British Journal of Applied Science & Technology
3(4): 735-747, 2013

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Classification of Days Using Locally Generated Magnetic Indices from Magnetic Data Acquisition System (Magdas) Ground Based Observatories at Three (3) Nigerian Stations

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Authors' contributions

This work was carried out in collaboration between all authors. Authors ABR and MYO designed the study. Authors UCA and ABR performed the statistical analysis, wrote the algorithm and computer code. Author UCA wrote the first draft of the manuscript and managed the analyses of the study. Author MYO and UCA managed the literature searches. All authors read and approved the final manuscript.

Research Article

Received 20th February 2013
Accepted 1st April 2013
Published 2nd May 2013

ABSTRACT

Investigation has been done concerning the mitigation of geomagnetic storm (a type of space weather that has the potential to cause damage across the globe with a single event) using locally generated magnetic Indices obtained from geomagnetic data from ground based Magdas magnetometers to classify the data into quiet and disturbed days thereby deducing the possible state of radio communications propagation over Nigeria. Physical mechanisms responsible for the characteristics of the ionosphere were identified. K (an index which measures the magnetic perturbations of the planetary field) and A (a linear measure of the Earth's field that provides a daily average level for geomagnetic activity) geomagnetic indices were generated locally using a simple algorithm and appropriate computer code, from MAGDAS magnetometers located at Abuja (9º 40'N, 7º 29'E), Ilorin (8º30'N, 4º33'E) and Lagos (6º27'N, 3º23'E) in Nigeria for the period 2006 – 2011 were used as the basis for the classification. Results showed that 31.85% of the days were found to be quiet while 39.36% of the days were found to be disturbed. The

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observed variations in the geomagnetic field responsible for the characteristics of the ionosphere over Nigeria comes probably from two principal sources, namely, transient variations - those generated by atmospheric processes such as ultraviolet radiation from the sun and partly by secular variations, which are due to internal disturbances within the Earth. Variations in the geomagnetic field are thus found to be responsible for the characteristics of the Ionosphere.

Keywords: Geomagnetic indices; quiet and disturbed days; radio propagation and communications.

1. INTRODUCTION

Over the last six years, disturbances in the Earth‘s geomagnetic field have disrupted the operation of critical infrastructures relying on space-based assets and have also resulted in terrestrial effects which have caused catastrophic consequences across the globe [1]. Tsunamis, hurricanes, flooding, earthquakes, and volcanic eruptions have led to hundreds of thousands of fatalities and billions of dollars in economic costs. In the past, geomagnetic storms have disrupted space-based assets such as a satellite‘s signal strength involved in the Global Positioning System (GPS) [2,3]. The Total Electron content (TEC) of the Earth‘s ionosphere which increases during a geomagnetic storm, increases the density of the ionosphere and leads to signal propagation delays to and from satellites [4] as well as terrestrial assets such as electric power transmission networks and satellite communication signal degradation. Extra-high-voltage (EHV) transformers and transmission lines—built to increase the reliability of electric power systems in cases of terrestrial hazards—are particularly vulnerable to geomagnetically induced currents (GICs) caused by the disturbance of Earth‘s geomagnetic field. In a bid to mitigate geomagnetic and ionospheric storms, there are many indicators that enable the high frequency (HF) radio propagation conditions to be predicted. However it is indicators of the level of solar radiation and geomagnetic activity that give the best clues to the possible state of radio communications propagation conditions via the ionosphere because the ionosphere is a particularly important region with regards to radio signal propagation and radio communications in general [5]. The main indicators are the solar flux and the geomagnetic indices. Using these it is possible to manually deduce what conditions may be like. Geomagnetic indices are simple measures of magnetic activity that occurs, typically, over periods of time of less than a few hours and which is recorded by magnetometers at ground-based observatories. Geomagnetic indices thus provide an estimate for the level of activity in the interaction between the Earth's magnetic field and the solar wind [6,7,8]. By comparing indices values, the relative activity level of the Magnetosphere and Ionosphere system is determined [9]. The variations that geomagnetic indices measures have their origin in the Earth’s ionosphere and magnetosphere.

There are two major types of geomagnetic indices: indices that separate and quantify the variations representative of a localized/isolated effect (e.g. Dst for the ring current variations) and indices that estimate the global energy input in the magnetosphere, which is the purpose of the so-called “planetary” indices (e.g. Kp and Ap), [10]. To indicate the state of geomagnetic activity, there are two indices used that are related to each other: K and A Index. Although different, these indices give indications of the severity of magnetic fluctuations, and hence the level of disturbances in the ionosphere.

The primary objective of this present work is to exploit for the first time locally obtained geomagnetic data from ground based MAGDAS magnetometers, installed in Africa, to classify days into quiet and disturbed days by engaging locally generated magnetic K and A indices.

2. METHODOLOGY

The primary data engaged in this study consists of horizontal component of the geomagnetic field obtained from Magnetic Data Acquisition System (MAGDAS) ground based observatories at three (3) Nigerian stations; viz: Abuja, Ilorin and Lagos, for the periods 2006-2011. The co-ordinates of these stations are shown in Table 1.

Table 1. Location and co-ordinates of MAGDAS ground based observatories in Nigeria

Station name	Geographic latitude	Geographic longitude	Geomagnetic latitude	Geomagnetic longitude	L	Dip lat
Abuja	8.99^0	7.39^0	-0.54^0	81.31^0	1.00^0	-0.95^0
Ilorin	8.50^0	4.68^0	-1.82^0	76.80^0	1.00^0	-2.96^0
Lagos	6.48^0	3.27^0	-3.04^0	75.33^0	1.00^0	-4.95^0

Similarly, Daily Disturbance Storm time index data for the years 2006 – 2011 were obtained from the world data center for geomagnetism, Kyoto - Japan, while the Daily sunspot number, list of International quiet days and daily mean global Ap and Kp indices were also obtained from the UK Solar System Data Centre.

MAGDAS, an acronym of the Magnetic Data Acquisition System, is a project of the Space Environment Research Centre of the Kyushu University, Japan, that has distributed about 15 magnetometers over Africa up to date [11].

The daily data was classified into quiet and disturbed days using the locally generated K and A magnetic indices. The criterion for classification is based on the Kp and Ap relationship tables as shown in Table 2. K index values of 0 and 1 and A index values of 0 and 4 indicates quiet conditions while K index values of 8 and 9 and A index values of 208 and 400 indicates disturbed conditions. The daily sunspot number (SSN) which is a proxy for solar activity and Disturbance Time Index (Dst) was plotted against the A, Ap, K and Kp index to understand the nature of variations and hence deduce the conditions of the ionosphere.

Table 2. Relationship between "K" and "A" Indices

A Index	K Index	Description
0	0	Quiet
4	1	Quiet
7	2	Unsettled
15	3	Unsettled
27	4	Active
48	5	Minor storm
80	6	Major storm
132	7	Severe storm
208	8	Very major storm
400	9	Very major storm

Source: Ian Poole, Understanding Solar Indices. Sept. 2002

Regression analysis which is a mathematical measure of the average relationship between two or more variables in terms of the original units of the data was performed in order to establish a better relationship between variables using the Matlab® software. Given the values of 'x', we can predict the values of 'y' using the regression equation;

$$y* = a + bx \quad .... \quad (1)$$

Where the coefficients a and b are given by

$$b = [n\sum xy - (\sum x)(\sum y) \div n(\sum x^2) - (\sum x)^2], a = \sum y - b\sum x / n \quad .... \quad (2)$$

$y*$ refers to the predicted value of y from a given value of x from the regression equation.

3. RESULTS AND DISSCUSSION

Table 3. Results of regression analysis for the three stations

REGRESS	ABU	ILR	LAG
Kp and SSN	0.1536	0.4555	0.22120
Kp and Dst	-0.1604	-0.4755	-0.2382
K and SSN	0.1159	0.2411	0.1974
K and Dst	-0.0664	-0.2048	-0.1296
A and SSN	4.4547	8.5998	7.8877
A and Dst	-2.3603	-7.6715	-4.9951
Ap and SSN	2.4638	7.0058	3.8521
Ap and Dst	-2.3672	-6.8901	-3.9738

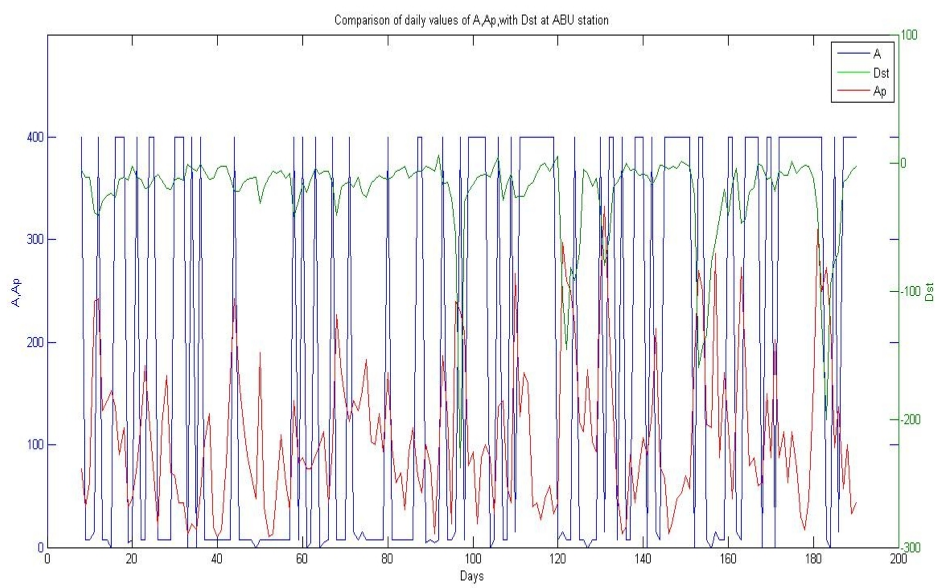

Fig. 1. Daily variations of A, Ap with Dst at ABU Stations

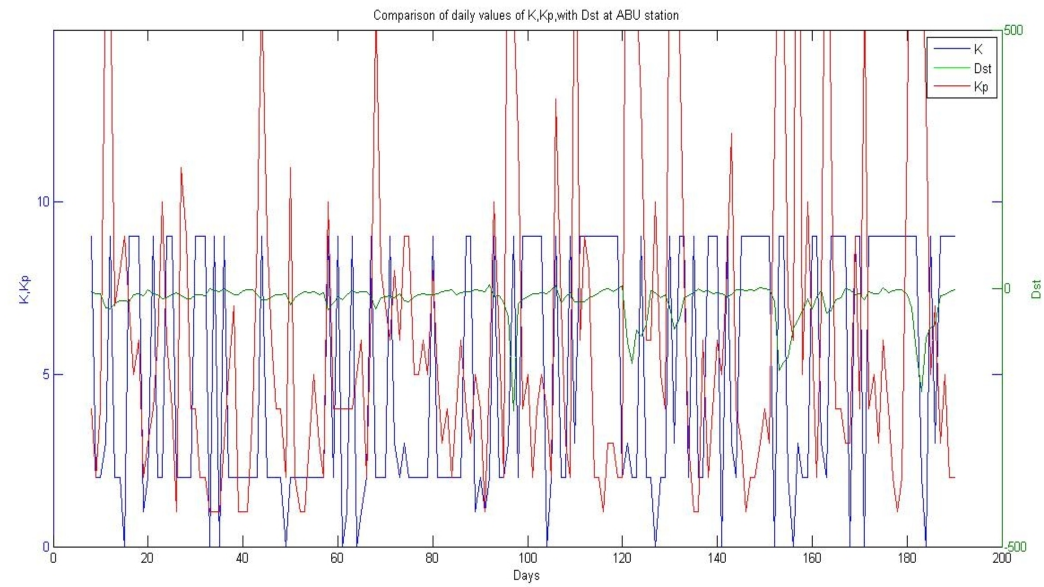

Fig. 2. Daily variations of K, Kp with Dst at ABU Stations

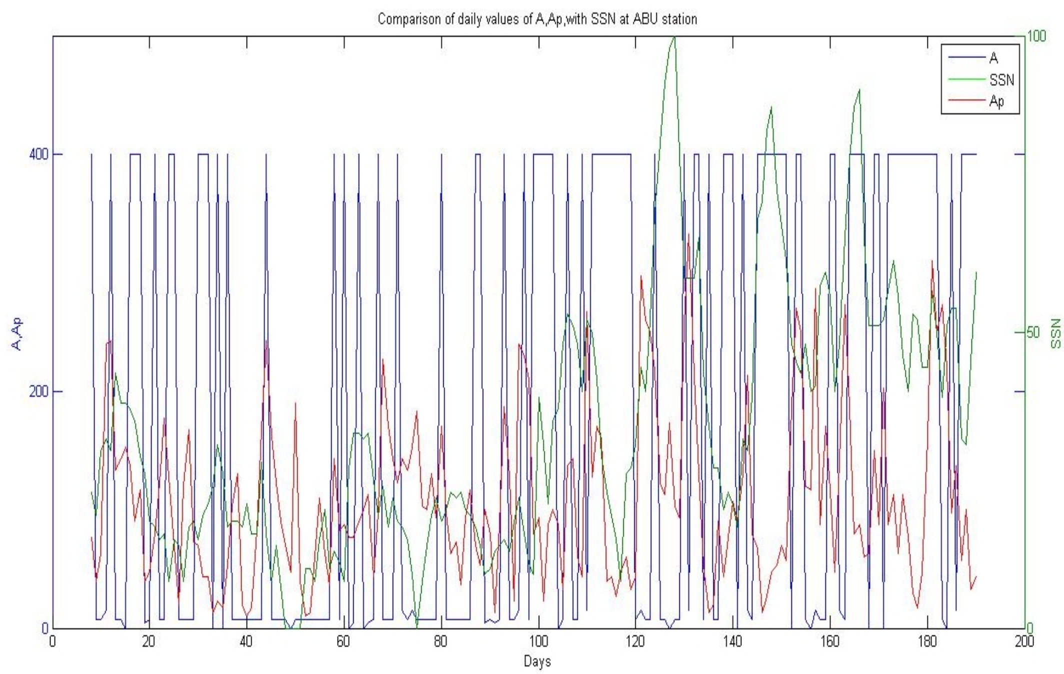

Fig. 3. Daily variations of A, Ap with SSN at ABU Stations

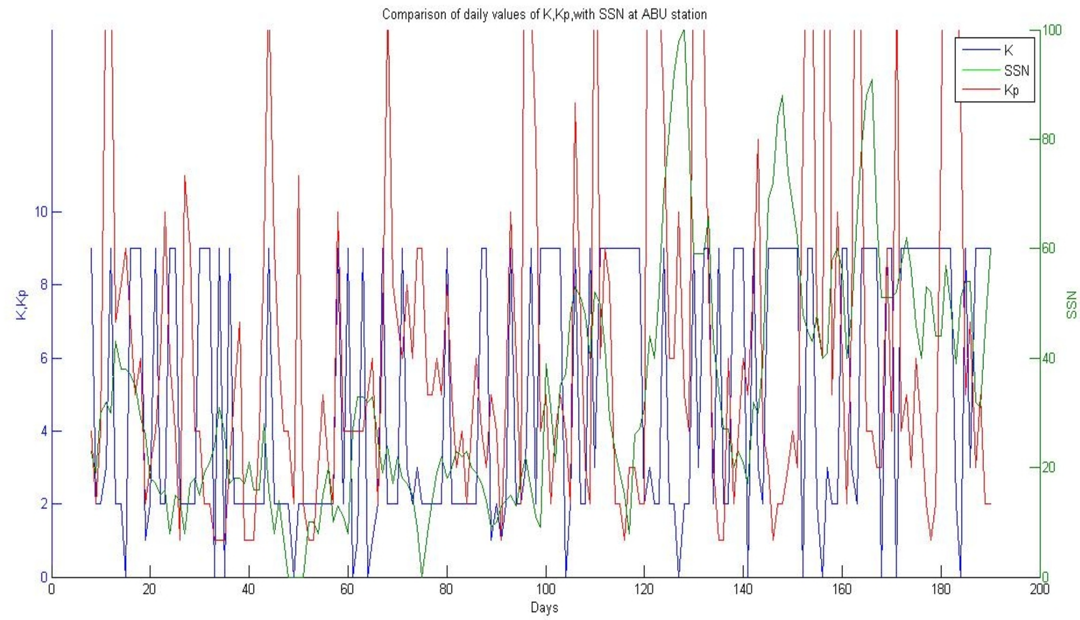

Fig. 4. Daily variations of K, Kp with SSN at ABU Stations

To determine the strength of the relationship between the dependent variables (K, Kp, A, Ap) and independent variables (SSN and Dst), the regression between the variables K, Kp, A, Ap and Dst index shows a negative regression coefficient and vice versa for SSN with a positive regression coefficient. We can safely infer that there is inverse proportionality between SSN and Dst index. This is in consonance with the plots obtained in Figs. 1, 2, 3, and 4. It was same for the respective stations. Dst index is characterized by geomagnetic disturbances lasting several hours, while the *K* and *K*p-indices are dependent on disturbances of shorter periods, this may be the cause of the difference in variations among the indices. Dst index for the stations have a negative linear relationship with K, Kp and A, Ap index. Dst index was relatively stable but there's a likelihood of geomagnetic storms with increase in years since large negative Dst values indicate an increase in the intensity of the ring current (geomagnetic storm). This is due to increased solar activity as we approach another solar cycle. If we take into account the fact that the interplanetary medium affects the geomagnetic activity less during the faster solar wind, we may deduce that the causes of the observed geomagnetic activity are inside the magnetosphere itself at these times [12]. "Unlike the K or Kp indices, which have larger values for more solar activity, smaller *Dst* index values indicate a strong equatorial ring current with high solar activity" [13]. The variation of Dst is higher than that of Ap as shown in Fig. 1. The Ap and Dst indices are highly correlated during the geomagnetic storms mainly because in both cases the ring current is a dominant contributor [14]. There is positive linear variability between K, Kp, A, and Ap indices with Sunspots number (SSN) as seen in Figs. 3 and 4. Sunspots are temporary dark polarized spots on the surface of the sun. They are the centers of activity of the sun. The sunspot number used here serves as the proxy of solar activity. During solar maximums, the sun's magnetic field lines are the most disturbed, this leads to intense geomagnetic storms. Thus there exist a good correlation between geomagnetic storm and solar activity features i.e. sunspot numbers as seen in Table 3.

Table 4. Classification of days

* LOCAL DAYS THAT CORRESPONDS WITH THE INTERNATIONAL QUIET AND DISTURBED DAYS						
Station	**Year**	**Month/Days**	**Quiet Days (QD)**	**Total QD**	**Disturbed Days (DD)**	**Total DD**
ABU	2010	NOV (8-30)	15, 19*	2	18, 12*, 16, 17, 18, 21, 24, 25, 30	9
		DEC (1-31)	3*, 5, 19, 31	4	1, 2, 4, 6, 14*, 28*, 30	7
	2011	JAN (1-31)	3, 1, 4, 28, 30*	5	2, 6, 10, 19*, 26, 27	6
		FEB (1-28)	12	1	1, 5*, 7, 8, 9, 10, 11, 14*, 17, 19, 20, 21,22, 23, 24, 25, 26, 27	18
		MAR (1-31)	7, 21	2	9, 10*, 12, 13, 15, 18, 19, 20, 22, 25, 26, 27, 28, 29, 30, 31	16
		APR (1-30)	1, 5, 17, 20	4	2*, 3, 9, 10, 13, 14, 15, 16, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30*	20
		MAY (1-9)	3	1	1*, 4, 6, 7, 8, 9	6
	2008	OCT (1-31)	3, 8, 13, 14, 15, 16, 21, 2, 6, 9*, 10, 11, 23, 27*	14	ALL OTHER DAYS DISTURBED (29*, 30*)	17
		NOV (1-30)	12, 9, 10, 11, 13, 14*, 16, 17, 18*, 19, 20, 21*, 22*, 24, 29, 30	16	1, 2, 3, 4, 5, 6, 7, 8*, 23, 25*, 26*, 27, 28	13
		DEC (1-31)	5, 6, 7, 9*, 11, 12	6	ALL OTHER DAYS DISTURBED (31*, 23*, 4*)	25
LAG	2009	JAN (1-31)	13, 22*, 16, 17, 21, 23*, 24*	7	ALL OTHER DAYS DISTURBED EXCEPT DAY 30. (3*, 26*, 19*, 1*, 31*)	23
		FEB (1-28)	5, 9, 10*, 15, 20, 2*, 6, 11, 12, 16, 18, 19*, 21, 22, 24, 25, 26, 27	18	1, 3, 4*, 7, 8, 14*, 17	7
		MAR (1-31)	3, 10, 13, 24, 28, 1, 2*, 4, 5, 6*, 7*, 8, 9*, 11, 12, 14, 15, 17, 18*, 19, 21, 22, 23, 25, 30,31	26	NIL	NIL
		APR (1-30)	11, 12, 30, 1, 2*, 4*, 6, 7*, 8, 9, 10, 14, 16, 17, 18, 19, 20, 21, 22, 23*, 25, 26, 27, 28, 29	25	NIL	NIL
		MAY (1-27)	5*, 8, 11, 16, 1, 2, 3, 6, 7, 9, 10, 12*, 15, 17*, 18, 19, 20, 21, 22, 23, 24, 25*	22	27	1

		JUN (19-30)	28, 30, 21, 22*, 26, 29	6	19, 20, 27	3
		JUL (1-31)	9, 22, 23, 30, 31, 1, 2*, 6, 8, 11, 12, 15, 16, 17*, 18*, 19*, 21, 24, 25, 26*, 27, 28, 29	23	3, 4, 5	3
		AUG (1-31)	2, 7, 20, 21, 28, 1, 3, 4, 5, 9, 10, 11, 12, 13, 14, 15*, 17*, 18, 19, 22, 23, 24*, 25, 26, 29*, 30, 31	27	8, 16	2
		SEP (1-18)	2, 3, 1, 5, 6, 7, 8, 9, 14, 15, 16, 17	12	12, 13, 18	3
		OCT (17-21)	NIL	NIL	17, 18, 20, 21	4
	2010	AUG (12-31)	24, 27, 14*, 18, 19, 20, 21*, 22*, 26, 28, 29*, 30*	12	12, 13, 16, 17, 23, 31	6
		SEP (1-30)	1, 2, 5, 13, 23, 27, 3, 4*, 6, 9, 10, 11*, 12*, 15, 17, 19, 20, 21, 22*, 25, 28, 29, 30*	23	NIL	NIL
		OCT (1-31)	4*, 9, 17, 25, 27, 1*, 2*, 3*, 5, 7, 8, 28, 29	13	12*, 13, 14, 16, 18, 19, 20, 21, 22, 31	10
		NOV (1-30)	9, 16, 17, 18, 1, 5, 6*, 7*, 13, 15, 19*, 20, 21, 29	14	2, 3, 4, 25, 30	5
		DEC (1-31)	9, 11*	2	ALL OTHER DAYS DISTURBED (14*, 20*, 28*, 15*, 13*)	29
	2011	JAN (1-31)	NIL	NIL	ALL DAYS DISTURBED (7*, 14*, 13*, 19*, 8*)	
		FEB (1-27)	NIL	NIL	ALL DAYS DISTURBED (4*, 18*, 5*, 6*, 14*)	
		SEP (1-30)	12, 14, 29	3	3, 4*, 5, 7, 8, 10, 13, 18*, 19, 20, 22	11
		OCT (1-31)	15, 29, 3, 18	4	2, 4, 5, 6, 7, 8, 12, 16, 17, 19, 20, 21*, 28, 30, 31	15
		NOV (1-30)	6, 10, 19, 20*, 26, 30, 18*	7	5, 7, 11*, 12, 13, 14, 17, 21, 22, 23, 27, 28, 29	13
		DEC (1-31)	11, 31*, 1, 2*, 9, 17, 29*, 30	8	4, 6*, 7*, 16, 19, 20, 21, 22, 23, 27	10
ILR	2007	JAN (1-31)	4, 13*, 14, 30	4	6, 8, 9, 11, 12, 20, 21, 24, 26, 27, 29*,31	12
		FEB (1-28)	4*, 6, 9, 8, 10, 11, 16, 18, 19	9	1, 2, 3, 7*, 13*, 14*, 15*, 17, 22, 23, 25, 26, 27, 28*	14

	MAR (1-31)	8, 24, 17, 30	4	1, 2, 3, 4, 5, 6*, 14*, 15, 16, 26, 27, 29	12
	AUG (20-31)	23*, 30	2	20, 21, 22, 24, 28, 31	6
	SEP (1-30)	8, 21, 22, 26, 5, 11*, 12*, 16, 23, 24, 25	11	4, 7, 9, 10, 13, 14, 29*, 30	8
	OCT (1-31)	6, 4	2	1, 2, 5, 14, 15, 16, 17, 18, 21, 24, 25*, 26*, 28	13
	NOV (1-30)	2*, 6*, 14, 23, 26, 1, 3*, 5, 17, 18, 21	11	7, 9, 13, 16, 19, 20*, 22, 27, 29	9
	DEC (1-31)	1, 3*, 12, 19, 26, 30, 2, 4*, 6, 7*, 13, 14, 15, 20, 22, 23, 25*	17	8, 10, 21*, 24, 27	5
2008	JAN(1-31)	5, 18, 23, 11, 16, 19, 22*, 24	8	6*, 7*, 21	3
	FEB(1-29)	3, 4, 14, 16, 21, 22*	6	6, 15, 27, 29*	4
	MAR(1-31)	18, 30, 3, 13, 22, 29	6	2, 6, 14, 15	4
	APR(1-30)	2*, 3*, 18, 12, 13, 14*	6	15, 25, 26, 28, 29	5
	MAY(1-31)	1, 6, 9*, 16, 19, 24, 15*, 17*, 26, 27	10	11, 12, 22, 31	4
	JUN(1-30)	2, 4, 7, 10*, 18, 24, 25, 26, 1, 3, 5*, 13, 27, 28, 29, 30	16	8, 14*, 19, 21, 22, 23	6
	JUL(1-31)	1, 16, 17, 19*, 20, 25, 26, 27, 2*, 6, 10, 12, 14, 15, 18, 21, 24, 28, 29, 30	20	3, 4, 5, 7, 13*, 23*, 31	7
	AUG(1-31)	6, 11, 8, 10, 12, 13, 20, 21, 22, 23, 24*, 26*, 30*	13	1, 2, 4, 5, 7, 18*, 19*, 25	8
	SEP(1-30)	21*, 8, 9, 10, 11, 12*, 22, 24*	8	1, 2, 4*, 6, 7*, 13, 14, 16*, 17, 20, 27, 28, 29, 30	14
	OCT(1-31)	4, 5, 11, 8, 9*, 10, 12	7	ALL OTHER DAYS DISTURBED (29*, 3*, 2*, 30*)	24
	NOV(1-30)	3*	1	ALL OTHER DAYS DISTURBED (25*, 8*, 9*, 26*, 16*)	29
	DEC(1-31)	NIL	NIL	ALL DAYS DISTURBED (6*, 31*, 5*, 23*, 4*)	31
2009	JAN(1-31)	NIL	NIL	ALL DAYS DISTURBED (3*, 26*, 19*, 1*, 31*)	31
	FEB(1-28)	NIL	NIL	ALL DAYS DISTURBED (14*, 4*, 27*, 15*, 24*)	28

	MAR(1-31)	NIL	NIL	ALL DAYS DISTURBED (13*, 14*, 8*, 25*, 15*)	31
	APR(1-30)	18, 27, 28, 17, 19, 20, 21, 22, 23*	9	1, 2, 3, 4, 5, 6, 7, 8, 9*, 11*, 10*, 12*, 13, 14, 15, 16, 24, 29, 30	19
	MAY(1-31)	2, 3, 5*, 6, 9, 11, 16, 23, 27*, 31, 10, 12*, 19, 22, 24, 30	16	1, 7*, 13, 14*, 15, 17, 18, 20, 21, 25, 28*	11
	JUN(1-30)	4, 7, 1*, 2, 5, 6, 11, 18, 22*	9	9, 10, 12, 14, 15, 16, 17, 19, 20, 21*, 24*, 25*, 26	13
	JUL(1-31)	1, 2*, 6, 26*, 29, 4, 5, 12, 19*, 28	10	3, 7, 8, 9, 13*, 14*, 15, 16, 17, 18, 20, 21, 22*, 24, 31	15
	AUG(1-31)	12, 15*, 29*, 31, 4, 11, 14, 16*, 17*, 18, 21, 22, 23, 24*, 26, 28	16	3, 5, 6*, 7, 8, 9, 10, 13, 25	9
	SEP(1-30)	15, 18, 19*, 5, 6, 7, 9, 12, 16, 24*, 25*, 29*	12	1, 3, 4*, 10, 20, 28*, 30	7
	OCT(1-22)	3*, 10*, 18, 1, 12, 13, 14*, 16, 17*, 19	10	2, 5, 6, 15, 20, 22*	6

Just before, during and just after the peak of a Sunspot Cycle, the increased number of sunspots sends more ultraviolet radiation to impact Earth's ionosphere. This results in much greater ionization of the F region of Earth's atmosphere that allows the ionosphere to refract higher radio frequencies back to Earth. On the other hand, around the minimum time of a Sunspot Cycle, the number of sunspots is so low that higher frequencies generated on the surface of Earth travel up and pass right on through Earth's ionosphere into outer space. That is, there is less absorption and a more stable ionosphere, resulting in the best propagation on lower frequencies. High SSNs are best for high frequency propagation while low SSNs are best for low frequency propagation [15]. Sometimes changes in the sun's activity can cause big changes in Kp. At other times, large Kp values can indicate sudden rearrangements of the Earth's magnetic field due to the solar wind.

In order to deduce the possible state of radio propagation, the daily data was classified into quiet and disturbed days as shown in Table 4 using the locally generated K and A magnetic indices. From Table 2, it can be seen that K index values of 0 and 1 and A index values of 0 and 4 indicates quiet conditions while K index values of 8 and 9 and A index values of 208 and 400 indicates disturbed conditions. The days are classified in order of sequence. The asterisk (*) sign signifies the local quiet and disturbed days that correspond to the international quiet and disturbed days. All days for the months of March, April 2009 and September 2010 were observed to be quiet for the LAG station and disturbed for the months of October 2009, January and February 2011. For the ILR station, August (2006), December (2008), January, February and March (2009) were observed to be disturbed. Expressing the quiet and disturbed days as a percentage for the observed stations, 31.85% of the days were found to be quiet while 39.36% of the days were found to be disturbed.

The extensive study of the geomagnetic storm effects in the ionosphere and thermosphere has revealed the primary physical mechanisms responsible for generating the large disturbances that are observed to occur in the ionosphere. Electric fields, thermospheric meridional winds and changes in the neutral gas composition are probable physical mechanisms to explain the *F*2 -region reaction to geomagnetic disturbances [16,17,18]. According to [19], the primary drivers of the ionospheric response to recurrent geomagnetic activity are thought to be changes in thermospheric neutral composition, temperature, and winds as well as auroral energetic particle precipitation. [20] Asserts that Scottish physicist Balfour Steward (1882) suggested that, the continuous but minor variations in earth's magnetic field might be caused by the presence of a layer of air capable of conducting electricity in the upper atmosphere. Movement of this layer in the terrestrial field could produce electric currents by dynamo effects; these currents could in turn generate magnetic fields which would be superimposed upon the normal magnetic field observed at the earth's surface since the ionosphere varies greatly because of changes in the sources of ionization and because it responds to changes in the neutral part of the upper atmosphere in which it is embedded. Since it responds to solar EUV radiation, the ionosphere varies over the 24-hour period between day and night time and over the 11-year cycle of solar activity [21].

4. CONCLUSION

It is safe to infer that the geomagnetic field near the surface of the Earth varies under the influence of solar wind. The observed variations in the geomagnetic field responsible for the characteristics of the ionosphere comes from two principal sources, namely, transient variations - those generated by atmospheric processes such as ultraviolet radiation from the sun and partly by secular variations, which are due to internal disturbances within the Earth. These variations can be attributed to Ionospheric current systems which are being driven by

Ionospheric tides which blow the ionized air across the lines of force of the geomagnetic field thereby generating electric fields to drive the electric current. The long-term variations are due to changes in the dynamo region, while the shorter term variations have their origin in electric current systems in the upper atmosphere and magnetosphere. Using Indicators of geomagnetic indices, locally generated K and A daily data was classified into quiet and disturbed days to manually deduce what the conditions of the ionosphere may be like and hence deduce the possible state of radio propagation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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