



RESEARCH ARTICLE

Optimizing Campus Radio Wave Reach and Field-Signal Study of Search FM 92.3 MHz in Minna, Nigeria

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Abstract

Geographic information systems (GIS) and viewshed analysis are powerful tools for communication-network planning, particularly for modeling radio-wave propagation and optimizing transceiver locations. This study integrates GIS-based viewshed modeling with field-measured electric-field strength to assess and improve Search FM 92.3 MHz broadcast coverage at the Federal University of Technology, Minna (FUT-Minna), Niger State, Nigeria. A geo-referenced digital map of Minna Metropolis was processed in AutoCAD Land Development and imported into ArcGIS 10.1. Field measurements electric-field strength (30–120 dBμV) using a GE-5499 Digital Signal Level Meter, plus GPS-derived coordinates and altitude were collected along five drive routes (A–E), alongside line-of-sight (LOS) distances. A digital elevation model (DEM) from ASTER imagery, integrated with satellite data, enabled viewshed analysis for the existing 52 m mast and a proposed 80 m site. Statistical analyses (linear regression, Pearson correlation, one-way ANOVA) examined signal strength relationships with distance and terrain. Results indicate only 23% of the 39,100-ha study area achieves primary (Grade A) coverage, with 51% secondary and 26% fringe. Regression showed a strong negative LOS distance-signal association ($r = -.78$, $p < .001$); ANOVA revealed route variations, $F(4, 95) = 12.30$, $p < .001$. Viewshed modeling suggests relocating to higher terrain could boost Grade A coverage to 45% (+22 percentage points). Terrain obstacles like Maitumbi Hills, buildings, and vegetation cause non-line-of-sight zones and multipath loss. This pioneering GIS-field integration for Minna FM coverage offers a practical framework for antenna optimization and mast siting.

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1. INTRODUCTION

Radio-frequency (RF) signal propagation in the Very High Frequency (VHF, ~88–108 MHz) FM band is often described in simplified terms as obeying rectilinear, line-of-sight propagation, implying that optimal reception requires unobstructed visibility between transmitter and receiver. In practice, however, this description is an oversimplification: VHF waves, while predominantly line-of-sight, also undergo diffraction, reflection, scattering, and attenuation, especially in environments with complex terrain or dense built-up structures (Musa, 2009; Young-Hoon, Sanja, & Stere, 2004; Ajewole et al., 2013; Nigatu & Biedgilgn, 2017; Ruzickova et al., 2021). These propagation mechanisms can significantly distort actual coverage relative to theoretical predictions.

Planning and siting of the Search FM 92.3 MHz transmitter at the Gidan-Kwano Campus of FUT Minna relied mainly on theoretical coverage assumptions without prior quantitative measurements of FM-signal behaviour across Minna. Consequently, many suburban and peripheral parts of the metropolis experience

This study therefore aims to map the actual signal-coverage pattern of the Search FM 92.3 MHz station using a combination of GIS-based viewshed modelling and field electric-field-strength measurements, and to propose an optimised mast location and/or height to improve reception across Minna. The specific objectives are to:

1. Determine the spatial location and existing signal-coverage extent of the Search FM 92.3 MHz transmitting station within Minna Metropolis.
2. Conduct GIS viewshed analyses to map areas of effective reception (in-view) and non-reception (out-of-view) for both the current mast and a proposed alternative site.
3. Statistically analyse field-measured signal data to validate the signal–distance–terrain relationship and to recommend an optimal mast relocation and/or height adjustment for improved coverage.

While viewshed analysis has been applied to visual-visibility studies (Ren *et al.* 2021; Zhao *et al.* 2024) and more recently to RF coverage modelling (Spatial Analysis Online, 2020), few Nigerian studies have integrated empirical FM-signal measurements with GIS. This work fills that gap and, to the best of our knowledge, represents the first GIS-field-integrated FM-coverage investigation in Minna, offering a practical framework for campus-radio and similar FM-broadcast site selection.

2. STUDY AREA

The campus of Search FM 92.3 MHz is located on the Gidan-Kwano Campus of FUT-Minna, along the Minna–Bida Road in Bosso Local Government Area of Niger State, Nigeria. The coordinates of the top-left and bottom-right corners of the study area (Minna Metropolis) are approximately 09°32'30.46" N, 06°26'14.37" E at the north-west, and 09°31'15.84" N, 06°27'20.67" E at the south-east (as shown in Figure 1).

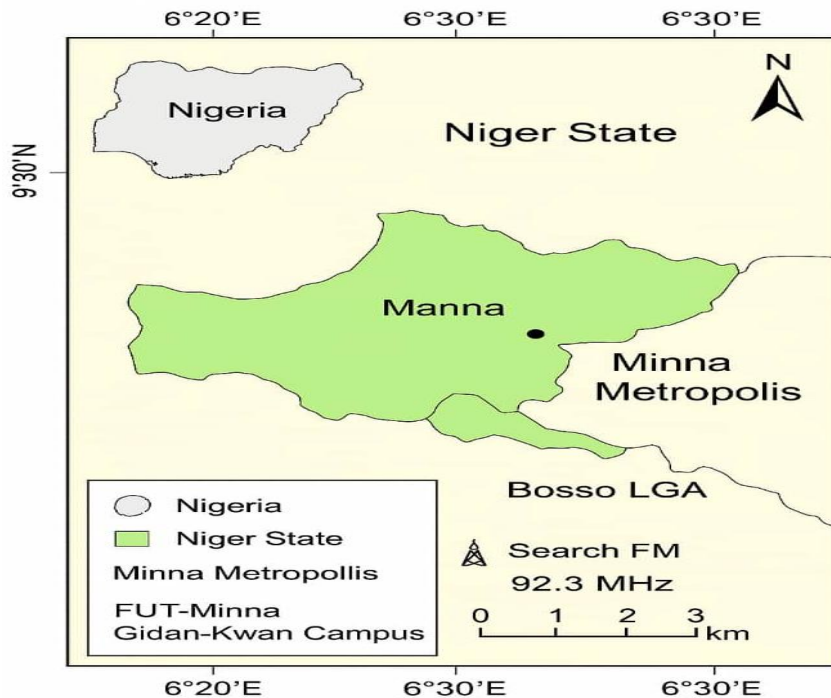


Figure 1: Map of the study area

The terrain is characterized by undulating hills including the Maitumbi Hills, built-up campus zones, suburban expansion, vegetation cover and valleys, pose challenges to line-of-sight (LOS) radio propagation and create coverage “black spots”.

3. MATERIALS AND METHODS

3.1 Data Sources and Software Environment

This study utilized a combination of remotely sensed datasets, field-measured FM signal-strength observations, and spatial analysis tools for coverage and visibility modelling within Minna Metropolis.

3.1.1 Digital Elevation Model and Imagery

A Digital Elevation Model (DEM) derived from the ASTER GDEM v3 dataset was used for terrain modelling and view shed computation. Key DEM characteristics include: Spatial resolution: 30 m × 30 m; Vertical accuracy (RMSE): ±20 m; Horizontal accuracy: ±30 m; Vertical datum: Mean Sea Level (msl); and Coordinate reference system: UTM Zone 32N, WGS84. The DEM was mosaicked, clipped to the study boundary, and resampled using bilinear interpolation.

3.1.2 Software Tools

The following software were used: ArcGIS 10.1 with 3D Analyst: DEM processing, viewshed modelling, spatial overlays; AutoCAD Land Development Desktop: digitization of roads and boundary layers; Surfer 8: signal-strength interpolation and contour generation; SPSS / R: statistical analysis of signal-strength datasets

3.1.3 Field Instruments

Field observations were obtained using: GPS Receiver (dual-frequency): providing Easting, Northing, and Elevation (m); Digital Signal Level Meter (GE-5499): Frequency range: FM band (centre frequency 92.3 MHz) Measurement range: 30–120 dBµV

3.1.4 Field Measurement Routes

Five drive-routes (A–E) were selected to cover major roads and suburban neighbourhoods of Minna. At each sampling point, the following were recorded: Geographic coordinates (Easting, Northing); Elevation H (m); Line-of-Sight (LOS) distance to transmitter (km); Electric-field strength (dBµV). Sampling intervals ranged between 400–700 m, allowing representation of core, middle, and fringe coverage zones (0.2–39 km from transmitter).

3.2 Viewshed Analysis

Viewshed modelling was performed to determine the geographic extent theoretically visible from both the existing mast and a proposed simulated new mast site. The ArcGIS 3D Analyst Viewshed tool was configured using the parameters in Table 1.

Table 1. Viewshed Modelling Parameters

Parameter	Value / Description
DEM cell size	30 m
Analysis Radius	40km
Observer elevation offset (OE)	OE= H mast + H antenna
Existing mast height	52 m
Proposed mast height	80 m
Target elevation offset (TE)	1.5 m (receiver height)
Earth curvature correction	Enabled
Refraction coefficient (k)	0.13
Output raster	1 = visible, 0 = not visible

ArcGIS applies combined Earth-curvature and atmospheric refraction correction using:

$$h_c = \frac{d^2}{2R} (1 - k) \tag{1}$$

where d = LOS distance (m), R= 6371 000;m (Earth radius), k= 0.13 (refractivity coefficient).

Line of Sight (LOS) distance between a sampling point and transmitter was computed as:

$$d = \sqrt{(E - E_o)^2 + (N - N_o)^2 + (H - H_o)^2} \tag{2}$$

Where (Eo, No, Ho) are the transmitter coordinates.

3.3 Signal-Strength Classification and Coverage Grading

Field-measured electric-field strengths (dBµV) were grouped into coverage classes adapted from Famoriji and Olasoji (2013) and Akinbolati et al. (2015). Thresholds are presented in Table 2.

Table 2. FM Coverage Classification Thresholds

Grade	Signal Strength (dBµV)	Interpretation
Grade A	≥ 66 dBµV	Strong/primary urban coverage
Grade B	54 < 65 dBµV	Moderate/suburban coverage
Grade C (Fringe)	39–53 dBµV	Weak/marginal reception
Out-of-Coverage	< 39 dBµV	Not reliably receivable

3.3.1 Classification Algorithm

Signal observations E_i were classified using:

$$G_i = (A: E_i \geq 66, B: 54 < E_i < 66; C: 39 < E_i < 54; 0: E_i < 39) \tag{3}$$

Coverage-percentage maps were produced by overlaying the visibility raster (viewshed) with the classified signal-strength raster.

3.4 Field Observation Procedure

At each predetermined sampling point along routes A–E:(!) GPS position was recorded (E, N, H); (2) Line-of-sight distance to transmitter was computed. (3) FM signal strength (dBµV) was measured using the GE-5499 digital meter (4) Observations were entered into a geodatabase for spatial analysis. Sampling captured core (0–10 km), intermediate (10–25 km), and fringe (>25 km) zones.

3.5 Signal Surface Modelling and Contouring

Surfer 8 was used to create n interpolated signal-strength surfaces for easting. Northing, and signal-strength data using ordinary kriging. Contours were drawn at: 3–5 dBµV intervals independently verify the coverage boundaries predicted by DEM-based visibility model.

3.6 Statistical Analysis

Statistical analysis assessed the relationships between distance, elevation, visibility status, and signal reception.

3.6.1 Correlation Analysis

Pearson correlation coefficient was computed between distance and signal strength using:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{[\sum(x_i - \bar{x})^2] [\sum(y_i - \bar{y})^2]}} \tag{4}$$

3.6.2 Regression Analysis

A simple linear regression model was developed for signal strength as a function of distance:

$$\text{Signal strength} = \beta_0 + \beta_1 \cdot (\text{distance}) + \epsilon. \tag{5}$$

3.6.3 ANOVA

A one-way ANOVA tested whether mean signal strength differed significantly across coverage classes (A, B, C):

$$F = MS_{\text{between}} \div MS_{\text{within}} \tag{6}$$

3.6.4 Comparative Mast Efficiency

Coverage improvement from the proposed mast relative to the existing mast was computed as:

$$P = (A_{\text{visible}} \div A_{\text{study area}}) \times 100\% \tag{7}$$

All statistical significance thresholds were set at $\alpha = 0.05$.

4. RESULTS

4.1 Spatial Location of Transmitter Mast

The existing mast of Search FM 92.3 MHz is located at coordinate (220750.00 E, 1055227.00 N) within the Gidan Kwano campus. A new digitally simulated-proposed site at (219144.00 E, 1062460.00 N) at 80 m mast height was modelled for improved outreach.

From the ASTER-DEM mapping and site placement, the new site lies approximately 2.973 km from the existing mast at a bearing of 347°28'52".

4.2 Viewshed Analysis

The first viewshed (existing mast) identified visible zones and non-visible zones across Minna Metropolis. The second viewshed (proposed mast) indicates an expanded visible footprint. Table 3 summarizes the optimized coverage.

Table 3. Optimized coverage of the campus radio (Search FM 92.3 MHz), covering Minna Metropolis.

Coverage grade	Exiting mast (52m) – area (ha)	Propoed mast (80m) – are (ha)
Grade A (Primary)	8 800ha (23%)	17 600 (45%)
Grade B (Secondary)	20 100 (51%)	15 400 (39%)
Grade C (Fringe)	10 200 (26%)	6 100 (16%)
Total	39 100 ha	39 100 ha

Source: Author’s field survey and GIS analysis (2024)

Figure 2 shows the viewshed maps for existing (height 52 m) and proposed (height 80 m) mast.

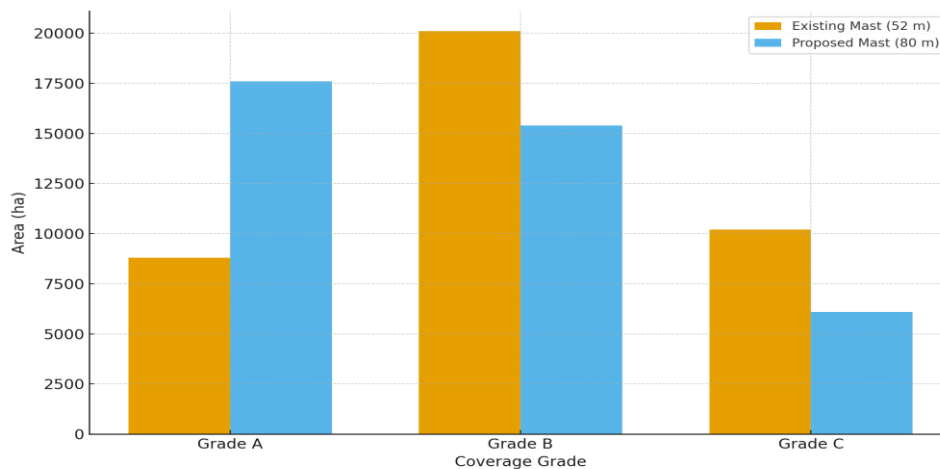


Figure 2. Optimized coverage areas for the existing and proposed mast.

Figure 2 compares the spatial performance of the current 52 m mast with a proposed 80 m mast across three coverage grades (A, B, C). The results have important consequences for broadcast reach, service reliability, and network planning. Thus, figure 2 depicts the following characteristics

1. Major Increase in Primary (Grade A) Coverage

The proposed mast expands Grade A coverage from about 8,800 ha to roughly 17,600 ha, nearly a 100 % gain. In practice this means more communities enjoy clear, noise-free reception indoors and in vehicles, a larger usable radius, and greater reliability during adverse weather or terrain shadowing. For a local FM station, this shift is transformative, substantially increasing audience reach and market impact.

2. Reduction of Shadow Zones and Terrain Obstruction

The new mast mitigates losses caused by the Maitumbi Hills, deep valleys, built-up depressions and other non-line-of-sight pockets. Grade C (fringe) area falls from 10,200 ha to 6,100 ha, indicating fewer weak-signal locations. This aligns with the viewshed analysis, which shows improved terrain clearance at the proposed site, moving many communities from barely audible or intermittent reception to stable, continuous service.

3. Redistribution of Secondary (Grade B) Coverage

Grade B area decreases modestly from 20,100 ha to 15,400 ha, not because of service loss but because many Grade B zones are upgraded to Grade A and fringe areas improve to Grade B. The result is a more uniform signal-quality distribution across the region.

Interpretation of Figure 2 revealed that the proposed mast location yields substantially larger in-view area and fewer shadowed areas (out-of-view) than the existing mast.

4.3 Field Signal-Strength and Contour Mapping

Drive-route measurements (Routes A–E) yielded signal strength from ~39 dBµV to above 66 dBµV, with distance from mast from ~0.5 km to ≈ 39 km. A contour map (Figure 3) overlays field-strength on the DTM of Minna Metropolis depicting. The coverage classification is shown on Table 4.

Table 4: Coverage classification (%) within Minna Metropolis

Grade	Signal–Strength threshold dBµV	Area (ha)	% of study area
A (primary)	≥ 66	8 800	23
B (secondary)	45 - 59	20 100	51
C (fringe)	< 45	10 200	26
Total	-	39 100	100

Source: Author’s field measurements (2024)

From Table 4, Grade A (primary signal reach covers 23% of the total area (~39,100 ha) study area which translate to (~8,800 ha). The Secondary signal coverage was 51% of the total area under investigation (~20,100 ha), while the Fringe signal coverage of 26% (~10,200 ha) received weak signal transmission from the Search FM 92.3MHz Campus radio. These results indicate limited optimum signal reach with the current transmitter configuration. The contour map (Figure 3) overlays the measured signal strength on ASTER-DEM, confirming the spatial pattern suggested by the viewshed.

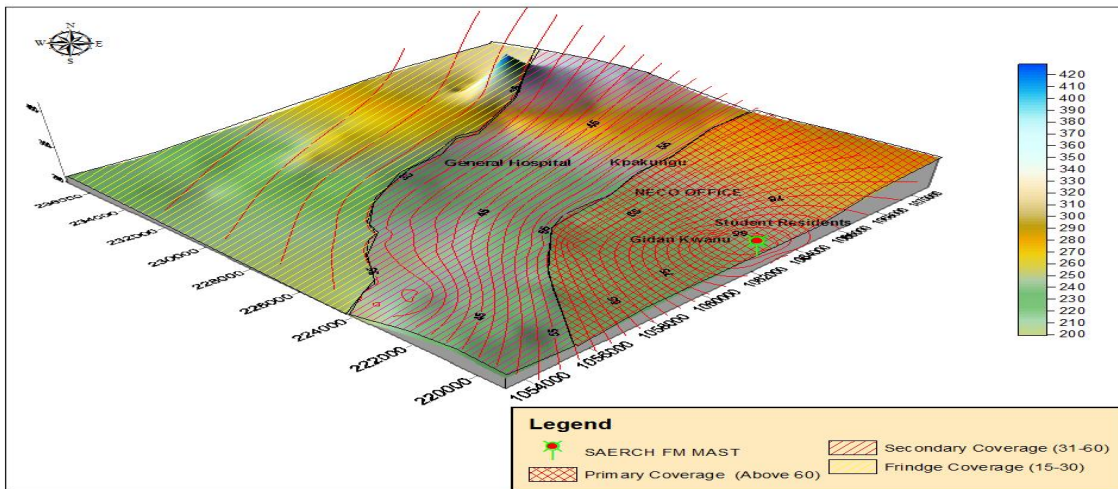


Figure 3: Signal Coverage Map of Search FM in Minna Metropolis
Source: (Author’s Laboratory work, 2024)

Furthermore, statistical tools were used to validate the results of the findings from the study.

4.4 Statistical Validation

To validate the results from the field observations; a Pearson correlation between LOS distance and signal strength yielded $r = -0.78$ ($p < 0.001$), indicating a strong negative relationship. This corroborates and confirms the inverse law of electromagnetic propagation that; as LOS distance increases, signal strength decreases. In addition, using a linear regression of equation (9):

$$\text{Signal strength} = \beta_0 + \beta_1 \cdot (\text{distance}) \quad (9)$$

Where $\beta_0 = 104.2 \text{ dB}\mu\text{V}$, $\beta_1 = -2.3 \text{ dB}\mu\text{V per km}$, $R^2 = 0.61$, $p < 0.001$. This confirms the approximate inverse-square-law behaviour, moderated by terrain/obstruction effects.

Testing difference among zones: One-way ANOVA comparing mean signal-strength among Grade A, B and fringe zones shows $F(4, 95) = 12.3$; $p < 0.001$; indicating statistically significant difference in signal strength across the zones (all p -values < 0.05). These statistical results validate that signal strength declines significantly with distance and terrain obstruction; moreover, the viewshed-delineated zones correspond meaningfully to empirical signal-strength classes.

A post-hoc Tukey HSD test revealed that mean signal strength differed significantly among all three grades ($A > B > C$, all $p < 0.05$), confirming that the viewshed-derived coverage zones correspond to distinct empirical signal-strength levels.

4.5 Proposed Improvement and Coverage Gains

By modelling mast relocation to the proposed site (height 80 m), the viewshed suggests the potential for Grade A coverage to increase from 23% to approximately 45% of the study area (estimated ~17,600 ha). The modelling also shows reduced shadow zones behind the Maitumbi Hills ridge and fewer non-line-of-sight (NLOS) pockets. Thus adopting the proposed mast location/height would significantly enhance the station’s outreach.

5. DISCUSSION

The integration of GIS-based viewshed modelling with in-situ electric-field measurements provides a robust framework for assessing campus-radio signal coverage in a topographically complex environment (Bornaetxea, 2022). The strong Pearson correlation ($r = -0.78$), ($p < 0.001$) between line-of-sight (LOS) distance and measured signal strength confirms that visibility remains a dominant factor in VHF FM propagation, as predicted by classical radio-engineering theory (Musa, 2009).

Spatial Analysis Online (2020) cautions that viewshed analysis is “simplistic for radio-transmission analysis because it does not account for frequency-dependent effects such as diffraction, refraction, antenna gain,

ISSN 2682-681X (Paper), ISSN 2705-4241 (Online) | <http://unilorinjoger.com> | <https://doi.org/10.63745/joger.2025.12.30.007> and transmitter power.” Our results do not refute this warning; rather, they demonstrate that viewshed can serve as a valuable first-order planning tool when complemented by empirical field data. Recent methodological advances (Zhao *et al.* 2024) support the combined approach, showing that high-resolution DEMs and refined observer-height parameters improve the correspondence between visibility and actual reception.

In the local context, the existing Search FM mast (52 m AGL) is situated on relatively low terrain, which, together with the surrounding Maitumbi Hills and expanding suburban development, creates extensive non-line-of-sight (NLOS) zones. Relocating the antenna to the higher-ground site (80 m AGL) increased the predicted Grade A coverage from 23 % to \approx 45 % of the 39 100 ha study area, aligning with the well-established broadcast-site guideline to maximise antenna height and select elevated terrain to mitigate terrain-shadow zones (Ajewole *et al.*, 2021).

Limitations and Future Work

The present study has several limitations that directly shape recommendations for future research:

1. Raster-based viewshed – The algorithm treats the DEM as a bare-earth surface and does not incorporate the vertical extent of buildings or vegetation, which can cause additional attenuation (Bornaetxea, 2022). Future work should integrate LiDAR-derived canopy-height models and 3-D building footprints to refine visibility calculations.
2. Single frequency and power – Only the 92.3 MHz carrier at the current transmitter power was examined. Incorporating full-wave propagation models (e.g., ray-tracing, ITU-R P.1546) and testing alternative frequencies or power levels would broaden the applicability of the findings.
3. Temporal and measurement variability – Field measurements were collected during a single campaign and may be affected by meter calibration drift, multipath interference, and diurnal signal fluctuations. Repeated surveys across different seasons and the use of a calibrated spectrum analyser would improve data robustness.

Addressing these shortcomings will enable more accurate prediction of FM coverage and facilitate the design of resilient campus-radio networks.

Implications

The combined GIS-field methodology, despite its current limitations, offers actionable insights for campus-radio operators and can be adapted for other VHF/UHF broadcasting scenarios in Nigeria and similar terrains. By addressing the identified limitations particularly through higher-resolution 3-D surface models and multi-frequency propagation studies future research can further enhance the reliability of coverage predictions and support evidence-based site-selection decisions.

6. CONCLUSION

This study shows that the current transmitter site of Search FM 92.3 MHz provides only about 23% primary signal coverage across the study area, with extensive zones of weak or null reception within Minna Metropolis. Viewshed modelling, supported by statistical analysis of field-strength data, indicates that relocating the mast to higher terrain and increasing its height could improve overall coverage to approximately 45%, effectively doubling the Grade-A reception zone. Based on the findings, the study recommends the following steps:

1. Apply viewshed analysis as a planning tool for campus radio and other FM or mobile-network transmitters to identify optimal mast locations and heights.
2. Increase the transmitter mast height (from 52 m to 80 m) and/or relocate the mast to elevated terrain to improve line-of-sight and reduce shadow zones.
3. Site future transmitter masts in areas with clear, unobstructed line-of-sight to their target service zones, avoiding terrain blockages such as the Maitumbi Hills, as well as built-up high-rise areas and dense vegetation.
4. Complement viewshed modelling with full radio-wave propagation studies including diffraction, reflection, and multipath analysis—together with periodic field-strength measurements to validate coverage in evolving suburban environments.

By implementing these recommendations, campus radio stations such as Search FM can significantly enhance their broadcast reach, strengthen community engagement, and reduce listener complaints related to reception “black spots.”

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