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Estimation and Comparison of Diffuse Solar Radiation over Iraq

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Abstract

Using sunshine duration, extraterrestrial radiation and global radiation are used as input parameters in four mathematical models. The daily average diffuse solar radiation in various (16) locations in Iraq have been estimated by using a thirty years solar radiation data within the period from (1961 – 1991). These locations had chosen randomly to cover the most geographic regions of Iraq. The maximum values of diffuse solar radiation are appeared in the summer season which is in range (2 - 9 MJ. m^{-2} day^{-1}) for (4 models), while the minimum values for solar radiation were in months January and December . These four models are compared between them to estimate the diffuse radiation values for different studied locations over Iraq.

Keywords: Iraq solar energy, sunshine, global radiation, diffuse solar radiation, direct solar radiation.

تخمين ومقارنة الإشعاع الشمسي المنتشر فوق العراق

الخلاصة:

استخدمت ساعات السطوع والشعاع الشمسي والإشعاع الشمسي الكلي كمدخلات في أربعة نماذج رياضية. لقد تم تخمين المعدل اليومي للإشعاع المنتشر لستة عشر موقعا مختلفا في العراق باستخدام بيانات الإشعاع الشمسي لثلاثين سنة خلال الفترة من (١٩٦١-١٩٩١). تم اختيار هذه المواقع بشكل عشوائي لتغطي كافة المناطق الجغرافية للعراق.وقد ظهرت القيم العظمى للإشعاع المنتشر في فصل الصيف وكانت تتراوح للنماذج الرياضية الأربعة بين(m^{-2} day^{-1} 2- 9 MJ.)،بينما القيمة الدنيا للإشعاع المتشتت كانت في شهر كانون الأول وكانون الثاني. قورنت هذه النماذج فيما بينها لتخمين قيم الإشعاع المنتشر لمختلف المواقع المدروسة في العراق.

كلمات الفهرسة :- الطاقة الشمسية في العراق ، ساعات السطوع ، الإشعاع الشمسي الكلي ، الإشعاع الشمسي المنتشر ، الإشعاع الشمسي المباشر .

1- Introduction

The global solar radiation data for most locations of the world are available [1-5]. The knowledge of the global at a particular place is important for design and assessment of the solar energy system [6]. The data of diffuse solar radiation are still unmeasured by meteorological stations for major parts of the world including Iraq.

Iraq lies between latitudes 29˚. 5´and 37˚.22´north and between longitude 38˚ 45´east and 48˚ 45´ east. The diffuse solar radiation depends on the global solar radiation, extraterrestrial radiation and sunshine hours etc…[7-11]. In present work, we calculate the diffuse solar radiation by using some empirical models which depend on the solar radiation. The stations selected in our present study are appendix(1). The global solar radiation, extraterrestrial radiation and sunshine duration data reported in this paper were supplied by relevant meteorological and solar radiation data were mainly taken from the Republic of Iraq Meteorological office (RIMO).

2- Theory

Diffuse radiation is the portion of solar radiation which arrives on the surface of the earth after the single or repeated dispersion in the atmosphere. The radiation intensity of the diffuse solar radiation depends on the variable of the sun, Rayleigh dispersion on pure air molecules, extinction by vapor particles and albedo of the ground as well as extinction in clouds. These are quit complicated physical process that are not easy to represent computationally [8]. The extraterrestrial solar radiation for each day of the year and for different latitude can be estimated from the solar constant, the solar declination and time of year [7].

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [w_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(w_s)] \quad \ldots\ldots\ldots\ldots (1)$$

R_a=extraterrestrial radiation [MJ. m^{-2}. day^{-1}]

G_{sc} = solar constant 0.082 [M J.m^{-2}. min $^{-1}$]

d_r = inverse related distance, Earth- Sun

W_s = Sun set hour angle [rad]

φ =latitude [rad]

δ = solar declination [rad]

Global solar radiation can be calculated with Angstrom formula which relates global solar radiation to extraterrestrial radiation and relative sunshine duration as follow[6].

$$R_s = \left[a_s + b_s \frac{n}{N} \right] R_a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

R_s = solar shortwave radiation [MJ. m^{-2}. day^{-1}]

n= actual duration of sunshine [hour]

N= maximum possible duration of sunshine or daylight hour [hour]

n /N= relative sunshine duration.

$a_s + b_s$ = regression constants

The following correlations are used to estimate the monthly mean daily diffuse solar radiation on a horizontal surface[9,10,11].

$$Hd_1 = [1.00 - 1.13Kt]\, R_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$Hd_2 = [0.958 - 0.982Kt] R_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$Hd_3 = 1.39 - 4.027Kt + 5.531Kt^2 + 3.108Kt^3] R_s \quad \ldots\ldots\ldots\ldots (5)$$

$$Hd_4 = [0.775 + 0.347 \frac{\pi}{180}(w_s - 90) - [0.505 + 0.261 \frac{\pi}{180}(w_s - 90)] \cos 2(Kt - 0.9)] R_s \ldots (6)$$

Hd =diffuse solar radiation

Kt= clearness index

$$Kt = \frac{R_s}{R_a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$W_s = \arccos\left[-\tan(\phi)\tan(\delta)\right] \quad \text{.....(8)}$$

The models (*Hd_1, Hd_2, Hd_3 and Hd_4*) depends on clearness index (k_t) and sun set hour angle (w_s). Clearness index (k_t) represent the ratio of global solar radiation to extraterrestrial radiation, the values of k_t always less than one which can be calculated theoretically and practically corresponding sunshine duration. Sun set hour angle (w_s) depends on the angle of solar declination and latitude which are calculated theoretically. The four models are a different according to the approximation of these coefficients.

3- Results and discussion

The selected locations in our present study were chosen randomly to cover the most geographic regions of Iraq. They were divided into three regions:

1. Al-Basrah, Al- Nasiriya, Al-Samaua and Al-Amara (south of Iraq)
2. Baghdad, Haditha, Al-Rutbah, Kerballa, Al-Hai, Al-Najaf and Al-Diwaniya (middle of Iraq)
3. Kirkuk, Khanoqin, Al-Sulaimaniya, Al-Mosul and Zakho (north of Iraq)

The data of solar constant, inverse related distance (Earth- Sun), sun set hour angle, latitude, solar declination, actual duration of sunshine and maximum possible duration of sunshine or daylight hour for each one of selected locations were supplied by the Republic of Iraq Meteorological office (RIMO). These data were used as an input parameters in equations 1,2 and 8. the calculated results of R_a and R_s were used in equation 7 to evaluate the clearness index. In the last , kt and ws were used in equations 3,4,5, and 6 (i.e four models of diffuse solar radiation). The measured values in a period (1961 – 1991) for all stations this result obtained by using the equations 1 and 2 to evaluate R_a and R_s as in table (1) and (2). The equations (3 - 6) are used to calculate the diffuse solar radiation Tables 3, 4, 5 and 6.

The maximum values for all locations are observed in April, May, June, July, and August, while the minimum values appeared in January, February, November and December for sixteen stations by depending on four models figure (1 (1-3)) for three regions. Figure (1-1) represent the diffuse solar radiation (MJ\m^2.day) in south locations of Iraq to compare the results of four models. The second model gives higher values from the other models. Figure (1-2) and (1-3) represent the middle and north region of Iraq respectively which have the same behavior, we can said the any

model have a specific behavior depend on geographical site in Iraq . The fourth model have a minimum values. The values of diffuse solar radiation have peak in summer reason due to long daylight hour. Table (7) represents the comparison among four models for all stations. Figures (2, 3, 4 and 5) represent the comparison for all locations depend on models (1, 2, 3and 4) respectively and show that the total diffuse solar radiation for all locations in Iraq ,the models have the same behavior for all locations . While the figures (6, 7 and 8) represent the relationship between clearness index with months of three regions in Iraq (i.e. south, middle and north), In the south of Iraq, the clearness index between (0.35 -0.7), in middle (0.5-0.7) and in north nearly between (0.4-0.7). Diffuse solar radiation results obtained for all locations carried out and comparison among four models, we observed small difference for all locations.

4- Conclusions

1. The study provides models for calculation of radiation data (R_a, R_s and Hd) on daily base for sixteen locations in Iraq.
2. The result show that the diffuse solar radiation decrease in winter and increase in summer.
3. From the results of all models which is believed to be applicable at anywhere in Iraq.
4. The values of diffuse solar radiation have peak in summer reason due to long daylight hour
5. The second model gives higher values from the other models and the fourth model
6. have a minimum values, this results depend on the relationship $\mathbf{H_d}$ with the author variables in the specific site .

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Appendix(1)

	Location	Latitudes(N)	Elevation(m)
١	Al-Basrah	30° 31′	2.4
٢	Al- Nasiriya	31° 01′	3
٣	Al-Samaua	31° 16′	6
٤	Al-Amara	31° 50′	7.5
٥	Al-Diwaniya	31° 57′	20.4
٦	Al-Najaf	31° 57′	50
٧	Al-Hai	32° 08′	14.9
٨	Kerballa	32° 34′	29.0
٩	Al-Rutbah	33° 02′	615.5
١٠	Baghdad	33° 18′	34.1
١١	Haditha	34° 08′	108
١٢	Khanoqin	34° 21′	202.2
١٣	Kirkuk	35° 28′	330.8
١٤	Al-Sulaimaniya	35° 32′	853.0
١٥	Al-Mosul	36° 19′	222.9
١٦	Zakho	37° 08′	442.

Table 1. the extraterrestrial solar radiation (R_a) for all selected locations (MJ. m^{-2}. day^{-1})**.**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Basrah	21	25.8	31.4	36.6	40	40.1	41.5	37.8	33.4	27.3	22.1	19.6
Nasiriya	20.7	25.9	31.2	36.5	39.9	40.9	40.5	37.8	33.1	27.1	21.7	20.2
Samaua	20.6	25.3	31.1	36.5	39.9	41.2	40.5	36.5	34	26..96	21.6	19.2
Amara	20.2	25	30.9	36.4	40	41.2	40.5	37.2	32.8	26.7	21.3	18.8
Diwaniya	20.1	25	31	36.4	39.6	41.2	40.5	37.7	32.8	26.8	21.3	18.8
Najaf	20.1	25	31	36.4	39.6	41.2	40.5	37.7	32.8	26.8	21.3	18.8
Hai	20.1	24.9	30.8	36.3	40	41.3	40.5	37.3	32.7	26.6	21.1	18.6
Kerballa	19.8	24.6	30.6	36.2	39.9	41.2	40.5	738	32.6	26.3	20.8	18.4
Rutbah	19.5	24.4	30.4	36.3	39.9	41.4	40.5	37.6	32.6	26.3	20.9	18.3
Baghdad	19.3	24.2	30.3	36.1	39.9	41.4	40.6	37.5	32.4	26	20.4	17.9
Haditha	20.9	23.8	30	35.9	39.9	41.5	40.6	37.4	32.1	52.6	20	17.5
Khanoqin	18.9	23.6	29.9	35.9	39.9	41.6	40.6	37.4	32	25.4	19.8	17.2
Kirkuk	18	23.1	29.5	35.6	39.9	41.5	40.7	37.2	31.6	24.9	19.2	16.6
Sulaimaniya	17.7	23	29.5	35.6	39.9	41.5	40.7	37.2	31.6	24.8	19.1	16.5
Mosul	17.5	23.4	29.1	35.4	39.9	41.5	40.6	37.1	31.3	24.5	18.7	16
Zakho	16.9	22.1	28.6	35.2	39.8	41.8	40.6	36.9	31	24	18.1	15.4

Table 2. the global solar radiation (R_s) for all selected locations (MJ. m^{-2}.day^{-1}).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Basrah	12.4	15.6	18.5	21.7	24.9	26.3	27	23.9	22.8	18.1	13.7	11.8
Nasiriya	11.7	15.2	17.9	20.9	23.9	23.9	24.3	23.5	21.6	11.1	12.9	11.5
Samaua	12.1	15	18.5	21.6	24	27	28.2	25.6	25	17.2	13	11
Amara	11.2	14.7	17.4	21.1	23.7	27.6	27.3	25.8	24.6	17.1	12.8	10.8
Diwaniya	11.5	14.6	18	21.1	23.5	27	27.3	25.7	22.1	16.9	11.9	10.7
Najaf	11.7	15	18	21.4	23.8	27.4	27.4	25.3	22	16.9	12.9	10.8
Hai	11.6	14.7	18.2	21.3	24.4	27.9	27.6	25.4	22.2	17.1	13.3	10.8
Kerballa	11.4	14.9	18.2	20.4	22.8	27.7	27.6	25.8	22.2	16.9	12.7	10.5
Rutbah	11.2	14.6	18.2	21.3	24.8	28.3	28.3	26.4	22.3	17	13	10.5
Baghdad	11.1	14.3	17.9	21.7	24.7	28.4	27.9	26.2	22.2	16.6	12.3	10.4
Haditha	11.5	14	17.7	21	24.9	27.7	27.7	52.5	21.6	16.4	12	9.66
Khanoqin	10.1	12.7	16.2	20.3	23.6	27.2	26.8	24.8	21	15.4	11.7	8.98
Kirkuk	9.17	12.3	15.7	19.9	24	26.5	26.4	25	21.3	15.4	11.2	8.36
Sulaimaniya	9.34	11.7	14.6	19.6	24.4	28.2	28	25.8	21.7	15.3	10.7	9.26
Mosul	7.87	12.3	15.8	19.7	27.6	28.3	28	25.7	21.6	15.4	10.6	8.12
Zakho	8.05	10.9	14.3	18.7	23.5	27.3	27.5	24.9	20.8	14.5	9.52	7.59

Table 3. the comparison for each location by four models.

Al-Basrah

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.13	5.02	6.36	7.18	7.37	6.84	7.27	6.82	5.23	4.61	3.97	3.76
Hdl2	4.69	5.74	7.18	8.15	8.62	8.47	8.86	8.11	6.6	5.62	4.77	4.34
Hdl3	3.73	4.5	5.7	6.48	6.87	6.74	7.11	6.48	5.28	4.49	3.81	3.44
Hdl4	3.11	4.02	4.95	6.04	7.16	7.68	6.74	6.75	6.19	4.74	3.45	2.92

Al-Nasiriya

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.3	5.2	6.3	7.3	7.9	8.1	7.8	7.04	5.7	6	4.25	4.21
Hdl2	4.7	5.9	7.1	8.2	9	9.1	8.9	8.2	6.9	6.2	4.8	4.6
Hdl3	3.7	4.6	5.6	6.5	7.2	7.29	7.1	6.5	5.52	5.08	3.8	3.71
Hdl4	2.93	3.93	4.78	5.82	6.86	7.09	7.04	6.64	5.87	2.92	3.25	2.84

Al-Samaua

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.1	4.99	6.07	7.16	7.7	7.17	6.21	5.35	4.37	4.95	4.19	3.9
Hdl2	4.7	5.62	6.92	8.14	8.85	8.64	7.9	6.93	6.03	5.83	4.8	7.37
Hdl3	3.73	4.51	5.5	6.47	7.05	6.91	6.3	5.51	4.71	4.66	3.82	3.47
Hdl4	3.03	3.87	4.95	6	6.89	7.89	8.16	8.01	6.8	4.49	3.29	2.72

Al-Amara

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.23	5.05	6.39	7.49	7.88	7	6.62	5.69	4.02	4.73	4.25	3.85
Hdl2	4.67	5.7	7.1	6.93	8.95	8.35	8.18	7.24	5.69	5.63	4.83	4.31
Hdl3	3.7	4.52	5.63	6.65	7.12	6.83	6.54	5.77	4.41	4.5	3.84	3.41
Hdl4	2.8	3.79	4.66	5.86	6.79	8.03	7.9	7.29	6.69	4.46	3.22	2.68

Al-Diwaniya

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.2	5.04	6.18	7.49	7.82	7.17	6.62	5.89	5.37	4.85	4.38	3.85
Hdl2	4.67	5.68	6.98	8.39	8.88	8.64	8.18	7.45	6.42	5.71	4.86	4.28
Hdl3	3.72	4.51	5.54	6.65	7.06	6.91	6.54	5.96	5.3	4.56	3.86	3.4
Hdl4	2.86	3.78	4.82	5.86	6.74	7.9	7.93	7.25	6.01	4.4	3.01	2.62

Al-Najaf

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.14	4.82	6.2	7.18	7.91	6.96	6.66	6.13	5.36	4.85	4.09	3.8
Hdl2	4.6	5.52	6.99	8.14	8.99	8.49	8.06	7.58	6.61	5.71	4.7	4.26
Hdl3	3.68	4.39	5.56	6.47	7.21	6.79	6.44	6.06	5.29	4.56	3.74	3.38
Hdl4	2.91	3.86	4.82	5.94	6.88	7.99	7.94	7.13	5.97	5.09	3.24	2.66

Al Hai

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.02	4.88	6.04	7.17	7.57	6.77	6.38	5.88	5.18	4.14	3.97	3.7
Hdl2	4.53	5.55	6.87	8.13	8.75	8.36	8	7.37	6.48	5.13	4.62	4.18
Hdl3	3.6	4.41	5.53	6.48	6.97	6.69	6.61	5.89	5.32	4.1	3.68	3.32
Hdl4	2.92	3.79	4.86	5.93	7	8.13	7.99	7.16	6.03	4.47	3.34	2.68

Kerballa

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.05	4.79	6.05	7.59	8.35	6.72	6.38	5.79	5.09	4.66	3.96	3.73
Hdl2	4.54	5.49	6.88	8.33	9.28	8.31	7.99	7.33	6.4	5.55	4.57	4.17
Hdl3	3.6	4.37	5.47	6.6	7.36	6.64	6.39	5.85	5.15	4.44	3.64	3.31
Hdl4	2.86	3.84	4.86	5.68	6.54	8.08	7.98	7.27	6.04	4.4	3.2	2.59

Al-Rutbah

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	3.99	4.7	6.06	7.34	7.42	6.39	6.23	5.52	5.1	4.69	3.88	3.74
Hdl2	4.47	5.39	6.89	8.27	8.65	8.22	7.94	7.15	6.45	5.59	4.52	4.19
Hdl3	3.54	4.22	5.75	6.73	6.91	6.57	6.33	5.68	5.16	4.47	3.61	3.32
Hdl4	2.84	3.77	9.89	5.93	7.12	8.26	8.2	7.45	6.05	4.43	3.27	2.61

Baghdad

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	3.93	4.76	5.95	7	7.68	6.4	6.93	5.77	5.13	4.78	3.95	3.68
Hdl2	4.4	5.41	6.76	8.01	9.12	8.22	8.09	7.35	6.43	5.63	4.53	4.12
Hdl3	3.49	4.3	5.38	6.38	7.07	6.57	6.46	5.86	5.04	4.5	3.6	3.27
Hdl4	2.77	3.69	4.78	6.05	7.1	8.27	8.08	7.39	6.02	4.34	3.1	2.57

Haditha

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.36	4.8	6.09	7.24	7.46	7.04	6.35	5.9	4.92	4.55	4.12	3.65
Hdl2	4.81	5.89	7.38	8.78	8.7	8.59	8.04	7.4	6.27	5.41	4.99	4.03
Hdl3	3.81	4.3	5.45	6.48	6.94	6.87	6.42	5.91	5.01	4.33	3.69	3.19
Hdl4	2.88	3.6	4.73	5.84	7.16	8.09	8.03	7.19	5.87	4.29	3.02	2.39

Khanoqin

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	4.06	5.09	6.51	7.44	7.87	7.22	6.78	6.23	5.56	4.96	4.12	3.7
Hdl2	4.43	5.56	7.07	8.27	8.94	8.69	8.31	7.67	6.7	5.84	4.58	4.01
Hdl3	3.51	4.4	5.79	6.56	7.11	6.95	6.85	6.33	5.36	4.53	3.63	3.18
Hdl4	2.53	3.28	4.33	5.64	6.79	7.94	7.77	6.98	5.7	4.03	2.83	2.22

Kirkuk

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	3.98	4.93	6.28	7.51	7.71	7.63	7.31	6.07	5.17	4.62	3.86	3.63
Hdl2	4.28	5.38	6.85	8.29	8.84	8.98	8.71	7.5	6.39	5.39	4.36	3.9
Hdl3	3.39	4.26	5.42	6.57	7.03	7.18	6.54	6	5.11	4.18	3.29	3.09
Hdl4	2.29	3.17	4.19	5.52	6.88	7.73	8.89	7.05	5.79	4.03	2.83	2.07

Al-Sulaimaniya

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	3.85	5.07	6.53	7.62	7.57	6.53	6.22	5.6	4.85	4.74	3.92	3.4
Hdl2	4.17	5.22	6.98	8.37	9.34	8.19	8.18	7.49	6.29	5.84	4.56	3.96
Hdl3	3.31	4.13	5.55	6.33	6.97	6.54	6.49	5.98	5.03	4.39	3.45	2.99
Hdl4	2.38	3.01	3.92	5.44	7	8.23	8.11	7.28	5.9	3.99	2.69	2.29

Al-Mosul

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	3.95	5.06	6.15	7.45	6.36	6.55	6.22	5.66	4.76	4.59	4	3.52
Hdl2	4.13	5.49	6.75	8.23	7.97	8.21	8.11	7.46	6.27	5.35	4.32	3.79
Hdl3	3.33	4.35	5.35	6.67	6.37	6.56	6.48	5.96	4.83	4.27	3.42	3.01
Hdl4	1.97	3.17	4.23	5.48	7.89	8.26	8.1	7.26	5.88	4.01	2.67	2.01

Zakho

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hdl1	3.77	4.86	6.36	7.51	8.09	7.25	6.66	6.03	5.04	4.65	3.92	3.38
Hdl2	3.99	5.2	6.79	8.19	9.12	8.72	8.17	7.45	6.22	5.33	4.16	3.61
Hdl3	3.19	4.39	5.65	6.49	7.24	6.97	6.53	5.96	4.98	4.46	3.29	3
Hdl4	2.01	2.81	3.88	5.21	6.74	7.96	7.89	7.01	5.64	3.79	2.4	1.88

Table 4. the estimated values of diffuse radiation by model (1) Hdl1

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Basrah	4.13	5.02	6.36	7.18	7.37	6.84	7.27	6.82	5.23	4.61	3.97	3.76
Nasiriya	4.3	5.2	6.3	7.3	7.9	8.1	7.8	7.04	5.7	6	4.25	4.21
Samaua	4.1	4.99	6.07	7.16	7.7	7.17	6.21	5.35	4.37	4.95	4.19	3.9
Amara	4.23	5.05	6.39	7.49	7.88	7	6.62	5.69	4.02	4.73	4.25	3.85
Diwaniya	4.2	5.04	6.18	7.49	7.82	7.17	6.62	5.89	5.37	4.85	4.38	3.85
Najaf	4.14	4.82	6.2	7.18	7.91	6.96	6.66	6.13	5.36	4.85	4.09	3.8
Hai	4.02	4.88	6.04	7.17	7.57	6.77	6.38	5.88	5.18	4.14	3.97	3.7
Kerballa	4.05	4.79	6.05	7.59	8.35	6.72	6.38	5.79	5.09	4.66	3.96	3.73
Rutbah	3.99	4.7	6.06	7.34	7.42	6.39	6.23	5.52	5.1	4.69	3.88	3.74
Baghdad	3.93	4.76	5.95	7	7.68	6.4	6.93	5.77	5.13	4.78	3.95	3.68
Haditha	4.36	4.8	6.09	7.24	7.46	7.04	6.35	5.9	4.92	4.55	4.12	3.65
Khanoqin	4.06	5.09	6.51	7.44	7.87	7.22	6.78	6.23	5.56	4.96	4.12	3.7
Kirkuk	3.98	4.93	6.28	7.51	7.71	7.63	7.31	6.07	5.17	4.62	3.86	3.63
Sulaimaniya	3.85	5.07	6.53	7.62	7.57	6.53	6.22	5.6	4.85	4.74	3.92	3.4
Mosul	3.95	5.06	6.15	7.45	6.11	6.55	6.22	5.66	4.76	4.59	4	3.25
Zakho	3.77	4.86	6.36	7.51	8.09	7.25	6.66	6.03	5.04	4.65	3.92	3.38

Table 5. the estimated values of diffuse radiation by model (2) Hdl2

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Basrah	4.69	5.74	7.18	8.15	8.62	8.47	8.86	8.11	6.6	5.62	4.77	4.34
Nasiriya	4.7	5.9	7.1	8.2	9	9.1	8.9	8.2	6.9	6.2	4.8	4.6
Samaua	4.7	5.62	6.92	8.14	8.85	8.64	7.9	6.93	6.03	5.83	4.8	4.37
Amara	4.67	5.7	7.1	8	8.95	8.35	8.18	7.24	5.69	5.63	4.83	4.31
Diwaniya	4.67	5.68	6.98	8.39	8.88	8.64	8.18	7.45	6.42	5.71	4.86	4.28
Najaf	4.6	5.52	6.99	8.14	8.99	8.49	8.06	7.58	6.61	5.71	4.7	4.26
Hai	4.53	5.55	6.87	8.13	8.75	8.36	8	7.37	6.48	5.13	4.62	4.18
Kerballa	4.54	5.49	6.88	8.33	9.28	8.31	7.99	7.33	6.4	5.55	4.57	4.17
Rutbah	4.47	5.39	6.89	8.27	8.65	8.22	7.94	7.15	6.45	5.59	4.52	4.19
Baghdad	4.4	5.41	6.76	8.01	9.12	8.22	8.09	7.35	6.43	5.63	4.53	4.12
Haditha	4.81	5.89	7.38	8.78	8.7	8.59	8.04	7.4	6.27	5.41	4.99	4.03
Khanoqin	4.43	5.56	7.07	8.27	8.94	8.69	8.31	7.67	6.7	5.84	4.58	4.01
Kirkuk	4.28	5.38	6.85	8.29	8.84	8.98	8.71	7.5	6.39	5.39	4.36	3.9
Sulaimaniya	4.17	5.22	6.98	8.37	9.34	8.19	8.18	7.49	6.29	5.84	4.56	3.96
Mosul	4.13	5.49	6.75	8.23	7.97	8.21	8.11	7.46	6.27	5.35	4.32	3.79
Zakho	3.99	5.2	6.79	8.19	9.12	8.72	8.17	7.45	6.22	5.33	4.16	3.61

Table 6. the estimated values of diffuse radiation by model (3) Hdl3

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Basrah	3.73	4.5	5.7	6.48	6.87	6.74	7.11	6.48	5.28	4.49	3.81	3.44
Nasiriya	3.7	4.6	5.6	6.5	7.2	7.29	7.1	6.5	5.52	5.08	3.8	3.71
Samaua	3.73	4.51	5.5	6.47	7.05	6.91	6.3	5.51	4.71	4.66	3.82	3.47
Amara	3.7	4.52	5.63	6.65	7.12	6.83	6.54	5.77	4.41	4.5	3.84	3.41
Diwaniya	3.72	4.51	5.54	6.65	7.06	6.91	6.54	5.96	5.3	4.56	3.86	3.4
Najaf	3.68	4.39	5.56	6.47	7.21	6.79	6.44	6.06	5.29	4.56	3.74	3.38
Hai	3.6	4.41	5.53	6.48	6.97	6.69	6.61	5.89	5.32	4.1	3.68	3.32
Kerballa	3.6	4.37	5.47	6.6	7.36	6.64	6.39	5.85	5.15	4.44	3.64	3.31
Rutbah	3.54	4.22	5.75	6.73	6.91	6.57	6.33	5.68	5.16	4.47	3.61	3.32
Baghdad	3.49	4.3	5.38	6.38	7.07	6.57	6.46	5.86	5.04	4.5	3.6	3.27
Haditha	3.81	4.3	5.45	6.48	6.94	6.87	6.42	5.91	5.01	4.33	3.69	3.19
Khanoqin	3.51	4.4	5.79	6.56	7.11	6.95	6.85	6.33	5.36	4.53	3.63	3.18
Kirkuk	3.39	4.26	5.42	6.57	7.03	7.18	6.54	6	5.11	4.18	3.29	3.09
Sulaimaniya	3.31	4.13	5.55	6.33	6.97	6.54	6.49	5.98	5.03	4.39	3.45	2.99
Mosul	3.33	4.35	5.35	6.67	6.37	6.56	6.48	5.96	4.83	4.27	3.42	3.01
Zakho	3.19	4.39	5.65	6.49	7.24	6.97	6.53	5.96	4.98	4.46	3.29	3

Table 7. the estimated values of diffuse radiation by model (4) Hdl4

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Basrah	3.11	4.02	4.95	6.04	7.16	7.68	7.6	6.75	6.19	4.74	3.45	2.92
Nasiriya	2.93	3.93	4.78	5.82	6.86	7.57	7.04	6.64	5.87	4.43	3.25	2.84
Samaua	3.11	4.02	4.95	6.04	7.16	7.68	8.16	6.75	6.19	4.74	3.45	2.92
Amara	2.8	3.79	4.66	5.86	6.79	8.03	7.9	7.29	6.69	4.46	3.22	2.68
Diwaniya	2.86	3.78	4.82	5.86	6.74	7.9	7.93	7.25	6.01	4.4	3.01	2.62
Najaf	2.91	3.86	4.82	5.94	6.88	7.99	7.94	7.13	5.97	5.09	3.24	2.66
Hai	2.92	3.79	4.86	5.93	7	8.13	7.99	7.16	6.03	4.47	3.34	2.68
Kerballa	2.86	3.84	4.86	5.68	6.54	8.08	7.98	7.27	6.04	4.4	3.2	2.59
Rutbah	2.84	3.77	4.87	5.93	7.12	8.26	8.2	7.45	6.05	4.43	3.27	2.61
Baghdad	2.77	3.69	4.78	6.05	7.1	8.27	8.08	7.39	6.02	4.34	3.1	2.57
Haditha	2.88	3.6	4.73	5.84	7.16	8.09	8.03	7.19	5.87	4.29	3.02	2.39
Khanoqin	2.53	3.28	4.33	5.64	6.79	7.94	7.77	6.98	5.7	4.03	2.83	2.22
Kirkuk	2.29	3.17	4.19	5.52	6.88	7.73	8.33	7.05	5.79	4.03	2.83	2.07
Sulaimaniya	2.38	3.01	3.92	5.44	7	8.23	8.11	7.28	5.9	3.99	2.69	2.29
Mosul	1.97	3.17	4.23	5.48	7.31	8.26	8.1	7.26	5.88	4.01	2.67	2.01
Zakho	2.01	2.81	3.88	5.21	6.74	7.96	7.89	7.01	5.64	3.79	2.4	1.88

Table 8. the clearness index ($Kt=R_s/R_a$) for northern stations.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kt"basrah"	0.59	0.6	0.58	0.59	0.62	0.65	0.64	0.63	0.68	0.66	0.62	0.59
Kt"nasiriya"	0.56	0.58	0.57	0.57	0.59	0.58	0.6	0.62	0.65	0.41	0.59	0.56
Kt"samaua"	0.58	0.59	0.59	0.59	0.6	0.65	0.69	0.7	0.73	0.63	0.6	0.57
Kt"amara	0.55	0.58	0.56	0.57	0.59	0.66	0.67	0.69	0.74	0.64	0.59	0.57

Table 9. the clearness index ($Kt=R_s/R_a$) for middle stations.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kt"diwaniya	0.56	0.58	0.58	0.57	0.59	0.65	0.67	0.68	0.67	0.63	0.56	0.56
Kt"najaf	0.57	0.6	0.58	0.58	0.59	0.66	0.67	0.67	0.66	0.63	0.6	0.57
Kt"hai"	0.58	0.59	0.59	0.58	0.61	0.67	0.68	0.68	0.67	0.64	0.62	0.58
Kt"kerball"	0.57	0.6	0.59	0.56	0.56	0.67	0.68	0.68	0.68	0.64	0.6	0.56
Kt"Rutbah"	0.57	0.6	0.59	0.58	0.62	0.68	0.7	0.68	0.64	0.62	0.62	0.57
Kt"baghdad"	0.57	0.59	0.59	0.6	0.61	0.68	0.68	0.69	0.68	0.63	0.6	0.57
Kt"haditha	0.55	0.58	0.58	0.58	0.62	0.66	0.68	0.68	0.67	0.64	0.59	0.55

Table 10. the clearness index ($Kt=R_s/R_a$) for southern stations.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kt"khanoqin"	0.53	0.53	0.54	0.56	0.59	0.65	0.66	0.66	0.65	0.6	0.56	0.52
Kt"kirkuk"	0.5	0.53	0.53	0.55	0.6	0.63	0.64	0.67	0.67	0.62	0.58	0.5
Kt"sulaimaniya"	0.52	0.5	0.49	0.54	0.61	0.68	0.68	0.69	0.68	0.61	0.56	0.56
Kt"mosul"	0.44	0.52	0.54	0.55	0.68	0.68	0.68	0.69	0.69	0.62	0.56	0.5
Kt"zakho"	0.47	0.49	0.49	0.53	0.58	0.65	0.67	0.67	0.67	0.6	0.52	0.49

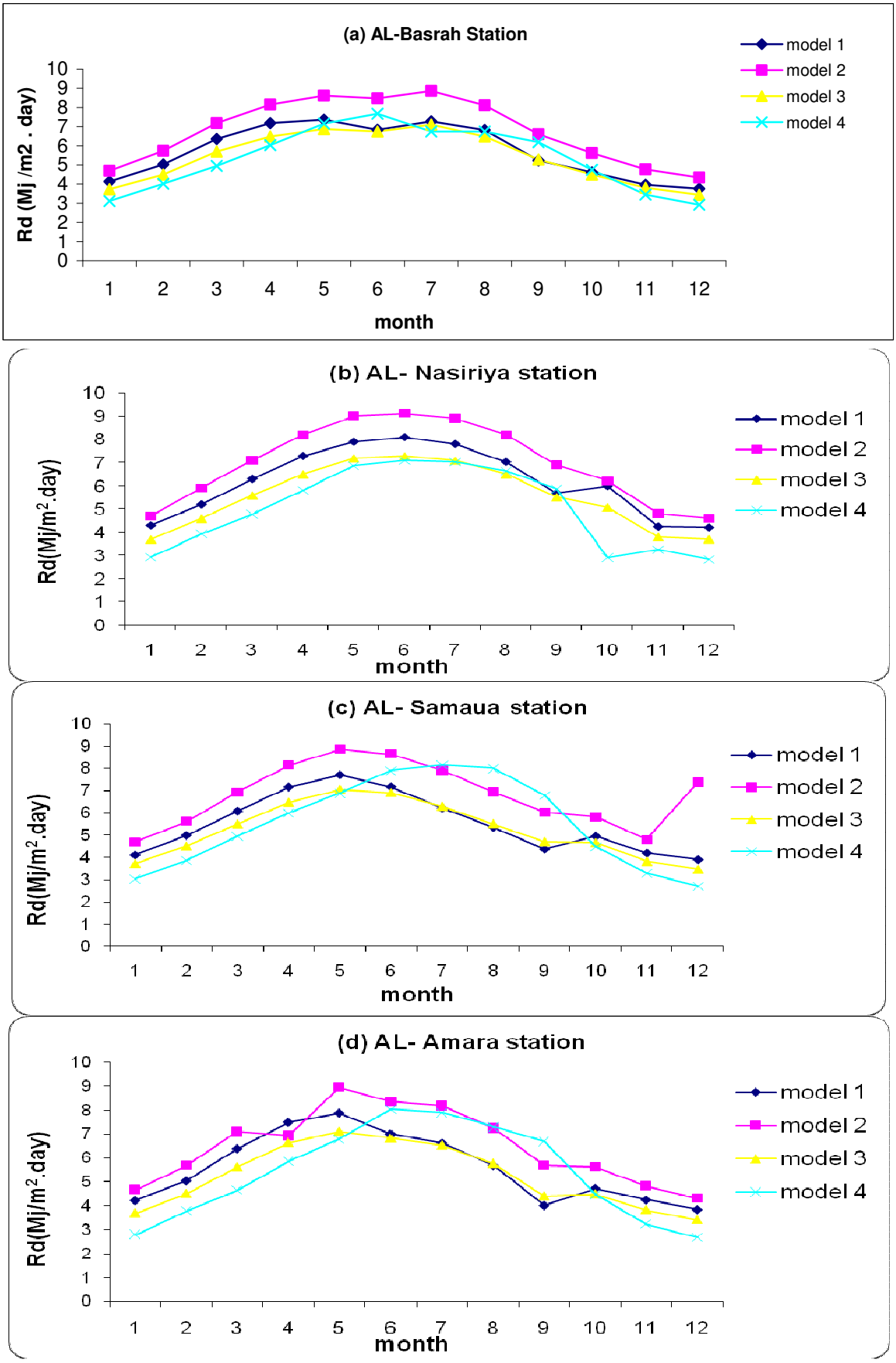
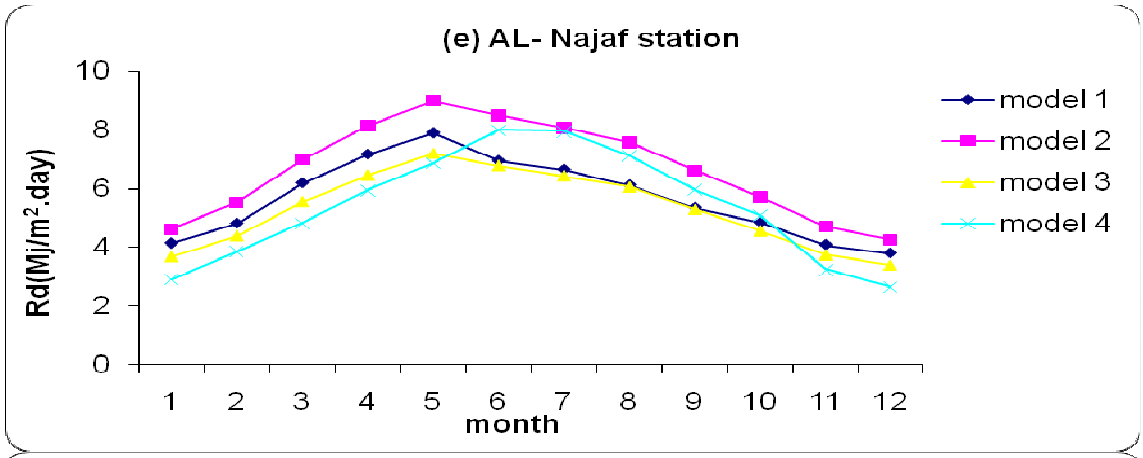
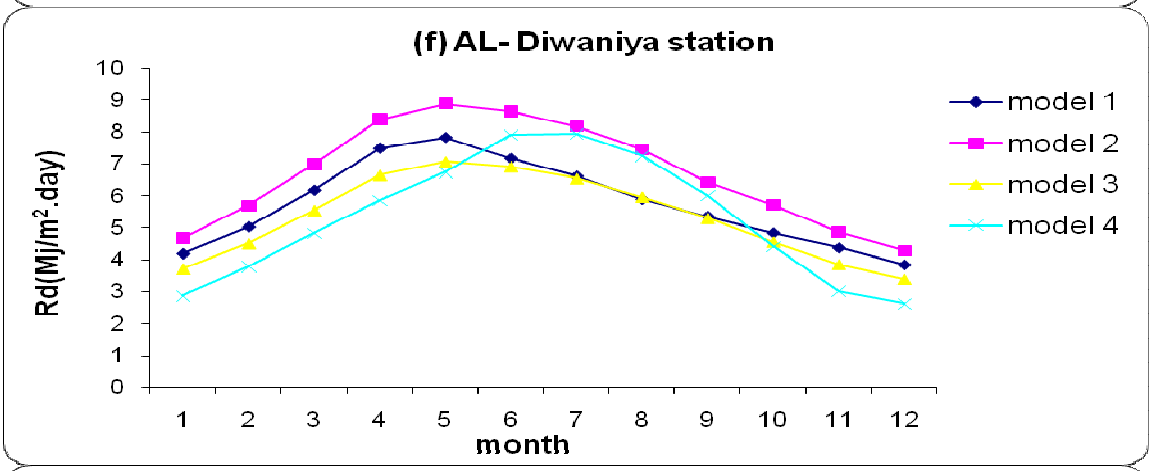
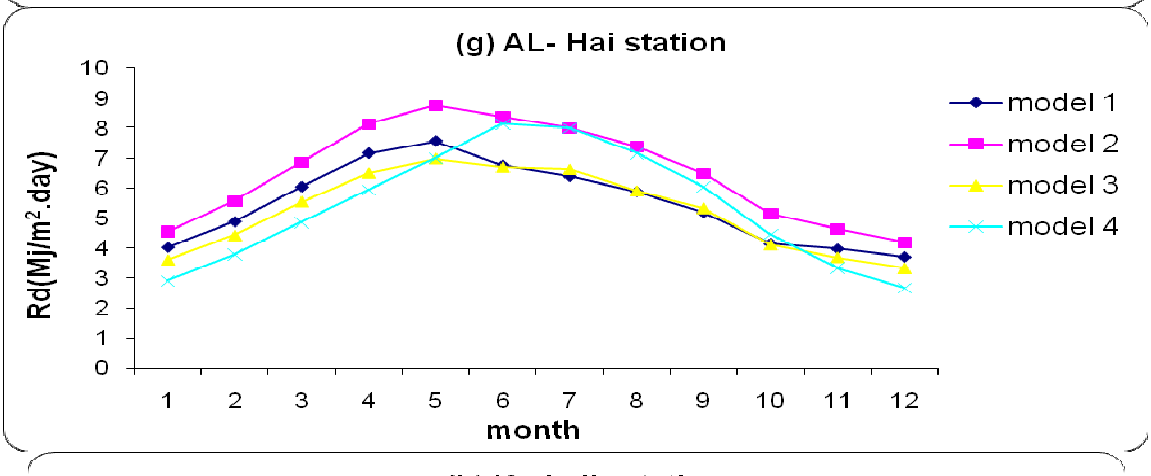
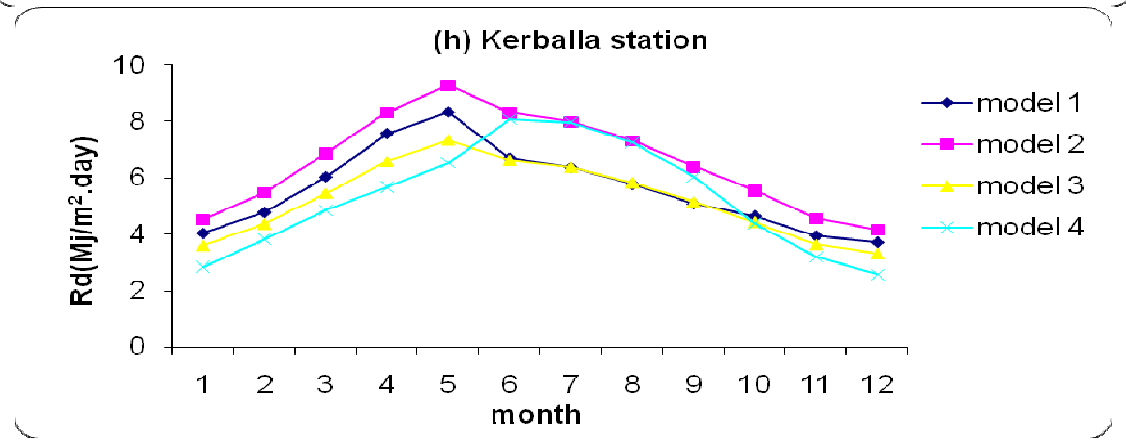


Fig (1-1) (a-d) represent the diffuse solar radiation (MJ\m^2.day) in south locations of Iraq (four models)


(e) AL- Najaf station
Rd(Mj/m2.day)
month
model 1
model 2
model 3
model 4


(f) AL- Diwaniya station
Rd(Mj/m2.day)
month
model 1
model 2
model 3
model 4


(g) AL- Hai station
Rd(Mj/m2.day)
month
model 1
model 2
model 3
model 4


(h) Kerballa station
Rd(Mj/m2.day)
month
model 1
model 2
model 3
model 4

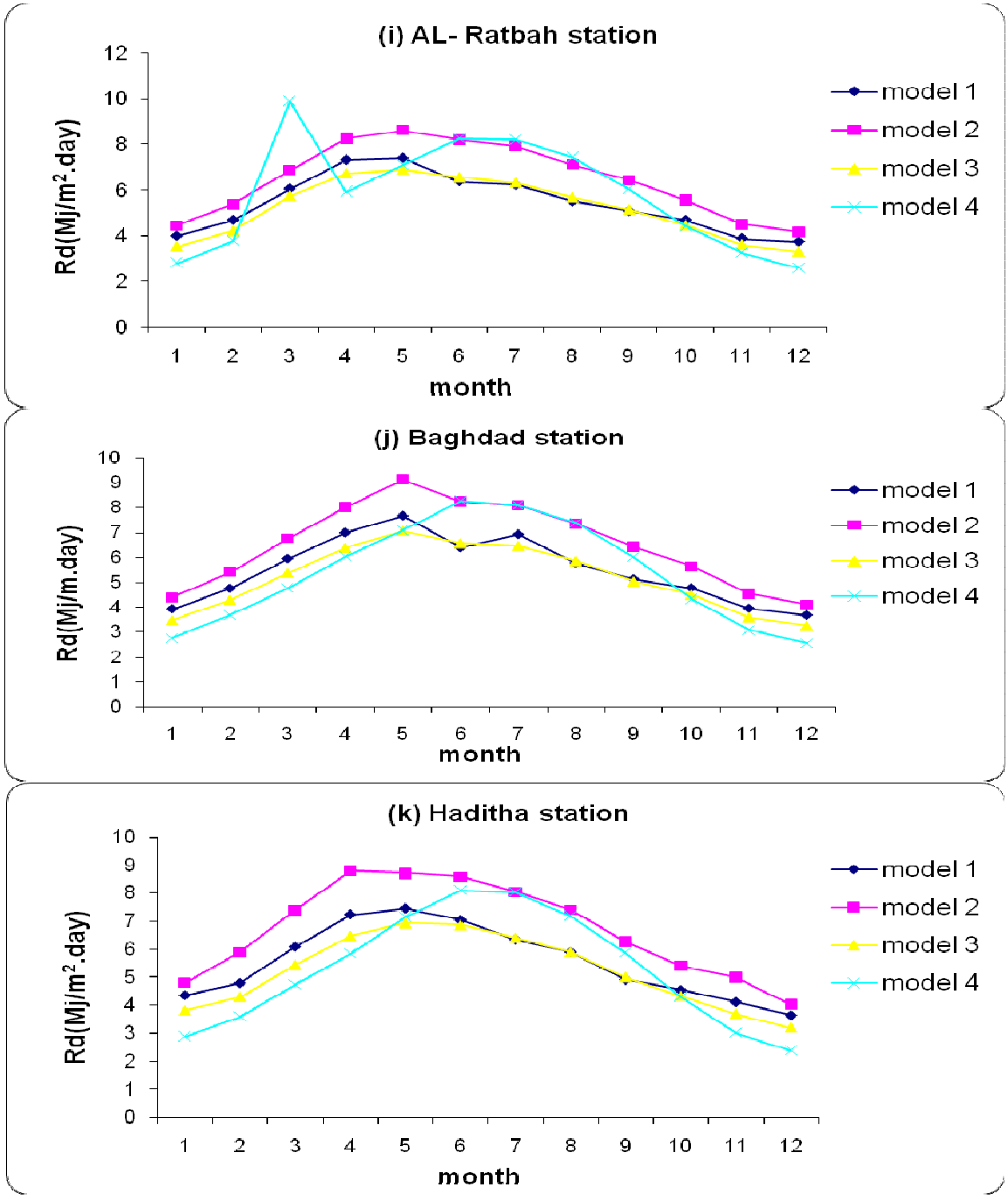


Fig (1-2) (e-k) represent the diffuse solar radiation (MJ\m^2.day) in middle locations of Iraq (four models)

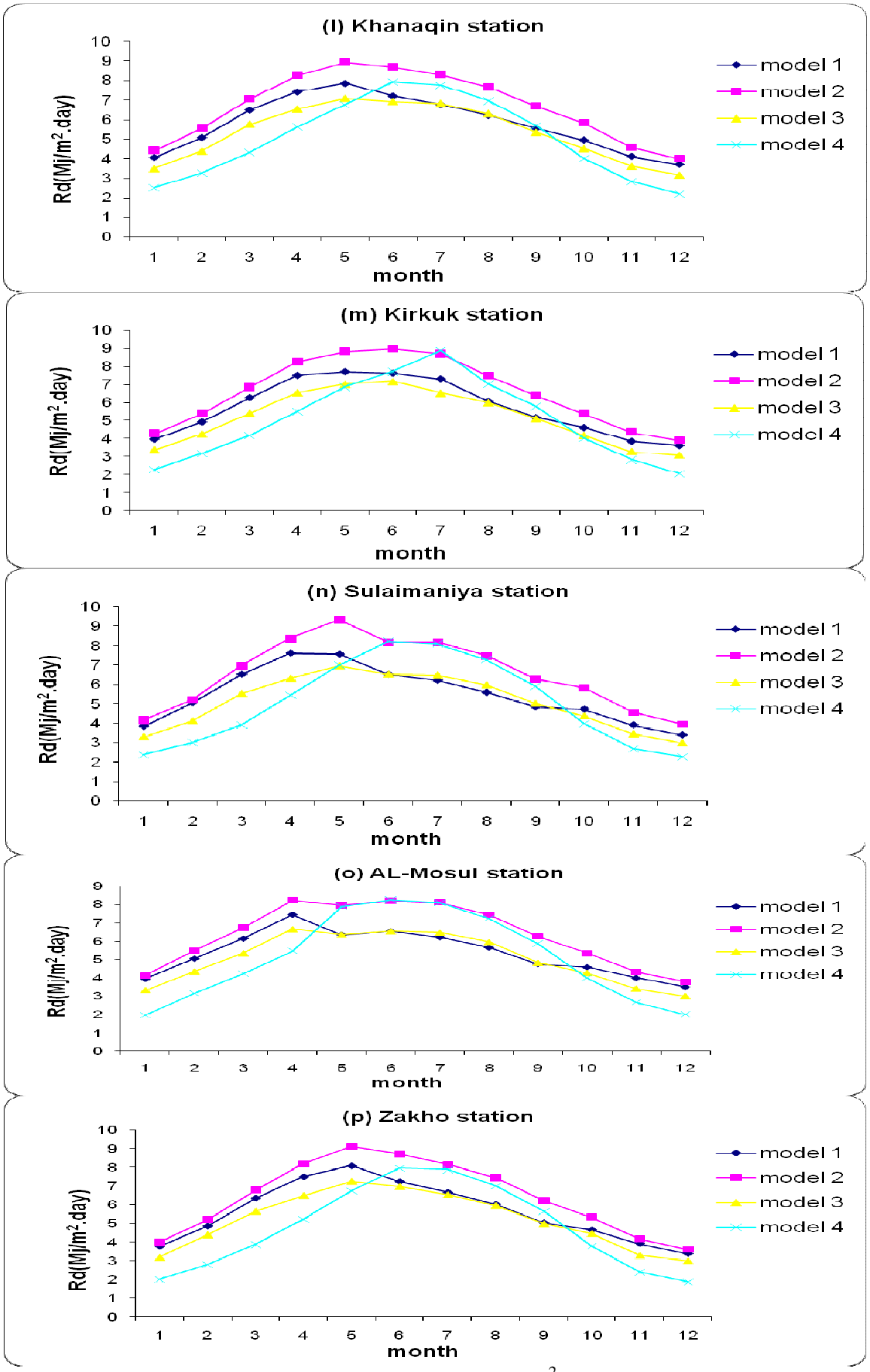


Fig (1-3) (l-p) represent the diffuse solar radiation (MJ\m^2.day) in south locations of Iraq (four models)

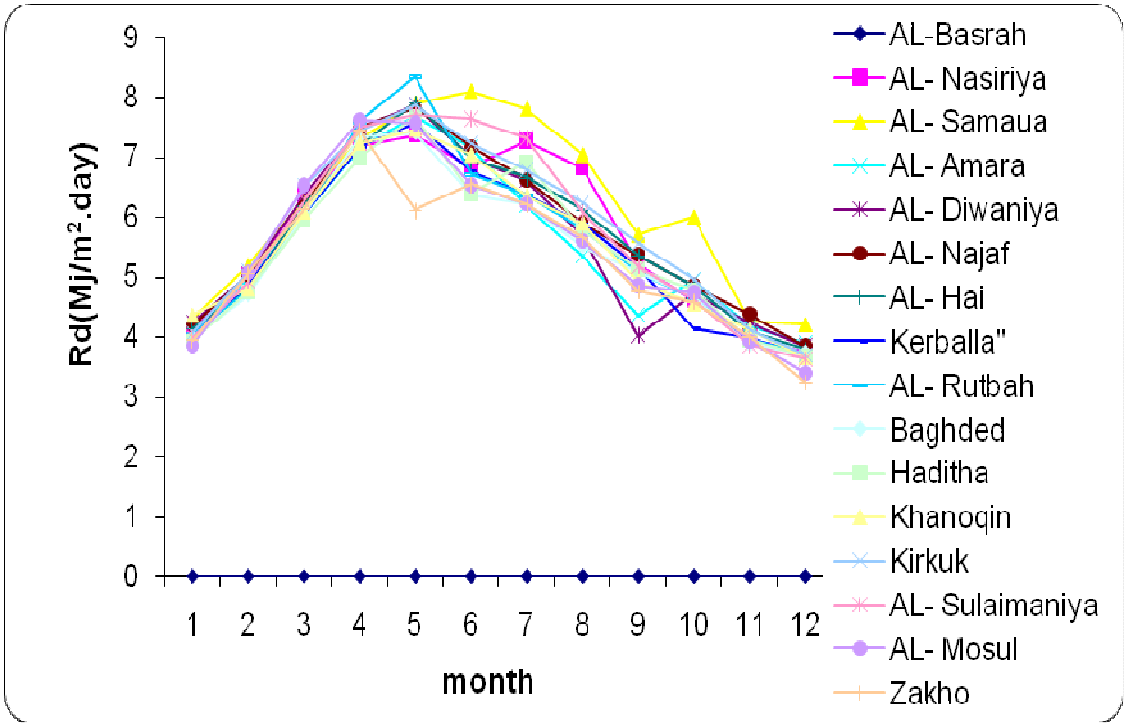


Fig.2. total diffuse solar radiation for all locations in Iraq by (model 1)

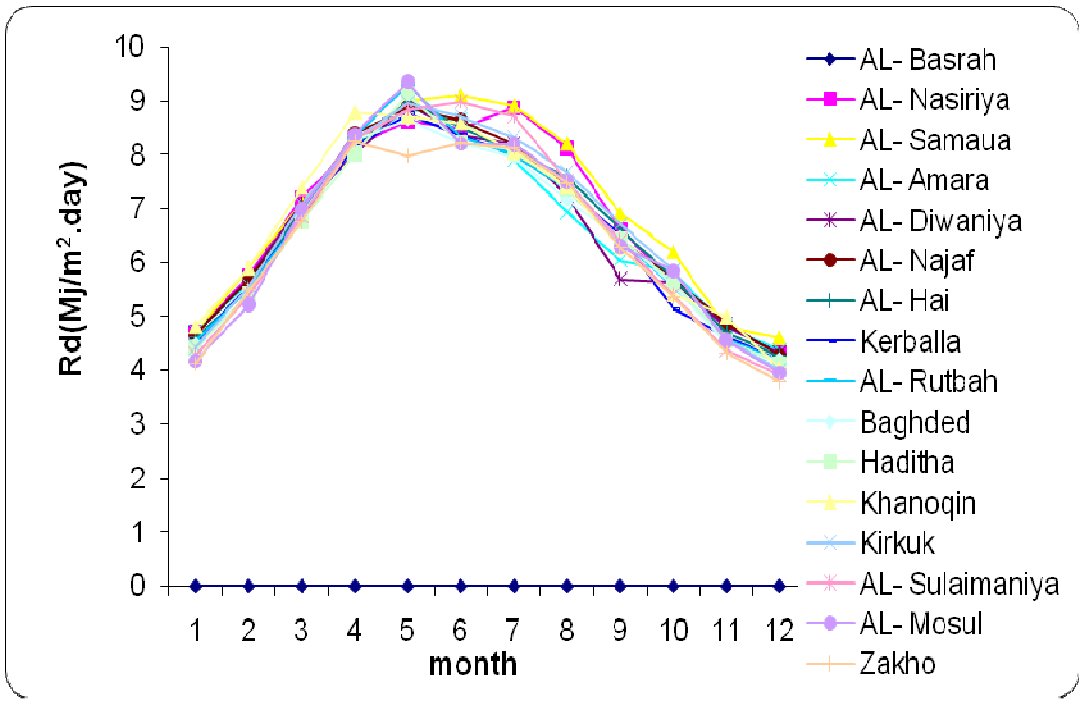


Fig. 3. total diffuse solar radiation for all locations in Iraq by (model 2)

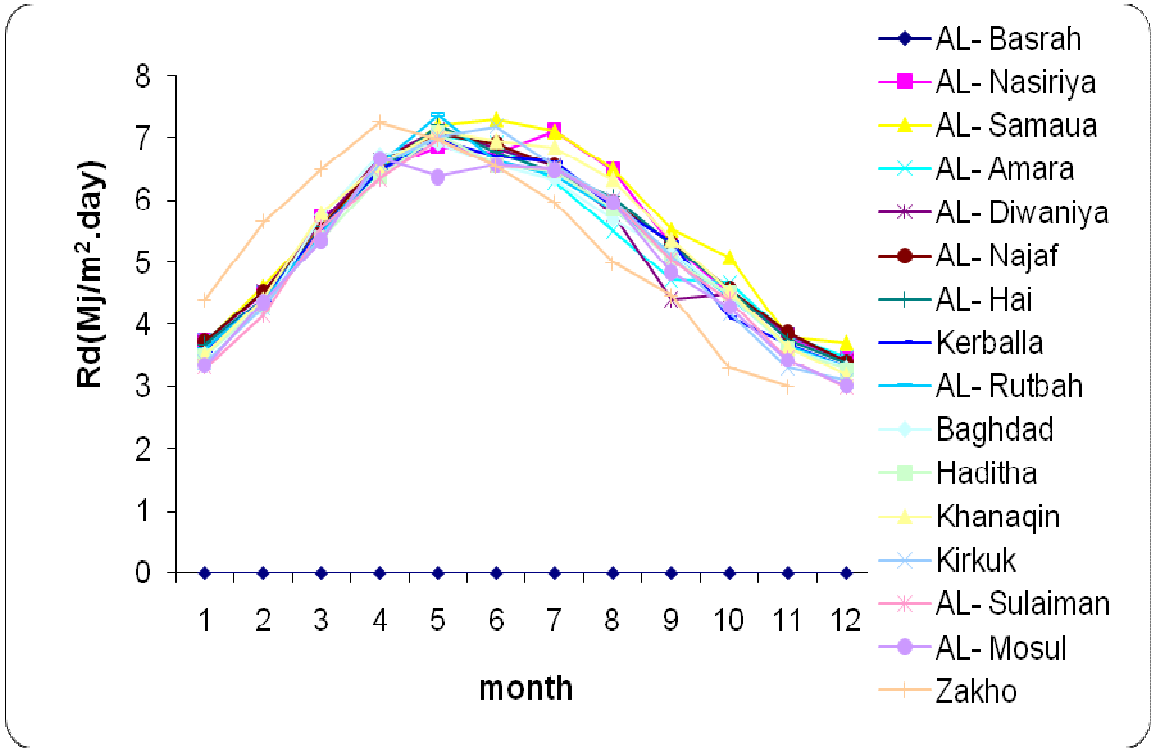


Fig. 4. total diffuse solar radiation for all locations in Iraq by (model 3)

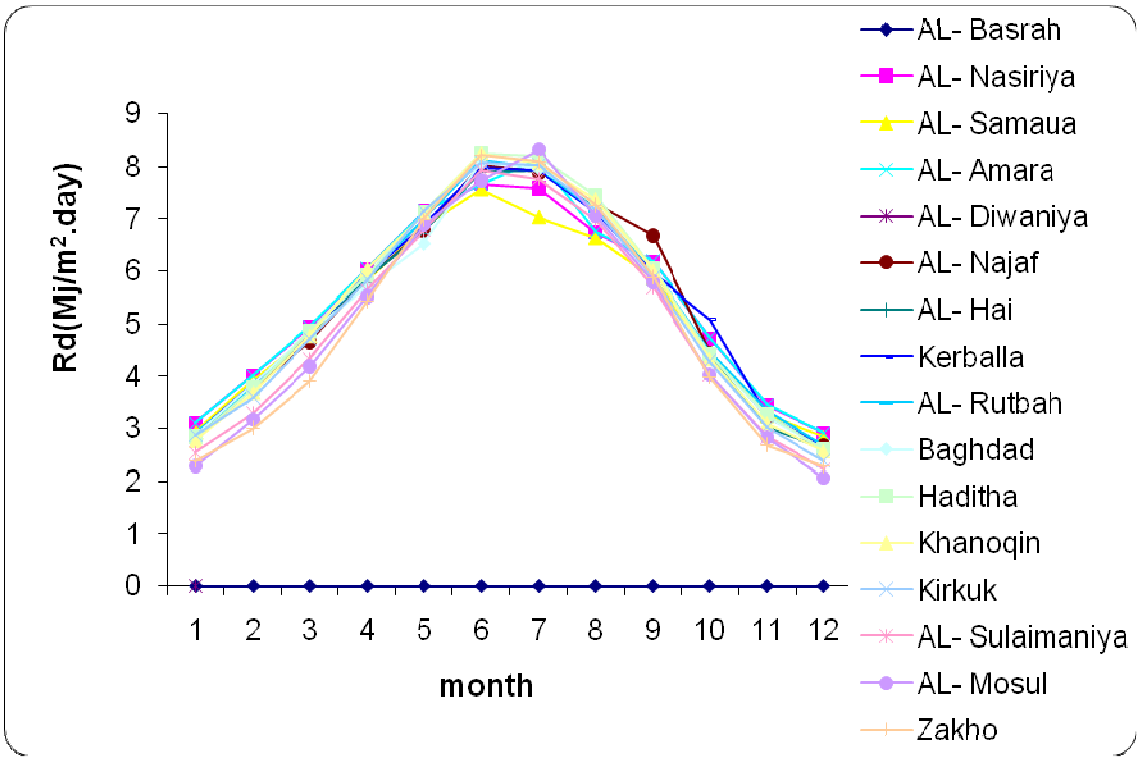


Fig. 5. total diffuse solar radiation for allocations in Iraq by (model4)

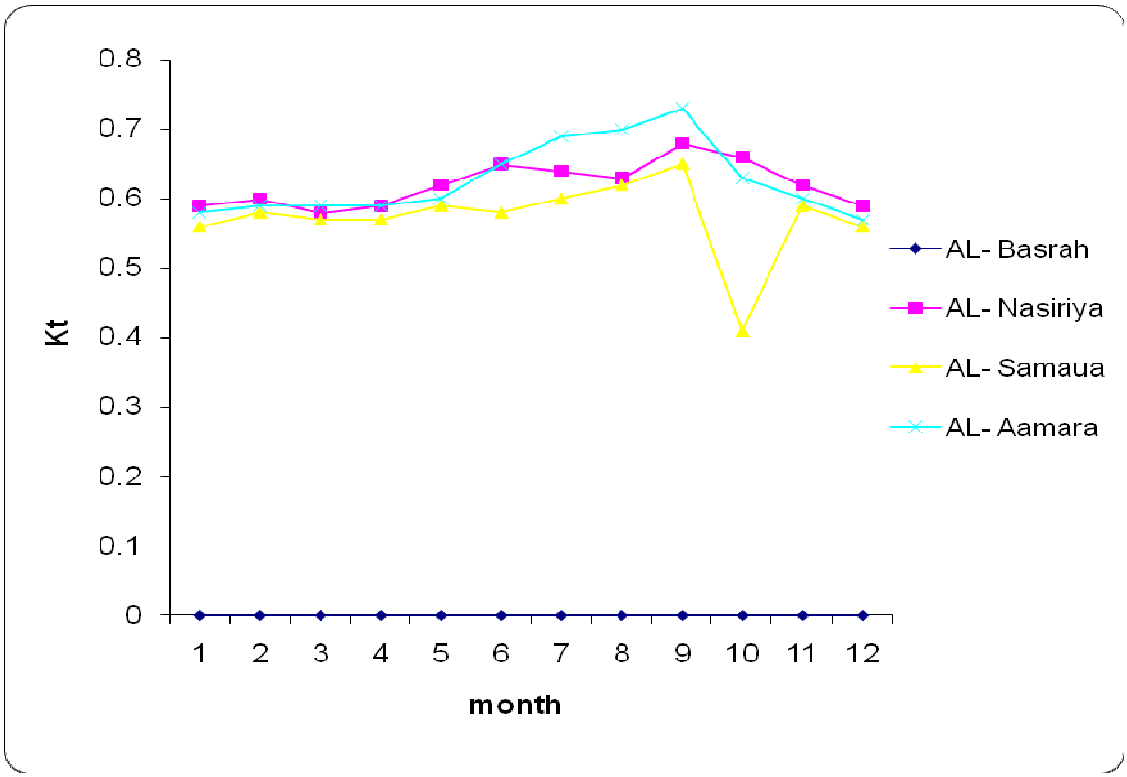


Fig. 6. the variation of Kt with month for (south of Iraq)

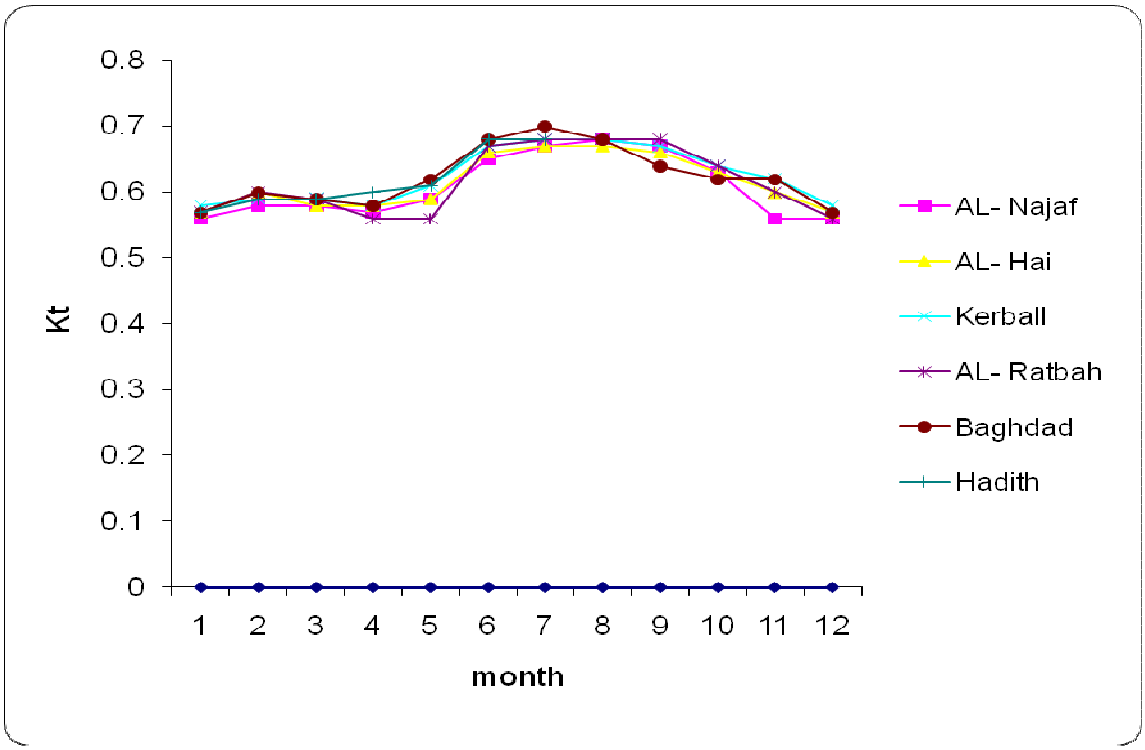


Fig. 7. the variation of Kt with month for (middle of Iraq)

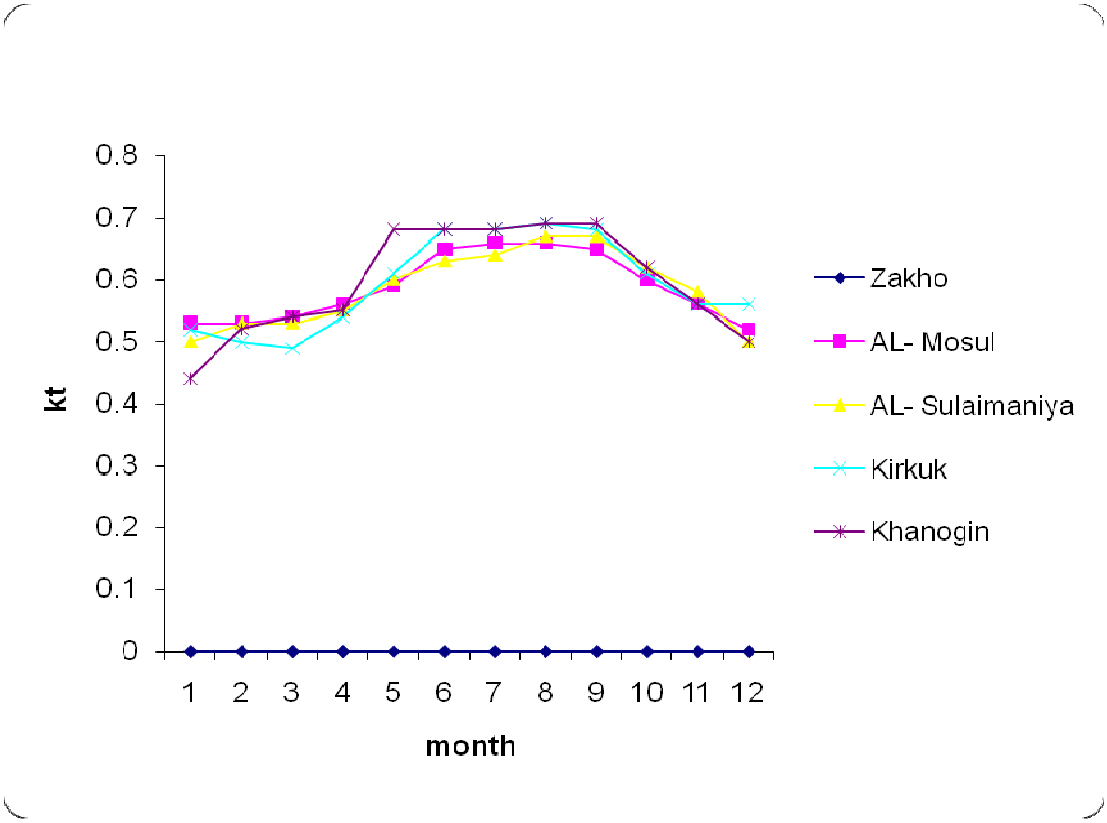


Fig. 8. the variation of Kt with month for (north of Iraq)