Determination of Ionospheric Parameters over Iraqi Zone

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Abstract
In this paper, an analytical study for the behavior of ionospheric parameters (Maximum Usable Frequency (MUF) and Optimum Traffic Frequency (FOT)) has been preformed between transmitter station (Baghdad) and many different receiver stations which are distributed randomly over Iraqi territory. The ionospheric parameters dataset has been made using ICEPAC communication model for annual time for the years 2009-2011 of the solar cycle 24. A simplified ionospheric model has been suggested which based on the correlated relationship between the geographical locations coordinates (longitudes & latitudes) of receiver stations and the dataset of the MUF and FOT parameters. The results of this study showed that the correlation between the ionospheric parameters and geographical location coordinates can be expressed as linear surface equation. The predicated ionospheric parameters values using the suggested empirical model show a good fitting with theoretical values that calculated using the international models.

Keywords: Ionospheric Propagation Parameters, Radio Wave Propagation, HF Communication.

حساب قيم المعاملات الأيونسفيرية فوق منطقة العراق

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الخلاصة:
في هذا البحث تم إجراء دراسة تحليلية لسلوك المعاملات الأيونسفيرية (MUF و FOT) بين المحطة المرسلة (بغداد) والعديد من محطات الإستلام المختلفة التي تتوزع عشوائيا فوق منطقة العراق. تم حساب قيم المعاملات الأيونسفيرية بأستخدام نموذج الإتصالات (ICEPAC) للفترة السنوية للأعوام (2009 – 2011) والواقعة ضمن الدورة الشمسية 24. كما تم إقتراح نموذج رياضي مبسط لحساب قيم المعاملات الأيونسفيرية إعتماداً على العلاقة الإرتباطية بين إحداثيات المواقع الجغرافية (خطوط الطول وخطوط العرض) لمحطات الإستلام وبيانات المعاملات الأيونسفيرية التي تم حسابها بأستخدام النموذج العالمي. أظهرت نتائج هذه الدراسة أن العلاقة الإرتباطية بين المعاملات الأيونسفيرية والإحداثيات الجغرافية لمواقع الإستلام يمكن التعبير عنها بمعادلة سطحية خطية. أن القيم التنبؤية للمعاملات الأيونسفيرية المحسوبة بأستخدام النموذج التجريبي المقترح أعطت تطابق جيد مع القيم النظرية التي تم حسابها بأستخدام النماذج العالمية.

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Introduction

The ionosphere is the part of the Earth's upper atmosphere that makes up less than one percent of the mass of the atmosphere above 50 km. It extends from about 50 km altitude to about 1000 km where it merges with near Earth space environment. Most of the ionosphere is electrically neutral, but when solar radiation strikes the chemical constituents of the atmosphere electrons are split from atoms and molecules to produce an ionized layer [1].

The ionosphere layer is varies greatly with the time of day. During the day, the solar flux increases as the Sun comes into view and the electron density in the ionosphere increases. This allows high frequencies to be propagated over long distances. At night when the solar flux is low, radio energy is absorbed less and the lower frequencies are propagated better [2].

The radio waves at high frequency (HF) band (3-30) MHz which is represented as a primary communication resource that are back to Earth a distance from the transmitting antenna by the ionosphere facilities reception of information from radio waves. Long distance propagation of HF depends on an invisible layer of charged particles which envelops the Earth known as the ionosphere and the curvature of the Earth [3].

HF Communication Ionospheric Parameters

The ionospheric parameters is represented an important parameters in HF communications to determine the best range of reliable frequencies that are reflected from the ionospheric layers between two terminals at specific time, as shown in figure (1). The MUF, LUF, and FOT parameters are representing the main ionospheric parameters that can determine the best communication frequencies [4], these parameters can be defined as follows:

I. The Maximum Usable Frequency (MUF): *Is the highest frequency that permits an acceptable level of performance for propagation via the ionosphere taking intoaccount system.* The median value of MUF parameter is only 50 % of the time.

II. The Optimum Traffic Frequency (FOT):

Is also called the optimum working frequency (OWF) and define as *the highest effective frequency that propagates by ionospheric refraction alone for specific path*. It is working only 90 % of the monthly time.

III. The Lowest Usable Frequency (LUF):

Is *the lowest frequency that can be propagated through ionosphere layer between two terminals on the surface of the Earth*. It is exceeded by the operational MUF on 10% of the specified period [5].

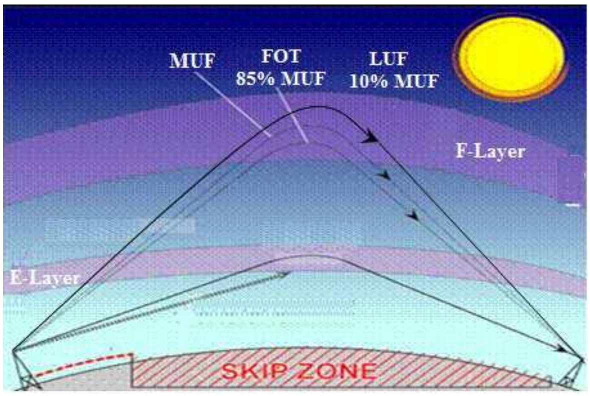


Figure 1- Illustrates the range of operation usable frequencies [5].

The predicted values of the MUF, LUF and FOT change in regular way due to the variations of the ionospheric factors over the day, the year and the 11-year sunspot cycle. Also, the ionospheric parameters values change progressively in the D, E and F layers depends on maximum electron density for each layer and the angle of incidence of the emitted radio wave [6]. Numerous studies over many years Bröms and Lundborg (1994) [7], Blagoveshchensky and Borisova (2000) [8], Fotiadis et al. (2003) [9], Barabashov et al. (2006) [10], Liu et al. (2008) [11], Walden (2010) [12] and Pietrella (2011) [13]) have been done to study the variation the ionospheric parameters behavior.

The Adopted International Communication Model

For many years, numerous organizations have developed HF ionospheric communication models in order to provide more accurate usable frequencies that are maintains between transmitter and receiver pointes over long distance.

The performance of HF communication models is evolved progressively, starting in the 1930's with uncoordinated studies by radio scientists and engineers in some countries.

The remarkable progress in computer systems over the past two decades has practically made to develop models of the ionosphere with the objective of making propagation predictions.

Currently, there are many HF prediction models generated by different organizations which have a wide range of applications in the world wide. The performance of HF models was provided many ionospheric reflection and propagation parameters like ionospheric characteristics, antenna patterns, MUF, LUF and FOT, take-off angles, propagation modes, sky-wave field strength, available receiver power, and SNR or service reliability [14].

In the present work, the Ionospheric Communications Enhanced Profile Analysis and Circuit (ICEPAC) model has been selected, because it's represent a full system performance model for high frequency (HF) radio communications circuits in the frequency range of 2 to 30 MHz.

ICEPAC model is represented the development Ionospheric Communications Analysis and Prediction (IONCAP) program. However, the ICEPAC model in America took over the completion of the IONCAP code by using technical expertise at both National Telecommunication and Information Administration (NTIA) and Institute for Telecommunication Sciences (ITS) [15].

Test and Results

The aim of this research is suggested simplified mathematical model to predict the ionospheric frequencies between transmitter station (Baghdad) and any other selected receiver station that located within the Iraqi region.

The ICEPAC communication model that represents one of the best recommended international HF communication models has been adopted to calculate the dataset values of the MUF and FOT parameters.

The years (2009-2011) have been selected to be the studied time period, because these years represent the beginning of solar cycle 24. Figure (2) illustrates the variation of monthly values of observed sunspots for selected years [16].

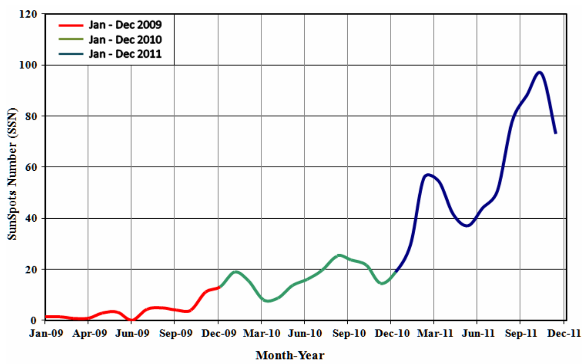


Figure 2- Sunspots number for years 2009-2011.

The Iraqi region which is laid within the longitudes range of (39.1 ^{O}E - 47.37 ^{O}E) and latitudes of (30.02 ^{O}N - 37.3 ^{O}N) has been considered for the studied area. The capital Baghdad which is located at geographical coordinates 44.42 ^{O}E and 33.32 ^{O}N had been selected to represent as a transmitter station and thirty one different locations which are distributed over Iraqi region have been represented as receiver stations, as shown in figure 3.

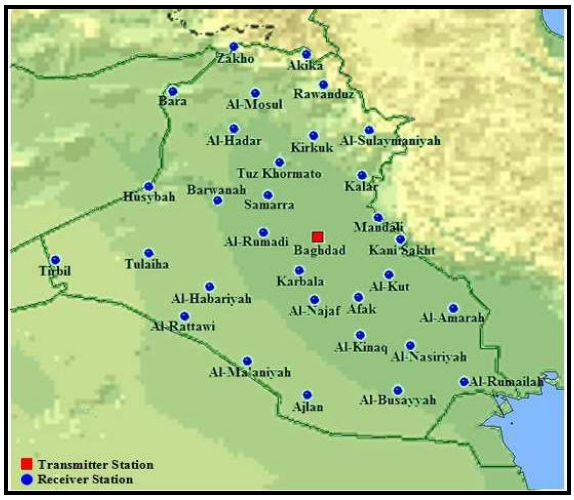


Figure 3- The locations of transmitter and receiver stations over local area.

The coordinates of geographical location coordinates (longitudes and latitudes) of the selected receivers laid over the Iraqi zone and bearing transmitter (T_X) to receiver (R_X) can be described in table (1).

Table 1- Illustrates the geographical locations of receiver stations and bearing parameter values (T_X to R_X).

Station Name	Geographical Location		Bearing (T_x to R_x) (Deg)
	Lon (^{0}E)	Lat (^{0}N)	
Afak	45	32	159.46
Ajlan	44.2	30.02	183.61
Akika	44.2	37.15	357.22
Al-Amarah	47.15	31.83	122.53
Al-Busayyah	46.02	30.11	156.82
Al-Habariyah	42.21	32.28	241.08
Al-Kinaq	45	31.25	166.62
Al-Kut	45.83	32.51	124.18
Al-Ma'aniyah	42.98	30.73	205.39
Al-Mosal	43.13	36.34	340.88
Al-Najaf	44.33	32	183.95
Al-Nasiriyah	46.27	31.05	145.14
Al-Rattawi	41.7	31.65	234.35

Al-Rumadi	43.3	33.42	276.22
Al-Rumailah	47.37	30.28	140.09
Bara	41.49	36.37	322.11
Barwanah	42.39	34.1	294.99
Hader	42.72	35.59	328.56
Husybah	40.99	34.39	291.02
Kalar	45.3	34.63	29.10
Kani Sakht	46.07	33.27	91.80
Karbala	44.03	32.62	205.22
Kirkuk	44.32	35.48	357.98
Mandali	45.56	33.74	66.02
Rawanduz	44.52	36.51	1.95
Samarra	43.38	34.2	315.65
Sulaymaniyah	45.43	35.55	20.31
Tirbil	39.1	32.85	264.75
Tulaiha	40.98	33	264.18
Tuz	43.64	34.88	337.50
Zakho	42.7	37.3	340.83

In this work, the values of the MUF and FOT parameters have been studied statistically by analyzing the generated dataset from the ICEPAC model for annual time period of the selected years of solar cycle 24. Table (2) shows samples of the statistical analysis data file that illustrate the annual statistics.

Table 2- Shows samples of statistical analysis of MUF & FOT parameters.

MUF (Baghdad - Karbala) (2011)													
Time	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Annual
0	3.11	3.6	3.9	5.33	6.5	6.48	6.5	6.2	5.74	6.2	6	5.36	5.0
1	3.23	3.7	4	5.33	6.4	6.3	6.2	6	5.74	6.1	5.9	5.34	5.0
2	3.42	3.9	4.2	5.33	6.1	6.03	5.9	5.7	5.6	5.9	5.8	5.35	5.0
3	3.24	3.8	4.2	5.06	5.6	5.6	5.4	5.3	5.2	5.6	5.4	4.99	4.8
4	2.7	3.3	3.6	4.53	5.2	5.26	5	4.9	4.81	5.1	4.7	4.3	4.4
5	2.47	2.8	3.2	4.33	5.2	5.41	5.1	5	4.96	5.3	4.8	4.15	4.4
6	3.11	3.1	3.6	5.08	5.9	6.09	5.8	5.7	5.71	6.3	6.1	5.32	5.2
7	4.35	4.1	5.1	6.59	7	6.87	6.5	6.5	6.56	7.7	8	7.54	6.4
8	5.51	5.6	6.6	8.07	7.9	7.32	6.9	6.8	7.03	8.6	9.6	9.68	7.5
9	6.3	6.7	7.5	8.98	8.6	7.51	6.9	6.8	7.21	9	10	10.9	8.1
10	6.81	7.2	8	9.54	9.2	7.74	7	6.8	7.44	9.3	11	11.3	8.6
11	7.09	7.3	8.4	10.1	10	8.21	7.4	7.1	7.88	9.8	11	11.4	9.0
12	7.02	7.2	8.6	10.6	11	8.79	7.9	7.5	8.32	10	11	11.3	9.4
13	6.8	7.2	8.7	10.7	11	9.24	8.3	7.9	8.57	10	12	11.3	9.6
14	6.72	7.2	8.5	10.5	11	9.37	8.4	8	8.58	10	12	11.4	9.7
15	6.68	7	8.5	10.1	11	9.22	8.3	7.9	8.44	10	12	11.3	9.6
16	6.27	6.6	8.3	9.75	10	9	8.1	7.7	8.24	10	11	10.8	9.4
17	5.43	5.9	7.7	9.15	10	8.87	8	7.6	8.09	9.5	10	9.86	9.0
18	4.51	5.1	6.6	8.25	9.3	8.67	8	7.5	7.94	8.8	9.4	8.65	8.5
19	3.87	4.5	5.6	7.27	8.5	8.24	7.8	7.4	7.67	8	8.3	7.59	8.0
20	3.55	4	4.8	6.49	7.6	7.66	7.4	7.1	7.21	7.3	7.4	6.82	7.5
21	3.45	3.7	4.3	6.01	7	7.19	7.1	6.7	6.66	6.9	6.8	6.31	7.2
22	3.37	3.6	4.1	5.71	6.7	6.91	6.9	6.5	6.18	6.6	6.5	5.93	7.0
23	3.22	3.6	3.9	5.48	6.6	6.69	6.7	6.3	5.86	6.4	6.3	5.59	6.9

FOT (Baghdad - Karbala) (2011)													
Time	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Annual
0	2.5	2.9	3.2	4.1	5.0	5.1	5.1	4.9	4.4	4.7	4.7	4.1	3.9
1	2.6	3.0	3.2	4.1	4.9	4.9	4.9	4.7	4.4	4.7	4.6	4.1	3.9
2	2.5	2.9	3.1	4.1	4.6	4.8	4.8	4.7	4.1	4.5	4.4	4.1	3.9
3	2.4	2.8	3.1	3.8	4.3	4.5	4.4	4.3	3.8	4.2	4.1	3.8	3.7
4	2.0	2.4	2.7	3.4	3.9	4.2	4.1	4.0	3.5	3.9	3.6	3.3	3.5
5	2.0	2.1	2.4	3.3	4.0	4.3	4.2	4.1	3.6	4.0	3.7	3.2	3.5
6	2.7	2.6	3.1	4.2	4.9	5.0	4.5	4.4	4.3	5.2	5.0	4.4	4.3
7	3.7	3.6	4.3	5.4	5.7	5.6	5.1	5.1	4.9	6.3	6.6	6.2	5.3
8	4.7	4.8	5.7	6.6	6.5	6.0	5.3	5.3	5.3	7.0	7.9	7.9	6.2
9	5.4	5.7	6.5	7.4	7.0	6.2	5.4	5.3	5.4	7.4	8.6	8.9	6.8
10	5.6	5.9	6.6	7.9	7.7	6.0	5.6	5.4	5.9	7.7	9.1	9.4	7.1
11	5.8	6.0	6.9	8.4	8.3	6.4	5.9	5.7	6.2	8.1	9.3	9.4	7.5
12	5.8	5.9	7.1	8.8	8.8	6.9	6.3	6.0	6.6	8.5	9.5	9.4	7.8
13	5.6	5.9	7.1	8.9	9.1	7.2	6.6	6.3	6.8	8.6	9.6	9.4	8.0
14	5.7	6.1	7.2	8.2	8.5	7.6	6.8	6.5	6.6	8.1	9.1	8.9	7.9
15	5.7	6.0	7.2	7.9	8.3	7.5	6.7	6.4	6.5	8.0	9.0	8.8	7.9
16	5.3	5.6	7.0	7.6	8.1	7.3	6.6	6.2	6.4	7.8	8.7	8.5	7.8
17	4.6	5.0	6.5	7.1	7.8	7.2	6.5	6.1	6.2	7.4	8.1	7.7	7.5
18	3.5	4.0	5.2	5.9	6.7	6.4	6.4	6.0	5.9	6.4	6.7	6.2	6.7
19	3.0	3.5	4.3	5.2	6.1	6.1	6.2	5.9	5.7	5.8	6.0	5.5	6.3
20	2.8	3.1	3.7	4.7	5.4	5.7	5.9	5.7	5.3	5.3	5.3	4.9	6.0
21	2.7	2.9	3.4	4.3	5.0	5.3	5.7	5.4	4.9	4.9	4.9	4.5	5.8
22	2.7	2.9	3.3	4.4	5.2	5.4	5.4	5.1	4.8	5.1	5.0	4.6	5.8
23	2.6	2.9	3.2	4.2	5.1	5.2	5.3	5.0	4.5	4.9	4.8	4.3	5.8

The construction of suggested mathematical model based on studying the correlated relationship between the geographical locations coordinates (longitude and Latitude) of receiver stations and the dataset of the MUF and FOT parameters that generated from the ICEPAC international communication model.

Depending on the statistical analysis results that have been made, the behavior of the ionospheric parameters basically depends on the the spherical geodesic parameter (Bearing) between the two stations; therefore the suggested empirical equation that describes the correlation relationship between the ionospheric parameters and geographical locations of the connection links has been proposed as *linear surface equation*:-

$$I_P = a_0 + a_1 G_{lat} + a_2 G_{lon}$$

Where

I_p = is the Ionospheric Parameter (MUF or FOT).

G_{lat} = is the latitude of receiving station.

G_{lon} = is the longitude of receiving station.

a_0, a_1, a_2 = are the Constant Coefficients.

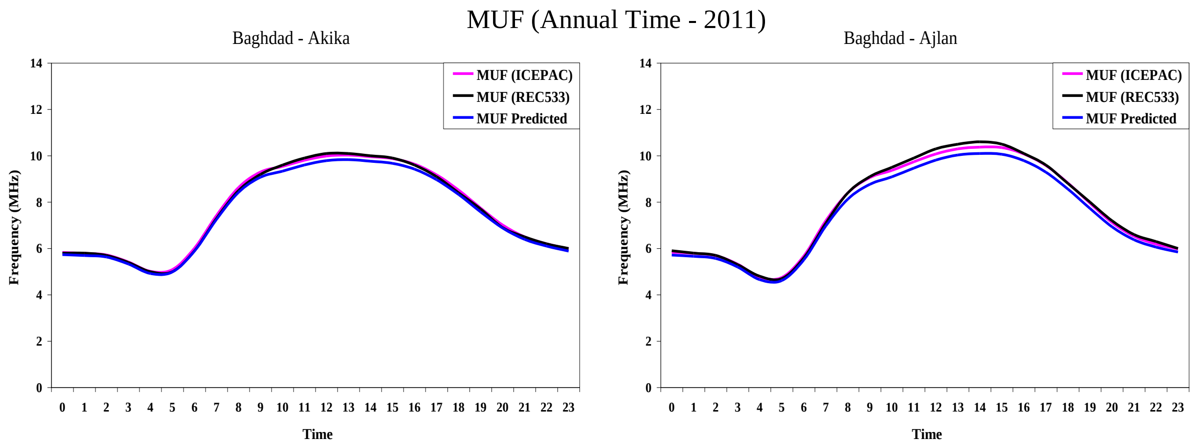
In order to get the set of the a's coefficients (a_0, a_1, a_2), the tested area had been classified according to it's bearing value into four tested sectors. Table (3) shows sample of the a's coefficients and the R-square values of the MUF and FOT parameters for the first tested sector for the year 2011.

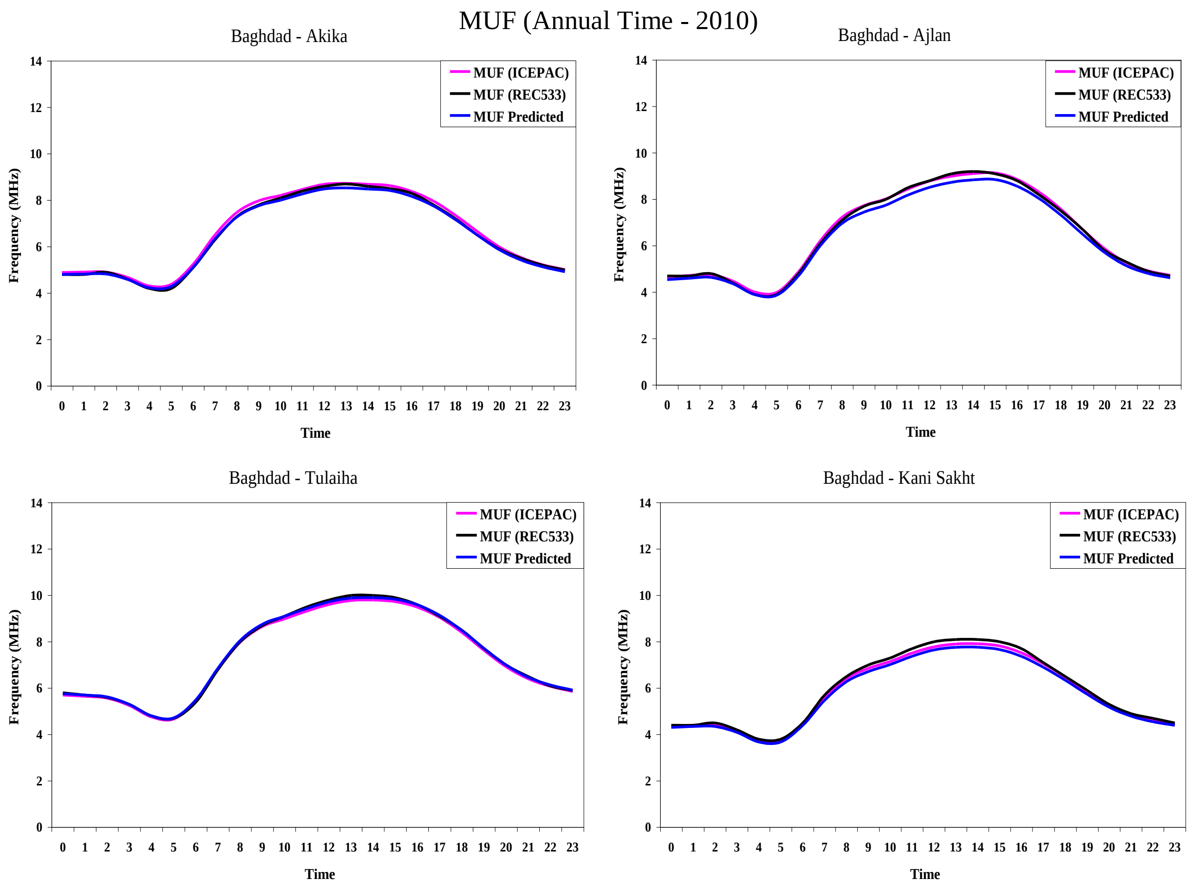
Table 3- Samples of the a's seasonal constant coefficients of the MUF & FOT parameters.

MUF (First Sector) (2011)				
Time	a_0	a_1	a_2	R^2
0	5.989	-0.168	0.106	0.958
1	5.703	-0.166	0.110	0.955
2	5.612	-0.161	0.107	0.947
3	4.964	-0.142	0.100	0.955
4	3.611	-0.120	0.104	0.943
5	1.879	-0.129	0.148	0.953
6	1.515	-0.197	0.222	0.958
7	2.740	-0.293	0.293	0.968
8	4.766	-0.349	0.310	0.964
9	6.199	-0.370	0.306	0.962
10	7.049	-0.351	0.282	0.960
11	7.894	-0.355	0.274	0.962
12	9.081	-0.369	0.264	0.960
13	10.635	-0.394	0.251	0.962
14	11.119	-0.418	0.258	0.964
15	11.707	-0.453	0.267	0.966
16	11.675	-0.460	0.266	0.968
17	11.282	-0.453	0.259	0.966
18	10.708	-0.401	0.220	0.966
19	9.419	-0.324	0.179	0.962
20	8.601	-0.251	0.130	0.960
21	7.531	-0.196	0.105	0.955
22	6.779	-0.171	0.098	0.953
23	6.461	-0.163	0.095	0.947

FOT (First Sector) (2011)				
Time	a_0	a_1	a_2	R^2
0	5.135	-0.128	0.073	0.958
1	4.441	-0.128	0.085	0.957
2	4.316	-0.123	0.082	0.953
3	3.929	-0.109	0.074	0.955
4	2.749	-0.091	0.079	0.945
5	1.786	-0.098	0.106	0.953
6	0.995	-0.159	0.185	0.962
7	1.978	-0.235	0.240	0.968
8	3.705	-0.282	0.255	0.964
9	4.949	-0.300	0.252	0.964
10	5.653	-0.286	0.232	0.964
11	6.312	-0.288	0.225	0.962
12	7.377	-0.301	0.216	0.960
13	8.548	-0.320	0.207	0.964
14	8.890	-0.335	0.207	0.964
15	9.408	-0.363	0.213	0.968
16	9.258	-0.369	0.216	0.966
17	9.243	-0.366	0.205	0.966
18	7.813	-0.298	0.168	0.966
19	7.086	-0.244	0.134	0.962
20	6.399	-0.188	0.098	0.957
21	5.731	-0.148	0.077	0.955
22	5.461	-0.135	0.074	0.953
23	5.135	-0.128	0.073	0.947

In order to verify the accuracy of simplified suggested model, the predicted values of the ionospheric parameters that calculated by substituting the values of the geographical location coordinates (i.e., Longitude (G_{lon}) and Latitude (G_{lat})) for each considered receiving station in the suggested empirical formula have been compared with theoretical values that calculated from the ICEPAC, REC533, VOACAP international models. Figures (4) and (5) present samples of the calculated results of predicted and theoretical ionospheric parameters for annual time for the years (2009-2011).


MUF (Annual Time - 2011)
Baghdad - Akika
Baghdad - Ajlan
Baghdad - Kani Sakht
Baghdad - Tulaiha
MUF (ICEPAC)
MUF (REC533)
MUF Predicted
Frequency (MHz)
Time


MUF (Annual Time - 2010)
Baghdad - Akika
Baghdad - Ajlan
Baghdad - Tulaiha
Baghdad - Kani Sakht
MUF (ICEPAC)
MUF (REC533)
MUF Predicted
Frequency (MHz)
Time

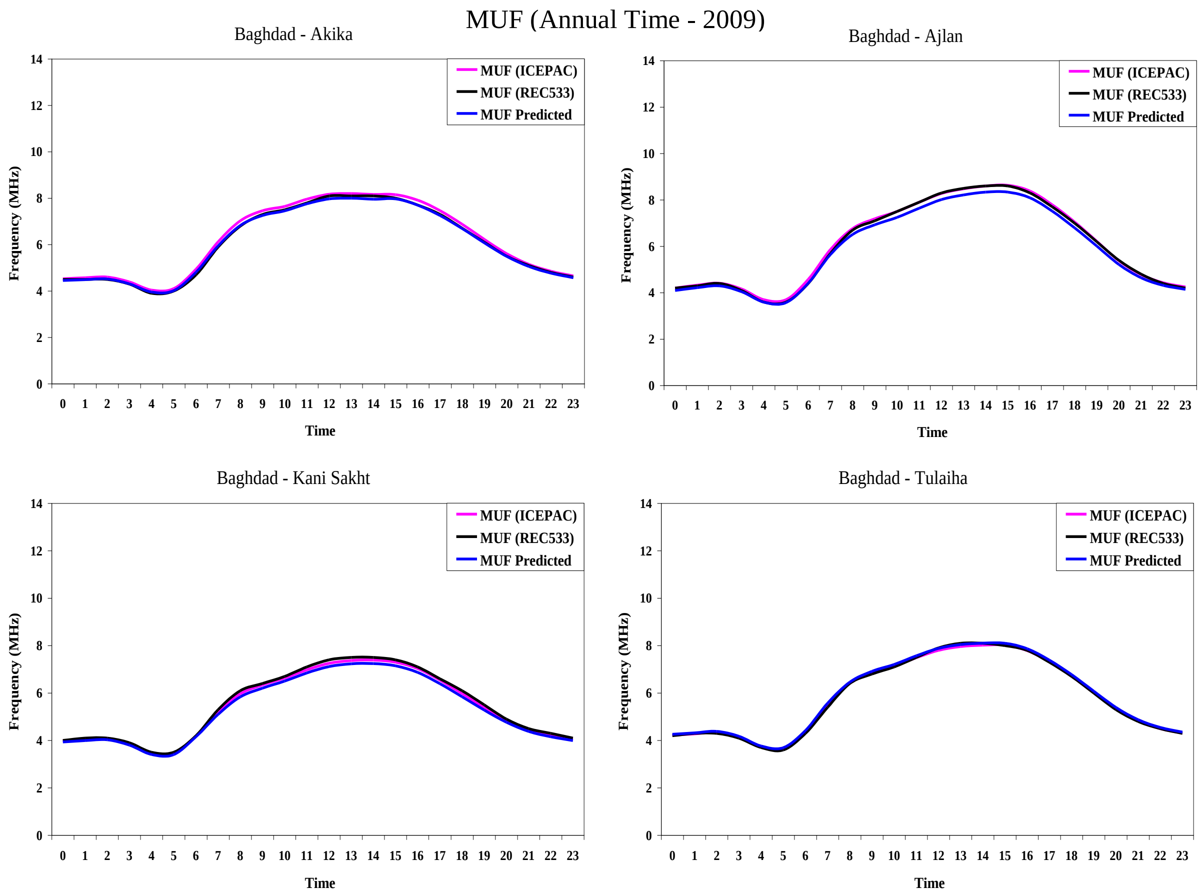
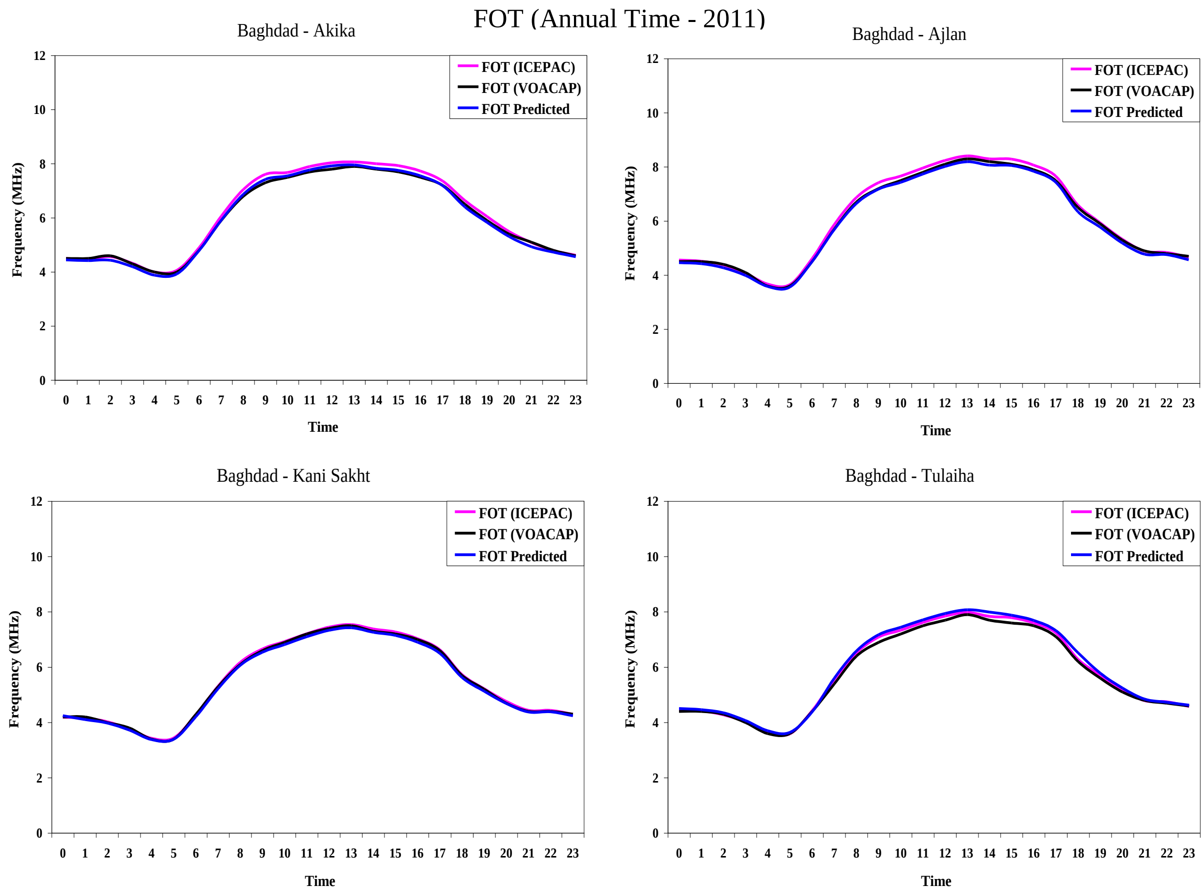


Figure 4- Describes the annual variation of theoretical and predicted values of MUF parameter.



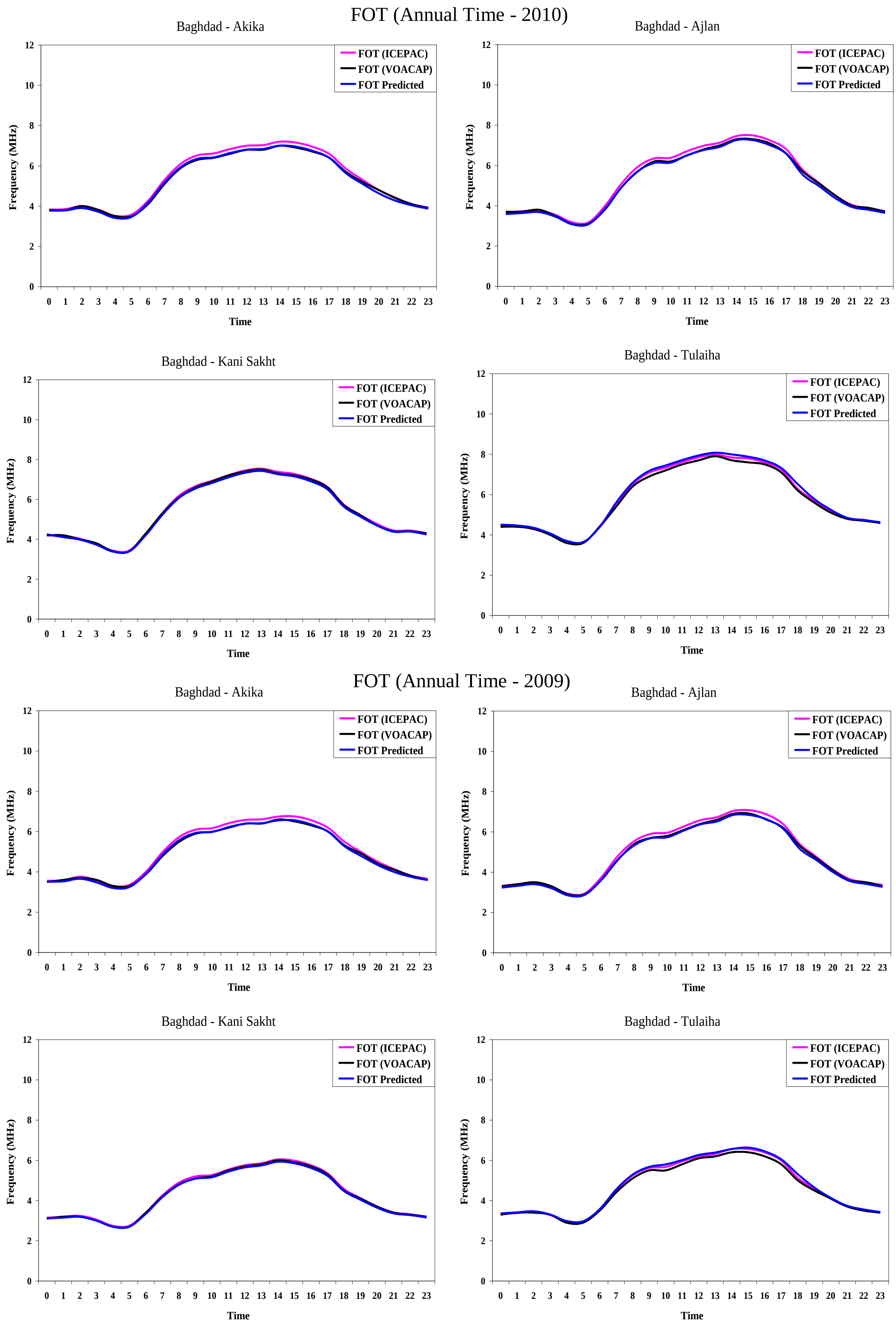


Figure 5- Describes the annual variation of theoretical and predicted values of FOT parameter.

Samples of the annual mean square error values (MSE) for MUF and FOT parameters are shown in table (4).

Table 4- Show samples of the annual MSE values of MUF and FOT parameters for the selected years.

Annual Time (MUF – 2011)		
Station	MSE	MSE
Akika	0.027	0.025
Ajlan	0.013	0.073
Kani Sakht	0.049	0.087
Tulaiha	0.003	0.007
Annual Time (MUF – 2010)		
Station	MSE	MSE (
Akika	0.006	0.026
Ajlan	0.012	0.049
Kani Sakht	0.046	0.039
Tulaiha	0.005	0.006
Annual Time (MUF – 2009)		
Station	MSE	MSE (
Akika	0.024	0.004
Ajlan	0.012	0.035
Kani Sakht	0.044	0.031
Tulaiha	0.004	0.007
Annual Time (FOT – 2011)		
Station	MSE	MSE
Akika	0.022	0.008
Ajlan	0.008	0.004
Kani Sakht	0.031	0.007
Tulaiha	0.008	0.033
Annual Time (FOT – 2010)		
Station	MSE	MSE
Akika	0.025	0.005
Ajlan	0.008	0.004
Kani Sakht	0.03	0.006
Tulaiha	0.005	0.025
Annual Time (FOT – 2009)		
Station	MSE	MSE
Akika	0.024	0.004
Ajlan	0.008	0.002
Kani Sakht	0.028	0.005
Tulaiha	0.004	0.027

Discussion and Conclusion

In this work, an analytical investigation for MUF and FOT parameters behavior has been achieved for annual period of years (2009-2011) over Iraqi territory.

Due to the complications of the statistical analysis results, the studied communication region had been divided into four sectors depending on the spherical geodesic parameter (Bearing) between the transmitter and receiver stations. The correlation relationship between the ionospheric parameters and geographical location coordinates of receiving stations for each sector has been studied for each sector of tested area, so the results of this investigation show the relation between them is linear surface equation.

The annual predications of the MUF and FOT parameters for the Iraqi zone that illustrated (samples) in figures (4) & (5) show a good fitting between the predicted values that are calculated using suggested mathematical model and theoretical values that calculated by executing ICEPAC, REC533 and VOACAP models. The evaluated MSE between the predicted and theoretical values that is illustrated in table (4) gave good results that show a good correlation and fitting between the two sets.

According to the above discussion, the following conclusions can be summarized:-

1. According to the statistical analysis results, the suggested empirical equation that describes the correlation relationship between the ionospheric parameters and geographical location coordinates of receiver stations has been proposed as linear surface equation.
2. The annual predicted values of ionospheric parameters using the suggested empirical model show a good fitting with theoretical values that calculated using the international models.
3. The MSE values between the predicted and theoretical values gave very acceptable results which show a good approaching and fitting between the two sets.

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