Correlation-based assessment of 4G LTE network performance during rainfall events in tropical regions

Ngozi C. Eli-Chukwu, Uma Uzubi Uma, Handel Emezue, Ogechi Akudo Nwogu, Ogah E. Oga, Calister N. Ogbonna-Mba, Samuel I. Ezichi
Department of Electrical/Electrnoics Engineering, Alex Ekwueme Federal University Ndufu Alike, Ebonyi State, Nigeria

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ABSTRACT

This paper presents a performance evaluation of a fourth-generation (4G) cellular network under adverse weather conditions in a tropical region. While the impact of rainfall on frequencies above 10 GHz is well documented, this study addresses the research gap concerning 4G LTE performance (sub-6 GHz) in high-precipitation environments such as Nigeria. Using a drive-test approach with TEMS Investigation software (v16.3), measurements were collected over 48 days between July and September 2025 along a fixed 15 km route in the Lagos metropolis on the MTN Nigeria network. Samples were recorded at 1-second intervals. Four critical key performance indicators (KPIs)—reference signal received power (RSRP), reference signal received quality (RSRQ), signal-to-interference-plus-noise ratio (SINR), and received signal strength indicator (RSSI)—were analyzed to determine their influence on the network performance index (NPI). Correlation analysis revealed that while RSRP exhibits no significant correlation with NPI during rainfall ($r_s = 0.009$), SINR and RSRQ demonstrate strong positive correlations ($r_s = 0.828$ and $r_s = 0.824$, respectively). Despite these high correlations, average performance values remained low (mean SINR = 23.72%), indicating significant rain-induced degradation. These findings provide a novel empirical basis for the development of weather-aware adaptive algorithms in tropical 4G network deployments.

Corresponding Author:

Uma Uzubi Uma
Department of Electrical/Electrnoics Engineering, Alex Ekwueme Federal University Ndufu Alike
Ebonyi State, Nigeria
Email: uma.uzubi@funai.edu.ng

1. INTRODUCTION

The global dependence on wireless communication has intensified the demand for high quality of service (QoS). However, wireless channels are highly susceptible to environmental factors, particularly heavy rainfall in tropical regions. In recent years, there has been a growing global dependence on wireless communication systems [1]. The demand for cellular network services continues to increase at a geometric rate [2], [3], leading to an exponential expansion in wireless network usage. The emergence of the internet of things (IoT), sensor technologies, and other connected media has further intensified the demand for reliable wireless infrastructure. These systems exhibit varying sensitivity levels and therefore require optimal QoS for efficient operation. Presently, wireless networks form an indispensable component of socio-economic activities across multiple sectors, becoming integral to daily human interaction and business processes [4]. Consequently, ensuring the optimal performance of wireless systems is essential for maintaining operational continuity and service sustainability. To achieve this, network operators must identify and mitigate key performance indicators (KPIs) that adversely affect performance. Many of these impairments are naturally induced, as wireless channels are highly susceptible to environmental factors such as rainfall and other adverse weather conditions [5]. Such conditions degrade signal quality and network reliability. Therefore, evaluating network performance under these circumstances is crucial for identifying KPIs that significantly impact service quality. This study focuses on assessing the 4G network KPIs that influence performance during periods of heavy rainfall.

Rainfall is a seasonal natural occurrence globally and is usually heavy in countries located in the tropical regions of the world. Over the years, climate change due to global warming has led to increased flooding, hurricanes, and other adverse weather events, giving rise to huge economic losses. The losses also affect telecommunication facilities, especially in developing countries. Therefore, there is a need to evaluate the performance indicators that affect cellular networks during rainfall to improve network quality. Since cellular networks are global, any effect on cellular network performance is critical.

During the rainy season, the radio environment of cellular networks experiences a decline that makes accessing and retaining services rendered by the network operator cumbersome. Since water conducts electricity, radio waves can be blocked and reflected during the rainy season. The effect on communication networks is usually more predominant in countries in tropical clime such as Nigeria, where the rate of rainfall could be as high as 200 cm annually. This will certainly affect the performance of cellular networks. This effect is not limited to tropical climes, as studies have shown a corresponding decline in cellular network performance in temperate regions. Rain attenuation results in outages that affect the quality of the signal, performance of cellular networks, link availability, deviation of the received signal, and restriction of the path length of radio communication signal, thereby limiting the utilization of higher frequencies for the line-of-sight microwave links [6]. Eli-Chukwu and Onoh [7] present the effect of rainfall on link quality in outdoor forest deployment and found that rainfall decreases link performance by 62 percent to the link with packet reception and 30 percent to the link having below 50 percent reception. This is caused by rainfall and water sitting on the nodes even after the rain. Al-samman *et al.* [8] considered some KPIs that are affected during rainfall and concluded that rainfall affects signal strength and equally observed a significant drop in the received signal strength indicator (RSSI). This corroborates the findings of Yaghoubi *et al.* [9] that received signal strength is susceptible to radio propagation conditions, during periods of high precipitation. Fong *et al.* [10] authors presented the results of a study carried out in southeast Nigeria and concluded that adverse weather conditions (rainy and harmattan season) affect the performance of cellular communication. The drop call rate was as high as 12.89% as against the standard practice of 2% and the block call rate was 8.76% as against the regulatory of 2%. Over time, research has been done to emphasize the importance of the 4G network and the effect of various network conditions on the cellular network.

Fourth-generation broadband cellular networks have revolutionized the mobile industry. It can hold video conferencing, high-definition mobile television, better circuit calls and many others. To do this requires low latency as most of the products are real-time interaction based. For instance, video conferencing and online gaming are real-time interactions, so anything that interrupts communication affects its performance. Rainfall is seen as one of the natural occurrences that affect the quality of the cellular network. With the high demand for data and real-time interaction which are some of the key usage cases of 4G networks, mitigating factors that will affect its performance are very crucial.

Various research conducted based on the impact of rainfall on electromagnetic waves considered only the electromagnetic waves with frequencies greater than 10 GHz since the impact of rainfall on the electromagnetic wave attenuation is reduced at lower frequencies [11]. Fan *et al.* [12] presented the effect of rain attenuation on S-band terrestrial links and found that heavy rainfall attenuates the communication signals thereby affecting the network performance negatively. Several factors contribute to significant link performance degradation. Most severe is the influence of the adverse atmospheric conditions that frequently appear, thus making the design of strongly connected networks a demanding issue. A good network link should successfully combat fog, rain, and snow, and derive analytical expressions for the node isolation probability, assuming a suitable path loss model [13] and equally examined the accuracy of Ku-band Ocean wind scatter meters which are affected by varying degrees of rain. The authors state that horizontal polarization measurements are more sensitive to rain than vertical polarization. Sensitivity to rain varies dramatically with wind speed, and the additional backscatter due to rain overshadows the rain-related attenuation. Thiagarajah *et al.* [14] state that network performance degradation is caused by long-lasting channel fluctuations such as rain fading, therefore required treatment carefully. A rain detection algorithm utilizing both temporal and spatial correlation of link status, aiming at efficiently distinguishing between long-term and short-term channel fading can be used to mitigate the effects of rain.

Rain fading may cause some links to fail, thereby threatening the connectivity of the network such as in millimetre wavelength mesh networks. Cellular network coverage is greatly affected by rainfall. Rain attenuation on the radio channel in a heavy rainfall region for wideband signals is in the 10–40 GHz frequency range. A lower frequency of 10 GHz is more affected by multipath due to a longer wavelength; it is still optimal in a heavy rainfall region due to high losses associated with higher frequency signals. In addition, for a path of over 1.5 km, the difference in horizontal and vertical polarization is significant [15]. One of the natural phenomena that significantly influences the performance of communication systems is rain attenuation. This is particularly true when the influence of rain is put into the context of point-to-multipoint, fixed cellular radio networks, in which spatial statistics of rain attenuation are as important as single-point temporal statistics [16].

Paul *et al.* [17] investigated the impact of rain attenuation on wireless communication systems and demonstrated that rainfall causes significant signal degradation due to absorption and scattering, leading to increased path loss and reduced link reliability. Their findings confirmed that higher rain intensity results in noticeable deterioration of signal quality, particularly affecting error performance in cellular networks. Xu *et al.* [18] investigated the impact of rainfall on cellular communication links using smartphone-collected measurements, revealing significant variations in signal metrics under rainy conditions. Michel *et al.* [19] investigated the impact of rain on LTE signal propagation in connected car scenarios using large-scale 3GPP minimization of drive test (MDT) measurements collected along the Italian A22 Motorway. By comparing LTE received signal received power (RSRP) under rainy and dry conditions, the study showed that wet environments significantly alter electromagnetic propagation even at LTE frequency bands below 3 GHz. The authors highlighted that rain effects on cellular propagation are critical for connected and autonomous mobility, particularly with the deployment of higher-frequency 5G bands that are more susceptible to rain attenuation.

Sheu *et al.* [20] studied the impact of tropospheric conditions on cellular signal propagation, showing that temperature, humidity, air pressure, and precipitation cause attenuation, scattering, and ducting, which degrade network performance. Using KPIs such as CSSR, HOSR, and RSCP, they found that humidity and rain significantly reduce signal quality, while ducting can enhance coverage. The study recommends real-time atmospheric monitoring, adaptive power control, and frequency tuning to improve network reliability and QoS.

Patra and Mitra [21] investigated rain fading in tropical regions, where heavy precipitation reduces RF signal power and degrades radio system performance. To mitigate rain-induced signal loss, the authors implemented a model using frequency diversification, adaptive power control, and waveform techniques. Their experiments, conducted at 26 GHz and 38 GHz, demonstrated that frequency diversification effectively improves system performance. Comparisons with existing rain attenuation models validated the proposed model across different distances, frequencies, and elevation angles.

Abdullahi and Abdulhamid [22] evaluated the performance of 4G/LTE networks in North-Central Nigeria using drive test measurements across major mobile network operators. KPIs such as network speed, latency, packet loss, coverage, and signal power were analyzed using propagation models including Okumura–Hata and Walfisch–Ikegami. The results showed that MTN achieved the best overall performance, followed by Airtel, while GLO and 9Mobile exhibited comparatively lower metrics. The study emphasizes the value of comprehensive KPI-based evaluation for improving network quality and user experience.

Despite the challenges facing cellular network providers during adverse weather conditions, the regulatory body and customers still want the set quality threshold to be met by the service providers. Hence, there is a constant need for network optimization, particularly during the rainy season as cellular signals are at their weakest during that period. Most studies were carried out on its impact on 2G and 3G networks. However, it is important to note that different network parameters have different parameters that are affected during adverse weather conditions. Little research has been conducted on the adverse weather effects on 4G networks. This paper studies the performance evaluation of parameters impacting cellular network QoS during the rainy season, the various parameters that influence performance and how they affect the overall network performance. The authors attempt to investigate the network parameters that are most affected due to rainfall in 4G networks. Four network performance indicators were monitored; RSRP, referenced signal received quality (RSRQ), signal-to- interference noise ratio (SINR), and received signal strength indicator (RSSI). This paper presents results from outdoor monitoring of the performance of these network parameters for forty-eight weeks within three months during heavy rainfall in Nigeria. The quality of the RSRP, RSRQ, SINR, and RSSI was checked whenever there was heavy rainfall. Correlations were performed with the benchmarked network data to ascertain each parameter's performance against network performance indicator benchmarked data.

Problem Statement and Research Gap: While previous research has focused extensively on rain attenuation in 2G and 3G networks or frequencies exceeding 10 GHz, little research has been conducted on the specific vulnerabilities of 4G LTE parameters during heavy precipitation. Furthermore, the relationship between signal power and actual link quality during storm events is often overlooked. This study aims to fill this gap by explicitly evaluating the NPI—a composite industry-standard metric representing the overall reliability and accessibility of the radio link—against individual KPIs. The main objective of this paper is as follows:

- To identify which 4G KPIs are most affected by heavy rainfall.
- To quantify the correlation between these KPIs and the NPI.
- To propose an optimization, focus for network operators to sustain reliability during adverse weather.

2. METHOD

The drive-test methodology utilized TEMS Investigation software (v16.3) installed on a high-performance laptop, a 4G-enabled TEMS mobile device, and a high-precision GPS receiver. Field measurements were conducted across the Lagos metropolis on the MTN Nigeria network (the sole operator for this study) over 48days from July to September 2025. Rainfall Characterization: Measurements were categorized during "Heavy Rainfall" events, typical of the Nigerian tropical rainy season. While specific rain-gauge sensors were deployed on the vehicle, data collection was synchronized with regional meteorological reports indicating precipitation intensities exceeding 50 mm/h. The drive-test route covered a mixture of urban canyons and open residential areas to ensure a diverse sampling of multipath fading and rain scattering.

3. RESULTS AND DISCUSSION

The analysis focused on four key parameters and their relationship with the NPI. A notable finding is the relationship between low performance values but high correlations. For instance, the SINR mean was observed at a low 23.72%, yet it maintained a high correlation ($r_s = 0.828$) with NPI. This indicates that while rainfall consistently suppresses signal quality to a low baseline, the overall network performance (NPI) remains extremely sensitive to the minor fluctuations of SINR during these periods. Table 1, Correlation Coefficients (r_s) for KPIs during Rainfall with the standard

- SINR: 0.828 (Strong)
- RSRQ: 0.824 (Strong)
- RSRP: 0.009 (Insignificant)

3.1. Network performance index correlation model

To establish the relationship between the NPI and selected KPIs—namely RSRP, RSRQ, SINR, and RSSI—data obtained from a 48-day drive test were analyzed. Based on the computed dataset, a correlation model was developed to determine the specific KPIs influencing 4G network performance during the rainy season. This relationship was derived by performing an independent correlation analysis between the NPI and each KPI. The degree of correlation indicates whether a given KPI exerts a positive or negative influence on overall network performance.

The correlation model is mathematically expressed using Spearman's rank correlation coefficient as:

$$r_s = 1 - \frac{6\sum d_q^2}{n(n^2-1)} \tag{1}$$

where n represents the number of observations for each network variable, $d_q$denotes the rank difference between the two variables under comparison (e.g., RSRP and NPI), and r_s is the correlation coefficient, which ranges from -1 to $+1$, indicating negative and positive relationships, respectively.

To further evaluate the mean performance of each KPI relative to the network performance benchmark, the expression in (2) was applied. This formulation enables proper assessment of the percentage performance of the coverage area with respect to the NPI:

$$\mu_q = \frac{1}{n}\sum_{i=1}^{n} q_i, \tag{2}$$

where μ_q represents the mean percentage value of each KPI (RSRP, RSRQ, SINR, and RSSI), and q_i denotes the individual percentage measurements for each observation.

Table 1. Daily percentage distribution of KPI thresholds and NPI during rainfall

Month	Day	RSRP ≥ -95 dBm (%)	RSRQ ≥ -14 dB (%)	SINR ≥ 10 dB (%)	RSSI ≥ -50 dBm (%)	NPI
July	1	68.75	60.33	49.67	48.18	2.84
	2	62.33	58.00	65.67	40.91	2.84
	3	64.25	58.67	51.33	43.00	2.72
	4	68.08	58.00	35.33	46.82	2.60
	5	68.58	57.00	31.33	47.18	2.55
	6	67.75	56.00	40.67	46.45	2.64
	7	66.83	57.00	47.00	45.82	2.71
	8	68.67	52.33	16.67	46.18	2.30
	9	63.67	50.33	1.33	40.45	1.95
	10	66.75	46.67	1.00	43.27	1.97
	11	66.00	51.67	7.00	43.18	2.10
	12	67.58	47.00	8.67	41.91	2.06
	13	62.25	52.33	15.67	39.36	2.12
	14	62.92	56.67	28.67	41.18	2.37
	15	62.58	57.00	47.67	41.09	2.54
	16	64.92	56.33	38.67	43.45	2.54
	17	74.75	46.67	6.33	50.64	2.23
	18	73.67	46.00	7.67	49.82	2.21
	19	73.83	46.00	3.67	50.09	2.17
	20	73.75	48.00	4.00	50.55	2.20
	21	74.42	48.33	6.33	51.45	2.26
	22	40.08	90.33	16.33	52.18	2.49
	23	74.92	56.67	26.00	54.00	2.64
	24	75.83	56.00	22.00	54.91	2.61
August	25	74.42	56.67	32.67	53.55	2.72
	26	75.42	56.67	34.00	54.64	2.76
	27	73.83	58.33	46.00	53.45	2.90
	28	77.67	57.33	33.00	57.45	2.82
	29	79.33	56.00	25.67	58.55	2.74
	30	76.75	58.00	46.00	56.09	2.96
	31	68.92	58.67	69.67	47.64	3.26
	32	65.58	59.00	75.33	45.45	3.07
	33	80.67	24.00	13.00	47.36	2.06
	34	67.83	56.33	19.33	46.27	2.37
	35	69.42	57.00	26.33	48.18	2.51
	36	69.17	58.33	27.00	48.27	2.53
September	37	71.50	57.33	22.33	51.00	2.53
	38	75.50	56.33	24.00	54.91	2.63
	39	79.00	54.67	11.67	58.18	2.54
	40	79.92	52.00	5.33	58.64	2.45
	41	79.50	51.67	5.67	58.00	2.44
	42	79.17	51.33	4.33	57.45	2.40
	43	79.25	51.00	4.33	57.55	2.40
	44	78.92	51.33	5.00	57.18	2.41
	45	79.08	52.00	5.00	57.55	2.42
	46	78.67	52.33	7.00	57.18	2.44
	47	76.75	53.33	14.33	55.27	2.50
	48	78.92	51.00	3.00	57.18	2.38

3.2. Analysis of network KPIs

RSRP is defined as the linear average of the power contributions of the resource elements carrying reference signals in a 4G LTE network. To determine the relationship between RSRP and the NPI, the correlation coefficient was computed using (1), yielding $r_s = 0.009$. This extremely low coefficient indicates a negligible relationship between RSRP and the NPI during the rainy season. Consequently, variations in RSRP have little or no influence on overall 4G network performance under rainfall conditions, as illustrated in Figure 1. Furthermore, the mean RSRP performance during the rainy season, computed using (2), was found to be 71.42%. This result suggests that rainfall has minimal impact on RSRP levels, reinforcing the observation that signal strength alone is not a reliable indicator of network performance degradation during adverse weather conditions.

RSRQ analysis is the KPI that shows the quality of the received reference signal. It provides further handover criteria when the RSRP report is not sufficient. When the data from the coverage was subjected to a correlation test by applying (1), the correlation coefficient had a positive correlation of $r_s = 0.824$. This indicates a positive relationship with the network performance. Further analysis as can be seen in Figure 2, shows that at various points where the RSRQ = $-14\ \text{dB} \geq 0\%$, the NPI rose. This corroborates the mean of 54.25% which indicates that the overall network performance was affected.

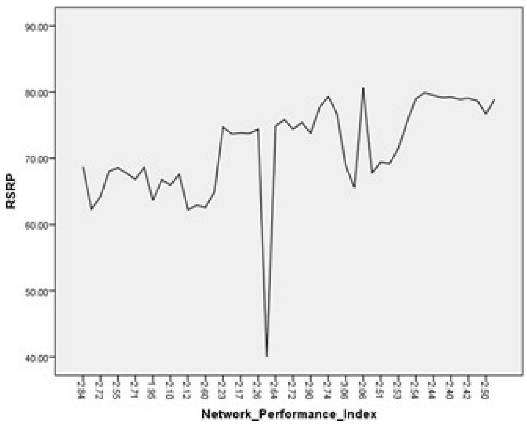

Figure 1. Comparing the RSRP and NPI

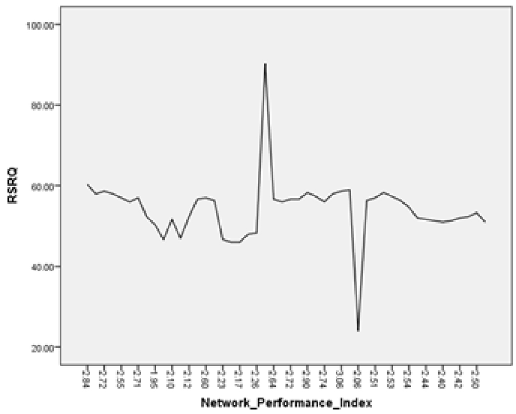

Figure 2. Comparing the RSRQ and NPI

SINR is a measure of the signal quality, interference, and noise quantity. It shows the strength of the required signal when compared to the system noise and interference. To calculate the correlation coefficient with the NPI, the data from the logfiles were subjected to a correlation test using (1). The result indicates a correlation coefficient of SINR performance $r_s = 0.828$ which shows a strong relationship with the overall network performance when compared to other network KPIs. Additionally, comparing the NPI with the SINR, the mean (SINR 10dB) is $23.72\,\%$ which as depicted does not help the overall network performance as shown in Figure 3. It was also observed that in some weeks where the SINR was 10dB 50%, the NPI $>\geq 2.8$. This is a clear indication that in adverse weather conditions, the SINR is greatly affected which suggests that signal quality within that period will be drastically affected [23]–[25].

RSSI it measures the total received power including all interference and thermal noise. Applying (1) gives a correlation coefficient of $r_s = 0.176$. Applying (1) and (2) the RSSI gives the following results: $r_s = 0.176$. The findings reveal an insignificant relationship between the RSSI and the NPI. The performance of the RSSI in the rainy season does not affect the overall network performance. The mean (RSSI $\geq -50\ \text{dBm}$) is 50.19%.

3.3. Optimization model

The approach of multiple linear regression was used to predict the NPI (y) using independent variables x_1 (RSRP), x_2 (RSRQ), x_3 (SINR), and x_4 (RSSI). The model is defined by (1) and (2):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \epsilon \tag{3}$$

Based on the regression coefficients (β), a unit increase in the foundational parameters leads to a 1.08-unit increase in NPI. Clarification of Priorities: Although SINR is the most strongly correlated with NPI, we recommend that optimization efforts be prioritized on RSRP and RSRQ. This is because SINR is a composite value highly affected by external noise and interference during rain, making it harder to control directly. By stabilizing RSRP and RSRQ through site-level tilt adjustments and power boosts, the more volatile SINR naturally stabilizes, leading to the predicted 1.08-unit gain in NPI.

The approach of multiple linear regression is used to predict the NPI (independent variable) using several explainable (dependent) variables. It leads to a model that fits a linear equation to the observed data.

Let the dependent variable be y and the independent variables x_js, the model format shown in Figure 4.

$$Y_i = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_p x_{ip} + e_i \tag{4}$$

$$Y_q = 0.003 + 0.012x_1 + 0.012x_2 + 0.013x_3 + 0.013x_4 \tag{5}$$

The significant value for the independent variables is 0 and as such they are all significant in predicting the NPI. But the RSRP and RSRQ most negatively affect the network performance during the rainy season as they both have a slower improvement rate. Although optimization is necessary on all the parameters considered, more focus should be on the RSRP and RSRQ because a unit improvement in the RSRP and RSRQ will yield a 1.08-unit improvement on SINR and RSSI.

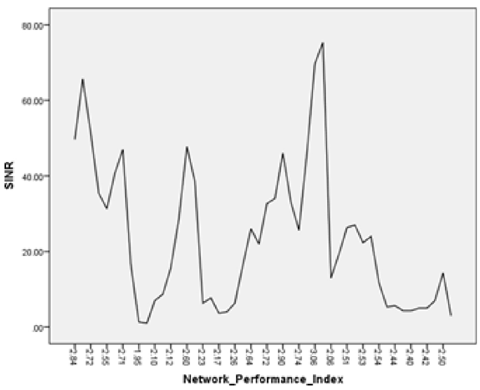

Figure 3. Comparing the RSRQ and NPI

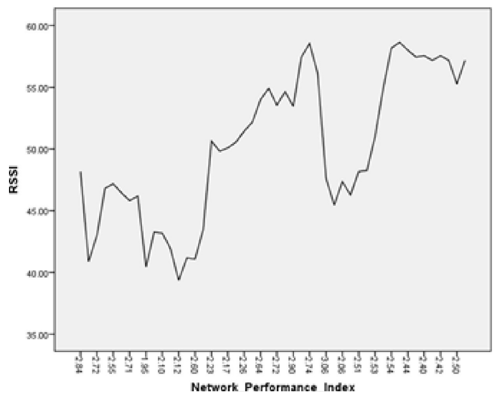

Figure 4. Comparing the RSSI and NPI

4. CONCLUSION

This study confirms that rainfall significantly degrades 4G performance in tropical regions. Significant Take-away: For robust network performance, operators must move beyond power-based (RSRP) monitoring alone and implement weather-aware algorithms that prioritize RSRQ and SINR stabilization during storms. Globally, wireless networks, especially cellular systems have become indispensable for communication. The increasing demand for seamless connectivity across consumer and industrial domains underscores the need for reliable network performance under all conditions, including severe rainfall. As climate change intensifies environmental disruptions, evaluating the impact of adverse weather on key network parameters becomes crucial for resilient telecommunication infrastructure. The study specifically targets the performance evaluation of a 4G cellular network under adverse weather conditions, particularly during the rainy season in tropical climate. This study focuses on the significant impact of environmental factors on network performance, which is crucial for optimizing service quality in adverse environmental condition by examining KPIs parameters (RSRP, RSRQ, SINR, and RSSI. Existing research on the impact of adverse weather condition on 2G, 3G, and 4G networks show that notable gap exists regarding the impact on 4G networks. This study aims to fill this gap by specifically evaluating 4G network performance during heavy rainfall by monitoring and analyzing KPIs (RSRP, RSRQ, SINR, and RSSI) during heavy rainfall.

The approach used in this study contributes to a deeper understanding of how these metrics interact under adverse weather, highlighting SINR as a critical factor influencing the NPI. The study identifies SINR as significantly correlated with NPI during the rainy season, stating its importance for service quality. That adverse weather affects the RSSI and SINR which contribute to the overall network quality. That during adverse weather conditions that network parameters were affected. Their result compared the effect of weather condition on network parameters during dry and rainy seasons, which suggests decline in network performance in rainy season as drop and block call rates were higher during the rainy season demonstrates that rain-induced impairments can lead to increased call drops, reduced data speeds, and compromised service availability. Their finding is consistent with result of the study depicting where the SINR was 10dB 50%, the NPI $\geq$ 2.8. This is a clear indication that in adverse weather conditions, the SINR is greatly affected which suggests that signal quality within that period will be drastically affected. These finding are not confined to tropical climates; temperate regions also experience similar effects, though, to varying degrees.

The impact of rainfall on 4G networks, as highlighted in this article, reveals significant challenges in maintaining QoS during heavy rainfall. Rain attenuation, characterized by signal degradation due to the absorption, scattering, and reflection of radio waves by raindrops, poses substantial hurdles for network operators. This degradation affects KPIs like RSRP, RSRQ, SINR, and RSSI, which are essential metrics for assessing the network QoS and user experience. Consequently, the study identifies a research gap in the lack of specific optimization strategies for enhancing SINR under adverse weather conditions. This gap emphasizes the need for practical solutions and technological advancements to improve network performance in such conditions. Comparing the impacts of RSRQ and RSSI on NPI, the study suggests a broader comparative analysis across different weather conditions and network generations. In conclusion, while rainfall poses significant challenges to cellular network performance, proactive measures rooted in technological innovation, regulatory oversight, and comprehensive network management strategies are pivotal in safeguarding the integrity and reliability of wireless communications, thereby meeting the evolving demands of global connectivity in the 21st century.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ngozi C. Eli-Chukwu	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Uma Uzubi Uma		✓				✓		✓	✓	✓	✓	✓		
Handel Emezue	✓		✓	✓		✓			✓		✓		✓	
Ogechi Akudo Nwogu					✓		✓			✓		✓		✓
Ogah E. Ogah					✓		✓			✓		✓		✓
Calister N. Ogbonna-Mba					✓		✓			✓		✓		✓
Samuel I. Ezichi					✓		✓			✓		✓		✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal Analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject Administration
Fu : **Fu**nding Acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, [Uma U.U.]

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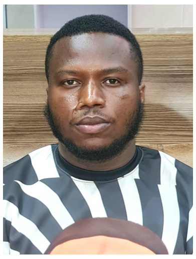
BIOGRAPHIES OF AUTHORS

Ngozi C. Eli-Chukwu an Associate Professor, Lecturer, and researcher in the Department of Electrical and Electronic Engineering at Alex Ekwueme Federal University Ndufu-Alike, Ebonyi State, Nigeria, where she has also served as the Director of Information and Communication Technology (ICT). She received the B.Eng. degree in Electrical and Electronic Engineering in 2003 and the M.Eng. degree in Electrical and Electronic Engineering (Communication Systems option) in 2008 from Enugu State University of Science and Technology, Nigeria. She also obtained a Postgraduate Diploma in Project Management from the University of Liverpool, United Kingdom, in 2015, and the Ph.D. degree in Electrical and Electronic Engineering (Communication Systems option) from ESUT, Nigeria. She is a Council for the Regulation of Engineering in Nigeria (COREN)–registered engineer and a Fellow of the Nigerian Society of Engineers (FNSE). Her research interests include wireless communications, radio wave propagation, 4G/5G network performance analysis, rain attenuation modeling, and the application of artificial intelligence in communication and sensing systems. She has published widely in reputable high-impact journals, and her works have received significant academic citations. She can be contacted at email: ngozieli@gmail.com.

Uma Uzubi Uma received the B.Eng. and M.Eng. degrees in electrical and electronic engineering from the Federal University of Technology, Owerri, Nigeria, in 2006, and the University of Port Harcourt, Nigeria, in 2011, respectively. He received the Ph.D. degree in electrical engineering, with a specialization in power systems and high-voltage engineering, from the University of Nigeria, Nsukka, Nigeria, in 2021. He is currently a Postdoctoral Researcher with the Department of Computer Science, Universidade Federal de Lavras, Brazil. He is also a Senior Lecturer with the Department of Electrical Engineering, Alex Ekwueme Federal University Ndufu-Alike (AE-FUNAI), Nigeria, where he served as the Head of Department from September 2022 to May 2025. His research interests include power system protection, smart grids, power system planning, and high-voltage engineering. He can be contacted at email:uma.uzubi@funai.edu.ng.



Handel Emezue is a Lecturer in the Department of Electrical and Electronic Engineering at Alex Ekwueme Federal University, Ndufu-Alike, Ebonyi State,Nigeria. He holds an MSc degree from the University of Ibadan and a BEng (Second Class Upper Division) in Computer Engineering from Caritas University. His research interests include software engineering, embedded systems, intelligent systems, cryptography, speech recognition, and smart monitoring systems. He has served as a consultant on national and international ICT projects, including UNICEF-supported initiatives. He is a registered engineer with the Council for the Regulation of Engineering in Nigeria and a member of IEEE and IAENG. He can be contacted at email: handel.emezue@funai.edu.ng.

Ogechi Akudo Nwogu an received her degree in Electrical/Electronics Engineering from Alex Ekwueme Federal University, Ndufu-Alike, Nigeria. Her research interests include embedded systems, renewable energy systems, and intelligent control. She has been involved in several academic and research activities related to modern electrical engineering applications. She can be contacted at email: ogechi.nwogu@funai.edu.ng.

Ogah E. Oga is a lecturer in the Department of Electrical/Electronics Engineering at Alex Ekwueme Federal University, Ndufu-Alike, Nigeria. He obtained his academic qualifications in Electrical Engineering and has several years of teaching and research experience. His research focuses on power systems, smart grid technologies, and energy management.

Calister N. Ogbonna-Mba is affiliated with the Department of Electrical/Electronics Engineering at Alex Ekwueme Federal University, Ndufu-Alike, Nigeria. Her research interests include signal processing, communication systems, and applied electronics. She actively contributes to research and academic development in her field.

Samuel I. Ezichi is a lecturer in the Department of Electrical and Electronic Engineering at Alex Ekwueme Federal University Ndufu-Alike, Ebonyi State Nigeria, where he specializes in engineering innovation, machine learning, and wireless communications. His research explores cutting-edge technological solutions to contemporary challenges in communication systems and intelligent automation. With a strong commitment to interdisciplinary collaboration, Samuel contributes to advancing the field through scholarly publications and academic mentorship. He can be contacted at email: ezichi.samuel@funia.edu.ng.