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Computation and Analysis of Spatio-Temporal Variability of Total Electron Content (TEC) of NIGNET CORS over Northern Part of Nigeria

Kamalu A.[1,*], Edan J. D.[2]

[1]Department of Surveying and Geoinformatics Kaduna Polytechnic, Kaduna Nigeria
[2]Department of Surveying and Geoinformatics, Modibbo Adama University of Technology, Yola, Nigeria
*Corresponding author: kamaluabdullahi@yahoo.com

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Abstract This paper focused on the determination of Spatial and Temporal variability of TEC over parts of Northern Nigeria. It computed and analyzed the year 2011 and 2013 TEC data, obtained from the Nigerian Global Navigation Satellite Systems Reference Network (NIGNET)'s ground-based GPS receivers installed at Six (6) different locations across Northern Nigeria. Results show that, the annual magnitude of TEC of 2013 was higher than that of 2011. The Diurnal analysis indicates TEC variation was minimum at pre-dawn (0-5 TECU) and increased during the day time attaining a maximum in the afternoon and decrease before sunset at all stations. The highest monthly average value was in November (34.49 and 31.39 TECU) and the minimum value in January (13.21 TECU) and September (18.91 TECU) at BKFP Station for 2011 and 2013 respectively. For seasonal variation, the equinox has the highest value of the GPS-TEC, followed by winter and the lowest value in the summer in all the stations for both years. The highest value of GPS-TEC was recorded at equinox in the year 2013 at FUTY (26.66 TECU) and 2011 at BKFP (26.63 TECU) stations respectively. The lowest value, was in summer at CGGT 2011(17.32 TECU) and 2013 (22.58 TECU). The spatial variation shows that TEC varies with latitude more than longitude. Further research is recommended on ionospheric effects and TEC variability during solar minima and solar maxima, as the research focused on ascending phase of solar cycle 24.

Keywords: *GPS, Total Electron Content (TEC), ionosphere, NIGNET, solar cycle*

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1. Introduction

Since the beginning of time, human beings have looked to the sky to determine their whereabouts. Traditionally, the Sun and the pattern of fixed stars have been their guides. But in the second millennium, constellations of man-made satellites have taken over as beacons to guide the way [1]. Global Navigation Satellite Systems (GNSS) consist of a network of satellites in medium Earth orbit that transmit radio signals in the L1 and L2 bands of the spectrum that are used to determine the position of a user that receives the signals [2]. Many studies such as [2,3,4] had revealed that signals from satellites orbiting the earth are delayed by the atmosphere as they travel to earth-bound receivers. A large part of this delay is caused by the ionosphere, which is found to be the ionized region of the Earth's upper atmosphere where there are sufficient number of free electrons that can largely affect the propagation of radio waves [4,5]. According to [6], the ionosphere has a spatiotemporal varying and dispersive structure whose properties affect the signals by attenuation, frequency shift and phase rotation, absorption and time delay, which induces a significant range error in the positioning and navigation system. The magnitude of this effect is determined by the amount of total electron content (TEC) and the frequency of electromagnetic wave [7]. The ionospheric parameter that has an over bearing influence on the Global Positioning System (GPS)-based navigation and communication system is the TEC [8], which is a by-product of GPS data [2]. It has been found that, this influence is directly proportional to the density of free electrons which could change the phase and strength of electromagnetic radio frequency waves [9].

Northern part of Nigeria is like other parts of the Globe experiencing ionospheric disturbance. The main problem is that TEC is highly variable with local time, space and level of solar and magnetic activities, which make it difficult for finding the magnitude of error expected [10]. It affects Navigation and positioning accuracy using GPS. This paper therefore, focuses on finding the magnitude of the spatial and temporal variations in GPS TEC using simultaneous observations from six Nigerian selected GNSS Network (NIGNET) GPS stations located in Northern part of Nigeria.

2. Materials and Methods

2.1. Data Acquisition Process

The study locations consist of six stations distributed over Northern part of Nigeria, a region within the equatorial and low latitude region [10]. The stations are OSGF located in Office of Surveyor General of the Federation Abuja, FUTY located in Modibbo Adama University of Technology, yoga, Adamawa State, BKFP located in Birnin Kebbi Polytechnic, Kebbi State, CGGT located in Centre for Geodesy and Geodynamic Toro, Bauchi State, ABUZ located in Ahmadu Bello University Zaria, Kaduna State and MDGR located in Maiduguri, Borno State respectively. Their spatial locations are shown in Figure 1 below. In the location of NIGNET COR stations, Universities and Research Centres were chosen purposely to link the network to scientific community and foster the use of the network [11]. The selected stations with their geographic coordinates are shown in Table 1.

Archived daily RINEX GPS observation data from Six NIGNET stations for the years 2011 and 2013 (January to December) were downloaded from NIGNET server www.nignet.net.The magnetically quiet and disturbed days engaged in this study were obtained from the lists of the international quietest and disturbed days (IQDDs) presented by the World Data Center for geomagnetism (WDC) and is available at http//:www.wdc.kugi.kyoto-u.ac.jp/. Five quietest days and five the most disturbed days were identified per month for the period of study (2011 and 2013). The selection of the years considered in the study is based on their similar solar activity and higher number of observations recorded. Sunspot Number were freely download from the Sunspot Index and Long-term Solar Observations (WDC-SILSO) Royal observatory of Belgium, Brussels available at www.sidc.be/silso/datafiles.

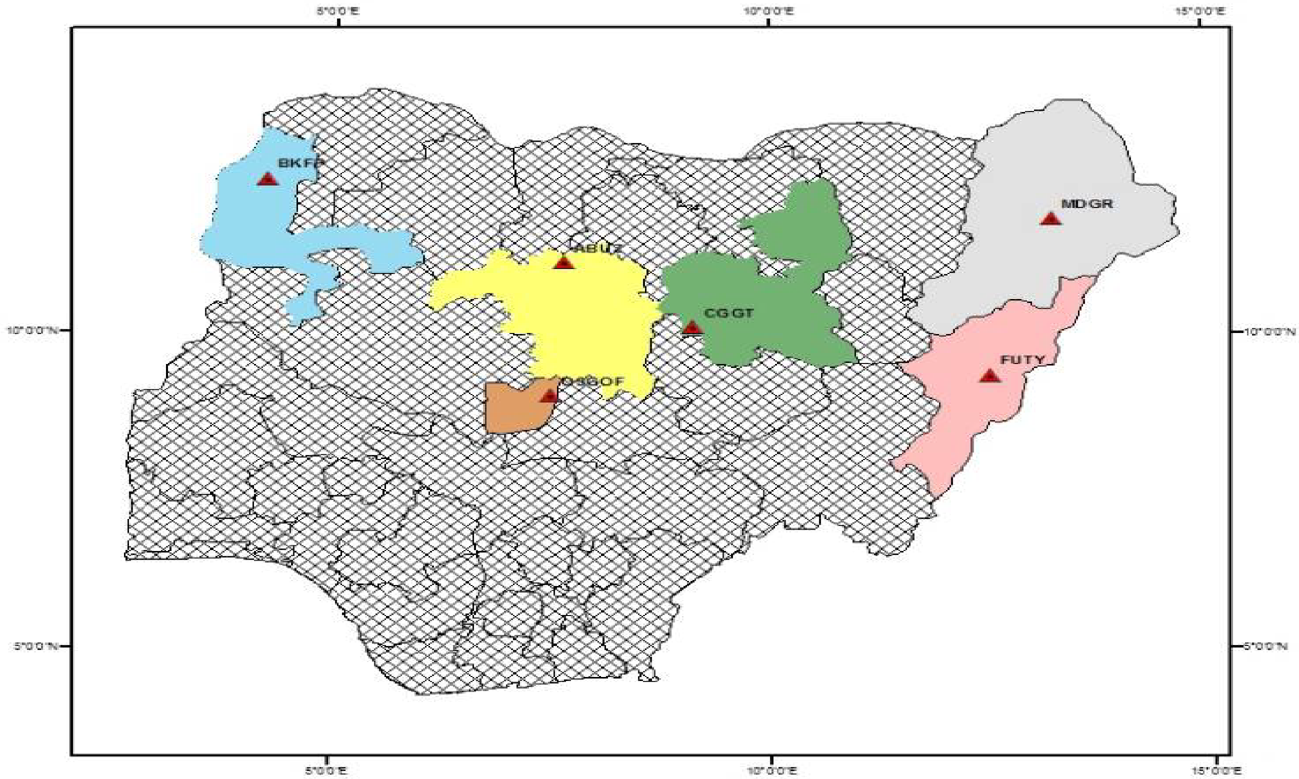


Figure 1. Locations of the Selected Nigerian GNSS COR Stations

Table 1. NIGNET COR Stations and their Geographical Locations

S/N	Station ID	Location	Latitude (Deg˚)	Longitude (Deg˚)	Elevation (m)
1	ABUZ	Zaria	11.15174	7.64869	706.1
2	BKFP	Birnin Kebbi	12.46858	4.22924	251.0
3	FUTY	Yola	9.349743	12.49780	248.4
4	OSGF	Abuja	9.027666	7.48634	533.6
5	CGGT	Bauchi	10.12309	9.11831	917.4
6	MDGR	Maiduguri	11.83809	13.23100	351.8

2.2. TEC Determination

The slant TEC (STEC) records obtained from GPS are polluted with satellite differential delay (bS, satellite bias) and receiver differential delay (bR, receiver bias), coupled with receiver inter-channel bias (bRX). This uncorrected STEC measured at every 1 min interval from the GPS receiver derived from all the visible satellites at all the stations are converted to vertical TEC (VTEC). VTEC can be expressed as

$$\mathbf{VTEC} = \mathbf{STEC} - \left[\ \mathbf{bR} + \mathbf{bS} + \mathbf{bRX}\right] / \mathbf{S.\ E} \qquad (1)$$

Where STEC is the uncorrected slant TEC measured by the receiver, S.E is the obliquity factor with zenith angle (z) at the ionospheric pierce point (IPP), E is the elevation angle of the satellites in degrees, and VTEC is the vertical TEC at the IPP. The S.E/ is defined by [10] as follows:

$$\mathbf{S.E} = \mathbf{1} / \mathbf{cos.z} = \{\mathbf{1} - (\mathbf{RE} - \mathbf{cos.E} / \mathbf{RE} + \mathbf{hS}\ )^{\mathbf{2}}\}^{-\mathbf{0.5}} \qquad 2$$

RE is the mean radius of the earth measured in km and hS is the height of the ionosphere from the surface of the earth, which is approximately equal to 350 km. These analyses from equations. (1) and (2) were implemented in the GPS TEC analysis software developed and freely distributed by the Institute for Scientific Research, Boston College, MA, USA. The GPS TEC software runs on a Windows operating system with the availability of internet. The raw RINEX GPS data were processed using this GPS TEC analysis software. This software reads raw data, processes cycle slips in phase data, reads satellite biases from International GNSS Service (IGS) code file (if not available, it calculates them), calculates receiver bias, and calculates the inter-channel biases for different satellites in the receiver. To eliminate the effect due to multipath, a minimum elevation angle of 20 is used. The VTEC data estimated are then subjected to a two-sigma (2σ) iteration, which is a measure of GPS point positioning accuracy (95% confidence level).

The TEC data were computed at minute intervals from GPS TEC analysis software developed by the Institute of Scientific Research, Boston College, USA. These minute GPS TEC data was then scaled down to hourly values using CSV file chunker for all six stations. The hourly values of GPS TEC for each individual hour for all the days of the research period (from 1 January to 31 December of 2011 and 2013) were collated together to obtained the Diurnal variations. The computed values were then take in to Microsoft excel which was used for analysis. Grapher 7, Golden Software 2007 was used for graphic generation.

The TEC Average value of each NIGNET station was determined using the whole data set. The formulae used for the analysis is given as shown in equation 3 below:

$$\mathbf{Average\ Value} = \frac{\Sigma xi}{n} \qquad 3$$

Where, n = Total number of observations, xi= Observed values

This allows the determination and computation of TEC Variations for all the station.

2.3. Seasonal Grouping

To study the seasonal variation of GPS-TEC for different years (2011 and 2013), each year has been classified into three seasons by [12], using Lloyd's seasonal classification based on the movement of the sun i.e. equinox or E Season (March, April, September and October), summer or June Solstice or J season (May, June, July and August) and winter, or December Solstice or D season (January, February, November, December.) as used by [7,9,13,14,15,16].

3. Result and Discussion

3.1. Presentation

In this paper the variability of GPS TEC has been studied and presented based on diurnal, monthly, seasonal and spatial analysis as well as five quietest and five the most disturbed days of each month using the data base from six selected NIGNET COR Stations located in Northern Nigeria for the period of two years (2011 and 2013) from January to December, (with an exception of some months when observations were disrupted by technical and power interruption problems especially in MDGR and CGGT Stations).

3.2. Determination of Total Electron Content (TEC)

The TEC values were determined and analysed over the study area accordingly based on Six GNSS COR Stations selected for the study. The average TEC value varies annually from one station to another depending on their location, and also the annual values at each station varies. Table 2 below show the average TEC values at each stations for two different years (2011 and 2013) and the annual TEC values were computed at selected time interval as shown in Figure 2.

Table 2. Mean Annual TEC values at NIGNET Selected Stations

STATIONS	YEAR	
	2013	2011
OSGF	24.05	23.38
FUTY	24.88	22.17
CGGT	-	22.07
ABUZ	24.31	22.25
MDGR	-	-
BKFP	24.83	22.47

The GPS TEC value in 2013 is always higher than that of 2011 as shown in Table 2. This is in good agreement with the result of [17] which attributed higher electron content value in the ionosphere during higher solar activity to increasing temperature variations in the thermosphere responding to simultaneous increase in solar activity and radiation intensity. The annual value at all stations for a particular year is within the range of same whole number except OSGF in 2011 which there was no data recorded in January and February for that particular Station and also the month of October for ABUZ in 2013. The data recorded for MDGR were not enough for this particular analysis. The result shows that the Stations located in Northern Part of Nigeria irrespective of their location exhibit almost the same value of TEC which have the same whole number value, but differ in decimal values. Also, the average Annual values were calculated at various epoch of observations as shown in Figure 2.

It has been observed from the Figure 2 that, the variation between annual data at 00:00 Universal Time, UT (01:00 Local Time LT) is minimum and continue decreasing until it reaches the coincident point at around 02:00 to 06:00 UT which the annual TEC data variation is negligible and start increasing it reach its peak where the variability is higher at about 12:00 to 16:00 and then start decreasing at sunset.

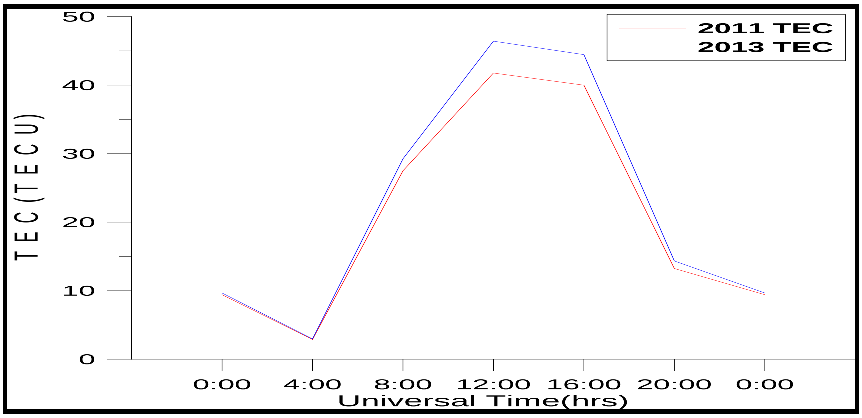


Figure 2. Mean Annual GPS TEC across selected NIGNET Stations

3.2. Determination of Spatial and Temporal Variations of GPS TEC

The Temporal variation of GPS TEC was determined based on daily (Diurnal), Monthly, Seasonal and Annual variation.

3.2.1. Daily (Diurnal) GPS TEC Variations

The Diurnal TEC variation was analysed based on daily observations as well as mean Diurnal values at four hours' interval. Both of which shows same pattern of hourly variability. Figure 3 (a-f) and Figure 4 shows diurnal TEC at some selected days of the year over selected NIGNET CORS stations in Northern Nigeria.

The diurnal variation of TEC over Northern Nigeria exhibits the characteristics typical of the low-latitude ionosphere in which the TEC variation is minimum at pre-dawn and increase with the time of the day attaining a maximum in the afternoon and decrease before sunset. For all stations the diurnal variation of hourly mean GPS-TEC is obtained, such that there is a gradual decrease in GPS-TEC between 00:00 to 04:00 Universal Time (UT) equivalent to 01:00 to 05:00 Local Time (LT) pre-dawn to sun up period, reaching a minimum between 05:00 to 06:00 LT with magnitude of 0 to 5 TECU, rises steeply during the sunrise period (07:00 to 09:00 LT), and then rises very slowly from 10:00 LT over the Northern Nigeria and steadily increase with the time of day attaining a maximum in the noon to afternoon and a gradual decrease after sunset. The observations of diurnal variation in GPS-TEC show that the time at which GPS-TEC reaches the diurnal peak vary from month to month and day to day. In general, the diurnal GPS-TEC attained their peak values mostly between 13:00 and 16:00 LT. In all these plots the diurnal variation shows a minimum TEC value (5 TECU) occurring around 05:00–06:00LT and a day maximum TEC value occurs at (13:00-16:00LT) in all the stations. This result is in good agreement with the result of [10,16,17,18,19,20,21]. This uncertainty in the day-to-day variations in TEC according to [6,10,14,15] may be attributed to: 1) the changes in the activity of the Sun itself and to the connected changes in the intensity of the incoming radiations; 2) the zenith angle (χ) at which they impinge on the Earth's upper atmosphere, in addition to the changes which take place in the Earth's magnetic field; 3) the equatorial electro jet (EEJ) strength, added to the effects due to the dynamics of the EIA and (4) local atmospheric conditions in the thermosphere, (5) geomagnetic Activities. Whereas [16] and [22] added the effect of 6) the meridional neutral winds (diffusion of transported electrons from the equator).

3.2.2. Monthly GPS TEC Variation

The month to month variability of the GPS TEC for each of the months of years 2011 and 2013 respectively at selected NIGNET CORS are shown in Figure 5 (a-e).

The Figure 5 (a-e) shows that the monthly variation of GPS TEC in 2011 is maximum during the month of November with magnitude varies from station to station ranging from 32.83 TECU to 34.49 TECU., while the minimum TEC value is observed during the month of January with magnitude ranging from 13.21TECU to 13.63 TECU respectively. In 2013 monthly GPS TEC variation is maximum during the month of November with magnitude varies from station to station ranging from 29.09 TECU to 31.39 TECU while the minimum TEC value is observed during the month of July with magnitude ranging from 19.94TECU to 20.58 TECU. However, in 2013 the OSGF which has maximum and minimum TEC values in the month of December and January respectively. The GPS TEC starts decreasing from the month of December and achieves peak in the month of March to April. Subsequently, it again starts decreasing and reaches minimum in the month of June or July. Interestingly, it starts increasing again and reaches maximum during the month of November, only to start decreasing and by the end of December it reaches to minimum for the start of next cycle.

The variability during the days of each month is averaged at a specific time interval (00:00, 04:00, 08:00, 12:00, 16:00 and 20:00). The monthly analysis at each epoch shows varying behavior depending on the station and the year under consideration. For both years at 00:00, the maximum TEC values were observed at equinoctial months. Whereas the minimum is in the months of June to July. Maximum and minimum TEC values occurred randomly at different months at 04:00. All other epoch observed maximum and minimum TEC values are mostly in the months of November and (January, June) respectively. This result is in good agreement with the result [7].

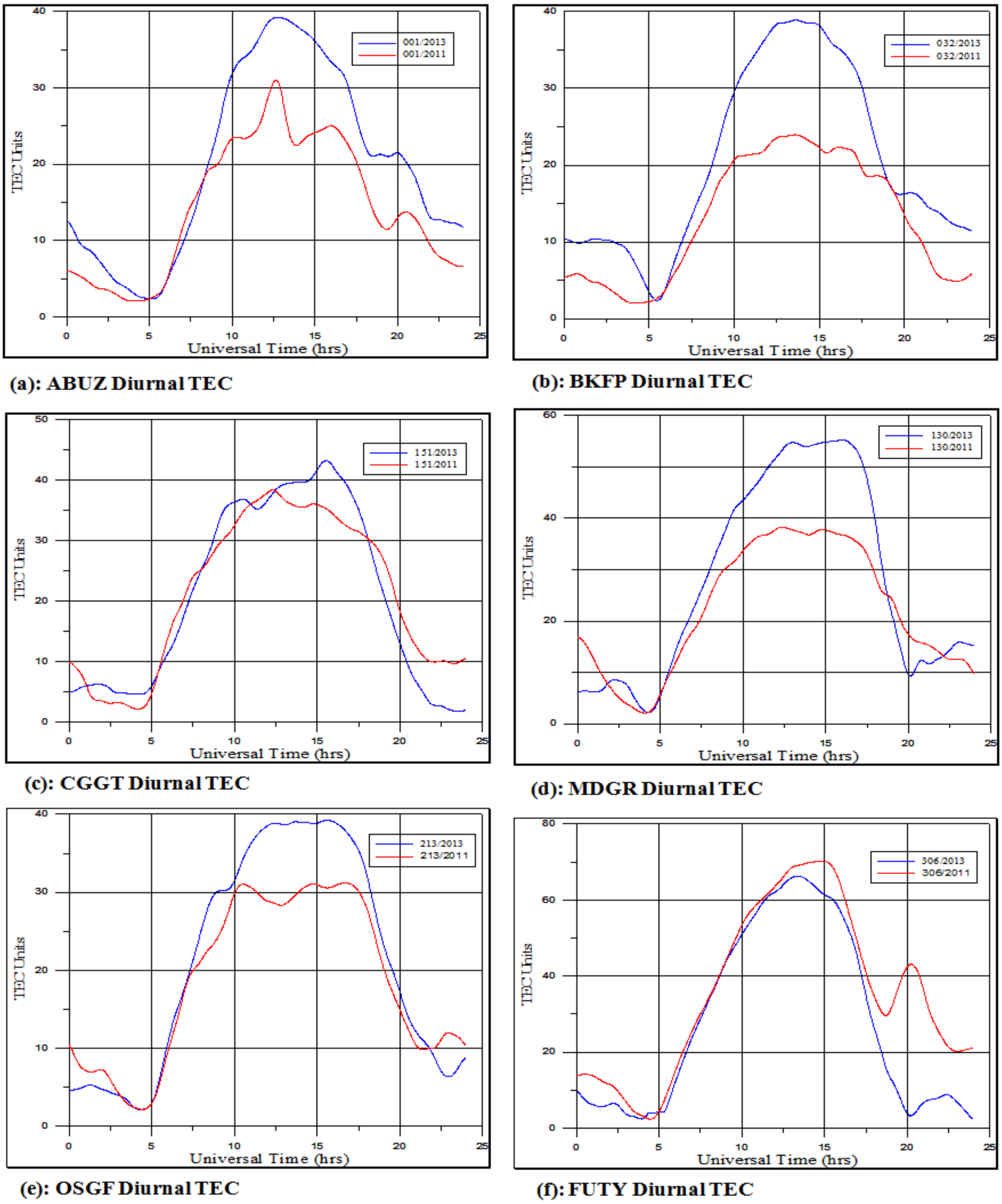


Figure 3 (a-f). Diurnal TEC at some selected days of the year over selected NIGNET CORS

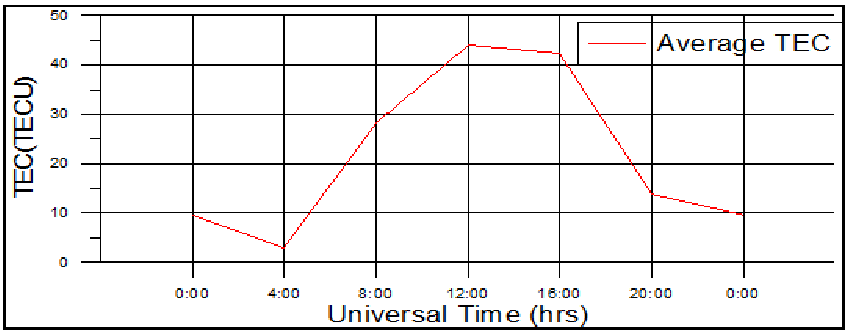


Figure 4. Mean Diurnal GPS TEC Profile over NIGNET Stations in Northern Nigeria

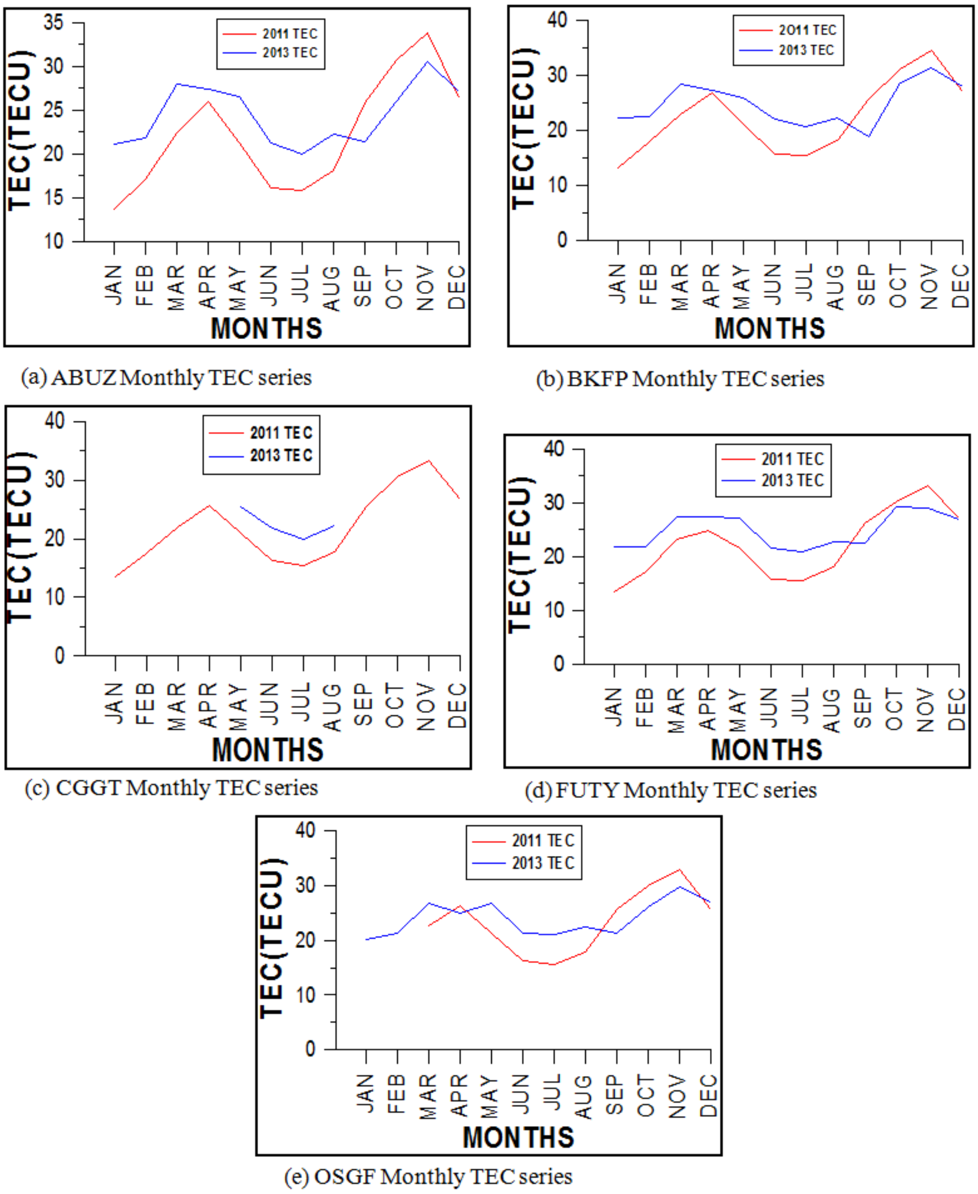


Figure 5(a-e). Monthly TEC Series over selected NIGNET Stations

3.2.3. Seasonal Variations of GPS TEC

For the determination of the seasonal variation in TEC across the stations considered for this project, Diurnal means of GPS-TEC for the study period at some designated hours (00:00, 04:00, 08:00, 12:00, 16:00 and 20:00) were obtained to derive the seasonal means for the three seasons under consideration (Equinox, Summer and Winter). The results show that TEC variability across the stations is higher in equinox followed by winter and least in summer at all the epoch. The Figure 6 below presents the Mean Seasonal GPS TEC values over selected NIGNET Stations in Northern Nigeria.

The seasonal analysis shows a semi-annual pattern, with a maximum in Equinox followed by winter and lowest in summer. It has been observed that the greater values of the GPS-TEC were observed in equinox for both years (2011 and 2013), followed by winter in all the stations and the lowest value in the summer. The highest value of GPS-TEC was recorded for equinoctial months in the year 2013 at FUTY (26.66 TECU) and 2011 at BKFP (26.63 TECU) stations respectively. The lowest value, however was observed in summer for both years at CGGT 2011(17.32 TECU) and 2013 (22.58 TECU). Also, the variation at each station for different years (2011 and 2013) show that equinox experienced least variation (0.20 to 1.38 TECU) followed by winter (2.22 to 2.87 TECU) and higher in summer (4.72 to 5.38) as shown in the Figure 7 (a-e).

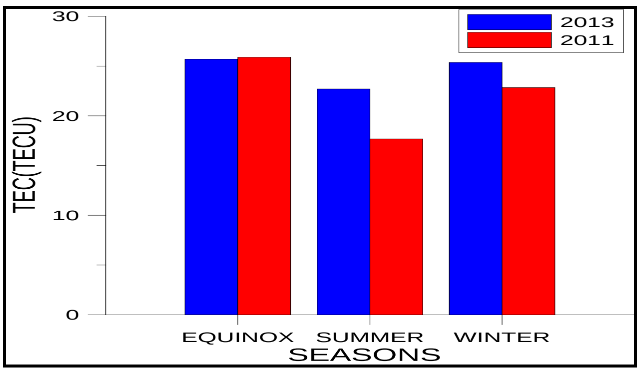
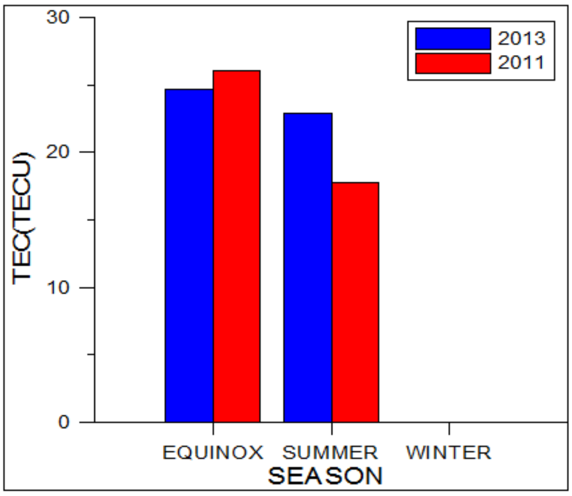
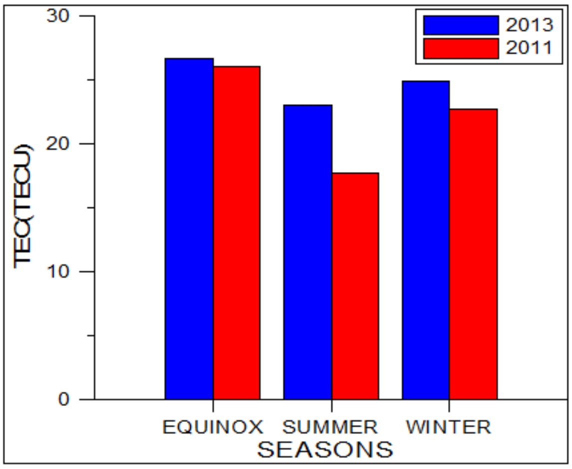


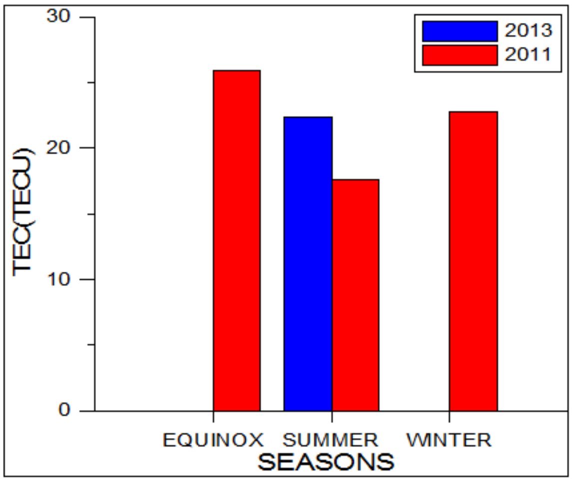
Figure 6. Mean Annual Seasonal Variation of GPS TEC



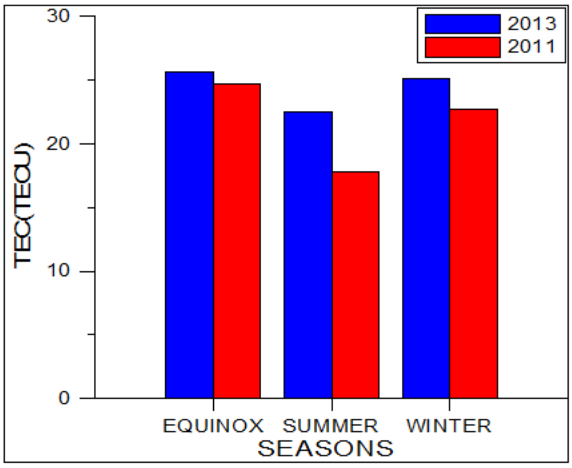
(a) OSGF Seasonal TEC



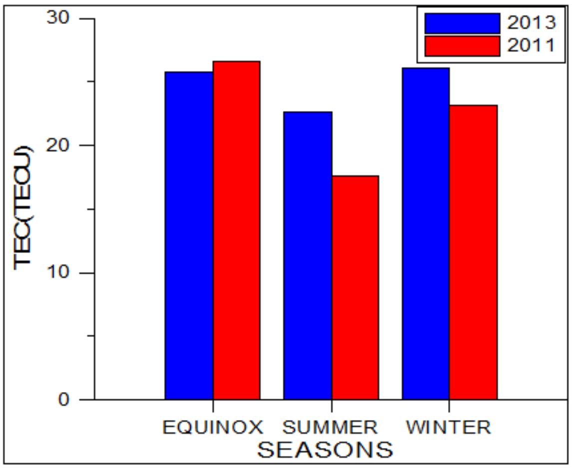
(b) FUTY Seasonal TEC



(c) CGGT Seasonal TEC



(d) ABUZ Seasonal TEC



(e) BKFP Seasonal TEC

Figure 7 (a-e).: Seasonal TEC Variations over selected NIGNET Stations

According to [6,10,14,15,16,22,23], the maximum ionospheric time delay occurred in equinox during these magnetic days, more significantly at low latitude which is probably due to the down welling of thermospheric gas. The down welling of thermospheric gas, mainly caused by storm-induced thermospheric winds which may cause the increase of ionization at low latitudes without any significant change in atom to molecule ratio.

3.3. Spatial Variations

For the purpose of examining the spatial variations of TEC over the NIGNET CORS, mean monthly TEC for each station were computed and they were shown using the Bar chart for each year. Figure 8 & Figure 9 show the monthly TEC of selected NIGNET stations with respect to their latitudes in ascending order for the years 2011 and 2013.

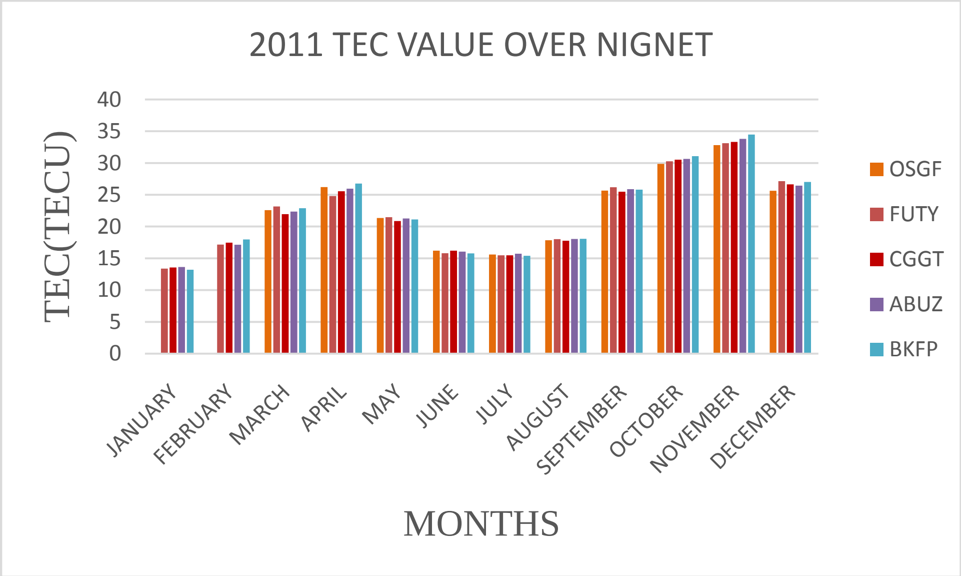


Figure 8. 2011 Average Monthly TEC of selected NIGNET stations

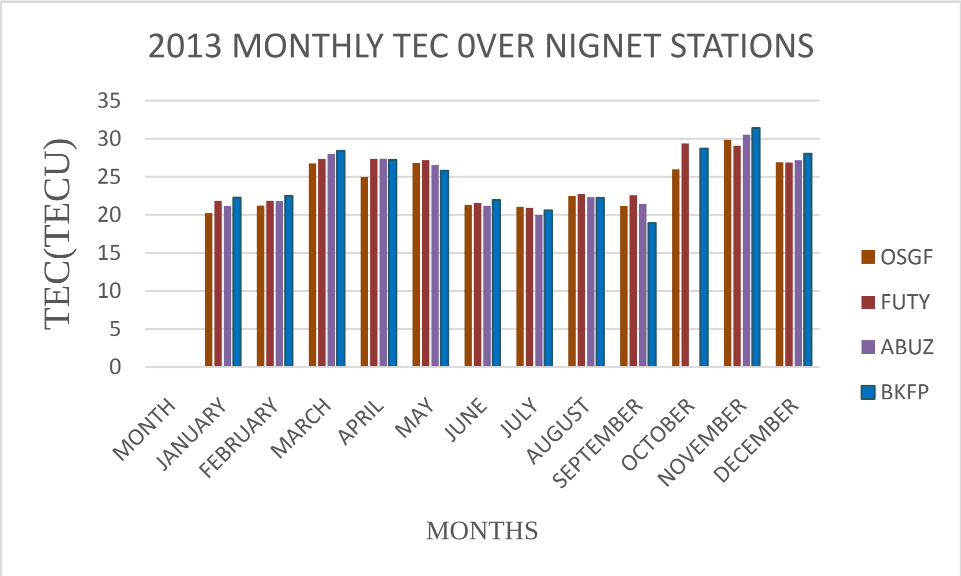


Figure 9. 2013 Average Monthly TEC of selected NIGNET stations

The result over NIGNET CORS shows irregular nature for the years considered for the study especially in 2013. The Correlation Coefficient (r^2) of the average monthly GPS TEC with respect to latitude and longitude were computed for the stations under consideration as shown in the Table 3 and Table 4;

From the Table 3 and Table 4, it was observed that GPS TEC are more correlated with latitude than longitude. The correlation coefficient (r^2) for both years with latitude are mostly highly and moderate correlated. However, with respect to longitude, the correlation is moderate and low correlated. All the stations are located within the same region, the variation between the lowest and highest latitude for stations is not more than 2° which is not enough to observe the variation spatially, as all the stations exhibit almost the same characteristics. It was found that those stations that are in higher latitude have lower TEC values most times than those in lower latitude except in the months of October, November and December for both years and months of January, February and March in 2013. [6,17,19] had earlier reported that the lower latitude stations experienced higher TEC than higher latitude stations.

Table 3. Correlation of GPS TEC data with Latitude

Months	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
2011 (r^2)	-0.40	0.73	0.02	0.64	-0.37	-0.47	-0.23	0.59	-0.04	0.95	0.99	0.45
2013 (r^2)	0.63	0.86	0.96	0.57	-0.57	0.47	-0.44	-0.77	-0.79	0.41	0.92	0.93

Table 4. Correlation of GPS TEC data with Longitude

Months	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
2011 (r^2)	0.33	0.77	0.15	-0.99	0.37	0.04	0.09	-0.19	0.44	-0.54	-0.69	0.19
2013 (r^2)	-0.06	0.41	-0.52	0.14	0.93	-0.38	0.30	0.95	0.94	0.30	-0.94	-0.79

3.4. TEC Variations during Geomagnetic Condition

To study Diurnal, Monthly and Seasonal mean variations of GPS TEC during Geomagnetic activities, five quietest and five the most disturbed days of each month were selected from the lists of the international quiet and disturbed days (IQDs). The mean TEC during these days of each month is utilized to study the seasonal and monthly variability of TEC during quiet and disturbed days at Six selected NIGNET COR Stations as shown in the Table 5, Table 6, Table 7 and Table 8.

Table 5. 2011 Average Seasonal Disturbed and Quiet GPS TEC

Seasons / stations	EQUINOX		SUMMER		WINTER	
	Quiet	**Disturbed**	**Quiet**	**Disturbed**	**Quiet**	**Disturbed**
OSGF	24.97	25.17	17.96	18.54	-	-
FUTY	25.25	27.80	17.57	18.53	21.48	22.49
CGGT	23.41	25.71	17.42	18.27	21.20	22.64
ABUZ	26.43	28.33	17.80	19.31	23.51	22.81
MDGR	25.40	28.03	17.61	18.38	-	-
BKFP	25.87	27.88	17.46	18.46	23.88	23.62

Table 6. 2013 Average Seasonal Disturbed and Quiet GPS TEC

Seasons / stations	**EQUINOX**		**SUMMER**		**WINTER**	
	Quiet	**Disturbed**	**Quiet**	**Disturbed**	**Quiet**	**Disturbed**
OSGF	23.21	26.40	22.65	24.82	22.86	26.96
FUTY	24.37	27.34	22.28	24.97	23.42	26.38
CGGT	-	-	20.60	24.59	-	-
ABUZ	24.33	27.17	22.45	24.90	23.22	27.40
MDGR	-	-	-	-	-	-
BKFP	22.98	26.57	22.60	24.74	23.93	28.33

Table 7. 2011 Average Monthly GPS TEC For Quiet And Disturbed Days

stations / Months	**OSGF**		**FUTY**		**CGGT**		**ABUZ**		**MDGR**		**BKFP**	
	Q	D	Q	D	Q	D	Q	D	Q	D	Q	D
JANUARY	-	-	12.58	13.32	12.75	13.82	12.27	13.58	-	-	12.18	13.41
FEBRUARY	-	-	15.70	17.02	16.20	17.18	22.77	15.73	-	-	23.36	18.82
MARCH	21.37	15.86	22.86	26.70	18.01	22.58	26.42	27.17	21.37	-	22.44	23.32
APRIL	25.01	28.03	24.74	27.78	24.83	27.88	25.13	28.11	25.51	28.21	25.76	28.53
MAY	20.23	23.52	20.00	23.30	20.02	23.48	19.91	26.55	20.41	23.07	19.15	22.98
JUNE	16.74	17.31	16.11	17.45	15.88	17.11	16.58	17.14	16.27	17.34	16.39	17.08
JULY	17.31	15.87	16.83	15.85	16.51	15.27	17.08	15.90	16.48	15.56	16.91	16.06
AUGUST	17.53	17.47	17.32	17.53	17.27	17.21	17.63	17.64	17.26	17.55	17.40	17.71
SEPTEMBER	23.57	26.40	23.35	25.85	21.28	22.53	23.68	26.65	23.69	24.11	24.20	27.94
OCTOBER	29.94	30.38	30.07	30.85	29.52	29.83	30.47	31.39	31.02	31.78	31.10	31.73
NOVEMBER	32.57	31.00	32.71	32.59	31.16	31.39	33.22	32.15	33.37	30.17	33.70	32.55
DECEMBER	25.61	28.32	24.92	27.05	24.67	28.17	25.79	29.79	31.74	35.46	26.28	29.71

Table 8. 2013 Average Monthly GPS TEC For Quiet And Disturbed Days

stations / Months	**OSGF**		**FUTY**		**CGGT**		**ABUZ**		**BKFP**	
	Q	D	Q	D	Q	D	Q	D	Q	D
JANUARY	20.36	23.45	22.22	23.52	-	-	20.47	23.41	21.98	24.62
FEBRUARY	21.71	22.25	20.84	21.81	-	-	22.19	23.08	22.40	23.93
MARCH	25.74	27.10	25.84	29.10	-	-	25.23	29.32	25.84	29.85
APRIL	22.45	25.95	24.72	25.66	-	-	24.72	26.58	24.94	25.79
MAY	25.76	27.64	26.52	28.62	19.90	27.47	26.19	27.57	25.92	26.84
JUNE	20.55	22.79	19.56	23.08	19.49	22.80	20.15	22.67	20.15	22.67
JULY	21.83	23.88	20.91	23.64	20.82	23.37	21.34	23.66	21.46	23.75
AUGUST	22.46	24.97	22.15	24.55	22.20	24.71	22.11	25.68	22.87	25.68
SEPTEMBER	20.47	23.41	21.25	23.83	-	24.75	20.92	23.65	-	20.54
OCTOBER	24.17	29.13	25.67	30.76	-	-	26.44	29.14	18.17	30.12
NOVEMBER	23.70	33.80	24.85	33.11	-	-	24.15	34.44	24.86	35.22
DECEMBER	25.67	28.36	25.79	27.09	-	-	26.08	28.67	26.49	29.53

The TEC during these days of each month is utilized to study the variability of TEC during quiet and disturbed days at each station. The Diurnal variations at each station show same pattern as all other days which is generally observed experiences an increase from about sunrise to a maximum around afternoon and then falls to a minimum at sunset. The average monthly and seasonal variations of TEC during quiet and disturbed days at Selected Stations indicate that; in general, the value of TEC during disturbed days is higher than the quiet days for each month and each season except in 2013 winter season at ABUZ and BKFP and the months of July and November in 2011 at each station respectively, where TEC during quiet period is higher than the TEC during disturbed period. The 2013 monthly average quiet and disturbed days has greater GPS TEC than corresponding dates in 2011 with exception of the months of April, September, October, November and December for all stations under considerations. The highest and lowest average TEC observed in the months November and January in 2011 for quietest and the most disturbed days, while the months of June and February has the lowest and months of May and November has the highest value of TEC in 2013 respectively. The maximum value of TEC during disturbed and quiet days occurred in equinox season while minimum in summer and moderate in winter. The spatial variations of quiet and disturbed days followed same pattern as explain in section 3.3 above. The result is in good agreement with the result of [13,15,16].

3.5. Determination of TEC Magnitude and Direction of Variations

For the determination of magnitude of TEC, average Diurnal TEC were used to obtain monthly and annual TEC at each station over the years 2011 and 2013 respectively. The direction of monthly variation was computed by finding the difference between monthly and annual average TEC at each station for a particular year as shown in the Table 9 and Table 10 below.

It has been observed that in each year, the months of March, April, October, November and December have negative (-) magnitude with additional of September in 2011 and May in 2013 and all other months have positive (+) variation. The negative and positive variations in those months show that those months have more and less magnitude than annual magnitude of their respective years.

Table 9. 2011 Monthly TEC magnitude and direction of variations

Months \ Stations	OSGF	FUTY	CGGT	ABUZ	BKFP
JANUARY	-	8.79	8.51	8.62	9.25
FEBRUARY	-	5.00	4.59	5.12	4.49
MARCH	0.80	-0.99	0.11	-0.11	-0.42
APRIL	-2.85	-2.63	-3.49	-3.70	-4.29
MAY	2.04	0.69	1.20	0.98	1.34
JUNE	7.18	6.36	5.87	6.18	6.69
JULY	7.77	6.68	6.59	6.51	7.07
AUGUST	5.54	4.14	4.30	4.20	4.38
SEPTEMBER	-2.29	-4.01	-3.42	-3.64	-3.33
OCTOBER	-6.49	-8.11	-8.45	-8.41	-8.61
NOVEMBER	-9.45	-10.95	-11.25	-11.54	-12.02
DECEMBER	-2.25	-4.97	-4.57	-4.19	-4.56

Table 10. 2013 Monthly TEC magnitude and direction of variations

Months \ stations	OSGF	FUTY	CGGT	ABUZ	BKFP
JANUARY	3.85	3.04	-	3.18	2.57
FEBRUARY	2.83	3.04	-	2.52	2.32
MARCH	-2.69	-2.45	-	-3.67	-3.56
APRIL	-0.91	-2.47	-	-3.06	-2.39
MAY	-2.74	-2.28	-3.14	-2.23	-0.98
JUNE	2.73	3.34	0.64	3.13	2.88
JULY	2.99	3.97	2.44	4.35	4.25
AUGUST	1.59	2.19	0.07	1.99	2.61
SEPTEMBER	2.89	2.32	-	2.88	5.92
OCTOBER	-1.92	-4.49	-	-	-3.87
NOVEMBER	-5.78	-4.20	-	-6.22	-6.57
DECEMBER	-2.84	-2.00	-	-2.87	-3.20

The minimum variation of TEC observed at ABUZ (-0.11 TECU) in March 2011 and OSGF (-0.91 TECU) April 2013 while the Maximum value for both years occurred in November. Both minimum and maximum values show negative direction. The highest maximum value is observed at BKFP (-12.02 TECU) in 2011 and (-6.57 TECU) in 2013.

The analysis at selected epoch of observations shows that the minimum variations is observed at 04:00 followed by 00:00 and 08:00 whereas the maximum variations observed at 16:00 followed by 12:00. This is in good agreement with the result of [14] and [10] which found that the spread of GPS TEC at the low-latitude stations in Nigeria is at a minimum during the nighttime and at a maximum during the daytime, which may be attributed to the high ionization due to intense solar radiation.

4. Summary, Conclusion and Recommendation

In this paper, six (6) selected NIGNET COR Stations has been used for the determination and analysis of spatial and temporal variations of Total Electron Content (TEC) in ascending phases of solar activity over Northern Nigeria. The result was compared with the previous research that had the same geographical conditions with the study area where available.

It has been observed that GPS TEC is highly variable parameter both with time and location. The average TEC value is obtained at specified time interval (00:00, 04:00, 08:00, 12:00, 16:00 and 20:00 hrs) for Diurnal, monthly and seasonal analysis. Generally, it was found that; the magnitude of TEC in 2013 always is greater than its corresponding value in 2011.It was revealed that the TEC has a Diurnal variation which increase from about sunrise to a maximum around afternoon and then falls to a minimum at sunset for both years in all the stations. The monthly analysis shows high TEC values in the month of November and low TEC values in the month of January and July for 2011 and 2013 respectively. The GPS TEC for both years is higher in equinox followed by winter and least in summer at all epoch of consideration in all the stations.

The spatial analysis show GPS TEC are more correlated with latitude than longitude. The variability of geomagnetic quietest and the most disturbed days show same Diurnal and Seasonal patterns with other days. The magnitude and direction of variation of GPS TEC were computed. The uncertainty in Spatial and Temporal variations of GPS-TEC, is Causing serious worry in predicting TEC values, as well as its application in positioning and navigation system.

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Statement of Competing Interests

The authors have no competing interests.

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