Original Research Article

STATISTICAL ANALYSIS ON THE IMPACT OF TROPOSPHERIC TEMPERATURE AND RELATIVE HUMIDITY ON DOWNLINK SATELLITE COMMUNICATION SYSTEM OVER WARRI, DELTA STATE

ABSTRACT

This study was aimed at analyzing the effect of temperature and relative humidity on downlink satellite communication systems over Warri, in Delta State, Nigeria. The data used in this study were temperature, relative humidity and radio signal strength (RSS) obtained from the Nigeria Meteorological Agency (NIMET) for the years 2018 and 2019 respectively, both from January to December. Davis Vantage Vue weather station was used to measure the temperature and relative humidity while Spectrum analyzer was used to measure RSS. Both instruments were set to function simultaneously. Results obtained for all the months shows that the level of radio signal strength under the influence of temperature is higher either RSS ≥ 65% compare to that of relative humidity either RSS ≤ 64% which also fluctuate the level of RSS on daily basis, throughout the years under review. It was realized that there is a variation in the refractive index of the medium through which the radiowaves are propagated, due to the variations in the temperature and relative humidity, these adversely affect the received signals strength over the downlink satellite communication systems.

Keywords: Troposphere, Temperature, Relative Humidity, Satellite Communication, Downlink Signal.

1. INTRODUCTION

Satellite communication is attracting more attention now than ever before because of its rapid deployments, larger bandwidths, and the capability of providing ubiquitous communications. One of the pre-requisite task of deploying satellite communication is the link budget calculation, which involves determining elevation angle, pointing loss, free space loss, fade margin for rain attenuation, cross-polarization due to rain, and atmospheric scintillations among others (Muhammad and Muhammad, 2015).

Radio waves are explained by their wave length which makes it possible to distinguish them as short waves, medium waves or millimeter wave. Generally it is observed that the higher the frequency of the radiowaves the smaller the wavelength requires a shorter antenna length and lower bandwidth efficiency which makes them susceptible to fading and thermal (temperature) and weather changes (humidity), but are less to atmospheric electrostatics,(Haliday, *et alI*,2015). Radio waves are produced by electrical oscillations and can be detected by resonant circuits in radio receivers. The reception process of radio wave involves a reverse process from the one that created the electromagnetic waves. When radio waves are broadcast they reach the receiving antennae and interact with the electric charges in the antennae wire. They are mostly in electric and magnetic fields of which either of them can be used (Cutnell, *et al*, 2016).

In the propagation of these radiowaves over a wide range of distances some setbacks such as attenuation are encountered which in most cases make the received signal noisy and unreasonable. Thus to improve on the signal quality of these received signals satellite communication systems are deployed to improve signal strength at the receiver end (Okechukwu, 2017).

Satellite links are used to provide communications over very large distances (global coverage). A ground station relays a signal up to theSatellite at a frequency known as the uplink frequency; the satellite receives this signal andre-broadcasts it on a downlink frequency to another ground station. If digital communicationssignaling is used; the signal may be regenerated before it is re-transmitted to Earth (Sean, 2015*)*.

In satellite communications, radio wave propagation is concerned mainly with the properties and effects of the medium situated between the transmitting and receiving antennas. Radio waves propagating within the Earth's atmosphere are affected by varying weather conditions either temperature, relative humidity among others. It would not be possible for radio communications signals to travel around the globe greater than the line of sight distance at higher frequencies or on the short wave bands, without the action of the atmosphere.

The troposphere is the most important region of the atmosphere as far as VHF and UHF radio waves are concerned. It is the lower layer of the atmosphere surrounding the earth that extends to a height of approximately 10 km above the sea level. All weather on earth occurs in the troposphere during normal conditions. The temperature decreases as height increases, and generally drops with increased altitude at about 10°C per km until the tropopause is reached, the point at which the atmospheric temperature begins to rise with altitude(Zhimwang et al., 2017).

The troposphere contains 99 % of the water vapour in the atmosphere. Water vapour concentrations vary with latitudinal position (north to south). They are greatest above the tropics, where they might be as high as 3 % and decrease toward the Polar Regions. Water in any state is an obstacle in the link of the electromagnetic wave. When the wave passes through the water particles, a part of its energy is absorbed and a part is scattered. Therefore the electromagnetic wave (radio wave) is attenuated. Prediction of the influence of these factors is very important in radio system design (Amajama, 2016).

Humidity is one of the elements that characterize the atmosphere; hence it plays an important role in the propagation of signal. Atmospheric humidity, which is the water content of the atmosphere, affects the permeability and permittivity of the atmosphere, since water has a different permeability and permittivity from free space or vacuum. Hence, atmospheric humidity has a force on radio signal, since they are electromagnetic waves. The propagation of electromagnetic waves is influenced by the permeability and permittivity of the medium in which they travel (Amajama, 2016).

Radio wave propagation is concerned mainly with the properties and effects of the medium situated between the transmitting and receiving antennas. Radio wave propagation within the troposphere are affected by various conditions such as temperature and relative Humidity among others.The effect of weather conditions on satellite links quality (especially signal strength) as observed by the breakages of audio and video signals have been explored in quite a few studies.

However, no clear consensus has been achieved so far. Some studies report that temperature is the dominating factor affecting Signal strength while others claim that relative Humidity is the main reason. With this contradictory results and conclusions, there seems to be a need for further studies hence the purpose of this study.

The conventional way of characterizing the satellite link behavior using bent-pipe transponders is to use carrier-to-noise ratio (C/N). The C/N ratio represents the dB difference between the desired carrier signal power and the undesired noise power at the receiver. It also indicates the received signal quality for both analog and digital transmissions. In satellite communication systems, the C/N calculation is often called a link power budget. The C/N calculation in decibel is shown in equation (1)

$$\left.\frac{C}{N}\right| dB = (P_t + G_t + G_r - L_P - A) - (K + T_n + B) - other\ losses(dB) \qquad (1)$$

Where P_t is transmitted power (dB)
G_t is gain of transmitting antennae
$G_r$is receiving antennae gain of the satellite
$L_p$path loss $10\log_{\left(4\pi R/_{\lambda}\right)} 2$ (dB)
A is rain attenuation (dB)
R is transmission distance (m)
λ is wavelength of signal (m)
K is Boltmann's constant = $1.38 \times 10^{-23}\ {}^{J}/_{K}$

T_n is noise constant (dBk) = 290k
B is noise bandwidth in which noise is measured (dBH$_Z$).

Other Losses such as Antenna pointing Losses, Atmospheric gaseous Losses, Power Amplifier back-Off, Link margin are also there. But these losses can be ignored in comparison to losses mentioned above.

The downlink carrier-to-noise ratio for the frequency translation satellite is found by following the same procedure that was used for the uplink, using the equivalent downlink parameters. Thus, at point (D)

$$C_{GR} = \frac{P_{ST}\, G_{ST} G_{GR}}{L_{DN} A_{DN}} \qquad (2)$$

$$\left(\frac{C}{n}\right)_{DN} = \frac{C_{GR}}{n_{GR}} = \frac{P_{ST}\,G_{ST}\,G_{GR}}{L_{DN}\,A_{DN}\,K\left[t_{DN}\left(1-\frac{1}{A_{DN}}\right)+t_{GA}\right]+290(nF_{GR}\;-1)b_{DN}} \qquad (3)$$

This result gives the downlink carrier-to-noise ratio expressed in a form where the downlink path losses and noise contributions are exclusively displayed

1.0 METHODOLOGY

The study was carried out in Warri, Delta State which lies on latitude 5.554^0N and longitude 5.793^0E with a tropical climate. Rainfall is significant most months of the year, and the short dry season has little effect. The mean annual temperature is 32.8°C, and annual rainfall amount is 3000 mm, rainfall period is between January to December, with the minimum value of 8.2 mm in January and over 536.6 mm in September. The data used in this study were temperature, relative humidity and radio signal strength (RSS) obtained from the Nigeria Meteorological Agency (NIMET) for the year 2018 and 2019, both from January to December. Davis Vantage Vue weather station was used to measured temperature and relative humidity while Spectrum analyzer was used to measure RSS. Both instruments were set to function simultaneously.RSS, temperature and relative humidity measurements were done concurrently and data were recorded at one minute integration time.

Radio propagation is influenced by the regions of the atmosphere through which the signal passes. The higher the altitude, the lower the temperature and intense relative humidity will be. This affects the refractive index of the air which in turn, affects the propagation signal.

Radio waves are often refracted by areas where the refractive index gradually changes. This occurs as the radio waves propagate through the atmosphere where small changes in refractive index. The refractive index of the air is higher close to the earth's surface falling slightly with height. The refractive index n of the atmosphere depends on the atmospheric pressure, temperature, relative humidity and water vapor pressure.

Therefore, the combine effect of temperature and relative humidity on radio signal was obtained using ITU-R recommendation P.453-11as shown below:

$$n = 1 + N \times 10^{-6} \qquad (4)$$

where the radio refractivity, N, is:

$$N = 77.6\frac{P_d}{T} + 72\frac{e}{T} + 3.75 \times 10^5\,\frac{e}{T^2} \qquad (5)$$

where:

e: water vapour pressure (mb) =$\frac{H}{5.752}$; H is relative humidity in (%)

P_d: dry atmospheric pressure (hPa)

P: total atmospheric pressure (hPa)

T: absolute temperature (K)

$$P = P_d + e \tag{6}$$

Since $P_d = P - e$, equation (6) can be rewritten as:

$$N = 77.6\frac{P}{T} - 5.6\frac{e}{T} + 3.75 \times 10^5 \frac{e}{T^2} \tag{7}$$

Where P is the atmospheric pressure, T is the absolute temperature in degree Kelvin and e is the partial pressure due to water vapor. The value of N varies with altitude since pressure; temperature and humidity normally decrease exponentially with height.

Water vapour pressure (e) is expanded as follows:

$$e = \frac{H}{5.752}\left[\theta^6 \times 10^{(10-9.834\theta)}\right] \tag{8}$$

Where H is the relative humidity in %, θ is the inverse temperature constant given as

$$\theta = \frac{300}{T}, \text{ T is temperature in Kelvin} \tag{9}$$

Given P_d =985hPa, the values of water vapour pressure, atmospheric pressure and refractive index were calculated for each of the day, month and year under study.

From equation (8), the water vapour pressure for day 1 of January 2018 is

$$e = \frac{76}{5.752}\left[\theta^6 \times 10^{(10-9.834\theta)}\right] \qquad \text{but}\theta = \frac{300}{303.45} = 0.988$$

$$e = \frac{76}{5.752}\left[0.988^6 \times 10^{(10-9.834\times0.988)}\right] = 23.389mb$$

From equation (6), the atmospheric pressure for day 1 of January 2018 is calculated as

$P = P_d + e = 985 + 23.389 = 1008.34$

From equation (7),

$$N = 77.6\frac{1008.4}{303.45} - 5.6\frac{23.289}{303.45} + 3.75 \times 10^5 \frac{23.289}{303.45^2} = 358.67$$

From equation (4), the refractive index for day 1 of January 2018 is

$$n = 1 + 358.67 \times 10^{-6} = 1.0004$$

The same steps was used to obtained the refractive index of the other days and months in 2018 and 2019 and presented in table 1 to

2.0 RESULTS

The results obtained from this study were determined based on ITU-R recommendation RA.769-2 and P.453-11. Impact of tropospheric temperature and relative humidity on radio signal strength were estimated on daily basis for each of the month and year under review while the combine effects of temperature and relative humidity were calculated on monthly basis for both the year 2018 and 2019.

Table 1: Impact of Temperature and Relative humidity on RSS for the month of January 2018

DAYS	IMPACT OF TEMPERATURE		IMPACT OF RELATIVE HUMIDITY	
	Temperature (K)	Signal Strength (%)	Relative Humidity (%)	Signal Strength (%)
1	303.45	68	76	56
2	303	68	78	57
3	302.1	67	77	57
4	302.9	67	77	56
5	303.35	67	76	57
6	302.5	66	78	62
7	303.15	67	75	57
8	302.1	67	76	64
9	303	68	77	61
10	303.4	68	75	57
11	302.5	68	75	56
12	302.1	67	75	60
13	302.5	68	78	56
14	303.4	67	77	56
15	302.95	66	76	56
16	302.05	66	76	57
17	302.9	67	78	56
18	303.4	66	76	65

19	302.6	66	75	64
20	303.3	66	78	62
21	302.3	66	77	56
22	303.25	67	76	56
23	303.6	67	74	57
24	302.75	66	76	56
25	302.3	67	78	58
26	302.75	67	76	57
27	302.45	68	75	57
28	303.35	66	77	57
29	303.7	67	78	58
30	302.85	66	78	58
31	302.4	66	76	56

Table 2: Impact of Temperature and Relative humidity on RSS for the month of February 2018

DAYS	IMPACT OF TEMPERATURE		IMPACT OF RELATIVE HUMIDITY	
	Temperature (K)	Signal Strength (%)	Relative Humidity (%)	Signal Strength (%)
1	301.9	66	74	59
2	302.0	67	73	59
3	302.0	67	73	60
4	302.1	68	73	58
5	302.1	68	74	59
6	302.1	68	72	60
7	302.2	67	71	60
8	302.2	68	72	59
9	302.2	67	71	61
10	302.3	66	72	60
11	302.3	66	72	59
12	302.3	67	70	61
13	302.4	66	72	60
14	302.5	65	70	62
15	302.3	65	69	62
16	302.1	66	71	60
17	302.3	67	69	65
18	302.7	65	67	63

19	302.5	68	68	64
20	302.5	67	67	65
21	302.4	65	66	65
22	302.5	66	68	65
23	302.3	66	68	64
24	302.4	65	68	64
25	302.4	68	68	63
26	302.2	66	68	64
27	302.2	68	69	63
28	302.4	66	69	64

Table 3: Impact of Temperature and Relative humidity on RSS for the month of March, 2018

DAYS	**IMPACT OF TEMPERATURE**		**IMPACT OF RELATIVE HUMIDITY**	
	Temperature (K)	**Signal Strength (%)**	**Relative Humidity (%)**	**Signal Strength (%)**
1	301.60	65	72	57
2	301.70	64	73	56
3	301.70	65	73	57
4	301.80	66	74	57
5	301.80	64	75	56
6	301.90	65	75	55
7	301.90	66	75	55
8	302.00	64	75	57
9	301.90	65	75	56
10	302.00	63	75	55
11	302.00	64	76	55
12	302.10	65	75	55
13	302.10	66	75	56
14	302.10	65	76	55
15	302.10	66	76	55
16	302.10	64	76	55
17	302.10	65	76	56
18	302.00	65	76	57

19	302.00	65	76	56
20	302.00	65	76	57
21	302.00	66	76	57
22	302.00	65	76	56
23	302.00	64	76	55
24	302.00	65	76	57
25	302.00	66	76	57
26	302.00	65	76	56
27	302.00	65	76	55
28	302.00	65	76	56
29	302.00	64	76	55
30	301.90	64	76	56
31	301.80	65	76	55

Table 4: Impact of Temperature and Relative humidity on RSS for the month of July 2018

DAYS	**IMPACT OF TEMPERATURE**		**IMPACT OF RELATIVE HUMIDITY**	
	Temperature (K)	**Signal Strength (%)**	**Relative Humidity (%)**	**Signal Strength (%)**
1	299.25	62	83	49
2	299.25	62	84	49
3	299.2	62	84	49
4	299.2	62	84	49
5	299.15	62	82	49
6	299.05	61	84	49
7	299	62	82	47
8	299	61	83	49
9	298.95	61	83	49
10	298.9	62	83	49
11	298.9	61	85	49
12	298.9	62	84	48
13	299.35	61	85	47
14	299.2	62	85	47
15	299.15	60	83	49
16	299.05	61	84	49

17	299.05	60	83	50
18	299.05	62	82	49
19	298.95	62	84	50
20	298.95	62	84	50
21	298.9	61	85	48
22	298.65	60	85	50
23	298.55	62	85	47
24	298.55	61	86	49
25	298.45	60	84	48
26	298.4	62	82	50
27	297.75	60	86	47
28	297.7	61	86	49
29	297.45	62	85	49
30	297.4	61	85	49
31	297.35	61	85	49

Table 5: Impact of Temperature and Relative humidity on RSS for August 2018

DAYS	**IMPACT OF TEMPERATURE**		**IMPACT OF RELATIVE HUMIDITY**	
	Temperature (K)	**Signal Strength (%)**	**Relative Humidity (%)**	**Signal Strength (%)**
1	298.95	64	87	50
2	299.05	65	87	50
3	299.05	64	87	51
4	299.1	64	87	50
5	299.1	65	88	51
6	299.15	64	88	51
7	299.15	65	88	50
8	299.15	64	88	50
9	299.2	65	88	50
10	299.15	63	88	50
11	298.65	64	88	51
12	298.7	65	88	51
13	297.85	64	88	51
14	297.95	64	89	51

15	298	64	89	51
16	298.05	65	89	51
17	298.05	65	89	51
18	298.45	65	89	51
19	298.4	64	89	51
20	298.45	64	89	53
21	298.5	65	90	53
22	298.5	64	90	54
23	298.5	64	88	53
24	298.55	65	87	51
25	298.6	66	86	51
26	298.65	65	85	49
27	298.55	66	86	50
28	298.8	66	87	49
29	298.85	67	87	49
30	298.85	65	86	49
31	298.8	65	86	49

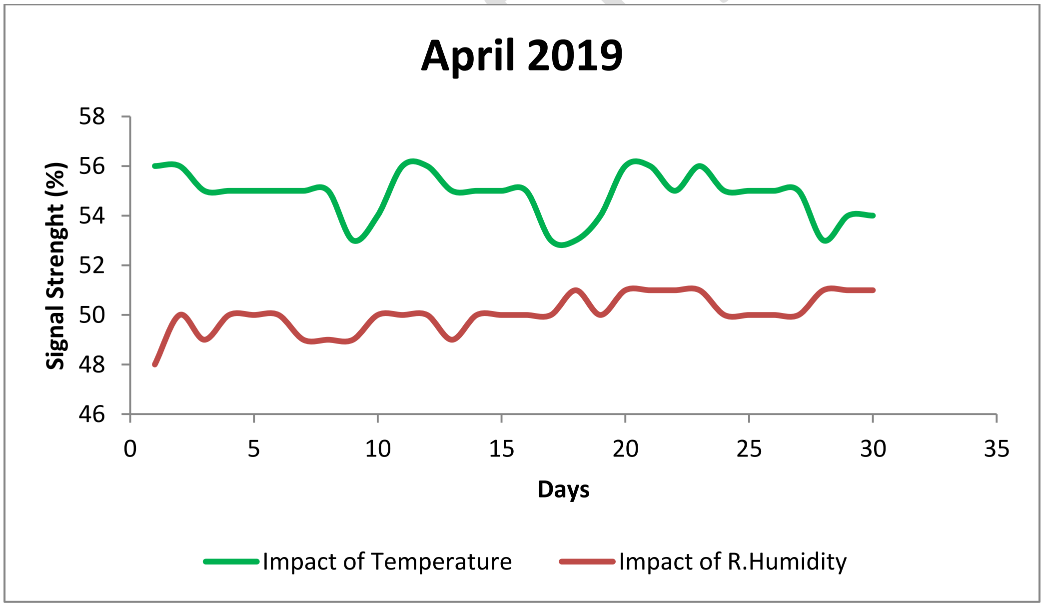

Figure 1: Comparing the effects of Temperature and Relative humidity on RSS for April, 2019.

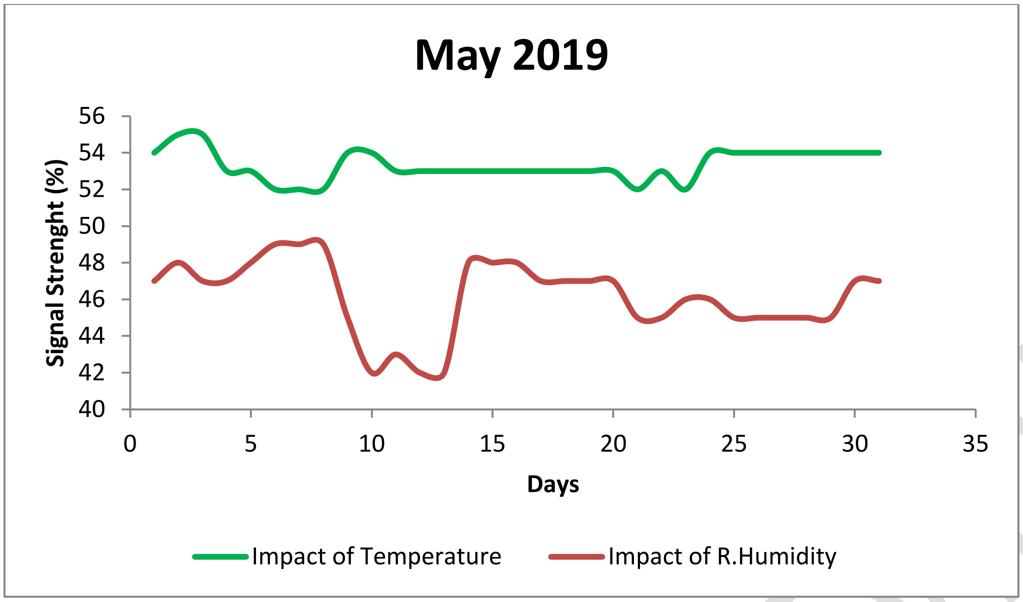

Figure 2: Comparing the effects of Temperature and Relative humidity on RSS for May, 2019.

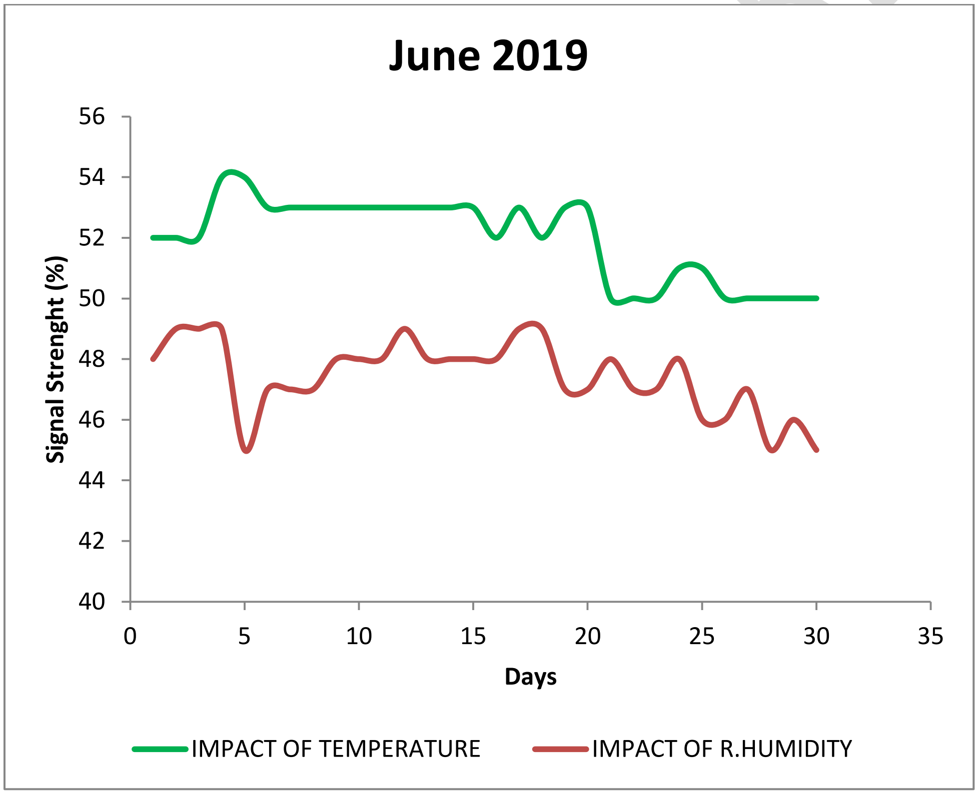

Figure 3: Comparing the effects of Temperature and Relative humidity on RSS for June, 2019

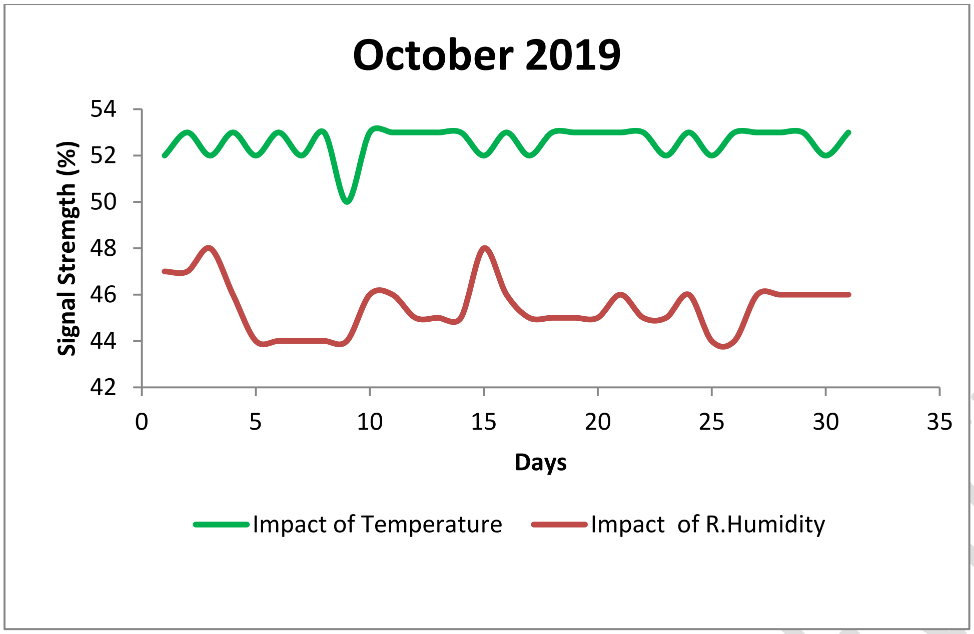

Figure 4: Comparing the effects of Temperature and Relative humidity on RSS for October 2019

3.0 DISCUSSIONS

Table 1 presents the impact of Temperature and Relative humidity on RSS for the month of January 2018. The result shows that the month of January 2018 recorded 302.85K and 76.45% as average temperature and relative humidity respectively. The level of RSS under the influence of temperature is RSS ≥ 65% andthat of relative humidity is RSS ≤ 64%. This revealed that 35% and 26%of the signal was loss due to variation in temperature and relative humidity respectively.

Table 2 presents the impact of Temperature and Relative humidity on RSS for the month of February 2018. The result shows that the month of February 2018 recorded 302.26K and 70.14% as average temperature and relative humidity respectively. The level of RSS under the influence of temperature is RSS ≥ 65% compare to that of relative humidity either RSS ≤ 65%.

Table 3 presents the impact of Temperature and Relative humidity on RSS for the month of March, 2018. The result shows that the month of March, 2018 recorded 301.90K and 75.40% as average temperature and relative humidity respectively. The result further shows that the level of

RSS under the influence of temperature is higher either RSS ≥ 65% compare to that of relative humidity either RSS ≤ 64% which also fluctuate the level of RSS on daily basis.

Table 4 presents the impact of Temperature and Relative humidity on RSS for the month of July 2018. The result shows that the month of July, 2018 recorded 298.73K and 61.32% as average temperature and relative humidity respectively. The result further shows that the level of RSS under the influence of temperature is higher either RSS ≥ 65% compare to that of relative humidity either RSS ≤ 64% which also fluctuate the level of RSS on daily basis.

Table 5 presents the impact of Temperature and Relative humidity on RSS for the month of August 2018 while figure 8compares the effect of temperature and relative humidity on RSS. The result shows that the month of August, 2018 recorded 298.67K and 87.77% as average temperature and relative humidity respectively. The result further shows that the level of RSS under the influence of temperature is higher either RSS ≥ 65% compare to that of relative humidity either RSS ≤ 64% which also fluctuate the level of RSS on daily basis.

Figure 1, 2, 3 and 4 compares the effects of Temperature and Relative humidity on RSS for the months of April, May, June and October 2019. The results shows that the level of RSS under the influence of Relative humidity is more severe compare to the influence of temperature.

4.0 CONCLUSIONS

The determination and comparison of the impact of tropospheric temperature with that of relative humidity on radio received signal strength as well as estimating the combine effect of temperature and relative humidity on radio signal propagation was achieved. Results obtained for all the months shows that the level of radio signal strength under the influence of temperature is higher either RSS ≥ 65% compare to that of relative humidity either RSS ≤ 64% which also fluctuate the level of RSS on daily basis.The result further reveals that the refractive index (n) calculated for the study area is above the standard and accepted value (N =1). This is due to the increase and constant variation in the temperature and relative humidity within the study area. According to ITU-Recommendation, increase in the value of N will always lead to propagation impairments known as super- refraction which mostly affects radio signal and then lead to signal interference.

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