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Correlations between the total Solar Radiation measured by the earth stations and ECMWF in different locations in Iraq

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Abstract : *The aim of this paper is to estimate the mean monthly values of solar radiation in four meteorological stations in Iraq (Mosul , Baghdad ,Rutba, Nasiriyah) for the period (1980-2010) from* $\boldsymbol{H_{ECMWF}}$ *data .five Mathematical Models were used for that (Linear Model , Quadratic Model , ln Model , Exponential Model .Power Model). The Performance of these Models were evaluated by comparing the calculated Solar Radiation from the Models and the measured Solar Radiation.Several statistical tests were used to control the validation and goodness of these Models. In terms of CorrelationCoefficient (R), Coefficientof Determination* (R^2)*, Mean Absolute Error (M A E) and Root Mean Square Error (RMSE) .The Coefficientof Determination* (R^2) *obtained from these Models were very high in all stations and ranged between (0.957-0.996).*
Results showed that Linear model gave the best fit between ($\boldsymbol{H_{Stat}}$ *and*$\boldsymbol{H_{ECMWF}}$*) in Mosul station where (*R^2*= 0.996).Quadratic Model gave the best fit between (*$\boldsymbol{H_{Stat}}$*and* $\boldsymbol{H_{ECMWF}}$*)in Baghdad station where (*R^2*= 0.996). Power Model gave the best fit between (*$\boldsymbol{H_{Stat}}$*and* $\boldsymbol{H_{ECMWF}}$*) in Rutba station where (*R^2*=0.983). Quadratic Model gave the best fit between (*$\boldsymbol{H_{Stat}}$ *and*$\boldsymbol{H_{ECMWF}}$*)in Nasiriyah station (*R^2*= 0.993).*
Key word*: Solar radiation,ECMWF, Meteorology, Weather forecast, Atmospheric Radiation*

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I. Introduction

Solar Radiation data are important tools for many areas of research and applications in various engineering and scientific fields including climatology, agro meteorology, hydrology and solar energy converting system design [1,2].Unfortunately the number of solar Radiation Observations sites in arid and semiarid regions is very poor.

In Iraq solar radiation measurements are available only for very limited stations. To overcome this shortage of data, researchers had employed different relations such as : linear, quadratic, logarithmic , power , forth order polynomial and various distributions such as Wiebull and sine wave for estimating global solar radiation for different locations in Iraq [3,4,5].The parameters used as inputs in the relationships also include astronomical factors (solar constant, world-sun distance, solar declination and hour angle); geographical factors (latitude, longitude and altitude)[6].

On the other hand, researchers around the world investigated empirical and statistical models whichconsist a simple regression between satellite measurements and corresponding measurements at the earth's surface[7]. Dedicated Centers such as the European Center for Medium Range Weather Forecasts (ECMWF) ,the National Aeronautics and space Administration (NASA) collet and provide data for climate studies , weather forecasting or other purposes [8] We chose to use (ECMWF) data base that have been tried and tested elsewhere [9] .ECMWF global radiation data were validated against ground based regional model simulation [10] meaning that it may also be possible to reproduce experiment in this region

The study aims to validate global solar radiation from ECMWF against ground measurements at four station (Mosul , Baghdad ,Rutba, Nasiriyah) in Iraq .

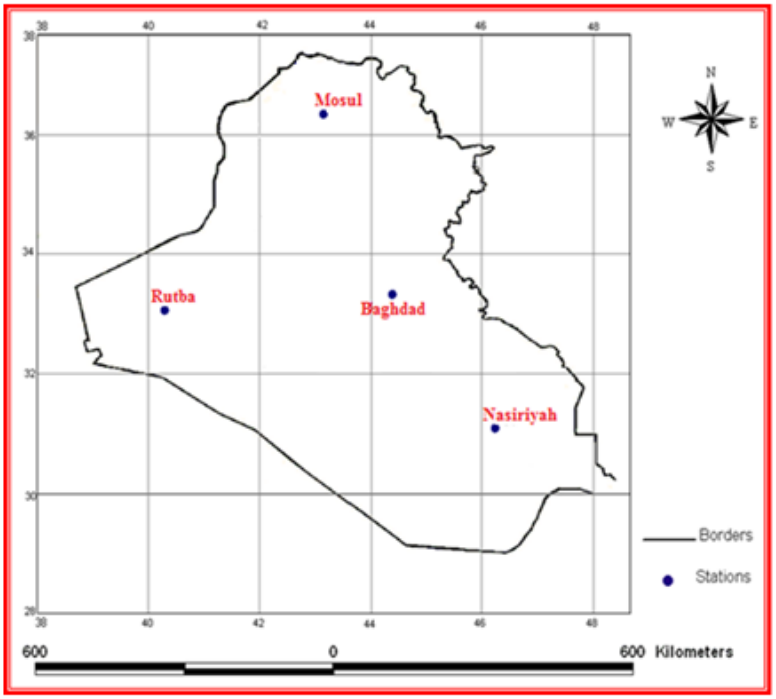
II. Data Source and Methodology

The estimated data of global solar Radiation was obtained from the European Center for Medium Rang Weather Forecasts (ECMWF) for four stations(Mosul , Baghdad ,Rutba, Nasiriyah) well distributed in Iraq for (1980-2010) .

ECMWF give solar Radiation data and other Meteorological data for any spot in the world using their latitude and longitude only.

Measured solar radiation datawas obtained from the earth stations(H_{Stat}).

Fig (1) show the locations of the four stations mentioned above on the map of Iraq.



Fig(1) : The location of all stations in Iraq

Table (1) : The Geographical Coordinate of all 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**

Five mathematical Models(Linear, Quadratic,ln, Exponential , Power) were used to test the correlations between the estimated and measured solar radiation in the four stations. Mean Absolute Error (MAE) , The Root Mean Square Error (MRSE) , Coefficient of Determination (R^2) and the Correlation Coefficient (R) were used for the purpose of evaluating the results .

III. Results and Discussion

1-Mean Monthly Values of $H_{Ecmwf}$and H_{Stat}.

Table (2) and fig (2) show the mean monthly values of H_{Ecmwf} and H_{Stat} for all stations during (1980-2010).

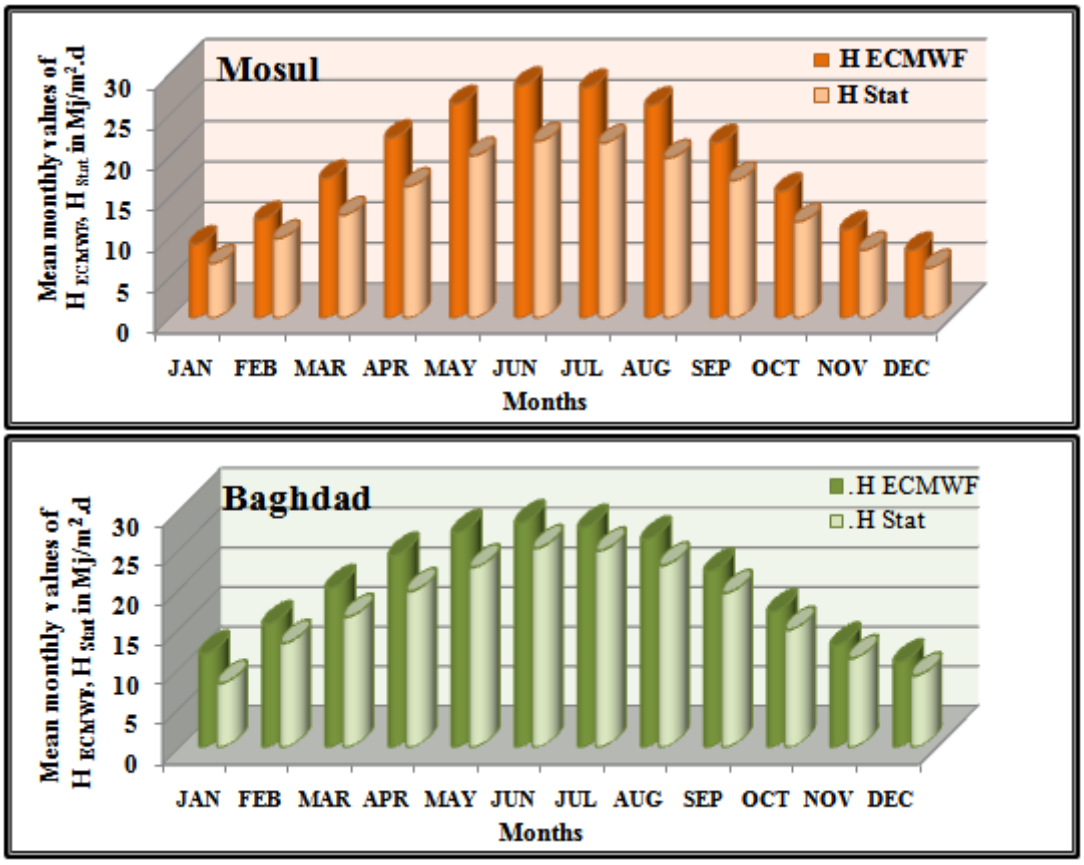
Table (2): Mean monthly values of H_{ECMWF}, H_{Stat} for all stations during the period (1980-2010).

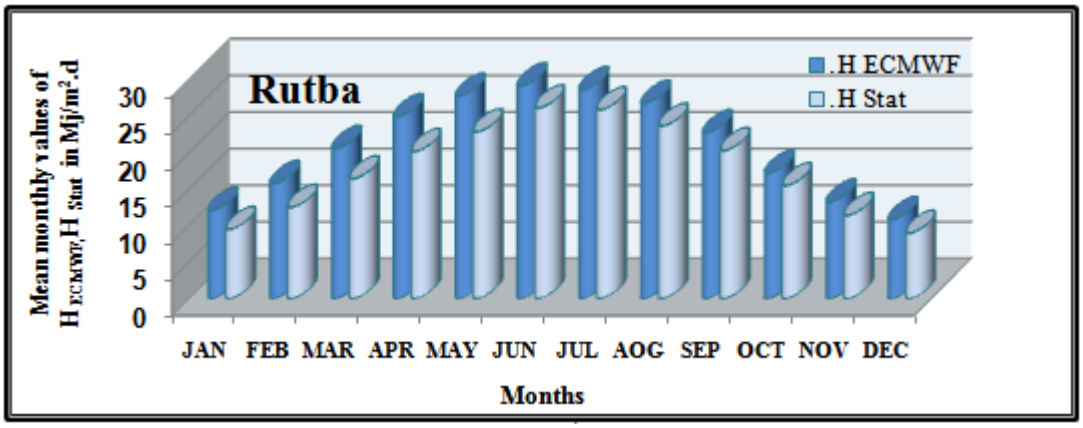
Stations \ Months		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mosul	H_{ECMWF}	8.99	12.02	17.08	22.03	26.24	28.51	28.23	26.06	21.47	15.48	10.78	8.23
	$H_{Stat.}$	6.66	9.71	12.60	16.12	19.90	21.70	21.45	19.60	16.86	11.80	8.28	6.10
Baghdad	H_{ECMWF}	11.71	15.45	19.99	24.08	26.94	28.17	27.58	26.11	22.09	16.95	12.74	10.62
	$H_{Stat.}$	9.90	13.07	16.37	19.60	22.61	25.04	24.72	22.86	19.39	14.73	11.14	8.95
Rutba	H_{ECMWF}	12.02	15.70	20.49	24.81	27.63	29.04	28.52	26.65	22.63	17.11	13.16	10.76
	$H_{Stat.}$	9.43	12.43	16.34	20.08	22.75	26.01	25.78	23.54	20.20	15.39	11.33	8.91
Nasiriyah	H_{ECMWF}	12.07	16.27	20.26	24.26	26.92	27.98	27.24	26.18	22.43	17.67	13.42	11.34
	$H_{Stat.}$	10.65	13.86	16.74	19.61	21.67	22.54	22.67	21.80	19.42	15.55	11.73	9.66

We can see from table(2) and fig (2) that the data of H_{Ecmwf} are slightly greater than that of H_{Stat} for all the months of the year in all stations .

The Maximum difference betweenH_{Ecmwf} and H_{Stat}appear in Mosul station where its ranged between (2.13-2.33)Mj/m^2.d in winter months , between (4.48-6.30) Mj/m^2.d in spring months , between (6.78-7.81) Mj/m^2.d in summer months and between (2.5-4.6) Mj/m^2.d in autumn months.

The Minimum difference was obtained in Baghdad station where it reneged between (1.67-3.7) Mj/m^2.d in winter months, between (3.6-4.1) Mj/m^2.d in spring months, between (2.8-3.2)Mj/m^2.d in summer months and between (1.6-2.7)Mj/m^2.d in autumn months .





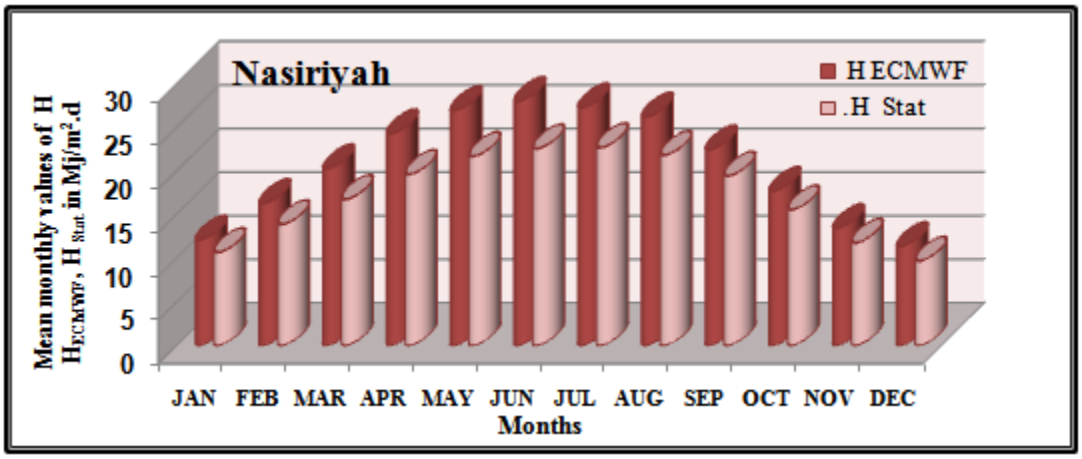


Fig (2) : Comparisons between Mean monthly values of H_{ECMWF}, H_{Stat} for all stations .

Table (3) show the standard deviation of H_{Ecmwf} and H_{Stat} for all stations during the period (1980-2010).SD for H_{Ecmwf} and $H_{Stat}$was ranged between (0.72-2.48) Mj/m^2.d in Mosul station , between (0.24-1.86) Mj/m^2.d in Baghdad , between (0.25-2.34) Mj/m^2.d in Rutba station and between (0.2-2.01)Mj/m^2.d in Nasiiyah stations.

Table (3): Stations deviation of H_{ECMWF}, H_{Stat} for all stations during the period (1980-2010).

Stations \ Months		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mosul	S.D ECMWF.	1.03	1.20	1.44	1.22	1.02	0.53	0.31	0.40	0.40	0.72	1.12	1.03
	S.D Stat.	0.72	1.14	1.63	1.84	2.39	2.48	2.05	2.31	2.04	1.42	1.22	0.91
Baghdad	S.D ECMWF.	0.62	0.69	0.85	0.87	0.73	0.26	0.24	0.29	0.29	0.65	0.78	0.48
	S.D Stat.	1.36	1.45	1.86	1.59	1.79	1.61	1.67	1.45	1.82	1.67	1.23	1.28
Rutba	S.D ECMWF.	0.70	0.86	0.86	0.75	0.67	0.25	0.52	0.45	0.78	0.72	0.81	0.51
	S.D Stat.	1.30	1.58	1.79	1.79	2.34	1.21	1.68	2.11	1.37	1.64	1.26	1.11
Nasiriyah	S.D ECMWF.	0.83	0.92	1.00	0.81	0.74	0.32	0.20	0.29	0.26	0.71	0.90	0.65
	S.D Stat.	1.00	1.23	1.59	1.43	1.86	2.01	1.83	2.15	1.40	1.51	1.17	0.96

Table (4) show the Coefficient of Variation of H_{Ecmwf} and H_{Stat} for all stations during the period (1980-2010).CV for H_{Ecmwf} and H_{Stat} was ranged between (1.1-14.9) for Mosul station, between (0.8-14.2) for Baghdad station**,**between (1.7-13.7) for Rutba stationandbetween (0.7-9.9) for Nasiriyah station**.**

Table (4) : Coefficient of Variations of H_{ECMWF}, H_{Stat} for all stations during the period (1980-2010).

Stations \ Months		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mosul	$C.V\%_{ECMWF}$	11.50	10.01	8.45	5.53	3.89	1.86	1.11	1.54	1.85	4.63	10.42	12.46
	$C.V\%_{Stat.}$	10.79	11.69	12.97	11.39	11.99	11.45	9.56	11.80	12.09	12.00	14.69	14.90
Baghdad	$C.V\%_{ECMWF}$	5.31	4.50	4.26	3.63	2.70	0.91	0.87	1.11	1.33	3.81	6.12	4.50
	$C.V\%_{Stat.}$	13.76	11.10	11.38	8.13	7.93	6.44	6.77	6.35	9.40	11.37	11.02	14.24
Rutba	$C.V\%_{ECMWF}$	5.83	5.45	4.19	3.00	2.43	0.86	1.82	1.69	3.47	4.22	6.13	4.77
	$C.V\%_{Stat.}$	13.75	12.69	10.94	8.90	10.30	4.65	6.52	8.95	6.79	10.67	11.14	12.48
Nasiriyah	$C.V\%_{ECMWF}$	6.91	5.67	4.94	3.33	2.75	1.13	0.72	1.13	1.15	4.00	6.71	5.76
	$C.V\%_{Stat.}$	9.35	8.91	9.49	7.29	8.61	8.94	8.09	9.85	7.23	9.72	9.93	9.90

2-Mean Seasonal Values of H_{Ecmwf} and H_{Stat}.

Fig (3) shows the Mean Seasonal Values of H_{Ecmwf} and H_{Stat} for all stations.

From the figure we can see the maximum values of H_{Ecmwf} and H_{Stat} in winter season was obtained in Nasiriya station(13.2 , 11.4) $Mj/m^2.d$, While the minimum values was obtained in Mosul station (9.2,7.5) $Mj/m^2.d$ .For spring season the maximum values of H_{Ecmwf} and H_{Stat} was obtained in Baghdad and Rutba stations (24.3 , 19 5) $Mj/m^2.d$ while the minimum values was obtained in Mosul station (21.7,16.2) $Mj/m^2.d$. For summer season the maximum values of H_{Ecmwf} and H_{Stat} was obtained in Rutba stations (28.2 , 25.1) $Mj/m^2.d$ while the minimum values was obtained in Nasiriyah station (26.5 ,22.3) $Mj/m^2.d$ .For Autumn season the maximum values of H_{Ecmwf} and H_{Stat} was obtained in Nasiriyah stations (17.8, 15.5) $Mj/m^2.d$ while the minimum values was obtained in Mosul station (15.9,12.3) $Mj/m^2.d$.

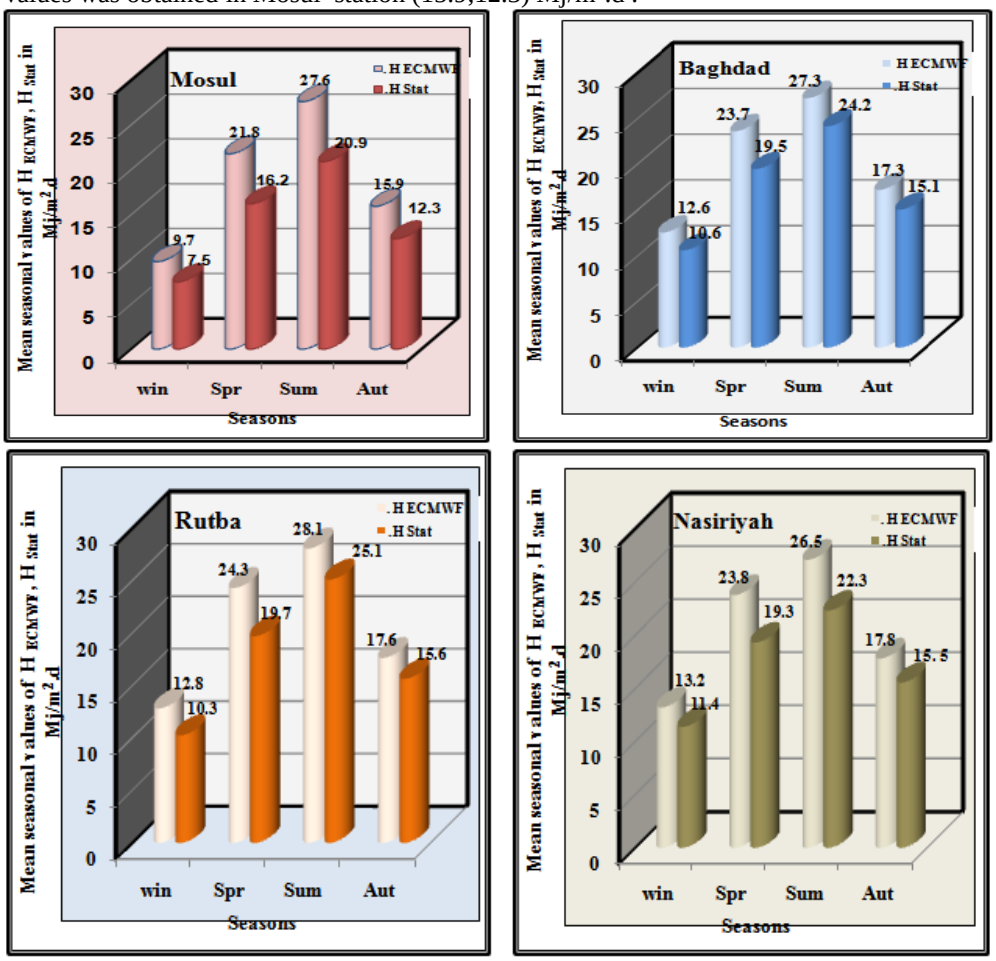


Fig (3) : Mean Seasonal Values of H_{ECMWF}, H_{Stat} for all stations .

3- Correlations between H_{ECWMF} and H_{Stat} in all Stations

Five Models were used to test the correlations between H_{ECWMF} and H_{Stat} in all Stations.Table (5) and fig (4,5,6,7) show these correlations in Mosul ,Baghdad, Rutba and Nasiriya station respectively.

Table (5) : Models with Regression Indicators for all stations.

Station	Correlations	R^2	R	%MAE	%RMAE
Mosul	$y = 0.7554x + 0.06$	0.996	0.998	2.03	2.67
	$y = -2E\text{-}05x^2 + 0.7563x + 0.0534$	0.996	0.998	2.07	2.69
	$y = 12.516\ln(x) - 21.359$	0.975	0.987	6.02	8.28
	$y = 4.316e^{0.0589x}$	0.969	0.984	6.59	7.74
	$y = 0.758x^{1.0003}$	0.996	0.998	1.97	2.64
Station	**Correlations**	**R^2**	**R**	**%MAE**	**%RMAE**
Baghdad	$y = 0.8846x - 0.5059$	0.989	0.994	2.48	2.64
	$y = 0.0037x^2 + 0.7738x - 0.0809$	0.996	0.998	3.53	3.87
	$y = 16.773\ln(x) - 32.3$	0.966	0.983	6.19	7.70
	$y = 4.8839e^{0.0591x}$	0.957	0.978	4.19	5.09
	$y = 0.6332x^{1.0965}$	0.973	0.986	3.78	4.19
Station	**Correlations**	**R^2**	**R**	**%MAE**	**%RMAE**
Rutba	$y = 0.9111x - 1.1899$	0.979	0.989	4.56	4.82
	$y = 0.0076x^2 + 0.6065x + 1.5582$	0.980	0.990	4.24	4.72
	$y = 17.026\ln(x) - 32.98$	0.957	0.978	6.12	7.90
	$y = 5.1776e^{0.0562x}$	0.973	0.986	4.61	5.89
	$y = 0.6921x^{1.0676}$	0.983	0.991	4.48	4.74
Station	**Correlations**	**R^2**	**R**	**%MAE**	**%RMAE**
Nasiriyah	$y = 0.7713x + 1.3458$	0.992	0.996	1.89	2.36
	$y = -0.0069x^2 + 1.0444x - 1.1115$	0.993	0.996	1.83	1.98
	$y = 14.418\ln(x) - 25.707$	0.988	0.994	2.58	3.10
	$y = 6.0591e^{0.0488x}$	0.975	0.987	3.68	4.64
	$y = 0.6332x^{1.0965}$	0.973	0.986	5.42	5.91

All the Models gave highly acceptable correlations between H_{ECWMF} and H_{Stat} in all stations where the coefficient of determination (R^2) forthese Models in all stations ranged between (0.957-0.996).Table (5) show also that the Mean Absolute Error (MAE) of all the Models in all stations was ranged between (1.8% -6.5 %) indicating an excellent fitting between H_{ECWMF} and H_{Stat} .From the table we can see also that the Root Mean Square Error (RMSE) of all the Models in all stations was ranged between (1.9- 8.2)which also show a good performance of all the Modell examined. Linear Model gave the best fit in Mosul station where (R^2=0.99) which mean that (99%) of H_{stat}can be accounted using H_{ECMWF} data.Quadratic Model gave the best fit between (H_{ECWMF} and H_{Stat})in Baghdad and Nasiriya station where (R^2=0.99).Power Model gave the best fit in Rutba station where (R^2=0.98).

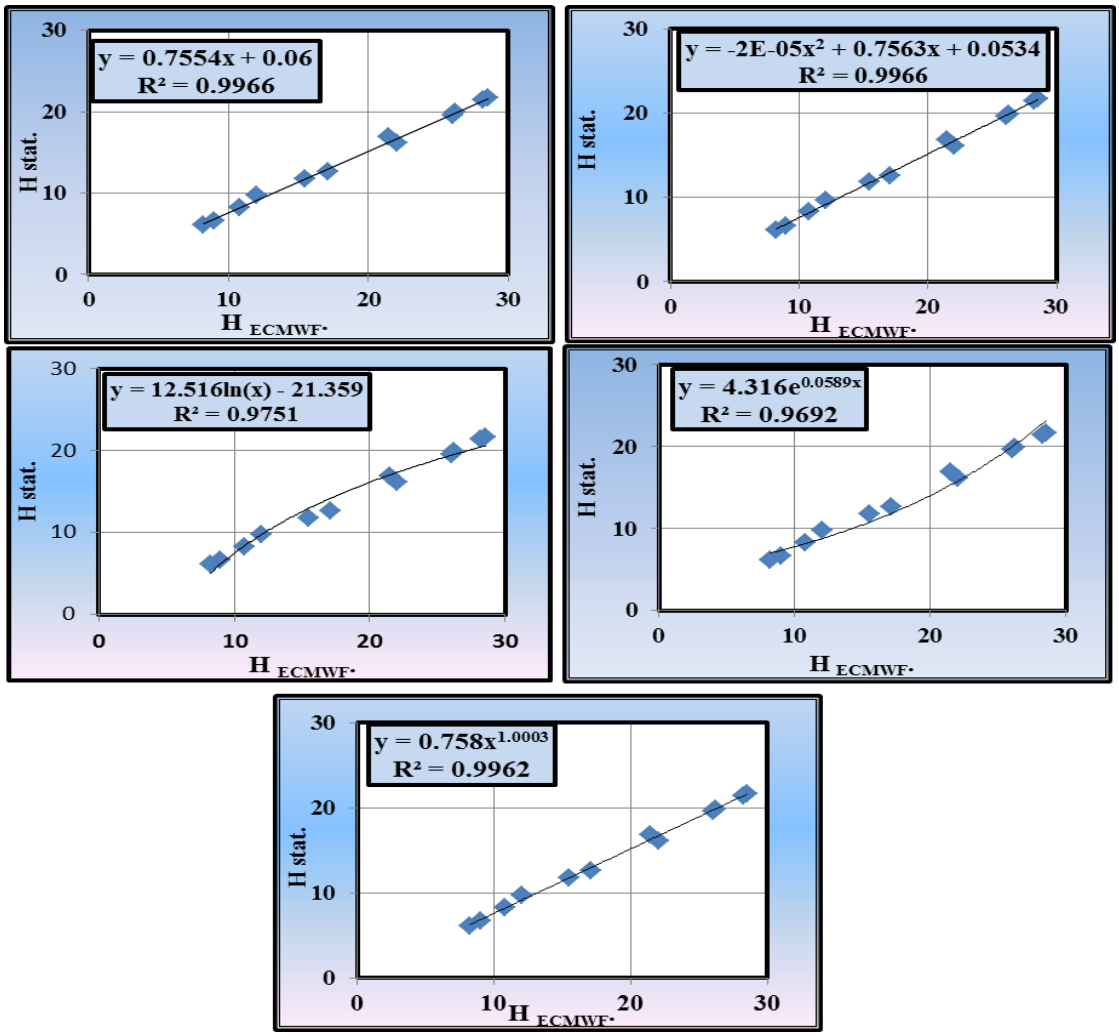
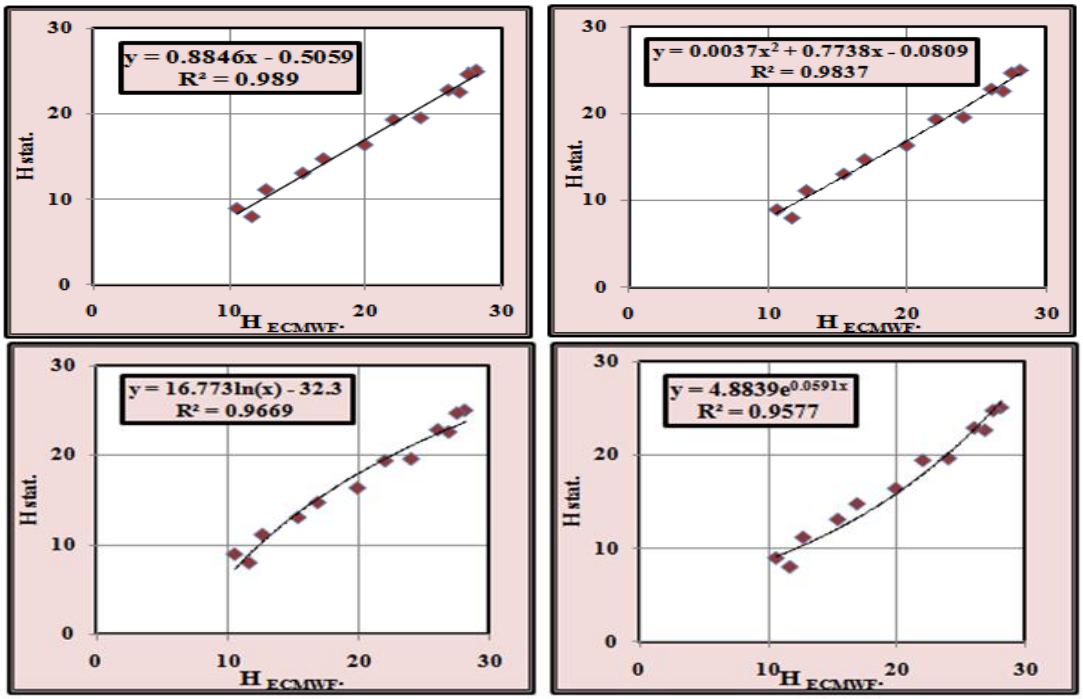


Fig (4): Correlations between H $_{ECMWF}$, H $_{Stat}$ using different Mathematical Models in Mosul Stations



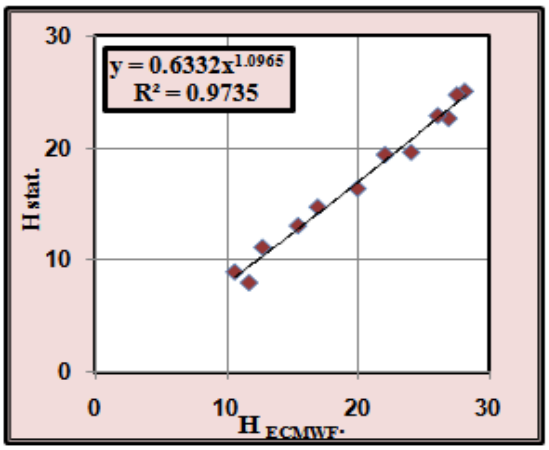


Fig (5): Correlations between H $_{ECMWF}$, H $_{Stat}$ using different Mathematical Models in Baghdad Stations.

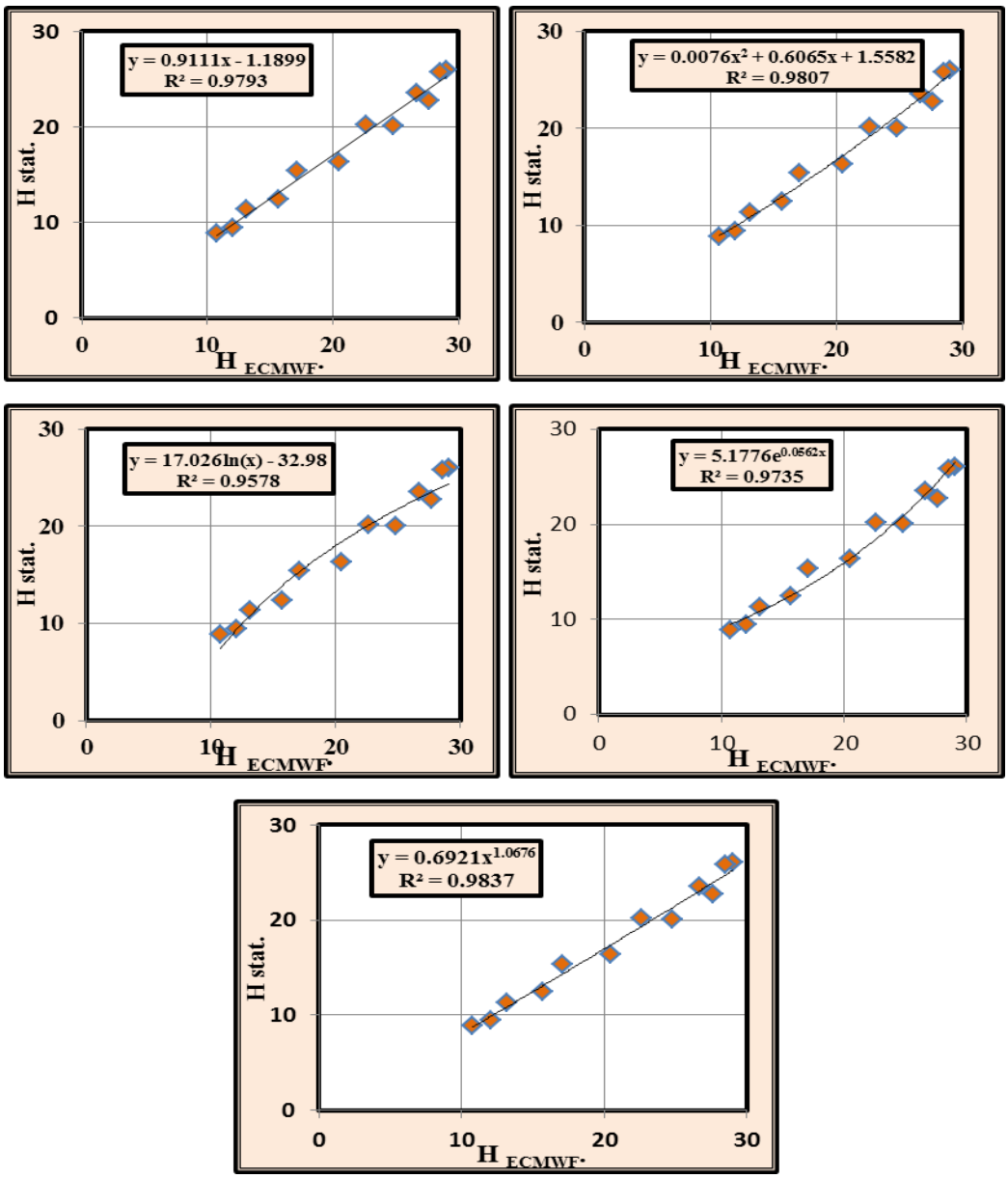


Fig (6): Correlations between H $_{ECMWF}$, H $_{Stat}$ using different Mathematical Models in Rutba Stations

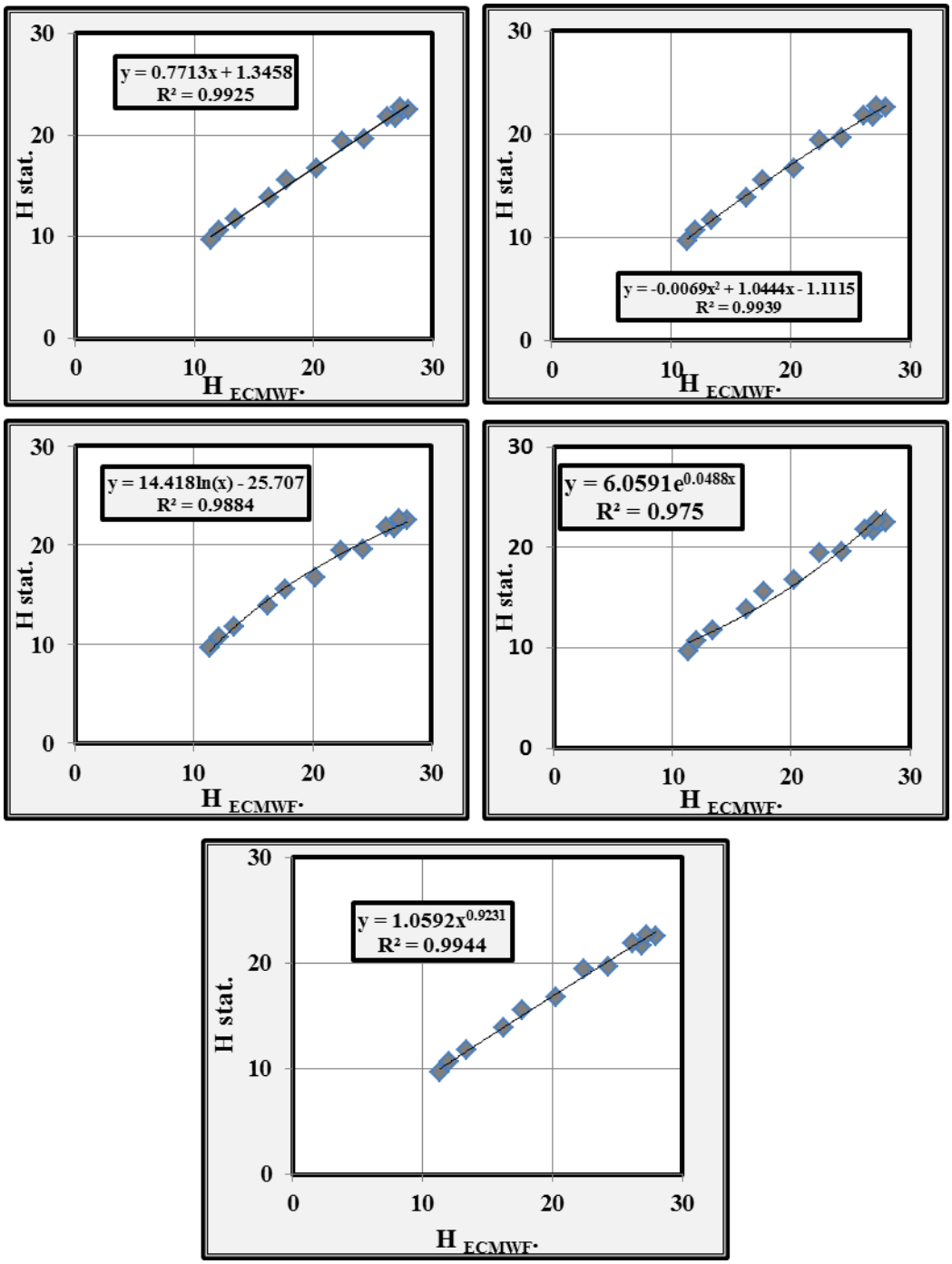


Fig (7): Correlations between H_{ECMWF}, H_{Stat} using different Mathematical Models in Nasiriyah Stations

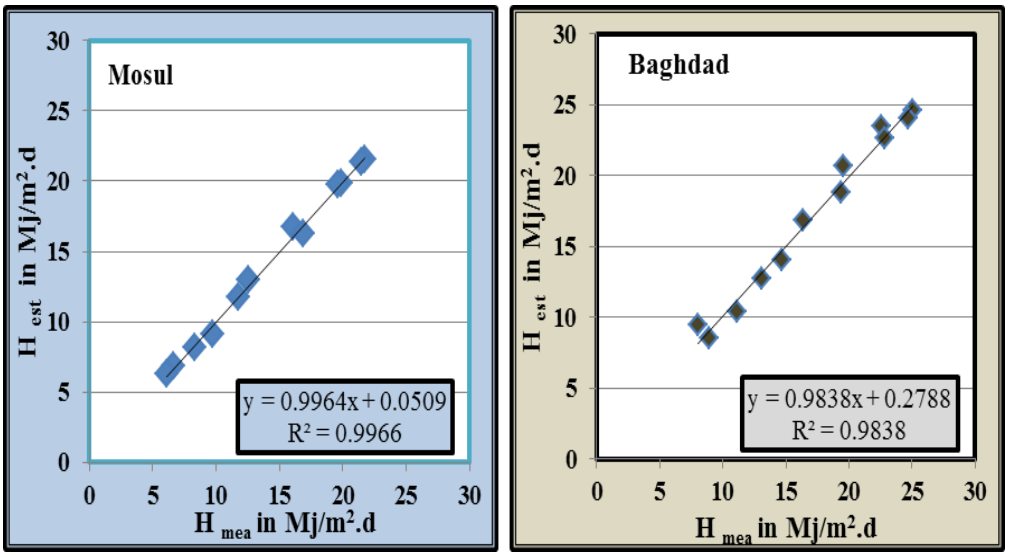
Table (6) show a comparison between H estimated from the Models and H measured for all stations

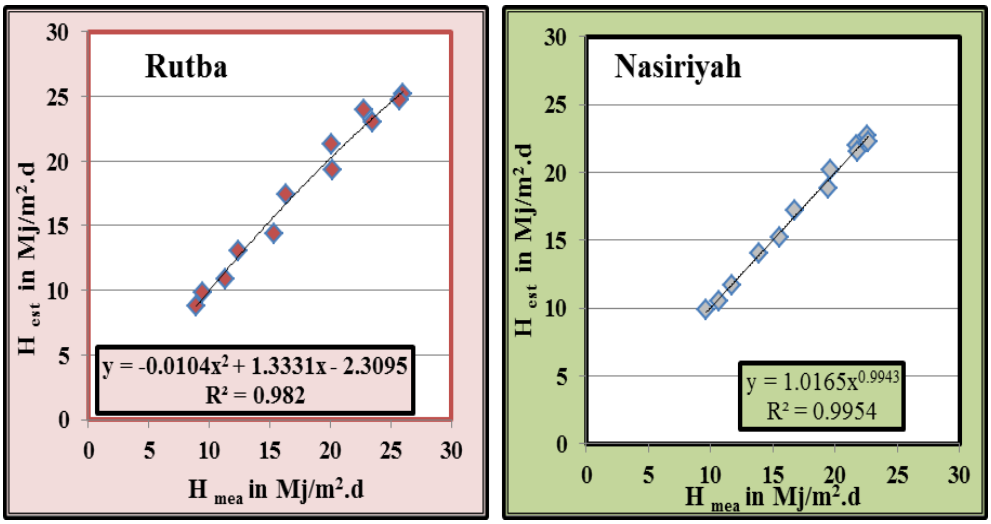
Table(6) : comparison between H estimations from the Models and Hmeasured for all stations.

Months	Mosul		Baghdad		Rutba		Nasiriyah	
	$H_{mea.}$	H_{est}	$H_{mea.}$	H_{est}	$H_{mea.}$	H_{est}	$H_{mea.}$	H_{est}
JAN	6.66	6.85	9.43	9.84	9.43	9.84	10.65	10.49
FEB	9.71	9.14	12.43	13.09	12.43	13.09	13.86	14.05
MAR	12.60	12.96	16.34	17.39	16.34	17.39	16.74	17.22
APR	16.12	16.70	20.08	21.33	20.08	21.33	19.61	20.16
MAY	19.90	19.88	22.75	23.93	22.75	23.93	21.67	22.00
JUN	21.70	21.60	26.01	25.24	26.01	25.24	22.54	22.71
JUL	21.45	21.38	25.78	24.76	25.78	24.76	22.67	22.22
AUG	19.60	19.75	23.54	23.03	23.54	23.03	21.80	21.50
SEP	16.86	16.28	20.20	19.34	20.20	19.34	19.42	18.84
OCT	11.80	11.75	15.39	14.35	15.39	14.35	15.55	15.19
NOV	8.28	8.20	11.33	10.84	11.33	10.84	11.73	11.66
DEC	6.10	6.28	8.91	8.74	8.91	8.74	9.66	9.84

A correlation between H estimated from the Models and H measured were performed in all stations and show in fig (8) .

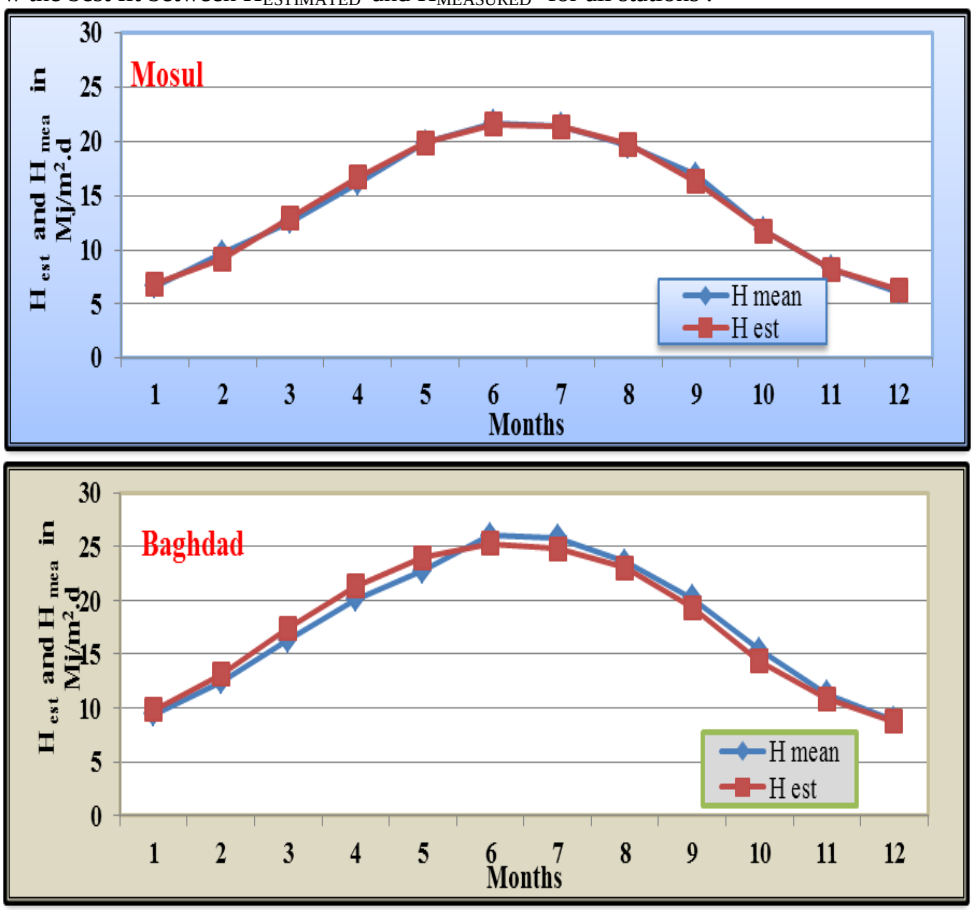
R^2 for these correlations were (0.99 , 0.98 , 0.98 , 0.99) in Mosul ,Baghdad, Rutba and Nasiriya respectively. This mean that there is a highly significance correlationsbetween H estimated and H measured in all stations.

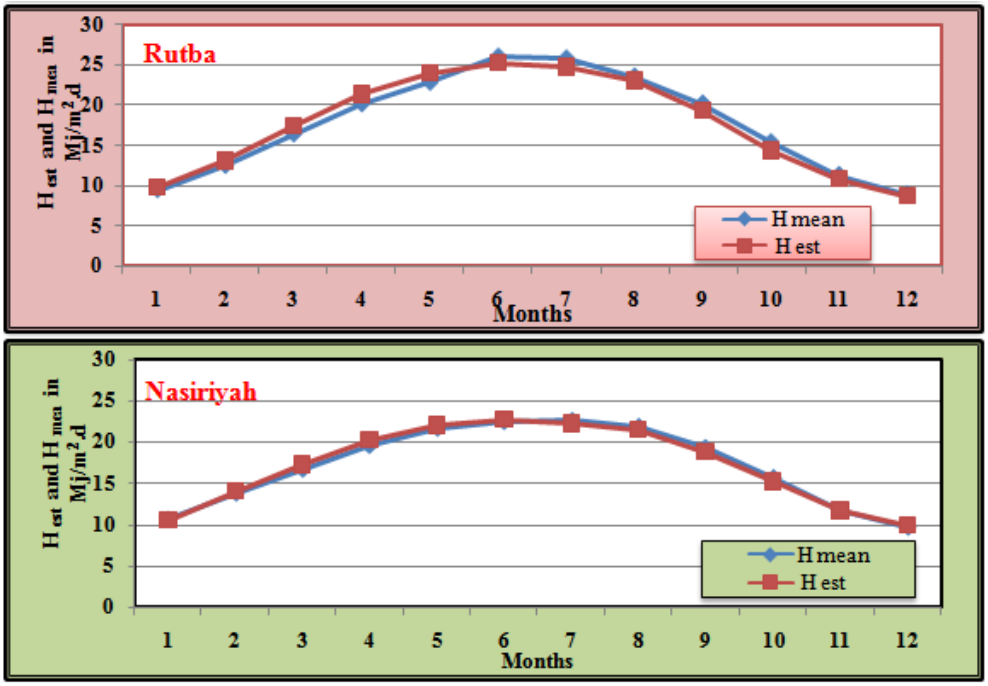




Fig(8): correlations between H estimations from the model and Hmeasured for all stations.

Fig (9) show the best fit between $H_{ESTIMATED}$ and $H_{MEASURED}$ for all stations .





Fig(9) : comparison between H_{est} and H_{mea} in all stations.

IV. Conclusion

A variety of regression Models between H_{ECWMF} and H_{Stat} have been performed in four stations well distributed in Iraq .

The significance and performance characteristicof the Models have been viewed using several statistical tests (R , R^2, MAE , RMSE).

All the models gave a highly acceptable correlations between H_{ECWMF} and H_{Stat} in all stations, where R^2 for these Models in all stations (Mosul , Baghdad , Rutba and Nasiriya) ranged between (0.957 – 0.996) .

All the Models gave MAE ranged between (1.8%-6.5 %) and gave RMSE ranged between (1.9%- 8.2 %).

Linear model gave the best fit between H_{ECWMF} and H_{Stat} in Mosul station , Quadratic model gave the best fit in Baghdad and Nasiriya stations , Power Model gave the best fit in Rutba station.

A high correlations were obtained between the measured and estimated solar radiation from the Models in all stations where R^2 of these correlations were ranged between (0.98-0.99)

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