------Jou. Raf. Sci., Vol. 20, No.4 pp 82-95, 2009------

Estimation of Net Radiation in Iraq

Waleed I. Al- Rijabo
Department of Physics
College of Education
Mosul University

Rajaa A. Basheer **Amal M. Banoosh**
Department of Physics
College of Science
Mosul University

(Received 20 / 4 / 2009 ; Accepted 5 / 10 / 2009)

ABSTRACT

FAO-56 Model was used to estimatenet Net Radiation falling on horizontal surface in Mosul, Baghdad and Nasiriyah stations for the time series (1980-2002). Results showed that there is a sort of relatedness between estimated and measured incoming short wave radiation(Rs) in the three stations, where the values of mean absolute error (M.A.E.) is not exceed (11,14,24)% in Baghdad, Nasiriyah and Mosul respectively. Rn estimated by the Model appear that Mosul station gives the lowest values of Rn in comparison with Baghdad and Nasiriyah stations, this is due to the amount of incoming solar radiation reached the earth surface. Summer months in Nasiryiah gave also values of Rn lower than that in Baghdad because of the sand storm which domain during the summer months in Nasiriyah. Two linear Regression Equations were found, the first between net radiation and net incoming short wave radiation (Rn & Rns) and the second between net radiation and net long wave radiation (Rn & Rnl) in each of the three stations. The correlation coefficient (R) found in the first relation is very high and ranged between (0.98 – 0.99), while the values of (R) in the second relation ranged between (0.67 – 0.87). Liner Regression Equations were also found between Rn and meteorological elements (Temperature, Relative Humidity, wind Speed and Sun Shine Ratio) in each of the three stations.

تخمين صافي الإشعاع في العراق

الملخص

تم استخدام النموذج الرياضي FAO-56 لتخمين محصلة الإشعاع الشمسي الساقط على السطح الأفقي في كل من مدينة الموصل وبغداد والناصرية للسلسلة الزمنية (1980- 2002) .

أظهرت النتائج وجود تقارب كبير بين قيم (Rs) المخمنة بواسطة النموذج مع قيمها المقاسة في المحطات الثلاث بحيث لم تتجاوز الـ (M . A .E.) (24,14,11) % في كل من محطات بغداد والناصرية والموصل على التوالي. Rn التي تم الحصول عليها بواسطة النموذج أظهرت ان محطة الموصل أعطت أوطأ القيم مقارنة بمحطتي بغداد والناصرية وذلك اعتماداً على كمية الإشعاع الشمسي الواصل إلى سطح الأرض ، كما ان أشهر الصيف في محطة الناصرية أظهرت قيماً أوطأ للـ Rn مقارنة بمحطة بغداد وذلك بسبب العواصف الرملية التي تسود خلال أشهر الصيف في الناصرية.

تم إيجاد معادلتي انحدار خطي مستقيم , الأولى بين Rns و Rn والثانية بين Rnl و Rn فـــي كـــل مـــن المحطات الثلاث, حيث أعطت العلاقة الأولى معامل ارتباط عالي تراوح بـــين (0.98 – 0.99) ، والثانيـــة أعطت معامل ارتباط تراوح بين (0.67 ــ 0.87). كما تم إيجاد علاقات الارتباط بـــين Rn وبعــض العناصر الانوائية (درجات الحرارة، الرطوبة النسبية، سرع الرياح، نسبة السطوع) في كل من المحطـــات الثلاث.

INTRODUCTION

The determination of earths radiation budget is essential for atmospheric medeling, climatic studies and for estimating reference crop evapotrnspiration (Steven and Knot, 2003; Alados *et al.*, 2003).

The net radiation (Rn) is the difference between incoming and outgoing radiation of both short and long wave lengths, so it represent the balance between the energy absorbed ,reflected and emitted by the earth surface (Kjaersgraard, 2007).

(Rn) is normally positive during the day time and negative during the night time. The total daily value for (Rn) is almost positive over a period of 24 hours, except in extreme conditions at high latitudes (FAO 56).

Incoming short wave radiation (Rs) have wave lengths ranged between (0.15 -3) micron and depend on: daytime hours, latitudes, season, thickness of the atmosphere, aerosols, clouds, water vapor and air molecules (Eric *et al.*,2003; Limia, 2005).

The outgoing short wave radiation is function of incoming solar radiation and the bulk surface albedo. The net incoming short wave radiation (Rns) represent the difference between the incoming and outgoing short wave radiation. The incoming long wave radiation depend on sky temperature and sky emissivity. The sky emissivity is a summary effect of all layers of the atmosphere which depend on cloud cover, humidity and temperature structure(Roger and Barry, 2003; Richard, 1997).

The outgoing long wave radiation depend on surface emissivity and surface temperature. The difference between the outgoing and incoming long wave radiation represent the net long wave radiation (Rn l) .

Almost the outgoing long wave radiation is greater than the incoming long wave radiation , So the (Rnl) represent energy losses.

In many biological, agronomic and engineering applications, Rn is required rather than total solar radiation (Dong *et al.*, 1992).

Many attempt have been made to relate Rn to Rs, air temperature, and other variables such as relative humidity and extraterrestrial radiation (Irmak *et al.*,2003; Offerle and Grimmond, 2003).

Nearly all the meteorological stations in Iraq haven’t net radiometers instruments, so we use the FAO model which is widely used for predicting Rn .

There locations in Iraq (Mosul, Baghdad, Nasiriyah) were used to study the net radiation during the period (1980 – 2002), where Mosul represent the northern part of Iraq, Baghdad represent the middle part of Iraq and Nasiriah represent the southern part of Iraq .

METHODOLOGY

FAO – 56 Model were used to determine the different components of solar radiation and long wave radiation .Extraterrestrial radiation (Ra) in (MJ m^{-2} day $^{-1}$) were calculated from the following formula :

$$Ra = \frac{24(60)}{\pi} Gsc\ dr\ [\ ws \sin(ø) \sin(\delta) + \cos(ø) \cos(\delta) \cos(ws)\ ] \qquad ……(1)$$

where:

Gsc = solar constant (0.082 MJm^{-2} min^{-1})
dr = inverse relative distance Earth – Sun
ws = sunset hour angle (rad)
ø = latitude (rad)
δ = solar declination (rad)

The inverse relative distance Earth-Sun (dr)and solar declination (δ) are given by :

$$dr = 1 + 0.033 \cos [\ 2\pi\ J / 365] \qquad …………………………………………. (2)$$

$$\delta = 0.409 \sin [\frac{2\pi}{365} J - 1.39\ ] \qquad ……………………………………………(3)$$

Where J = number of the day in the year
The sunset hour angle (Ws) is given by:

$$Ws = \arccos [\ - \tan(ø) \tan(\delta)] \qquad …………………………………………...…(4)$$

The day light hours (N) are given by:

$$N = \frac{24}{\pi} Ws \qquad ………………………………………………...……… ..(5)$$

The incoming short wave radiation (Rs) is given by:

$$Rs =[\ 0.25 + 0.5\ n / N\ ]\ Ra \qquad …………………………………………………(6)$$

Where Rs is in (MJ m^{-2} day $^{-1}$) and n /N is a relative sunshine duration
The net short wave radiation (Rns) resulting from the balance between incoming (Rns) and reflected solar radiation is given by:

$$Rns = (\ 1 – \alpha\ )\ Rs \qquad ……………………………………………….. ………….(7)$$

Rns and Rs are in (MJ m^{-2} day $^{-1}$) , α is the albedo .

The net outgoing long wave radiation (Rn1) in (MJ m^{-2} day $^{-1}$) is given by :

$$Rnl = \sigma \left[\frac{T max , K^4 + Tmin , k^4}{2} \right] (0.34 - 0.14 \sqrt{ea}) (1.35 \frac{Rs}{Rso} - 0.35) \quad .....(8)$$

Where :

σ = Stefan-Boltzman constant (4.903×10^{-9} MJ K^{-4} m^{-2} day^{-1})

Tmax = maximum absolute temperature during 24 – hour period
Tmin = minimum absolute temperature during 24-hour period
ea = actual vapour pressure (kpa)
Rs/Rso = relative short wave radiation
Rso = clear sky radiation (MJ m^{-2} day^{-1})

Rso is given by the following formula:

$$Rso = (0.75 + 2\times10^{-5} \ Z) Ra \quad ..... (9)$$

Where Z = station elevation above sea level (m).
The net radiation Rn is the difference between the incoming net short wave radiation and Rns and the outgoing net long wave radiation Rn1:

$$Rn = Rns - Rn1 \quad .....(10)$$

Three meterological station (Mosul, Baghdad and Nasiriyah) were used to test this model. The latitude, longitude, altitude and years of observations for these stations were presented in table (1).

Table 1: The geographical informations of the three stations (Mosul, Baghdad, and Nasiriyah) For the time series(1980-2002).

Stations	**Latitude**	**Longitude**	**Altitude (m)**
Mosul	36º 19´	43º 09´	223
Baghdad	33º 14´	44º 14´	32
Nasiriyah	31º 05´	46º 14´	3

The mean monthly metrological elements (Tmax, Tmin, Tmean, Rs, Sunshine duration (n),Relative Humidity, Wind Speed, Maximum Possible Sunshine (N), Sunshine Ratio) for the three stations were presented in the appendix (1 ,2 , 3).
The mean monthly values of radiation elements (Ra, Rso, Rns, Rnl and Rn) were estimated using the FAO56 model and presented in the appendix (4, 5, 6).
Mean Absolute Error Was used to show the deviations between the measured and estimated values of Rs in the three stations,
where :

$$M.A.E. = \frac{1}{n} \sum_{1}^{n} \left| \frac{Gi - Fi}{Fi} \right| \quad \text{……………………………………………….(11)}$$

Gi = estimated values , Fi = measured values (Bodescu-1988).
Comparison between the mean monthly values of Rn in the three stations were performed .
Correlations between Rn and radiation elements (Rs, Rns, Rnl) were found in the three stations.
Correlations between Rn and different metrological elements (Temp. , RH, wind speed and n/N) were found also.

RESULTS AND DISCUSSION

1.Comparison between measured and estimated values of incoming short wave radiation (Rs) :

The values of (Rs) estimated by Model and that measured by the actinography in Mosul, Baghdad and Nasiriyah stations during the months of the year were presented by table (2) .

Table 2: Mean monthly values of estimated and measured Rs in Mosul, Baghdad and Nasiriyah stations in (MJ /m² . d).

Stations \ Months		Jan.	Feb.	Mar.	Apr.	May	Jun.	July.	Aug.	Sep.	Oct	Nov	Dec	M.A.E.%
Mosul	**Rs est.**	**8.3**	**11.2**	**15.6**	**20**	**24.2**	**27.8**	**27.3**	**25.1**	**21.2**	**15.1**	**10.1**	**7.8**	**24**
	Rs Mean	**6.6**	**9.5**	**12.1**	**16.3**	**19**	**21.4**	**21**	**19.7**	**17**	**12.2**	**8.4**	**6.2**	
Baghdad	**Rs est.**	**10.9**	**14.3**	**18.2**	**21.6**	**25**	**28.2**	**27.6**	**26**	**21.8**	**16.4**	**12.3**	**10.1**	**11**
	Rs mean	**9.9**	**13**	**16.5**	**20.1**	**22**	**24.7**	**24.3**	**22.5**	**19.3**	**14.8**	**10.8**	**8.8**	
Nasiriyah	**Rs est.**	**11.6**	**14.8**	**18**	**12**	**23.4**	**24.9**	**24.8**	**23.8**	**21.4**	**16.9**	**12.8**	**10.7**	**14**
	Rs mean	**9.9**	**12.9**	**15.9**	**19.4**	**20.8**	**21.6**	**21.8**	**20.5**	**18.8**	**15**	**10.4**	**9**	

From the table we can see a good agreement between the estimated and measured values of Rs specially in Baghdad and Nasiriyah.

The Mean Absolute Error found does not exceed (11, 14 , 24)% in Baghdad, Nasiriyah and Mosul respectively.

Linear regression equations between estimated and measured values of Rs were presented in fig. (1) for the three stations. The correlation coefficient found between the estimated and measured values were (0.973, 0.975, 0.973) in Mosul, Baghdad and Nasiriyah respectively. This mean that their is a high correlations between the estimated and measured values of Rs. In our research we use the measured values of Rs for computing Rn because its available .

2. Evaluation of Net Radiation in Mosul , Baghdad and Nasiriyah stations.

Fig.(2) show clearly that the net radiation (Rn) in Mosul station is less than that in Baghdad and Nasiriyah, this is due to the amount of incoming short wave radiation received in Mosul is less than that in Baghdad and Nasiriyah .

The values of Rn during the summer months in Baghdad is higher than that in Nasiriyah, this is because of the dust storm during the summer months in Nasiriyah which affect greatly the amount of the incoming short wave radiation received on horizontal surface.

3.Correlations between Rn and different solar radiation components

Fig. (3) shows the liner regressions obtained between Rn and Rns in Mosul, Baghdad, Nasiriyah stations. The correlation coefficient found for these relations are (0.98, 0.99, 0.99) in Mosul, Baghdad and Nasiriyah respectively. This indicated there is a highly correlations between Rn and Rns .

Fig. (4) Shows the correlations between Rn and Rnl in Mosul, Baghdad and Nasiriyah stations. The correlation coefficient in the three stations are variable and can be arranged according to there magnitude as (0.87, 0.77, o.67) in Baghdad, Mosul and Nasiriyah respectively.

We can mentioned here that the values of (R) is less that between Rn and Rns. Liner regression equations were also found between Rns and Rnl which are presented in fig.(5). A highly correlation coefficients were found for these relations which can be arranged according to their magnitude as (0.91, 0.87, 0.75) for Baghdad ,Mosul and Nasiriyah station respectively .

4.Correlations between net radiation and different meteorological elements

Fig.(6) shows the correlations between the mean monthly values of obtained Rn and temperature in Mosul, Baghdad and Nasiriyah stations .

A highly positive correlations were found and the correlation coefficient are (0.88, 0.95,0.86) in Baghdad, Mosul, Nasiriyah .

Fig.(7) shows a highly negative correlations between the mean monthly values of Rn and relative humidity. The values of correlation coefficient found for these correlations are (0.82, 0.93, 0.89) for Mosul, Baghdad and Nasiriyah stations respectively.

Fig.(8) shows a highly positive correlations between the mean monthly values of Rn and wind speed. The values of (R) found for these correlations are (o.89, 0.89, 0.87) for Mosul, Baghdad and Nasyriah stations respectively.

Fig.(9) show a positive correlations between the mean monthly values of Rn and sunshine ratio (n/N) .

The correlations coefficients obtained are (0.77, 0.77) for Baghdad and Mosul stations respectively. Nasiriyah station did not give a good correlation between Rn and n / N .

CONCLUSION

The main conclusions are :

1. A good agreement has been found between estimated and measured values of Rs, where the value of M . A . E. does not exceed (11 , 14 , 24) % in Baghdad, Nasiriyah and Mosul stations respectively .

2. The lower values of Rn was obtained in Mosul station in comparison with Baghdad and Nasiriyah. The summer months in Nasiryiah station gave values of Rn less than that in Baghdad, this is due to sand storm existing during these months in Nasiriyah.
3. Two Linear Regression Equations were found between (Rn and Rns) and (Rn and Rnl) in each of the three stations, which give relatively high correlation coefficients.
4. Linear Regression Equations has been found between Rn and other meteorological elements (Temperature, Relative Humidity, Wind Speed, Sun Shine Ratio) in each of the three stations.

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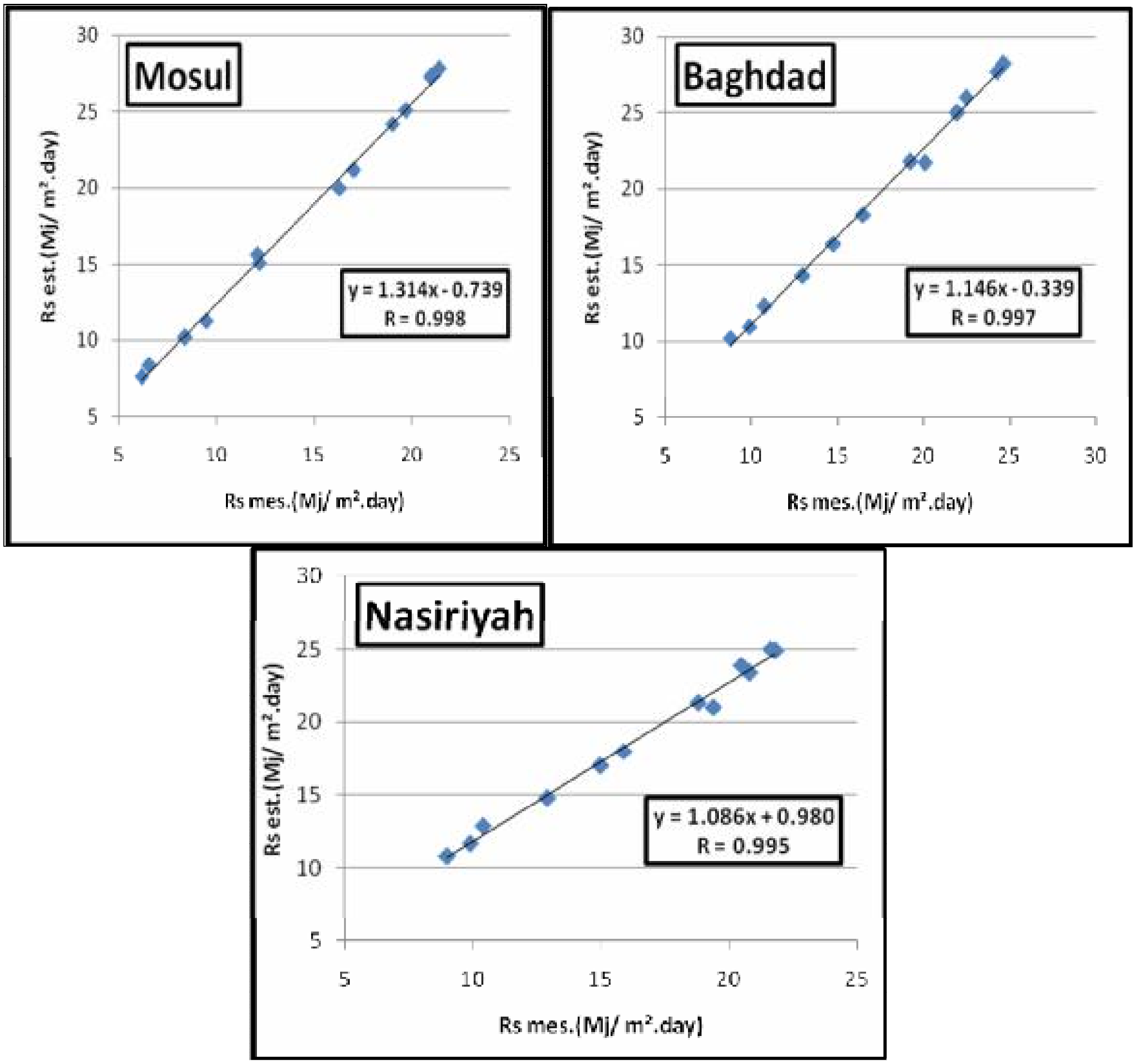


Fig 1: Correlations between estimated and measured values of Rs in Mosul , Baghdad , and Nasiriyah stations.

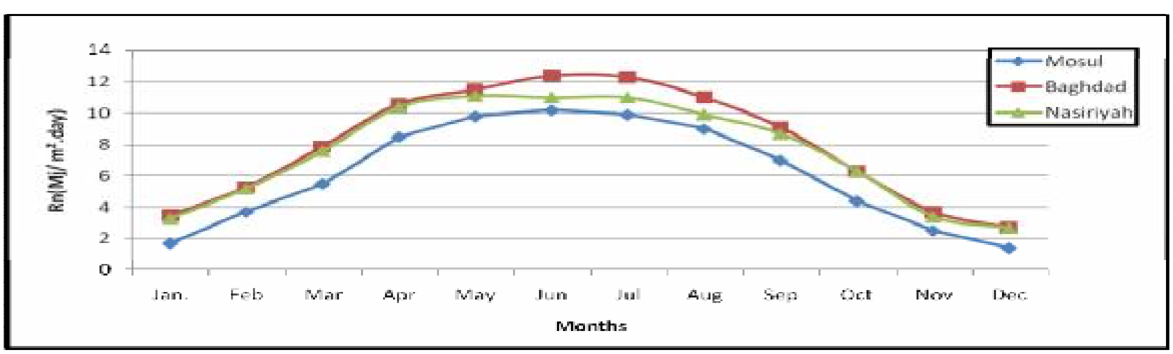


Fig 2 : Mean monthly values of net radiation in Mosul , Baghdad and Nasiriyah stations.

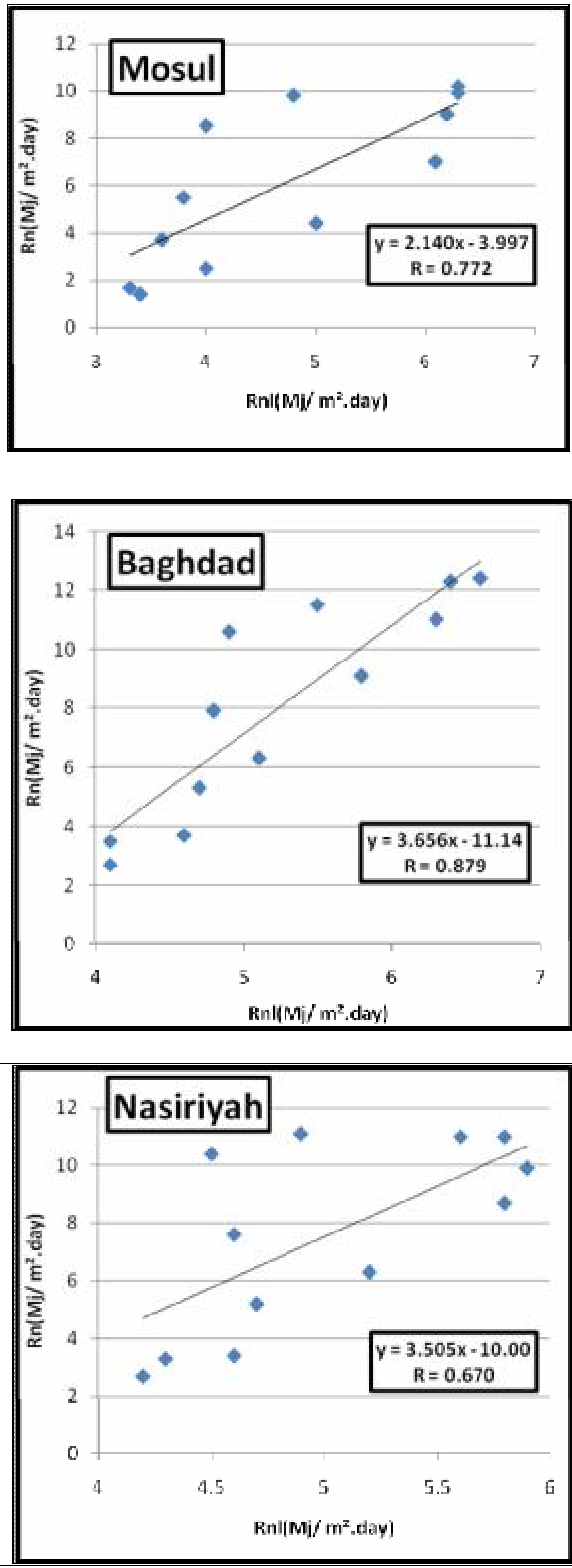


Fig 4: Correlations between Rn & Rnl in Mosul , Baghdad and Nasiriyah stations.

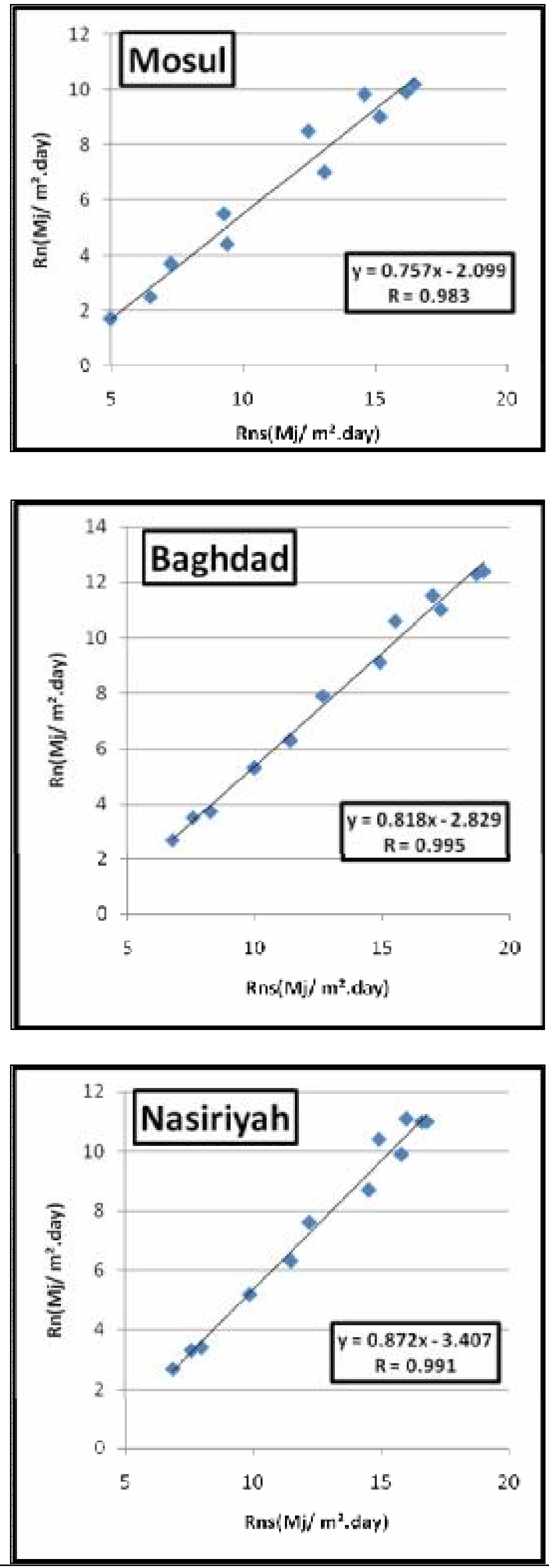


Fig 3: Correlations between Rn & Rns in Mosul , Baghdad and Nasiriyah stations.

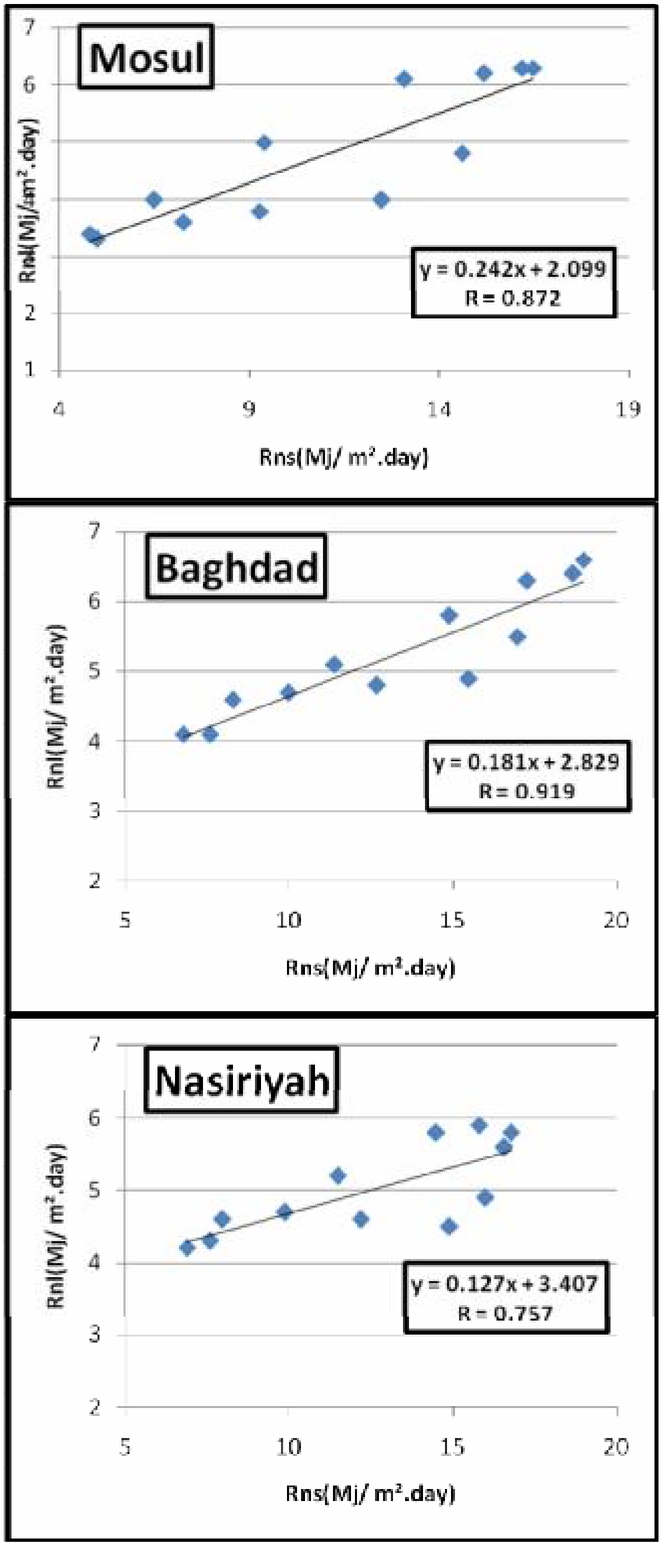


Fig 5: Correlations between Rns and Rnl in Mosul, Baghdad and Nasiriyah stations.

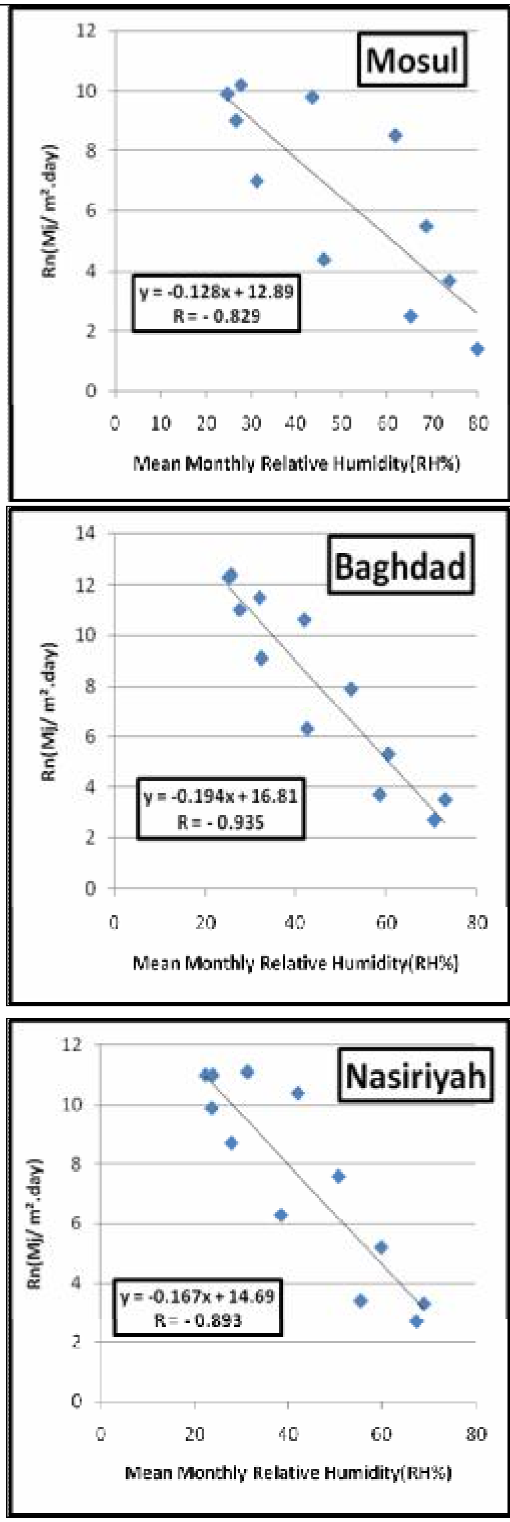


Fig 7:Correlations between Rn and RH% in Mosul, Baghdad and Nasiriyah stations.

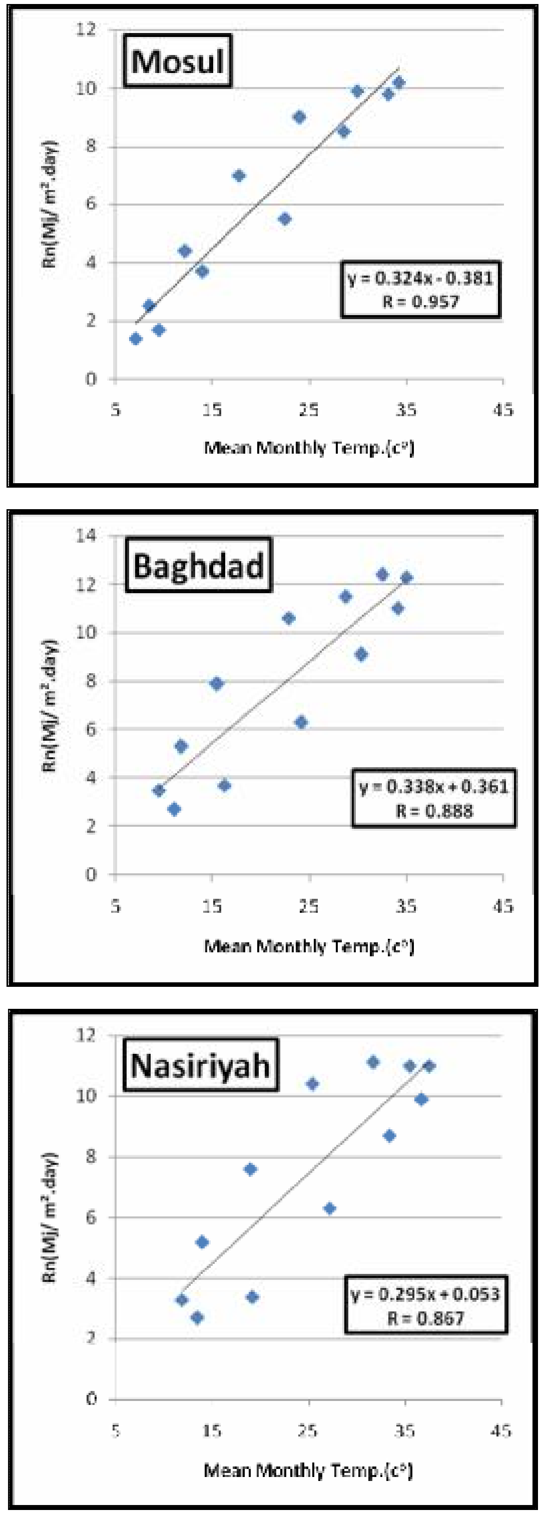
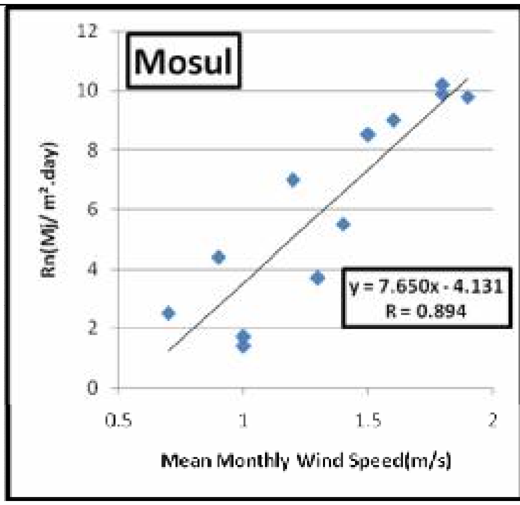
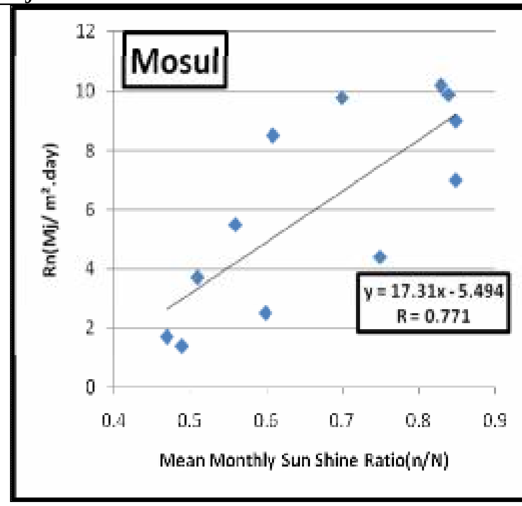
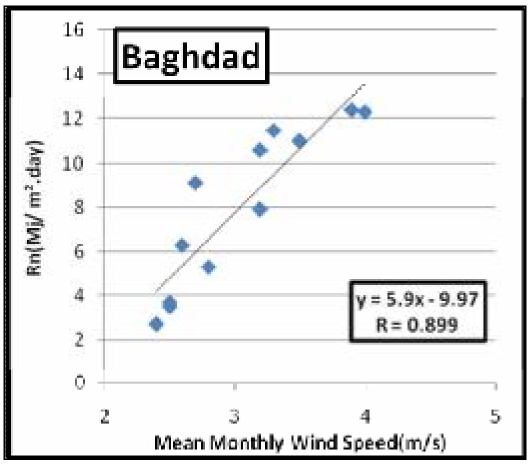


Fig 6:Correlations between Rn and Temp. in Mosul, Baghdad and Nasiriyah stations.







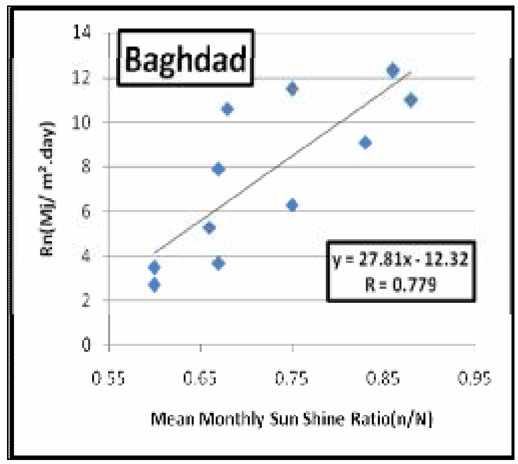


Fig 9: Correlations between Rn and n/N in Mosul and Baghdad stations.

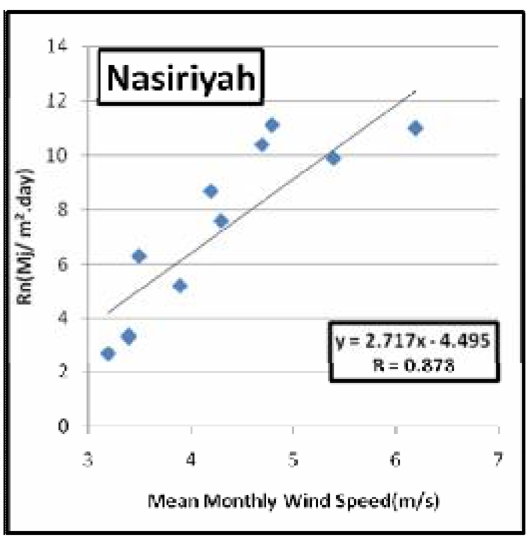


Fig 8 : Correlations between Rn and Wind Speed in Mosul, Baghdad and Nasiriyah Stations.

Appendix 1: Mean monthly values of meteorological elements for (Mosul)station during the period (1980- 2002)

Months / Met. elements	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	ec.
T min (c°)	2.5	3	6.3	10.9	15.8	21.1	25	23.9	18.8	13.3	7.4	4
T max (c°)	12.4	14.6	18.9	25.1	32.7	39.3	43.2	42.5	38.1	30.2	20.9	13.9
T mean (c°)	9.5	14	22.5	28.5	33.1	34.2	29.9	24	17.8	12.2	8.5	7.1
RH (%)	80.2	73.8	68.7	61.8	43.7	27.6	24.7	26.7	31.3	46.2	65.2	79.7
Wind Speed (m/s)	1	1.3	1.4	1.5	1.9	1.8	1.8	1.6	1.2	0.9	0.7	1
Rs (Mj/m².day)	6.6	9.5	12.1	16.3	19	21.4	21	19.7	17	12.2	8.4	6.2
n (hrs)	4.6	5.5	6.6	8	9.9	12	12	11.4	10.4	8.2	6	4.7
N (hrs)	9.8	10.4	11.8	13	14	14.5	14.2	13.3	12.2	11	10	9.5
n /N	0.47	0.51	0.56	0.61	0.70	0.83	0.84	0.85	0.85	0.75	0.60	0.49

Appendix 2: Mean monthly values of meteorological elements for (Baghdad) station during the period (1980- 2002)

Months / Met. elements	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
T min (c°)	4.2	5,6	9,7	15.4	20,2	23,4	25,8	24,7	20.7	69.7	9.8	5.4
T max (c°)	15.7	18.4	22.6	30.1	36.5	41.3	44.2	42.9	40	33.1	23.6	17.4
T mean (c°)	9.5	11.8	15.5	22.9	28.7	32.5	35	34.1	30.3	24.2	16.3	11.1
RH (%)	73	60.5	52.3	42	32	25.6	25.1	27.5	32.4	42.6	58.6	70.6
Wind Speed(m/s)	2.5	2.8	3.2	3.2	3.3	3.9	4	3.5	2.7	2.6	2.5	2.4
Rs (Mj/m².day)	9.9	13	16.5	20.1	22	24.7	24.3	22.5	19.3	14.8	10.8	8.8
n (hrs)	6.1	7.2	8.0	8.8	10.2	12.2	12	11.6	10.2	8.4	6.8	6
N (hrs)	10.1	10.8	11.8	12.8	13.7	14.1	13.9	13.2	12.2	11.2	10.3	9.9
n /N	0.6	0.66	0.67	0.68	0.75	0.86	0.86	0.88	0.83	0.75	0.67	0.6

Appendix 3 : Mean monthly values of meteorological elements for (Nasiriyah) station during the period (1980-2002)

Months / Met. elements	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
T min (c°)	6.4	8	12.4	18.7	23.6	26.3	28.3	27.6	24.3	19.3	12.8	7.7
T max (c°)	17.3	20	25.2	31.8	38.7	43	45.2	45	42	35.4	26	19.4
T mean (c°)	11.9	14	19	25.4	31.7	35.5	37.5	36.7	33.4	27.2	19.2	13.5
RH (%)	69.1	60	50.9	42.2	31.2	23.8	22.3	23.6	27.8	38.6	55.6	67.4
Wind speed (m/s)	3.4	3.9	4.3	4.7	4.8	6.2	6.2	5.4	4.2	3.5	3.4	3.2
Rs (Mj/m².day)	9.9	12.9	15.9	19.4	20.8	21.6	21.8	20.5	18.8	15	10.4	9
n (hrs)	6.5	7.4	7.6	8.2	9	9.2	10	10	9.6	8.5	7.2	6.3
N (hrs)	10.9	10.9	11.6	12.8	13.6	14	13.8	13.1	12.1	11.2	10.4	10
n /N	0.64	0.67	0.64	0.64	0.66	0.70	0.72	0.76	0.79	0.76	0.69	0.62

Appendix (4) : Mean monthly values of radiation elements in(Mosul) city during the period (1980-2002)

Months / Radiation elements	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
RA(Mj/ m².day)	17.3	22.3	29.4	35.8	40.1	41.7	40.8	37.1	31.3	24.2	18.5	15.9
RS((Mj/ m².day)	6.6	9.5	12.1	16.3	19	21.4	21	19.7	17	12.2	8.4	6.2
RSO(Mj/ m².day)	13	16.8	22.1	27	30.3	31.5	30.7	28	23.6	18.3	14	12
Rns(Mj/ m².day)	5	7.3	9.3	12.5	14.6	16.5	16.2	15.2	13.1	9.4	6.5	4.8
Rnl(Mj/ m².day)	3.3	3.6	3.8	4	4.8	6.3	6.3	6.2	6.1	5	4	3.4
Rn(Mj/ m².day)	1.7	3.7	5.5	8.5	9.8	10.2	9.9	9	7	4.4	2.5	1.4

Appendix 5: Mean monthly values of radiation elements in(Baghdad) city during the period(1980-2002)

Months / Radiation elements	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
RA(Mj/ m².day)	19.8	24.5	31	36.6	40.2	41.4	40.6	37.7	32.7	26.3	20.9	18.4
RS((Mj/ m².day)	9.9	13	16.5	20.1	22	24.7	24.3	22.5	19.3	14.8	10.8	8.8
RSO(Mj/ m².day)	14.8	18.4	23.3	27.5	30.2	31	30.5	28.3	24.5	19.7	15.7	13.8
Rns(Mj/ m².day)	7.6	10	12.7	15.5	17	19	18.7	17.3	14.9	11.4	8.3	6.8
Rnl(Mj/ m².day)	4.1	4.7	4.8	4.9	5.5	6.6	6.4	6.3	5.8	5.1	4.6	4.1
Rn(Mj/ m².day)	3.5	5.3	7.9	10.6	11.5	12.4	12.3	11	9.1	6.3	3.7	2.7

Appendix 6: Mean monthly values of radiation elements in(Nasiriyah) city during the period(1980-1991)

Months / Radiation elements	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
RA(Mj/ m².day)	20.4	25	31.4	36.8	40.2	41.3	40.6	37.8	33	26.8	21.6	19.1
RS((Mj/ m².day)	9.9	12.9	15.9	19.4	20.8	21.6	21.8	20.5	18.8	15	10.4	9
RSO(Mj/ m².day)	15.3	18.8	23.6	27.6	30.1	31	30.4	28.3	24.8	20.1	16.2	14.3
Rns(Mj/ m².day)	7.6	9.9	12.2	14.9	16	16.6	16.8	15.8	14.5	11.5	8	6.9
Rnl(Mj/ m².day)	4.3	4.7	4.6	4.5	4.9	5.6	5.8	5.9	5.8	5.2	4.6	4.2
Rn(Mj/ m².day)	3.3	5.2	7.6	10.4	11.1	11	11	9.9	8.7	6.3	3.4	2.7