Integration of Remotely Sensed Digital Elevation Model Data and Geographic Information System Facilities to Estimate Net Solar Radiation Variances in Iraq (1987-2017)

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Abstract
The calculation of potential earth’s surface solar radiation is imperative for analyzing the atmosphere-vegetation-soil interaction process. Therefore, many schemes were introduced with direct (using net radiometer) or indirect (using air temperature or air plus soil temperatures) formulas. Three combinations of factors are known to control the \( R_n \) value; the astronomical based factors which determine the general spatial distribution of \( R_n \) values, the climatological factors which determine the assigned spatial variation of those values, and the topographical factors that influence climatological factors rates (i.e. have indirect effects on \( R_n \) values).

For Iraq, the ecosystem influences of global warming were obvious in the 1980s and the \( R_n \) rates approached peak values. Thereafter, the general behavior of \( R_n \) rates was geographically-based, i.e. increasing rates in the middle and southern regions and descending rates in the northern parts, since it was spatially correlated in a reverse manner with RH values. In the present study, this issue was clarified by utilizing the standard annual mean \( R_n \) rate known for Iraq’s weather, which was 9.8 MJ·m\(^{-2}\)·year\(^{-1}\). The results showed that, in 1987, the area with annual mean \( R_n \) equal or higher than this annual standard rate was 305088.09 km\(^2\). The area was reduced to 241984.77 km\(^2\) in 1997, followed by an expansion to 294491.136 km\(^2\) in 2007, and another reduction to 277272.542 km\(^2\) in 2017.

Keywords: extraterrestrial radiation, relative humidity, global warming, and MENA region
Introduction

The determination of potential earth’s surface solar radiation (commonly called the net solar radiation \( R_n \)) has a great importance in the analysis of the interaction processes of atmosphere-vegetation-soil in many fields, such as soil science, geotechnical engineering, environmental engineering, and agronomy [1, 2]. \( R_n \) stands for sun’s effective energy that reaches earth’s or crop’s surface, heats the soil and the surrounding air, and evaporates and transpires the water from the planet [3]. It represents the summation of “short plus long” wave radiation [4]. In any place on the earth, there are factors that interact to build a general pattern of net solar radiation values (i.e. specified spatial distribution of \( R_n \) values). These factors include the orbital movement of earth around the sun, that determines weather seasons (i.e. daily sun duration hours), and the geographical location according to latitude circles, which determines radiation incident angle (i.e. radiation path length inside the atmosphere) [5]. On the other hand, there are climatological factors that are responsible for causing variations in \( R_n \) spatial distribution. These factors are related to global and regional weather influences [6]. The most important factor is relative humidity (RH), as the near-surface water vapor absorbs, scatters, and reflects huge portions of \( R_n \) and contributes to fog, cloud, and rain generation. The value of RH inversely affects solar radiation [7, 8]. In addition, climatological and topographical factor have noticeable effects on \( R_n \), since they influence radiation path length in the atmosphere, air temperature, and humidity [9]. \( R_n \) could be measured in the field, using a net radiometer after some calibration to a parameter that is known as net radiometer sensitivity, or calculated using many equations that fall into two main methods; the first method merely depends on air temperature [10] while the second depends on both air and soil temperatures [11]. The calculation scheme is preferred because of the measurement errors that range from 10% to 25% of the measurement readings. In this research, the common scheme presented by an earlier study [1] was selected to calculate daily \( R_n \) for Iraq in the interval 1987-2017, utilizing the available meteorological data supplied by the Iraqi Meteorological and Seismic Organization. This scheme stated that:

\[
R_n = R_{ns} - R_{nl} = (1-\alpha) R_s - R_{nl}
\]  

Where:
- \( R_{ns} \) = net solar radiation (MJ. m\(^{-2}\). day\(^{-1}\)),
- \( R_{nl} \) = net long-wave radiation leaving the earth’s surface (MJ. m\(^{-2}\). day\(^{-1}\)),
- \( \alpha \) = radiation reflectance coefficient (albedo = 0.23),
- \( R_s \) = calculated or measured short-wave radiation that reaches earth’s surface plane.

Net long-wave radiation can be calculated using the following equation:

\[
R_{nl} = \sigma \left[ \left( T_{\text{max}} + 273 \right)^4 + \left( T_{\text{min}} + 273 \right)^4 \right] \frac{0.34 - 0.14(e_a)^{0.5}}{2} \left( 1.35 \frac{R_s}{R_{st}} - 0.35 \right)
\]

where:
- \( \sigma \) = constant of Stefan-Boltzmann (4.903 \times 10^{-8} (MJ. K\(^{-4}\). day\(^{-1}\)),
- \( T_{\text{max}} \) = the maximum temperature,
T_{min} = \text{the minimum temperature},
R_{so} = \text{calculated radiation of the clear sky (MJ m}^{-2}\text{ day}^{-1}),
\text{The rate of } R_s/R_{so} \text{ in Equation (2) will not exceed 1.}

Clear sky radiation is determined by:

\[ R_{so} = (0.75 \times 2 \times 10^{-5} z) R_a \]  

where:
Z = \text{elevation in meters above the sea level (for each station acquired from the digital elevation model),}
R_a = \text{extraterrestrial radiation (MJ. m}^{-2}\text{. day}^{-1}),
\text{is stated by:}

\[ R_a = \frac{24}{\pi} G_{sc} d_r \left[ \omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s) \right] \]  

where:
G_{sc} = \text{the solar constant} = 4.92 \text{ (MJ. m}^{-2}\text{. h}^{-1}),
d_r = \text{inverse of the square of relative Earth to Sun distance},
\omega_s = \text{sunrise hour angle (radians)},
\varphi = \text{latitude (radians)},
\delta = \text{solar declination (radians)},
The inverse of the square for relative Earth to Sun distance is given by:

\[ d_r = 1 + 0.033 \cos \left( \frac{2\pi J}{365} \right) \]  

where:
J is any day of the year and given by:

\[ J = D_M - 32 + \ln \left( \frac{275M}{9} \right) + 2\ln \left( \frac{3}{M+1} \right) + \ln \left( \frac{M}{100} - \frac{\text{Mod}(Y,4)}{4} + 0.975 \right) \]  

where:
D_M = \text{day of the month},
M = \text{month of the year},
Y = \text{year (4 digits)},
The latitude in degrees is converted to radians measurement by:

\[ \text{Radians} = \frac{\pi}{180} \times \text{degrees latitude} \]  

The declination of solar radiation is:

\[ \delta = 0.409 \sin \left( \frac{2\pi J}{365} - 1.39 \right) \]  

While sunset angle is:

\[ \omega_s = \arccos \left[ -\tan(\varphi) \tan(\delta) \right] \]  

\textbf{Study Area}

Iraq is one of the WANA (West Asia and North Africa) region countries, which is commonly called MENA region. It lays in the northeastern part of this region, with climate that is described to be arid to semi-arid, as annual rainfall does not exceed 250-300 millimeters. Iraq coordinates are:

Longitudes; (38º 45') to (48º 45') East.
Latitudes; (29º 5’) to (37º 22’) North. Its area is 438,320 square kilometers, with 21% constituting water plane surfaces (i.e. lagoons, marshes, and rivers), as shown in Figure-1.

**Figure 1-** Geographical location of the study area within the WANA region

The green-house gases are known to cause rapidly increment in global warming effects, which become more severe as average air temperature increases, relative humidity rates decrease, and overall annual rainfall decreases. For Iraq, this results in an increment in net solar radiation and evapotranspiration rates, so that a lack in water resources is becoming an obvious fact, causing a rapid reduction in Iraq’s animal and agricultural resources.

**Materials and Methods**

In 1980s, the environmental influences of global warming were clear and reached peak values. Using this fact as a start point, this research adopted the aim of quantitatively revealing the fluctuations of these influences on Iraq’s annually net solar radiation rates during the last thirty years. To accomplish this purpose, two kinds of data were adopted; The first kind of data was specified meteorological readings from 9 stations, which were selected to have a comprehensive distribution in order to cover all Iraq’s area, for ten year intervals during a temporal range of 1987 to 2017, as illustrated in Figure-2.
The weather readings were composed of monthly mean relative humidity, monthly mean maximum temperature, and monthly mean minimum temperature. The second kind of data was the height (Z) above sea level (m ASL) for each station. These data were acquired from ASTER “Global-Digital Elevation Model” satellite image for Iraq with spatial resolution equal to 30 meters for each pixel, as shown in Figure-3.
**Figure 3**- Global Digital Elevation Model of Iraq with 30 m pixel spatial resolution.

The utilized equations for determining net solar radiation are daily measurement equations; each mean monthly meteorological reading was expanded to be daily reading, by adopting a mathematical rule (the mean of a list of values could stand for each value, but the reverse is not true). The remaining information \( (R_a, R_s, R_{so}, R_{ns}, R_{nl}, and e_a) \) were calculated, where the remotely sensed acquired height \((Z)\) was used to calculate \(R_{so}\).

Table-1 is an illustrative example of daily variables utilized for net solar radiation determination of Baghdad in the first of January, 1987.

| \(d_r\) | \(\Phi\) | \(\delta\) | \(\omega_s\) | \(R_a\) | \(Z\) | \(R_{so}\) | \(T_{max}\) | \(T_{min}\) | \(R_{nl}\) | \(R_s\) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.0329 | 0.5791 | -0.401 | 1.289 | 18.046 | 31 | 13.545 | 18.6 | 2.6 | 4.1307 | 11.549 |

By using these variables in equation (1), the results of daily \(R_n\). Then, the annual mean \(R_n\) values of each assigned year were calculated, as shown in Table-2.

**Table 2**- Annual mean \(R_n\) values for the studied meteorological stations (1987, 1997, 2007, and 2017).

| Admin. | longitude (Dec. deg.) | latitude (Dec. deg.) | 1987’s \(R_n\) (MJ.m\(^{-2}\).year\(^{-1}\)) | 1997’s \(R_n\) (MJ.m\(^{-2}\).year\(^{-1}\)) | 2007’s \(R_n\) (MJ.m\(^{-2}\).year\(^{-1}\)) | 2017’s \(R_n\) (MJ.m\(^{-2}\).year\(^{-1}\)) |
|---|---|---|---|---|---|---|
| Baghdad | 44.35256 | 33.273364 | 10.22 | 9.932 | 10 | 10.117 |
| Basra | 47.47 | 30.31 | 9.807 | 9.889 | 9.816 | 9.938 |
| Dewaniya | 44.57 | 31.57 | 9.799 | 9.875 | 9.899 | 10.483 |
| Emara | 47.20497 | 31.810161 | 9.947 | 9.869 | 9.861 | 9.765 |
| Karkuk | 44.36666 | 35.410581 | 9.11 | 9.153 | 9.545 | 8.479 |
| Nasiriya | 46.31705 | 31.001656 | 10 | 10.021 | 9.914 | 10.113 |
| Rutba | 40.27356 | 33.056428 | 9.827 | 9.779 | 9.871 | 9.974 |
| Hai | 46.07636 | 32.126716 | 9.643 | 9.753 | 9.685 | 9.617 |
| Mosul | 43.15425 | 36.28746 | 9.842 | 9.902 | 9.503 | 9.4 |

The next step was converting each year’s \(R_n\) annual mean reading into a point shapefile using Arc GIS 10.5 environment. Then, the Inverse Distance Weighting (IDW) spatial interpolation Arc tool was utilized to estimate the annual mean net solar radiation for all Iraq’s area, as shown in Figure-4.
Figure 4- A. The annual mean net solar radiation of Iraq in 1987, B. The annual mean net solar radiation of Iraq in 1997, C. The annual mean net solar radiation of Iraq in 2007, and D. the annual mean net solar radiation of Iraq in 2017.

Results and Discussion

In arid to semi-arid regions such as Iraq, the main climatological factor that affects \( R_n \) is relative humidity; effects of clouds, dust, and other particles, as well as topographic features, are considered less important. Iraq’s daily climate is a result of two regions of climate interaction; these are the subtropical aridity of the Arabian Desert and the subtropical humidity of the Arabian Gulf. RH annual mean values for Iraq are stated to range between 31 and 50%. Topographic factors in Iraq's northern
parts cause relative humidity rates higher than those in the middle and southern parts. The rates of RH annual means and their variations in the studied time-interval due to those two climate interaction are illustrated in Table-3.

**Table 3-** Annual mean relative humidity rates and their variations for some Iraqi administrative regions (1987)

| Administrative area | 1987 | 1997 | 2007 | 2017 | 1997-1987 percentage variation | 2007-1987 percentage variation | 2017-1987 percentage variation |
|---------------------|------|------|------|------|---------------------------------|---------------------------------|---------------------------------|
| Baghdad             | 41.2 | 47.4 | 39   | 37.8 | 15.04854                        | -5.33981                        | -8.25243                        |
| Basra               | 41.7 | 43.4 | 40.3 | 37.4 | 4.076739                         | -3.35731                        | -10.3118                        |
| Dewaniya            | 48   | 49.8 | 45   | 45.9 | 3.75                             | -6.25                           | -4.375                          |
| Emara               | 47.1 | 46.6 | 46.9 | 38  | -1.06157                         | -0.42463                        | -19.3206                        |
| karkuk              | 43.2 | 50   | 44.3 | 46.8 | 15.74074                        | 2.546296                        | 8.333333                        |
| Nasiriya            | 38.3 | 45.8 | 39.3 | 33.2 | 19.58225                        | 2.610966                        | -13.3159                        |
| Rutba               | 46.7 | 51.3 | 45   | 43  | 9.850107                         | -3.64026                        | -7.92291                        |
| Hai                 | 45.8 | 42.7 | 41.9 | 40.4 | -6.76856                        | -8.51528                        | -11.7904                        |
| Mosul               | 50   | 54.8 | 50.5 | 52  | 9.6                             | 1                               | 4                               |

in the studied time-interval variations of relative humidity rates restricted (Rn annual means) to change. This is shown in Table-4.

**Table 4-** Percentage variation of net solar radiation values for some Iraqi administrative regions (1987).

| Administrative areas | (1997-1987) percentage variation | (2007-1987) percentage variation | (2017-1987) percentage variation |
|----------------------|---------------------------------|---------------------------------|---------------------------------|
| Dewaniya             | 0.81716                         | 1.02145                         | 7.048008                        |
| Emara                | -0.70423                        | -0.80483                        | -1.81087                        |
| Hai                  | 1.141079                        | 0.414938                        | -0.3112                         |
| Karkuk               | 0.439078                        | -6.25686                        | -7.02525                        |
| Mosul                | 0.609756                        | -3.45528                        | -4.47154                        |
| Nasiriya             | 0.2                             | -0.9                            | 1.1                             |
| Baghdad              | -2.83757                        | -2.15264                        | -1.07632                        |
| Basra                | 0.816327                        | 0.102041                        | 1.326531                        |
| Rutba                | -0.50916                        | 0.509165                        | 1.527495                        |

As can be quantitatively noticed from Table-4, the 1980s decade had the peak Rn rates all over Iraq. Then, the general behavior of Rn rates was geographically based, i.e. raising in the middle and southern regions and descending in the northern regions). However, to clarify this behavior of the net solar radiation rates since 1987, a standard annual mean Rn rate of Iraq weather was selected as a basis to evaluate the areas with equal or higher values compared to this standard. This selected standard annual mean Rn value was $9.8\text{MJ.m}^{-2}\text{.year}^{-1}$. This "geographically based phenomenon" is shown in Figure-5.
Conclusions

- Annual mean values of relative humidity for Iraq ranged 31-50%, which resulted from the interaction of subtropical arid climate of the Arabian Desert and subtropical humid climate of the Arabian Gulf.
- Relative humidity rates in Iraq's northern parts were higher than those in the middle and southern parts, because of the topographic factor effects.
• In Iraq, Rn is majorly influenced by relative humidity, as compared to effects of clouds, dust, and topographic features which are considered less important.

• In this work, it is obvious that the 1980s decade had the peak Rn rates all over Iraq. After that, the general behavior of net solar radiation rates was geographically based, i.e. raising in middle and southern regions and descending in the northern parts of Iraq.

References
1. Hanan, A. and Hasan, B. 2008. The role of geographic information system in laban valley basin morphometric characteristics study, MSc thesis, king Saud university.
2. Hajam, R.A., Hamid A., and Bhat, S.U. 2013. Application of Morphometric Analysis for Geo-Hydrological Studies Using Geo-Spatial Technology. *Hydrology Current Research Journal*, 4(3): 1-12
3. Atiiaa, A.M. and Abdul-Qadir, A.M. 2012. Using fuzzy logic for estimating monthly pan evaporation from meteorological data in Emara/ South of Iraq, *Baghdad Science Journal*, 9(1): 133-140
4. Jain, V. and Sinha, R. 2003. Evaluation of Geomorphic Control on Flood Hazard through Geomorphic Instantaneous Unit Hydrograph. *Current Science*, 85(11): 26-32
5. AL-Salihi, A. M., M. K. M. and Mohammed, A. J. 2010. Estimation of Global Solar Radiation on Horizontal Surface Using Routine Meteorological Measurements for Different Cities in Iraq. *Asian Journal of Scientific Research*, 3(4): 240-248
6. Alados I, Foyo-Moreno I, Olmo FJ, Alados-Arboledas L. 2003. Relationship between net radiation and solar radiation for semi-arid shrub-land. *Agricultural and Forest Meteorology journal*, 116(3): 221-7.
7. Jawad, L.A. 2019. The Al-Abiadh Valley Drainage Basin Environmental Aspects Extraction Using Quantitatively Morphometric Analyses of Shuttle Radar Topographic Mission Data, *Baghdad Science Journal*, 2019, 16(1): 97-103
8. Mudashiru, R., Olawuyi B.M., Yusuf, A.I. and Oyelakin M.A. 2017. Morphometric Analysis of Asa and Oyun River Basins, North Central Nigeria Using Geographical Information System, *American Journal of Civil Engineering*, 5(6): 379-393
9. Long D, Gao Y, Singh VP. 2010. Estimation of daily average net radiation from M ODIS data and DEM over the Baiyangdian watershed in North China for clear sky days, *Journal of Hydrology*, 38(3): 217-33.
10. Jawad, L.A. 2016. The Climatic Quality Index Determination for Iraq Using Meteorological Stations Data, *Iraqi Journal of Science*, 57(4C): 3005-3016
11. Rubio E, Caselles V. and Badenas C. 1997. Emissivity measurements of several soils and vegetation types in the 8 - 4 mm wave band: analysis of two field methods. *Remote Sensing of Environment*, 59(3): 490 - 521.