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Assessment of Human Exposure to Radio Frequency Radiation from Mobile Based Transceiving Stations

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Abstract: Telecommunication has become an integral part of our lives which helps to provide and access a wide range of services including communication, entertainment, information and education. The widespread use of mobile phones and the installation of radio transmission antennas have raised global concerns about potential health risks associated with exposure to electromagnetic radiation. The objective of this study was to evaluate human exposure to radiofrequency (RF) radiation emitted by mobile base transceiver stations in Iba Community, Ojo Local Government Area, Lagos, Nigeria. An assessment was carried out by measuring the power density, electric field strength, and magnetic field strength over a distance of 100m from four base stations using TES 92 Electrosmog broadband survey meter. The results of the measurements were analysed and a model was developed to describe the distribution of RF radiation around a base station. The measured power densities spanned from the lowest to the highest values, 2.649mW/m^2 to 34.950mW/m^2 for MBTS 1, 4.427mW/m^2 to 28.370mW/m^2 for MBTS 2, 3.486mW/m^2 to 37.120mW/m^2 for MBTS 3, and 0.089mW/m^2 to 17.730mW/m^2 for MBTS 4 respectively with the highest value being approximately 0.8% of the ICNIRP limit of 4.5W/m^2. All the results were found to be below 4.5W/m^2 for power density stipulated by the International Commission for Non Ionizing Radiation Protection (ICNIRP). The correlation coefficient values of -0.5342, -0.5378, -0.4552 and -0.3465 also revealed that the RF emission should not present significant human health concern.

Keywords: *Power Density, Radiofrequency Exposure Level, Electric Field Strength.*

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I. INTRODUCTION

Telecommunications have become an essential component of our lives which helps to provide services through a wide range of media including telephone lines, entertainment, information and learning. This wireless technology depends on a vast network of stationary antennas or base stations to transmit information using radio frequency waves or signals that travel at the speed of light (Hardell et al., 2009). In addition to telecommunications base stations, sources of radio frequency radiation include transmission towers, radar systems, and common household electrical and electronic devices such as microwave ovens, televisions, radios, and remote controls. Public concern is increasing over the potential health effects of electromagnetic radiation emitted by telecommunications infrastructure and equipment. However, it is important to recognize that electromagnetic radiation from telecommunications equipment is often misinterpreted as being the same or similar to nuclear or radioactive radiation (Kheifets et al., 2006). Several factors contribute to public anxieties, including the media reports of recent, unverified scientific studies, which breed doubt and the sense of possible hazards that have not yet been identified. Therefore, due to the significant number of mobile phone users, it is important to study and comprehend the possible health effects of mobile phones that transmit radio waves via a network of fixed antennas known as base tranceiver stations (BTS)., and is important to communicate (Milani et al., 2001).

In Nigeria, there are concerns over possible radiation-related effects of residing close to communication base stations. Living close to a base station has been linked to physiological stressors, such as headaches and dizziness. But these have not been scientifically confirmed. However, there are international recommendations on the levels of some relevant environmental parameters that can serve as preventive safety measures against excessive exposures to microwave radiation from base stations. There is need to conduct surveys around base stations to ensure the recommended values of these parameters are not being exceeded. No record that such studies have been carried out in Iba, Ojo Local Government, Lagos State. The study

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assess the levels of electric power density, magnetic flux and SAR around selected masts (base stations) in Iba, Ojo Local Government, Lagos State. The objectives to achieve the above are as highlighted below: This study generates data and information on the levels of RF radiation emitted by the mobile phone base stations erected within the public domains and how they compare to recommended limits of ICNIRP. This further allays the fears and the insinuations surrounding the health effects of RF radiation from base stations. In order to achieve this, this study was conducted in accordance to the standards and recommendations of the World Health Organization (WHO), the Institute of Electrical and Electronics Engineers (IEEE) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

- *Electromagnetic Radiation*

A form of energy that surrounds us is known as Electromagnetic (EM) radiation and this can be in the form of radio waves, microwaves, X-rays, and gamma rays. Sunlight is another form of electromagnetic energy, but visible light makes up only a small portion of the electromagnetic spectrum and covers a wide range of electromagnetic wavelengths (Milham & Ossiander, 2001). Electricity and magnetism were once considered separate forces. However, in 1873 Scottish physicist James Clerk Maxwell developed a unified theory of electromagnetism. The study of electromagnetism is about how charged particles interact with each other and magnetic fields (Choi et al., 2020).

The fundamental equations of electromagnetism, Maxwell's equations, imply that a time-varying electric field produces a time-varying magnetic field, and vice versa. These changing fields are therefore called 'interdependent' and together form a propagating electromagnetic wave. The ratio of the strength of the electric and magnetic field components is constant in an electromagnetic wave and is called the characteristic impedance (η) of the medium in which the wave propagates. The characteristic impedance of free space and air is 377 ohms (Vecchia et al., 2009).

Because man-made waves typically exhibit noise-like frequency changes over time, causing the energy they carry to be dispersed over a range of frequencies, the perfect sinusoidal case depicted in Figure 1, where a wave has a sharply defined frequency, is somewhat ideal. Certain sources of waves may fluctuate over time in totally random ways without clearly showing sinusoidal patterns.. Some field waveforms, especially industrial sources, can have distorted shapes while maintaining periodicity. This corresponds to the presence of harmonic content at multiples of the fundamental frequency (Vecchia et al., 2009).

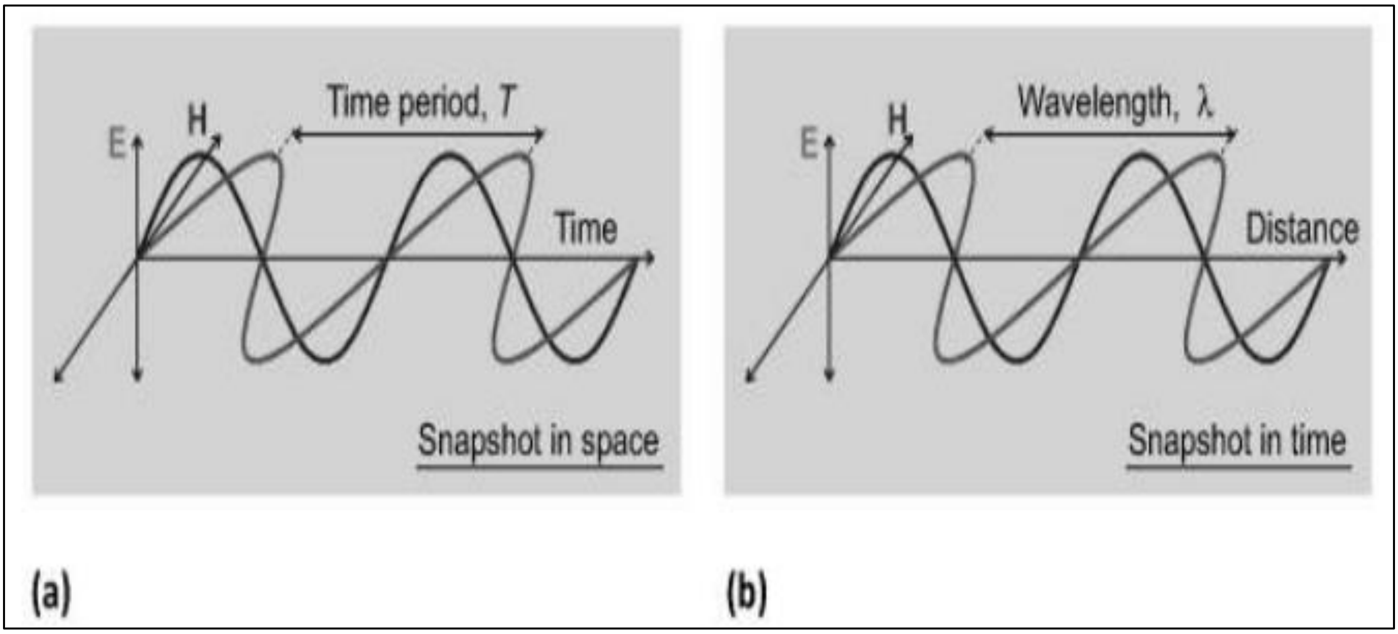

Fig 1 A Sinusoidally Varying Electromagnetic wave viewed (a) in Time at a Point in Space and (b) in Space at a Point in Time
Source: Adapted from ICNIRP (2010).

- *Electromagnetic Spectrum*

Electromagnetic radiation covers a wide range of wavelengths and frequencies. The electromagnetic spectrum is the name given to this range. As illustrated in Fig. 2, the electromagnetic spectrum is often separated into seven areas of decreasing wavelength and increasing energy and frequency. Common names are radio waves, microwaves, infrared (IR), visible light, ultraviolet (UV) X-rays, and gamma rays. Low-energy radiation, such as radio waves, is usually expressed as a frequency. Microwave, infrared, visible, and ultraviolet are usually expressed as wavelengths, and high-energy radiation such as X-rays and gamma rays in terms of energy per photon (Lucas, 2015).

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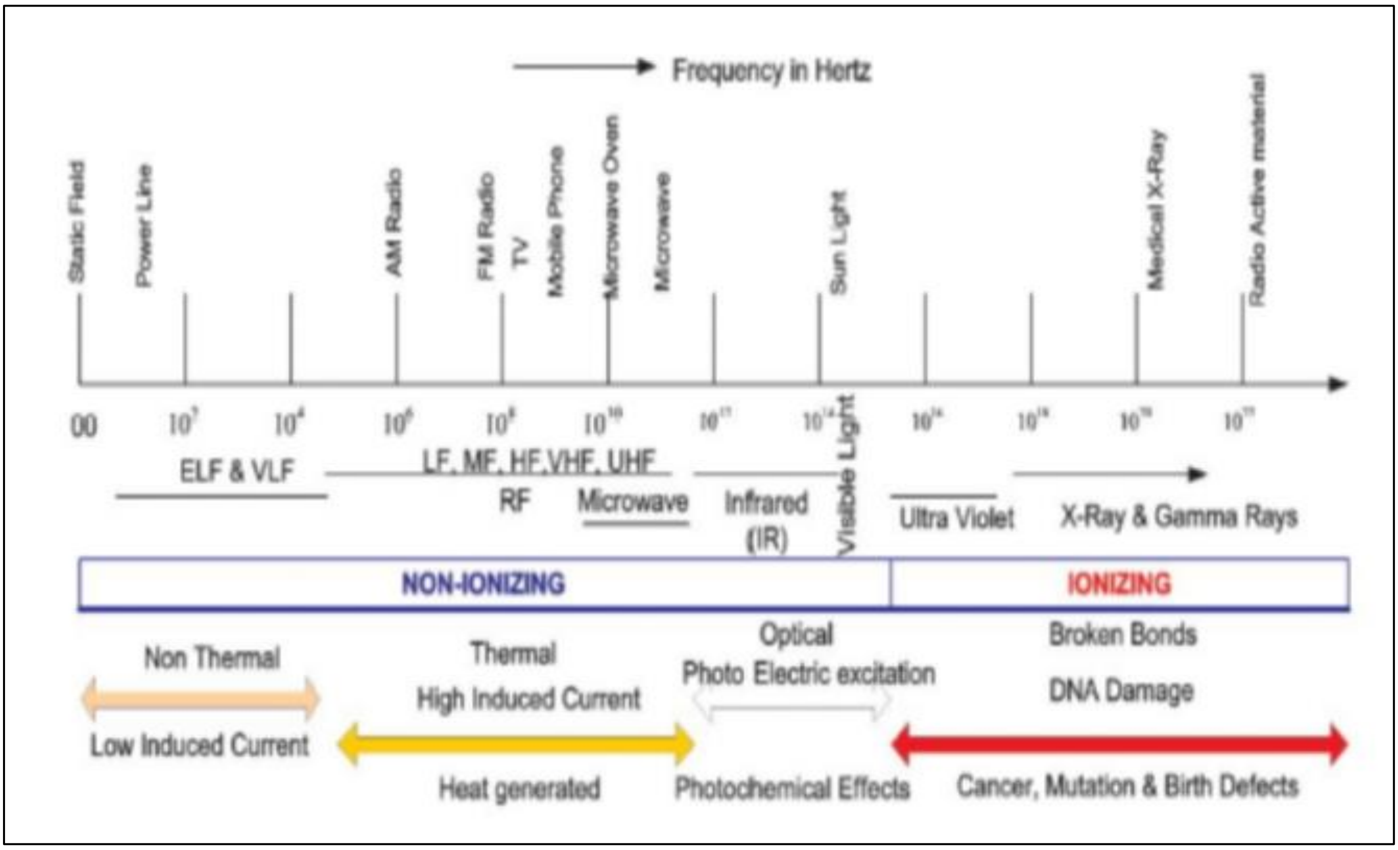

Fig 2 Electromagnetic Frequency Range (Hedendahl et al., 2017).

➢ *Electromagnetic Radiation and Human Health*

Radiation is the propagation of energy in the form of waves or particles in space or other media. It is divided into two parts namely: Ionizing radiation and Non Ionizing radiation**.** Ionizing radiation contains enough electromagnetic energy to separate atoms and molecules from tissue and to change chemical reactions in the body (completely or partially converting molecules into ions). X-rays and gamma rays are the two main forms of ionizing radiation. These rays are known to cause damage, hence, there is a need to wear a lead vest when taking X-rays of our bodies, and the nuclear power plant is surrounded by a thick shield. People are constantly exposed to low levels of ionizing radiation from natural sources. This type of radiation is called natural background radiation. The lower part of the frequency spectrum is considered non-ionized. Electromagnetic waves (EMR) below the energy level required for atomic-level effects.

➢ *Radiofrequency radiation (RFR)*

We are currently living in a generation that is heavily dependent on technology. Whether for personal or business use, wireless devices such as cell phones are widely used throughout the world, and exposure to radio frequency (RF) radiation is widespread, including in public places (Carlberg et al., 2019). Radio Frequency Radiation (RFR) is a field that is part of the electromagnetic spectrum with frequencies ranging from 30 kHz to 300 GHz. Within this frequency range, the electric and magnetic fields that together form the electromagnetic field are related to each other and are considered together in the measurement (Foster & Glaser, 2007). This frequency range corresponds to free-space wavelengths ranging from 10 km to 1 mm. Radio frequency electromagnetic fields (RF-EMF) can easily be used for communication purposes as radio waves.

➢ *Exposure to Radio Frequency (RF) Radiation*

Public exposure to radio frequency (RF) electromagnetic fields (EMF) in today's cities comes from a variety of sources, including cellular base stations, televisions and cell towers, wireless local area networks (WLANs), emergency services cellular networks, and RF identification systems. Source, microwave oven, anti-theft door, etc. Additionally, personal use of mobile and cordless phones, two-way radios, WiFi, Bluetooth, and other wireless devices can significantly increase personal exposure. With the development of communication technology, network-connected mobile devices have spread, and the load is increasing more and more. This also exposed the public to RF-EMF (Koppel et al., 2019).

Occupational RF exposure occurs in workers involved in a variety of industrial processes, particularly dielectric heaters for wood lamination and plastic sealing, and the use of industrial induction heaters. Workers in the broadcasting, transportation, communications, and military industries can be exposed to relatively high levels of RF exposure when working near RF transmitter antennas and radar systems. Sources of exposure in occupational settings are likely to be RF Polyvinyl chloride (PVC) welding machine and radar systems, while magnetic resonance imaging, a widely used diagnostic method, is a potential source of exposure for medical staff and patients.

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Roosli (2014) opined that wherever electricity is produced, distributed, or utilized in the workplace, there is occupational exposure to electric, magnetic, and electromagnetic fields (EMF). EMF is defined by its frequency (in Hertz or cycles per second) and the strength of the electric and magnetic field vectors when utilized as an operating mechanism (e.g. radio broadcasting). Frequency determines the biophysical interaction mechanisms and thus the biological effects of EMFs, while electric field strength influences the strength of potential biological responses. Rarely, but higher exposures occur in occupational settings. For example, US Navy workers exposed to radar may have received exposures in excess of 100 mW/cm^2 (Groves et al., 2002).

➢ *Mobile Phone Base Stations*

A cellular base station is a radio transmitter with an antenna mounted on a free-standing mast or building. A radio signal is sent through a cable to an antenna and sent as radio waves to an area or cell around a base station. A typical large base station installation consists of a technical room containing a mast with electronics and antennas. Several antenna types are used for transmission. Plate-shaped sector antennas and bar-shaped omni-directional antennas are used for communication with mobile phones. Dish antennas form the end devices of point-to-point microwave links that communicate with other base stations and interconnect networks. Base stations may be interconnected by underground cables instead of microwave links. Base stations can be hundreds of meters away in big cities and kilometers away in rural areas, depending on the location of the base station and mobile phone usage (Özdemir & Kargi, 2011).

➢ *Transmissions from Base Stations*

Base stations in areas with low cell phone usage may have only one transmitter connected to the antenna. So they only transmit on one frequency (Viel et al., 2009). Base stations in congested areas may have 10 or more transmitters attached to their antennas, transmitting on multiple frequencies simultaneously and capable of handling communication with many cell phones (Rappaport et al., 2013). Each base station's transmitter power is set to a level that allows cell phones to be used within the area the base station is designed to cover, but not outside the coverage area. Higher power is required to cover larger cells and to cover cells in difficult terrain (Özdemir & Kargi, 2011). Individual macrocellular base station transmitters typically have a maximum power of about 5-10 Watts (W), but when multiple transmitters are present, the total power radiated by the antenna can be as high as about 100W.

➢ *Principle of RF Signal Detection and Measuring*

In space, radiofrequency signals carry energies that can be transformed by an RF receiver into a measurable electric current or voltage. A receiving antenna is where RF signals are detected in a receiver. This antenna receives the signal as an induced voltage that sends current into an RF tuner or filter. From a band of frequencies, the RF tuner chooses the desired signal frequency. A signal amplifier is used to amplify the selected signal, which typically has a low voltage or current. In order for the detector to effectively detect the signal, the amplifier increases its amplitude. The detected signal is transferred into a power or DC amplifier before the value of the signal power density or electric field intensity of the signal is indicated on the meter. Figure 2.3 provides an illustration of an RF detection system.

➢ *Review of Related Studies*

Annida et al. (2021), investigated radio-frequency radiation exposure from selected transceiver base stations in Ogbomoso, Oyo State, Nigeria, which covers four local government regions, namely South Ogbomoso, North Ogbomoso and Ogo-oluwa and the Surulere local government area. The area lies between latitude $8^0 08^I$N and longitude $4^0 15^I$E. Twelve Base Transceiver Stations (BTS) were randomly selected covering three network providers: MTN, Airtel and Globacom. It was chosen for its proximity to residential areas, hospitals and offices. Measurements were performed using an electrosmog measurement device measuring between 50 MHz and 3.5 GHz. Using an electrosmog measurement device, they measured the power density (W/m^2) at 12 locations each with different radii (in meters) from 25 to 400 m. Average power densities were measured at 25, 50, 100, 200, 300, and 400 m. A total of 72 measurements were performed on 6 samples of 12 BTSs each. From their results, it seems that the maximum power density value was observed at 25 m away from the GLO BTS and the minimum power density value was observed at 400 m away from the MTN BTS. The maximum power density achieved was below the maximum permissible limits of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for GSM 900. Thus, the hazard index for radiofrequency radiation exposure in and around Ogbomoso was below the limits recommended by ICNIRP.

II. MATERIALS AND METHOD

➢ *Materials*

- Electrosmog meter (EXTECH-480836)
- Distance measuring tape
- Safety boot
- GPS meter

➢ *Instrumentation*

An Electrosmog meter (EXTECH-480836) was used to measure electric field intensities, magnetic field intensities and electric power densities. It monitors high-frequency radiation in the 50 MHz to 3.5 GHz frequency range, non-directional measurement with a triaxial measurement probe, and measures for 900 MHz, 1800 MHz, and 2.7 GHz. Its units of measurements are mV/m, V/m, mA/m, A/m, mW/m^2, W/cm^2, etc. The Electrosmog meter was hand-held in a vertical direction with the sensor facing towards the source of the EMFs when the measurements were taken.

➢ *Study Area*

Iba Local Council Development Area is one of the local development areas founded in 2003 under Ojo Local Government Area in Lagos State, Nigeria. Its geographical latitude is 6°29’54’’N and a longitude of 3°11’4’’E.

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According to the report of the National Population Census conducted in 2006, the population of Iba is about 162,917 people recorded with different types of business, craftwork and academic institutions located in the area. To save time and money, some studies of RF exposure around the world first stratified the study areas and selected some relevant locations. RF power density around GSM masts was measured using this approach in Australia (Line et al., 2000). The study area was quite large, and four suitable locations within the area were chosen for measurements.

➢ *Measurement of EMF and Power Density*

The geographical positions of the Base Stations were determined using GPS 76 (Garmin Model). Measurements were taken uniformly across four (4) base transceiver stations (BTS), covering three (3) networks providers: MTN, Airtel and Globacom in Iba community, Ojo Local Government, Lagos State with the use of a handheld Electrosmog meter. They were selected based on their proximity to residential areas, hospitals, offices etc. The Electrosmog meter was used to measure the electric field strength (V/M), magnetic field strength (A/m) and power density (W/m^2) for the 4 locations at interval of 5m in every 5 minutes of exposure between 0 - 100m respectively. The RF Electrosmog meter's bandwidth was set to "wide" in order to measure a greater range of radiation. The total of the measured vertical and horizontal RF field densities was used to calculate the effective power density. The measurements were made at a height of one meter above the ground. As recommended by Ismail et al. (2010), each measurement was taken by holding the electrosmog meter 2 meters above the ground and away from the body, aiming it in either direction toward the antenna sectors. Three repeated readings were taken for each variable at each point of the sampled locations and the average was calculated for further analysis. Altogether, 80 measurements were made, 20 samples from each 4 BTS. In order to avoid the movement of the Electrosmog meter during measurements and excessive field magnitude values as a result to electrostatic charges, and to make sure (where possible) that movement of cars and phones calls were reduced before taking measurements precautions were taken.

➢ *Data Analysis*

The data obtained from the measurement of magnetic field strength and power density was used to calculate magnetic flux density and Specific Absorption Rate (SAR) following the method adopted by ICNIRP as shown in equation 1 and 2.

$$B = \mu_0 H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where;

$B = \text{permeability } (4\pi \times 10^{-7})$

$H = \text{magnetic field strength (V/m)}$

The Specific Absorption Rate (SAR) is the unit of measurement for the amount of radio frequency energy absorbed by a body when using a wireless device. It was computed using equation 2 (Briggs-Kamara *et al*., 2018)

$$SAR = \frac{P_d \times H_{sa}}{W_A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where,

$P_d = \text{power density } (W/m^2)$

$H_{sa} = \text{human surface area } (18000 cm^2 \text{ or } 1.8 m^2)$

$W_A = \text{average weight of human (68kg)}$

The data were computed and analyzed using SPSS software. The analyzed data was compared to the standard safety limit recommended by ICNIRP (2020).

III. RESULTS AND DISCUSSION

➢ *Results*

The study identified four mast (base stations); MBTS1, MBTS2, MBTS3 and MBTS4 with the levels of power density, magnetic flux and SAR in Iba Community, Ojo Local Government area in Lagos. The average GSM signal power density, magnetic field strength, electric field strength and specific absorption rate for four (4) different sites were measured to estimate the intensity of radiation emitted from each site. The magnetic flux density was determined from the magnetic field strength multiplied by the permeability of free space while the specific absorption rate was derived using equation (2) and the power density measurements were made at distances 5 - 100m with interval of 5m which was measured in milliwatts per square meter (mW/m^2) unit. The average power density, electric field intensity, magnetic field and specific absorption rate measurements with maximum and minimum values respectively for the four base stations are shown in table 1 while table 2 shows the individual power density and average power density as a function of distance for each base station.

Table 1 Descriptive Analysis of Variance of Power Density, Electric Field, Magnetic Field and Specific Absorption Rate for Various Stations from Distance of 5 to 100m

Parameters	**MBTS1**	**MBTS2**	**MBTS3**	**MBTS4**
Power Density (mW/m^2)	7.19±7.02	12.96±6.21	15.84±8.43	6.31±4.45
Minimum PD (mW/m^2)	2.65	4.43	3.49	0.09
Maximum PD (mW/m^2)	34.95	28.37	37.12	17.73
Electric Field (V/m)	1.55±0.58	2.16±0.50	2.36±0.65	1.42±0.61
Minimum (V/m)	1.00	1.29	1.15	0.18
Maximum (V/m)	3.63	3.27	3.74	2.59

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Magnetic Field (mA/m)	4.10±1.55	5.72±1.32	6.26±1.72	3.77±1.63
Minimum (mA/m)	2.65	3.43	3.04	0.49
Maximum (mA/m)	9.63	8.68	9.92	6.86
SAR (mW/kg)	0.19±0.19	0.34±0.16	0.42±0.22	0.17±0.12
Minimum (mW/kg)	0.07	0.12	0.09	0.00
Maximum (mW/kg)	0.93	0.75	0.98	0.47

Table 2 Mean Variation of Power Densities with Distance from MBTS 1, 2, 3 & 4

DISTANCE (m)	MBTS 1	MBTS 2	MBTS 3	MBTS 4	STDEV (mW/m^2)	MEAN (mW/m^2)
5	34.95	10.35	10.62	6.74	12.98	15.66
10	5.54	8.70	11.82	7.62	5.24	8.42
15	4.82	16.57	17.02	10.87	5.10	12.32
20	6.74	26.37	24.06	4.99	11.23	15.54
25	7.51	28.37	30.96	4.92	13.62	17.94
30	9.84	17.14	37.12	6.13	13.82	17.56
35	6.73	14.59	24.22	7.88	8.03	13.35
40	4.31	19.45	17.86	8.84	7.25	12.61
45	12.89	15.70	18.67	7.22	4.87	13.62
50	7.50	11.45	12.70	8.24	2.50	9.97
55	6.98	8.33	11.71	12.07	2.51	9.77
60	5.47	10.17	15.37	17.73	5.48	12.18
65	7.43	13.13	11.63	2.34	4.84	8.63
70	3.26	7.64	14.50	1.85	5.69	6.81
75	3.11	7.98	11.48	2.99	4.11	6.39
80	4.13	4.43	4.28	4.16	0.13	4.25
85	3.16	8.26	3.49	0.53	3.22	3.86
90	2.65	8.57	6.92	0.09	3.89	4.56
95	3.68	12.11	11.53	0.61	5.73	6.98
100	3.19	9.93	20.89	10.34	7.31	11.09

Table 3 Paired Samples Test of Power Densities Between MBTS 1, 2, 3 & 4

Paired MBTS	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
1 & 2	-5.76785	9.04101	2.02163	-9.99917	-1.53653	-2.853	19	.010
1 & 3	-8.64855	10.65348	2.38219	-13.63453	-3.66257	-3.631	19	.002
1 & 4	.88615	7.87268	1.76039	-2.79838	4.57068	.503	19	.620
2 & 3	-2.88070	5.65240	1.26391	-5.52610	-.23530	-2.279	19	.034
2 & 4	6.65400	7.39741	1.65411	3.19190	10.11610	4.023	19	.001
3 & 4	9.53470	8.47318	1.89466	5.56913	13.50027	5.032	19	.000

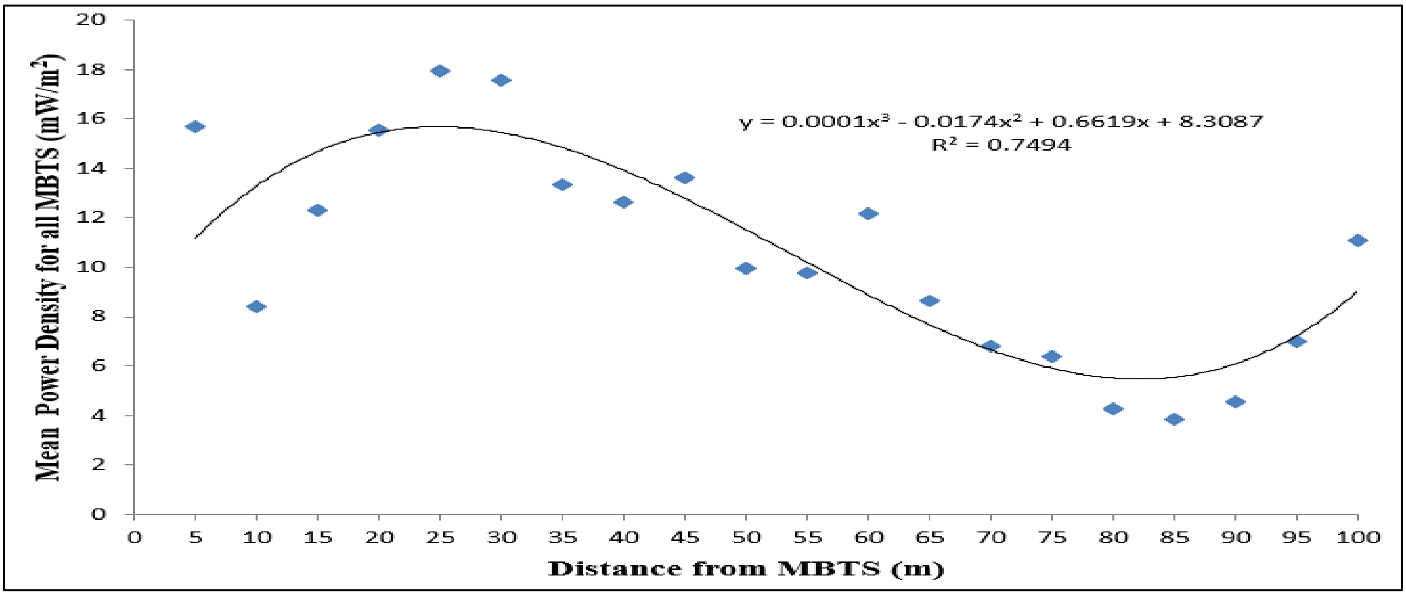

Fig 3 Variation of Mean Power Density (mW/m^2) with Distance (m) from MBTS 1, 2, 3 & 4

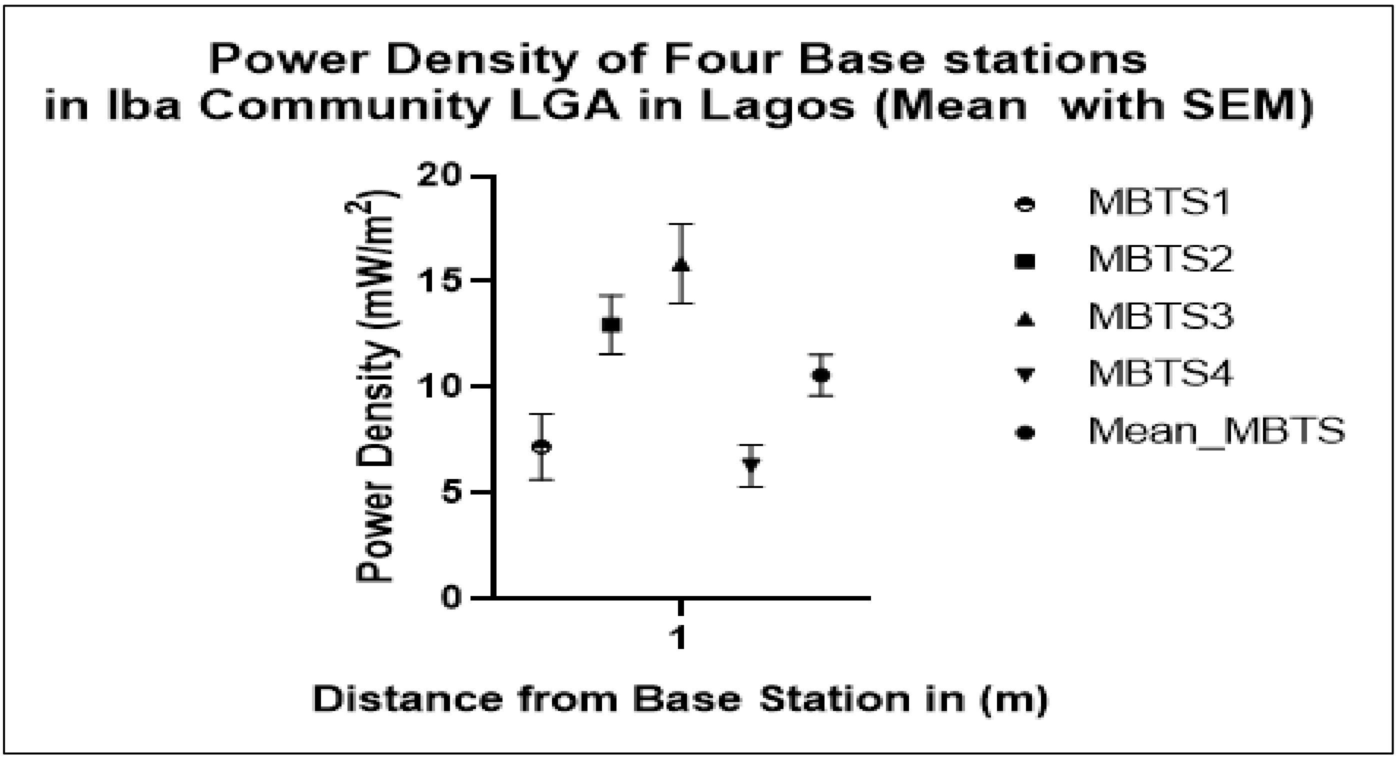

Fig 4 Graph of Standard deviation Error of each mean of Power Density

➢ *Paired Sample Test of Power Density Between MBTS 1, 2, 3 & 4*

The base station significance was compared by pairing the sample test using SPSS as shown in table 3. The pairing of Base station 1 and 4 compared was not significant because of the high value of $p > 0.05$ with a mean difference of 0.88615. While other base stations pairing compared was significant with value of $p < 0.05$.

➢ *Model Development*

Fig. 3 show the mean variation analysis of power density for all the four base stations using Microsoft Excel 2013 tool to determine the polynomial equation which now serve as model for the work.

- *The Polynomial Equation was Computed as:*

$$y = 0.0001x^3 - 0.0174x^2 + 0.6619x + 8.3087 \quad \text{...............(3)}$$

$$R^2 = 0.7494$$

Equation (3) is a third order polynomial equation and this serves as the developed model for the base stations with the coefficient of determination (R^2) of approximately 0.7494. The developed model will offer a reasonable approximation for predicting signal loss over a certain distance for the Iba Community, Ojo Local Government Area, Lagos, Nigeria.

The power density ranged from 3.49 to 37.12mW/m^2 at MBTS 3 and 2.65 to 34.95mW/m^2 at MBTS 2 Compared to the 10mW/m^2 and 30mW/m^2 results obtained by Visser et al. (2008), and it was found to be within the range of their findings. In all, the upper limit of power density at each measurement site was 34.95, 28.37, 37.12, and 17.73mW/m^2 for MBTS 1, MBTS 2, MBTS 3, and MBTS 4, respectively, with the highest value being approximately 0.8% of the ICNIRP limit of 4.5W/m^2 for signals up to 900MHz. Hence, worst-case scenario of power density of the various RF sources within 900MHz in Iba, Ojo Local Government Area, Lagos, Nigeria is less than the ICNIRP recommended limits, showing no risk of any health effect to the public in this community.

According to Table 2, the maximum value of SAR due to MBTS signals was 0.93, 0.75, 0.98, and 0.47mW/kg for MBTS 1, MBTS 2, MBTS 3, and MBTS 4, respectively. The maximum value of SAR at MBTS 3 is about 0.05% of the 2 W/kg recommended limit by the ICNIRP. This observation also confirms no risk of any health effects from the BTS masts on the public.

IV. CONCLUSION

The investigation of radiofrequency radiation exposure around 4 randomly selected base station in Iba, Ojo Local government area in Lagos, Nigeria was carried out. Radiofrequency spectral measurements were made to determine maximum power density, electric field strength, magnetic field strength and specific absorption rate around BTS masts in each base station.

The maximum mean value power density due to RF emissions from MBTSs in Iba, Ojo Local Government Area, Lagos, Nigeria is about 0.4% of the 4.5W/kg recommended limit by the ICNIRP which is far less than the ICNIRP recommended limits. It can be concluded from this study that there is no risk of any health effect from MBTS on the general in this area.

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