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The Suggested Reciprocal Relationship between Maximum, Minimum and Optimum Usable Frequency Parameters Over Iraqi Zone

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Abstract:
In this work, the relationship between the ionospheric parameters (Maximum Usable Frequency (MUF), Lowest Usable Frequency (LUF) and Optimum working Frequency (OWF)) has been studied for the ionosphere layer over the Iraqi zone. The capital Baghdad (44.42°E, 33.32°N) has been selected to represent the transmitter station and many other cities that spread over Iraqi region have represented as receiver stations. The REC533 communication model considered as one of the modern radio broadcasting version of ITU has been used to calculate the LUF parameter, while the MUF and OWF ionospheric parameters have been generated using ASAPS international communication model which represents one of the most advanced and accurate HF sky wave propagation models. The study has been conducted for the annual and seasonal time periods of the years (2009 and 2014) of the solar cycle 24. The results of the seasonal and annual tests have indicated that the interrelationship between the MUF and OWF with LUF was a fourth order polynomial equation, while the reciprocal relationship between the MUF and OWF was a simple relationship that could be represented by a linear regression equation. The reciprocal relationships between MUF, LUF and OWF parameters (present values) have shown a good fitting with the data generated using the international models (predicted values) and theoretical values calculated from the criterion equation.

Key words: Ionospheric Parameters, Lowest Usable Frequency (LUF), Maximum Usable Frequency (MUF), Optimum Working Frequency (OWF), Radio Wave Propagation.

Introduction:
The ionosphere is one of the Earth's atmosphere regions, which is expanded from about 60 to 1000 km. This region is formed by the interaction of solar radiation with uncharged particles from the upper part of the Earth's atmosphere by ions and electrons (1). The ionospheric layer depends on the electronic density, so this layer is sub-divided into four layers: Layer D (60 to 90 km), E and ES layers (90 to 140 km), F1 and F2 layers (140 to 420 km) and Topside layer (420 to 1000 km) (2).

The Maximum Usable Frequency (MUF), Optimum Workable Frequency (OWF) and Lowest Usable Frequency (LUF) are the ionospheric parameters; these parameters describe the acceptable operation frequencies of a radio service between given terminals. These parameters are affected by the primary factors influence (electron density of ionization), so these parameters will increase with higher ionization density and decrease with lower ionization density (3). The highest frequency that will reflect back to Earth by the ionized layers, the median value of (MUF) parameter is only 50% of the time (4). The (OWF) is defined as the best or "optimum" frequency to use at a given hour on a given circuit; it is possible to get value of the estimation of (OWF) by taking 85% of the (MUF) parameter. The (LUF) is defined as the lowest frequency that can be used in any radio communication between any two specified points at a particular angle of incidence. The median value of (LUF) parameter is 10% of the (MUF) parameter (5). The predicted values of (MUF, OWF and LUF) are constantly changing due to changes in ionospheric factors during the day, year and 11-year sunspot cycle. In addition, the values of the ionospheric parameter gradually change in the D, E, and F layers depending on the maximum electron density for each layer and the incidence angle of the emitted radio wave, as shown in Fig. 1 (6). In this research, the correlation relationship between (MUF), (OWF) and (LUF) parameters has been studied for solar cycle 24 over Iraqi region.

The aim of this research is to study the behavior and correlation between the ionospheric parameters, Maximum Usable Frequency (MUF), Lowest Usable Frequency (LUF) and Optimum Working Frequency (OWF) for the communication links between transmitting and receiving stations over Iraqi Region.

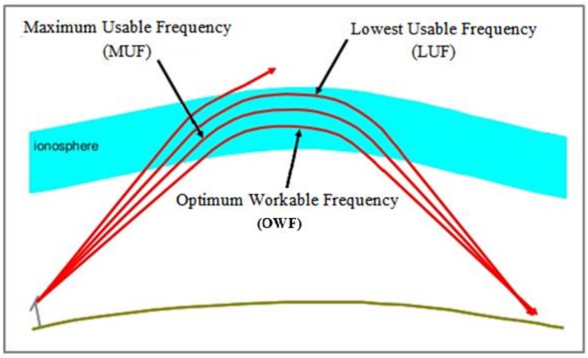

Figure 1. Ionospheric Propagation Parameters (7)

Radio Waves Propagation Methods:

The radio wave is lower in frequency part of the electromagnetic spectrum; this part of spectrum is Sub-divided into a series of bands. Propagation of long-range radio waves [High frequency band (3-30 MHz)] is considered one of the vital strategic wireless communication systems, since the Earth's surface is approximately spherical and the electromagnetic waves travel in straight lines in a uniform atmosphere, radio communication at a distance becomes possible through the reflection of radio waves form the ionosphere (i.e. the upper atmosphere layer) (8). The ionosphere affects radio signals differently depending on their frequency. Radio signals with frequencies more than 30 MHz, usually penetrate the ionosphere and are therefore useful for ground-space communications. While radio waves with frequencies below 30 MHz are called high frequencies (HF), the ionosphere can act as an effective reflector and allow radio communication at a distance of several thousand kilometers (9). There are several ways that HF radio waves may travel, ground waves are radio waves that travel near the surface of the Earth. It's also called surface wave, sometimes called line-of-sight wave (LOS), VHF signals (and signals at higher frequencies) propagate in straight lines directly from one antenna to another, and sky waves frequently known as the ionospheric waves, are radiated in a skyward direction and refunded to Earth at some distant place due to refraction from the layer of ionosphere. This method of propagation is comparatively unaffected by the Earth's surface and might propagate signals over long distances (10).

HF International Communication Models:

In this project, the Advanced Stand Alone Prediction System (ASAPS) and Recommendation 533 (REC533) models have been selected as international models for the analysis of HF-links performance in the frequency range (3-30 MHz). The ASAPS international model that is considered as one of the most advanced and accurate HF sky wave propagation model has been adopted to determine the values of the MUF and OWF parameters, and the REC533 propagation prediction model could assess the reliability and compatibility between frequencies (3 - 30 MHz). The propagation program was provided by Working Party 6A (WP6A) to the ITU in July 1993. This represents one of the modern radios broadcasting versions of ITU and recommended the entire world has been selected to obtain the LUF parameter between transmitter and receiver locations over studied area.

Test and Result:

The years of 2009 and 2014 have been adopted to be a time period of study, because the selected years represent a beginning and peak of the solar cycle 24. The monthly sunspot numbers for the selected years are shown in Table 1 (11):

Table 1. Monthly Sunspot Number of Solar Cycle 24 (12)

Months	Sunspot number					
Name	2009	2010	2011	2012	2013	2014
January	1.3	13.2	18.8	58.3	62.9	81.8
February	1.4	18.8	29.6	32.9	38.1	102.3
March	0.7	15.3	55.8	64.3	57.9	91.9
April	0.8	8.0	54.4	55.2	72.4	84.7
May	2.9	8.7	41.5	69.0	78.7	75.2
June	2.9	13.6	37.0	64.5	52.5	71.0
July	3.2	16.1	43.8	66.5	57.0	72.5
August	0.0	19.6	50.6	63.0	66.0	74.7
September	4.3	25.2	78.0	61.4	37.0	87.6
October	4.8	23.5	88.0	53.3	85.6	60.6
November	4.1	21.5	96.7	61.8	77.6	70.1
December	10.8	14.4	73.0	40.8	90.3	78.0
Annual	3.1	16.5	55.7	57.6	64.7	79.3

In this study, Baghdad city (44.42^{o}E, 33.32^{o}N) has been selected to represent as a transmitting station with other forty five different selected receiving stations laid within the studied region. The selected connection locations that are used in the local communication study are illustrated in Fig.2.

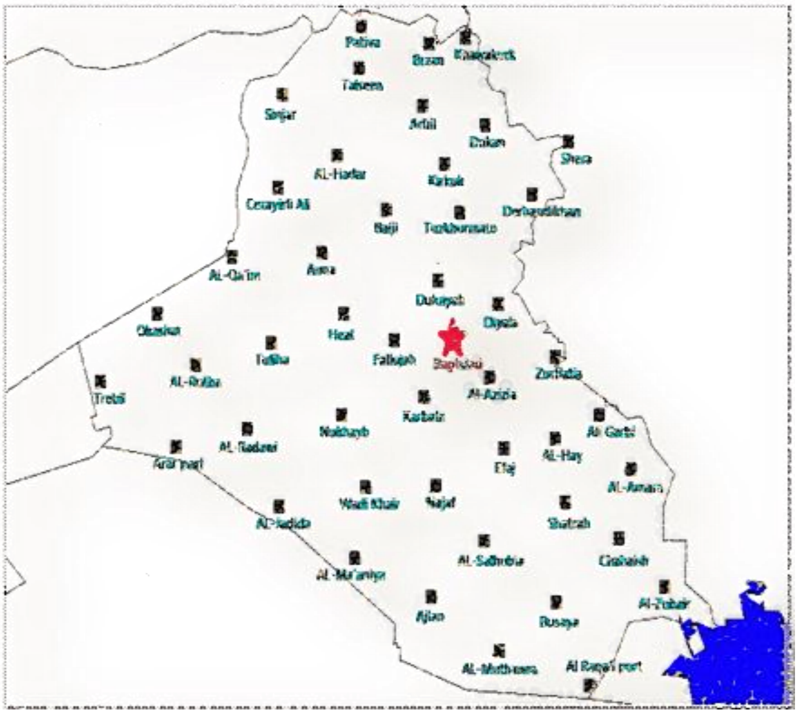

Figure 2. The selected receiving stations around the capital Baghdad (transmitting station).

The spherical geodesic parameters *Path Length* and *Bearing* (transmitter to receiver (T_x to R_x) and vice versa (R_x to T_x)) have been calculated for all the selected receiver stations distributed over the studied zone. The values of the calculated geodesic parameter and the geographical location coordinates (longitude and latitude) have been illustrated in Table 2:-

Table 2. Calculated geographical and geodesic parameter values of the connection links over Iraqi zone

Receiver station	Location		Distance (Km.)	Path Length (Rad.)	Bearing (Deg.)					
					T_x to R_x			R_x to T_x		
	Longitude (E)	Latitude (N)			Method (1)	Method (2)	Average	Method (1)	Method (2)	average
Sinjar	41.51	36.19	410.300	0.064	140.310	140.300	140.300	320.310	320.300	320.300
Bativa	43.00	37.10	435.300	0.068	163.270	163.260	163.260	343.270	343.260	343.260
Khawakurk	44.41	37.30	439.200	0.068	179.640	179.640	179.640	359.640	359.640	359.640
Dokan	44.57	35.56	439.200	0.068	175.940	175.940	175.940	355.940	355.940	355.940
Arbil	44.00	36.11	308.800	0.048	173.540	173.540	173.540	353.540	353.540	353.540
AL-Hadar	42.44	35.34	284.000	0.044	141.170	141.160	141.160	321.170	321.160	321.160
Baiji	43.29	34.55	167.000	0.026	143.000	143.000	143.000	323.000	323.000	323.000
Derbandikhan	45.41	35.60	267.400	0.042	159.320	159.320	159.320	339.320	339.320	339.320
Tuzkhurmato	44.37	34.52	130.100	0.020	179.590	180.400	179.990	359.590	360.400	359.990
Duluiyah	44.15	34.08	118.600	0.018	169.690	169.690	169.690	349.690	349.690	349.690
Diyala	45.80	33.46	132.300	0.020	95.300	95.300	95.300	275.300	275.300	275.300
Heat	42.49	33.37	175.500	0.027	90.720	90.720	90.720	270.720	270.720	270.720
Anna	41.59	34.22	275.300	0.043	110.560	110.560	110.560	290.560	290.560	290.560
AL-Qa'im	41.50	34.22	283.100	0.044	109.970	109.970	109.970	289.970	289.970	289.970
Okashat	39.58	33.40	445.700	0.070	90.710	90.710	90.710	270.710	270.710	270.710
Trebil	39.60	32.51	455.700	0.071	101.820	101.820	101.820	281.820	281.820	281.820
Tuliha	41.42	33.21	275.500	0.043	93.230	93.230	93.230	273.230	273.230	273.230
AL-Radawi	41.70	31.65	314.400	0.049	126.950	126.940	126.940	306.950	306.940	306.940
Nukhayb	42.45	32.25	217.900	0.034	124.140	126.130	126.130	304.140	304.130	304.130
AL-Ma'aniya	42.58	30.43	366.400	0.057	152.370	152.370	152.370	332.370	332.370	332.370
Ajlan	44.27	30.40	328.100	0.051	178.180	178.180	178.180	358.180	358.180	358.180
Busaya	46.20	30.11	399.200	0.062	154.460	154.460	154.460	334.460	334.460	334.460
Karbala	44.10	32.37	112.000	0.017	166.500	166.500	166.500	346.500	346.500	346.500
Najaf	44.10	31.34	225.000	0.035	173.280	173.280	173.280	353.280	353.280	353.280
Al-Azizia	45.30	32.54	120.400	0.018	134.550	134.550	134.550	314.550	314.550	314.550
Zurbatia	46.40	33.90	196.700	0.030	108.100	108.100	108.100	288.100	288.100	288.100
AL-Hay	46.20	32.10	219.700	0.034	129.220	129.220	129.220	309.220	309.220	309.220

AL-Amara	47.90	31.49	389.700	0.061	122.040	122.040	122.040	302.040	302.040	302.040
As Samawah	45.16	31.19	251.100	0.039	163.020	163.020	163.020	343.020	343.020	343.020
Chabaish	46.58	30.57	372.300	0.058	146.120	146.120	146.120	326.120	326.120	326.120
Al-Zubair	47.42	30.22	451.200	0.070	140.460	140.450	140.450	320.460	320.450	320.450
Shera	46.14	35.46	284.800	0.044	145.460	145.460	145.460	325.460	325.460	325.460
Ali Garbi	46.41	32.27	224.500	0.035	122.330	122.330	122.330	302.330	302.330	302.330
Barzan	44.20	36.55	356.200	0.055	177.360	177.360	177.360	357.360	357.360	357.360
Talseen	43.20	36.36	351.500	0.055	162.170	162.160	162.160	342.170	342.160	342.160
Kirkuk	44.19	35.27	214.200	0.033	175.320	175.320	175.320	355.320	355.320	355.320
Shatrah	46.10	31.24	284.900	0.044	145.430	145.430	145.430	325.430	325.430	325.430
AL-Jadida	41.48	31.21	361.800	0.056	131.110	131.110	131.110	311.120	311.110	311.110
AL-Rutba	40.17	33.20	395.360	0.062	86.900	86.760	86.830	269.230	273.230	271.230
Arar port	40.12	32.40	411.500	0.064	104.870	104.870	104.870	284.870	284.870	284.870
AL-Muthanna	45.10	29.35	449.900	0.070	171.260	171.260	171.260	351.260	351.260	351.260
AL-Salhubia	44.57	30.55	311.800	0.049	176.700	176.700	176.700	356.700	356.700	356.700
WadiKhair	43.70	31.37	229.200	0.036	163.820	163.820	163.820	343.820	343.820	343.820
Cezayirli Ali	42.10	35.10	286.000	0.044	132.870	132.870	132.870	312.870	312.870	312.870
Fallujah	43.35	33.22	96.800	0.015	81.410	81.410	81.410	261.410	261.410	261.410
Efaj	45.14	32.30	136.600	0.021	148.690	148.690	148.690	328.690	328.690	328.690

In this research the international communication model "ASAPS" has been used to calculate the dataset of the MUF and OWF parameters, while the dataset of the LUF parameter has been determined using the "REC533" international communication model. The behavior of MUF, LUF and OWF parameters have been studied statistically by analyzing the generated dataset from the ASAPS and REC533 models for annual and seasonal time periods for the selected years .

The seasonal ionospheric parameter variation has been investigated for four seasons. Table 3, illustrates sample of the seasonal and annual statistical analysis results of MUF, OWF and LUF parameters resulted from the execution of the picked international models for the link (Baghdad - Zurbatia).

Table 3. Samples of statistical analysis of MUF, OWF and LUF parameters for the adopted years to the link (Baghdad- zurbatia).

UT	MUF					OWF					LUF				
Hour	Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn	Annual
0	4.67	6.00	5.90	4.77	5.33	3.53	4.80	4.87	3.63	4.21	2.00	2.00	2.00	2.00	2.00
1	4.33	5.60	5.67	4.50	5.03	3.27	4.47	4.73	3.47	3.98	2.00	2.00	2.00	2.00	2.00
2	3.97	5.67	5.73	4.40	4.94	3.03	4.47	4.77	3.37	3.91	2.00	2.00	2.00	2.00	2.00
3	4.03	6.57	6.70	5.53	5.71	3.27	5.23	5.27	4.40	4.54	2.00	2.00	2.00	2.00	2.00
4	6.10	8.20	7.57	7.97	7.46	5.23	6.53	5.67	6.67	6.03	2.00	2.07	2.57	2.00	2.16
5	8.73	9.07	7.80	9.17	8.69	7.50	7.30	5.87	7.63	7.08	2.40	3.73	4.17	2.43	3.18
6	9.70	9.77	8.10	9.87	9.36	8.33	7.83	6.03	8.20	7.60	3.70	4.80	4.93	3.33	4.19
7	10.30	10.23	8.47	10.23	9.81	8.83	8.33	6.53	8.47	8.04	4.37	5.33	5.37	4.37	4.86
8	10.63	10.87	8.97	10.53	10.25	9.10	8.97	7.07	8.77	8.48	4.73	5.73	5.73	4.83	5.26
9	10.63	11.47	9.33	10.77	10.55	9.10	9.40	7.37	8.97	8.71	4.90	5.90	5.87	5.07	5.43
10	10.50	11.67	9.50	10.83	10.63	9.00	9.60	7.53	9.03	8.79	4.77	5.67	5.67	4.97	5.27
11	10.47	11.53	9.43	10.70	10.53	8.90	9.27	7.40	8.80	8.59	4.27	5.27	5.37	4.60	4.88
12	10.20	11.27	9.37	10.57	10.35	8.70	8.87	7.23	8.60	8.35	3.40	4.57	4.87	3.80	4.16
13	9.80	11.00	9.23	10.43	10.12	8.37	8.70	7.13	8.50	8.18	2.10	3.57	4.07	2.60	3.08
14	8.97	10.70	9.10	9.90	9.67	7.67	8.43	7.00	8.00	7.78	2.00	2.10	2.47	2.00	2.14
15	7.83	10.33	8.97	8.97	9.03	6.53	7.87	6.80	7.00	7.05	2.00	2.00	2.00	2.00	2.00
16	7.00	9.53	8.73	7.73	8.25	5.60	7.10	6.50	5.83	6.26	2.00	2.00	2.00	2.00	2.00
17	6.23	8.30	8.23	6.73	7.38	5.00	6.23	6.13	5.07	5.61	2.00	2.00	2.00	2.00	2.00
18	5.53	7.50	7.60	6.17	6.70	4.40	5.60	5.67	4.67	5.08	2.00	2.00	2.00	2.00	2.00
19	5.33	7.20	7.07	5.87	6.37	4.20	5.43	5.33	4.47	4.86	2.00	2.00	2.00	2.00	2.00
20	5.10	6.93	6.73	5.53	6.08	4.03	5.37	5.20	4.30	4.73	2.00	2.00	2.00	2.00	2.00
21	5.00	6.77	6.57	5.33	5.92	3.97	5.20	5.03	4.17	4.59	2.00	2.00	2.00	2.00	2.00
22	4.97	6.60	6.40	5.20	5.79	3.93	5.10	4.93	4.00	4.49	2.00	2.00	2.00	2.00	2.00
23	4.83	6.37	6.23	4.97	5.60	3.73	4.97	4.97	3.83	4.38	2.00	2.00	2.00	2.00	2.00

The seasonal and annual variations of the ionospheric parameters have been performed for the selected receiver stations over Iraqi zone. Fig. 3 shows samples of the seasonal variations of the MUF, FOT, and LUF parameter for the studied years (2009 and 2014). Also samples of the ionospheric parameter variations for some selected links for annual times of the studied years have been presented in Fig. 4.

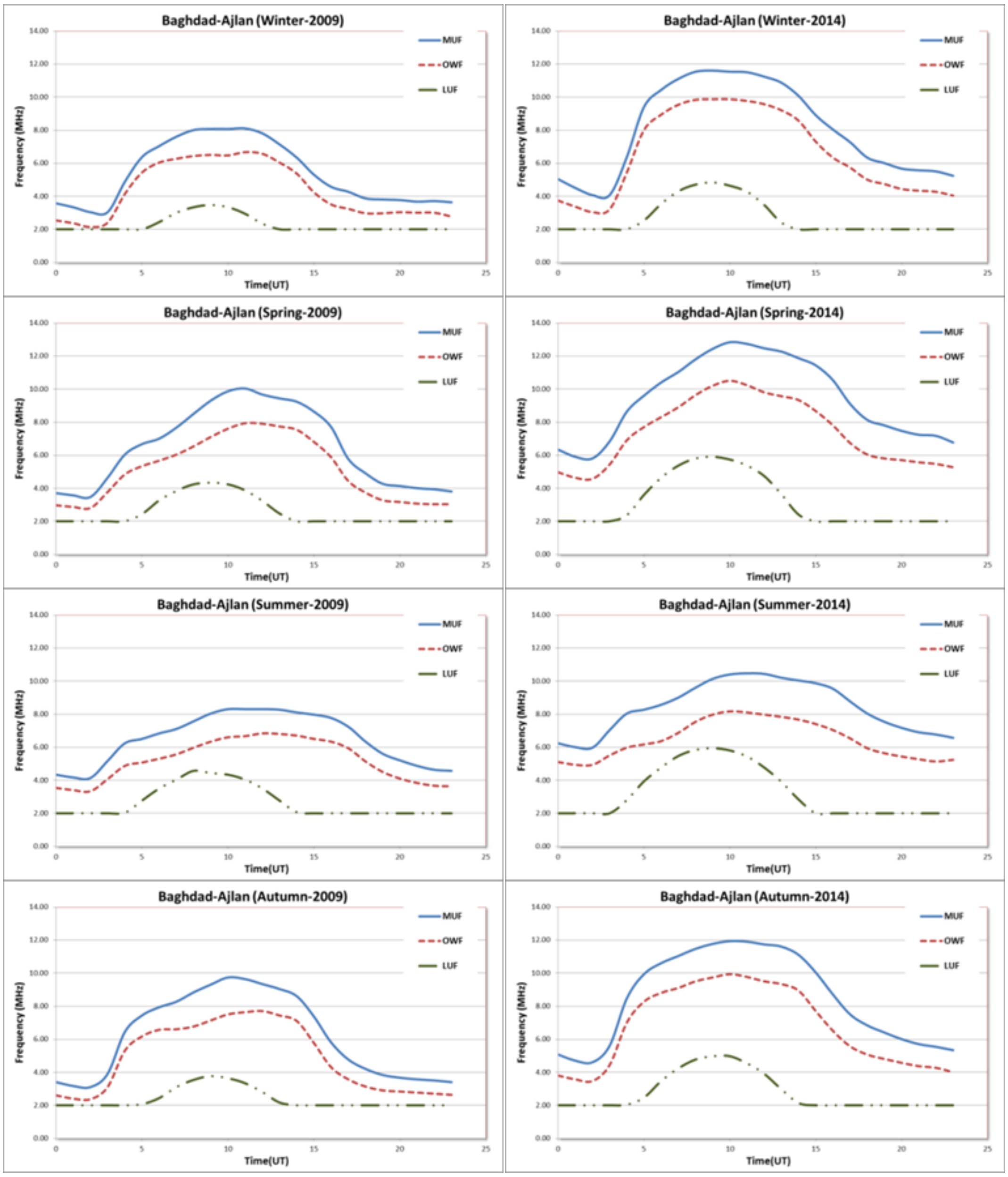

Figure 3. Seasonal variations of the MUF, LUF, and FOT Parameters for the years 2009 and 2014.

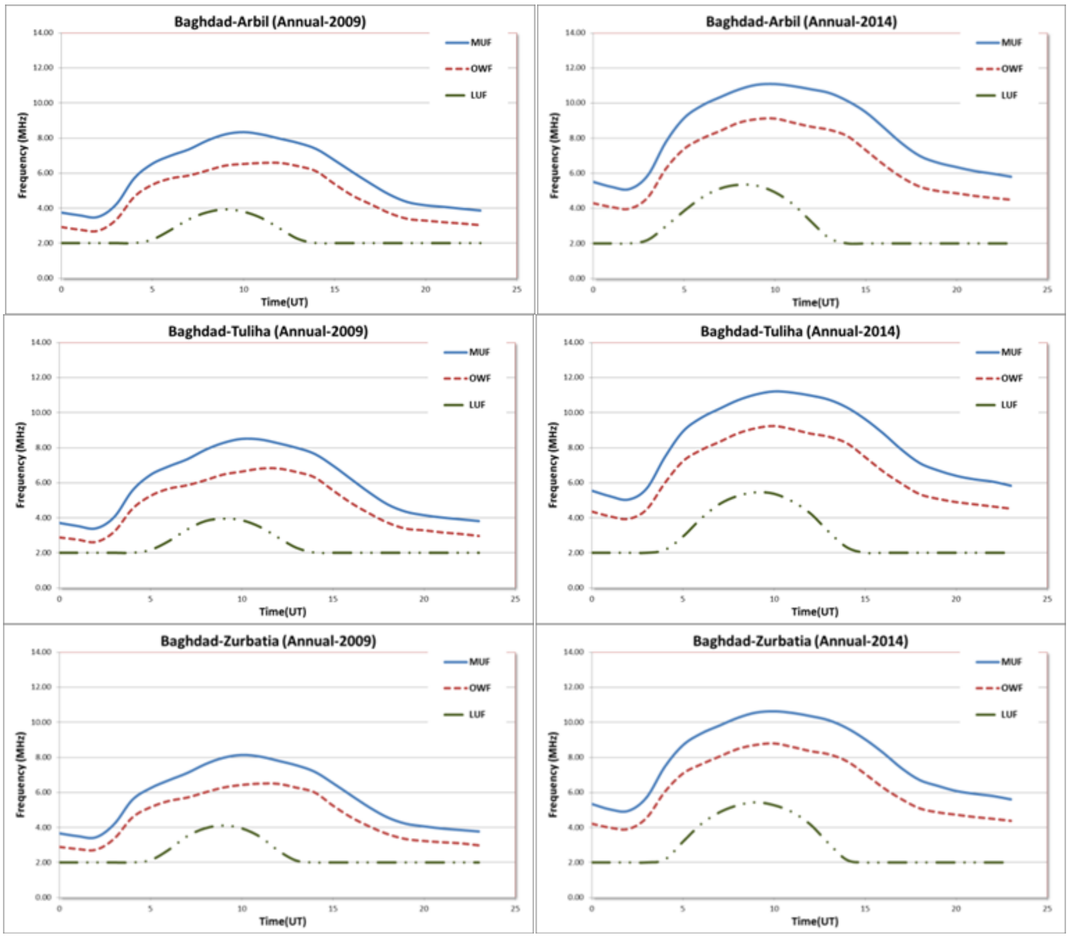

Figure 4. Annual variations of the MUF, LUF, and FOT Parameters for the years 2009 and 2014.

The analytical study of the generated dataset for the ionospheric parameters (MUF, LUF and OWF) has been conducted to examine the probability of getting a reciprocated correlation between these parameters. In order to investigate the correlation between the selected parameters, the study has been made for the annual and seasonal time periods of the adopted study years. Fig 5 shows sample of the annual and seasonal correlation between ionospheric parameters for the link (Baghdad- Zurbatia).

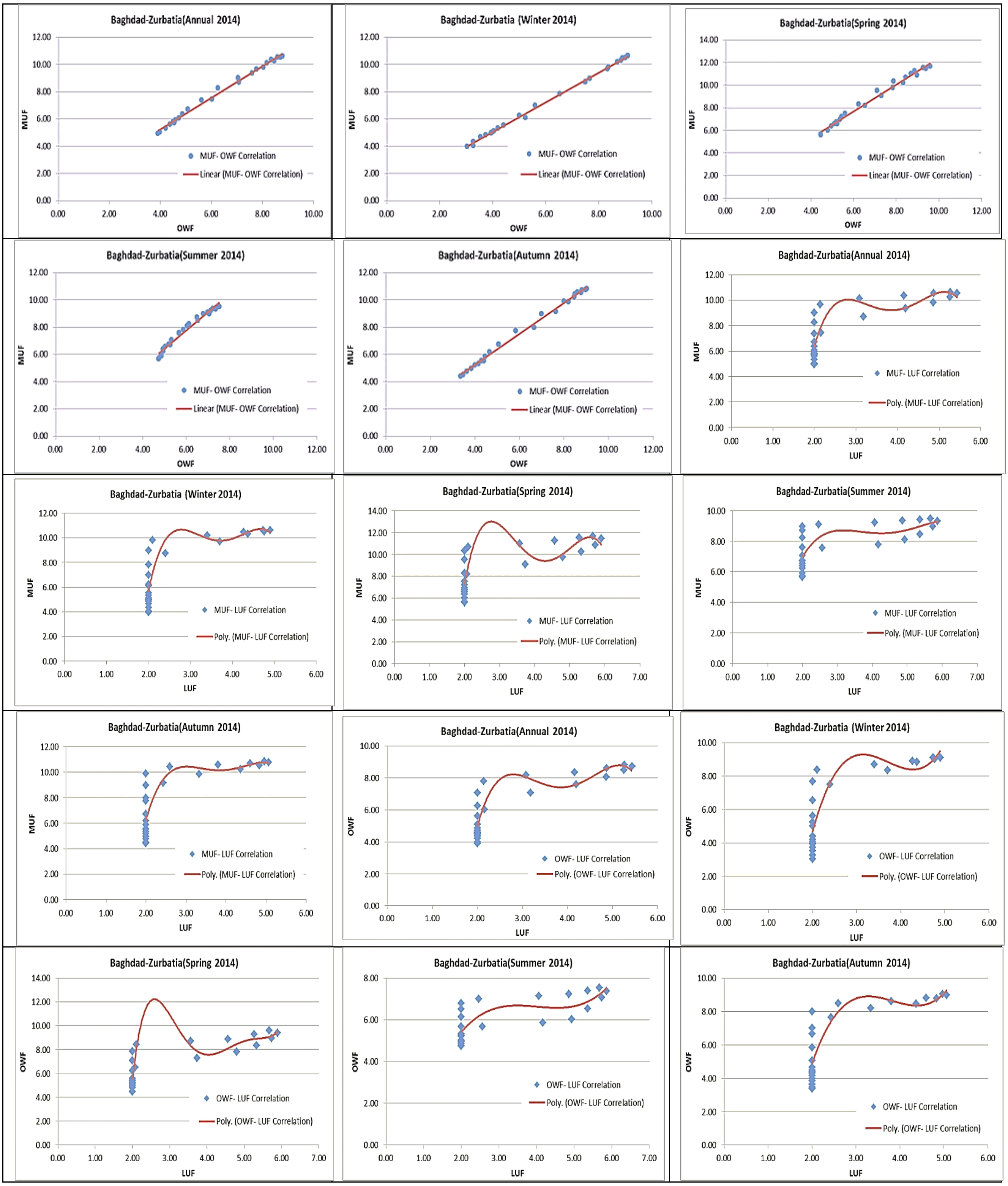

Figure 5. Sample of the regression correlation between Ionospheric parameters for the year 2014 of the link (Baghdad- Zurbatia)

The results of the analytical study showed that the correlation between ionospheric parameters can be expressed by a polynomial relationship, so the proposed reciprocal correlation equations between the tested parameters could be expressed as follows:

$$Y = \sum_{i=0}^{n} a_i X^i \qquad \text{......... 1}$$

$$\mathrm{Y} = \mathrm{a_o} + \mathrm{a_1 x^1} + \mathrm{a_2 x^2} + \cdots + \mathrm{a_5 x^5} \qquad \text{......... 2}$$

So, the suggested reciprocal correlation equations can be expressed by the following set of equations:

$$\text{MUF} = \sum_{i=0}^{n} \mathrm{a_i}\,(OWF)^i \qquad \ldots\ldots\ldots 3$$

$$\text{MUF} = \sum_{i=0}^{n} \mathrm{a_i}\,(LUF)^i \qquad \ldots\ldots\ldots 4$$

$$\text{OWF} = \sum_{i=0}^{n} \mathrm{a_i}\,(MUF)^i \qquad \ldots\ldots\ldots 5$$

$$\text{OWF} = \sum_{i=0}^{n} \mathrm{a_i}\,(LUF)^i \qquad \ldots\ldots\ldots 6$$

$$\text{LUF} = \sum_{i=0}^{n} \mathrm{a_i}\,(MUF)^i \qquad \ldots\ldots\ldots 7$$

$$\text{LUF} = \sum_{i=0}^{n} \mathrm{a_i}\,(OWF)^i \qquad \ldots\ldots\ldots 8$$

The reciprocal correlation between MUF, OWF and LUF parameters have been determined for the annual and seasonal times of the years 2009 and 2014. Based on the results of the statistical analytical study, the equation of reciprocal correlation turned out to be a polynomial equation of the *Fourth Order*. Table 4 shows sample of correlation coefficients (a_o, a_1, a_2, a_3 and a_4) and the correlation parameter (R^2) of the yearly and seasonal periods of the presumed years.

Table 4. Sample of the correlation coefficients and correlation parameter for the sample links (Baghdad- Ajlan) of the seasonal and annual times of the years 2009, 2014

Baghdad- Ajlan (2009)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.218	1.210	0.000	0.000	0.000	0.995
MUF (LUF)	- 308.520	417.010	- 203.520	43.587	-3.454	0.676
OWF (MUF)	- 0.156	0.821	0.000	0.000	0.000	0.995
OWF (LUF)	- 261.710	351.670	- 170.750	36.398	-2.874	0.666
LUF (MUF)	0.672	1.256	-0.396	0.047	-0.001	0.660
LUF (OWF)	- 15.070	16.828	- 5.962	0.892	-0.047	0.602
Winter	**a_o**	**a_1**	**a_2**	**a_3**	**a_4**	**R^2**
MUF (OWF)	0.463	1.132	0.000	0.000	0.000	0.991
MUF (LUF)	- 436.250	618.760	- 322.000	74.103	-6.358	0.702
OWF (MUF)	- 0.366	0.875	0.000	0.000	0.000	0.991
OWF (LUF)	- 355.950	495.720	-252.75	56.942	-4.783	0.659
LUF (MUF)	5.290	- 3.159	1.112	- 0.170	0.009	0.871
LUF (OWF)	- 0.257	2.078	- 0.608	0.056	7E-06	0.738
Spring	**a_o**	**a_1**	**a_2**	**a_3**	**a_4**	**R^2**
MUF (OWF)	0.095	1.248	0.000	0.000	0.000	0.994
MUF (LUF)	- 146.940	187.080	- 83.357	16.262	-1.169	0.536
OWF (MUF)	- 0.046	0.796	0.000	0.000	0.000	0.994
OWF (LUF)	- 117.250	147.680	- 65.051	12.566	-0.897	0.526
LUF (MUF)	23.993	- 14.905	3.587	- 0.364	0.013	0.509
Summer	**a_o**	**a_1**	**a_2**	**a_3**	**a_4**	**R^2**
MUF (OWF)	0.196	1.209	0.000	0.000	0.000	0.992
MUF (LUF)	- 181.100	239.170	- 111.070	22.401	-1.657	0.446
OWF (MUF)	- 0.123	0.820	0.000	0.000	0.000	0.992
OWF (LUF)	- 148.240	195.710	- 90.895	18.332	-1.356	0.393
LUF (MUF)	64.877	- 41.162	9.819	- 1.015	0.038	0.391
LUF (OWF)	35.505	- 23.730	5.745	- 0.540	0.015	0.365
Autumn	**a_o**	**a_1**	**a_2**	**a_3**	**a_4**	**R^2**
MUF (OWF)	0.267	1.212	0.000	0.000	0.000	0.992
MUF (LUF)	- 778.960	1089.700	- 557.870	125.310	-10.424	0.684
OWF (MUF)	- 0.183	0.818	0.000	0.000	0.000	0.992
OWF (LUF)	- 664.950	925.630	- 471.580	105.410	-8.730	0.666
LUF (MUF)	0.790	0.863	- 0.201	0.016	-0.0001	0.709
LUF (OWF)	- 7.026	9.005	- 3.167	0.460	-0.023	0.568

Baghdad- Ajlan (2014)						
Annual	a_o	a_1	a_2	a_3	a_4	R^2
MUF (OWF)	0.658	1.165	0.000	0.000	0.000	0.992
MUF (LUF)	- 78.773	95.249	- 37.395	6.384	-0.398	0.728
OWF (MUF)	- 0.513	0.852	0.000	0.000	0.000	0.992
OWF (LUF)	- 73.161	87.467	- 34.430	5.883	-0.367	0.793
LUF (MUF)	5.856	- 2.024	0.414	- 0.040	0.001	0.749
LUF (OWF)	3.662	- 1.027	0.265	- 0.037	0.002	0.818
Winter	$\mathbf{a_o}$	$\mathbf{a_1}$	$\mathbf{a_2}$	$\mathbf{a_3}$	$\mathbf{a_4}$	$\mathbf{R^2}$
MUF (OWF)	0.831	1.087	0.000	0.000	0.000	0.997
MUF (LUF)	- 139.870	169.480	- 70.320	12.749	-0.851	0.749
OWF (MUF)	- 0.746	0.917	0.000	0.000	0.000	0.997
OWF (LUF)	- 131.670	158.520	- 65.794	11.936	-0.797	0.762
LUF (MUF)	12.685	- 6.890	1.614	- 0.163	0.006	0.906
LUF (OWF)	10.233	- 6.605	1.907	- 0.235	0.010	0.923
Spring	$\mathbf{a_o}$	$\mathbf{a_1}$	$\mathbf{a_2}$	$\mathbf{a_3}$	$\mathbf{a_4}$	$\mathbf{R^2}$
MUF (OWF)	0.591	1.195	0.000	0.000	0.000	0.986
MUF (LUF)	- 65.973	79.437	- 29.780	4.806	-0.281	0.653
OWF (MUF)	- 0.391	0.825	0.000	0.000	0.000	0.986
OWF (LUF)	- 59.774	70.803	- 26.526	4.268	-0.248	0.745
LUF (MUF)	77.814	- 35.129	5.934	- 0.435	0.011	0.644
Summer	$\mathbf{a_o}$	$\mathbf{a_1}$	$\mathbf{a_2}$	$\mathbf{a_3}$	$\mathbf{a_4}$	$\mathbf{R^2}$
MUF (OWF)	- 0.213	1.335	0.000	0.000	0.000	0.975
MUF (LUF)	15.112	22.689	- 7.781	1.159	-0.062	0.518
OWF (MUF)	0.315	0.730	0.000	0.000	0.000	0.975
OWF (LUF)	- 8.343	13.691	- 4.448	0.616	-0.029	0.577
LUF (MUF)	540.89	- 272.800	51.030	- 4.185	0.127	0.528
LUF (OWF)	849.800	- 547.180	130.900	- 13.762	0.537	0.621
Autumn	$\mathbf{a_o}$	$\mathbf{a_1}$	$\mathbf{a_2}$	$\mathbf{a_3}$	$\mathbf{a_4}$	$\mathbf{R^2}$
MUF (OWF)	0.802	1.137	0.000	0.000	0.000	0.993
MUF (LUF)	- 198.490	242.170	- 102.270	18.732	-1.257	0.755
OWF (MUF)	- 0.655	0.873	0.000	0.000	0.000	0.993
OWF (LUF)	- 183.790	223.260	- 94.387	17.297	-1.160	0.802
LUF (MUF)	4.239	- 1.690	0.463	- 0.054	0.002	0.807
LUF (OWF)	4.457	- 2.268	0.759	- 0.109	0.005	0.886

According to the results obtained from the statistical analysis and depending on the values of the reciprocal correlations between (LUF and MUF), (LUF and OWF) parameters, it can be noticed that there is a weak correlation between these sets of parameters. Therefore, the reciprocal correlations between these sets are not going to be considered in this work. The data of the OWF and MUF parameters have been calculated for the years 2009 and 2014 using the suggested reciprocal correlation equations (eq. 3 - 6) based on the correlation coefficients (a_o, a_1, a_2, a_3 and a_4) that have been shown in Table (4). The generated datasets (Present) have been compared with other calculated values generated using the international models ASAPS and REC533 (predicted) and the theoretical criterion equation (OWF = 0.85 x MUF) *W. Suparta, et al.* (12) (theoretical). Tables 5, 6, 7, 8, and 9 show samples of comparative between the Present, predicted and theoretical annual and seasonal (winter, spring, summer and autumn) OWF results of the years 2009 and 2014 respectively related to the (OWF and MUF) reciprocal correlation for the link (Baghdad–Ajlan) beside the values of the Mean Square Error (MSE) of the present values comparing to the theoretical and predicted values.

Table 5. Comparison between Present, Predicted and theoretical value of the OWF parameter for the link (Baghdad – Ajlan) of the annual time of the years 2009 and 2014

	Baghdad- Ajlan (Annual- 2009)						Baghdad- Ajlan (Annual- 2014)					
UT	MUF	OWF					MUF	OWF				
		Predicted	Theoretical	Present	MSE			Predicted	Theoretical	Present	MSE	
					Theo.	Present					Theo.	Present
0	3.75	2.91	3.18	2.93	0.078	0.000	5.67	4.40	4.82	4.32	0.174	0.007
1	3.56	2.76	3.02	2.77	0.071	0.001	5.28	4.13	4.48	3.98	0.129	0.020
2	3.43	2.66	2.92	2.67	0.068	0.000	5.11	4.00	4.34	3.84	0.117	0.026
3	4.18	3.33	3.56	3.28	0.050	0.001	5.88	4.64	5.00	4.50	0.129	0.020
4	5.89	4.78	5.01	4.69	0.050	0.011	7.88	6.33	6.69	6.20	0.136	0.016
5	6.74	5.50	5.73	5.38	0.053	0.012	9.30	7.53	7.91	7.41	0.138	0.015
6	7.20	5.89	6.12	5.76	0.052	0.008	10.00	8.10	8.50	8.01	0.160	0.008
7	7.66	6.12	6.51	6.14	0.154	0.001	10.54	8.60	8.96	8.47	0.130	0.017
8	8.23	6.43	6.99	6.60	0.321	0.027	11.10	9.13	9.44	8.95	0.096	0.032
9	8.68	6.77	7.37	6.97	0.369	0.031	11.48	9.44	9.76	9.27	0.102	0.029
10	8.99	7.04	7.64	7.23	0.362	0.035	11.68	9.62	9.92	9.44	0.094	0.033
11	9.02	7.23	7.66	7.25	0.193	0.000	11.65	9.47	9.90	9.41	0.190	0.003
12	8.78	7.25	7.46	7.06	0.044	0.032	11.47	9.21	9.75	9.26	0.290	0.002
13	8.47	7.00	7.20	6.80	0.039	0.038	11.23	8.98	9.55	9.06	0.319	0.006
14	8.07	6.68	6.86	6.47	0.033	0.034	10.77	8.63	9.15	8.66	0.277	0.001
15	7.32	5.83	6.22	5.86	0.155	0.000	10.06	7.77	8.55	8.06	0.613	0.085
16	6.46	5.00	5.49	5.15	0.240	0.014	9.20	6.92	7.82	7.33	0.816	0.168
17	5.51	4.29	4.68	4.37	0.152	0.004	8.16	6.14	6.93	6.44	0.629	0.088
18	4.83	3.74	4.10	3.81	0.129	0.003	7.33	5.51	6.23	5.74	0.526	0.052
19	4.38	3.41	3.72	3.44	0.096	0.001	6.93	5.24	5.89	5.39	0.425	0.023
20	4.19	3.28	3.56	3.29	0.078	0.000	6.58	5.03	5.59	5.09	0.308	0.003
21	4.03	3.17	3.42	3.15	0.065	0.000	6.35	4.88	5.40	4.90	0.264	0.000
22	3.94	3.10	3.35	3.08	0.063	0.000	6.24	4.78	5.31	4.81	0.273	0.000
23	3.85	3.02	3.27	3.01	0.065	0.000	5.98	4.63	5.08	4.58	0.198	0.003
				Average MSE	**0.124**	**0.013**				**Average MSE**	**0.272**	**0.027**

Table 6. Comparison between Present, Predicted and theoretical value of the OWF parameter for the link (Baghdad – Ajlan) of the seasonal time (Winter) of the years 2009 and 2014

	Baghdad- Ajlan (Winter- 2009)						Baghdad- Ajlan (Winter- 2014)					
UT	MUF	OWF					MUF	OWF				
		Predicted	Theoretical	Present	MSE			Predicted	Theoretical	Present	MSE	
					Theo.	Present					Theo.	Present
0	3.57	2.53	3.03	2.76	0.248	0.049	5.03	3.73	4.28	3.87	0.297	0.019
1	3.33	2.37	2.83	2.55	0.218	0.034	4.50	3.37	3.83	3.38	0.210	0.000
2	3.03	2.13	2.58	2.29	0.198	0.024	4.07	3.03	3.46	2.98	0.179	0.002
3	3.03	2.40	2.58	2.29	0.032	0.012	4.07	3.20	3.46	2.98	0.066	0.046
4	4.87	4.13	4.14	3.89	0.000	0.058	6.37	5.43	5.41	5.10	0.000	0.114
5	6.37	5.43	5.41	5.21	0.000	0.052	9.40	8.00	7.99	7.88	0.000	0.015
6	7.03	6.03	5.98	5.79	0.003	0.059	10.43	8.93	8.87	8.83	0.004	0.011
7	7.60	6.27	6.46	6.29	0.037	0.000	11.10	9.53	9.44	9.44	0.010	0.009
8	8.00	6.43	6.80	6.64	0.134	0.041	11.53	9.83	9.80	9.84	0.001	0.000
9	8.07	6.50	6.86	6.69	0.127	0.038	11.60	9.87	9.86	9.90	0.000	0.001
10	8.07	6.47	6.86	6.69	0.152	0.052	11.53	9.87	9.80	9.84	0.004	0.001
11	8.10	6.67	6.89	6.72	0.048	0.003	11.50	9.77	9.78	9.81	0.000	0.002
12	7.80	6.57	6.63	6.46	0.004	0.011	11.23	9.57	9.55	9.56	0.000	0.000
13	7.13	6.03	6.06	5.88	0.001	0.024	10.87	9.20	9.24	9.22	0.001	0.001
14	6.33	5.37	5.38	5.18	0.000	0.036	10.07	8.57	8.56	8.49	0.000	0.006
15	5.30	4.23	4.51	4.27	0.074	0.002	8.90	7.30	7.57	7.42	0.070	0.014
16	4.57	3.50	3.88	3.63	0.146	0.017	8.03	6.33	6.83	6.62	0.245	0.085
17	4.27	3.23	3.63	3.37	0.155	0.018	7.27	5.73	6.18	5.92	0.197	0.035
18	3.87	2.97	3.29	3.02	0.102	0.003	6.33	5.00	5.38	5.06	0.147	0.004
19	3.80	2.97	3.23	2.96	0.069	0.000	6.00	4.73	5.10	4.76	0.134	0.001
20	3.77	3.03	3.20	2.93	0.028	0.011	5.67	4.43	4.82	4.45	0.147	0.000
21	3.67	3.00	3.12	2.84	0.014	0.025	5.57	4.33	4.73	4.36	0.159	0.001
22	3.70	3.00	3.15	2.87	0.021	0.016	5.50	4.27	4.68	4.30	0.167	0.001
23	3.63	2.77	3.09	2.81	0.103	0.002	5.23	4.03	4.45	4.06	0.172	0.000
				Average MSE	**0.080**	**0.024**				**Average MSE**	**0.092**	**0.015**

Table 7. Comparison between Present, Predicted and theoretical value of the OWF parameter for the link (Baghdad – Ajlan) of the seasonal time (Spring) of the years 2009 and 2014

Baghdad- Ajlan (Spring- 2009)							Baghdad- Ajlan (Spring- 2014)					
UT	MUF	OWF					MUF	OWF				
		Predicted	Theoretical	Present	MSE			Predicted	Theoretical	Present	MSE	
					Theo.	Present					Theo.	Present
0	3.70	2.97	3.15	2.90	0.032	0.005	6.33	4.97	5.38	4.84	0.174	0.016
1	3.57	2.87	3.03	2.79	0.027	0.005	5.90	4.63	5.02	4.48	0.146	0.023
2	3.47	2.80	2.95	2.71	0.022	0.007	5.80	4.57	4.93	4.40	0.132	0.028
3	4.63	3.77	3.94	3.64	0.029	0.015	6.83	5.43	5.81	5.25	0.141	0.033
4	6.03	4.83	5.13	4.76	0.087	0.006	8.63	6.90	7.34	6.74	0.192	0.026
5	6.67	5.33	5.67	5.26	0.111	0.005	9.60	7.70	8.16	7.54	0.212	0.027
6	7.00	5.67	5.95	5.53	0.080	0.020	10.40	8.30	8.84	8.20	0.292	0.011
7	7.67	6.03	6.52	6.06	0.234	0.001	11.03	8.90	9.38	8.72	0.229	0.032
8	8.50	6.53	7.23	6.72	0.478	0.035	11.80	9.63	10.03	9.35	0.157	0.079
9	9.30	7.10	7.91	7.36	0.648	0.066	12.43	10.20	10.57	9.88	0.136	0.105
10	9.87	7.60	8.39	7.81	0.619	0.043	12.83	10.50	10.91	10.21	0.167	0.086
11	10.03	7.93	8.53	7.94	0.354	0.000	12.73	10.23	10.82	10.12	0.348	0.012
12	9.67	7.90	8.22	7.65	0.100	0.063	12.47	9.80	10.60	9.90	0.635	0.011
13	9.43	7.73	8.02	7.46	0.081	0.073	12.27	9.57	10.43	9.74	0.740	0.029
14	9.23	7.53	7.85	7.30	0.099	0.052	11.87	9.33	10.09	9.41	0.568	0.006
15	8.63	6.80	7.34	6.83	0.290	0.001	11.43	8.67	9.72	9.05	1.106	0.147
16	7.70	5.87	6.55	6.08	0.460	0.047	10.53	7.80	8.95	8.31	1.330	0.257
17	5.77	4.43	4.90	4.54	0.219	0.012	9.10	6.73	7.74	7.12	1.003	0.152
18	4.90	3.73	4.17	3.85	0.186	0.015	8.13	6.03	6.91	6.32	0.774	0.085
19	4.27	3.27	3.63	3.35	0.130	0.007	7.80	5.80	6.63	6.05	0.689	0.062
20	4.13	3.17	3.51	3.24	0.120	0.006	7.47	5.70	6.35	5.77	0.418	0.006
21	4.00	3.07	3.40	3.14	0.111	0.005	7.23	5.57	6.15	5.58	0.338	0.000
22	3.93	3.03	3.34	3.09	0.096	0.003	7.17	5.47	6.09	5.53	0.391	0.004
23	3.80	3.03	3.23	2.98	0.039	0.003	6.77	5.27	5.75	5.20	0.235	0.005
				Average MSE	**0.194**	**0.021**				**Average MSE**	**0.440**	**0.052**

Table 8. Comparison between Present, Predicted and theoretical value of the OWF parameter for the link (Baghdad – Ajlan) of the seasonal time (Summer) of the years 2009 and 2014

Baghdad- Ajlan (Summer- 2009)							Baghdad- Ajlan (Summer- 2014)					
UT	MUF	OWF					MUF	OWF				
		Predicted	Theoretical	Present	MSE			Predicted	Theoretical	Present	MSE	
					Theo.	Present					Theo.	Present
0	4.33	3.53	3.68	3.43	0.023	0.010	6.23	5.10	5.30	4.87	0.039	0.055
1	4.17	3.40	3.54	3.30	0.020	0.011	6.00	4.93	5.10	4.70	0.028	0.056
2	4.13	3.33	3.51	3.27	0.032	0.004	5.97	4.93	5.07	4.67	0.019	0.069
3	5.17	4.07	4.39	4.12	0.106	0.003	7.03	5.50	5.98	5.45	0.229	0.002
4	6.23	4.87	5.30	4.99	0.186	0.016	8.03	5.97	6.83	6.18	0.742	0.046
5	6.50	5.07	5.53	5.21	0.210	0.021	8.27	6.17	7.03	6.35	0.740	0.034
6	6.83	5.30	5.81	5.49	0.258	0.034	8.57	6.37	7.28	6.57	0.837	0.041
7	7.10	5.57	6.04	5.70	0.219	0.019	9.00	6.87	7.65	6.89	0.614	0.000
8	7.57	5.97	6.43	6.09	0.216	0.015	9.60	7.53	8.16	7.32	0.393	0.044
9	8.03	6.33	6.83	6.47	0.245	0.019	10.13	7.97	8.61	7.71	0.418	0.064
10	8.30	6.60	7.06	6.69	0.207	0.008	10.40	8.17	8.84	7.91	0.453	0.067
11	8.30	6.67	7.06	6.69	0.151	0.001	10.47	8.10	8.90	7.96	0.635	0.021
12	8.30	6.83	7.06	6.69	0.049	0.021	10.43	7.97	8.87	7.93	0.813	0.001
13	8.27	6.80	7.03	6.66	0.051	0.019	10.20	7.83	8.67	7.76	0.700	0.005
14	8.10	6.70	6.89	6.52	0.034	0.031	10.03	7.67	8.53	7.64	0.742	0.001
15	7.97	6.50	6.77	6.42	0.074	0.007	9.87	7.40	8.39	7.52	0.974	0.014
16	7.77	6.33	6.60	6.25	0.072	0.007	9.53	7.03	8.10	7.28	1.145	0.058
17	7.23	5.93	6.15	5.81	0.046	0.014	8.77	6.53	7.45	6.72	0.843	0.033
18	6.33	5.13	5.38	5.07	0.062	0.003	8.03	5.93	6.83	6.18	0.801	0.061
19	5.60	4.50	4.76	4.47	0.068	0.001	7.53	5.63	6.40	5.82	0.593	0.033
20	5.20	4.10	4.42	4.14	0.102	0.002	7.17	5.43	6.09	5.55	0.433	0.013
21	4.87	3.83	4.14	3.87	0.092	0.001	6.90	5.27	5.87	5.35	0.358	0.007
22	4.63	3.67	3.94	3.68	0.074	0.000	6.77	5.13	5.75	5.26	0.382	0.015
23	4.57	3.63	3.88	3.62	0.062	0.000	6.57	5.23	5.58	5.11	0.121	0.015
				Average MSE	**0.111**	**0.011**				**Average MSE**	**0.544**	**0.032**

Table 9. Comparison between Present, Predicted and theoretical value of the OWF parameter for the link (Baghdad – Ajlan) of the seasonal time (Autumn) of the years 2009 and 2014

Baghdad- Ajlan (Autumn- 2009)							Baghdad- Ajlan (Autumn- 2014)					
UT	MUF	OWF					MUF	OWF				
		Predicted	Theoretical	Present	MSE			Predicted	Theoretical	Present	MSE	
					Theo.	Present					Theo.	Present
0	3.40	2.60	2.89	2.60	0.084	0.000	5.07	3.80	4.31	3.77	0.257	0.001
1	3.17	2.40	2.69	2.41	0.085	0.000	4.70	3.57	4.00	3.45	0.183	0.014
2	3.10	2.37	2.64	2.36	0.072	0.000	4.60	3.47	3.91	3.36	0.197	0.011
3	3.90	3.10	3.32	3.01	0.046	0.008	5.60	4.43	4.76	4.23	0.107	0.040
4	6.43	5.30	5.47	5.08	0.028	0.046	8.47	7.00	7.20	6.74	0.039	0.070
5	7.43	6.17	6.32	5.90	0.023	0.069	9.93	8.27	8.44	8.02	0.031	0.063
6	7.93	6.57	6.74	6.31	0.031	0.064	10.60	8.80	9.01	8.60	0.044	0.041
7	8.27	6.60	7.03	6.59	0.182	0.000	11.03	9.10	9.38	8.98	0.077	0.015
8	8.83	6.77	7.51	7.05	0.550	0.080	11.47	9.50	9.75	9.36	0.061	0.021
9	9.30	7.13	7.91	7.43	0.595	0.089	11.77	9.73	10.00	9.62	0.072	0.014
10	9.73	7.50	8.27	7.79	0.598	0.082	11.93	9.93	10.14	9.76	0.044	0.029
11	9.63	7.63	8.19	7.71	0.308	0.005	11.90	9.77	10.12	9.73	0.121	0.001
12	9.33	7.70	7.93	7.46	0.054	0.058	11.73	9.50	9.97	9.59	0.224	0.008
13	9.03	7.43	7.68	7.21	0.060	0.048	11.60	9.33	9.86	9.47	0.277	0.019
14	8.60	7.10	7.31	6.86	0.044	0.058	11.10	8.93	9.44	9.04	0.252	0.010
15	7.37	5.77	6.26	5.85	0.245	0.007	10.03	7.70	8.53	8.10	0.686	0.163
16	5.80	4.30	4.93	4.57	0.397	0.071	8.70	6.50	7.40	6.94	0.801	0.194
17	4.77	3.57	4.05	3.72	0.235	0.024	7.50	5.57	6.38	5.89	0.653	0.106
18	4.20	3.13	3.57	3.26	0.191	0.015	6.83	5.07	5.81	5.31	0.550	0.059
19	3.83	2.90	3.26	2.96	0.128	0.003	6.40	4.80	5.44	4.93	0.410	0.017
20	3.67	2.83	3.12	2.82	0.080	0.000	6.00	4.57	5.10	4.58	0.284	0.000
21	3.57	2.77	3.03	2.74	0.070	0.001	5.70	4.37	4.85	4.32	0.229	0.002
22	3.50	2.70	2.98	2.68	0.076	0.000	5.53	4.27	4.70	4.18	0.191	0.008
23	3.40	2.63	2.89	2.60	0.066	0.001	5.33	4.00	4.53	4.00	0.284	0.000
				Average MSE	**0.177**	**0.030**				**Average MSE**	**0.253**	**0.038**

The correlated relationships between ionospheric parameters have been conducted. The seasonal and annual tests for the correlation between these parameters showed that the reciprocal correlation between MUF and OWF can be represented by a linear regression equation, while the reciprocal correlations between (MUF and LUF), (OWF and LUF) are a polynomial which represented by a fourth order polynomial equation (Quadratic Polynomial Equation). The correlation coefficients shown in Table 4 illustrate that the suggested reciprocal equations can give a good fit between these parameters standing on the values of (R^2).

Tables 5, 6, 7, 8, and 9 show a comparison between theoretical, predicted and present annual and seasonal correlation values of (MUF and OWF) for a sample link of (Baghdad–Ajlan) for the years 2009 and 2014. The results generated from the suggested correlation equations show a good fitting with the other results. *Bröms M. et al.* (13) noted the good agreement between oblique and vertical sounder data and the linear relationship between variations of MUF and LUF for F2-layer. Also, *Aqeel Z. Aziz et al.* (6), illustrated that the results of an analytical study for the behavior of (MUF and OWF) parameters over Iraqi territory showed a good fitting between the predicted values (suggested mathematical model) and theoretical values that calculated using ICEPAC, REC533 and VOACAP models. Depending on the values of the MSE, it can be noticed that the values generated using the suggested reciprocal correlation equation comparing with the values calculated from the international model were closer than those values calculated using the theoretical criterion equation. The presented Tables show that the correlation between the two parameters is good, where it gives generally mean square error (MSE) within the average value of (0.011-0.544).

Conclusions:

The behavior of MUF, LUF and OWF ionospheric parameters studied for the years (2009 and 2014) of the solar cycle 24 over Iraqi region shows a stabilized and regular variation for the annual time of selected years. The results of the seasonal analytical study for the behavior of MUF, LUF and OWF parameters over Iraqi zone show a wide variation in the behavior of these parameters. The variation in the summer time (2009) shows more variation than in (2014) that due to the influence of the solar activity on the structure of ionosphere layer. The correlation between MUF and OWF parameters is simple, and can be expressed by linear regression. The reciprocal correlation between MUF, OWF with LUF parameters are polynomial and can be expressed by a fourth order polynomial equation. The MSE between the present and predicted values is within the range (0.011-0.544), so the present ionospheric parameters values show more accurate values than those of the dataset generated from the theoretical criterion equation. The value of any ionospheric parameter can be determined depending on the value of another one.

Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Baghdad.

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العلاقة التبادلية المقترحة بين معاملات الترددات المستخدمة القصوى والدنيا والمثلى فوق منطقة العراق

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الخلاصة:

تم في هذا البحث دراسة العلاقة بين المعاملات الأيونوسفيرية (MUF, LUF and OWF) لطبقه الغلاف الأيوني فوق منطقة العراق. لقد تم اختيار العاصمة بغداد (44.42°E, 33.32°N) لتمثل محطه الإرسال بينما العديد من المدن الأخرى التي انتشرت فوق المنطقة العراقية تم اختيارها لتمثل محطات استقبال. استخدم نموذج الاتصالات REC533 الذي يعتبر أحد إصدارات الأرسال الحديثة للاتحاد الدولي للاتصالات لحساب معامل الـ LUF، في حين ان المعاملات الأيونسفيرية (OWF, MUF) فقد تم حسابها باستخدام نموذج الاتصالات الدولي ASAPS الذي يعد واحدا من أكثر نماذج اتصالات الترددات العالية دقة وتطوراً. لقد أجريت الدراسة للفترات الزمنية السنوية والفصلية للسنوات (2009 و2014) من الدورة الشمسية 24. بينت نتائج الاختبارات الفصلية والسنوية ان العلاقة التبادلية بين معاملات (OWF, MUF) مع معامل الـ LUF هي معادله متعددة الحدود من المرتبة الرابعة، في حين ان العلاقة التبادلية بين معاملات الـ (OWF, MUF) هي علاقة بسيطة يمكن تمثيلها بمعادله انحدار خطيه. كما أظهرت العلاقات التبادلية بين معاملات الـ MUF, LUF, OWF (القيم الحالية) تطابقاً جيداً مع البيانات المحسوبة من استخدام النماذج الدولية (القيم المتوقعة) والقيم النظرية المحسوبة من المعيار الدولي المعتمد.

الكلمات المفتاحية: المعلمات الأيونوسفير، التردد المستخدم الأدنى (LUF)، التردد المستخدم الأعلى (MUF)، أفضل تردد مستخدم (OWF)، انتشار الموجات الراديوية.