

ASSESSMENT OF THE IMPACT OF SOLAR IRRADIANCE ON FM- RADIO SIGNAL STRENGTH: A MACHINE LEARNING APPROACH

ABSTRACT

This study investigated the impact of solar irradiance on FM radio signal strength in Abuja, Nigeria, using an experimental research method. Measurements of solar irradiance and FM signal strength were carried out during the rainy season months of June and July 2025 and the dry season months of October and November 2025. The aim of the study was to examine the relationship between solar irradiance and FM radio signal behaviour under different atmospheric conditions. The FM radio signal studied was measured on the frequency of 102.3 MHz. The collected data were analysed using graphical methods and machine learning models, namely linear regression, gradient boosting, and random forest models. The results obtained from both rainy and dry seasons revealed that solar irradiance has an inverse relationship with FM signal strength. Higher signal strengths were mostly recorded during the morning and evening periods when irradiance levels were low, while weaker signal strengths were observed during the afternoon when solar irradiance was highest. The machine learning models further confirmed this relationship, with all models producing coefficients of determination (R^2) above 80%, indicating that solar irradiance significantly influences FM signal strength variation. Among the models tested, the Gradient Boosting model showed the best performance, having the highest R^2 values of 0.91 during the rainy season and 0.9704 during the dry season, alongside the lowest mean squared error values. The study concluded that increased solar irradiance contributes to the reduction of FM radio signal strength due to atmospheric changes such as temperature increase, thermal expansion, and humidity variation, which can increase the absorption and scattering of FM/VHF radio waves.

Keyword: Atmospheric components, Irradiance, Machine learning, Signal attenuation, Signal strength

INTRODUCTION

Irradiance, or solar irradiance, is defined as the solar energy received at a particular location at a particular time or period of time. It is also defined as the amount of power delivered by the sun on a specific area at a given time. Radio wave propagation is influenced by the properties of the earth and atmosphere, given that the curvature of the earth and the condition of the atmosphere can refract electromagnetic waves either in the direction of upwards, away from it, or downwards to the earth's surface (Dagang, 2021). Also, in the work by Ezekoye and Obodo (2007), on the topic "The Effects of Solar Radiations on Telecommunications," it

was reported that solar activity can result in the experiencing of disturbances by telecommunications signals or networks. It has also been reported that solar radiation contributes to the ionization of the atmosphere, which can alter the strength of the transmitted VLF radio waves (Merola, 2006), and not just that, but solar radiations and other solar activities affect the total electron content of the ionosphere and also affect various radio frequencies used in telecommunications (Ezekoye and Obodo, 2007; and Nor et al., 2015). According to Yusuf (2011), the variability of the signal strength of some radio stations in the daytime can be attributed to the solar activity in the atmosphere. Solar radio emission can result

in the decrease in carrier-to-noise ratio, which translates to an increase in the path loss exponent values for the large-scale propagation path loss channel models, given that higher path loss exponent values were observed in hot and sunny weather during the day (41°–42°C) compared with the counterpart measurements taken at night in cool and clear weather (20°–38°C) (Ahmed et al., 2017 & Giuliano et al., 2022). The Sun is a decisive element for the control and development of several natural processes on the Earth, and, in addition, solar activity can also have certain effects on some human activities, such as radiofrequency communications (Mendoza-Barcenas, 2020). Based on the available materials published in this research area, little attention is given to the effect of solar irradiance on the wireless communication, even though solar irradiance contributes to the variations in some other atmospheric components. This work was done in Abuja, North-Central Nigeria, where such work has not been done in recent times.

BRIEF ABOUT ABUJA, THE STUDY AREA

Abuja, the capital city of Nigeria is located between latitudes 8°25' and 9°20' North and longitudes 6°45' and 7°39' East. Abuja is characterised by a tropical wet and dry climate, with two major seasons which the rainy season and the dry season. The rainy season occurs from April to September, and the dry season from October to March. The average annual temperature in Abuja ranges between 25°C and 32°C, although higher temperatures are commonly experienced during the dry season. Annual rainfall is generally between 1,100 mm and 1,600 mm, with relatively high humidity during the rainy months. The vegetation of Abuja is mainly Guinea Savannah, consisting of grasses, scattered trees, shrubs, and patches of woodland. The topography of the area is

undulating, with plains, rocky hills, and isolated highlands (Abdullahi et al, 2024).

RESEARCH METHODOLOGY

This study adopted an experimental research method to investigate the impact of solar irradiance on FM radio signal strength in Abuja, Nigeria. The research involved the direct measurement of solar irradiance and FM radio signal strength at a selected location within Abuja during both the rainy (June and July) and dry (October and November) seasons of 2025. The FM radio signal studied was measured on the frequency of 102.3 MHz, using digital RF signal meter while solar irradiance was measured using a Pyranometer. The data measurement was carried out from 8:00 am to 6:00 pm daily at 30-minute intervals in order to capture the variation of both solar irradiance and signal strength throughout the day. The data recorded during June and July 2025 were grouped and averaged to represent the rainy season, while that during October and November 2025 were averaged to represent the dry season. The data obtained from the measurements were analysed using graphical methods to observe the daily and seasonal behaviour of solar irradiance and FM signal strength. In addition, machine learning models, namely Linear Regression, Gradient Boosting, and Random Forest models, were applied to examine the relationship between solar irradiance and FM signal strength and to evaluate the predictive performance of each model. The performance of the models was assessed using two statistical indicators; the coefficient of determination (R^2) and Mean Squared Error (MSE). This approach made it possible to clearly determine the level at which the changes or variations in solar irradiance influence FM radio signal strength in the study area.

RESULTS AND DISCUSSION

Results of the relationship between solar irradiance and FM signal strength

Fig. 1.0 and fig. 2.0 show the graphical representation of the variation of average solar irradiance and FM signal strength from 8:00 am to 6:00 pm. From fig. 1.0, in the rainy season, it can be observed that the irradiance generally was very low in the morning (around 8 AM) and rose to a high point around 10:00 AM and fell and rose again, though in a non-uniform nature, until it reached the peak around midday and then gradually decreased towards the evening (around 6 PM). In the same way, in the same rainy season, the FM signal was higher in the morning period but began to fall slowly as the day progressed, and the fall continues until the signal reaches the lowest level at around 3:30 PM, from where it started rising again until around 5:30 PM, when it experienced a slight decrease before it continued to rise further. The behavior of FM signal strength appears to show an inverse trend to that of the solar irradiance. That is, as the irradiance increases towards midday, the FM signal tends to decrease, reaching its lowest point around the same time the irradiance is highest, and in another related way, as the irradiance decreases in the afternoon, the FM signal generally starts to rise again. This implies that as the sun's intensity (irradiance) increases, the FM signal strength tends to fall or decrease, and when the sun's intensity decreases, the FM signal tends to increase. In simple terms, the FM signal strength was higher in the morning and evening periods but lower in the daytime or at noon.

Also, from fig. 2.0, which is for the dry season (October and November, 2025), the figure shows that the average solar irradiance

was low in the morning from 8:00 AM and then began to rise slowly until around 9:30 AM, when there was a spike in the sun intensity or solar irradiance at around 10:00 AM, after which it reached its peak level at 11:30 AM and 12:30 PM. From this period, the average irradiance began to fall slowly until around 2:30 PM, when it began to rise to another high level at 3:30 PM, from when it experienced a continuous decrease to the end, though a slight increase was experienced at 6:00 PM. It can be simply stated that the solar irradiance in the study area was high in the noon period or between 11:00 AM and 4:30 PM but lower in the early morning period and late afternoon towards the evening.

Also, it can be observed that the average FM signal strength from the radio station exhibited variations throughout the day, from 8:00 am when the readings started to 6:00 pm when the readings ended. The FM signal strength was very high at the beginning, or in the morning when there was little sunlight, and the signal continued to fall slightly but not uniformly until it reached its lowest level around 2:30 PM. From this point, it surged to a certain higher level, but that height or strength could not be sustained at that noon time as it fell again and this time began to slowly increase in a steady form until the end at 6:00 PM. In simple terms, the FM signal strength was higher in the morning and evening periods but lower in the daytime or at noon. But just like in the rainy season, the variation in the FM signal strength and that of the solar irradiance tends to be in opposite form such that when the solar irradiance is increasing, the FM signal strength is decreasing, and when the solar irradiance is decreasing, the FM radio signal strength is increasing; thus, they can be said to be inversely related in both seasons.

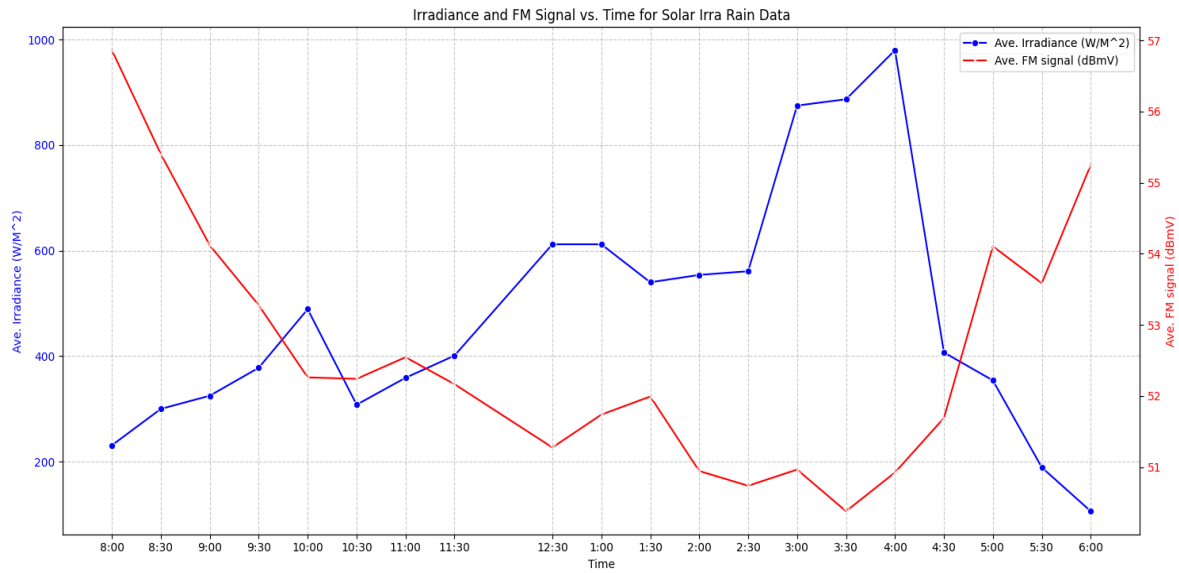


Fig. 1.0: Graphical representation of the variation of average solar irradiance and FM signal strength in rainy season

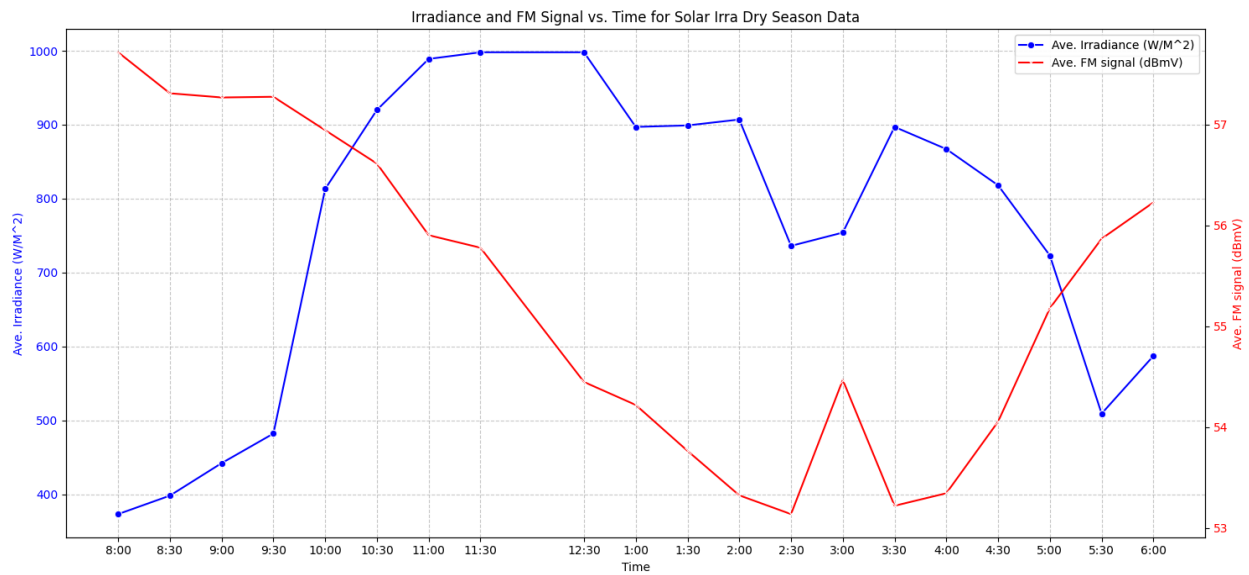


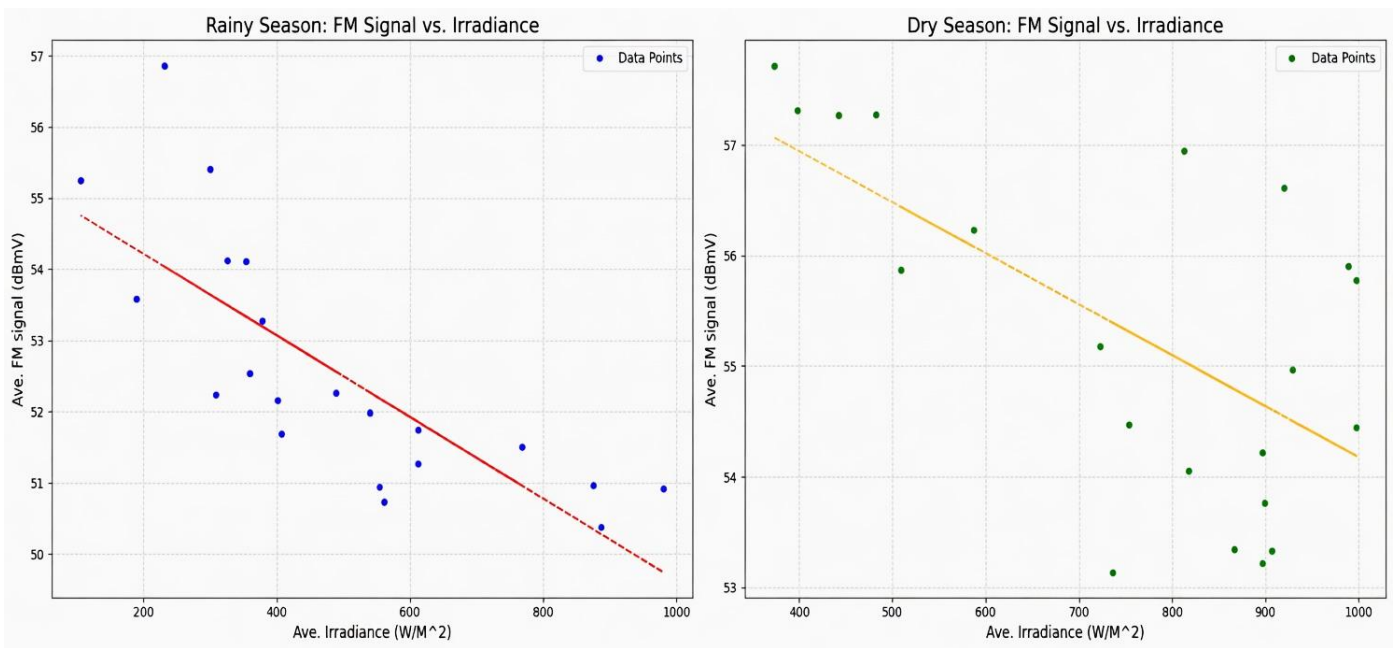
Fig. 2.0: Graphical representation of the variation of average solar irradiance and FM signal strength in dry season

Also, figure 3 shows the graph of average FM signal strength against the solar irradiance in the rainy season and dry season, respectively. From the figure for rainy season, it was

shown that there was a general downward trend, which implies an inverse relationship between the FM signal strength and the solar irradiance. In other words, as the irradiance

increases, the FM signal tends to decrease, though with some scattering. Also, from the figure for the dry season, similar to the rainy season scenario, an inverse relationship between the FM radio signal strength and solar irradiance was observed. The figure shows that as the solar irradiance in the area increases, the FM signal received from the radio station tends to decrease, and vice versa. From both the rainy season and dry season figures, irrespective of the nature or

degree of the relationship, it can be said that both plots visually confirm the inverse relationship between solar irradiance and FM signal strength for both seasons given that, as solar irradiance goes up, the FM signal tends to go down, or as the solar irradiance increases, the FM radio signal strength decreases (fig. 3.0).



Figs. 3: Graph of average FM signal strength against the solar Irradiance in rainy season and dry season

Comparison of solar irradiance in the rainy season with the dry season

Based on the descriptive statistics for irradiance, it was shown that the average irradiance was 487.43 W/m² in the rainy season, while the average irradiance was 758.86 W/m² in the dry season. This shows that the dry season experiences significantly higher average solar irradiance than the rainy season, which could be due to

fewer clouds and more direct sunlight in the dry season, leading to higher overall radiation levels. Also, the standard deviation of the solar irradiance in the rainy season was 237.60 W/m², while in the dry season, the standard deviation was 208.58 W/m². It means that the hourly solar irradiance in the dry season varies about 237.60 W/m² from the mean value of the dry season solar irradiance, whereas the hourly solar irradiance in the rainy season varies about

208.58 W/m² from the mean value of the rainy season solar irradiance, implying that the solar irradiance values are more spread out in the dry season than in the rainy season. This indicates that the irradiance in the dry season fluctuates more or is less stable compared to the rainy season. Furthermore, the minimum and maximum irradiance in the rainy season were 106 W/m² (min) and 980 W/m² (max), while in the dry season, the values were 373 W/m² (min) and 998 W/m² (max).

It can be said that both the minimum and maximum irradiance values are substantially higher in the dry season compared to the rainy season's minimum and maximum values, though the maximum value in the dry season was a bit higher too. This suggests that even in the rainy season, there can be periods of very high irradiance, but these are likely less frequent, leading to a lower average, as the dry season consistently maintains higher minimum and higher overall peaks.

Comparison of FM Signal in Rainy Season with Dry Season

From the descriptive statistics analysis for the FM signal for both seasons, it was shown that the average FM signal was 52.57 dBmV in the rainy season, while the average FM signal was 55.29 dBmV in the dry season. This shows that the dry season displays a notably higher average FM signal compared to the rainy season. Since the solar irradiance and FM signal are inversely related, that is, higher irradiance leads to a lower FM signal, and given that the dry season has significantly higher average solar irradiance, one might expect a lower FM signal, but this is not in this case. This suggests that other environmental factors such as humidity, atmospheric moisture, or rain attenuation,

which are prevalent in the rainy season, might have a greater impact on FM signal strength, overriding the effect of lower irradiance.

Furthermore, the standard deviation of the FM radio signal strength in the rainy season was 1.75 dBmV, while the standard deviation in the dry season was 1.54 dBmV. The rainy season exhibits a slightly higher standard deviation for the FM signal. This indicates that the FM signal in the rainy season fluctuates more or is less stable compared to the dry season. This increased variability could be attributed to the inconsistent and dynamic weather conditions characteristic of the rainy season, such as intermittent heavy rain, varying cloud cover, and changes in atmospheric moisture.

In addition, examining the minimum and maximum FM signals in the two seasons, it was observed that the minimum FM signal strength was 50.38 dBmV (min), while the maximum was 56.86 dBmV in the rainy season, while in the dry season, the minimum was 53.14 dBmV, while the maximum value was 57.72 dBmV. It can be observed from the results here that the dry season generally presents higher minimum and maximum FM signal values compared to the rainy season, aligning with its higher mean signal, which could also be a result of rain attenuation, which occurs in the rainy season and results in signal scattering, absorption, and diffraction.

Results of Regression, Random Forest and Gradient boosting models analysis for rainy season

4.4.1 Regression model result

The linear regression model equation is given as (1);

$$FM = 55.36 - 0.0057 \text{ Irradiance} \text{ ---- } 1$$

Where FM represents the FM radio signal strength.

The regression analysis shows that the intercept was 55.36, and this represents the estimated FM signal when the average irradiance is 0 W/m². This can be interpreted as the baseline FM signal with no solar irradiance. Also, the coefficient for irradiance was -0.0057, and this indicates that for every one-unit increase in irradiance, the FM signal is expected to decrease by 0.0057. This suggests an inverse relationship, meaning that as solar irradiance increases, the FM signal tends to decrease. Also, the analysis of linear regression showed that R-squared was 0.9004, while the mean squared error (MSE) was 0.2882. The linear regression model for the rainy season shows a strong R-squared of 0.9004, and this means that about 90% of the variance in FM signal strength can be explained by solar irradiance using a linear relationship. The result also shows that the MSE was 0.2882, which means the average squared difference between the actual and predicted values of the FM signal.

Gradient Boosting Regression Result

In the rainy season, the R-squared, or coefficient of determination, value was 0.91. The R-squared value of 0.91 for the rainy season means that 91% of the variance in the FM signal can be explained by the irradiance when using the gradient boosting model. Also, the Mean Squared Error (MSE) in the rainy season was 0.065. This measures the average squared difference between the estimated values and the actual value. That is, the MSE value of 0.065 shows that the average squared difference between the actual and predicted FM signal values was 0.065.

Random Forest Regression Results

The analysis of the random forest showed that the R-squared was 0.89. The R-squared of 0.89 means that approximately 89% of the variance in the FM signal can be explained by the irradiance using the Random Forest model. Also, the Mean Squared Error (MSE) was 0.2611. The MSE value of 0.261 means that the average squared difference between the actual and predicted FM signal values is 0.261.

Results of Regression, Random Forest and Gradient boosting models analysis for Dry season

Linear Regression Model result for Dry Season

The linear regression model Equation for dry season is given as (2):

$$FM = 58.78 - 0.0046 \text{ Irradiance} \text{ ----- } 2$$

In this equation, the intercept is 58.7843. It means the estimated FM signal is 58.7843 dBmV when the average irradiance is 0 W/m². That is, if there were *no solar irradiance* (i.e., at night or in complete darkness), the model predicts an average FM signal strength of approximately 58.78 dBmV. Also, the coefficient for irradiance was -0.0046. The coefficient of -0.0046 indicates an inverse relationship. In this, the coefficient of -0.0046 means that for every increase of 1 W/m² in solar irradiance, the average FM signal is expected to decrease by 0.0046 dBmV. This reinforces the inverse relationship observed in previous analyses, given that as solar irradiance increases, the FM signal tends to decrease.

Also, the analysis of the linear regression showed that the R-squared value was 0.9064 and the mean squared error (MSE) was 0.2104. The linear regression model exhibits an R-squared of 0.9064, indicating that

approximately 90.64% of the variability in FM signal strength can be explained by solar irradiance in a linear fashion. Also, the MSE was 0.2104, meaning that the average squared difference between the actual and predicted FM signal values was 0.2104.

Gradient Boosting Regression Model result

The analysis of the gradient boosting shows that the R-squared value was 0.9704. This means that approximately 97.04% of the variability in the FM signal can be explained by the irradiance when using this gradient boosting model. This implies that solar irradiance is a dominant factor influencing the FM signal during this dry season. Also, the Mean Squared Error (MSE) was 0.0665. The MSE of 0.0665 shows that the model's predictions are, on average, very close to the true observed values. The MSE of 0.0665 means that the average squared difference between the actual and predicted FM signal values was 0.0665.

Random Forest Regression Model result

The analysis of the gradient boosting shows that the R-squared was 0.9064. The R-squared value of 0.9064 implies that about 90.64% of the variance or change in the FM signal can be explained by the irradiance using the Random Forest model. Also, the mean squared error was 0.2104. An MSE of 0.2104 means that the average squared difference between actual and predicted values is 0.2104.

CONCLUSION

This study investigated the impact of solar irradiance on FM radio signal strength using an experimental research method. Measurements of solar irradiance and FM signal strength were carried out in Abuja,

Nigeria, during the rainy season months of June and July 2025 and the dry season months of October and November 2025. The results from both seasons showed that solar irradiance has an inverse relationship with FM signal strength. This means that as solar irradiance increases, the FM signal strength decreases, while lower irradiance levels are associated with stronger signal reception.

The results presented in Figures 1 and 2 showed that stronger FM signals were mostly observed during the morning and evening periods when solar irradiance was low. In contrast, weaker signal strengths were recorded during the afternoon when irradiance was highest. Similar trends were also observed in Figure 3. The machine learning models used in the study, namely Linear Regression, Gradient Boosting, and Random Forest, further confirmed this relationship. All three models produced coefficients of determination (R^2) above 80%, indicating that solar irradiance explains a significant portion of the variation in FM signal strength.

From the findings, it can be concluded that increased solar irradiance contributes to a reduction in FM radio signal strength within the study area. This may be due to atmospheric changes such as temperature increase, thermal expansion, and humidity variations during periods of intense solar heating, which can increase the absorption and scattering of FM/VHF radio waves.

The findings agree with the study by Marhamah et al. (2028), which reported weaker radio signals during daytime periods except around sunrise and sunset. Among the machine learning models tested, the Gradient Boosting model performed best in both rainy and dry seasons, having the highest R^2 values (0.91 and 0.9704) and the lowest MSE values (0.065 and 0.066).

RECOMMENDATION

It is recommended that similar studies be conducted in other locations across Nigeria, particularly in regions with higher temperatures or different climatic conditions compared to Abuja, in order to further evaluate the influence of atmospheric conditions on signal propagation.

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