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Analytical Study for the Annual TEC Parameter Variations for the Solar Cycle 24 over Iraqi Zone

Athra'a D. Khudhur*, Khalid A. Hadi
Department of Astronomy and Space, College of Science, University of Baghdad, Baghdad, Iraq.

Abstract
In this research, the TEC parameter has been determined for the ionosphere layer over the Iraqi zone. The calculations of this parameter have been conducted using the IRI model that considered as one of the recommended international models which used to calculate the ionosphere parameter (TEC). The determinations have been made for several sites or sites that located within the Iraqi territory. The years (2011-2013) of the solar cycle 24 have been adopted to make the determinations for the TEC parameter.The capital Baghdad has been selected to represent the transmitter station and many different communication points which are located in different directions around the transmitter station have been represented as receiving stations.

K**eywords:** Total Electron Content (TEC), HF communication, Ionospheric Parameters.

دراسة تحليلية للتغير السنوي لمعامل المحتوى الالكتروني الكلي باستخدام موديل ال IRI فوق منطقة العراق

عذراء ضياء خضر*، خالد عبد الكريم هادي
قسم الفلك والفضاء ، كلية العلوم ، جامعة بغداد ، بغداد ، العراق.

الخلاصة
تم في هذا البحث حساب كل من معامل المحتوى الألكتروني الكلي (TEC) لطبقة الأيونوسفير فوق منطقة العراق. لقد تم أجراء الحسابات لهذا المعامل بأستخدام نموذج الـ IRI الذي يعد احد النماذج العالمية المعتمدة (الموثوقة) والتي تستخدم لحساب المعاملات الأيونسفيرية وبضمنها معامل الـ TEC ولقد تم أجراء الحسابات للعديد من المواقع الواقعة ضمن حدود الأراضي العراقية. كما تم في هذا البحث أختيار الأعوام (2011، 2012، 2013) والتي تقع ضمن الدورة الشمسية 24 لأجراء الحسابات للمعاملات المذكورة. أن الغرض من هذه الدراسة هو حساب مدى تأثير عاملي الأرتفاع والنشاط الشمسي المتمثل بعدد البقع الشمسية (الدورة الشمسية) على المحتوى الألكتروني الأعلى لطبقة اليونسفير لمواقع متعددة موزعة فوق نطاق منطقة العراق للدورة الشمسية 24.

Introduction

Radio waves are part of the broad electromagnetic spectrum that extends from the very low frequencies up to the extremely high frequencies of cosmic rays. Between these two extremes are bands of frequencies that are found in everyday uses: audio frequencies, radio frequencies, infrared light, ultraviolet light and x-rays [1]. The range of radio waves is divided into many bands extended

*Email: Athraa.astro@yahoo.com

form very low frequency of 3 kHz to extreme high frequency of 300 GHz. The radio waves having high frequency (HF) band between 3 MHz to 30 MHz are reflected from one of the upper atmospheric layers (ionosphere) and can be transmitted over large distances.

The ionosphere is the earth's atmospheric region in which particles are ionized. It ranges from the altitude of about 60 km to 1000 km. It plays an important role in radio communications [2]. The free electrons in the ionosphere cause HF radio waves to be refracted (bent) and eventually reflected back to earth. The greater the density of electrons, the higher the frequencies that can be reflected. During the day there may be four regions present called the D, E, F1 and F2 regions. At night the D, E and F1 regions become very much depleted of free electrons, leaving only the F2 region available for communications [3].

Total Electron Content (TEC)

The total electron content (TEC) is one of the universal measures of the ionosphere. It is the total number of electrons along a particular line of sight between the receiver and the GPS satellite in a column of $1m^2$ cross-sectional area as illustrated in Figure-1 [4].

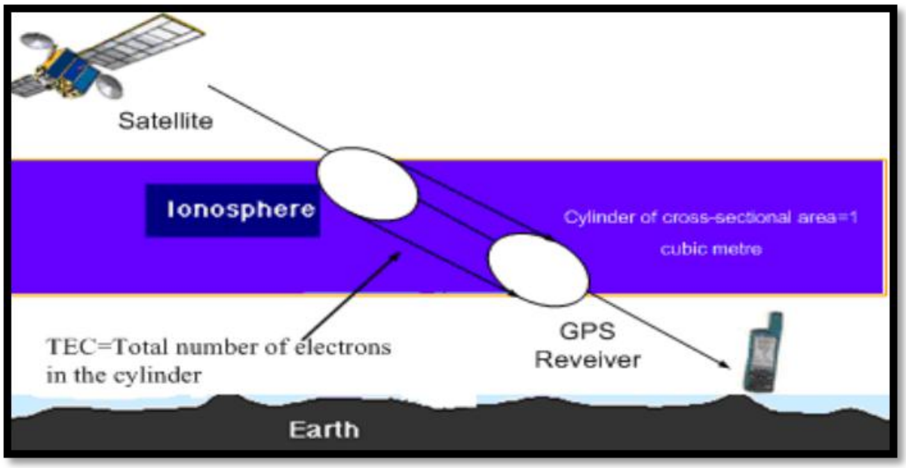


Figure 1- Representation of the TEC [4].

TEC is measured in units of 10^{16} electrons meter per square area, where 10^{16} electrons/m² = 1TEC unit (TECU). The TEC can be expressed by the following equation: [5]

$$TEC=\int Ne\ dh \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

Ne = the electron density along the ray paths from satellite to receiver.

TEC = total electron content.

TEC measurements can be obtained from navigational systems such as Global Positioning Systems (GPS), geostationary satellites, or ionosondes. It is important that the ability to model the ionosphere, and including the topside ionosphere, is improved for GPS applications, and in fact, GPS observations can themselves be used to determine properties of the ionosphere [6].

International Reference Ionosphere model (IRI)

The International Reference Ionosphere (IRI) model was initiated by the Committee on Space Research (COSPAR) and by the International Union of Radio Science (URSI) in the late sixties with the goal of establishing an international standard for the specification of ionospheric parameters based on all worldwide available data from ground-based as well as satellite observations [7].

In the present work, the International Reference Ionosphere (IRI) model has been selected, because it's represent a full system performance model for high frequency (HF) radio communication circuits in the frequency range 3 to 30 MHz.

IRI has been steadily improved with newer data and better modeling techniques leading to the release of a number of key editions of the model including the IRI-78 [8], IRI-85 [9], IRI-1990 [10], IRI-2000 [11], and IRI-2007 [12]. The model progressed from a set of tables of representative values to an analytical representation of densities and temperatures on the whole globe. It is a data-based model, as requested by COSPAR and URSI, and was developed making use of all available and reliable data sources for the ionospheric plasma. This includes the worldwide network of ionosondes that has monitored ionospheric electron densities at and below the F-peak for more than half a century, the powerful incoherent scatter radars that measure plasma densities, temperatures, and velocities throughout the whole ionosphere [13].

The model was made available in electronic form as a FORTRAN program and more recently also as an interactive web interface accessible from the IRI homepage.IRI describes the monthly average of the electron density, electron temperature, ion composition (O^+, H^+, N^+, He^+, O^{+2}, NO^+), ion temperature, and ion drift. An effort is underway to also include a measure of the ionospheric variability during the month in terms of a description [14].

The International Reference Ionosphere (IRI) is the Realism standard for ionospheric parameters and is widely used to specify ionospheric conditions. For many applications the Total Electron Content (TEC) is the parameter of interest because it determines the ionosphere's refractive and retarding effect on radio signals [15]. TEC consists of a bottomside portion (electrons below the F2 peak) and a topside portion (electrons above the F2 peak). The bottomside contributes only about 20% of the TEC. The dominant contribution comes from the topside (>80%) and the topside electron density profile is therefore of utmost importance for many IRI users [16].

Test and Results

In this work, the ionospheric parameter (TEC) has been calculated for the time period (2011-2013) for the region over Iraqi zone. The study has been made to investigate the variations of the ionosphere layer during the tested years.

The IRI communication model that represents one of the best recommended international ionospheric models for radio propagation studies has been adopted to calculate the dataset values of the TEC parameter.

The years of 2011, 2012, and 2013 have been selected to be the studied time period, which lodges within the solar cycle 24. The monthly values of solar flux (F10.7) and the monthly observed sunspot number (SSN) for the selected years have been picked. Table-1 shows the adjusted solar flux for each month of the years (2011-2013) [17]. Table-2 shows the monthly values of the observed sunspots for the selected years [18].

Table 1-Monthly values of the adjusted Solar flux (F10.7).

Month Name	F10.7		
	2011	2012	2013
January	80.73	130.49	122.78
February	92.26	104.29	101.90
March	122.91	114.53	110.22
April	113.61	114.14	125.84
May	97.79	124.12	134.33
June	98.88	124.19	114.25
July	97.43	142.31	119.29
August	104.16	118.75	117.75
September	136.68	124.70	103.91
October	136.52	122.22	131.92
November	150.23	118.45	145.55
December	137.07	104.87	143.49

Table 2-The observed sunspot number (SSN).

Month Name	SSN		
	2011	2012	2013
January	31	65.5	58.7
February	33.5	66.9	58.4
March	36.9	66.8	57.5
April	41.8	64.6	57.8
May	47.6	61.7	59.8
June	53.2	58.9	62.6
July	57.3	57.8	63.6
August	59.1	58.2	62.6
September	59.6	58.1	61.5
October	59.9	58.6	59
November	61.1	59.7	55.5
December	63.4	59.6	52.7

The determination of the TEC parameter has been achieved for many communication links between Baghdad city (44.42 ^{o}E& 33.32 ^{o}N) (transmitter station) and another thirty six cities (receiver stations) that are laid on different geographical locations over the Iraqi local zone, as shown in figure-2.

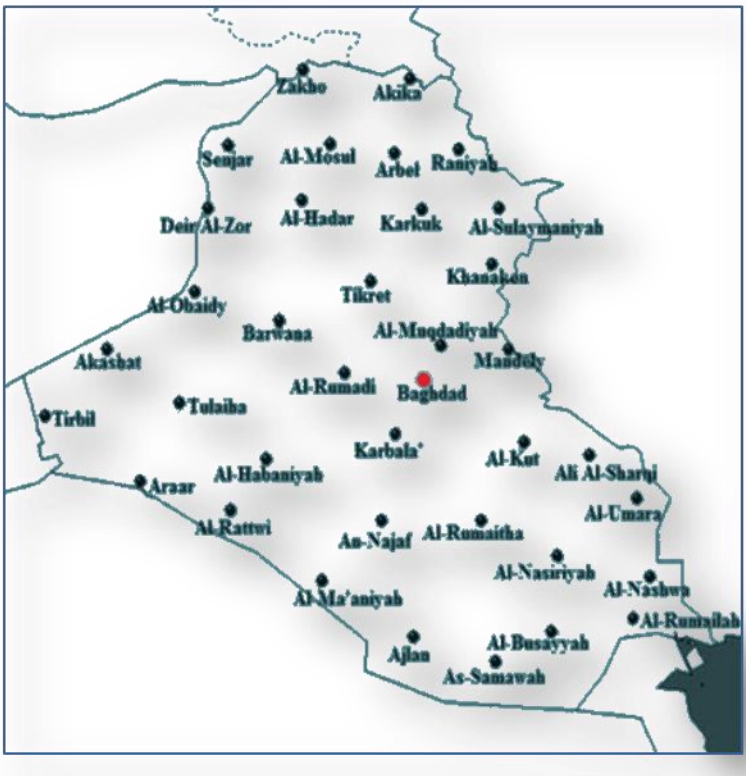


Figure 2- Show the locations of the transmitter and receiver stations over the local area

The geographical location coordinates and the geodesic parameters [distance - path length - bearing transmitter to receiver (Tx to Rx) and bearing receiver to transmitter (Rx to Tx)] have been calculated using the Matlab program (geodesic parameters). The calculated parameters for the selected connection links over local zone are presented in table-3:

Table 3- Geographical and geodesic parameter values of the connection links over the Iraqi local zone.

Station Name	Geographical locations		Distance (Km)	Bearing T_X to R_X (deg)	Bearing R_X to T_X (deg)	Path length (rad)
	Lon (°E)	Lat (°N)				
Ajlan	44.27	30.04	366.54	183.05	2.94	0.06
Akashat	40.58	33.25	358.33	296.63	87.51	0.06
Akika	44.20	37.15	425.74	356.52	176.36	0.07
Al-Busayyah	46.02	30.11	388.75	203.31	22.47	0.06
Al-Habaniyah	42.21	32.28	238.33	241.26	60.06	0.04
Al-Hadar	42.72	35.59	296.50	328.50	147.53	0.05
Ali Al-Sharqi	46.73	32.31	243.27	242.77	61.52	0.04
Al-Kut	45.82	32.53	157.46	235.95	55.20	0.02
Al-Ma'aniyah	42.98	30.73	320.13	205.70	24.93	0.05
Al-Mosul	43.13	36.34	355.48	340.95	160.21	0.06
Al-Muqdadiyah	44.91	33.96	83.04	327.89	147.62	0.01
Al-Nashwa	47.58	30.81	408.59	227.52	45.85	0.06
Al-Nasiriyah	46.27	31.05	307.33	214.85	33.86	0.05
Al-Obaidy	41.21	34.41	320.95	292.89	111.10	0.05
Al-Rattwi	41.70	31.65	317.27	234.58	53.00	0.05
Al-Rumadi	43.30	33.42	105.52	275.77	95.15	0.02
Al-Rumailah	47.37	30.28	438.84	220.10	38.55	0.07
Al-Rumaitha	45.20	31.51	215.12	199.71	19.30	0.03
Al-Sulaymaniyah	45.48	35.50	260.08	338.46	157.86	0.04
Al-Umara	47.17	31.86	304.62	238.28	56.80	0.05
An-Najaf	43.81	31.50	211.87	196.00	15.67	0.03
Araar	40.30	32.00	414.33	250.20	67.97	0.07
Arbel	44.52	36.18	317.36	357.27	177.18	0.05
As-Samawah	45.41	29.71	413.55	193.09	12.58	0.06
Barwana	42.38	34.08	207.38	294.31	113.17	0.03
Deir-Alzor	41.41	35.33	355.82	309.56	127.85	0.06
Karbala'a	44.03	32.60	89.43	204.59	24.37	0.01
Karkuk	44.38	35.47	238.26	357.07	176.99	0.04
Khanaken	45.38	34.80	185.60	332.10	151.57	0.03
Mandely	45.60	33.73	117.34	292.62	111.97	0.02
Raniyah	44.88	36.25	327.63	352.65	172.39	0.05
Senjar	41.68	36.33	417.88	323.83	142.26	0.07
Tikret	43.66	34.58	156.25	333.14	152.71	0.02
Tirbil	39.10	32.85	499.89	265.32	82.41	0.08
Tulaiha	40.98	33.00	323.55	264.42	82.00	0.05
Zakho	42.70	37.30	469.00	340.99	160.00	0.07

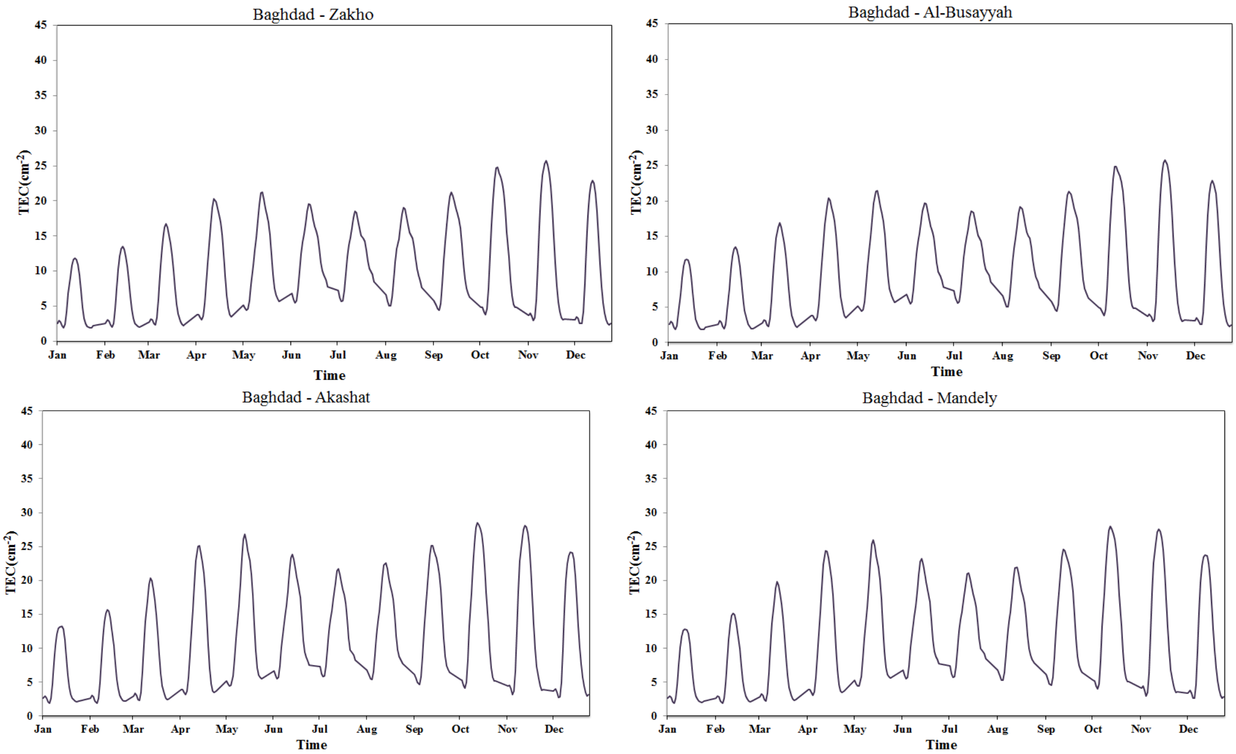
In this work, the behavior of the TEC parameter has been studied statistically. The analytical study has been made to the generated dataset from the IRI model for the seasonal and annual time periods of the selected years within solar cycle 24.

The study of the annual behavior of TEC parameter between transmitter and receiver stations has been made for the chosen years (2011, 2012, 2013) of the solar cycle 24. The statistical analysis has been made by taking into consideration the local mean time (LMT) of the city of Baghdad (Transmitter Station). Table-4 shows a sample of the statistical analysis data file that illustrates the annual statistics.

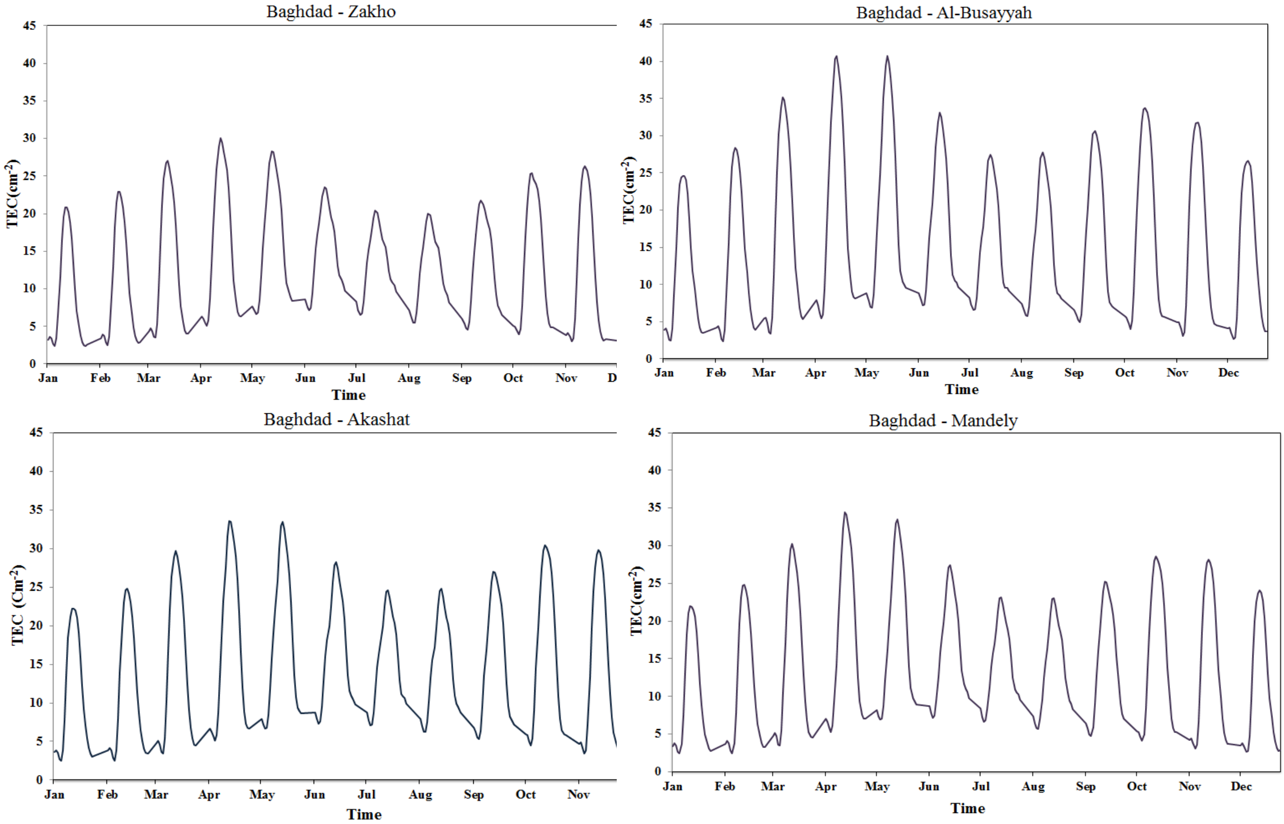
Table 4- Sample of statistical analysis of TEC parameter.

TEC (cm^{-2}) parameter (Baghdad – Ajlan) (2013)												
Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.9	4.2	5.3	7.3	8.4	8.8	8.6	7.9	7.0	6.3	5.2	4.3
2	4.1	4.4	5.4	6.8	7.5	7.9	7.7	7.0	6.4	6.0	5.2	4.4
3	3.5	3.8	4.6	5.8	6.7	7.3	7.0	6.4	5.5	5.0	4.3	3.7
4	2.6	2.7	3.4	5.0	6.6	7.4	7.1	6.3	5.2	4.4	3.3	2.8
5	2.5	2.3	3.2	5.7	8.3	9.3	8.7	7.5	6.5	5.4	3.9	3.0
6	4.1	3.9	5.4	8.9	12.0	12.8	11.8	10.4	9.9	9.4	7.5	5.7
7	8.6	8.4	10.8	14.3	16.4	16.4	14.9	13.7	14.4	15.6	14.5	11.7
8	15.0	15.2	17.9	20.0	20.2	18.8	16.9	16.2	18.2	21.3	21.6	18.5
9	20.4	21.4	24.3	25.2	23.9	21.0	18.4	18.2	21.5	26.0	26.7	23.3
10	23.3	25.4	29.3	30.6	28.7	24.5	21.2	21.3	25.4	30.1	30.0	25.8
11	24.3	27.3	32.7	35.8	34.3	28.8	24.8	25.2	29.2	33.3	32.0	26.9
12	24.6	28.0	34.2	39.1	38.6	32.2	27.7	28.2	31.5	34.9	33.0	27.4
13	24.7	27.7	33.8	39.5	40.0	33.4	28.6	29.1	32.0	35.1	33.0	27.6
14	24.2	26.6	32.3	38.1	39.1	32.9	28.0	28.4	31.4	34.6	32.2	26.9
15	22.3	24.7	30.5	36.3	37.1	31.3	26.8	27.0	30.3	33.5	30.4	24.8
16	18.8	21.8	27.9	33.8	34.6	29.5	25.4	25.5	28.8	31.2	27.0	21.3
17	14.9	18.1	24.3	30.1	31.2	27.3	23.9	23.8	26.6	27.8	22.6	17.3
18	11.8	14.4	20.0	25.0	26.5	23.9	21.5	21.6	23.3	23.2	18.1	13.8
19	9.4	11.2	15.5	19.2	20.3	18.8	17.4	17.7	18.4	17.6	13.8	10.9
20	7.4	8.6	11.4	13.8	14.6	13.9	13.1	13.4	13.1	12.3	10.2	8.3
21	5.6	6.6	8.5	10.2	11.2	11.3	10.7	10.5	9.7	8.8	7.7	6.2
22	4.3	5.2	6.6	8.3	9.8	10.5	10.0	9.3	8.1	7.1	6.1	4.8
23	3.7	4.2	5.5	7.6	9.4	10.3	10.0	9.0	7.6	6.4	5.2	4.0
24	3.6	3.9	5.1	7.5	9.1	9.7	9.6	8.6	7.4	6.3	4.9	3.9

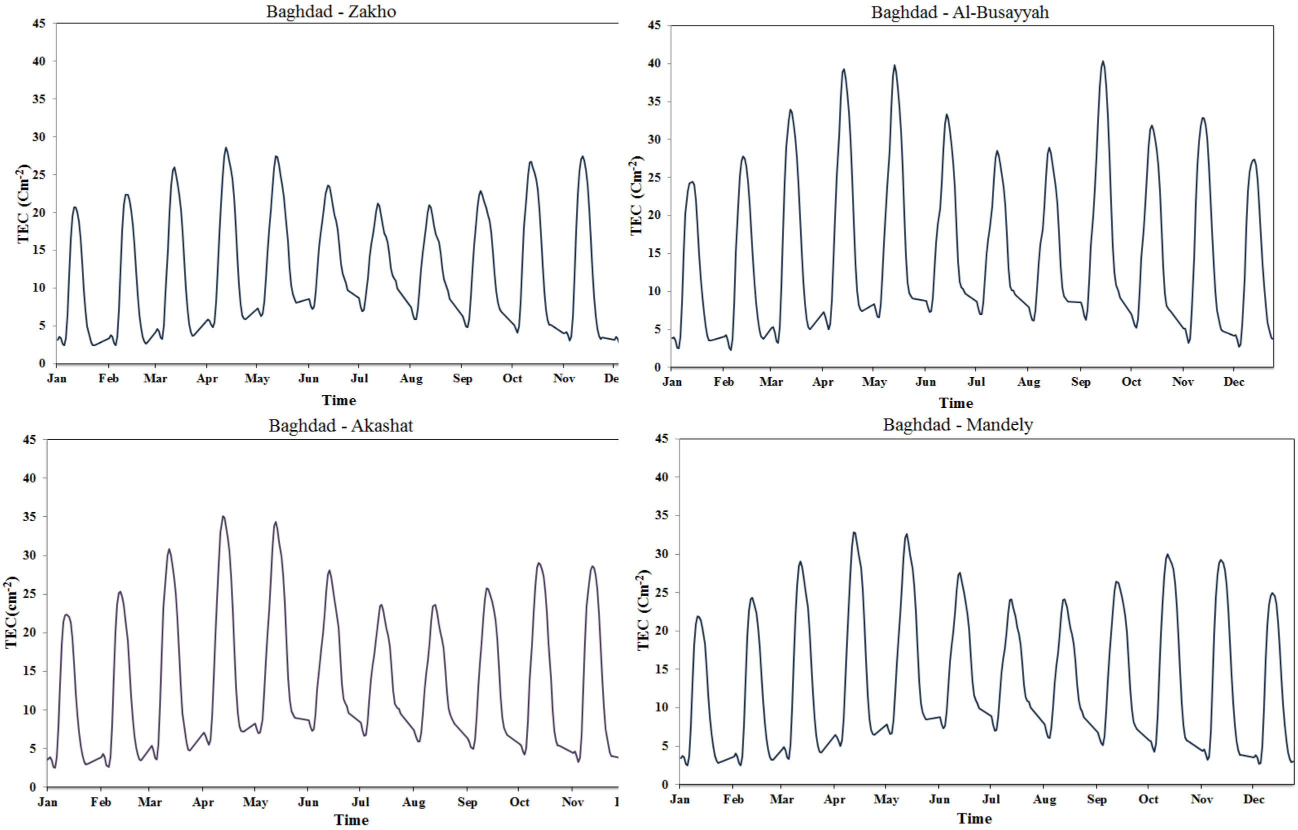
Figure-3 shows samples of the statistical analysis results of the annual time variations for the TEC parameter that have been conducted for the years (2011, 2012 and 2013), respectively.



TEC (Annual Time – 2011)



TEC (Annual Time – 2012)



TEC (Annual Time – 2013)

Figure 3- Samples of the annual behavior of TEC parameter for the years (2011-2013).

Figures-4 and -5 show the contour and surface distribution diagrams between the annual TEC parameter and the geographical location coordinates (longitude & latitude) of the receiving stations that cover the studied area of the Iraqi zone for the years (2011, 2012 and 2013).

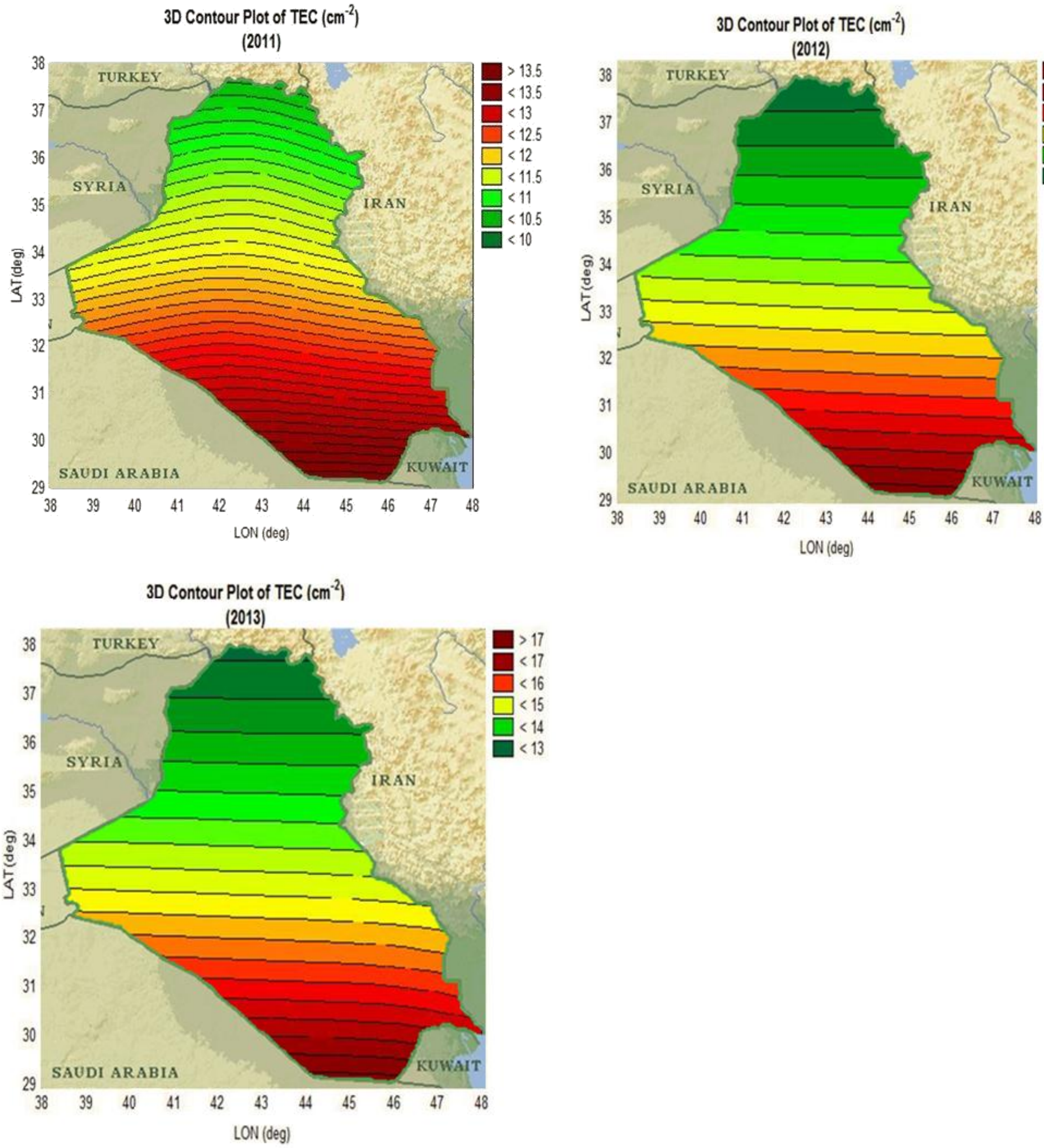


Figure 4- Illustrate the annual contour distribution of the TEC parameter with the geographical coordinates (long. & lat.) for the years (2011-2013).

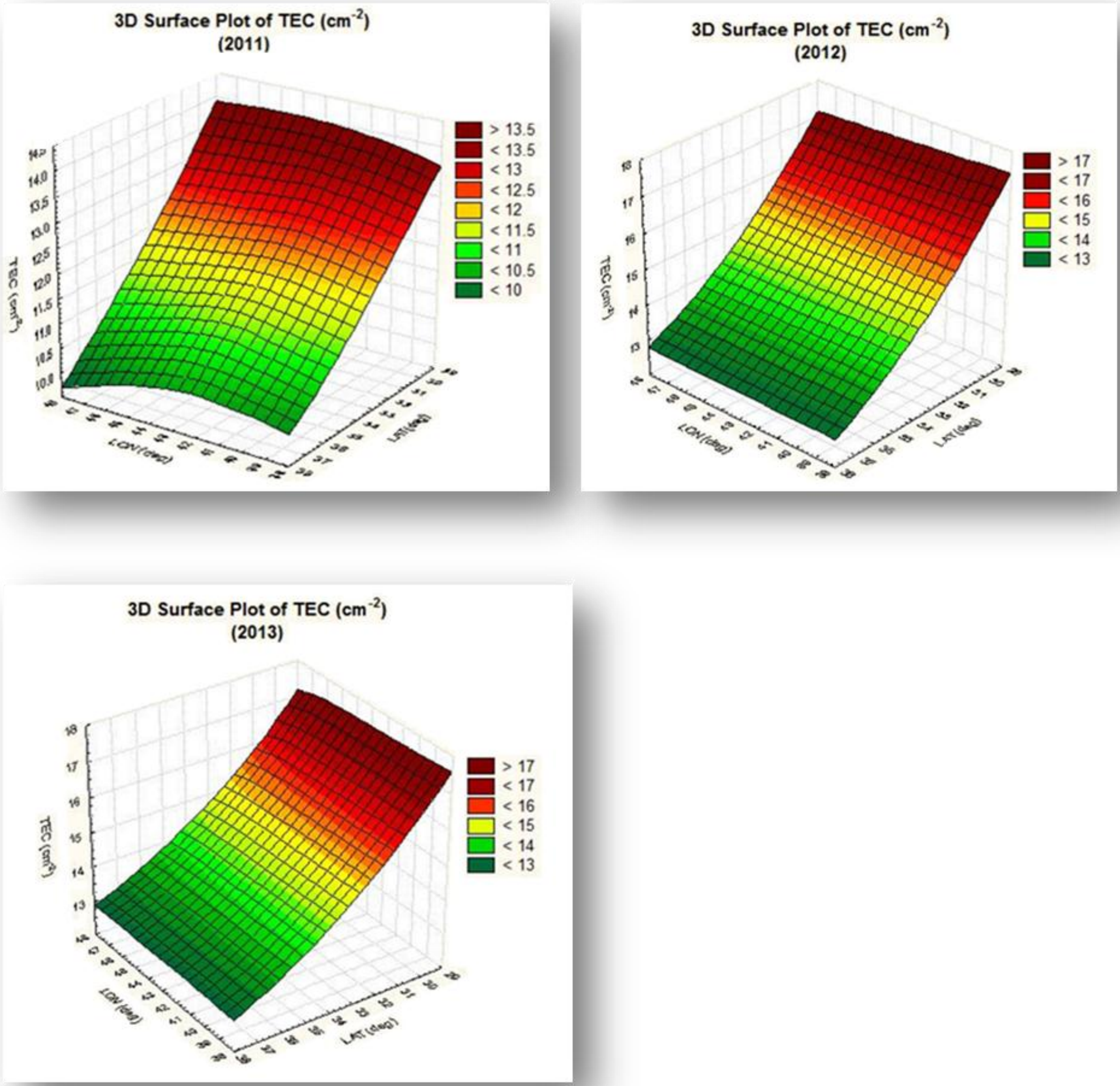


Figure 5- shows the annual surface distribution of the TEC parameter with the geographical coordinates (long. & lat.) for the years (2011-2013).

Discussion and Conclusion

The results of the analytical study that have been made for the datasets generated using IRI model for of the TEC ionospheric parameters will be discussed. The calculation of the TEC parameter has been achieved for the Iraqi local zone by considering Baghdad province as a transmitter station and many other different cities around the transmitter station have been represented as receiving stations.The behavior of the ionospheric parameter (TEC) has been studied for the years (2011-2013) of the solar cycle 24.

The analytical study for the local zone have been made for the annual variations of the TEC parameter that have been conducted for the years (2011, 2012 and 2013), as shown in figures 3.

Figure-4 shows the contour distribution diagrams between the parameters and the geographical location coordinates (longitude & latitude) of the receiving stations that cover the studied area of the Iraqi zone for all the tested years.

Figure-5 shows the surface distribution diagrams between the parameters and the geographical location coordinates (longitude & latitude) of the receiving stations that cover the studied area for the years (2011, 2012 and 2013).

From the results of this study, it can be noticed that the annual values of the TEC parameter during 2011 was within the range (10-13.5 cm^2) while its value was about (13-17 cm^2) for the years 2012 and 2013. The calculated TEC values of 2011 were lower than that of 2012 also the results of 2013 show higher values than 2012. The increment of the TEC parameter was due to the increment of the solar activity for the studied years. Also, it had been noticed that the annual TEC values show higher values in the southern region of the studied area. The TEC values were decreased slightly within increasing the latitudes and that decrement may due to the impact of the thermal equator on the structure of the ionosphere over the studied area.

According to the above discussion, it can be concluded that the values of the annual variation of the TEC parameter are increased with time. The increment of the TEC parameter was due to the increment of the solar activity for the studied years.

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