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Effect of Wooded Channels on 519.25-MHz UHF Radio Wave Propagation

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Abstract: *The effect of vegetation on 519.25-MHz UHF radio wave propagation was investigated in wooded areas of Calabar, located in Cross River State, Nigeria. The primary objective of the study was to collect statistical data on signal strength at various depths within forested channels, in order to evaluate signal losses caused by vegetation. Measurements were taken using a digital Cable Television (CATV) meter/analyzer (Model DLM3-T) connected to a 4-meter-high slot receiver antenna. During each measurement, the receiver antenna was carefully adjusted to achieve the best possible signal quality, as displayed on the CATV analyzer screen, before recording the signal strength. All measurements were taken on the downlink only. The results indicate that significant UHF signal loss occurs when the height of the transmitting antenna exceeds the average tree height in a wooded area. This loss is primarily due to the obstruction caused by the canopy—comprising both foliaged (leaf-covered) and non-foliaged (bare-branched) sections—which interferes with end-to-end communication. It was also found that signal loss patterns are more strongly influenced by the type and density of vegetation than by the depth of the wooded channel. Furthermore, a noticeable discrepancy was observed between the measured signal losses and predictions made by the early ITU model, highlighting its limitations in such environments. Seasonal variations also played a significant role, with greater signal losses recorded during the rainy season due to denser foliage compared to the dry season, when vegetation was sparser.*

Keywords: Radio wave, Vegetation, Wooded channel, Ultra High Frequency (UHF) and Signal strength

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1.0 Introduction

Maintaining optimal and high-quality signal strength is critical in wireless communication networks. Among the key factors that affect wireless signal propagation, vegetation plays a significant role in signal degradation. Both experimental and theoretical efforts have been made to model path loss at various frequencies, ranging from Ultra High Frequency (UHF) to millimeter-wave bands. Over the years, studies have shown that the presence of vegetation in the propagation path significantly impacts the quality of service (QoS) in wireless networks. The complex structure of foliage—comprising irregularly distributed branches, twigs, leaves, and trunks—causes electromagnetic wave attenuation and interference (Meng et al., 2009; Peden et al., 2010). These effects have serious implications for the design and performance of modern wireless communication systems.

Signals transmitted by wireless networks, such as UHF television broadcasts, are influenced by several environmental factors that are often overlooked or inadequately addressed by theoretical models and simulations (Liao et al., 2007; Ndzi et al., 2012; Kulsoom et al., 2021; Barrios-Ulloa et al., 2022). Vegetation is a key component of outdoor communication environments, and its interaction with UHF signals is the subject of ongoing research. In general, vegetation in the transmission path causes two primary effects on UHF signals: scattering and attenuation. Scattering disrupts the integrity of the signal, while attenuation increases signal fading (Tewari et al., 1990).

Vegetation can severely disrupt television reception in unpredictable ways. It can cause a drastic reduction in signal strength, even after long periods of stable reception. In some cases, one television network may experience significant signal loss due to vegetation, while others remain unaffected (Adebayo & Olusegun, 2018; Al Salameh, 2019). Foliage affects signal strength but not visual reception directly. Even when foliage is not located directly between the transmitter and the receiving antenna, nearby vegetation can still influence signal quality. Therefore, operating UHF networks in forested regions requires a deep understanding of vegetation-induced signal loss and the development of accurate predictive models for deployment planning (Blaunstein et al., 2003).

Seasonal variations also play a significant role in signal performance. During the rainy season, increased moisture and denser foliage lead to greater signal attenuation. Additionally, wind-induced movement of tree branches causes signal fluctuations due to varying propagation paths (Leonardo et al., 2019; Hang et al., 2023). Vegetation has a more pronounced impact at higher frequencies. UHF signals exhibit light-like propagation behavior, making them susceptible to obstructions from trees, buildings, or terrain features—similar to the way light is blocked or reflected (Nick et al., 2003; Ayekomilogbon et al., 2013).

This study aims to examine the effect of vegetation on UHF television signal propagation. One major challenge is the variability introduced by seasonal and weather conditions, particularly in areas with already weak signal strength (Meng et al., 2009; Leonardo et al., 2019; Geng et al., 2022). When foliage is below rooftop level, signal reception is typically unaffected, provided that an appropriate UHF antenna is properly mounted. However, when foliage extends above rooftop level, the antenna should ideally be installed above the vegetation line. This can be achieved by mounting the antenna on a tall mast or using a remote antenna placed at a higher elevation. Alternatively, if there are no significant obstructions, the receiving antenna may be placed beneath the main branches. Careful consideration of foliage height is therefore essential when determining optimal antenna placement (Valentin, 2009; Leonardo et al., 2019; Irwin et al., 2021). If the antenna is mounted below the foliage, signal strength may be significantly reduced. In such cases, a high-gain antenna combined with a specialized amplifier may be required to maintain adequate reception.

To investigate these effects, a field experiment was conducted to collect sufficient data on how vegetation influences radio wave propagation. Signal strength was measured across various wooded channels at different depths to quantify attenuation levels. This study focuses on the impact of vegetated environments in Cross River State, Nigeria, on the propagation of a UHF signal at approximately 519.25 MHz—corresponding to the broadcast frequency of Cross River Broadcasting Corporation Television (CRBC-TV), Calabar. According to definitions by the International Telecommunication Union (ITU) and the

Institute of Electrical and Electronics Engineers (IEEE), this frequency falls within the UHF band.

2.0 Methodology

2.1 Description of the Wooded Channels

The first site of investigation, located at 4°56'56.2"N, 8°20'42.0"E, is a narrow wooded channel predominantly composed of *Pride of Barbados* trees. These trees have an average trunk diameter of approximately 1 meter, a mean height of about 20 meters, and are spaced roughly 3 meters apart. The total depth of the channel is around 100 meters, with level topography and sparse undergrowth.

The second site, situated approximately 2 kilometers away at 4°56'35.4"N, 8°20'48.2"E, features a densely wooded channel dominated by palm trees. The trees are spaced between 2 and 3 meters apart, with an average height of about 15 meters. This site has a depth of approximately 250 meters, an undulating topography, and short grass as undergrowth.

The third site, located at 4°20'31.7"N, 8°10'49.7"E, is primarily composed of mahogany trees. These trees have an average trunk diameter of about 2 meters, an average height of 20 meters, and are spaced roughly 3 meters apart. The channel at this location is extensive (effectively infinite in depth), with a level topography and minimal undergrowth.

2.2 The Radio Wave Experiments

Experiments were carried out in forested regions of Cross River State, Nigeria. Signal strength measurements were obtained using a digital Cable Television (CATV) meter/analyzer (Model "DLM3-T"), which was connected to a slot-type receiving antenna mounted at a height of 4 meters. During each measurement, the receiving antenna was carefully adjusted to ensure optimal alignment until the best signal quality—typically corresponding to the highest signal strength—was displayed on the analyzer screen. Only downlink signal strengths were recorded in this study.

2.3 Transmitter Properties

The transmitter used in this study is a 1 kW TV–UHF solid-state transmitter, model Type T-V-/C-s. All RF coaxial connections are standardized to an impedance of 50 ohms. The transmitter is equipped with a high-quality IF modulation TV exciter and a super-linear power amplifier, which help to minimize signal distortion and ensure stable, reliable UHF television broadcast signals.

This equipment is installed on the first floor of the Cross River Broadcasting Corporation (CRBC) headquarters in Calabar, Cross River State, Nigeria. The transmitting antenna, located at the base station, is cylindrical in shape and designed to emit omnidirectional radiation, meaning it radiates signals uniformly in all directions—including into the forested areas of Calabar, where field measurements were taken.

The base station's key transmission parameters are as follows:Transmitter power (Pt): 35 dBm,Antenna gain (Gt): 13 dBi,Cable losses (Lc): 6.1 dB and Antenna height (Ht): 50 meters

2.4 Early ITU Vegetation Model

The vegetation model of Early ITU is a "radio propagation model" which calculates the path loss caused by one or more trees between two "point-to-point" distant communication links. The ITU adopted this model. This model is usually used when a telecommunication link encounters vegetation along its path and finds suitability when "point-to-point" microwave links cuts through a wooded channel. In most cases, this model is used to predict microwave link path losses. The coverage range of foliage depths and frequencies for this model is not given. Equation (1) depicts the mathematical formulation of the model.

$$L = 0.2 f^{0.3} d^{0.6} \quad (1)$$

where, L is the Loss as a result of foliage (dB), f is the transmission frequency (MHz) and d is the foliage depth along the path of connection (m). This equation is scaled in megahertz (MHz) for the transmission frequency. The foliage depth must also be measured in meters. The model does, however, have a critical flaw in that it yields impractical results at high frequencies (John, 2005).

3.0 Results and discussion

Figs. 1, 2 and 3 show the signal strength loss against the depth of channel from first, second and third wooded sites or channels respectively. It could be seen that there is no consistent pattern. The correlations between the signal strength (mdB) and depth (m) in the first, second and third wooded channels are R = -0.17, R = -0.06 and R = -0.25 respectively. The standard deviations of the foliage or vegetation losses in the three wooded channels also were σ = 3.24mdB, σ = 2.23mdB and σ = 3.13mdB respectively. This is as a result of signal loss from the foliaged and the non-foliaged (trunks and branches) parts dependent on the obstruction of the radio wave propagation. Here scattering or reflection, absorption and diffraction losses could be encountered as the foliage and non-foliaged parts of the vegetation interfere with the radio wave.

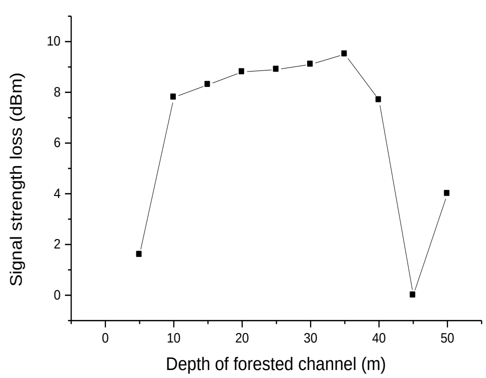

Fig. 1 Signal strength loss against depth of channel from first wooded site

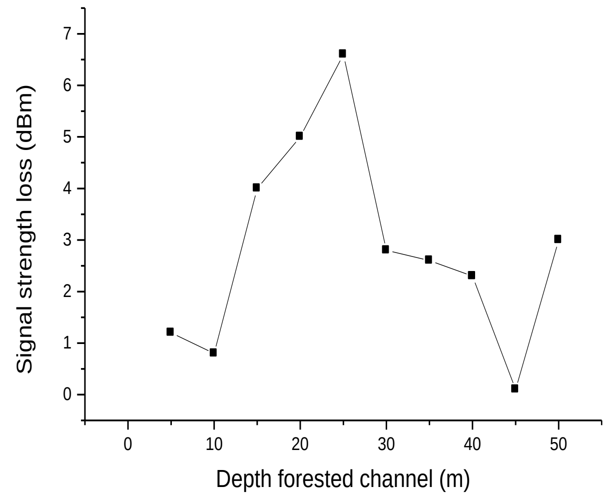

Fig. 2 Signal strength loss against depth of channel from second wooded site

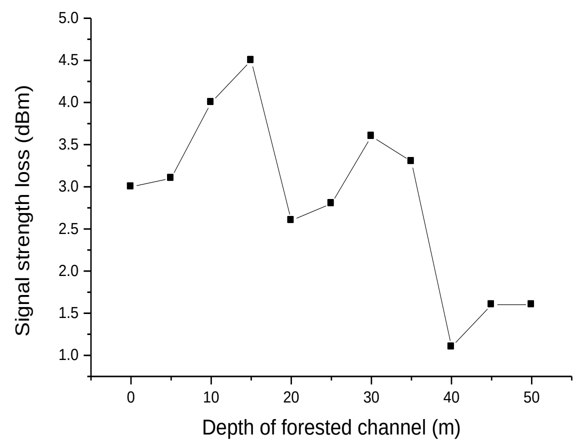

Fig. 3 Signal strength loss against depth of channel from third wooded site

Figs. 1, 2, and 3 show a gradual increase in signal loss with increasing channel depth. This trend is primarily attributed to the increasing density of both foliaged and non-foliaged components of the tree canopy. These elements progressively obstruct the line-of-sight (LOS) communication between the transmitter and receiver antennas and limit the receiver's exposure to sky wave components of the signal. As one progresses deeper into the channel, there are regions where canopy density decreases, allowing for a partial re-establishment of LOS communication and improved reception of sky waves. In such zones, signal loss diminishes, and signal strength increases, often peaking at the terminal edge of a canopy cluster. Here, it appears as though the vegetation has little to no obstructive effect, resulting in signal conditions similar to an open path.

However, as the channel continues and new canopy layers emerge, signal loss increases again, driven by the renewed obstruction of both LOS and sky wave components. This pattern of alternating signal strength peaks and troughs is due to the non-uniform and undulating distribution of tree canopies, which vary in length, breadth, and height across the forested path.

From this behavior, it is clear that signal attenuation in wooded environments is primarily influenced by canopy density and structure, rather than by the mere presence of tree trunks, which contribute minimally to surface wave obstruction.

Consequently, for UHF signal propagation in forested environments, channel depth alone is not a reliable predictor of signal loss. More critical factors include:The volume of sky wave energy reaching the receiver antenna. The quality of end-to-end communication, determined by the visibility between transmitter and receiver antennas.The structural nature of the foliage, where broader and denser leaves introduce more signal degradation than narrower and sparser ones.

Moreover, seasonal variation plays a significant role. Signal loss is typically greater in the wet season, when foliage is lush and abundant, than in the dry season, when vegetation is sparse and withered, thus causing less obstruction.

Overall, there is no consistent or linear relationship between signal strength loss and the physical depth of the wooded channel. Instead, the vegetation structure and canopy distribution dictate the pattern of signal attenuation. Path loss only becomes notably significant at very deep distances, and even then, it is modulated by the vegetation characteristics along the path.

Figs. 4, 5, and 6 present comparisons between the measured signal losses and the predictions from the Early ITU vegetation loss model for the first, second, and third wooded sites, respectively. The results show significant discrepancies: the measured signal strength losses exhibit a non-linear profile, characterized by sharp fluctuations (spikes and dips) across different depths. This contrasts sharply with the linear increase in attenuation predicted by the Early ITU model.

These findings underscore the importance of site-specific vegetation characteristics, which are not adequately captured by generalized models. The complex interplay of canopy density, structure, and sky wave reception must be considered when modeling or predicting UHF signal propagation through forested environments.

In Fig. 4, the measured signal loss initially follows a trend somewhat parallel to the Early ITU model, but diverges noticeably at a depth of approximately 35 meters. This deviation is attributed to the reconnection of end-to-end communication between the transmitter and receiver antennas, as well as an increased incidence of sky wave reception due to reduced canopy obstruction at that point. By 40 meters into the channel, the foliage density—both foliaged and non-foliaged components—further decreases, resulting in enhanced signal strength and thus a drop in vegetation-induced loss.

Similarly, Fig. 5 shows that the measured signal loss initially rises gradually, mirroring the Early ITU model. However, around 25 meters into the channel, a marked deviation occurs between the two curves. This is due to the sudden clearance of vegetation, marking the terminal edge of a dense canopy, where line-of-sight communication is re-established and sky waves more readily reach the receiver antenna, leading to a notable decrease in signal attenuation.

In Fig. 6, the measured loss is again partially aligned with the Early ITU model up to around 20 meters depth. Beyond this point, the measured curve diverges tangentially due to a progressive thinning of the tree canopy, resulting in lower signal obstruction and corresponding improvement in signal strength. Fig. 10 provides a broader comparison of the measured and modelled signal losses, showing generally similar rising trends in both curves. However, distinct spikes occur at the 45-meter and 85-meter marks, where canopy collapses or clearings are observed. These localized dips in signal attenuation correspond to reduced vegetation density, allowing more sky wave energy and improved signal propagation, thereby causing sharp reductions in loss.

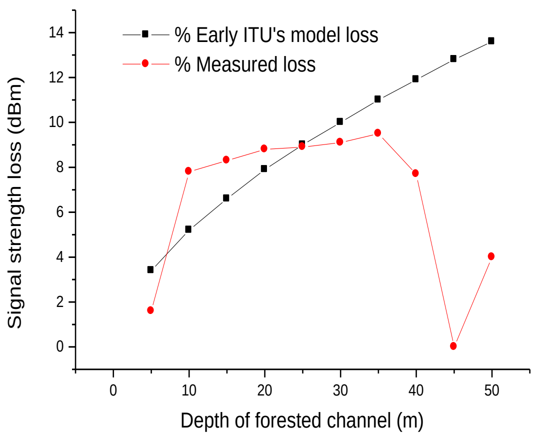

Fig. 4 Comparison between the Early ITU's model with measured losses from first forest

In Fig. 6, the measured loss is again partially aligned with the Early ITU model up to around 20 meters depth. Beyond this point, the measured curve diverges tangentially due to a progressive thinning of the tree canopy, resulting in lower signal obstruction and corresponding improvement in signal strength. Fig. 10 provides a broader comparison of the measured and modelled signal losses, showing generally similar rising trends in both curves. However, distinct spikes occur at the 45-meter and 85-meter marks, where canopy collapses or clearings are observed. These localized dips in signal attenuation correspond to reduced vegetation density, allowing more sky wave energy and improved signal propagation, thereby causing sharp reductions in loss.

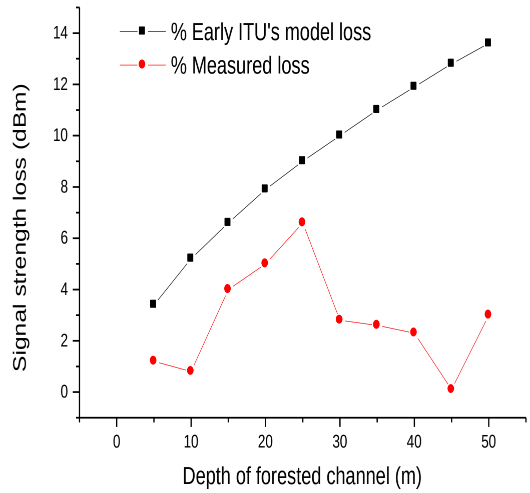

Fig. 5 Comparison between the Early ITU's model with measured losses from second forest

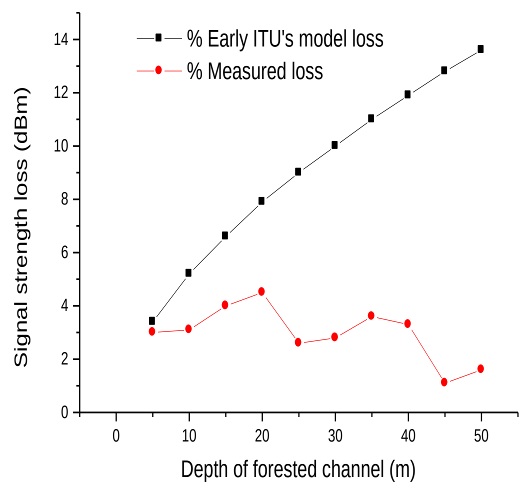

Fig. 6 Comparison between the Early ITU's model with measured losses from third forest

Figs. 7, 8, and 9 present linear regression fits of signal strength loss versus channel depth across six wooded channels. Notably, no consistent relationship is observed between signal attenuation and depth alone: Figs. 7 and 8 (first and second wooded channels) display negative linear relationships, indicating that signal loss decreases slightly with depth, possibly due to structural gaps in the canopy or periodic reconnections of end-to-end visibility. Fig. 9, which represents data from the third, fourth, and fifth wooded channels, shows positive linear trends, suggesting that signal loss increases with depth, especially in more uniformly dense or elongated forest segments. These findings reinforce the notion that the structural characteristics of the vegetation canopy—rather than mere depth—play a dominant role in determining signal attenuation. In simpler terms, foliage density, canopy continuity, and obstruction of sky waves and line-of-sight paths contribute more significantly to signal degradation than the distance alone. However, path loss becomes increasingly relevant at very large channel depths, particularly where dense vegetation remains continuous, as shown in Fig. 9.

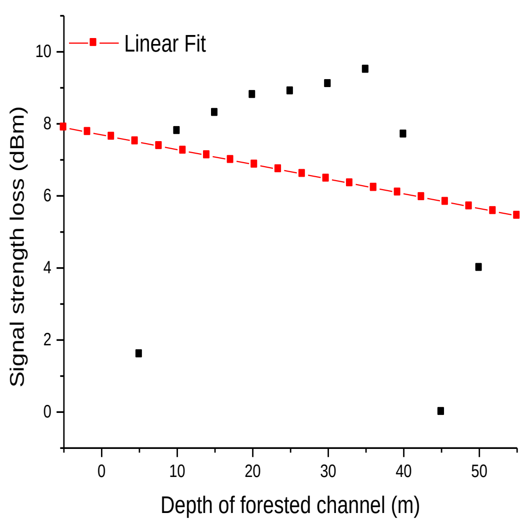

Fig. 7 Linear fit of signal strength loss against depth of channel from first forest

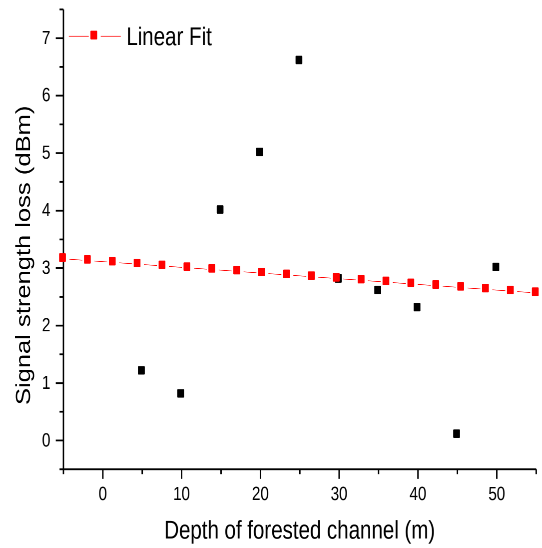

Fig. 8 Linear fit of signal strength loss against depth of channel from second forest

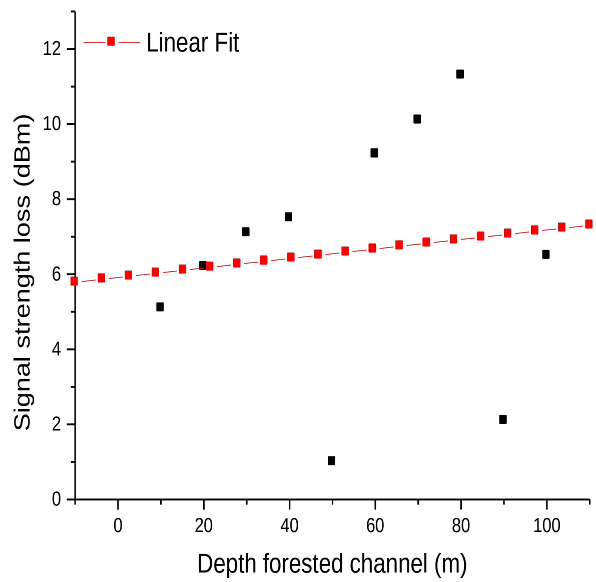

Fig. 9 Linear fit of signal strength loss against depth of channel from fourth forest

4.0 Conclusions

This study demonstrates that in forested environments, UHF signal strength losses are primarily influenced by the structure and density of tree canopies, rather than by tree trunks or channel depth alone. When the transmitter antenna is positioned above the average tree height, signal attenuation is mostly due to the obstruction caused by foliaged and non-foliaged canopy layers, which block both direct line-of-sight communication and the reception of sky waves at the receiver antenna. The findings confirm that denser and broader foliage results in higher signal loss, and that canopy-induced attenuation is more significant than conventional path loss, especially in channels with undulating or irregular vegetation patterns. Seasonal variations also play a role, with greater attenuation observed during the wet season due to increased foliage density.

Ultimately, the nature and arrangement of vegetation—including foliage type, canopy spread, and spacing—are more critical factors in determining UHF signal behavior in wooded areas than mere channel depth. These insights are valuable for designing more effective communication systems in forested terrains, including broadcast, mobile, and remote sensing applications.

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Declaration

Consent for publication

Not applicable

Availability of data

Data shall be made available on demand.

Competing interests

The authors declared no conflict of interest

Ethical Consideration

Not applicable

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Authors' Contribution

Joseph Amajama: Conceptualized the research study, designed the experimental methodology, and supervised the overall project. He was also responsible for data collection and analysis.

Eyime Echeng Eyime: Conducted the literature review, developed data analysis models, and performed statistical analyses of the experimental results. Also, he contributed to the interpretation of findings and drafting of the manuscript.

Samuel Eyeh Mopta: Assisted in experimental setup and data acquisition, contributed to the discussion of results, and reviewed the manuscript for technical accuracy and clarity.

Efa Ubi Ikpi: Participated in data validation, contributed to refining the analysis methods, and provided critical revisions to the manuscript to enhance clarity and rigor.