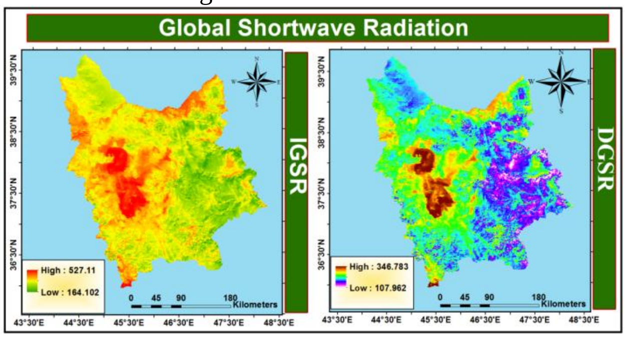

Figure 5: Instantaneous global solar radiation(left side) and daily global solar radiation(right side)

3.5. Validation

Validation is a fundamental step in estimating solar radiation using remote sensing data. The root-mean-square error (RMSE) has been frequently used to measure the differences between values predicted by a model or an estimator and the values that actually observed in the field through some calibrated instruments. RMSE is an acceptable measure of precision in most of modeling procedures. The value of RMSE is always positive, and representing zero in the ideal case.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2} \qquad (15)$$

Where:

p_i and O_i are the estimated and measured values respectively, n is the number of observations.

To validate the proposed data, we used the site measurements in the Tabriz and Urmia. Figure. 6 shows a histogram of the difference between the actual and estimated GSR for these stations. Therefore, the GSR estimated from MODIS data was compared to the measurements of meteorological data and the results are shown that the RMSE of the MODIS derived GSR with the proposed methodology and the field measured GSR are 41.25 W/m2

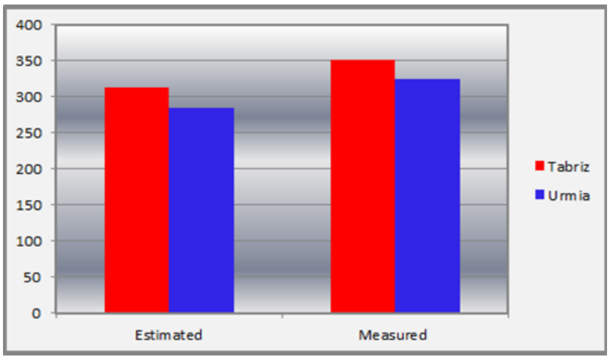

Figure 6: Histogram of estimated and measured global solar radiation for Tabriz and Urmia station

4. Conclusions

The Global Solar Radiation (GSR) constitutes the fundamental parameter that governs the climate of the lower atmosphere. Therefore, estimation of this parameter is very important and essential to agricultural, environmental, hydrological and ecological models.

In this study, we have used MODIS data with respect to high spatial and spectral resolution to estimate the GSR.

Estimating daily GSR using MODIS data, and considering methodology that has been proposed by Tang et al. (2006) and also Tasumi et al. (2000), To validate the global solar radiation that is estimated from the MODIS data. We compared proposed data with the measurements of meteorological data and validation results indicate that the RMS error is less than 41 W/m2

Finally, the error quantity in this method is compared to the values that have been estimated by Tang et al. (2006) at the Yu Cheng field site, China. Therefore, the error in this method is evaluated as approximately 41.25 W/m2 in the northwest of Iran by using MODIS satellite which is 21 W/m2 times more than that in China. The reason may be due to the difference in

The atmospheric conditions between China and Iran or ground measurement which are used, because these stations in Iran are not calibrated and are contains many errors, but more research in this field is needed.

It is proposed to consider atmospheric parameters such as cloud, water vapor and aerosol for estimating solar radiation. Also considering dust that is a new climatic phenomenon especially in west of Iran, and make some distributions, in future studies could be so important.

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