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ARTICLE

Spatial and Temporal Variation of Clearness Index in Iraq

Waleed I. Al-Rijabo[a], **Rajaa A. Basheer**[b] and **Amal M. Banoosh**[b]

[a] *College of Education of Pure Science, Mosul University, Mosul, Iraq.*

[b] *College of Education, University of Al-Hamdaniya, Al-Hamdaniya, Iraq.*

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Abstract: This study deals with the spatial and temporal variation of clearness index (KT) in different meteorological stations, well distributed in Iraq, during the period between 1995 and 2015. The results indicate that the clearness index varies with the geographical location and period of the year. Monthly values of clearness index (KT) in the months of January and December show the lowest values of the index ranging between 0.38 and 0.64. Meanwhile, August shows the highest values ranging between 0.53 and 0.71. Seasonal variation of KT is well noted. The range of (0.40 to 0.58) has been measured in winter, while the range of (0.53 to 0.70) has been detected in summer season. The annual variation of KT shows a range between (0.47 - 0.64) in all stations. The standard deviation (SD) of the monthly values of KT ranged between (0.01-0.06) for all stations, while the coefficient of variation (CV) for the monthly values of KT ranged between (2-10) percent.

Keywords: Clearness index, Global solar radiation, Extraterrestrial radiation, Time series, CV, SD.

Introduction

Clearness index (KT) is defined as the ratio of global solar radiation at ground level on a horizontal surface (H) to the extraterrestrial global solar radiation (H_o) [1].

In other words, KT is a measurement of the extinction of solar radiation due to the atmospheric events; i.e., the interaction of radiation with the clouds, air pollution and other atmospheric constituents [2, 3].

* Low clearness index means low global radiation which usually attributes to a cloudy sky with a high portion of diffuse components.
* High values of clearness index mean high global radiation, which is dominated by direct component [4, 5].

The following are the standard values of KT due to the daily clearness index in comparison to partition day of the type (clear, partially cloudy and cloudy), as has been taken from [6].

Clear day: $KT > 0.65$; partially cloudy day $0.35 < KT < 0.65$ cloudy day: $KT < 0.35$.

KT is really an important parameter in designing a renewable-energy source system; it can provide information concerning the real solar radiation in comparison with the available solar radiation [7].

Clearness index reflects both of the meteorological variation and climatic change in the troposphere depending on the location [8].

Evaluation of clearness index requires some astronomic calculations at the top of the troposphere, which take the time of the year into account [9].

Clearness index is affected by air pollution in both urban and rural areas. Therefore, it may serve as an indicator of air quality and air pollution by fine particles, particularly for upper atmospheric layers such as the stratosphere [10].

Corresponding Author: Rajaa A. Basheer **Email**: rajaadaaboul@yahoo.com

Over industrial and densely inhabited areas, the atmospheric pollution is greater than elsewhere, because the presence of aerosol particles and other pollutant materials in these areas is intense [11].

Large variation in KT occurs at both the temporal and the spatial scale. The regional features of KT and the effects of the atmospheric parameters on KT have not been sufficiently investigated, whereas the complex interactions of clouds, aerosols and pollutants occur throughout the year [12].

Material Methods

The mean monthly values of total global solar radiation were obtained from Iraqi meteorological stations from 1995 until 2015 using 18 stations well distributed in Iraq. The missing data of the total solar radiation in some stations was estimated by means of using Glover model with local parameter [13].

The model:

$$\mathbf{H = H_{\circ} [- 0.35 + 0.66 \cos (\Phi) + 0.46 (\frac{n}{N})]}$$

where Φ represents the latitude in (rad) and $(\frac{n}{N})$ means the sunshine ratio.

Table 1 shows the geographical coordinators of the different stations and Fig. 1 shows the location of the different stations in Iraq.

TABLE 1. Geographical coordinators of the different stations.

Station	Latitude	Longitude	Altitude (m)	Station	Latitude	Longitude	Altitude (m)
Zakho	37.13°	42.68°	433	Rutba	33.03°	40.61°	631
Mosul	36.32°	43.15°	223	Kut	32.42°	44.75°	19
Sinjar	36.32°	41.83°	465	Nukhaib	32.03°	42.25°	305
Erbil	36.18°	44.00°	420	Karbala	32.62°	44.01°	29
Sulaimaniya	35.55°	45.41°	883	Amara	31.83°	47.16°	9
Kirkuk	35.47°	44.40°	331	Samawa	31.30°	45.31°	11
Baiji	34.60°	43.48°	115	Nasiriyah	31.08°	46.23°	3
Anna	34.47°	41.95°	139	Salman	30.50°	44.53°	220
Baghdad	33.30°	44.23°	32	Basra	30.52°	47.61°	2

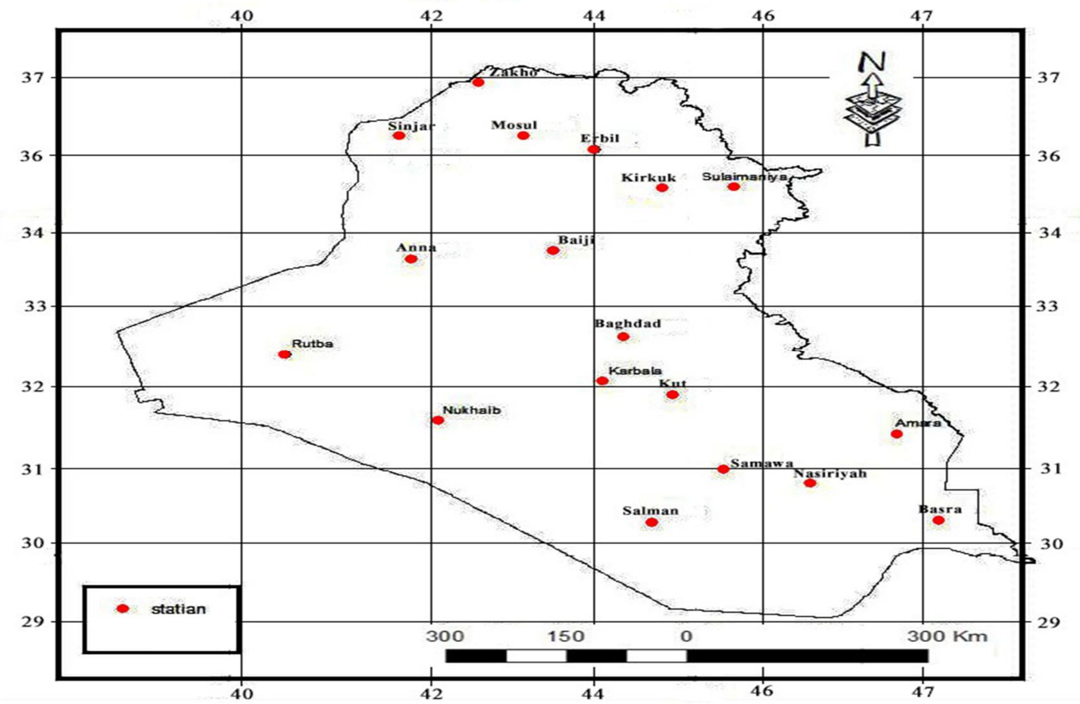

FIG .1. The location of the different stations in Iraq.

The mean monthly values of extraterrestrial radiation ($H_\circ$) are calculated by using the following equation [11].

$$H_\circ = \frac{24\,(60)}{\pi}\; Gsc \;\; dr \;\; [Ws \sin(\Phi) \sin(\delta) + \cos(\Phi) \cos(\delta) \sin(Ws)] \quad (1)$$

where:

Gsc: is the solar constant (0.082 MJ / m^2.min),

dr: is the inverse relative Earth-Sun distance,

Ws: is the sunset hour angle (rad),

Φ: is the latitude (rad) and

Δ: is the solar declination (rad).

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

$$dr = 1+0.033 \cos\left[\frac{2\pi J}{365}\right] \quad (2)$$

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

where J is the day number of the year.

The sunset hour angle (Ws) is given by the following equation:

$$Ws = \arccos\,[-\tan(\Phi) \tan(\delta)] \quad (4)$$

And the number of day light hours (N) are given by the following equation:

$$N = 24/\pi \; Ws\,. \quad (5)$$

The clearness index was found in 18 meteorological stations of Zakho, Mosul, Sinjar, Erbil, Sulaimaniya, Kirkuk, Baiji, Anna, Baghdad, Rutba, Kut, Nukhaib, Amara, Karbala, Samawa, Nasiriya, Salman and Basra distributed all over Iraq for the duration (1995 to 2015). Tables (2, 3) show the monthly, seasonally and annual values of KT for all stations.

GIS (V.9.3) and Surfer (V.10) were used as maps of the spatial variation of the mean monthly and seasonally values of KT obtained in Iraq.

TABLE 2. Mean monthly values of clearness index (KT) in different stations in Iraq during the period (1995-2015).

Months Stations		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
	H_o	16.8	21.8	29	35.6	40.1	41.8	40.8	37	31	23.8	18	15.4
Zakho	H	7.6	10.2	13.6	17.6	21.6	24.6	24.7	22.8	18.7	13.0	8.7	7.1
	Kt	0.45	0.47	0.47	0.49	0.54	0.59	0.61	0.62	0.60	0.55	0.49	0.46
	H_o	17.3	22.3	29.4	35.8	40.1	41.7	40.8	37.1	31.3	24.2	18.5	15.9
Mosul	H	6.7	9.7	12.6	16.1	19.9	21.7	21.5	19.6	16.9	11.8	8.3	6.1
	Kt	0.39	0.44	0.43	0.45	0.50	0.52	0.53	0.53	0.54	0.49	0.45	0.38
	H_o	17.3	22.3	29.4	35.8	40.1	41.7	40.8	37.1	31.3	24.2	18.5	15.9
Sinjar	H	8.0	10.6	14.5	18.3	22.0	24.7	24.5	22.5	18.9	13.6	9.7	7.5
	Kt	0.46	0.48	0.49	0.51	0.55	0.59	0.60	0.61	0.60	0.56	0.52	0.48
	H_o	17.4	22.3	29.4	35.8	40.2	41.7	40.8	37.2	31.4	24.3	18.6	16
Erbil	H	8.0	10.8	14.5	17.6	21.5	24.5	23.9	22.4	18.8	13.5	9.5	7.3
	Kt	0.46	0.49	0.49	0.49	0.54	0.59	0.59	0.60	0.60	0.55	0.51	0.46
	H_o	17.8	22.7	29.7	36	40.2	41.7	40.8	37.3	31.6	24.6	19	16.4
Sulaimaniya	H	8.2	10.5	13.7	17.8	21.9	24.7	24.4	22.7	18.9	13.4	9.5	7.7
	Kt	0.46	0.46	0.46	0.49	0.55	0.59	0.60	0.61	0.60	0.55	0.50	0.47
	H_o	17.8	22.7	29.7	36	40.2	41.7	40.8	37.3	31.6	24.7	19	16.4
Kirkuk	H	7.7	10.2	13.3	16.9	20.7	23.0	23.5	21.9	18.8	13.6	9.4	7.0
	Kt	0.43	0.45	0.45	0.47	0.52	0.55	0.58	0.59	0.60	0.55	0.50	0.43
	H_o	18.3	23.2	30.1	36.2	40.2	41.6	40.7	37.4	31.9	25.1	19.5	16.9
Baiji	H	8.7	11.6	15.1	18.3	21.8	24.6	24.0	22.4	19.1	13.9	10.0	7.9
	Kt	0.47	0.50	0.50	0.51	0.54	0.59	0.59	0.60	0.60	0.55	0.51	0.47
	H_o	18.4	23.3	30.1	36.2	40.2	41.6	40.7	37.4	32	25.2	19.6	17
Anna	H	8.9	12.0	15.7	18.7	21.9	24.7	24.1	22.6	19.1	14.2	10.2	8.0
	Kt	0.49	0.52	0.52	0.52	0.55	0.59	0.59	0.60	0.60	0.56	0.52	0.47

Months Stations		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
	H_o	19.1	23.9	30.6	36.4	40.2	41.5	40.7	37.6	32.4	25.8	20.3	17.7
Baghdad	H	10.3	13.4	16.5	20.2	22.9	25.3	25.1	23.1	19.8	15.3	11.2	9.0
	Kt	0.54	0.56	0.54	0.56	0.57	0.61	0.62	0.61	0.61	0.59	0.55	0.51
	H_o	19.3	24.1	30.7	36.5	40.2	41.5	40.7	37.6	32.4	25.9	20.5	17.9
Rutba	H	9.2	12.4	16.3	20.4	23.1	26.1	25.9	23.5	20.3	15.6	11.2	9.2
	Kt	0.48	0.52	0.53	0.56	0.58	0.63	0.64	0.63	0.63	0.60	0.55	0.51
	H_o	19.7	24.4	30.9	36.6	40.2	41.4	40.7	37.7	32.6	26.2	20.8	18.3
Kut	H	9.9	12.8	16.3	19.6	22.6	25.2	24.7	23.1	19.9	15.2	11.1	9.2
	Kt	0.50	0.53	0.53	0.54	0.56	0.61	0.61	0.61	0.61	0.58	0.53	0.50
	H_o	19.9	24.6	31.1	36.7	40.2	41.4	40.6	37.7	32.8	26.4	21	18.5
Nukhaib	H	9.9	15.7	19.7	23.0	25.3	28.6	28.2	26.6	22.8	17.6	13.6	11.0
	Kt	0.57	0.64	0.63	0.63	0.63	0.69	0.69	0.71	0.70	0.67	0.65	0.59
	H_o	19.5	24.3	30.9	36.5	40.2	41.5	40.7	37.6	32.6	26.1	20.7	18.2
Karbala	H	9.6	12.6	16.2	19.1	22.0	24.4	24.2	22.4	19.3	14.5	11.0	9.0
	Kt	0.49	0.52	0.52	0.52	0.55	0.59	0.59	0.60	0.59	0.56	0.53	0.49
	H_o	20	24.7	31.2	36.7	40.2	41.4	40.6	37.7	32.8	26.5	21.1	18.6
Amara	H	9.8	12.9	16.0	19.5	22.2	24.6	23.9	22.8	19.4	14.9	11.1	9.2
	Kt	0.49	0.52	0.51	0.53	0.55	0.59	0.59	0.61	0.59	0.56	0.53	0.49
	H_o	20.3	25	31.4	36.8	40.2	41.3	40.6	37.8	33	26.7	21.5	19
Samawa	H	10.6	13.5	16.8	19.7	22.3	24.8	24.8	23.4	19.8	15.4	11.7	9.7
	Kt	0.52	0.54	0.54	0.54	0.55	0.60	0.61	0.62	0.60	0.58	0.54	0.51
	H_o	20.5	25.1	31.4	36.8	40.2	41.3	40.6	37.8	33.1	26.8	21.6	19.1
Nasiriya	H	10.6	13.9	16.7	19.7	21.4	21.8	22.3	21.2	19.3	15.4	11.6	9.6
	Kt	0.52	0.55	0.53	0.54	0.53	0.53	0.55	0.56	0.58	0.58	0.54	0.50
	H_o	20.8	25.4	31.7	36.9	40.2	41.2	40.5	37.9	33.2	27.1	21.9	19.5
Salman	H	9.9	16.0	19.3	23.1	25.4	28.3	28.2	26.5	22.9	17.6	13.9	11.7
	Kt	0.55	0.63	0.61	0.63	0.63	0.69	0.70	0.70	0.69	0.65	0.63	0.60
	H_o	20.8	25.4	31.6	36.9	40.2	41.2	40.5	37.9	33.2	27.1	21.9	19.4
Basra	H	10.5	13.5	16.7	19.5	22.2	24.4	23.8	22.6	19.9	15.6	11.9	10.1
	Kt	0.51	0.53	0.53	0.53	0.55	0.59	0.59	0.60	0.60	0.57	0.54	0.52

TABLE 3. Mean seasonal and annual values of KT in different stations in Iraq.

Seasons/Stations	Winter	Spring	Summer	Autumn	Annual mean
Zakho	0.46	0.50	0.60	0.55	0.53
Mosul	0.40	0.46	0.53	0.50	0.47
Sinjar	0.47	0.52	0.60	0.56	0.54
Erbil	0.47	0.51	0.60	0.55	0.53
Sulaimaniya	0.46	0.50	0.60	0.55	0.53
Kirkuk	0.44	0.48	0.57	0.55	0.51
Baiji	0.48	0.52	0.59	0.55	0.54
Anna	0.51	0.53	0.60	0.56	0.55
Baghdad	0.54	0.56	0.61	0.59	0.57
Rutba	0.50	0.56	0.63	0.59	0.57
Kut	0.51	0.54	0.61	0.57	0.56
Nukhaib	0.58	0.63	0.70	0.67	0.64
Karbala	0.50	0.53	0.59	0.56	0.55

Seasons/Stations	Winter	Spring	Summer	Autumn	Annual mean
Amara	0.50	0.53	0.60	0.56	0.55
Samawa	0.52	0.54	0.61	0.57	0.56
Nasiriya	0.52	0.53	0.55	0.57	0.54
Salman	0.57	0.62	0.70	0.66	0.64
Basra	0.52	0.54	0.59	0.57	0.55

For studying the temporal variations of clearness index, five stations were selected which represent the north, middle and south parts of Iraq. These stations were (Mosul, Baiji, Baghdad, Kut and Amara).

The mean monthly, seasonally and annually values of KT in five of the selected stations were obtained by using Matlab (V.6.5) and Microsoft Office Excel 2011 different histograms.

The CV and SD for the monthly values of KT in these stations are calculated. Coefficient of variation (CV) represents the ratio of standard deviation to the mean. It's a useful statistic for comparing the degree of variation from one data series to another. Standard deviation (SD) is a statistic that measures the dispersion of a dataset relative to its mean.

Results and Discussion

Mean Monthly Values of KT in Different Stations

Table 2 shows the mean monthly values of KT in different stations in Iraq during the period (1995-2015).

The lowest KT values occurred in January, February and December, as these months are being characterized by high concentration of clouds and water vapor, in addition to that the angle of incidence of the solar radiation in these months is considered low.

Table 2 shows that the maximum value of KT during winter months is obtained in Nukhaib and Salman stations with the range of (0.61 - 0.64), while the minimum values are obtained in Mosul station with the range of (0.38-0.44).

In the months of spring (March, April and May), the table shows that the values of KT are slightly increased. Mosul station shows minimum values of a range between (0.43-0.50). Nukhaib and Salman stations reveal maximum values ranging between (0.61 -0.63).

The highest values of KT occurred most frequently between June and August. These months typically tend to have less cloud cover in the sky.

The maximum value of KT during summer months was obtained in Nukhaib and Salman stations with the range of (0.69 - 0.71), while the minimum values were obtained in Mosul station with the range of (0.52- 0.53).

Mean Seasonally Values of KT in Different Stations

Table 3 shows the mean seasonally values of KT in all the studied Iraqi stations during the period (1995- 2015).

The maximum mean seasonal values of KT were obtained in Nukhaib station with the values of (0.58, 0.63, 0.70 and 0.67) in the seasons of winter, spring, summer and autumn, respectively.

The minimum seasonal values of KT were obtained in Mosul station with values of (0.40, 0.46, 0.53 and 0. 50) in the seasons of winter, spring, summer and autumn, respectively.

Mean Annual Values of KT in Different Stations

Table 3 shows the mean annual values of KT in different stations. The maximum mean annual value of KT was obtained in Nukhaib and Salman stations with a value of (0.64), while the minimum mean annual value of KT was obtained in Mosul station with a value of (0.47).

Standard Deviation and Coefficient of Variation of KT in Different Stations

For studying the standard deviation (SD) and coefficient of variation (CV) of KT, five stations are selected to represent the north, middle and south parts of Iraq.

These stations are (Mosul, Baiji, Baghdad, Kut and Amara).

Table 4 shows the standard deviation (SD) and Table 5 reflects the coefficient of variation (CV) of the monthly values of KT during the period (1995-2015) for the five chosen stations.

We can see from Table 4 that the standard deviation of KT ranged between (0.01 - 0.05) for all stations during the months of those years.

From Table 5, we can see in winter months that the maximum values of (CV) in all stations ranged among: (6-13), (5-10), (6-7), (3-4) and (5-8), in Mosul, Baiji, Baghdad, Kut and Amara stations, respectively.

The minimum values of (CV) are obtained in summer months with the ranges of (3-4), (4-6), (6-7), (2-4), (3-4) in these stations, respectively.

TABLE 4. Standard deviation (SD) of mean monthly values of (KT) for the selected stations during the period (1995-2015).

Months/Stations	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mosul	0.04	0.03	0.03	0.03	0.03	0.02	0.01	0.02	0.03	0.04	0.04	0.06
Baiji	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.04	0.04	0.04
Baghdad	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.03	0.04	0.05	0.05	0.03
Kut	0.02	0.02	0.01	0.04	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02
Amara	0.04	0.04	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.02	0.03	0.02

TABLE 5. Coefficient of variation (CV %) of mean monthly values of (KT) for the selected stations during (1995-2015).

Months/Stations	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mosul	10	6	6	6	6	4	3	3	5	7	9	13
Baiji	5	5	3	4	6	6	5	4	3	8	8	10
Baghdad	6	7	7	8	8	7	6	6	7	9	10	7
Kut	3	4	2	7	4	3	4	2	2	4	5	4
Amara	8	8	4	6	4	4	4	3	3	4	6	5

Spatial Variation of KT in Different Regions in IRAQ

Figs. (2-a, b, c, d) show the spatial variation of the mean monthly values of clearness index during the period (1995-2015). From the figures, we can select three different regions:

The First Region*:* represents the north part of Iraq till Baiji station. The values of KT in this region ranged between: (0.38 - 0.50) in winter months, (0.43 - 0.55) in spring months, (0.52 - 0.62) in summer months and (0.45 - 0.60) in autumn months, respectively.

The Second Region: extends from the middle part of Iraq towards the south-east of it. This region includes the stations of (Anna, Baghdad, Rutba, Kut, Karbala, Amara, Samawa, Nasiriya and Basra).

The values of KT in this region ranged between (0.47 - 0.56) in winter months, (0.51 - 0.58) in spring months, (0.53 - 0.63) in summer months and (0.51-0.63) in autumn months, respectively.

The Third Region: formulates the south-west of Iraq and involves (Nukhaib, Salman) stations. The values of KT in this region ranged between (0.55 - 0.64) in winter months, (0.61 - 0.63) in spring months, (0.69 - 0.71) in summer months and (0.63 - 0.70) in autumn months, respectively.

In all these stations, August represents the maximum value of KT and December stands for the minimum value of KT.

Fig. 3 shows the spatial variation of the mean seasonally values of (KT).

From the figure we can nearly see three regions in all the seasons. The first region represents the north of Iraq till Baiji and Anna stations. The second region formulates the middle of Iraq toward the south-east of Iraq. The third region stands for the south-west of Iraq (Nukhaib and Salman) stations. The maximum value of KT in all these seasons was obtained in Nukhaib station, while the minimum value of KT in all stations was obtained in Mosul station.

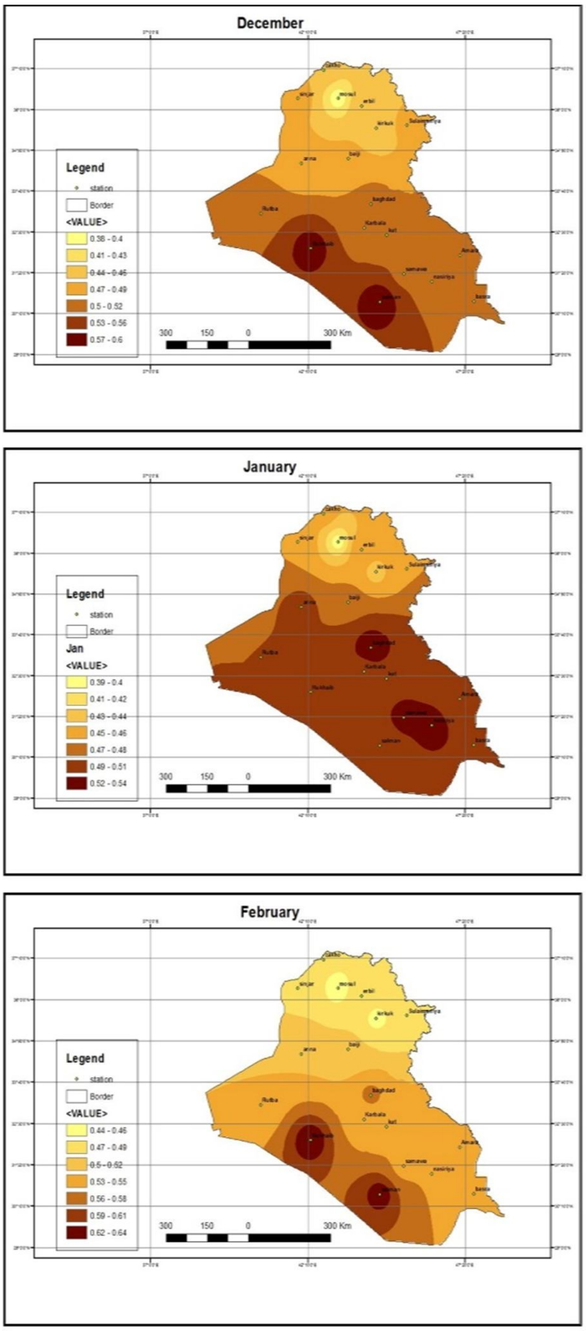

FIG. 2-a. Spatial variation of KT during winter months.

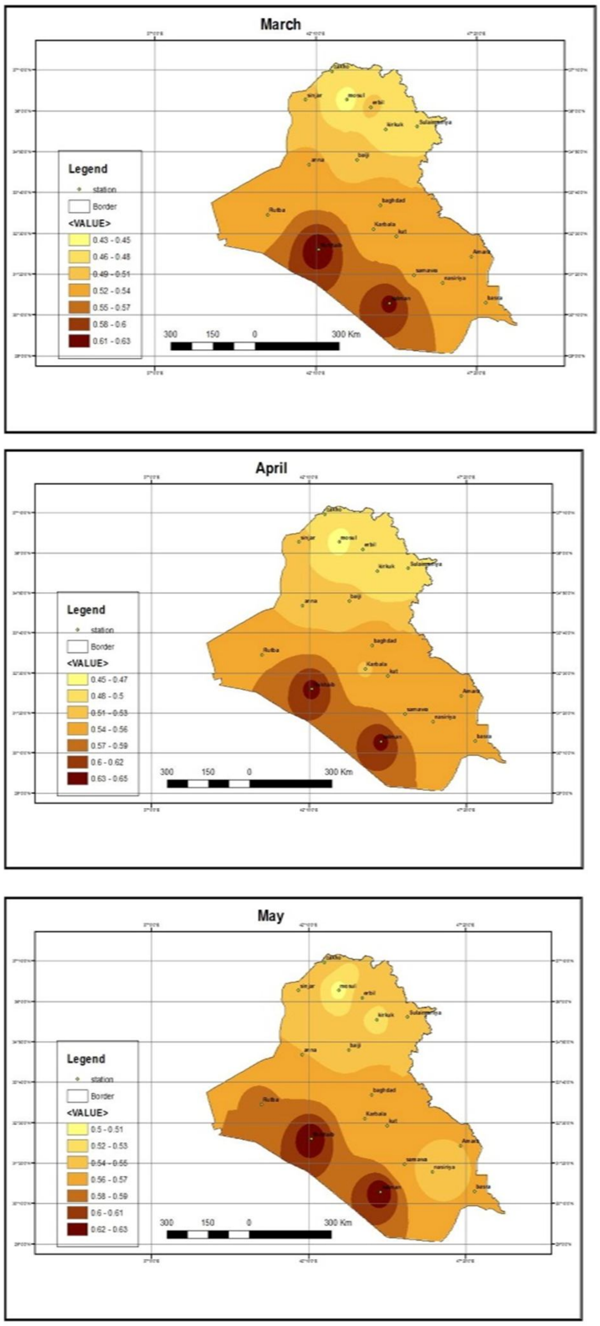

FIG. 2-b. Spatial variation of KT during spring months.

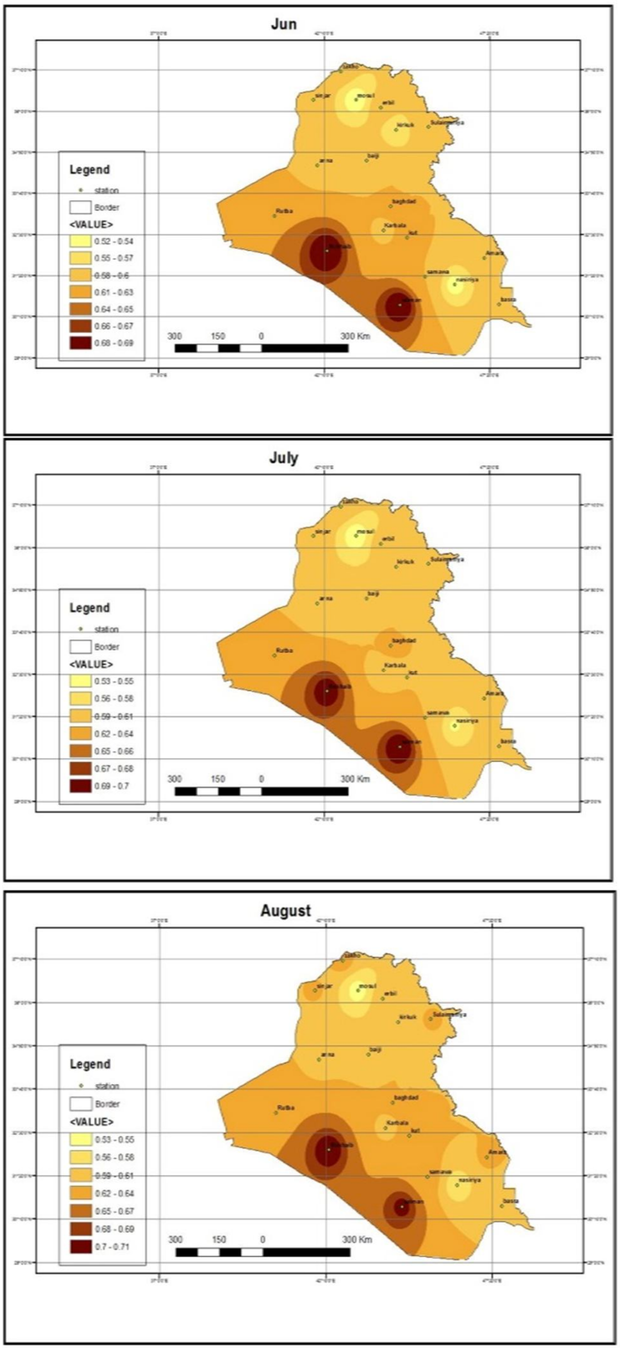

FIG. 2-c. Spatial variation of KT during summer months.

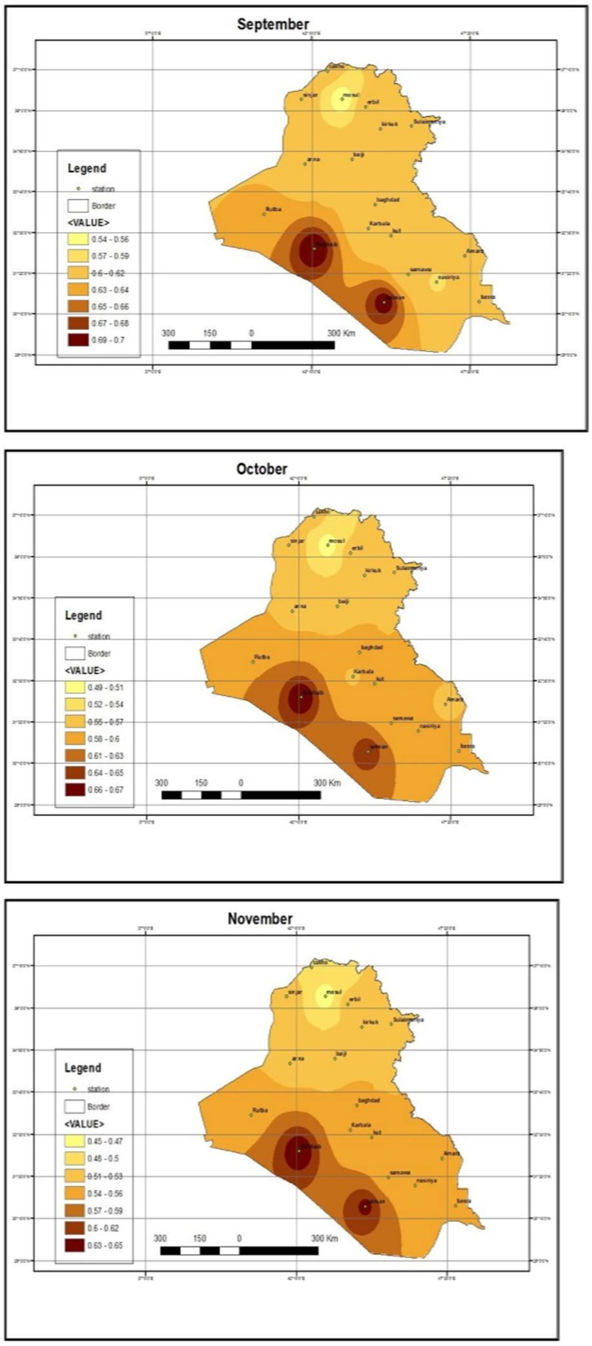

FIG. 2-d. Spatial variation of KT during autumn months.

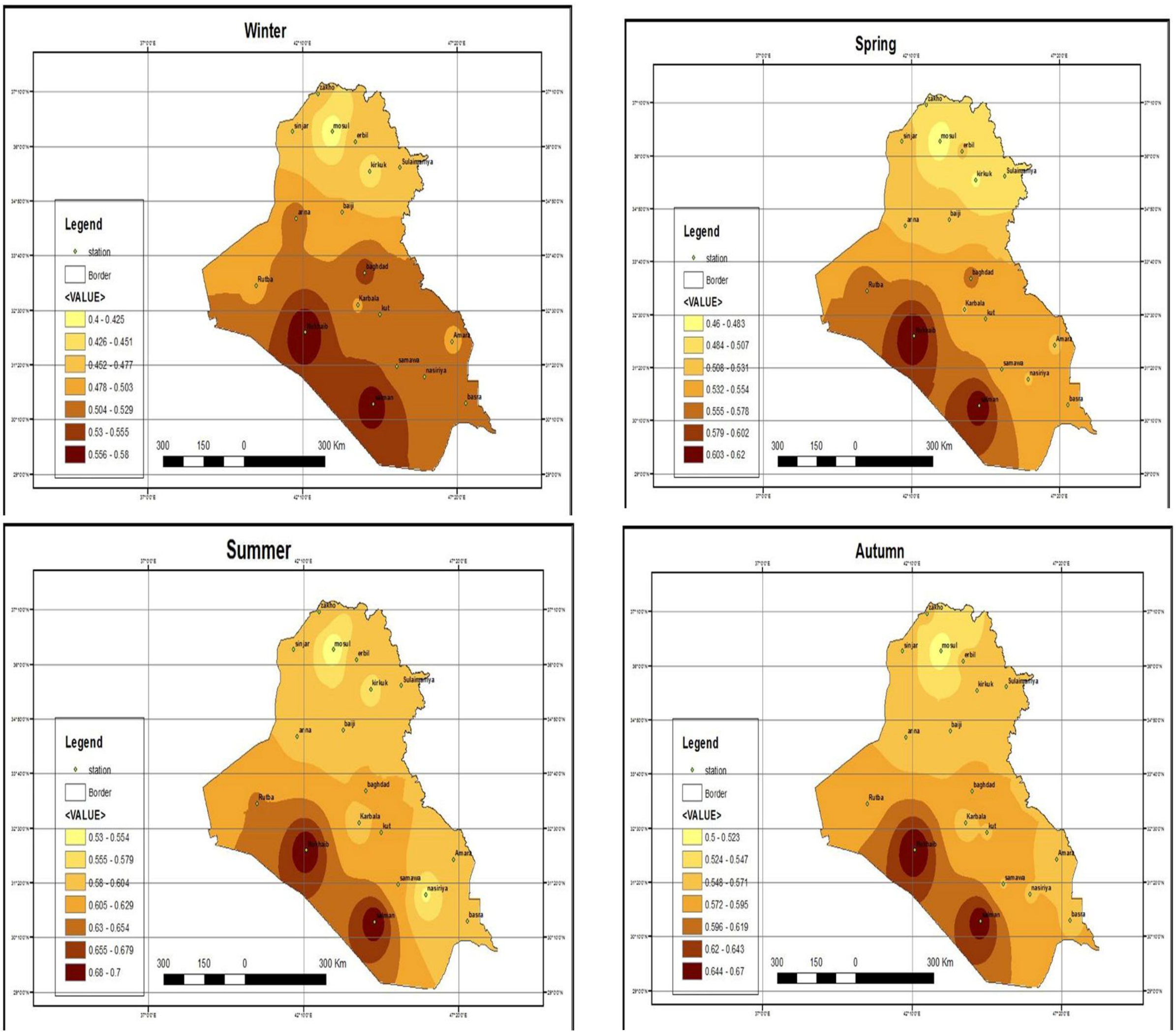

FIG. 3. Spatial variation of KT in the four seasons in Iraq.

Conclusions

In this study, solar radiation was used to evaluate the clearness index in 18 stations well distributed in Iraq during the period (1995-2015). Spatial and temporal variations of KT were studied.

The results showed that:

1. KT over Iraq varies with the geographical location and period of the year.
2. Spatial variation of KT in Iraq shows that Iraq can be divided into three zones: north, middle towards the south-east and south-west region.
3. The minimum monthly value of KT was obtained in Mosul station in December (0.38), while the maximum monthly value of KT was obtained in Nukhaib and Salman stations in Aug.(0.71)
4. The mean annual values of KT ranged between (0.47 - 0.64) in all those stations.
5. The SD of the monthly values of KT ranged between (0.01 - 0.06) for all the stations, while the CV values ranged between (2 - 13) %.

References

[1] Serban, C., Proceedings of the 3rd International Conference on Maritime and Naval Science and Engineering, (2009).

[2] Sanusi, Y.K. and Ojo., M.O., IOSR Journal of Applied Physics, 7 (5) (2015) 45.

[3] Yusuf, A., International Journal of Physical Sciences Research, 1 (1) (2017) 53.

[4] Li, D.H.W., Lau, C.C.S. and Lam, J.C., Building and Environment, 39 (1) (2004) 101.

[5] Al-Rijabo, W.I. and Zahraa, M.H., IOSR Journal of Applied Physics, 5 (4) (2013) 08.

[6] Kudish, A.I. and Ianetz, A., Energy Conversion and Management, 37 (4) (1996) 405.

[7] Nematollahi, O., Alamdari, P. and Alemrajabi, A., 10th International Conference on Sustainable Energy Technologies, Istanbul, Turkey, (2011).

[8] Waewsak, J. and Chancham, C., Thammasat Int. J. Sc. Tech., 15 (2) (2010) 54.

[9] Al-Rijabo, W.I. and Yunis, F., Jordan J. Phys., 4 (2) (2011) 107.

[10] Yeonjin, J., Hana, L., Jaemin, K., Youngbum, C., Jhoon, K. and Yusn, G.L., Atmosphere, 7 (4) (2016) 55.

[11] Zakey, A.S., Abdelwahab, M.M. and Maker, P.A., Atmospheric Environment, 38 (11) (2004) 1579.

[12] Karapantsios, T.D., Hatzimmoisiadis, K.A. and Balouktsis, A.I., Renewable Energy, 17 (1999) 169.

[13] Iqbal, M., "An Introduction to Solar Radiation", (Academic Press, New York, 1983).