ADSUJSR 13 (2) (2025) 40 - 48
Adamawa State University Journal of Scientific Research
(ADSUJSR)
http://www.adsujsr.adsu.edu.ng
ISSN: 2705-1900 (Online); ISSN: 2251-0702 (Print)

SAFETY DISTANCE FOR INSTALLING GSM MAST IN RESIDENTIAL AREAS IN NIGERIA USING ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM APPROACH: FURTHER STUDY

***Kennedy G. Gaya**
Department of Pure and Applied Physics, Adamawa State University, Mubi.
**Corresponding Author email: kennedygaya1@gmail.com*
ORCID: 0009-0005-1329-193X

Received in July 2025
Accepted in August 2025

Abstract
The importance of communication cannot be over emphasized as it serves as one of the simplest and easiest means of communication. This work focused on determination of safety distance for installing Global System for Mobile Communication in residential areas. ANFIS model techniques was used to predict the power density measured from the GSM mast at different distance from 10m – 50m at an interval of 5m. From the result of the prediction, the mean absolute percentage error (MAPE) was found to be 10.88% with model efficiency validated as 89.12%. Specific absorption rate (SAR) was obtained as 1.05x10-4 W/Kg<<0.08; 1.05x10^-4 W/Kg <<2.00 W/Kg from the power density predicted which was compared with the standard of SAR values given by international commission of non-ionizing radiation protection (ICNIRP) and was found to be far below the recommended level. Thus, it is safe to install GSM mast at a minimum distance of 10m from residential area as an additional safety margins.

Keywords: Power Density, Distance, ANFIS, Specific Absorption Rate and Safety.

Introduction

Safety distance, (ICNIRP, 2020) implicitly defines as the distance about an electromagnetic field (EMF) source within which exposure levels (e.g. power density, electric/magnetic field strength) exceed the maximum permissible exposure (MPE) values for safe human exposure. In general, safety distance is usually determined based on theoretical models based on transmission of electromagnetic waves (EMW). Occupational safety relied on the measurement of safety distance. It is calculated using the Power density (W/m²), Transmitted power (W) and Antenna gain. Distance (m) and frequency (Hz). The global system for mobile communication system (GSM) has significantly improved communication system in Nigeria. However, Nigerians are now concerned about the health challenges associated with GSM masts located closed or near a resident. Certain groups are of the opinion that non-ionized radiation is inimical to health. In another way, living near GSM masts for an extended period can cause several illnesses which include cancer, chronic headaches, loss of reproductive organs and brain damage (Dariusz et al., 2002; Santini et al., 2003; Lennart et al., 2007; Akintola et al., 2009 and Shangchen et al., 2009). However, several groups including the Mobile Manufacturer Forum (MMF), which produces GSM and ME operators and the ICNIRP (International Committee on Non-Ionized Radiation) argue that GSM mast radiation has insufficient energy to significantly affect human health (Shalangwa, 2010; Mamilus and Anthoney, 2012). Long-term exposure to non-ionized radiation has also been linked to adverse effects on the brain (Leif et al., 2003), eyes (Hayland,2000), pregnant women and the testicles (Sahar and Jabir, 2013) according to many research studies. However, Regression and correlation are the primary techniques used in evaluating radiation (Akintola et al., 2009; Shalangwa, 2010; Shalangwa, 2011 and Mamilus and Anthoney, 2012). The unchecked placement of GSM masts in residential areas across Nigeria poses serious public health risks to people's wellbeing due to long-term exposure to radiofrequency electromagnetic fields (RF-EMF). These risks include potential thermal and non-thermal effects on human health, as well as increased SAR that may lead to tissue heating or other biological effects. However, ANFIS can accurately predict the minimum safety distance by integrating various input data, resulting in lower error rates compared to traditional empirical or linear regression methods. Its unique hybrid architecture combines adaptive learning from neural networks with the rule-based interpretability of fuzzy logic systems, making it preferable over other predictive or machine learning models. Additionally, ANFIS utilizes fuzzy if-then rules to leverage expert knowledge, making it less data-hungry and more interpretable for stakeholders such as regulators and health authorities. The study aims to estimate the safety distance on which GSM masts should be sited in the residential areas by calculating the SAR and further correlate with the basic restrictions of the whole body and localized established by the ICNIRP (ICNIRP, 2009). Finally, a recommended safety distance for the installation of GSM masts was be suggested.

Mubi town in Adamawa State was taken as a case study for research. The town is the second largest urban center in the state. It is characterized by the presence of numerous GSM masts strategically positioned along different areas. This investigation specifically focused on the GSM mast located in the Lokuwa area, primarily due to its proximity to several educational institutions situated within that area. Among these institutions are Federal Polytechnic Mubi, Adamawa State University Mubi, College of Health Technology, Government Technical College, Government Secondary School, and Mundra Model School, among others. Frequently, students spend most of their time engaging in activities within this area. Therefore, it is imperative to assess the levels of radiation exposure in this area. Communication is facilitated via point-to-point connections in relation to the GSM mast established in the residential areas.

Materials and Method

The materials employed in this study comprises of GSM Mast, measuring tape, table and an Electromagnetic Meter (EMM). The EMM possesses distinctive attributes for data acquisition including Data Memory, Ticker, Audible Warning Alert, Audible Pulse, Dose Exposure Chart, Multi-Function Key components and a Digital Display which was positioned at a height of 1 meter on a table, distanced from the base of the GSM mast to ensure the measurement of density of power at a given distance (D). The necessary distance between the table's base and the GSM mast is determined using the Measuring Tape. There are two phases to these measurements. Over the period of seven days, power density assessments were conducted at various distances (10–50 m), which represent the actual power density (P). The previous power density (B) was determined by repeating the same measurement settings for an additional seven days after the first one. Table 2 displays the average values of each power density that was measured while figure 1 shows the correlation between Distance and both the Actual and previous radiation density.

Table 1 provides a comprehensive overview of the antenna parameters implemented within the study area.

Table 1: Standard GSM Parameters for GSM Mast installed

Parameters	Specifications
Operational Temperature	-20 to +600C
Storage Temperature	-30 to +750C
Transmitter’s Gain	45 (dBm)

GSM Mast Height	32 m
E-Plane Beam Width	100 degree
Polarization	Vertical
Carrier Frequency	900/1800 (MHz)
H-Plane Beam Width	Omni Directional
Bandwidth	Broadband
VSWR	2:1

Table 2: Power Densities Measured

$D(m)$	$P(\mu Wm^{-1})$	$B(\mu Wm^{-1})$
10	36.96	37.16
15	13.02	02.52
20	08.76	09.29
25	07.03	07.49
30	06.58	06.13
35	02.95	03.03
40	01.97	02.00
45	01.67	01.78
50	02.20	02.32

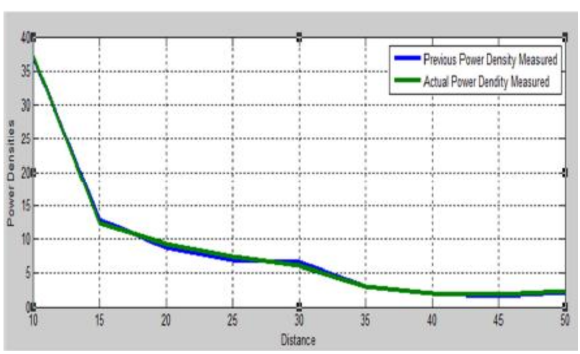

Figure 1: Power Densities against Distance

Figure 1 shows that the power densities (P and A) decrease with increasing distance (D).

Adaptive Neuro-Fuzzy Inference System

The ANFIS model is developed by integrating the principle of FL and ANN. This integration is aimed at enhancing the importance of distinct methodologies. It is aligned with the IF-THEN fuzzy logic rule formation (Yen and Langari, 1999) and possesses ability for addressing nonlinear functions due to its learning capacity. This system is recognized as a generic algorithm for the assessment of various inputs. However, as shown in Figure 2, only two inputs will be considered in this study. The input and the expert rules developed are first multiplexed and sent into the ANFIS. The input is then processed by the ANFIS's rules, which result in a predicted output.

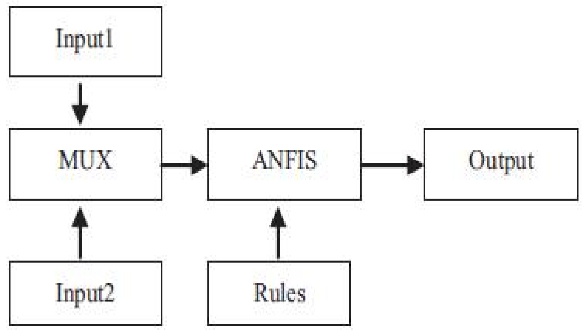

Figure 2: Block diagram of the ANFIS structure.

Fuzzification

As previously stated, ANN and fuzzy logic are combined to create ANFIS. The first thing to think about is fuzzing of input/output data. Predictions are typically achieved by fuzzing inputs and outputs based on the range of values (maximum and minimum).

Classification of membership function, input and output data

'A' is categorized as an output, D and P as inputs. Although there are several kinds of MF(s) which include triangular, gaussian, gbell etc. The generic MF (gbell) is used in this work due to its ability and flexibility in handling all kinds of data. As antecedents of the ANFIS rules, it includes, for instance, vector x and additional nonlinear parameters a, b, and c.

$$\mu_A(x) = \frac{1}{1+\left[\frac{x-c}{a}\right]^{2b}} \quad (1)$$

If altered appropriately, a, b, and c change the general gbell shape, and x can be D, P, or A.

Rules formation and model implementation

The ANFIS network model is developed as shown in Figure 3 since the data consists of two inputs and one output.

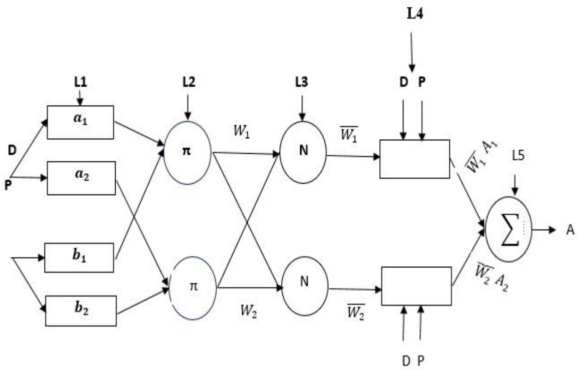

Figure 3: ANFIS network model.

Table 3: Block diagram comparison with ANFIS model Network Structure

Figure 2	Figure 3
Inputs	L1
Multiplexing	L2-L3
ANFIS/Rules	L4
Output	L5

Table 4: Linguistic terms and intervals of Distance

Linguistic terms	Intervals		
	a	b	c
D1	10.01	1.994	10.01
D2	9.999	1.988	30
D3	9.999	2.009	50

Table 5: Linguistic terms and intervals of Previous power density

Linguistic terms	Intervals		
	a	b	c
P1	8.8224	1.995	1.67
P2	8.832	1.984	19.31
P3	8.823	1.999	36.96

Table 6: Linguistic terms and intervals of Actual power density

Linguistic terms	Intervals
A1	14.96
A2	8.271
A3	41.41
A4	0.1462
A5	32.73
A6	15.55
A7	2.435
A8	69.65
A9	6.865

ANFIS Input/Output Interface.

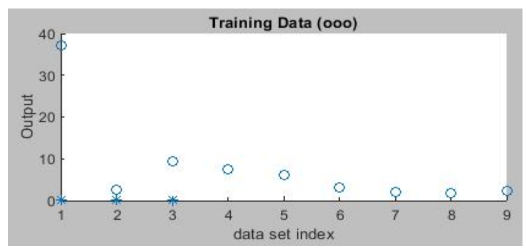

Figure 4: ANFIS training data points

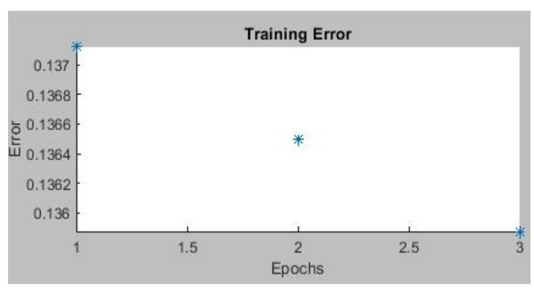

Figure 5: ANFIS Epochs training

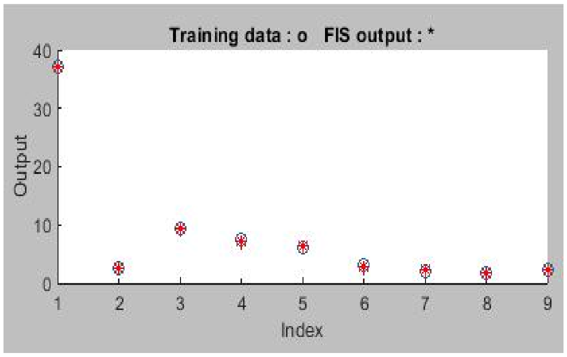

Figure 6: ANFIS FIS training output

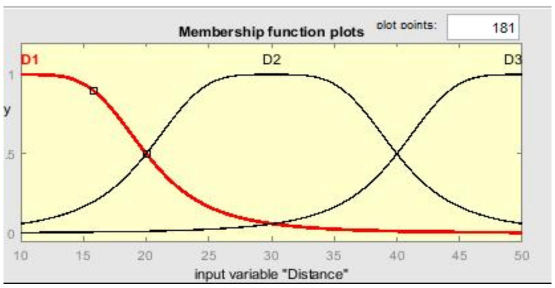

Figure 7: MF of Distance

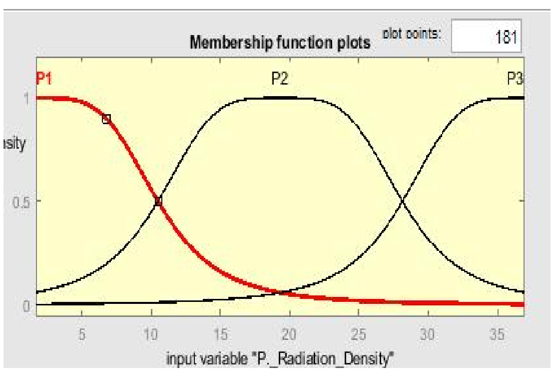

Figure 8: MF of Previous power density

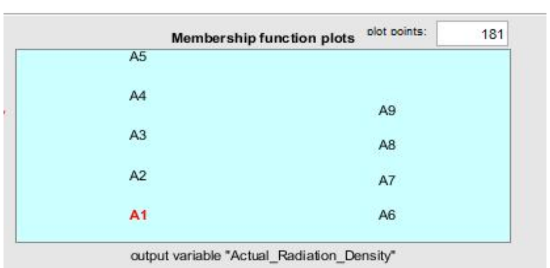

Figure 9: MF of the Actual power density

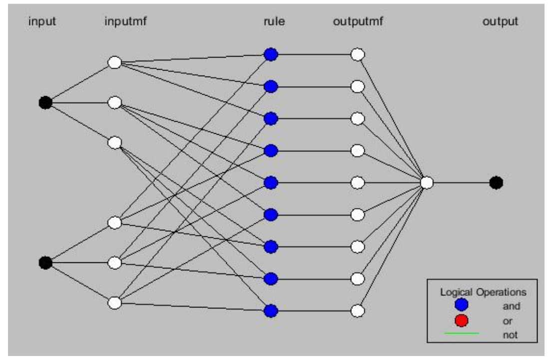

Figure 10: Simulated ANFIS network model.

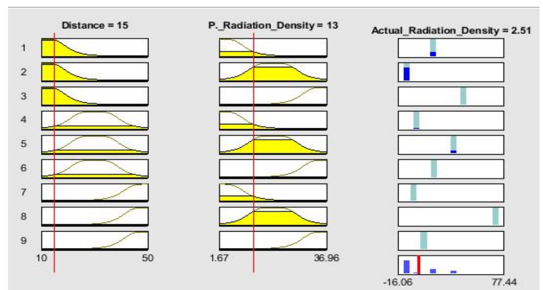

Figure 11: Rule viewer.

Two input networks of ANFIS are represented by fuzzy sets a_1, a_2, b_1 and b_2. The gbell generalized MF of equation (1) defines the MF of a and b. according to Figure 2. Inputs are represented by L1, multiplexers by L2, ANFIS rules by L4, and output by L5. Using the network model depicted in Figure 1, rules are generated as shown in Figure 13.

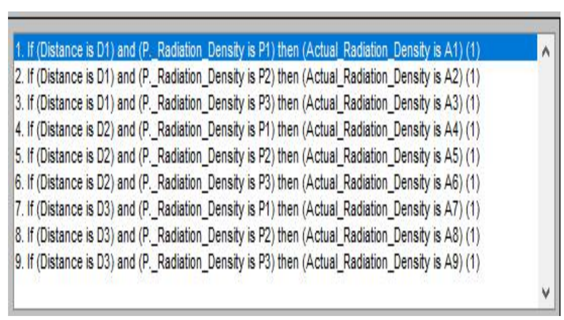

Figure 12: ANFIS rule generated

L1: The average weight is determined using the equation given in (2).

$$R_a = \frac{W_1 f_1 + W_2 f_2}{W_1 + W_2} \tag{2}$$

As shown in (3) and (4), each node in L1 automatically produces a member grade of linguistic values a_1, a_2, b1, and b_2. These values are then used to define the MF, also referred to as nonlinear functions.

$$Y_{i,1} = \mu(a_1)\,D, i - 1,2,3 \quad (3)$$

$$Y_{i,1} = \mu(b_1 - 1)\,P, i - 1,2,3 \quad (4)$$

Where D or P is the input at the ith node and a_1 or b_1 is a linguistic phrase that is normally used to denote HIGH, LOW, or MODERATE. L2: Every node in this layer denoted by the letter P multiplies the two incoming signals. For instance, a_1b_1 or a_2b_2 is multiplexed and (5) can be used to indicate a rule's firing strength.

$$Y_{i,2} = W_i = \mu a_i(D)\mu a_i(P) \quad (5)$$

L3: This layer's nodes are all labeled N. The ith node uses Eq. (6) to determine the ith rule firing strength.

$$Y_{i,3} = W_i = \frac{W_i}{W_1+W_2}, i = 1,2,3 \quad (6)$$

L4: Each node in this case is an adaptable node, as indicated in (7)

$$Y_{i,4} = W_iA_i = W_iD_iY(t) + P_iY(t-1) + r_1 \quad (7)$$

where, p_1, q_1, r_1, and w_i are the antecedents, and L5: the final outcome is found as

$$R = \frac{\sum W_iA_i}{W_i} \quad (8)$$

Propagation and Error Analysis

The (ANFIS) is enhanced by a hybrid learning algorithm (Least Squares + Backpropagation) that is used to enhance the accuracy and training performance of the algorithm. This calcification employed Backpropagation as a gradient technique to reduce the error function of the network between the actual and the predicted output.

Equation (9) provides the mean absolute percentage error (MAPE), which is used to determine the prediction accuracy.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Actual-Predicted}{Actual}\right| \times 100\% \quad (9)$$

The Coefficient of Determination was determined using

$$R^2=1-\frac{\sum(A-P)^2}{\sum(A-M)^2}, \quad (10)$$

where 'A' is the actual, P' is the predicted and 'M' is the mean of the target values.

Specific Absorption Rate and Power Density

In theory, the electric field (E) and magnetic field (H) combine to form power density.

Which is often derived from the Poynting theorem, which is provided by

$$P = (E \times H) \quad (11)$$

where the relationship between the total magnetic and electric field is seen in (12)

$$\frac{E}{H} = \sqrt{\frac{\mu}{\varepsilon}} \quad (12)$$

The characteristic impedance denoted by Z as stated in (12) is the impedance dimension in ohms that is found in equation (13).

$$Z = \frac{E}{H} = \sqrt{\frac{\mu}{\varepsilon}} \quad (13)$$

A free space's characteristic impedance may be Z $=Z_O$, $\mu = \mu_0$ and $\varepsilon = \varepsilon_0$ for any medium conducting or not. However, Equation (14) becomes

$$Z_O = \sqrt{\frac{\mu_o}{\varepsilon_o}} = 120\pi = 377\Omega \quad (14)$$

where the permeability of free space is denoted by μ_0, and the permittivity ε_0. Using Equation (15), the power density obtained from the GSM mast will be assessed.

$$P_o = \frac{E^2}{Z_o} \quad (15)$$

In the x, y, and z planes, the electric field, E, takes all of its components as

$$E^2 = E_x^2 + E_y^2 + E_z^2 \quad (16)$$

Equation (17) is used to calculate the specific absorption rate (SAR).

$$SAR = (\beta) = \sigma\frac{E^2}{P} = C\frac{dT}{dt}, t \to 0 \quad (17)$$

If the specific heat capacity (c) and the temperature (T) influence are disregarded. Combining (15) and (17) will produce the SAR level as expressed in (18).

$$\beta = \frac{377\sigma P_o}{\rho} \quad (18)$$

where P_o is the power density obtained from the GSM mast, σ is the conductivity measured in $(\Omega^{-1}m^{-1})$, and ρ in (Kgm^{-3}) is the mass density.

Equation (18) is used to determine the precise absorption rate of a localized or entire body part, which describes the rate at which radiofrequency (RF) energy is absorbed by the human or animal body can lead to the destruction of human tissues or organs (Shalangwa, 2011; Mushtaq and Vijay,2013).

Result and Discussion

Linguistic terms and intervals

Figures 7 and 8 show the MF of the input parameters that correlate to MF intervals, while Tables 4-6 show the linguistic terms and the intervals of the MFs of D, P, and A.

Simulated result

One randomly selected sample of data is simulated by the network shown in Figures 7 and 8. For example, P=13 and D=15. As shown in Figure 11, it displayed A= 2.51 and all subsequent values of A were also obtained in the same way.

Model validation

The validation of the model is based on Figure 13. With a matching model efficiency of 89.12%, the MAPE is found to be 10.88%.

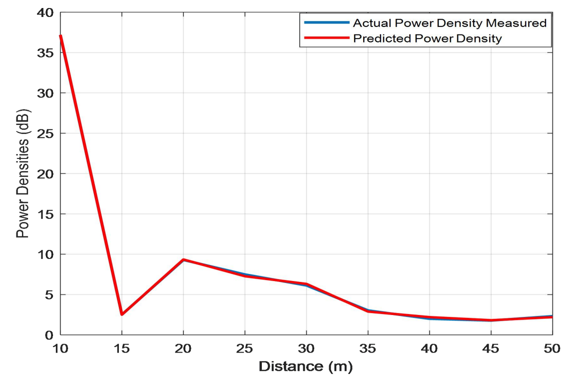

Figure 13: Actual and Predicted Radiation Densities

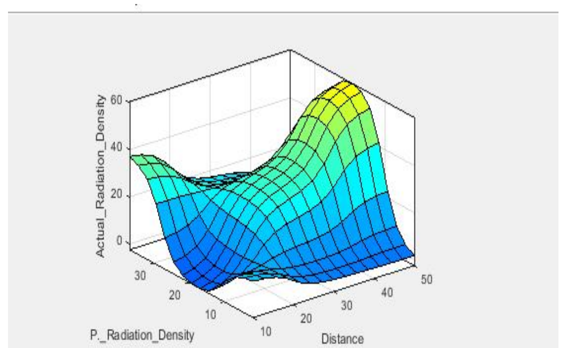

Figure 14: Parameters Surface viewer

A similar relationship between the actual and predicted power densities can be seen in the result in figure 13. The power density was found to decrease with increasing in distance and rises with decrease in distance vice versa as previously stated. As stated earlier, the ANFIS model has been developed to predict the power densities observed at 10, 15, 20, 25, 30, 35, 40, 45, and 50 meters, respectively. The predicted power density's average is marginally higher than the real power density by 37.2 (μWm^{-1}), 2.51 (μWm^{-1}), 9.35 (μWm^{-1}), 7.27 (μWm^{-1}), 6.32, 2.89 (μWm^{-1}), 2.2 (μWm^{-1}), 1.82 (μWm^{-1}), and 2.2 (μWm^{-1}) respectively. However, it has been discovered that the power density decreases with increasing distance and increases with decreasing distance vice versa. From

Equation (9), model efficiency was validated as 89.12% with MAPE computed as 10.88.

Comparison of the standard SAR level with the computed SAR

At 10 meters, the computed SAR maximum level is 1.05×10^{-4} W/Kg. The computed SAR value was then compared with the typical SAR level values for the entire body portion by 2.00W/Kg and localize (10g/tissue) by 2.00W/Kg which fall below recommended level by ICNIPR as depicted in figure (15). However, for a model to explain how well the variance in a data, $R^2=1$. Thus, the (R^2) was determine as 1.0016 which shows that the model explain the variance in the data perfectly. This work recommends that 10m from the residential building is safe to install GSM mast. The level of SAR obtained at all the distance is validated to 99.9% safe for people to stay since 1.05×10^{-4} W/Kg $<<$ 0.08, $1.05\text{x}10^{-4}$ W/Kg $<< 2.00$ W/Kg. While The SAR continuously stays below limits, indicating that there are no upward deviations in the results.

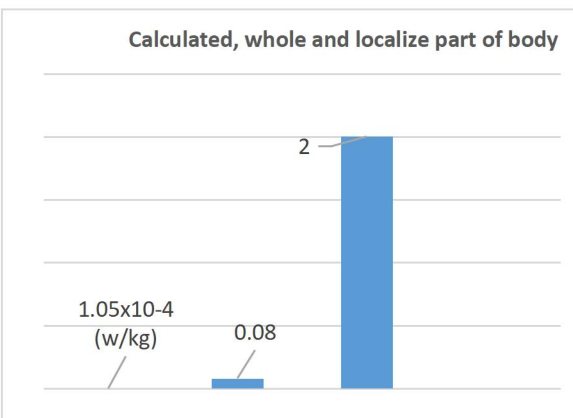

Figure 15: Comparison of SAR levels

Conclusion

Many Nigerians are now concerned about the health impacts of the power density radiated by GSM phone masts located in residential areas. However, the introduction of GSM technology has greatly improved the country's telecommunications situation. In this work, the power density measured is used in determining the SAR level while the ANFIS model is used to predict the power density emitted from the GSM mast. A good distance to place a GSM tower in a residential area is 10 meters according to the SAR level that was determined, which is in line with the 10m Minimum distance from base of a telecoms mast to a domicile, as recommended by ICNIPR and WHO. However, the Health implications of SAR levels below ICNIRP limits, as in this study, are generally considered minimal by mainstream regulatory bodies. Furthermore, it is recommended that multidisciplinary research be conducted to guarantee more promising outcomes.

Conflict of Interest: The author declares that no conflict of interest is attached to this work

References

Akintola, A; Busari, AA; Awodele, O; Olayemi SO (2009). The Hazards of Non-Ionizing Radiation of Telecommunication Mast in an Urban Area of Lagos, Nigeria. *Afric. J Biomed. Res.* 12(1):31-35

Dariusz, L; Sakari, J; Jukka, R; Reetta, K (2002). Non-Thermal Activation of the hsp27/p38 MAPK Stress

Hyland, GJ (2000). How Exposure to GSM Base Station Radiation Can Adversely Affects Human. Department of Physics International Institute of Biophysics University of Warwick.

ICNIRP Guidelines (2020). Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz). *Health Physics*. 118(5): 483–524.

ICNIRP, (2009). Summary of the ICNIPR's General Public Safety Guidelines for Limiting Radiation Exposure and SAR. Available on http//: www.ICNIRP.com

J, Yen and R. Langari (1999). Fuzzy logic intelligence, control and information. Patience hall, 1999.

Lennart, H; Michael, C; Fredric, S; Kjell, HM; Morgan, L (2007). Long Term Used of Cellular Mobile Phone and Brain Tumor; Increased Risk Associated with Use Greater or Equal to 10 Years. *J. Occupational Environ. Med,* 64 (9):1-5

Leif, SA; Jacob, E; Lars, LEM; Bertil, R; Persson, R(2003). Nerve Cell Damage in Mammalian Brain after Exposure to Microwave Phone. *J. Environ. Health Perspective,* 7:881 – 883.

Mamilus, AA; Anthoney, NN (2012). GSM Base Station Radiation Level: A Case Study of University of Nigeria Environment" *Int. J. Sci. Technol. Res.,* 8:102 – 107

Mushtaq, AB; Vijay, K (2013). Calculation of SAR and Measurement of Temperature Change of Human Head due to Mobile Phone Waves at Frequencies 900MHz and 1800MHz. *Advaves in Phy. Theo. Application,* 16:1 – 10.

Pathway by Mobile Phone Radiation in Human Endothelial Cells, Molecular Mechanism for Cancer and Blood Barrier Related Effects" Blackwell Verlay Publishers, 70:120 – 129.

Santini, R; Santini, P; Danze, JM; LeRuz, P; Seigne, M (2003). Survey Study of People Living in the Vicinity of Cellular Phone Base Stations. Electromagnetic Biology and Medicine.

Shangchen, X; Leizhangy, XW; Maoquan, L; Chunbai, C; Mindi, H; Guangbin, Z; Zhenping, Y (2009). Exposure to 1800MHz Radio Frequency Radiation Induces Oxidative Damage to Mitochondrial DNA in Primary Cultured Neutrons. *Science Direct,* 4: 1-8

Sahar, AA; Jabir, SA (2013). SAR Simulation in Human Head Exposed to RF Signals and Safety Precautions. 3(9). Available online @ www.ijcset.net

Shalangwa, DA (2011). Review of Residential Exposure from Radio Frequency (RF) of Global System for Mobile Communication (GSM) Base Station (BS). *SENRA Academic publishers, Burnaby, British Columbia* 5(1): 1405 - 1411

Shalangwa, DA (2010). Measurement of Exposure of Radio Frequency Field (RF) Radiation from Global System for Mobile Communication (GSM) Mast. *J. Elec. Elec. Eng. Res.,* 3:75 – 84

S. Banik, M. Anwer, A.F.M.K. Khan, R.A. Rouf, F.H. Chanchary, Forecasting Bangladeshi monsoon rainfall using neural network and genetic algorithm approaches, Int. Technol. Manage. Rev. 2 (1) (2009) 1100–1107