DOI: 10.24996/ijs.2022.63.6.38

ISSN: 0067-2904

# Demonstration of Net Solar Radiation Geographical Behavior Revers Correlation with Relative Humidity in Iraq

**Laith Azeez**

*Department of Remount Sensing, Collage of Since, University of Bagdad, Iraq*

Received: 13/7/2020 Accepted: 3/10/2021 Published: 30/6/2022

**Abstract**

It is common that extraterrestrial solar radiation $R_a$ value lessen due to the interaction with atmosphere components to result a net solar radiation $R_n$ value about one third of $R_a$ for most measurements on earth. Net solar radiation had major impact on air temperature ($T_o$) value statement. So, its estimation is crucial for analyzing the interaction of (atmosphere-vegetation-soil).

Many methodologies available for this aim directly (with radiometer) or indirectly (with air temperature-based formula or soil plus air temperatures-based formula). The peak influences of global warming phenomenon were in eighties decade of the last century, yielding Iraq $R_n$ rates to get climax after that $R_n$ rates behaved in geographical based style, so those rates raised in middle and south regions of Iraq, and descending in its northern parts. The reason (as demonstrated in this research) was the spatial correlation in a reverse manner with RH rates all over Iraq.

**Keywords:** relative humidity, global warming, GIS, and extraterrestrial solar radiation

# أثبات الارتباط العكسي للسلوك الجغرافي للاشعاع الشمسي الصافي مع الرطوبة النسبية في العراق

**ليث عزيز**

وحدة الاستشعار عن بعد، كلية العلوم، جامعة بغداد، بغداد، العراق

**الخلاصة**

من المتعارف ان قيمة الاشعاع الشمسي خارج الغلاف الجوي$R_a$ تقل بسبب التفاعل مع مكونات الغلاف الجوي لتنتج اشعاعا شمسيا صافيا$R_n$ قيمته تقارب الثلث من قيمة ال $R_a$ لاغلب القراءات على كوكب الارض. الاشعاع الشمسي الصافي له تاثير بالغ في تحديد قيمة درجة حرارة الهواء $T_o$. لذلك تحديد قيمة ال $R_n$ يعد امرا جوهريا في تحليل عملية التفاعل بين (الغلاف الجوي– النبات–التربة).

كثير من الطرق متوفرة لهذا الغرض منها مباشرة (باستعمال جهازال radiometer) ومنها غير المباشرة (باستعمال صيغ تعتمد على حرارة الهواء أو حرارة التربة مع الهواء معا). التأثيرات العظمى لظاهرة الاحتباس الحراري كانت في العقد الثمانيني من القرن الماضي، جاعلة نسب ال $R_n$ في ذروتها خلال ذلك العقد وبعد ذلك اصبح سلوكها وفقا لمنحى جغرافي، لذلك نسب ال$R_n$ زادت في مناطق وسط وجنوبي العراق وقلت في اجزاءه الشمالية. السبب وراء هذا السلوك (كما تم اثباته بهذا البحث) هو الارتباط المكاني وبسياق عكسي مع قيم الرطوبة النسبية في عموم العراق.

*Email: laithazeez@scbaghdad.edu.iq

**Introduction**

At any place on earth, the net solar radiation ($R_n$) value stated according many factors; Those could be categorized into three kinds of factor groups; the first kind of these factors had astronomical reference (the extraterrestrial solar radiation which influenced by earth's temporal distance from the sun and the location distance from the equator line) [1,2]. Second kind had climatic reference (clouds, fog, suspended dust grains, suspended particles in the air such as smoke and carbon oxides molecules, and relative humidity) [2]. The third kind had topographical reference that relates to existence of mountains, water surface planes, and vegan land cover, because the existence of those surface features increase relative humidity rates at the region yielding $R_n$ rates decrement, while neighboring regions $R_n$ rates are not affected [3,4]. The difference among the climatic factors kind and other kinds' factors is that every climate factor suffers many random variations around the year, while other kinds' variations happened in common behavior such as the earth's temporal distance from the sun, so that the identification of every climate variable that had major influence on $R_n$ value is vital because any sudden variation in its value leads to same variation in $R_n$'s one [5]. For Iraq, its weather is considered arid to semi-arid one which resulted from two different areas weather interaction; those are (Arabian Gulf) subtropical humidity weather and (Arabian Desert) subtropical aridity weather [6]. The importance of net solar radiation determination (measured or calculated) being from crucial fact which is: at any place, net solar radiation value is considered to be the major factor that determines air temperature near ground surface ($T_o$) which controls maximum temperature ($T_{max}$) and minimum temperature ($T_{min}$) during the day [7]. The experimental equation for $R_n$ calculation includes only measurable variables. However; it was efficient in assessing $R_n$ values with very small root mean square error comparing with measured values [8], this equation is:

Note: Move all these equations to the section material and methods or add new section as experimental equations within section material and methods, please.

$$R_n = R_{ns} - R_{nl} = (1-\alpha)\, R_s - R_{nl} \quad \ldots\ldots (1)$$

Where:

$R_n$ = 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 or (albedo = 0.23)

$R_s$ = calculated or measured short-wave radiation that reaches earth's surface plane (MJ. $m^{-2}$. $day^{-1}$), as given in the following equation:

$$Rs_s = 0.16 \times R_a \times (T_{max}-T_{min})^{0.5} \quad \ldots\ldots (2)$$

$e_a$ = actual water vapor pressure KPa, as given in the following equation:

$$e_a = 0.611 \times \exp\,(17.27T_{min} / T_{min}+273.3) \quad \ldots\ldots (3)$$

$$e_s = 0.611 \times ((17.27T_{max} / T_{max}+273.3) + (17.27T_{min} / T_{min}+273.3)) \quad \ldots\ldots (4)$$

$$RH = (e_a/e_s) \times 100\% \quad \ldots\ldots (5)$$

$$R_{nl} = \sigma\left[\frac{(T_{max}+273)^4+(T_{min}+273)^4}{2}\right]\left[0.34-0.14(e_a)^{0.5}\right]\left(1.35\frac{R_s}{R_{so}}-0.35\right) \quad \ldots\ldots (6)$$

Where:

σ; Constant of Stefan-Boltzmann = (4.903 × 10-9(MJ. $K^{-4}$. day-$^{1}$).

$T_{max}$; the maximum temperature.

$T_{min}$; the minimum temperature.

$R_{so;}$ calculated radiation of the clear sky (MJ m-2 day-1).

The rate Rs/Rso in Equation (6) won't exceed 1.

Clear sky radiation determined by:

$$R_{so} = (.75 \times 2 \times 10^{-5}\, z)\, R_a \quad \ldots\ldots (7)$$

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

$$R_a = \frac{24}{\pi} G_{sc} d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right] \quad \text{… (8)}$$

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

$$d_r = 1 + 0.033\cos\left(2\pi\frac{J}{365}\right) \quad \text{……. (9)}$$

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

$$J = D_M - 32 + Int\left(\frac{275M}{9}\right) + 2Int\left(\frac{3}{M+1}\right) + Int\left(\frac{M}{100} - \frac{Mod(Y,4)}{4} + 0.975\right) \quad \text{……. (10)}$$

Where:
$D_M$ ; day of the month.
M; month of the year.
Y; year (4 digits).
The latitude in degrees is converted to radians measurement by:

$$\text{Radians} = \frac{\pi}{180} \times \text{degrees latitude} \quad \text{……. (11)}$$

The declination of solar radiation is:

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right) \quad \text{……. (12),}$$

while the sunset angle is:

$$\omega_s = \arccos\left[-\tan(\varphi)\tan(\delta)\right] \quad \text{…. …. (13)}$$

The utilized variables are:
(**$d_r$, $\Phi$, $\delta$, $\omega_s$, $R_a$, $R_a$, Z, $R_{so}$, $T_{max}$, $T_{min}$, $e_a$, $R_{nl}$, and $R_s$** ).
The aim of this search is the recognition of most effective climate variable or variables in Iraq on net solar radiation behavior.

**Study Area**

Iraq locates in the northeastern part of west Asia region with rainfall annually summation range between (250-300) mm which restrict Iraq weather to be arid to semi-arid [9]. Iraq geographic area extensions are (38º 45') _ (48º 45') East and (29º 5') _ (37º 22') North. Iraq regions covered 438,320 square kilometers with 21% of this area as water surfaces such as marshes, lakes, lagoons, and rivers. This can be seen in Figure 1.

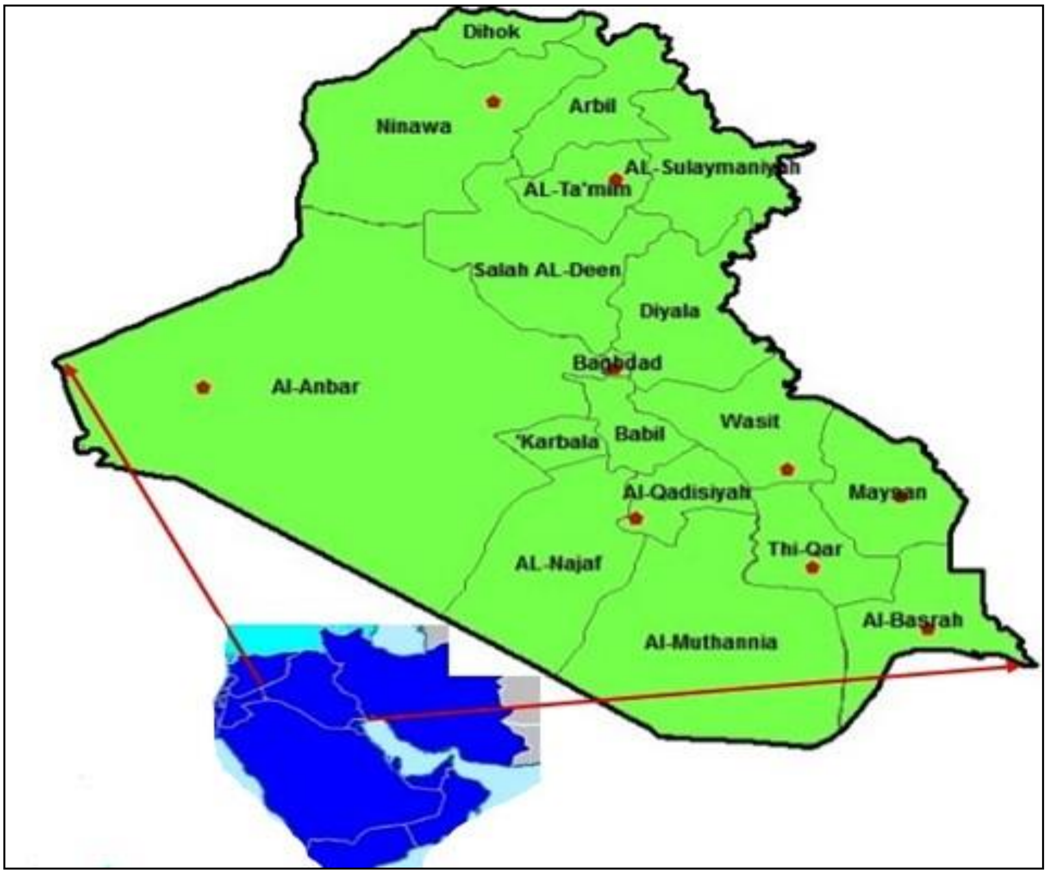


**Figure1-**Geographic location of the study area in North Asia region with the position of adopted meteorological stations.

**Material and Methods**

To recognize the most effective climate variable in Iraq on $R_n$ behavior, the readings of $R_n$ and climate factors values must be taken for a long time period in order to certify the behavior correlation between $R_n$ and the specified climate factor, so the readings for each decade were acquired from 1987 to 2017 (i.e. 1987, 1997, 2007, and 2017). Iraq's area coverage was achieved using nine meteorological stations (that are geographically well distributed inside Iraq) to get climate data. To obtain accurate height for each meteorological station which is important to calculate ($R_{SO}$) value, the Digital Elevation Model mosaic satellite imagery of Iraq was formed using tail imageries of ASTER Global DEM sat. with (30 by 30) meters pixel resolution.

To avoid the $R_n$ value variation due to the variation of earth distance from sun (i.e., due to the variation of astronomical origin factor); the annual average value for $R_n$ was adopted in this search, the average value function is to fix "earth- sun" distance at one interval only. The $R_n$ annual average readings for (1978 -2017) were illustrated in Table 1:

**Table 1-**Iraq's $R_n$ annual average data for the years (1987, 1997, 2007, and 2017)

| Admin. | Longitude (Dec.Deg.) | Latitude (Dec.Deg.) | 1987 $R_n$ ($MJ.m^{-2}.day^{-2}$) | 1997 $R_n$ ($MJ.m^{-2}.day^{-2}$) | 2007 $R_n$ ($MJ.m^{-2}.day^{-2}$) | 2017 $R_n$ ($MJ.m^{-2}.day^{-2}$) |
|---|---|---|---|---|---|---|
| **Basra** | **47.47** | **30.31** | **9.807** | **9.889** | **9.816** | **9.938** |
| **Nasiriya** | **46.31705** | **31.001656** | **10** | **10.021** | **9.914** | **10.113** |
| **Al Diwaniyah** | **44.57** | **31.57** | **9.799** | **9.875** | **9.899** | **10.483** |
| **Amara** | **47.20497** | **31.810161** | **9.947** | **9.869** | **9.861** | **9.765** |
| **Al hai** | **46.07636** | **32.126716** | **9.643** | **9.753** | **9.685** | **9.617** |
| **Al-Rutba** | **40.27356** | **33.056428** | **9.827** | **9.779** | **9.871** | **9.974** |
| **Baghdad** | **44.35256** | **33.273364** | **10.22** | **9.932** | **10** | **10.117** |
| **Kirkuk** | **44.36666** | **35.410581** | **9.11** | **9.153** | **9.545** | **8.479** |
| **Mosul** | **43.15425** | **36.28746** | **9.842** | **9.902** | **9.503** | **8.236** |

The factors in the equation (2) and others which control any region daily weather were studied factors; those are ($T_{max}$, $T_{min}$, RH, wind speed, and rainfall).

The next table (Table 2) is an illustrative example for these factors and annual average readings in 1987.

**Table 2-**Iraq's annual average readings for ($T_{max}$, $T_{min}$, RH, wind speed) and annual rainfall in 1987

| Admin. | 1987 max. temp.($c^{\circ}$) | 1987 min. temp.($c^{\circ}$) | RH (%) | Wind speed ($m.sec^{-1}$) | Rainfall (mm) |
|---|---|---|---|---|---|
| **Basra** | **27.1** | **13.3** | **41.7** | **4.15** | **87.1** |
| **Nasiriya** | **30.9** | **15.2** | **38.3** | **5.5** | **74.6** |
| **Al Diwaniyah** | **27.7** | **12.8** | **48** | **3.15** | **77.8** |
| **Amara** | **32.4** | **18.7** | **47.1** | **3.55** | **117.1** |
| **Al hai** | **33.3** | **19.6** | **45.8** | **4.35** | **150** |
| **Al-Rutba** | **32.7** | **18.2** | **46.7** | **3.19** | **91.5** |
| **Baghdad** | **33** | **18.3** | **41.2** | **3.41** | **49.9** |
| **Kirkuk** | **32.1** | **17.9** | **43.2** | **1.53** | **306** |
| **Mosul** | **29** | **16.6** | **50** | **1.64** | **343.4** |

## Results and Discussions

The behavior correlation between $R_n$ and any climate variable could be observed using two dimensional charts, as shown in Figures (2-7).

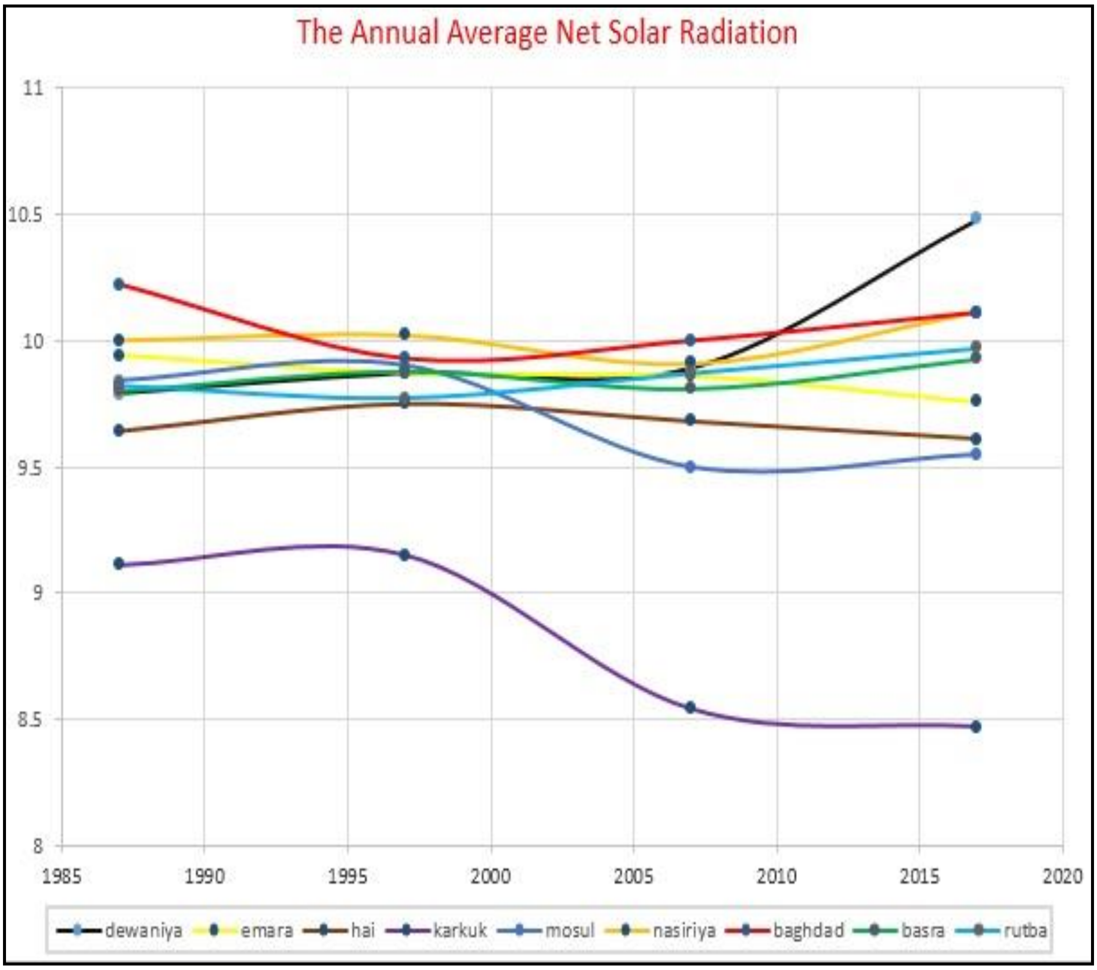


**Figure 2-** Annual average net solar radiation.

The experimental equations used to assess $R_{ns}$ and $R_{nl}$ values were the reason of variance between actual $R_n$ value and the potential one, because the formula of those equations utilized measurable variables and did not contain all affecting variables on $R_n$ value such as wind speed, rainfall, fog, smoke,...etc.. They are mainly temperature based equations, so the Figure 2 illustrates that Kirkuk always had the lowest $R_n$ values in Iraq because of the small gradient between daily $T_{max}$ and $T_{min}$ for this province comparing with other provinces in Iraq which affect $R_s$ value, as shown in equation (2).

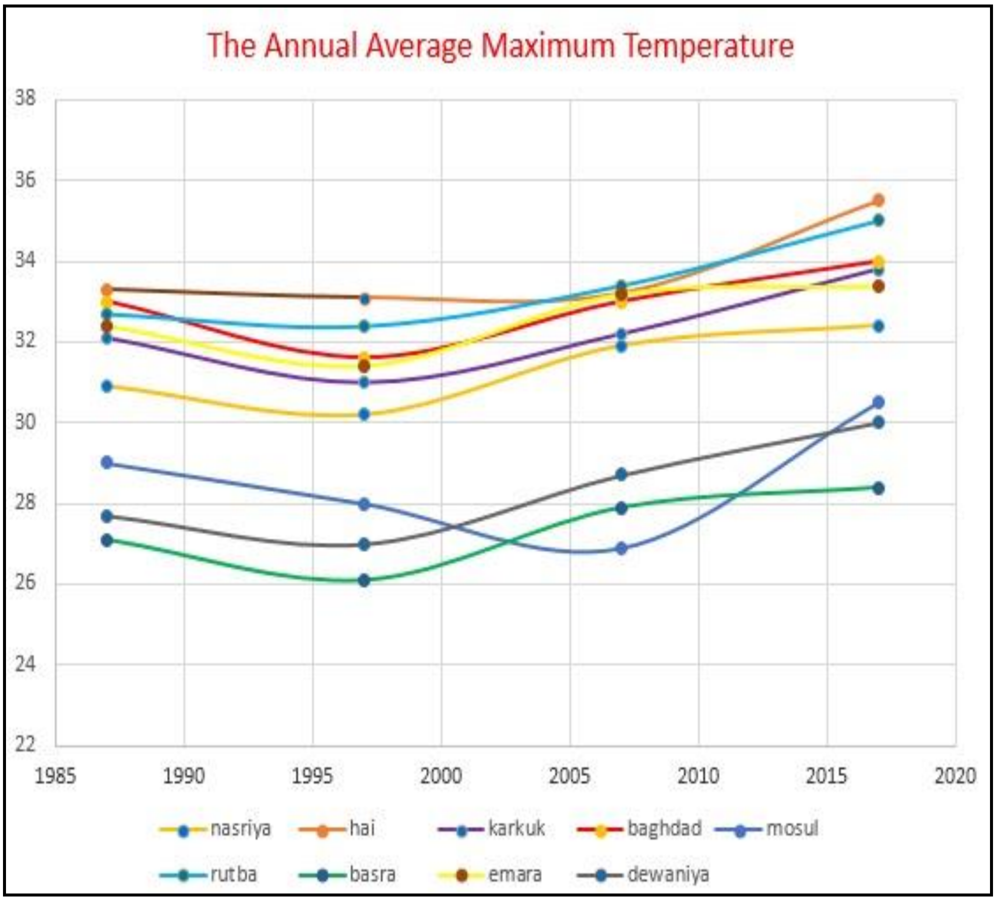


**Figure 3-** The annual average maximum temperature.

Figure 3 revealed the fact of air maximum temperature mainly dependence on $R_n$ (i.e., the directional property between the annual mean of $R_n$ and $T_{max}$ without an exact behavior correlation), so that an illustrative example will be taken for Kirkuk station in 1987 on 1 January and 1 February, as shown in Table 3.

**Table 3**-Illustrative example of Kirkuk station variables that changed between 1 January and 1 February in 1987

| day | Tmax (c°) | Tmin (c°) | Uz m | Rs ($MJ.m^{-2}.day^{-2}$) | Ea KPa | Rso ($MJ.m^{-2}.day^{-2}$) | Rns ($MJ.m^{-2}.day^{-2}$) | Rnl ($MJ.m^{-2}.day^{-2}$) | Rn ($MJ.m^{-2}.day^{-2}$) |
|---|---|---|---|---|---|---|---|---|---|
| **01-Jan.** | **16.6** | **5** | **0.8** | **9.129902** | **0.872** | **12.67637** | **7.030025** | **3.210765** | **3.81926** |
| **01-Feb.** | **18.6** | **8.1** | **1.6** | **10.45536** | **1.081** | **15.25817** | **8.05063** | **3.073568** | **4.977061** |

On 1 January $R_n$ was 3.8192 and $T_{max}$ was 16.6, while on 1 February $R_n$ was 4.977061with an increment 30.31 % and $T_{max}$ was 18.6 with an increment 12.04 %.

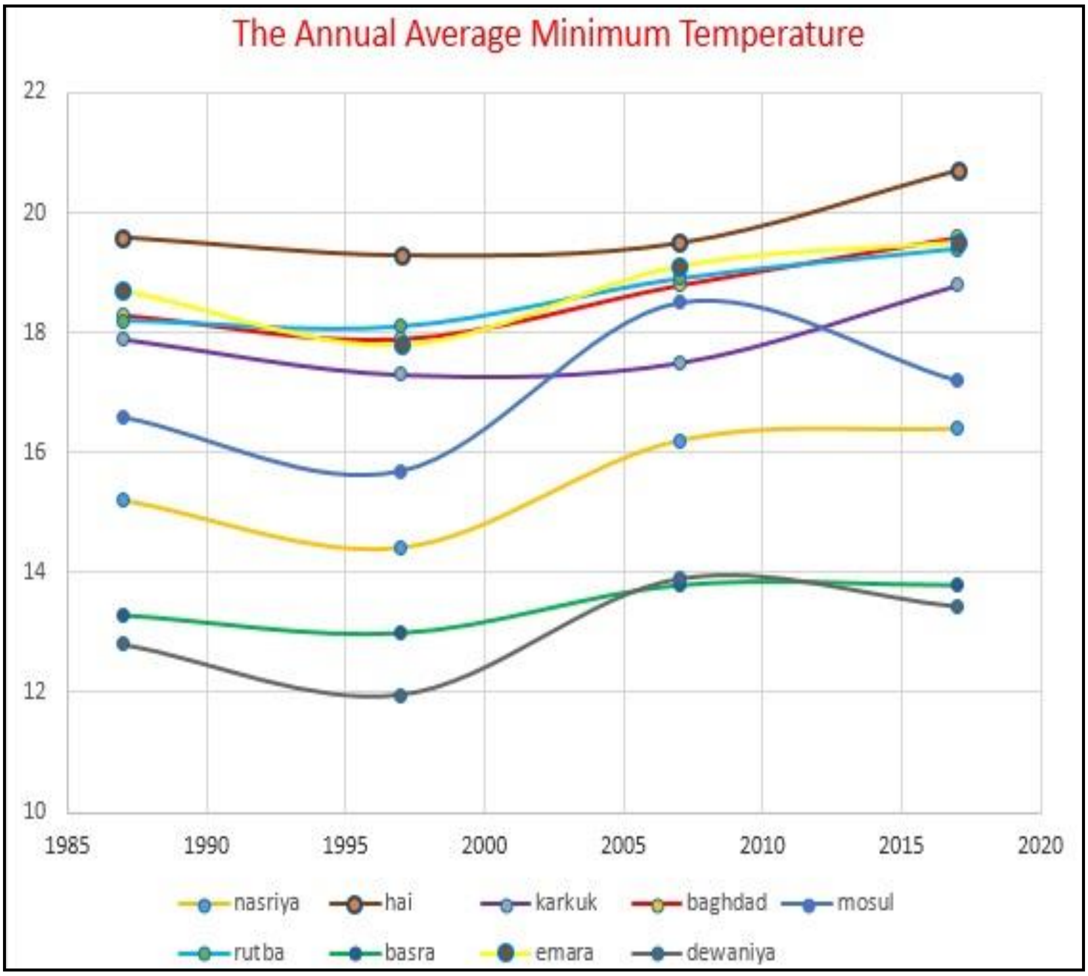


**Figure 4-**The annual average minimum temperature.

Figure (4) showed the main dependence fact of air minimum temperature on $R_n$ (i.e. the directional property between the annual mean of $R_n$ and $T_{max}$ without an exact behavior correlation), so the same example in Table 3 was taken as follows.

On 1 January $R_n$ was 3.8192 and $T_{min}$ was 5, whereas on 1 February $R_n$ was 4.977061 with an increment 30.31 % and $T_{min}$ was 8.1 with an increment 62 %.

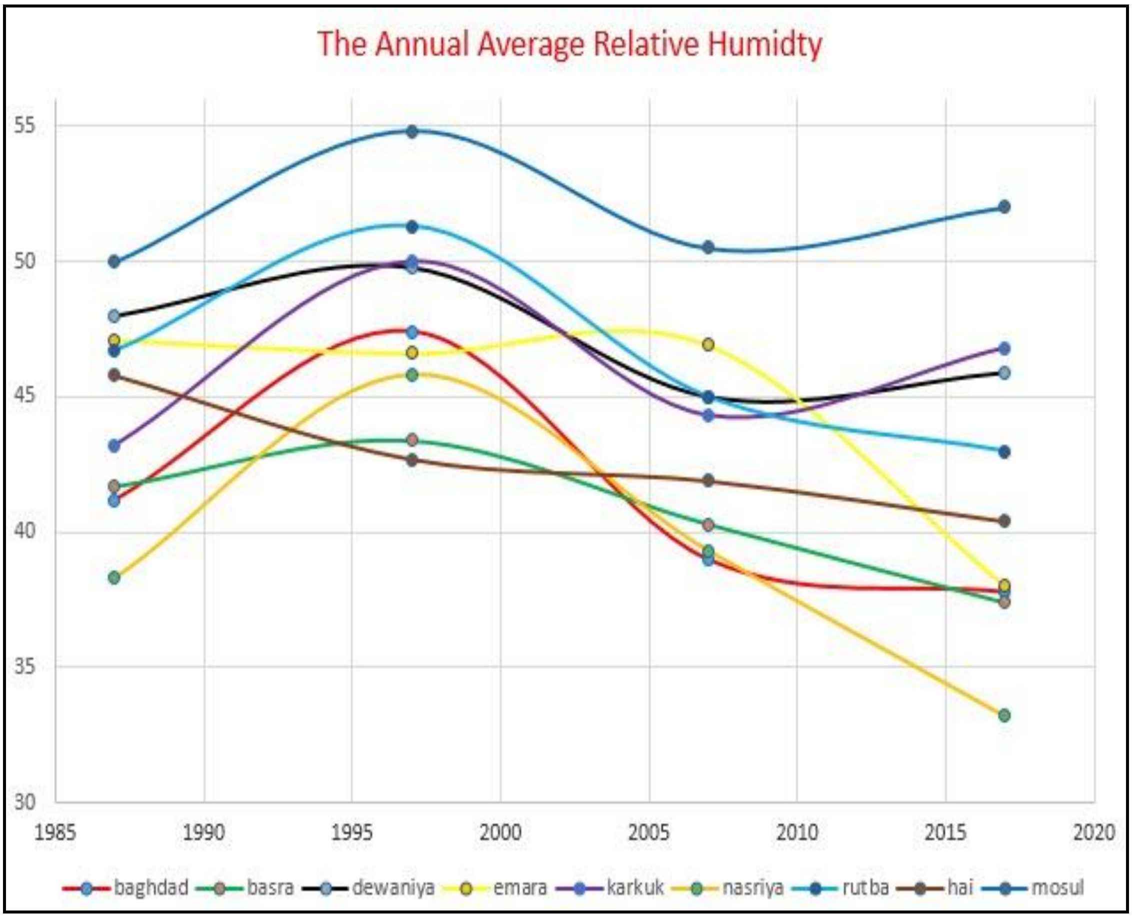


**Figure 5-**The annual average relative humidity.

Figure 5 clarified the general behavior of reverse correlation between RH and $R_n$ values, since RH influenced by actual water vapor pressure $e_a$ value as shown in equation(5). RH affected $R_n$ value in a reverse manner while its effect on $T_{max}$ and $T_{min}$ values in a direct manner. Tables 4 and 5 illustrate this behavior using $R_n$ and RH variations in 1987 for all adopted stations.

**Table 4-**1987's Rn value for all adopted stations and their percentage variations in 1997, 2007, and 2017.

| Administrative | $R_n$ 1987 (MJ.m$^{-2}$.day$^{-2}$) | 97-87 variation % | 007-87variation % | 17-87 variation % |
|---|---|---|---|---|
| Basra | 9.8 | 0.81633 | 0.10204 | 1.32653 |
| Nasiriya | 10 | 0.2 | -0.9 | 1.1 |
| Al Diwaniyah | 9.79 | 0.81716 | 1.02145 | 7.04801 |
| Amara | 9.94 | -0.70423 | -0.80483 | -1.81087 |
| Al hai | 9.64 | 1.14108 | 0.41494 | -0.3112 |
| Al Rutba | 9.82 | -0.50916 | 0.50916 | 1.52749 |
| Baghdad | 10.22 | -2.83757 | -2.15264 | -1.07632 |
| Kirkuk | 9.11 | 0.43908 | -6.25686 | -7.02525 |
| Mosul | 9.84 | 0.60976 | -3.45528 | -2.94715 |

**Table 50**1987's RH value for all adopted stations and their percentage variations in 1997, 2007, and 2017

| administrative | RH 1987 (%) | 97-87 variation% | 007-87 variation% | 017-87 variation% |
|---|---|---|---|---|
| **Basra** | **41.7** | **4.076739** | **-3.35731** | **-10.3118** |
| **Nasiriya** | **38.3** | **19.58225** | **2.610966** | **-13.3159** |
| **Al Diwaniyah** | **48** | **3.75** | **-6.25** | **-4.375** |
| **Amara** | **47.1** | **-1.06157** | **-0.42463** | **-19.3206** |
| **Al-hai** | **45.8** | **-6.76856** | **-8.51528** | **-11.7904** |
| **Al Rutba** | **46.7** | **9.850107** | **-3.64026** | **-7.92291** |
| **Baghdad** | **41.2** | **15.04854** | **-5.33981** | **-8.25243** |
| **Kirkuk** | **43.2** | **15.74074** | **2.546296** | **8.333333** |
| **Mosul** | **50** | **9.6** | **1** | **4** |

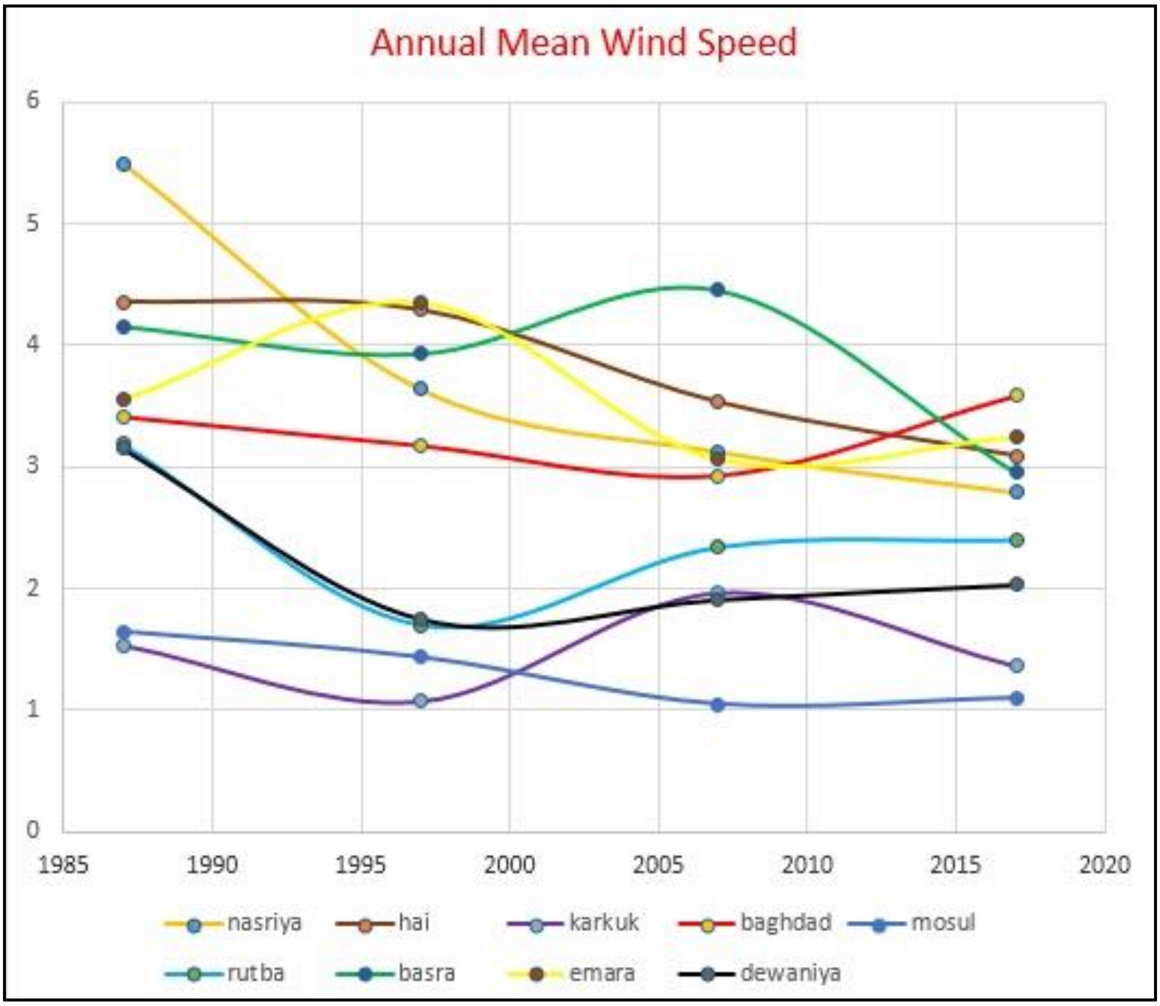


**Figure 6-**The annual average wind speed.

From figure 6, the directional property between the annual mean of $R_n$ and wind speed was displayed without an exact behavior correlation, since the wind speed depends on air temperature To, so the previous example in Table 3 was used as the following:
The $R_n$ value was 3.8192 and $U_z$ value was 0.8 on 1 January, but on 1 February $R_n$ value was 4.97706 with an increment 30.31 % and $U_z$ value was 1.6 with an increment 100% for same date.

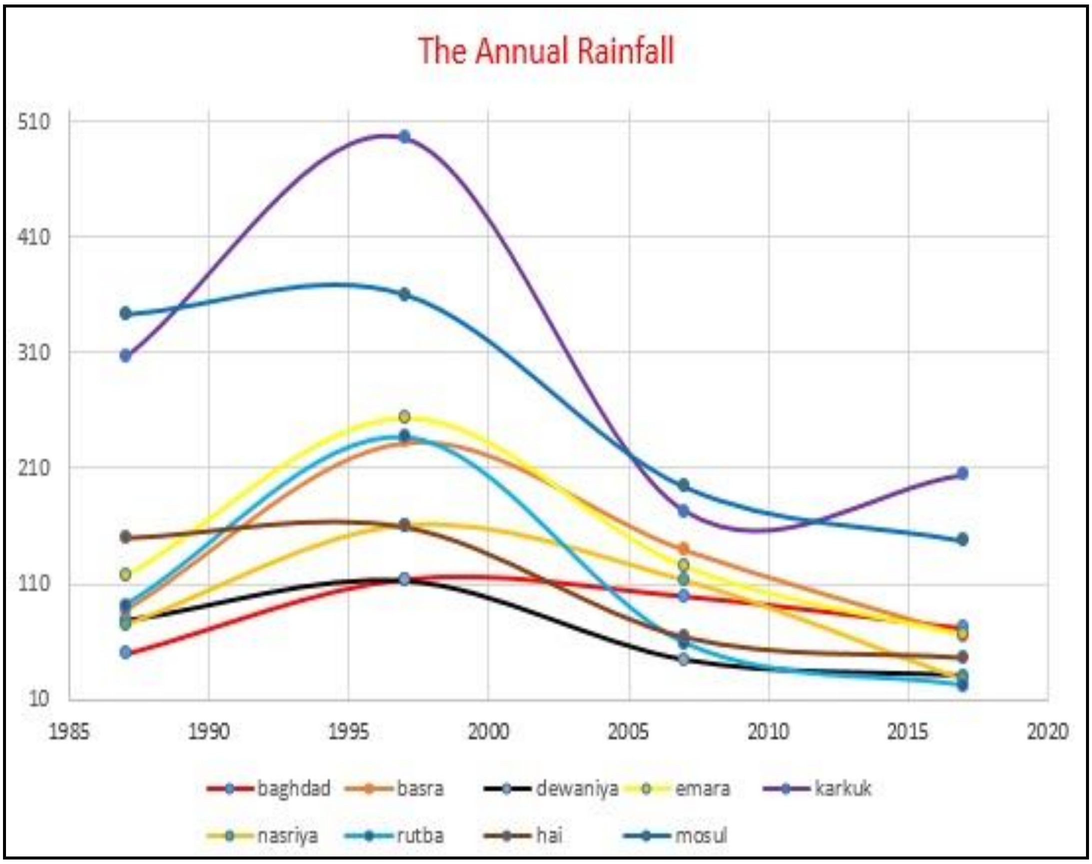


**Figure 7-** The annual rainfall.

Rainfall decreases the $R_n$ actual value but not measured potential one, since it was not involved in $R_n$ calculation equation. Rainfall level can be used as evidence for the $R_n$ value decrement or increment for each station. The utilizing of the charts refers to a general (since the existence of some variations) behavior correlation between $R_n$ and relative humidity. To certify this spatial correlation behavior, mapping technique has been adopted for Iraq's $R_n$ and RH values in the interest interval. The maps achieved using Arc GIS (10.5) software and utilizing $R_n$ and RH annual averaged values as geographically referenced information (i.e., the point shapefile and data table) with a distinctive spatial interpolation technique (Inverse Distance Weighted) to estimate $R_n$ and RH values for all Iraq area as shown in Figures 8 and 9. Inverse Distance Weighted is a deterministic spatial interpolation approximation to expect the unknown value at a place by adopting many known values with corresponding weighted values. The basic formula can be seen in equation (12).

$$x^* = \frac{w_1 x_1 + w_2 x_2 + w_3 x_3 + \ldots + w_n x_n}{w_1 + w_2 + w_3 + \ldots + w_n} \quad \ldots\ldots. (12)$$

Where: **x*** is the unknown value at a place to be stated, w is the weight, and x is the known point value. The weight is an inverse distance of a point to each known point value that is used in the calculation.

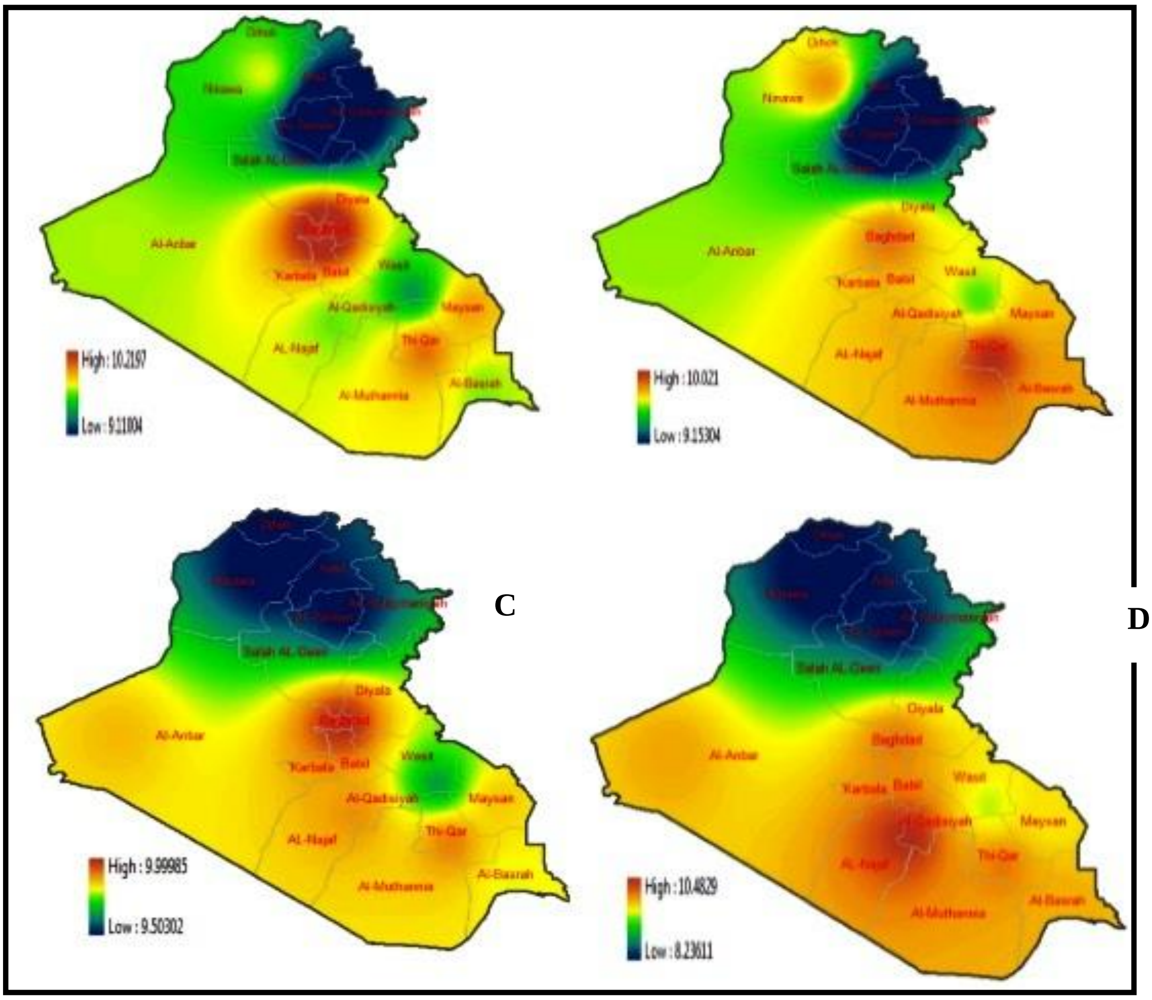


**Figure 8-**A) The annual mean net solar radiation of Iraq in 1987, B) The annual mean net solar radiation of Iraq in 1997, C) The annual mean net solar radiation of Iraq in 2007, and D) the annual mean net solar radiation of Iraq in 2017.

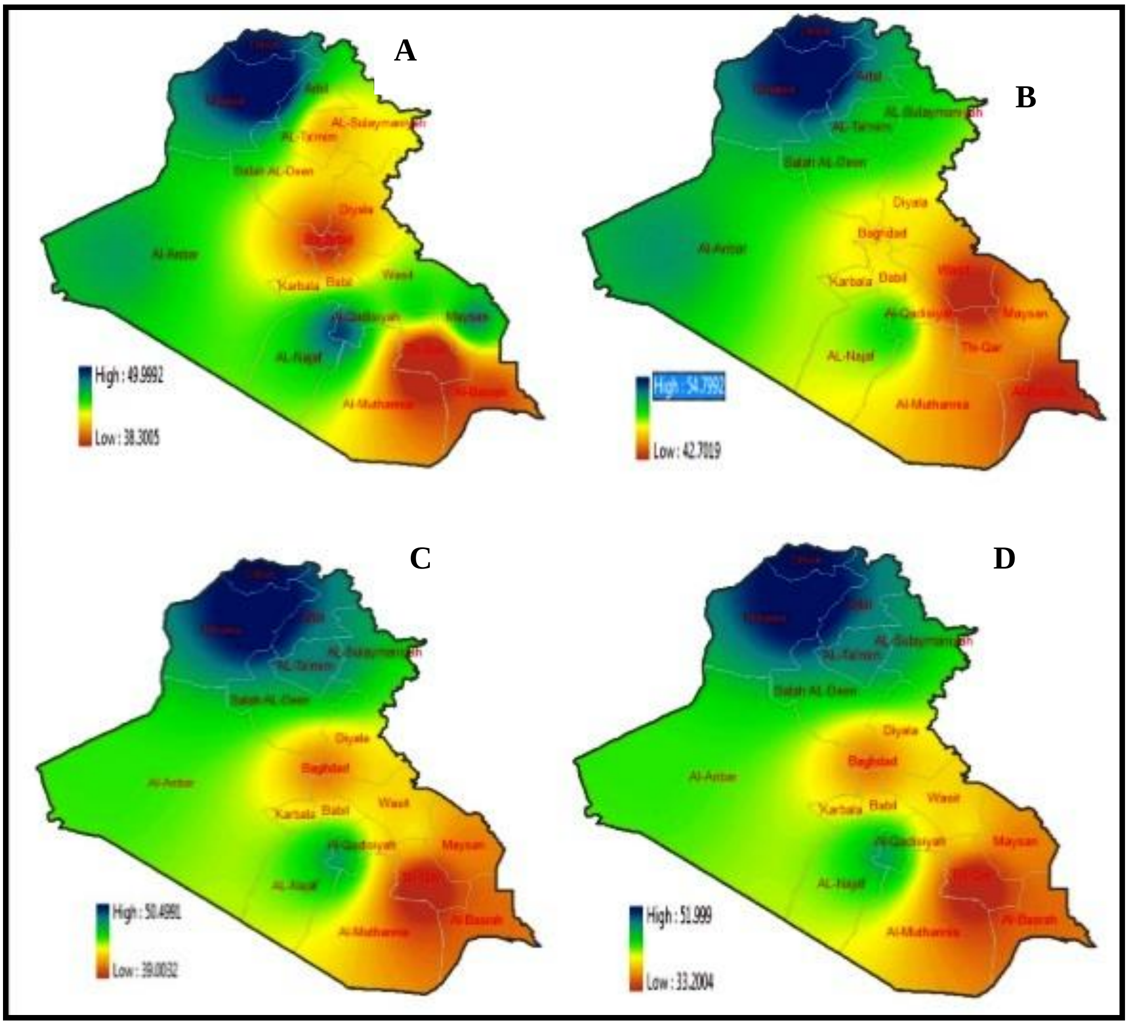


**Figure 9-A**) The annual mean Relative Humidity of Iraq in 1987, B) The annual mean Relative Humidity of Iraq in 1997, C) The annual mean Relative Humidity of Iraq in 2007, and D) the annual mean Relative Humidity of Iraq in 2017

The mapping technique revealed the "general spatial correlation in reverse manner" between $R_n$ and RH values all over Iraq.

**Conclusions**

This research shows that:

- Since RH value influences by actual water vapor pressure $e_a$ value, so its value affects $R_n$ value in reverse manner with general correlation.
- Integrative utilization of GIS and remote sensing facilities is optimum for net solar radiation rates mapping, variations monitoring, and behavior analyzing.
- In Iraq as an arid region, net solar radiation is considered as an astronomical based phenomenon that has geographic extension influenced majorly by some climate factors and minorly by topographic terrains.
- In Iraq, the global warming based relative humidity declination reached its climax at eighties decade of last century, which yielded net solar radiation rates to climax rise at that decade.
- In Iraq, for the later three decades after eighties, the behavior of $R_n$ rates correlated generally (with the existence of some anomalies) in reversal manner versus RH rates yielding the $R_n$ raising in middle and south and $R_n$ descending in the north parts.

- The $R_n$ rate controls $T_{max}$ and $T_{min}$ values in different ways (i.e., the influence of $T_{max}$ is less than $T_{min}$ with the change of $R_n$ value).
- The $R_n$ value increased if the gradient of $T_{max}$ to $T_{min}$ is large and vice versa because of $R_{ns}$ increment and $R_{nl}$ decrement.

**References**

**[1]** J. Hofierka, "Direct solar radiation modelling within an open GIS environment", *Proceedings of the Joint European GI Conference 1997*, Vienna: 575- 584.

**[2]** AL-Salihi, A. M., M, K. M., & Mohammed, A. J., " Estimation of Global Solar Radiation on Horizontal Surface Using Routine Meteorological Measurements for Different Cities in Iraq", *Asian Journal of Scientific Research*, vol. 93, no. 4, pp. 240-248, June 2010

**[3]** Beyer, H.G., Czeplak, G., Terzenbach, U., Wald, L., "Assessment of the method used to construct clearness index maps for the new European solar radiation atlas", (ESRA). *Solar Energy*, vol. 6, no. 1, pp.389-397,March 1997

**[4]** McKenney, D.W, Mackey, B.G., Zavitz, B.L., "Calibration and sensitivity analysis of a spatially-distributed solar radiation model", *International Journal of Geographical Information Science*, vol. 13, no. 1, pp. 49-65 1999

**[5]** Atiaa, A.M., and Abdul-Qadir, A.M., "Using fuzzy logic for estimating monthly pan evaporation from meteorological data in Emara / South of Iraq", *Baghdad Science Journal*, vol. 9, no. 1, pp. 133-140, May 2012

**[6]** Jawad, L.A., "The Climatic Quality Index Determination for Iraq Using Meteorological Stations Data", *Iraqi Journal of Science*, vol. 57, no. 4C, pp. 3005-3016, July 2016.

**[7]** Kumar, L., Skidmore, A.K., Knowles, E., "modelling topographic variation in solar radiation in a GIS environment: *International Journal of Geographical Information Science*, vol. 11, no. 5, pp. 475-497, Sep.1997.

**[8]** Anas A. Mohamed, L. Azeez, Faleh H. Mahmood, "The use of ground penetrating radar to assess the concrete", *Iraqi Journal of Science*, vol. 60, no. 9, pp. 2095-2101, 2019

**[9]** Jawad, L.A., "The Al-Abiadh Valley Drainage Basin Environmental Aspects Extraction Using Quantitatively Morphometric Analyses of Shuttle Radar Topographic Mission Data", *Baghdad Science Journal*, vol. 16, no. 1, pp. 97-103, 2019