Assessment of Electromagnetic Field Radiation from Mobile Base Transceiver Stations in Ijebu-Igbo, Ogun State, Nigeria

A. I. O. Yussuff[1], A. O. Adewole
[1]Department of Electronic and Computer Engineering, Lagos State University, Lagos, Nigeria
Department of Electrical/Electronic Engineering, Abraham Adesanya Polytechnic, Ogun State, Nigeria
Email: abayomi.yussuff@lasu.edu.ng, kunleadewole2008@gmail.com

Abstract

Exposure to electromagnetic radiation emanating from ten randomly selected GSM Mobile Base Transceiver Stations (MBTSs) antennas in different regions of Ijebu-Igbo, Ogun State, Southwest, Nigeria, was assessed according to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. This was to determine the exposure level at these MBTS in relation to the specification in the guidelines. Measurements of the maximum Power Density of radio signals were taken for sites operating in GSM900–1800MHz and correlated with the ICNIRP specifications. The result indicated that the maximum exposure levels in all the MBTSs were well below the ICNIRP guidelines. The maximum power densities measured at different MBTS masts were found to be in the range of 0.0001188W/m² to 0.0217359W/m². These findings suggest that radiations emanating from the assessed base stations are in the safe range specified in the guidelines and as such they do not constitute health risk.

Keywords: Electromagnetic waves, Mobile Phone, Base Stations, power density, radiation level.

1.0 INTRODUCTION

The use of mobile phones devices has grown phenomenally in the last two decades and as a result, it has brought about a new wave of electromagnetic radiation. Electromagnetic wave radiation emanating from MBTS antennas can be reflected, refracted, scattered or absorbed by human tissues tissues (Gye and Park, 2012; McIntosh et al., 2005). Some electromagnetic radiation has ionizing effect on human tissues and this has raised concern over possible severe health risks on the populace due to radiating electromagnetic waves emanating from MBTS antennas located within Ijebu-Igbo metropolis, especially for those living very close to these MBTSs. Consequently, most of the MBTS antennas beams are directed away at safe distances from humans. Some mobile service providers had implemented GSM900, GSM1800, WCDMA/UMTS, EVDO as well as 4G Long Term Evolution (LTE). The tower antenna transmits power between the frequency range of 869-894MHz for CDMA, 935-960MHz for GSM900 band, 1810-1880MHz for GSM1800 band, 2110-2170MHz for 3G and 700MHz-2600MHz for 4G network. Since the number of MBTS installations in Ijebu-Igbo is expected to increase, there is serious concern about the health effects of electromagnetic radiation from these mobile cellular sites, although the immediate effects to exposure to lower level of radiations from mobile phones and MBTS antennas have not been clearly established yet. While abundant literature has established that there is insignificant effect of electromagnetic radiation from base stations on human health in several countries of the world; no such evidential information is available in Nigeria particularly for cities outside administrative cities of the states and the federal capital territory.

Some of the effects of exposure of humans to high amount of electromagnetic radiation has been reported to affect human nervous tissues and organs (Gupta, 2019; Sinik et al., 2019). Again, researches have been conducted through experimentation or simulation to study the thermo-physiological effect of electromagnetic radiation on human body. Kaur and Khan (2019) observed that the absorbed electromagnetic wave radiation resulting from microwave sources can lead to severe biological effects such as thermal heating of internal organs of human. Therefore, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the European Union (EU), American National Standards Institute(ANSI), the Institute of Electrical and Electronic Engineers (IEEE), the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), and national bodies such as National Environmental Standards and Regulations Enforcement Agency (NESREA) and Nigeria Communication Commission (NCC) have established rules to protect the populace from enormous electromagnetic wave emitted from Radio Frequency (RF) transmitting antenna (ICNIRP,2009; IEEE,2019; EUR-OP,1999; NCC,2009 and NESREA,2004). According to ICNIRP, for GSM networks operating at 900MHz, the maximum permissible Power Density is 4.5W/m^2, while for 1800MHz and 2100MHz mobile network, it is 9W/m^2 and 0.5 W/m^2 respectively.

Ozen et al. (2007) investigated the exposure level of radio, TV and GSM transmitters in different urban area of Antalya city in Turkey. The measurements of RF signals were performed for radio and TV transmitters, and GSM sites operating in GSM900, GSM1800 and 3G (UMTS). It was discovered that radio transmitter radiates stronger local signal than 1800MHz GSM transmitter and that GSM exposure level was not above 10% permitted limit. Anglesio et al. (2001) conducted a review or survey in Torino a town in north-west Italy to assess exposure level to electromagnetic wave emanating from different MBTS antenna. The exposure level of the electromagnetic field strength was evaluated by considering different factors such as height of the antenna from the ground level, location of the urban area and different frequency bands in use. A review of electromagnetic radiation levels for five different cities in Australia for all accessible mobile frequency bands (CDMA800, GSM900, GSM1800 and 3G) deployed were conducted by Henderson and Bangay (2006). Measurements were taken in the range of 50m to 500m from 60 different MBTS. The maximum recorded Power Density from single base station was 0.0078W/m^2 which means the highest estimated exposure level of 0.2% of the overall public permitted limit. Investigation carried out in Germany, demonstrated that 3G bands have decreased output power and are consequently of less concern than regular GSM bands (Baumann et al., 2006), while in Romania, Miclaus and Bechet (2007) used a free-space propagation model in ideal condition to make a rough estimation of exposure and compliance distance from the transmitting antenna. It was observed that the measured radiation values were well below the maximum permitted level. Again, Cooper et al. (2006) surveyed radiation exposure radiation level by selecting twenty microcells and picocell base stations in the UK. Exposures level were in the range of 0.002-2% of the ICNIRP public reference level and reported a limit of 8.6% of the permitted level from most base station. Measurements taken close to microcell were found to be higher than those close to macrocell. Furthermore, assessments of electromagnetic radiation from different fifty MBTS operating on GSM900-1800 were carried out in Khartoum State, Sudan by Ahmed et al. (2016). Aaronia Hyper LOG 4040 X meter was used for taking measurements at various distances of 1 to10m and 10 to100m from MBTS antennas. The average Power Density of 0.00595W/m^2 and Power Ratio of -52dBm were recorded and compared with ICNIRP and World Health Organization permitted limits. These measurements were found to be below these guidelines.

In Nigeria, Ahanek and Nzeako (2012) investigated the exposure level around different MBTS antennas around university environment in Nsukka, Enugu State. Maximum radiation level was found to be at a distance where the main beam reaches the ground while the value obtained closer to the antenna is lower. The measured values were reported to vary a bit from the calculated values. This was reportedly attributed to some environmental factors such as attenuation caused by reflection from buildings, trees or any object within vicinity.

The maximum level recorded was 1.3mW/m^2 and the total sum of radiation was approximately 2mW/m^2 within the university of Nigeria, Nsukka environment. Again, Joseph et al. (2016) carried out extensive EMF strength measurements in randomly selected base station in Ikoyi, Lagos State, to determine the electromagnetic radiation level. Measurements were taken on streets, squares and other accessible public places. From the data gathered from the study the field strength obtained was found to vary from 0.0000309V/m to 0.0123V/m, which is also within the ICNIRP exposure allowed limit. The results also showed a large spatial variation in Electric field strength data values which was attributed to obstacles. The measured electric field strength was found to attenuate and decrease with the distance away from the base station antenna; attributed to side lobe effects. In a study conducted by Akinyemi et al. (2014), power density measurements were carried within 100m distance from different MBTS antenna in Ikeja, the power density recorded range from 0.7mW/m^2 to 280mW/m^2. The maximum power densities from some MBTS antennas were quite higher than the ICNIRP exposure limit. It was also reported that the effect on human was at its peak when the base station transmitter is transmitting at 100 Watts. In a similar study carried out by Aminu et al. (2014) in Kaduna, measurement and evaluation of electromagnetic wave radiation from selected MBTS antenna of four major mobile phone operators for Airtel, MTN, Etisalat and Glo was carried out. Handheld spectrum analyzer was used for taking measurement of electric field intensity and Power Density. It was found that the maximum exposure to electromagnetic radiation in all selected and investigated mobile sites were far below the ICNIRP stipulated guidelines. Furthermore, Ibrahim et al. (2019), reported the exposure level of radio frequency radiation and Power Density distribution around different GSM base station in Keffi town, Nasarawa State. Measurements were taken using Radio frequency meter (Electrosmog ED-155A). Electromagnetic radiation level was recorded at distance of 50 to 190m away from different MBTS antenna. Fifteen mobile base stations were randomly selected for four major mobile phone operators. Their findings revealed that different base stations were found to have different average power density and all average power density values were well within the exposure safety limit set by ICNIRP. Elechi et al. (2019) presented a report on the level of exposure to radio frequency radiation in five different MBTS in Obio/Akpor local government areas in Rivers State. Readings were taken by using EMF meter. Electric field intensity for different MBTS were recorded to a maximum distance of 300m away from each of the base stations of different mobile phone operators mast for MTN, Glo and Airtel. Specific Absorption Rate (SAR) was employed to determine the exposure level to electromagnetic radiation. The SAR and Power Density were assessed from the measured electric field strength and the results were compared with that of ICNIRP guidelines. It was reported that the mean amount of SAR for the five base station antenna were all within the range of 0.0037W/kg to 0.0084 W/kg and the Power Density from 1.5183 W/m^2 to 9.5083 W/m^2, also reportedly within ICNIRP recommended limit.

This paper presents analysis of power density measurements obtained from ten MBTSs in five different metropolises in Ijebu-Igbo, Ogun State, Nigeria. The measured data were compared with globally established maximum permissible standards by CNIRP in order to determine if the electromagnetic waves emanating these antennas under investigation are within stipulated safe limits.

2.0 MATERIALS AND METHOD

Data were sourced from a total number of ten (10) MBTS sites at GSM 900/GSM 1800/WCDMA band. Measurements were taken 20m to 100m away from each base station mast at intervals of 20m. The entire areas within a MBTS were scanned until the points of maximum readings were obtained, and these points were identified as the locations for measurements. The Electric field intensity and Power Density measurements were taken by using hand held broadband 3 axis RF Field meter operating in the frequency range of 50 MHz to 3.5 GHz. It has three-axes measurements mode, and was set to the triaxial measurement mode with maximum instantaneous measurement mode. And, Electric field strength and power density data were recorded at each point. Also, a GPS meter was used to know the location of each of the MBTS.

Abraham Adesanya Polytechnic is situated in Ijebu-Igbo, Ogun State. Ijebu-Igbo (lat. 6°58'N; long. 4°0'E) is located in the southwestern geographic region of Nigeria. It has the largest landmass in the entire Ijebu region, comprising Oke-Sopen, Oke-Agbo, Ojowo, Atikori, and Japara municipals. At least a base station was selected from each of these areas in order to cover the entire Ijebu-Igbo environs. Fig. 1a shows the GPS locations of the GSM (900/1800MHz) MBTS sites in the residential area (locations of the assessment sites) of Ijebu-Igbo town. The total number of base station considered for this study is ten. The surveyed sites are represented by alphabets A to J. Fig. 1b shows one of the MBTS.

(a) (b)

Figure 1: (a) Locations of the GSM [900/1800 MHz] base stations, and (b) One of the MBTS masts

2.1 POWER DENSITY

The Power Density, (P.D) is related to E-field and H-field vectors by using Poynting theorem, as given in Eq. 1.

$$\text{P.D} = \frac{1}{2} \text{Re} [\bar{E} \times \bar{H}] \quad (1)$$

Mathematically, the Power Density of an antenna can be expressed as:

$$\text{P.D} = \frac{|E_{rms}|^2}{Z_O} = Z_O . |H_{rms}|^2 \quad (2)$$

where, $\bar{E}$ and $\bar{H}$ represent the electric and magnetic field intensity of the electromagnetic waves.

$$\text{Zo} = \sqrt{\frac{uo}{\varepsilon o}} \quad (3)$$

Zo is the characteristic impedance,

$\mu 0 = 4\pi \times 10{-}7$ H/m, and $\varepsilon o = \frac{10^{-9}}{36\pi}$

Then, $E_{RMS} = \frac{\sqrt{30 N Prad G}}{R}$ (4)

Where, N is the number of carriers (antennas), P_{rad} is the radiated power, G is the radiation gain for the antenna, and R is the distance from the base station.

Eq. 4 into Eq. 2 gives power density (Eq. 5).

$$P.D = \frac{30 Prad\ G}{R^2 Zo} \quad (5)$$

The equivalent Power Density,

$$P.D = 0.0796N \frac{Prad}{R^2} \times 10^{\frac{G}{10}} \quad (6)$$

For a single human being exposed to a single base station antenna, N=1 in Eq. 6.

3.0 RESULTS AND DISCUSSION

The measurement data obtained for this study are shown in Tables 1-10. The Tables show the measured power density and electric field strength for base stations A to E measured at 20, 40, 60, 80 and 100 m respectively from the mobile base stations.

Table 1. Distance, Electric field and Power Density Measurements for Base Station A

GSM LOCATION SITE (900/1800MHz)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m^2)
LONGITUDE	**LATITUDE**			
4° 0'9''E	**6° 59'6''N**	20	1.1246	0.0033540
		40	1.2905	0.0041750
		60	1.8711	0.0092870
		80	1.2856	0.0043830
		100	2.744	0.0199700

Table 2. Distance, Electric field and Power Density Measurements for Base Station B

GSM LOCATION SITE (900/1800MHz)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m^2)
LONGITUDE	**LATITUDE**			
4° 0'13''E	**6° 59'33''N**	20	0.3498	0.0003256
		40	0.4119	0.0004500
		60	0.4314	0.0005636
		80	0.4785	0.0006073
		100	2.8624	0.0217359

Table 3. Distance, Electric field and Power Density Measurements for Base Station C

GSM LOCATION SITE (900/1800MHZ)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m^2)
LONGITUDE	**LATITUDE**			
4° 0'13''E	**7° 0'38''N**	20	1.0037	0.0002673
		40	1.1628	0.0003586
		60	1.8675	0.0009251
		80	0.9652	0.0002471
		100	0.9774	0.0025339

Table 4. Distance, Electric field and Power Density Measurements for Base Station D

GSM LOCATION SITE (900/1800MHZ)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m^2)
LONGITUDE	LATITUDE			
4° 0'35''E	6° 59'4''N	20	1.0906	0.0031549
		40	2.8135	0.0209900
		60	1.5434	0.0063185
		80	2.7731	0.0203982
		100	2.3592	0.0147600

Table 5. Distance, Electric field and Power Density Measurements for Base Station E

GSM LOCATION SITE (900/1800MHZ)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m^2)
LONGITUDE	LATITUDE			
4° 0'27''E	6° 58'52''N	20	0.2117	0.0001188
		40	1.2065	0.0038611
		60	1.1005	0.0032120
		80	0.5315	0.0007493
		100	0.4255	0.0004802

Table 6. Distance, Electric field and Power Density Measurements for Base Station F

GSM LOCATION SITE (900/1800MHZ)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m^2)
LONGITUDE	LATITUDE			
3° 59'47''E	6° 58'56''N	20	0.3546	0.0003335
		40	0.9658	0.0024740
		60	1.5057	0.0060136
		80	1.3524	0.0048514
		100	0.4581	0.0005566

Table 7. Distance, Electric field and Power Density Measurements for Base Station G

GSM LOCATION SITE (900/1800MHZ)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m^2)
LONGITUDE	LATITUDE			
4° 0'0''E	6° 58'42''N	20	2.6051	0.0180012
		40	1.2434	0.0041012
		60	0.9922	0.0026111
		80	0.6757	0.0012111
		100	0.5174	0.0007101

Table 8. Distance, Electric field and Power Density Measurements for Base Station H

GSM LOCATION SITE (900/1800MHZ)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m^2)
LONGITUDE	LATITUDE			
3° 59'51''E	6° 58'18N	20	0.3781	0.0003793
		40	0.8025	0.0017083
		60	0.8030	0.0017103
		80	0.7209	0.0013785
		100	0.6180	0.0010130

Table 9. Distance, Electric field and Power Density Measurements for Base Station I

GSM LOCATION SITE (900/1800MHZ)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m²)
LONGITUDE	LATITUDE			
3° 59'10''E	6° 57'49''N	20	0.5786	0.0008880
		40	0.6274	0.0010425
		60	1.2312	0.0040211
		80	0.8348	0.0018485
		100	0.6667	0.0011790

Table 10. Distance, Electric field and Power Density Measurements for Base Station J

GSM LOCATION SITE (900/1800MHZ)		Distance from Mast (m)	Electric Field (V/m)	Power density (W/m²)
LONGITUDE	LATITUDE			
4° 0'13''E	6° 57'17''N	20	0.3085	0.0002525
		40	0.3149	0.0002631
		60	0.4225	0.0004735
		80	0.6757	0.0012111
		100	0.4682	0.0005815

The graphical representations of power density with distance for each base station antenna were plotted using MATLAB are shown in Fig. 2a-b. Plot of measured power densities against distance for base stations A to E is depicted in Fig. 2a, while that of I to J is displayed in Fig. 2b.

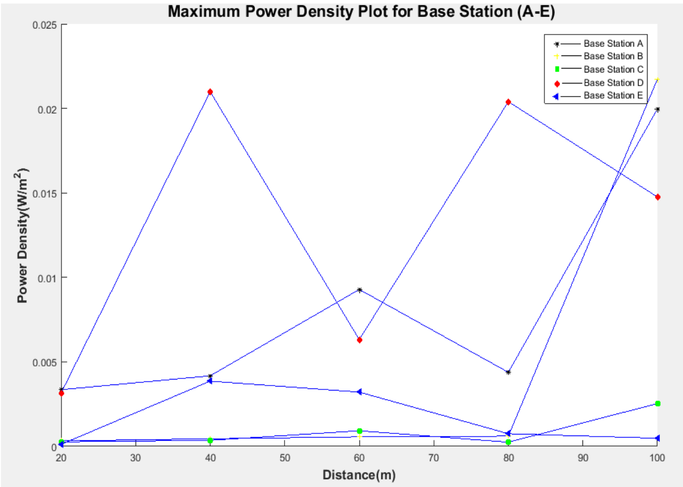

Figure 2a: Plot of Maximum Power Density for Base Station versus Distance from the Mast (A-E)

The ICNIRP reference in Table 11 shows the maximum permissible power density limits for GSM networks operating at various frequency bands (ICNIRP, 2009).

Table 11. ICNIRP Reference Levels for Different GSM Frequency Bands (ICNIRP, 2009)

Frequency Band (MHz)	Electric Field Intensity (V/m)	Power Density (W/m²)
800	39	4.035
900	41	4.459
1800	58	8.923
2100	61	9.870

The power densities measured at various MBTS were analysed and plotted. In Fig. 2a, base station D presented maximum exposure to electromagnetic energy, with a peak at around 0.022W/m^2, while all the other base stations measured values are well below 0.01W/m^2. Although, at a distance of 100 meters from base stations A and E, a spike in electromagnetic energy was experienced. This difference may be due to interference from other radio transmitting equipment around these two base stations. In Fig. 2b, only base station F produced spike in RF energy at a distance of 20 meters from the base station. This could just be an outlier, because there is no justifiable evidence for this. Power densities measured at other base stations are well below 0.008W/m^2. In Fig. 2a-b, it can be observed that the power density at the base of the MBTS is quite low. It however increases gradually as one move away from the base station and decreases at greater distance. This indicates that the power densities were not concentrated within any particular area, which could be due to the directivity of the antennas used in the base stations.

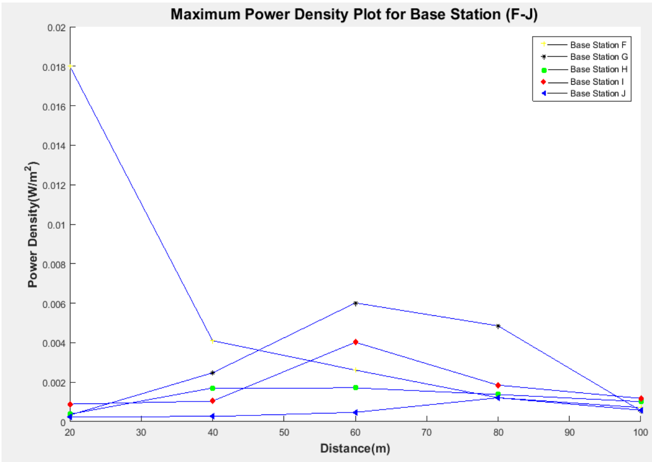

Figure 2b: Plot of Maximum Power Density for Base Station versus Distance from the Mast against (F-J)

Again, it was observed that the maximum power densities are 0.0001188W/m^2 and 0.0217359 W/m^2 for GSM900MHz and GSM1800MHz, which is below the ICNIRP maximum standard values of 4.459W/m^2 and 8.923W/m^2 for GSM900MHz and GSM1800MHz, respectively (See Table 11). The average power density for each point of measurement for all the base stations were also plotted on a bar chart as depicted in Figure 3. It shows the distribution of the average power density at different distance from the base station antenna. The maximum mean value 0.0064W/m² occurs at 100 meters away from the base station antenna.

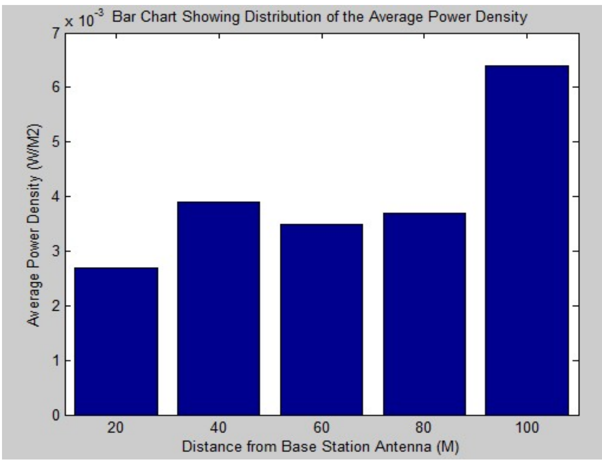

Figure 3: Average Power Density versus different distance from the base station antenna.

Table 12 compares the mean square (μ_{ei}), standard deviation (σ_{ei}) and root mean square (D_{ei}) error for power densities for the ten MBTSs. The formulae for computing these parameters are given in Eq. 7-9.

Table 12. Comparisons of Power Densities Mean, standard Deviation Root Mean Square Errors for MBTSs A to J at 900 MHz

MBTS	A	B	C	D	E	F	G	H	I	J
μ_{ei}	-0.0998	-0.0999	-0.1000	-0.0997	-0.1000	-0.0999	-0.0999	-0.1000	-0.1000	-0.1000
σ_{ei}	0.0046	0.0023	0.0035	0.0065	0.0029	0.0018	0.0028	0.0032	0.0028	0.0037
D_{ei}	0.0997	0.0999	0.1000	0.0995	0.1000	0.1000	0.0998	0.1000	0.1000	0.1001

The standard deviation of the error distribution is given as:

$$\sigma_{ei} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} e_i^2 - (\mu_{ei})^2} \quad (7)$$

where e_i is the percentage error and μ_{ei} is the mean square error for each exceedance of time percentage; expressed as:

$$\mu_{ei} = \frac{1}{N}\sum_{i=1}^{N} e_i \quad (8)$$

where *i* is the individual test variable and *N* is the total number of test variables.

The μ_{ei} and σ_{ei} are then used to compute the RMS (Root Mean Square) error,

$$D_{ei} = \left[(\mu_{ei})^2 - (\sigma_{ei})^2\right]^{1/2} \quad (9)$$

The statistical errors produced the small values which indicates that the power densities measured at the various locations of interest are well below the ICNIRP maximum standards. Hence, the locations of these MBTSs do not pose any health risk to the people residing close these GSM MBTSs.

4.0 CONCLUSIONS

The power densities around ten MBTSs located in five different regions of Ijebu-Igbo were measured and analyzed. These measured power densities in all assessable GSM sites were found to be in the range of 0.0001188 W/m^2 to 0.0217359 W/m^2 with average value not above 0.0064 W/m^2. The measured maximum power density is lower than those specified by ICNIRP. Furthermore, no MBTS site exceeded the official limit of ICNIRP recommendations of permissible Power Density of 4.459 W/m^2 and 8.923 W/m^2 for GSM networks operating at 900 MHz and 1800 MHz respectively. The statistical errors analysis conducted also revealed that the power density errors produced when compared to the ICNIRP stipulated standards are small, indicating that the power densities measured at the various locations of interest are well below the ICNIRP maximum standards. Therefore, there is no significant risk of electromagnetic radiation exposure to humans residing close to the GSM MBTS sites in the locations investigated in Ijebu-Igbo, Ogun State, Nigeria.

REFERENCES

Ahanek, M. and Nzeako, A. (2012). GSM base station radiation level: a case study of University of Nigeria environment. *International Journal of Scientific and Technology Research*, 1(8):102-107.

Ahmed, M. Osman, M. Fatherlrahman, H. Salih, I. Mousa, M. and Idriss, H. (2016). Investigation of electromagnetic radiation emitted from mobile base stations in Khartoum state, Sudan. *International Journal of Scientific and Research Publications*, 2016; 6(4):98-107.

Akinyemi, L. Shoewu, O. Pinponsu, O. Emagbetere, J. and Edeko F. (2014). Effects of Base Transceiver Station (BTS) on humans in Ikeja area of Lagos State. *Pacific Journal of Science and technology,* 15(2):173-179.

Aminu, A. Danladi, A. Yahaya, H, and Zakariyya, H. (2014). Measurement of electromagnetic waves radiated from Base Transceiver Stations (BTS) for assessing exposure limit in Kaduna State. *International Journal of Engineering and Science*, 3(8):28-34.

Anglesio, L. Benedetto, A. Bonino, A. Colla, D. Martire, F. Fusette, S. and d'Amore, G. (2001). Population exposure to electromagnetic fields generated by radio base stations: evaluation of the urban background by using provisional model and instrumental measurements. *Radiation Protection Docimetry*, 97(4):355–357.

Baumann, J. Landstorfer, F. Geisbuch, L. and Georg R. (2006). Evaluation of radiation exposure by UMTS mobile phones. *Electronics letters*, 42(4):225–250.

Cooper, T. Mann, S. Khalid, M. and Blackwell, R. (2006). Public exposure to radio waves near GSM microcell and picocell base stations. *Journal of radiological medicine*, 26(2):199-211.

Elechi, P. Orike, S. and Agugharam, P. (2019). Analysis and evaluation of specific absorption rate of GSM signal in Port- Harcourt, Nigeria. *Journal of Engineering Research and Reports,* 5(4):1-10.

EUR-OP (1999). Council recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz). https://eurlex.europa.eu/LexUriServ/, Accessed December 6, 2019.

Gupta M. (2019). Specific Absorption Rate and temperature change evaluation of human body due to electromagnetic waves. *International Journal of Electronics Engineering*, 11(1):216-220.

Gye, M. and Park, C. (2012). Effect of electromagnetic field exposure on the reproductive system. *Journal of clinical and experimental reproductive medicine*, 39(1):1-9.

Henderson, S. and Bangay, M. (2006). Survey of RF exposure levels from mobile telephone base stations in Australia. *Bioelectromagnetics*, 27(1):73–76.

Ibrahim, U. Mohammed, M. Mustapha, I. Mundi, A. and Yahaya, I. (2019). Investigation of Radio-Frequency power density distribution around GSM mast in Keffi Town, Nigeria. *Asian Journal of Research and Reviews in Physics*,2(2):1-6.

ICNIRP (2009). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). *Health physics*, 74(4):594-522.

IEEE (2019). IEEE standard for safety levels with respect to human exposure to electric, magnetic, and electromagnetic fields, 0 Hz to 300 GHz. IEEE Int. Committee on Electromagnetic Safety, 1–238.

Joseph, I. Viranjay. M. and Omashere, O. (2016). Spatial variation of the electromagnetic radiations due to exposure to telecommunication base station transmitters in a pilot region. *International Journal of Applied Engineering Research*, 11(22):10994-11001.

Kaur, J. and Khan S. Thermal changes in human abdomen exposed to microwaves: a model study. *Journal of Advanced Electromagnetic*, 8(3):64-75.

McIntosh, R. Anderson, V. and McKenzie, R. (2005). A numerical evaluation of SAR distribution and temperature changes around a metallic plate in the head of a RF exposed worker, *Bioelectromagnetics*, 26(5):377-388.

Miclaus, S. and Bechet, P. (2007). Estimated and measured values of the radio frequency radiation power density around cellular base stations. *Journal of Physics*, 52(3-4):429-440.

NCC (2009). The guidelines on technical specifications for the Installation of telecommunications masts and tower. https://www.ncc.gov.ng/docman-main/legal-regulatory/guidelines/65-guidelines-for-the-installation-of-telecommunications-masts-and-towers-1/file. Accessed December 6, 2019.

NESREA (2004). National Environmental (Standards for Telecommunications and Broadcast Facilities) regulations. http://extwprlegs1.fao.org/docs/pdf/nig120569.pdf. Accessed December 6, 2019.

Ozen, S. Helhel, S. and Colak, O. (2007). Electromagnetic field measurements of radio transmitters in urban area and exposure analysis. *Microwave and optical technology letters,* 49(7):1572–1574.

Sinik, V. Despotovic, Z. Ketin, S. and Marceta, U. (2019). Radiation of high frequency electromagnetic fields, biological effects and health consequences. Paper presented at: IX International Conference Industrial Engineering and Environmental Protection; October 3-4, 2019, Zrenjanin, Serbia.