TRANSACTIONS ON
ELECTROMAGNETIC
SPECTRUM

Analysis and characterization of Inter-Events of Ku-Band Satellite Signals Over a Mountainous Region in Ikere-Ekiti, Nigeria

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Received: 12 January 2024
Revised: 18 February 2024
Accepted: 25 February 2024

Research Article
Vol.3 / No.2 / 2024
Doi: 10.5281/zenodo.10728176

Abstract: Analysis and characterization of a 10-month measurement of Ku-band signals and rain rate events over a mountainous location, Ikere Ekiti (7.4991° N, 5.2319° E), in southwestern Nigeria is presented. The Ku-band at a signal frequency of 12.245 GHz from the EUTELSAT W4/W7 Satellite was at an orbital location of 36.0°E, and horizontal polarization was made along concurrent rain rate events using an automatic weather station. The characteristics of inter-event signals during rainfall events were examined at different periods of the year, seasonally and diurnally, to ascertain the level of signal degradation. It was found that signals suffer more degradation during the intense rainy period, which covers nearly half of the year. Based on time series, the highest occurrence of a rain rate of 150 mm/hr was observed in September, with a corresponding attenuation of about 25 dB. When the measured rain rate was compared with the ITU-R value at 0.01% exceedance, it was found that the ITU-R value showed a deviation up to 15.2% from the actual measurement. In addition to the effect of multipath fading due to the mountainous terrain, a significant value of about 25 dB will be required to compensate for signal loss in Ikere to achieve good quality of signal, especially during the daytime.

Keywords: Rain attenuation; inter-events analysis; mountainous region; Ku-band signals; seasonal variation.

Cite this paper as: Omole OV, Gbenro SO, Oludare , EO, Agbele AT. Analysis and characterization of Inter-Events of Ku-Band Satellite Signals Over a Mountainous Region in Ikere-Ekiti, Nigeria. *Transactions On Electromagnetic Spectrum* 2024; 3(2): 59-66, Doi: 10.5281/zenodo.10728176

1. INTRODUCTION

For the purpose of receiving signals from satellite systems operating in the Ku band, advances in high-capacity satellite (HCS) technology have made the use of satellite digital television essential. Direct-to-home satellite TV, high-speed data transfer, High-Definition Multimedia Services (HDMS), and other innovations have all been made possible using HCS technology. In the same way, the development of wireless communication technologies such as mobile phones, which have become a part of our daily lives, and other services offered such as telemedicine, security networking, and tele-education in addition to data transmission are all routed through HCS [1]. Therefore, technology design, deployment, and management methods are required for better fixed and satellite network or service performance. The propagation medium is essential for determining the effectiveness, availability, and quality of satellite services because studies have shown that the atmosphere's influence on electromagnetic waves tends to increase with frequency [2,3]. Compared to temperate locations, the climatology of the Nigerian environment is complex. As a result, a typical location like Ikere-Ekiti, Nigeria, will be used for the real-time measurement of climatological variables such as the distribution of rain accumulation and the time series of rain-induced attenuation, among others. Because of the location's peculiarities, including its mountainous topography and undulating landscape, which have historically led to poor communication, network systems for both fixed and mobile terrestrial connections have been the reason for picking this particular location. An appropriate Ku-band satellite mitigation method has been identified from the investigation.

The advent of satellite-based digital communication has accelerated the development of small-size communication services, such as end-to-end services with extremely small apertures and terminals with ultra-small apertures for multimedia services [4-6]. Low-frequency C-bands have become extremely congested as the use of satellite services has grown in popularity. Therefore, complete acceptance of the Ku frequency bands is necessary to deliver satellite television and high-speed data services to both rural and urban areas.

The Ku frequency band satellite systems have a number of benefits over the C-band satellite networks that are currently in use. One of these benefits is the reduction of congestion in the lower frequency bands, which are typically utilized by terrestrial lines. The capacity to leverage wider bandwidths also makes spectrum conservation measures more affordable to execute and enables the geostationary arc to be used more effectively. Additionally, compared to antennas of comparable size operating at lower frequencies, Ku-band antennas have better gain. It also offers a new spectral environment, which will enable the deployment of new and advanced satellite system architectures with new features [7-10].

Interestingly, the impact of the atmosphere on electromagnetic wave propagation has an effect on its frequency. An in-depth understanding of this impact is necessary so that the Ku-band channels can be fully utilized. Unfortunately, many factors impair satellite communication networks operating at the Ku and other higher frequency bands. These factors include rain attenuation, gaseous absorption, cloud attenuation, melting layer attenuation, and tropospheric scintillation, to mention but a few. Among these factors, those associated with hydrometeors in the form of liquid water dominate the influence of the atmosphere on space-to-Earth and Earth-space satellite transmission links. The raindrop size distribution (DSD) plays a very important role in meteorology (determination of radar reflectivity and consequently rain rate, classification of precipitation, flood prediction), thereby affecting microwave radio-communication (determination of rain attenuation), among others.

The modeling of rain attenuation on satellite paths has been extensively researched by multiple groups. These models can generally be categorized into two types: physical methods and empirical methods. Physical methods describe the behavior of storms and other physical phenomena, while empirical methods rely on measurements from a database. Notable scholars in the field of propagation studies, such as [11-14,18]; have contributed to this area of research. Attenuation due to rain is always obtained through prediction methods based on the 1-minute rain rate, which may not justify the true state of the attenuation (dB) actually needed by the system engineers for link design. The rain attenuation experienced at Ku-band has a dominant effect on signal attenuation in space as well as cloud attenuation [15-16]. In Ref. [7] opined that a slight difference in the atmospheric condition has a significant effect on earth-sky channel performance, especially at frequencies above 10 GHz. The ultimate goal of this research is, therefore, to provide detailed mechanistic and structural information on inter-events of rain attenuation and the influence of signal propagation, especially at Ku-band. The information is vital for the design of communication terrestrial and satellite signals, especially in a mountainous region like Ikere Ekiti, which is the study location. This will improve the quality of signals (QoS) in hilly environments like the study station. It will also improve the QoS of the existing satellite services in the sub-region [17].

2. DATA ACQUISITION AND ANALYSIS ADOPTED

Over the years, the College of Education, Ikere-Ekiti (7.4991° N, 5.2319° E) (now Bamidele Olumilua University of Education, Science and Technology, Ikere, (BOUESTI) in particular, and most of the town have experienced fluctuations and poor networks in the telecommunication broadband systems due to the topography of the institution. The institution is situated in between the top hills, which contributed immensely to this challenge. Consequently, there is a need to carry out a real-time measurement of signal attenuation and to propose suitable mitigation measures, especially for an area like BOUESTI and the Ikere-Ekiti community at large, which is one of the largest communities in Ekiti State. The city is also very close to the capital city of Ekiti State (Ado-Ekiti), where most people working in the capital city reside. Since the topographical terrain does not favor both fixed and mobile wireless communication networks, a drastic measure must be put in place to resolve the problem of erratic network services in the area that this research is attempting to resolve, among others.

In order to accomplish the established goals, a satellite dish has been installed at a designated location within the Physics Department, BOUESTI (7.4991° N, 5.2319° E), with an elevation of 42^0 E. The purpose of this dish is to receive signals from the EUTELSAT W4/W7 satellite positioned at an orbital location of 036.0 ^{0}E longitude, operating at a frequency of 12.245 GHz. The Vantage Vue weather station was used alongside the Garmin Handheld Global Positioning Station (GPS) to generate the needed data. The indoor units (placed with one of the physics labs) are made up of a Ku-band data logger, an integrated sensors suite logger, a SATlink digital satellite meter, a YT 400 spectrum analyzer, a data acquisition system, and a personal computer (laptop). Based on the propagation measurement, the down-converted and the beacon receiver of the Ku-band signal from EUTELSAT W4/W7 are linked to a digi-Sat metre and a spectrum analyzer for signal level monitoring and logging into a computer unit. The signals from a low-noise block (LNB) are collocated with the outdoor unit of the Davis Vantage Vue weather station within a secured garden beside the Physics building. The set-up is available for 96% of the duration of measurement, while the remaining 4% of downtime is for routine maintenance and the changing of batteries. To ensure the accuracy of the data, the rain rate measured is compared with nearby rain gauge data.

However, the rain rate data and received signal levels are measured at a frequency of 10 seconds and then integrated over a period of 1 minute. The intermediate frequency (IF) is passed through a spectrum analyzer, decoder, and computer. The spectrum analyzer captures samples of the observed spectrum for specific time intervals. The received signal data is sampled every minute. The measurement's attenuation dynamic range is approximately 22 dB below the level observed during clear sky conditions. To account for orbital variations that might affect the received signal level, we calculate the average clear-day signal level from the previous day as well as the day after any rainy days with rain attenuation [7,18]. An automated data logger is configured to receive and transfer this data to a personal computer for further analysis. Data recorded on rainy days is used to determine rain-induced attenuation, while non-rainy days are filtered out for clearer analysis purposes.

The data extracted underwent pre-processing, which involved synchronizing the beacon data and rain events data based on the same time stamps. To ensure the quality of the data, any partially missing or erroneous data was eliminated. Additionally, instrumental drifts were accounted for by evaluating the attenuation reference level using complementary measurements from a spectrum analyzer. In line with the findings of Maitra's work in 2004, the clear sky reference level of the beacon-measured data was determined through an averaging technique comparing data before and after rainy days. By applying the given expression, one can calculate the dynamical trend of rain-influenced attenuation, A(t), based on the measured data.

$$A_{(t)}\ (dB) = RSL_{clear\ sky} - RSL_{rainy\ days} \tag{1}$$

where RSL means Received Signal Loss

3. RESULTS AND DISCUSSION

This section presents results of the analysis of the data acquired from the study location-based rain rates and signal received levels.

3.1. Rainfall accumulation and rain rate

The data graphically represented in Figure 1 displays the average monthly rainfall accumulation in Ikere-Ekiti, a hilly region situated in southwestern Nigeria. Upon careful observation of Figure 1, it becomes evident that the pattern of rainfall is seasonal and exhibits consistency across the area, with a higher frequency during the rainy season. Additional analysis of this figure reveals that September exhibited the largest amount of accumulated rainfall, approximately 247 mm, closely followed by June at around 210 mm. Conversely, January experienced minimal precipitation, measuring below 5 mm per hour. Consequently, it would be prudent to delve deeper into an examination of months characterized by intense rainfall such as June and September to identify the most unfavorable periods in Ikere.

The plotted data in Figure 2 illustrates the cumulative distributions of rain rates at the measured site. The rain rate measurements mainly indicate convective rainfall at this location. Consequently, there is minimal variation in the rain rate values for higher time percentages (10% and 1%) at this site. The trends depicted in Figure 2 reveal that as the rain rate increases, the slope curve gradually decreases from a large negative value. During stratiform rain structures, particularly at higher time percentages, widespread rainfall with lower rates can be observed. In contrast, the convective nature becomes more apparent at lower time percentages, which is characteristic of tropical rain patterns. In these instances, water droplets within clouds are vertically transported to encourage coalescence of water particles, resulting in heavy convective rainfall (Schumacher and Houze, 2003).

The transformation from stratiform rain to convective rain occurs as rain rates increase. A comparison between the actual measurements and the ITU-R model reveals a deviation of up to 15.2% at the 0.01% exceedance level. Specifically, at rain rates of 118 mm/hr and 100 mm/hr, the actual values differ from the ITU-R values used.

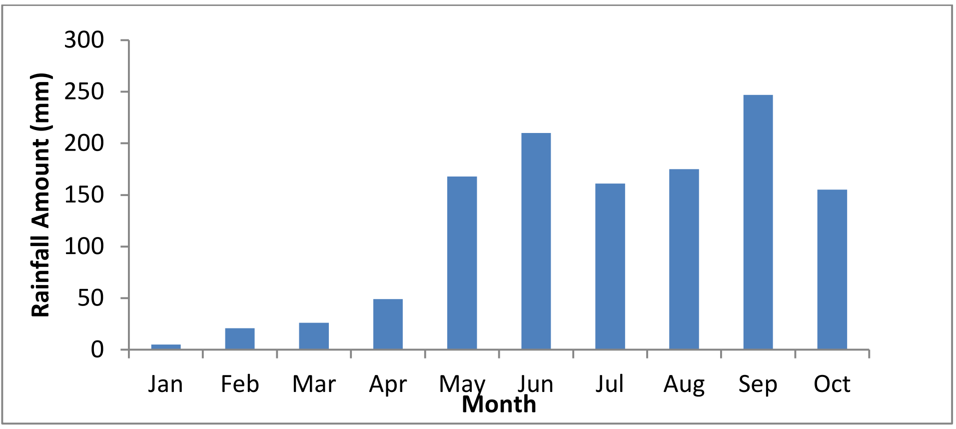


Figure 1. Average monthly rainfall accumulation for the period of measurement

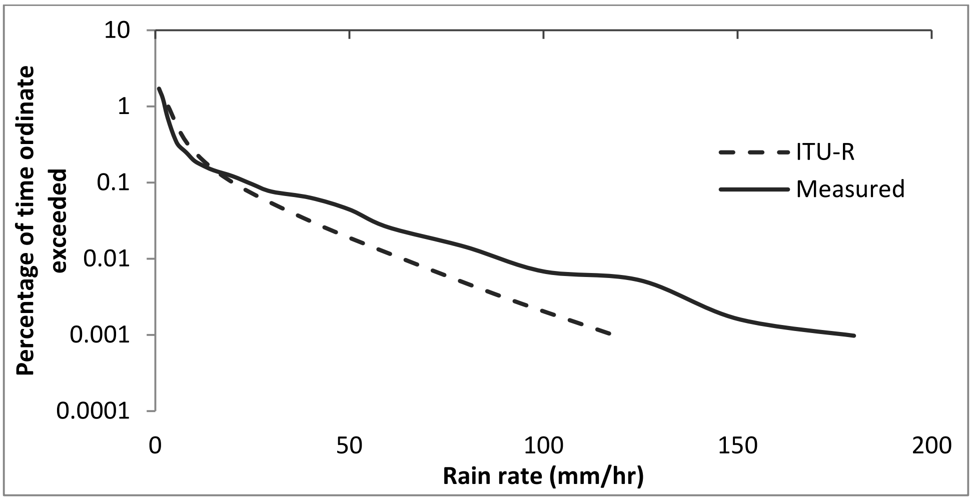


Figure 2. Distribution of measured rain rate compared with the ITU-R model.

Figure 3 shows the time series of the rain rate during heavy rainfall on July 14, 2023, with rain falling throughout the day. The rain event reached its peak (89 mm/hr) during the afternoon hours. The peak period represents the peak of business hours, when many business transactions will take place. It implies that business transactions associated with signal transmission are bound to encounter degradation due to rain in addition to fading in the mountainous region of Ikere metropolis.

3.2. Results on inter-event of signal transmission

Figure 4 (a-c) also presents the plot of the measured and the associated received signal levels at 12.245 GHz in April, July, and September, respectively. Rainfall events were recorded on different days in the specified months. The result generally shows that rain events occur at different times of the day. For example, a rain event occurs during the evening hours till late in the night in April, the afternoon to evening hours in July, and the morning to evening hours in September. The result also shows that the received signal level experienced a decrease to about 15 dB during the rain event in April, while it decreased sharply to about 25 dB during intense rainfall in September. As the rain rate values increase, there is a decrease in the received signal strength (RSS) values. This trend leads to higher signal attenuation during rainy conditions. The receiver's dynamic range varies from -43.3 dBm to -83.4 dBm, and it experiences significant signal loss when faced with heavy rain, typically at a rate of about 115 mm/hr. Figure 5 presents the result of a typical measured rain rate event, estimated rain attenuation, and the associated received signal strength at 12.245 GHz. The results show how the signal attenuates with the received signal strength and the corresponding rain rate.

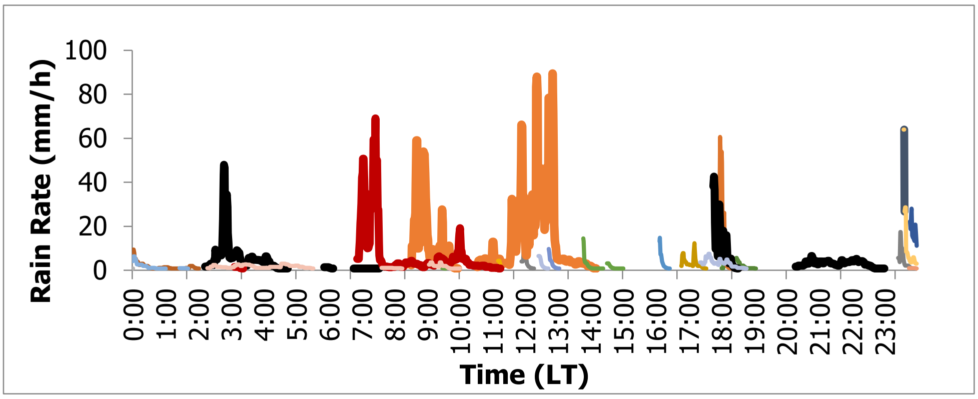
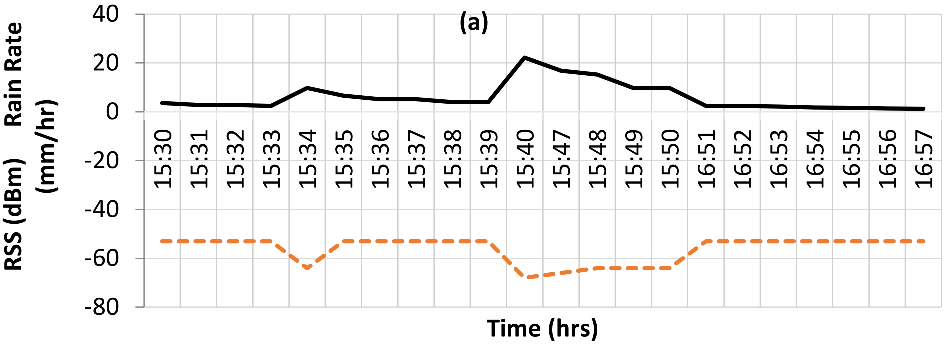
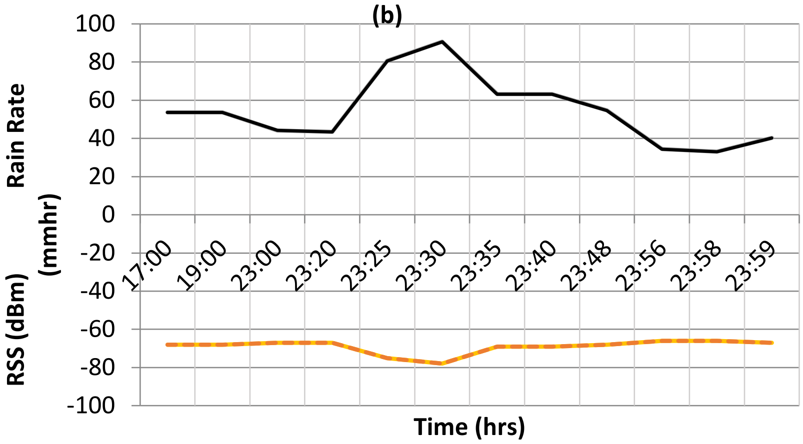


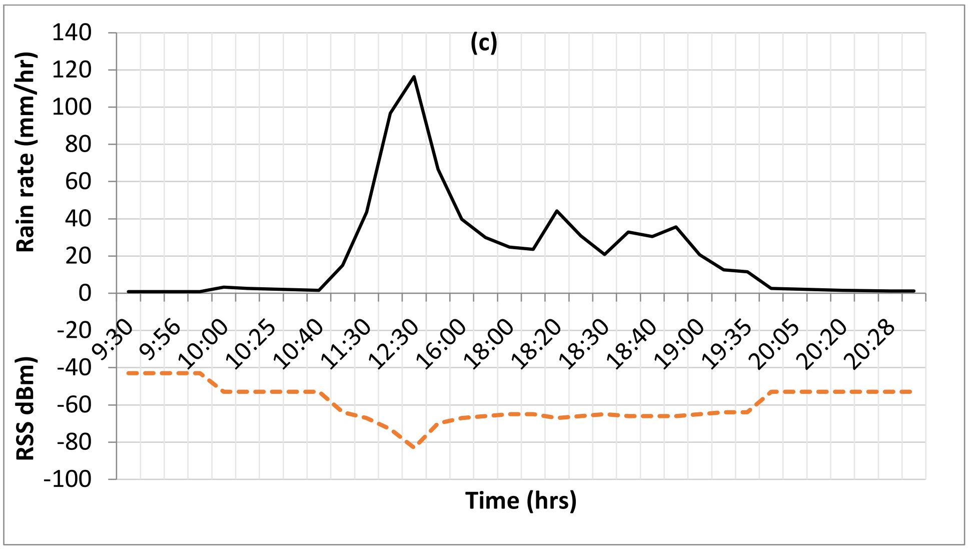
Figure 3. Measured time series rain rate event during a heavy rainfall event on a typical day



(a) April 2023



(b) July 2023



(c) September 2023

Figure 4. Measured rain rate event and the associated received signal strength at 12. 245 GHz

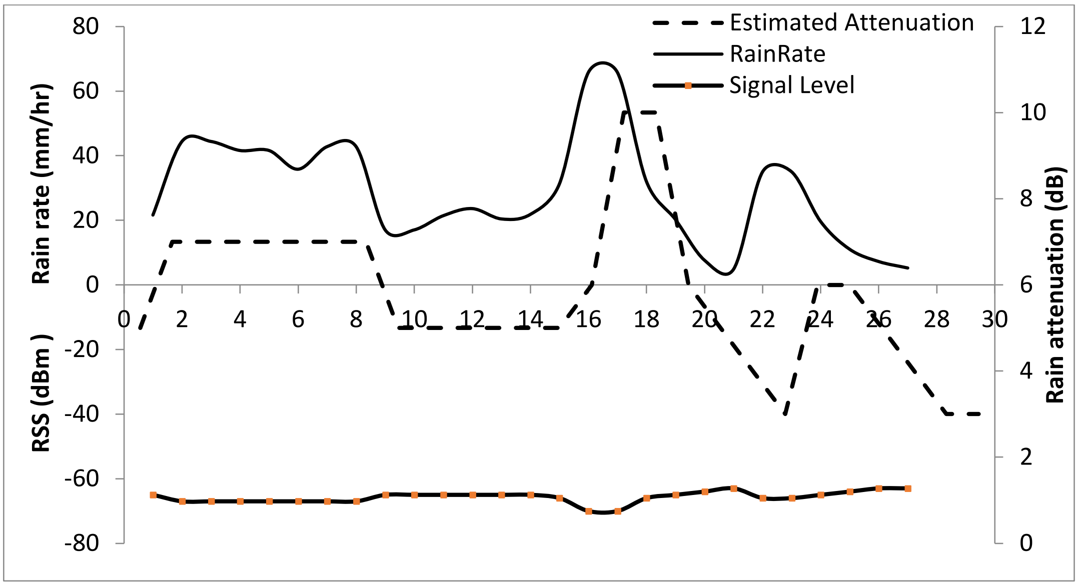


Figure 5. A typical measured rain rate event, estimated rain attenuation and the associated received signal strength at 12. 245 GHz

4. CONCLUSION

This paper analyses and characterizes signal impairment during inter-events along the link of Ku-band satellite signals over a mountainous region in Ikere-Ekiti, Nigeria. The analysis and characterization of rain-induced signal data from January to October 2023 have been conducted based on a year's rain rate measurements. The findings reveal that September experienced the highest rainfall accumulation, reaching approximately 247 mm. In second place is June with a rainfall accumulation of about 210 mm, while January had the lowest accumulation with less than 5 mm per hour. Furthermore, the rain rate at the experimental location during 0.01% of the time was determined to be 118 mm/h, deviating from the ITU-R value by approximately 15.2%.

It has been found that the received signal level experienced a decrease to about 15 dB during the rain event in April, while it decreased sharply to about 25 dB during intense rainfall in September. The high trend of the received signal loss during intense rain is of concern to system engineers, who will need to compensate to avoid partial or total signal degradation in the region. The result will be beneficial to the design of 5G and future-generation networks in the area. However, further research is recommended in the area of path loss measurement to compensate for signal fading due to multipath arising from the topography of the region.

Acknowledgements:

The authors would like to express their gratitude to the Tertiary Education Trust Fund (Tetfund) for generously providing grants for this research. Additionally, we would like to extend our thanks to the Prof. Olufemi Victor Adeoluwa Vice Chancellor of Bamidele Olumilua University of Education Science and Technology Ikere, as well as the Centre for Research and Development at Bamidele Olumilua University of Education Science and Technology Ikere, Nigeria, and Prof. Joseph Ojo for their invaluable support.

Declaration of Conflict of Interest:

The authors declare no conflict of interest in this research. All authors agree to the submission of the paper to this journal.

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