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Estimation of Diffuse Solar Radiation over IRAQ

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Abstract: *Mean monthly , seasonally and annually values of Diffuse Solar Radiation (Hd) were found in four meteorological stations (Mosul , Baghdad , Ratba , Nasiriyah) well distributed in IRAQ using four common mathematical Models (Page , Iqbal , liu-Jordan,Abdul-Salam) for the time series (1980-2010).*
The maximum mean monthly values of diffuse solar radiation for all stations were obtained in summer months where its values ranged between (5.99-9.56 MJ/m^2.d), while the minimum values was obtained in December and January where its Values ranged between (2.92 – 4.96 MJ/m^2.d) .
Linear Regression Equations were found between the mean monthly values of clearness Index (KT) and the mean monthly values of (Kd) in four stations .
A high correlation coefficient (R) were obtained for these regression models where its values ranged between (0.92-0.99).
Key words*: clearness Index , Diffuse Solar radiation , Total Solar Radiation , Time Series , R^2*

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I. Introduction

Solar energy is one of the most promising renewable sources ,this is because it is envirenmentaly frendly ,abundant and easy to utilize [1,2].
The knowledge of the amount of the available Solar energy and its variability over any geographical region is very paramount for solar energy utilization , especially in the absence and Scarcity of reliable monthly solar radiation data [1,3,4] .
The Solar radiation measuring network generally record only the total daily radiation on horizontal surface [5].
The Solar global radiation is divided in two components ; diffuse solar radiation , which is results from scattering of solar radiation caused by gases in the Earth's atmosphere , dispersed water droplets and particulates.

While direct solar radiation some time called beam radiation is used to describe solar radiation travelling on a straight line from the sun down to the surface of the Earth . This is one that have not been scattered [1,6].
The data of diffuse solar radiation are still un measured by meteorological stations for major parts of the world including Iraq [7].

Global solar radiation in Iraq are measured in some stations while diffuse solar radiation is not observed experimentally in any meteorological station of the country.
Empirical correlations are usually used to extract diffuse and direct solar radiation from the global solar radiation obtained over a horizontal surface from the location under study [8,9,10].
Due to the lack of Studies on diffuse solar radiation in Iraq , Four mathmatical models (Page ,Lui-Jordan ,Iqbal and Abdul Salam) wear used to estimate diffuse solar radiation in four stations well distributed in Iraq (Mosul , Baghdad , Ratba , Nasiriyah) for the period (1980-2010).

II. Methodology

From Iraq meteorological Organization , sunshine duration and Total solar radiation were taken for (Mosul , Baghdad ,Ratba , Nasiriyah) station for the period (1980-2010).
The missing data of total solar radiation were obtained using Glover model with local constant.

$$\mathbf{H = H_0 [-0.847+1.259 \cos(Ø)+0.473(n/N)]} \quad \ldots\ldots \quad (1)$$

Where H: Total solar radiation .
H_0: Extraterrestrial radiation .
n/N: Sunshine Ratio
The geographical Coordinate of different stations were presented in table (1).

Table (1): Latitude , longitude and Elevation of the four stations.

Stations	longitude	latitude	Elevation
Mosul	**43º 09´**	**36º 19´**	**223**
Baghdad	**44º 24´**	**33º 18´**	**32**
Rutba	**40º 17´**	**33º 02´**	**630**
Nasiriyah	**46º 14´**	**31º 05´**	**5**

The following table show the mean monthly values of (n , N , n/N) for the four station during the period (1980-2010).

Table (2): Mean monthly values of (n , N , n/N) for the four station .

Months / Stations		JAN	FEB	MAR	APR	MAY	JUN		JUL	AUG	SEP	OCT	NOV	DEC
Mosul	**n**	**4.68**	**5.65**	**6.81**	**7.85**	**9.92**	**12.15**		**11.93**	**11.34**	**10.33**	**8.12**	**6.37**	**4.57**
	N	**9.81**	**10.64**	**11.77**	**12.94**	**13.96**	**14.46**		**14.22**	**13.34**	**12.21**	**11.00**	**10.02**	**9.53**
	n/N	**0.477**	**0.531**	**0.579**	**0.607**	**0.711**	**0.840**		**0.839**	**0.850**	**0.846**	**0.738**	**0.636**	**0.480**
Baghdad	**n**	**6.06**	**7.23**	**8.01**	**8.68**	**10.16**	**12.05**		**11.86**	**11.53**	**10.10**	**8.29**	**7.12**	**6.11**
	N	**10.05**	**10.79**	**11.80**	**12.84**	**13.75**	**14.19**		**13.98**	**13.20**	**12.19**	**11.11**	**10.24**	**9.80**
	n/N	**0.603**	**0.670**	**0.679**	**0.676**	**0.739**	**0.849**		**0.848**	**0.873**	**0.829**	**0.746**	**0.695**	**0.623**
Rutba	**n**	**6.49**	**7.35**	**8.10**	**8.75**	**10.03**	**12.36**		**12.36**	**11.67**	**10.54**	**8.75**	**7.56**	**6.20**
	N	**10.07**	**10.80**	**11.80**	**12.83**	**13.73**	**14.17**		**13.96**	**13.18**	**12.18**	**11.12**	**10.26**	**9.83**
	n/N	**0.644**	**0.681**	**0.686**	**0.682**	**0.731**	**0.872**		**0.885**	**0.885**	**0.865**	**0.787**	**0.737**	**0.631**
Nasiriyah	**n**	**6.53**	**7.40**	**7.59**	**8.22**	**9.09**	**9.92**		**10.03**	**10.00**	**9.63**	**8.46**	**7.13**	**6.27**
	N	**10.21**	**10.89**	**11.81**	**12.77**	**13.60**	**14.01**		**13.81**	**13.10**	**12.17**	**11.18**	**10.39**	**9.99**
	n/N	**0.640**	**0.680**	**0.643**	**0.644**	**0.668**	**0.708**		**0.726**	**0.763**	**0.791**	**0.757**	**0.686**	**0.628**

Extraterrestrial radiation (**H_0**) was calculated from the solar constant (Gsc) and the solar declination angle () and the sequence of the day at the middle of the month of the year according to the following relationship

H_0= Gsc dr … (2)

Ra=extraterrestrial radiation [**MJ/m^2.d**]

Gsc = solar constant 0.082 [**MJ/m^2.d**]

dr = inverse related distance, Earth- Sun

Ws = Sun set hour angle [rad]

=latitude [rad] = solar declination angle

inverse related distance, Earth- Sun (dr) was calculated according to the following

dr = 1 + 0.033 cos[…..…….. (3)

Sunset hour angle (Ws)**:** The hourly sunset angle is calculated from the latitude and solar declination angle according to the following relationship

…..…….. (4)

The daylight hours, N, are given by : **…..……..** (5)

The following correlation are used to estimate the monthly mean diffuse solar radiation on horizontal surface :

Page Model : …..…….. (6)

Iqbal Model : …..…….. (7)

Liu-Jordan Model … (8)

Abdul Salam Model : …..…….. (9)

Mathlab and Microsoft Office Excel were used to calculate diffuse solar radiation and plot simple correlation relationships.

III. Results and Discussion

Mean Monthly Values of (Hd) in all stations

Tables (3,4,5,6) and Figures (1,2,3,4) showed the mean monthly values of diffuse solar radiation (Hd) in (MJ/m^2.d) for the stations (Mosul , Baghdad, Ratba , Nasirhiya) based on considered Models (Page ,Lui-Jordan ,Iqbal and Abdul Salam) during the period (1980-2010).

Table (3) : Mean monthly Diffuse solar radiation in (MJ/m^2.d)For Mosul during the period (1980-2010) based on the considered models

Months model	JAN	FEB	MAR	APR	MAY	JUN	JUL	AOG	SEP	OCT	NOV	DEC
Hd(page)	**3.75**	**4.86**	**6.34**	**7.77**	**8.57**	**8.78**	**8.57**	**7.75**	**6.45**	**5.20**	**4.00**	**3.39**
Hd(Iqbal)	**3.85**	**5.09**	**6.63**	**8.18**	**9.22**	**9.56**	**9.36**	**8.47**	**7.11**	**5.57**	**4.21**	**3.49**
Hd(L.J)	**3.22**	**4.13**	**5.40**	**6.61**	**7.37**	**7.61**	**7.44**	**6.76**	**5.66**	**4.46**	**3.42**	**2.92**
Hd(Abdul Salam)	**3.96**	**5.38**	**6.49**	**7.96**	**8.21**	**6.80**	**6.77**	**5.99**	**5.21**	**4.62**	**3.90**	**3.58**

Table (4) : Mean monthly Diffuse solar radiation in (MJ/m^2.d)For Baghdad during the period (1980-2010) based on the considered models

Months model	JAN	FEB	MAR	APR	MAY	JUN	JUL	AOG	SEP	OCT	NOV	DEC
Hd(page)	**4.04**	**4.90**	**6.28**	**7.55**	**8.12**	**7.89**	**7.66**	**7.06**	**6.13**	**5.07**	**4.14**	**3.74**
Hd(Iqbal)	**4.39**	**5.42**	**6.91**	**8.30**	**9.07**	**9.09**	**8.86**	**8.17**	**7.05**	**5.72**	**4.59**	**4.05**
Hd(L.J)	**3.50**	**4.31**	**5.50**	**6.59**	**7.21**	**7.24**	**7.06**	**6.51**	**5.62**	**4.55**	**3.65**	**3.24**
Hd(Abdul Salam)	**4.96**	**5.88**	**7.20**	**8.69**	**8.94**	**7.71**	**7.62**	**6.63**	**6.20**	**5.63**	**4.72**	**4.28**

Table (5) : Mean monthly Diffuse solar radiation in (MJ/m^2.d)For Ratba during the period (1980-2010) based on the considered models

Months model	JAN	FEB	MAR	APR	MAY	JUN	JUL	AOG	SEP	OCT	NOV	DEC
Hd(page)	**4.22**	**5.14**	**6.42**	**7.44**	**8.17**	**7.61**	**7.38**	**6.87**	**6.04**	**5.06**	**4.21**	**3.87**
Hd(Iqbal)	**4.49**	**5.55**	**7.00**	**8.24**	**9.05**	**8.88**	**8.64**	**8.02**	**6.99**	**5.72**	**4.63**	**4.14**
Hd(L.J)	**3.59**	**4.42**	**5.56**	**6.54**	**7.20**	**7.08**	**6.90**	**6.39**	**5.57**	**4.55**	**3.68**	**3.30**
Hd(Abdul Salam)	**4.38**	**5.46**	**6.96**	**8.75**	**8.91**	**7.45**	**7.13**	**6.60**	**5.89**	**5.26**	**4.30**	**4.18**

Table (6) : Mean monthly Diffuse solar radiation in (MJ/m^2.d)For Nasiriyah during the period (1980-2010) based on the considered models

Months model	JAN	FEB	MAR	APR	MAY	JUN	JUL	AOG	SEP	OCT	NOV	DEC
Hd(page)	**4.43**	**5.23**	**6.54**	**7.69**	**8.34**	**8.44**	**8.28**	**7.47**	**6.49**	**5.33**	**4.55**	**4.12**
Hd(Iqbal)	**4.77**	**5.75**	**7.16**	**8.42**	**9.17**	**9.36**	**9.22**	**8.43**	**7.37**	**6.01**	**4.97**	**4.42**
Hd(L.J)	**3.80**	**4.57**	**5.69**	**6.69**	**7.29**	**7.45**	**7.32**	**6.71**	**5.86**	**4.78**	**3.94**	**3.53**
Hd(Abdul Salam)	**4.88**	**5.93**	**7.80**	**9.06**	**9.63**	**9.41**	**9.13**	**8.11**	**6.82**	**5.76**	**5.01**	**4.51**

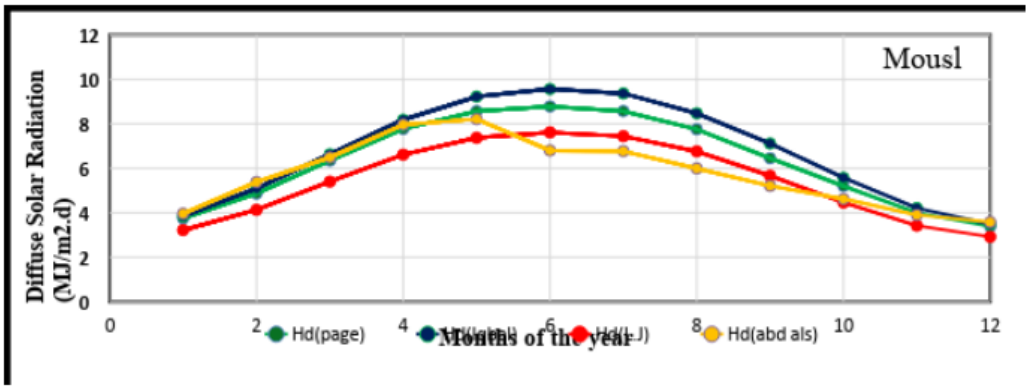


Fig (1) : Mean monthly values of diffuse solar radiation calculated from differeant Models in Mosul station during the peroid (1980-2010).

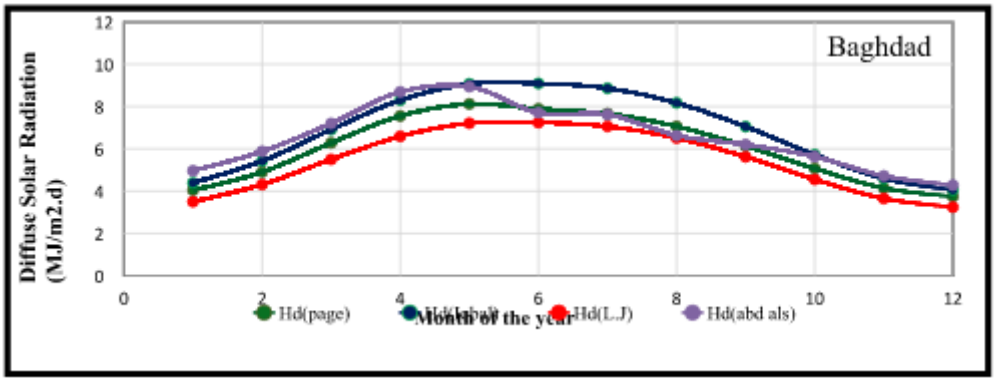


Fig (2) : Mean monthly values of diffuse solar radiation calculated from differeant Models in Baghdad station during the peroid (1980-2010).

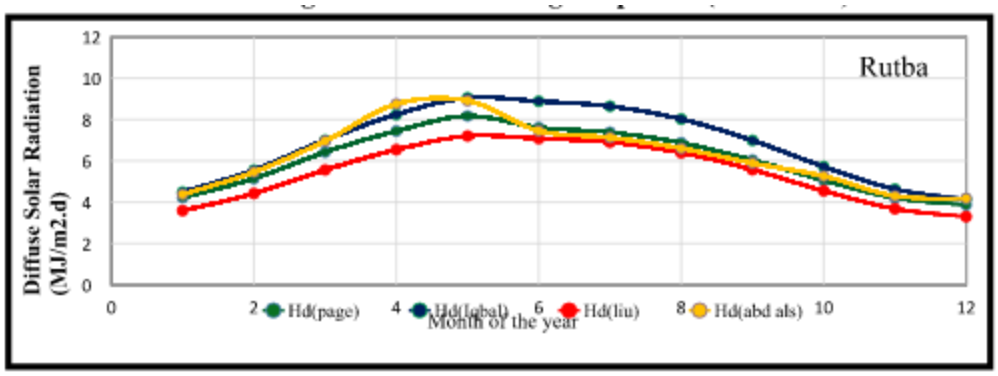


Fig (3) : Mean monthly values of diffuse solar radiation calculated from differeant Models in Rutba station during the peroid (1980-2010)

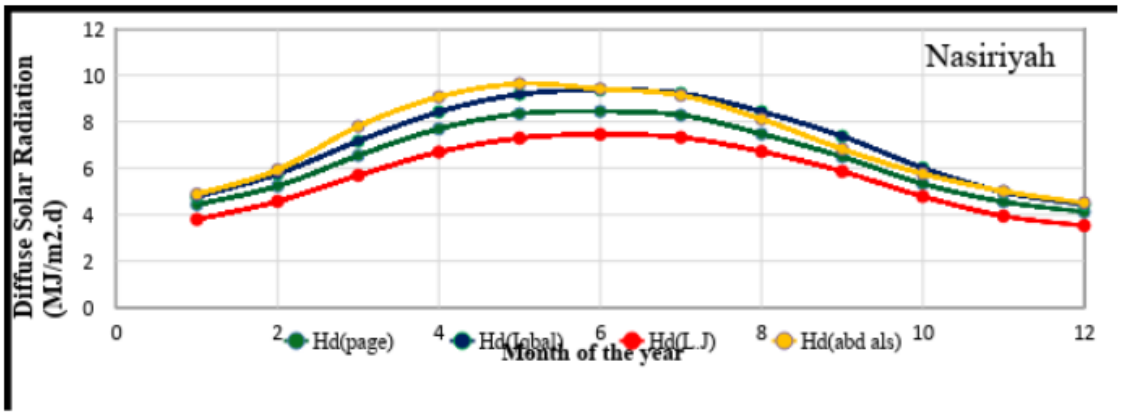


Fig (4) : Mean monthly values of diffuse solar radiation calculated from differeant Models in Nasiriyah station during the peroid (1980-2010).

We can said that any model have specific behavior depen on geographical site in Iraq.
From the tables (3,4,5,6) and figures (1,2,3,4) we can deduce :

- The values of diffuse radiation have a peak in summer months due to long daylight hour ,where its values ranged between (6.87-8.78 MJ/m^2.d) ,(8.02-9.56 MJ/m^2.d) ,(6.39-7.61 MJ/m^2.d), (5.99-9.41 MJ/m^2.d) according to (Page Model , Iqbal Model Lui-Jordan Model , and Abdul Salam Model) Respectively
- The Minimum values of diffuse solar radiation in all stations were obtained in December and January months where it value ranged between (3.39-4.43 MJ/m^2.d) ,(3.49-4.77 MJ/m^2.d) ,(2.92-3.80 MJ/m^2.d) ,(3.58-4.96 MJ/m^2.d) according to Page , Iqbal , Lui-Jordan , and Abdul Salam Model Respectively
- There is a good agreement between the values estimated by Page and Iqbal Models in comparison with the other modeals.

Mean Seasonally and Annually Values of Hd

Table (7) and fig (5) show the mean seasonally values of diffuse solar radiation (Hd) in (MJ/m^2.d) for the different stations based on the different Models during the period (1980-2010).

Table (7): Mean seasonally and annually values of diffuse solar radiation in (MJ/m^2.d) during the period (1980-2010) for all station .

Stations Models	Mosul					Baghdad					Ratba					Nasiriyah				
	win	Spr	Sum	Aut	Ann	win	Spr	Sum	Aut	Ann	win	Spr	Sum	Aut	Ann	win	Spr	Sum	Aut	Ann
page	4.0	7.56	8.37	5.22	6.29	4.23	7.32	7.54	5.11	6.05	4.41	7.34	7.29	5.10	6.04	4.59	7.52	8.06	5.46	6.41
Iqbal	4.14	8.01	9.13	5.63	6.73	4.62	8.09	8.71	5.79	6.80	4.73	8.10	8.51	5.78	6.78	4.98	8.25	9.00	6.12	7.09
Liu-Jor	3.42	6.46	7.27	4.51	5.42	3.68	6.43	6.94	4.61	5.42	3.77	6.43	6.79	4.60	5.40	3.97	6.56	7.16	4.86	5.64
Abdul sal	4.31	7.55	6.52	4.58	5.74	5.04	8.28	7.32	5.52	6.54	4.67	8.21	7.06	5.15	6.27	5.11	8.83	8.88	5.86	7.17

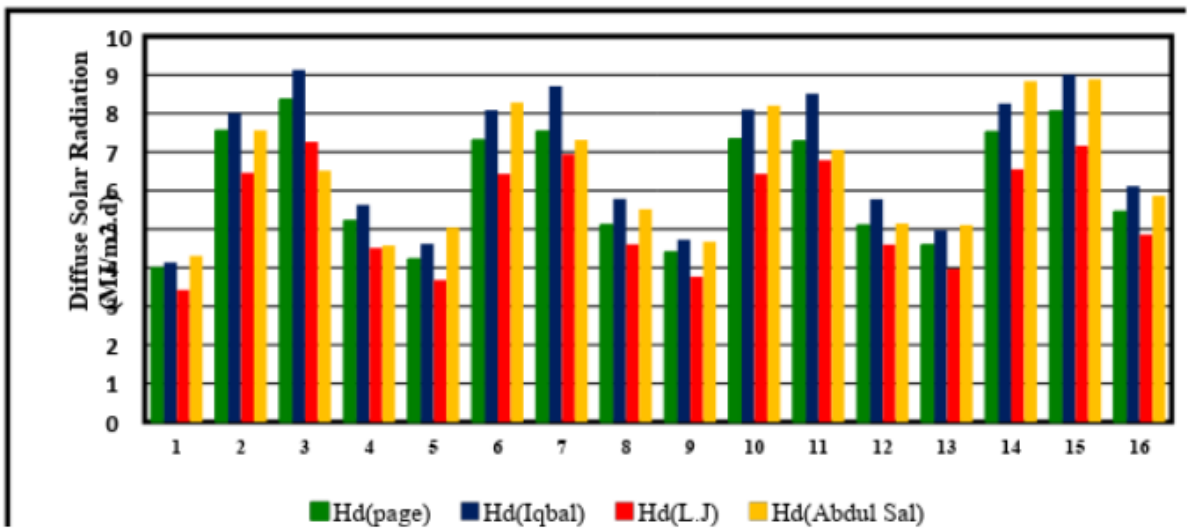


Fig: (5) Mean seasonally Vales of diffuse solar radiation in**)** MJ/m.^{2}d **(**during the period (1980-2010) for all station**.**

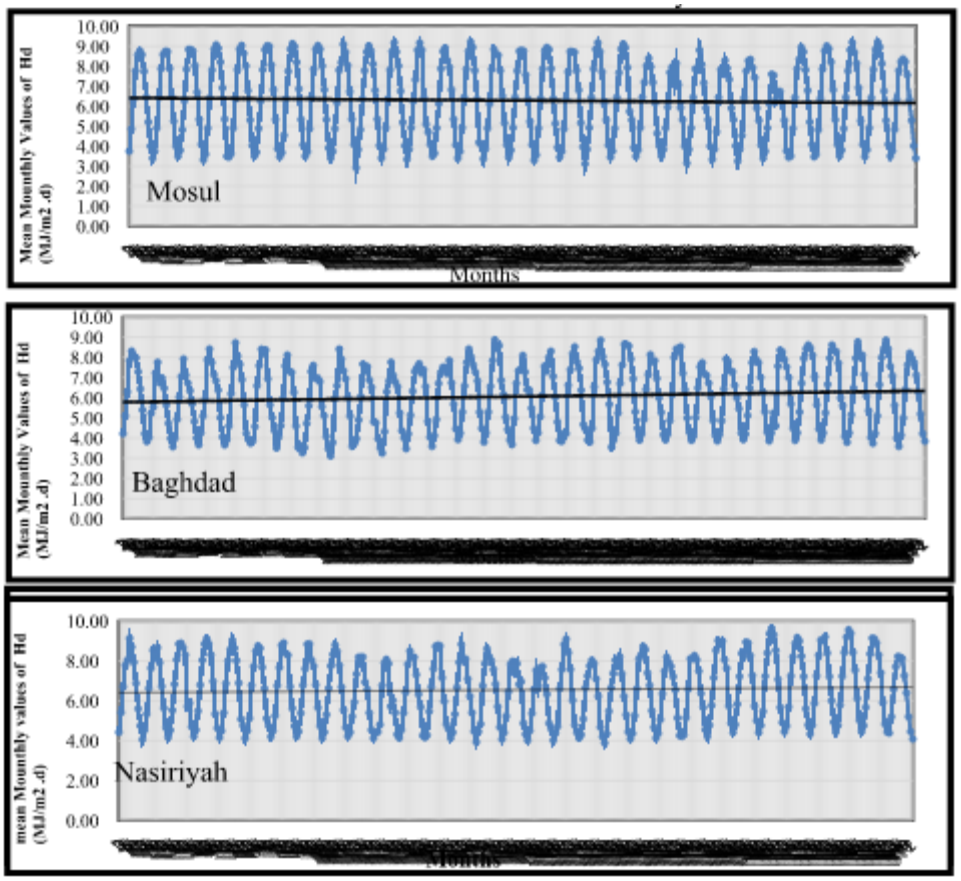
From the table and the figure we can see that the Maximum value of) Hd (was obtained in spring and summer seasons , where its values ranged between 6.46-9.13) MJ/m.^{2}d (in Mosul station 6.43-8.71), MJ/m.^{2}d (in Baghdad station 6.43-8.51), MJ/m.^{2}d (in Ratba station and 4.86-9.00) MJ/m.^{2}d (in Nasiriyah stations .

The Minimum value of (Hd) was obtained in winter and Autumn seasons and ranged between (5.63-3.42 MJ/m^2.d) in Mosul station ,(5.79-3.68 MJ/m^2.d) in Baghdad station ,(5.78-3.77 MJ/m^2.d) in Ratba station and (6.12-3.97 MJ/m^2.d) in Nasiriyah stations. Table (7) show also the mean annual values of Hd in all stations,where its ranged in all models between(5.42-6.75) , (5.42-6.8) , (5.4-6.78) , (5.64-7.1)MJ/m^2.d in Mosul , Baghdad , Ratba and Nasiriyah stations respectively .

Study of the Time Series for the monthly values of Hd in all Stations

Fig (6) show the diffuse radiation Time series for the four meteorological stations (Mosul , Baghdad , Ratba , Nasiriyah). Linear best fit calculating for the period (1980-2010) shows a positive trend in Baghdad ,Ratba ,Nasiriyah stations and a negative trend in Mosul stations . The Linear Regression equations for all station:

Hd = -0.0007x + 6.411 …… for Mosul station
Hd = 0.0015x + 5.7743 …… for Baghdad station
Hd = 0.0003x + 5.9396 …… for Ratba station
Hd = 0.0008x + 6.4007 …… for Nasiriyah station



Fig(6): Time series of mean monthly values of Hd in different stations

Correlation between Mean Monthly Values of Kd Verses KT in different Stations

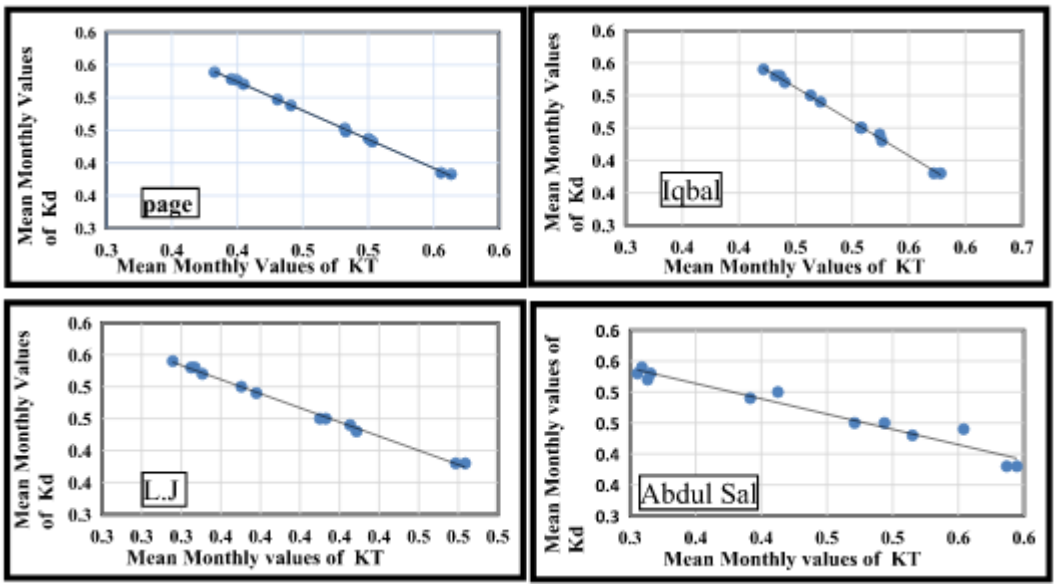
Figure (7,8,9,10) show the plots of KT verses KT for the aforementioned models . All the four considered Models for the diffuse solar radiation have nearly linear trend with coefficient of determination (R^2) for page Model (R^2=0.99 in Mosul , Baghdad , Ratba station , in Nasiriyah station R^2 = 0.98) . Iqbal Model give (R^2 =0.99 in all stations). Liu-Jordan Model (R^2 = 0.99 in Mosul and Ratba stations ,in Nasiriyah station R^2=0.98 , for Baghdad station R^2=0.95). Abdul-Salam Model give R^2 equal to : 0.95 , 0.97 , 0.92 ,0.86 for Mosul, Baghdad , Ratba ,Nasiriyah stations respectively .

R^2 for (Page , Iqbal ,liu-Jodan) Models in all stations were ranged between (0.98-0.99). Abaul Salam Modal give R^2 in all stations ranged between (0.86-0.97). this mean that there is a highly correlations between Kd and KT . These Models can be used accurately to calculate the diffuse solar radiation for the four stations . The following table show the correlations relating Kd and KT in all stations .

Table (8): Models with Regression for all station

Station	**Correlations / Page**	**R**	**R^2**
Mosul	**Kd = -0.8829KT + 0.8774**	**0.99**	**0.99**
Baghdad	**Kd = -0.9342 KT + 0.8972**	**0.99**	**0.99**
Ratba	**Kd = -0.9217 KT + 0.8936**	**0.99**	**0.99**
Nasiriyah	**Kd = -0.9958 KT + 0.9199**	**0.98**	**0.98**
Station	**Correlations / Iqbal**	**R**	**R^2**
Mosul	**Kd = -1.0506 KT + 0.985**	**0.99**	**0.99**
Baghdad	**Kd = -1.0659 KT + 0.9889**	**0.99**	**0.99**
Ratba	**Kd = -1.086 KT + 0.9957**	**0.99**	**0.99**
Nasiriyah	**Kd = -1.2289 KT + 1.0561**	**0.98**	**0.98**
Station	**Correlations / Liu-Jordan**	**R**	**R^2**
Mosul	**Kd = -1.1109 KT + 0.9112**	**0.99**	**0.99**
Baghdad	**Kd = -1.3319 KT + 0.9868**	**0.99**	**0.99**
Ratba	**Kd = -1.3632 KT + 0.9954**	**0.99**	**0.99**
Nasiriyah	**Kd = -1.5233 KT + 1.0489**	**0.98**	**0.98**

Station	Correlations / Abdul Salam	R	R^2
Mosul	Kd = -0.4941 KT + 0.6867	0.97	0.95
Baghdad	Kd = -0.4865 KT + 0.7547	0.98	0.97
Ratba	Kd = -0.706 KT + 0.8279	0.95	0.92
Nasiriyah	Kd = -0.6819 KT + 0.8321	0.92	0.86



Fig(7): Mean Monthly values of Kd against KT for Mosul station (1980-2010) using all models

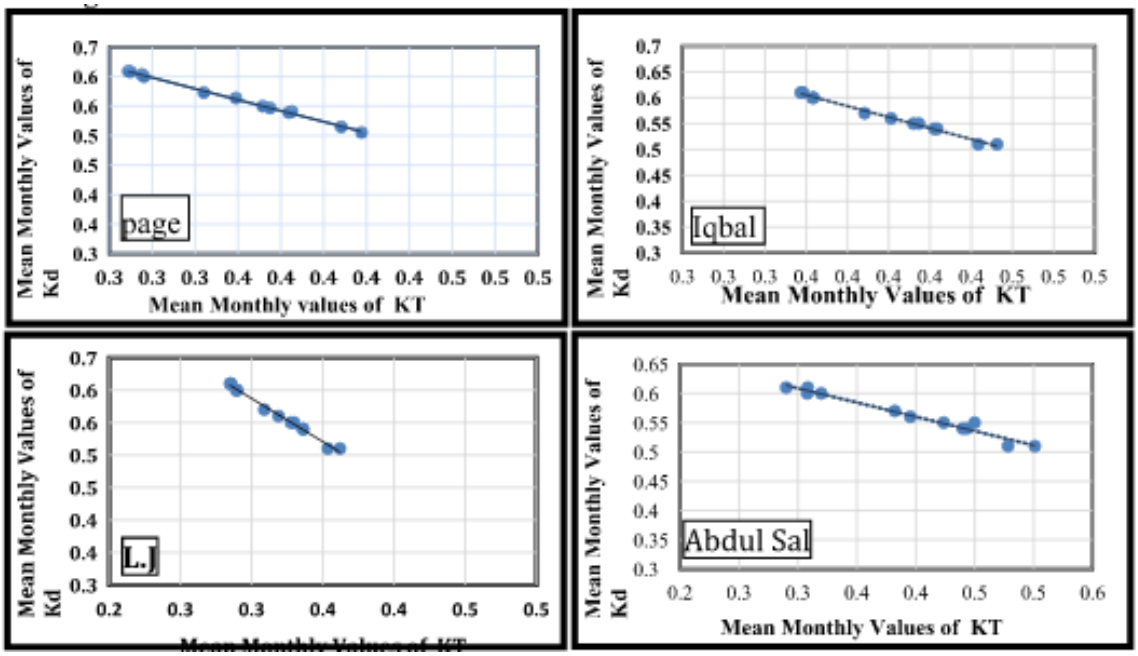


Fig:(8) Mean Monthly values of Kd against KT for Baghdad station (1980-2010) using all models

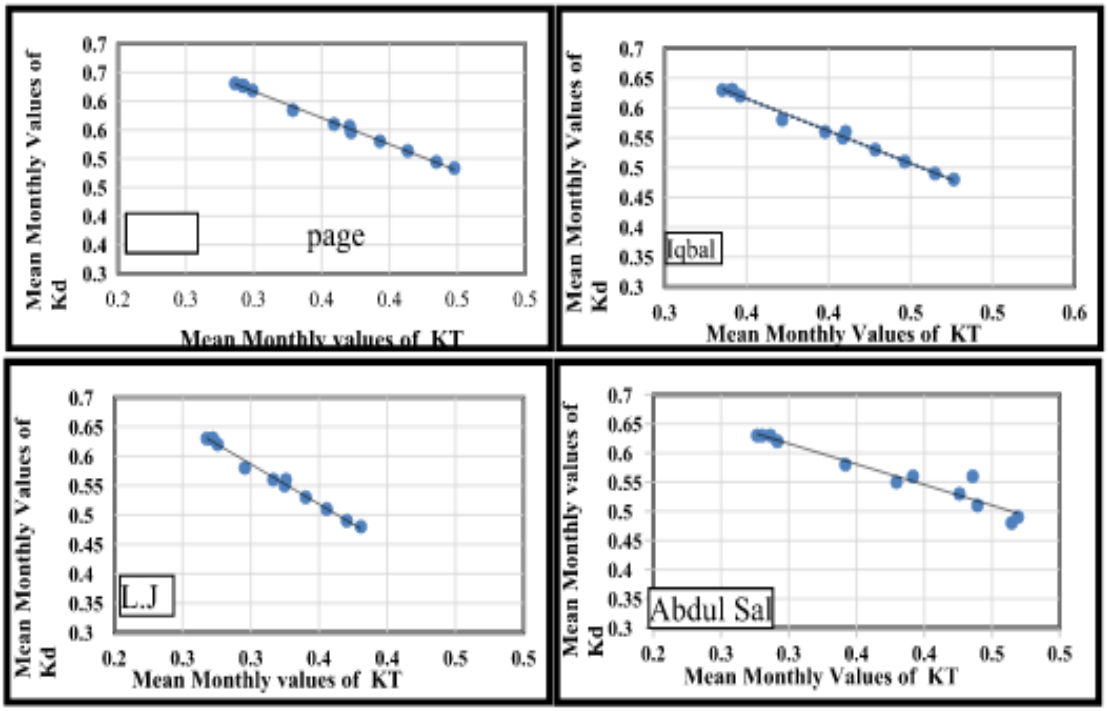


Fig:(9) Mean Monthly values of Kd against KT for Ratba station (1980-2010) using all models

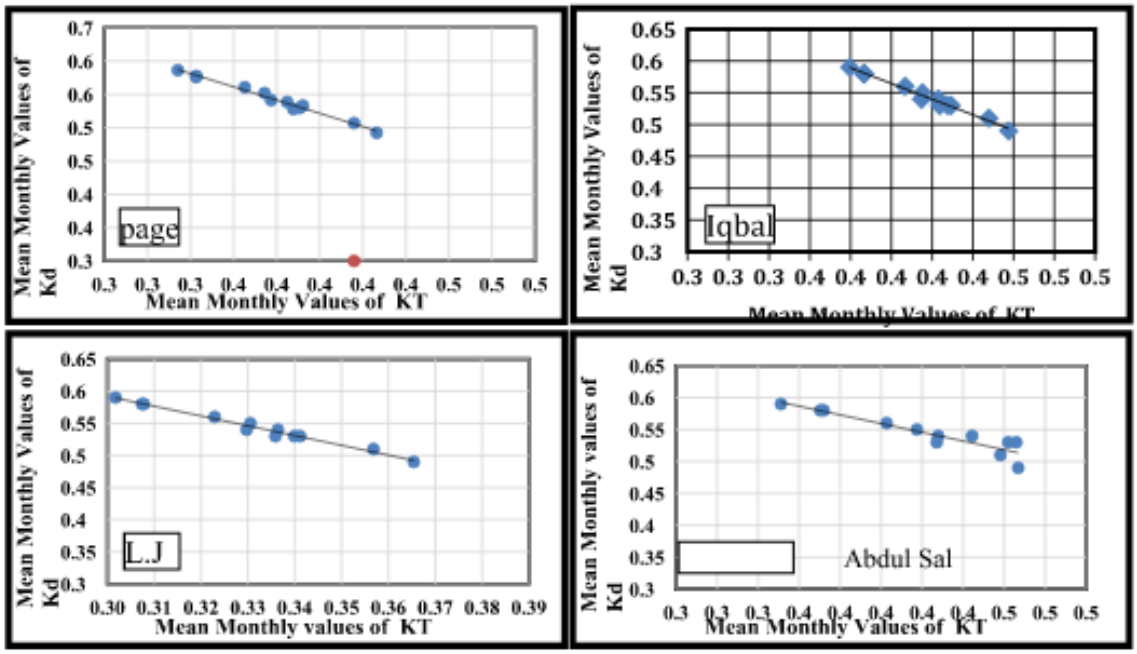


Fig:(10) Mean Monthly values of Kd against KT for Nasiriyah station (1980-2010) using all models

IV. Conclusion

Four Mathmatical Models (Page , Iqbal , Liu-Jordan , Abdul-Salam) were used to estimate the diffuse Solar radiation in four stations (Mosul , Baghdad , Ratba , Nasiriyah)well distributed in Iraq for the time series (1980-2010). We can deduces from the results :

- The maximum values of (Hd) in all stations was obtained in summer months , while the minimum values was obtained in winter months .
- The maximum seasonal values of (Hd) was obtained in summer season due to long day time hour where its values ranged between (7.3-9.13MJ/m^2.d) while winter season show minimum values ranged between (4.0-5.1 MJ/m^2.d) .
- Iqbal Model give higher seasonal values of (KT), while Page Model give lower values .

- Mean annual values of (Hd) was ranged between:(5.42-6.75) , (5.42-6.8) , (5.4-6.78) , (5.64-7.1)MJ/m^2.d in Mosul , Baghdad , Ratba and Nasiriyah stations respectively .
- A high correlation coefficient (R) was obtained between KT and Kd for all the models where its ranged between (0.92-0.99).

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