FUDMA Journal of Engineering and Technology
ISSN: 3092-9385
https://sites.google.com/fudutsinma.edu.ng/fjet
Volume 1, Issue 2, 2025, 132-140

Real-Time Evaluation of Rain-Induced Signal Degradation on Digital Satellite Television Links in Minna, Nigeria

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Abstract

This paper documents the results of the investigation of real-time evaluation of rain-induced signal degradation on digital satellite television links in Minna (9º 37"N, 6º 30"E), Nigeria. Two aspects of analyses are involved. One is the prediction of rain-induced attenuation for earth-space links at Ku band using the ITU-R P.618-12 attenuation model, while the other is the real-time measurement of the exact television signal strength during clear sky and during rainfall. This study was set up as a preliminary assessment. The results obtained revealed significant differences between the predicted and the measured rain attenuation values. The ITU-R P.618-12 model predicted an attenuation value of 16 dB at 0.01%-time exceedance. For the real-time signal measurement, signal levels that ranged between 80 and 83 dBµV were recorded during clear sky. However, during rainfall, these values degraded to the range of 69 to 78 dBµV, thereby resulting to a range of 5 - 11 dBµV signal level degradation.

Keywords: *Digital satellite television, rain rate, rain attenuation, real-time evaluation.*

1.0 Introduction

The demand for communication systems among professionals and subscribers has skyrocketed in recent years, causing the lower frequency bands to become congested. In order to satisfy the high demand for high-quality service, migration to the higher frequency bands of Ku and Ka has become essential. The present transition from analogue to digital terrestrial television broadcasting and the growing popularity of digital satellite television are two instances of this technological progress. Even though satellite communication is highly dependable and efficient in the higher frequency bands, reliability and efficiency are seriously threatened by the significant problem of rain-induced attenuation. Above a frequency of 10 GHz, digital satellite television, like other communication systems experiences signal destruction/disruption, which affects the quality of television content during high intensity rainfall. The consequences of this phenomenon on system performance and availability in these frequency bands must thus be carefully and thoroughly studied, especially in the tropics where high intensity rainfall is experienced.

The impacted frequency may exceed 10 GHz in temperate regions. In contrast, because of the heavier rainfall and bigger raindrops found in the tropical and equatorial regions, it can be as low as 7 GHz there [1] – [6]. Therefore, it is imperative to find a way to compensate for these unpleasant losses encountered in the tropics by providing solutions through the study of rain-induced attenuation.

This study has attracted a lot of attention from around the world since rain weakens digital satellite television signals. In order to predict rain attenuation, a number of models have been developed. However, the precision of locally recorded rainfall data still determines how accurate these models are. Therefore, it is crucial to measure the necessary data in real time.

It is worthy to note here that similar works on rain rate and rain attenuation have been carried out in the study area and other areas in Nigeria by the authors [7] – [12] but direct satellite signal measurements have been impossible because of lack of equipment.

In this research, a combination of digital satellite meter with an inbuilt spectrum analyzer, a digital television decoder with an outdoor receiver dish and a Ku LNB (Low Noise Block downconverter) were used to collect digital satellite television signals. The rain data was sourced from the Nigerian Meteorological Agency (NiMet).

2.0 Review of Related Works

Due to the shortcomings in the performance of rain-induced attenuation models, a number of commendable *in-situ* experimental efforts to ascertain the level of attenuation by rain in the higher frequency bands have been

Received: 08/07/2025; Revised: 17/07/2025; Accepted: 17/07/2025; Published: 08/08/2025

conducted outside Nigeria. A few of such efforts are worthy of mention here. In India, rain attenuation for Ku band satellite signals was measured [13]. The experimental set up comprised a 96 cm parabolic dish pointing towards INSAT 4A, GSAT-10 satellites. The Ku band signal was monitored using 9.5-10 GHz LNBF and spectrum analyzer. The data was stored by a Lab-View (VI) data logger at 10 seconds interval and a Percival disdrometer was used to measure the rain events. In the study, rain attenuation was also predicted using the DAH (Dissanayake, Allnutt and Haidara), ITU-R and Simple Attenuation models. Major differences between the measured and the predicted attenuation values were revealed in the reported results.

[14] also used satellite beacons to study rain attenuation at Ku and Ka frequency bands in Delhi, India. Signals at the Ku and Ka bands from the GSAT-8 and IPSTAR (Thaicomm-4) satellites, respectively, were measured at 1-second intervals using the beacon receiver. The beacon power level was simultaneously measured using a spectrum analyzer. Significant discrepancies between the measured and predicted rain attenuation were shown by the results. At the Ku band, the differences in values ranged from 2.1 dB to 3.7 dB, while at the Ka band, they ranged from 1.5 dB to 4.5 dB.

Additionally, in South Korea, the variation of rain rate and rain attenuation on Ka-band satellite communication was investigated by [15]. Two satellite beacon receivers were installed to measure signals at Ku and Ka bands from the Koreasat 6. A low noise block (LNB) was used to convert the Ka-band signal to an intermediate frequency signal. The LNB output was fed to a signal selector and that from the signal selector was fed to a spectrum analyzer. The rainfall rate was also measured using a laser optical disdrometer. In comparison with the existing ITU-R model, results obtained from their work also revealed differences between measured and predicted attenuation.

Several attempts have been made at predicting rain rate and rain attenuation for satellite communication links in Nigeria. However, the work of [3] is the only reported effort to have evaluated rain-degraded digital satellite television reception using real-time rain impairments in the form of signal attenuation. In the research, the Davis Vantage Vue electronic weather station was setup to measure rain rate, while the combined equipment of digital satellite meter, parabolic antenna and a spectrum analyzer measured the signal attenuation. According to the study's findings, satellite links with lower elevation angles were more prone to signal loss, and when received signals were suddenly squelched, the digital television content was completely lost around rain rate of 64 mm/h.

3.0 Methodology

The data measurement comprises two setups: The digital satellite signal measurement and the precipitation measurement.

3.1 Digital Satellite Signal Measurement

A parabolic dish was installed to establish a link with an active communication satellite, the Nigerian Communication Satellite (NIGCOMSAT-1R), which delivers digital television content over Nigeria. A digital satellite meter (GTMedia Finder) embedded with a spectrum analyzer and a Ku-band LNB was used. Logging was done at 1-hour interval. The equipment setup in the Physics Department of Federal University of Technology, Minna is shown in Figure 1.

Figure 1: (a) The weather station and outdoor dish (b) The indoor digital satellite meter receiver at Federal University of Technology, Minna

3.1.1 The NIGCOMSAT-1R

This geostationary satellite, designed to meet the broadcast and telecommunication needs of clients, service providers, and Navigational requirements across the sub-Saharan region of Africa, part of Europe, and Asia, is equipped with a quad-band (C, Ku, Ka, and L transponders). It has an orbital home of 42.5 degrees east [16]. The NIGCOMSAT-1R deliver Direct To Home (DTH) services in the free-to-air mode. The received signals monitored in this paper were transmitted from the Ku-band transponder.

3.2 The Rainfall Analysis

This research utilised data obtained from the Nigerian Meteorological Agency (NiMet). The data are long-term, measured over 33 years in the study area, and the Casella tipping bucket rain gauge was used for the data collection.

3.2.1 Rainfall Rate

The rain rate was evaluated using Chebil model [17] which is given as:

$$R_{0.01}(mm/h) = \alpha M^{\beta} \tag{1}$$

where $R_{0.01}$ is the point rain intensity exceeded at time percentage of 0.01%, M is the mean annual accumulation of rain, while α and β are the regression coefficients whose values are 12.2903 and 0.2973 respectively.

3.2.2 Rain Attenuation Analysis

The rain attenuation was analysed using the ITU-R P.618-12 model [18], which is the most widely accepted and reliable model for estimating rain attenuation in satellite communication systems [19]. The step-by-step analysis using this model is explained in equations (2) – (17).

Step 1: Obtain the rain height, H_R from:

$$H_R = h_o + 0.36 \text{ km} \tag{2}$$

where h_o is the 0°C isotherm height above mean sea level.

Step 2: Obtain the slant path length L_s, below the rain height from:

$$L_S = \frac{H_R - H_S}{Sin\ \theta} \tag{3}$$

where θ is the elevation angle and H_S is the height of the location.

Step 3: Obtain the horizontal projection, L_G, of the slant path length from:

$$L_G = L_S \text{ Cos } \theta \tag{4}$$

Step 4: Obtain the point rainfall rate, $R_{0.01}$ (mm/h) exceeded for 0.01% of an average year.

Step 5: Obtain the Specific attenuation, $\gamma_{R0.01}$ (dB/km) for 0.01% of time:

$$\gamma_{R_{0.01}} = k\, R_{0.01}^{\alpha} \tag{5}$$

where parameters k and α are given in ITU-R P.838-3 [20].

Step 6: Calculate the horizontal reduction factor, $r_{h0.01}$ for 0.01% of time using:

$$r_{h0.01} = \frac{1}{1 + 0.78\sqrt{\left(\frac{L_G * \gamma_{R_{0.01}}}{f}\right)} - 0.38[1 - \exp(-2L_G)]} \tag{6}$$

where f is the frequency in GHz.

Step 7: Calculate the vertical adjustment factor, $v_{0.01}$ (km):

$$L_R = \frac{L_G r_{0.01}}{\cos\theta}, for\, \rho > \theta \tag{7}$$

Or

$$L_R = \frac{H_R - H_S}{\sin\theta}, for\, \rho \leq \theta \tag{8}$$

where

$$\rho = \tan^{-1}\left(\frac{H_R - H_S}{L_G r_{h0.01}}\right) \tag{9}$$

Therefore,

$$v_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left[31\left(1 - \exp\left(-\frac{\theta}{[1+\sigma]}\right)\right)\frac{\sqrt{L_G\, \gamma_{R0.01}}}{f^2} - 0.45\right]} \tag{10}$$

where

$\sigma = 36 - |\varphi|, for\, |\varphi| < 36°$ or $\sigma = 0, for\, |\varphi| \geq 36°$

φ is the latitude of the station.

Step 8: Compute the effective path length $L_{eff}(km)$ as:

$$L_E = L_R v_{0.01} \tag{11}$$

Step 9: Obtain the predicted rain attenuation exceeded for 0.01% of an average year from:

$$A_{0.01} = \gamma_{R0.01} L_E \tag{12}$$

Step 10: The attenuation for other percentage exceedances are obtained using:

$$A_p(dB) = A_{0.01}\left(\frac{p}{0.01}\right)^{-[0.655 + 0.033\ln(p) - 0.045\ln(A_{0.01}) - z\sin\theta(1-p)]} \tag{13}$$

where p is the percentage probability of interest, and z is given by:

$$if\, p \geq 1\%,\ z = 0 \tag{14}$$

$$if\, p < 1\%,\ z = 0 \ \text{ if } \ |\varphi| \geq 36° \tag{15}$$

$$z = -0.005(|\varphi| - 36) for\, \theta \geq 25°\ and\ |\varphi| < 36° \tag{16}$$

$$z = -0.005(|\varphi| - 36) + 1.8 - 4.25\sin\theta, for\, \theta < 25°\ and\ |\varphi| < 36° \tag{17}$$

4.0 Results and Discussion

4.1 Average Rainfall Analysis

The average monthly rainfall analysis in Minna is shown in Figure 2. It is observed that the dry season months from January to April, and from November to December recorded very low rainfall values, while the wet season months from May to October recorded higher rainfall values. The highest value of 267 mm was recorded in August. This finding implies that August is likely to have a higher signal level degradation.

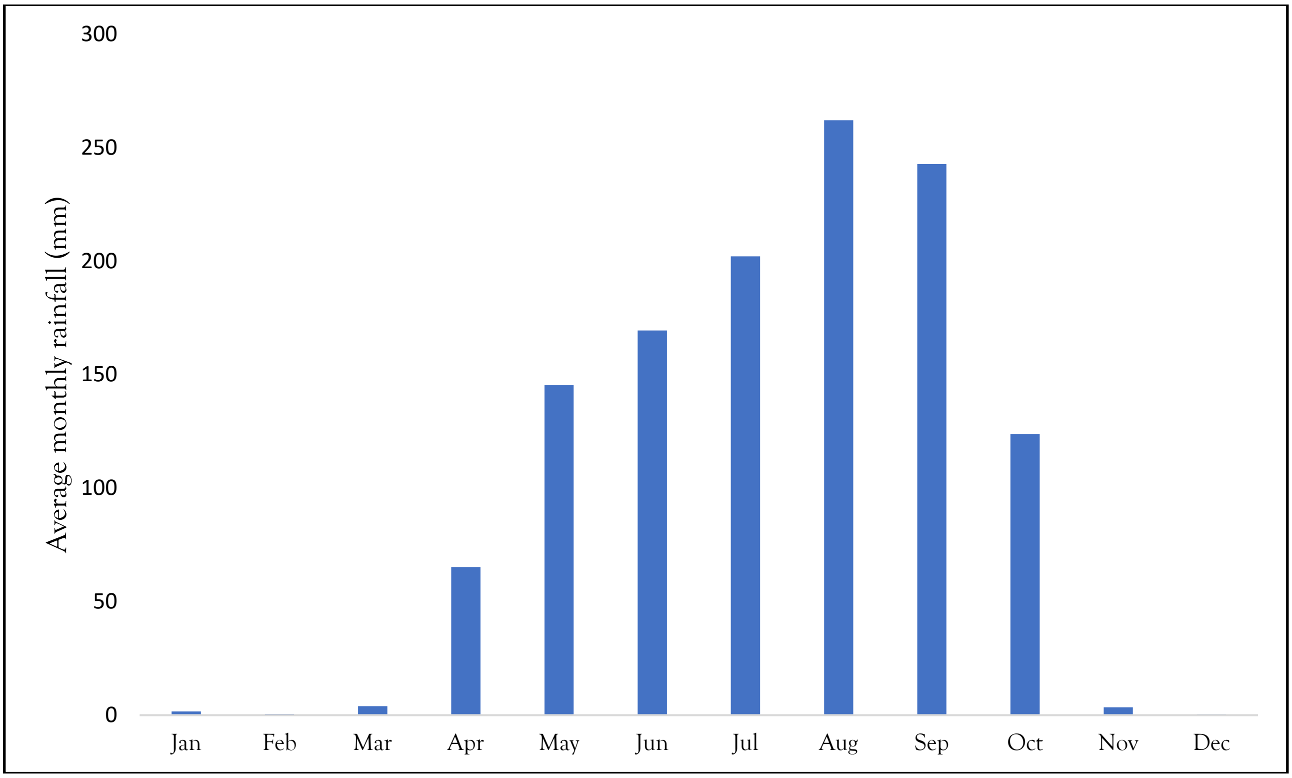

Figure 2: Average monthly rainfall analysis in Minna

4.2 Rainfall Rate Analysis

The average annual rainfall and the computed point rainfall rate $R_{0.01}$ with other parameters are given in Table 1. It is observed that the computed rainfall rate is 103.2 mm/h.

Table 1: Relevant parameters for Minna

Lat (°N)	Long (°E)	Height (m)	Average Annual rain (mm)	$R_{0.01}$ (mm/h)
9.54	6.54	249	1201	103.2

Source: Igwe, *et al.* (2025)

4.3 Rain Attenuation Analysis

One of the input parameters of the ITU-R P.618-12 model, which was used to predict the rain attenuation, was the point rainfall rate calculated using the Chebil model. The Ku-band's central frequency, 12.675 GHz was used. The elevation angle of NIGCOMSAT-1R over the Atlantic Ocean Region (AOR), 42.5°, was taken into consideration.

The results for the calculated parameters pertinent to satellite links at the Ku frequency band in Minna are displayed in Table 2.

Table 2: Computed parameters of satellite links at 42.5° by ITU-R P.618 model

H_R (km)	L_S (km)	L_G (km)	L_E (km)
			Ku-mid (f=12.675)
4.79	6.72	4.95	3.04

Source: Igwe, *et al.* (2025)

Thus, Figure 3 shows the cumulative distribution of the rain-induced attenuation at Ku-band.

Received: 08/07/2025; Revised: 17/07/2025; Accepted: 17/07/2025; Published: 08/08/2025

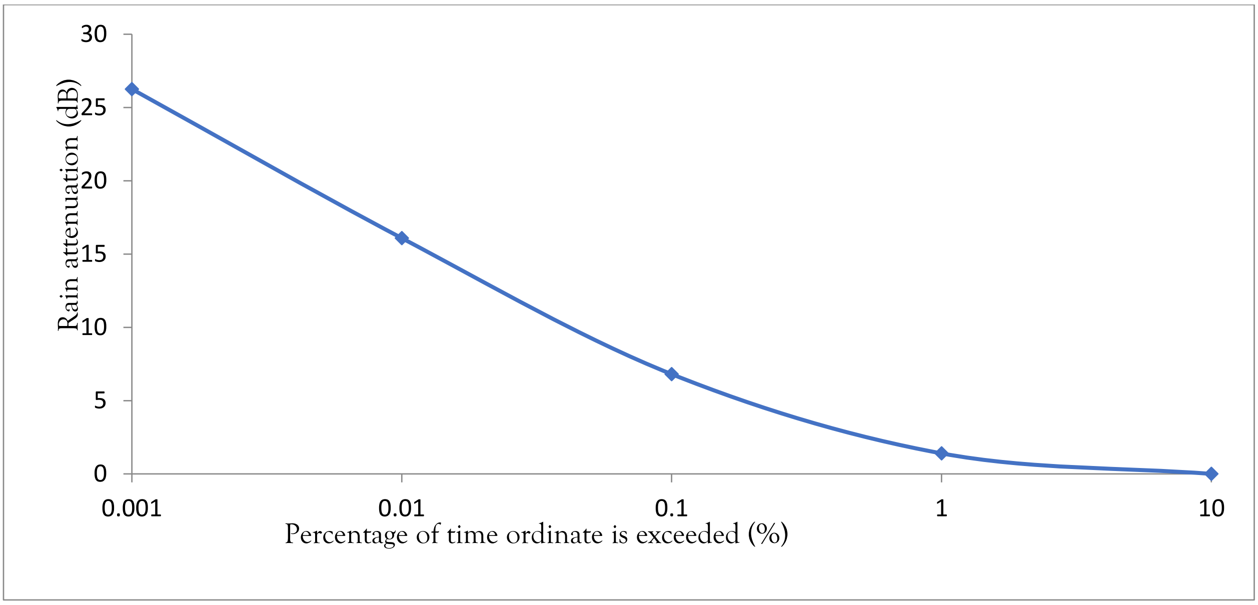

Figure 3: Rain attenuation's cumulative distribution at Ku-band, 42.5°

Figure 3 provides a graphical representation of rain attenuation that a signal experiences at different time percentages of the year for the Ku band and at 42.5° elevation angle. For 0.01-time percentage of the year (equivalent to 53 minutes per year), which is the standard and most commonly used time exceedance percentage in rain attenuation modelling for communication system design, the predicted rain attenuation for Minna is 16 dB. It reflects the worst-case rain attenuation that occurs only during the most intense 0.01% of time in a year.

4.4 Digital Satellite Signal Analysis

Figure 4 shows a sample of the signal data and its spectrum measured using the GTMedia digital satellite meter.

Figure 4: Sample measured data and spectrum

Figure 5 shows the digital television signals measured so far from April to June, 2025.

Received: 08/07/2025; Revised: 17/07/2025; Accepted: 17/07/2025; Published: 08/08/2025

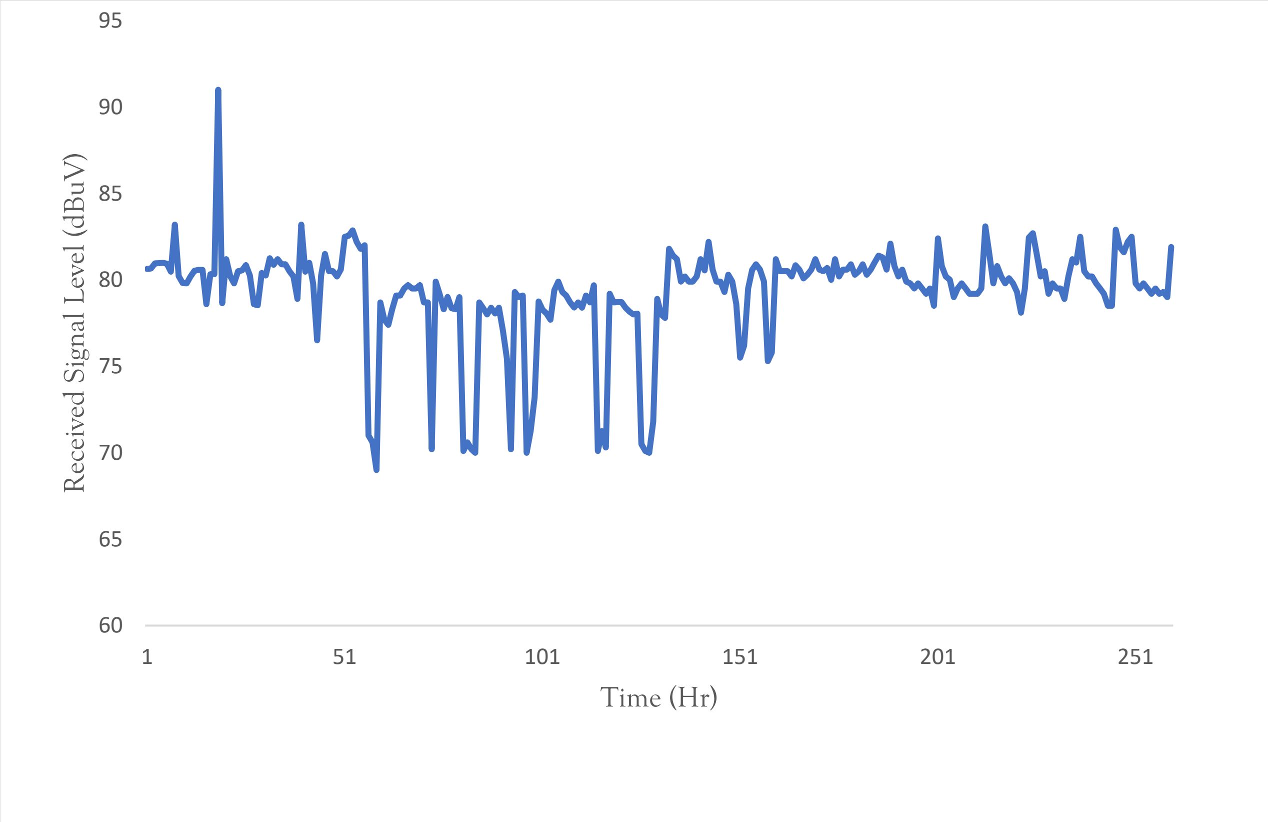

Figure 5: Measured real-time digital television signals

In Figure 5, the Received Signal Level (RSL) was measured at one-hour intervals, and a total of 260 data points was recorded. During clear sky, the RSL recorded was between 80 dBμV and 83 dBμV. However, during rainfall, these values dropped to a range of 69 - 78 dBμV, thereby attenuating the signals by a range of 5 - 11 dBμV. This period of low signal strength is represented by the deep portions of the graph. This finding illustrates the effect of rain attenuation in June 2025. Like the predicted value by the ITU-R P.618-12 model, this measured rain attenuation value is less than 20 dB. Therefore, this value which causes an outage for approximately 53 minutes in a year, is still within the allowable propagation loss margin. This is because satellites that operate at 10 GHz and above are designed to withstand losses that are less or equal to 20 dB on their links [21]. At higher frequencies, like the Ka and V bands, the measured or computed attenuation is expected to exceed this value.

Additionally, comparing this measured value with the predicted value from the ITU-R P.618-12 attenuation model, it is observed that there are significant discrepancies between both values.

5.0 Conclusion

Real-time evaluation of rain-induced signal degradation on digital satellite television links in Minna, Nigeria has been conducted. The analysis involved the computation of rainfall rate using the Chebil model, which was subsequently used as an input parameter for predicting rain attenuation for the links at Ku band. The rain attenuation model employed is the ITU-R P.618-12. The real-time measurement of the exact television signal strength was also achieved through the use of a digital satellite meter. The results showed significant discrepancies between the predicted and the measured rain attenuation. A value of 16 dB was predicted, while values that ranged from 5 to 11 dBμV were measured in real-time. For the Ku band, these values remain within the allowable propagation loss margin, corresponding to an outage of approximately 1 hour in a year. These results will be helpful to operators and consumers of services from the NIGCOMSAT-1R satellite outfit. This is a preliminary report as measurement is still ongoing.

Acknowledgement

The authors appreciate the Nigerian Tertiary Education Trust Fund (TETFUND), Nigeria for funding this research through the Institution Based Research Innovation (IBRI).

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Received: 08/07/2025; Revised: 17/07/2025; Accepted: 17/07/2025; Published: 08/08/2025

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Received: 08/07/2025; Revised: 17/07/2025; Accepted: 17/07/2025; Published: 08/08/2025