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Assessment of Radiated Electromagnetic Waves from Base Station Antennas using Calculation and Field Measurement Techniques

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Abstract-** For about a century now, several telecommunication devices have been developed by engineers and scientists to assist man for easy information communication and reception. A popular one among the telecommunication devices is the base station antennas which uses radiofrequency electromagnetic wave energy to broadcast radio information signals during operation. The main concern of these BS antennas and their cellular phone devices is the possible adverse human and public health effect of the amount of electromagnetic (EM) wave radiations that emanate from them, especially at proximity during usage. The exposure to EM waves emanating from BSs is a continuous process, and it irradiates the entire body parts and tissues exposed to them at different levels based on position and separation distance. In this work, a combination of both analytical calculation and field strength measurement approach is proposed to the amount EM waves radiation from a randomly selected BS antennas operating in a typical urban residential area of Benin City. With calculation method, highest power density values for operator A and B are 2.34 and 1.17W/m^2. By means of field measurement, highest power density values are 0.0016 W/m^2, 0.0024 W/m^2, 0.0021 W/m^{2}for operator A and 0.0019 W/m^2, 0.0021W/m^2, 0.0004 W/m^2 for operator B. By comparing the above results with the recommended safety limit of 9W/m^2 by ICNIRP for the public, it is clear that the level of electromagnetic radiation from the investigated antennas are safe for human health.

***Keywords:** Telecommunication devices, Base station, Antennas, Public health, Electromagnetic radiation, Power density.*

I. INTRODUCTION

The globalapplication of mobile telephony systems has been on the rise since thedevelopment and introduction of diverse digital communication system technologies like GSM 1800 and GSM 900 inthe1990s. The introduction of digital communication systems has caused the proliferation of many millions of mobile cellular telephone devices in every municipality worldwide. Today, about 80% of the world's population of is using cellular telephones for one purpose or the other.

A global mobility report by a telecommunications and multinational networking company, Ericsson, revealed that Nigeria rated fourth amongst the top five countries with the highest cellular telephone subscriptions rate in the first quarter of 2018 (Ericsson Mobility Report, 2018). Specifically as displayed in figure 1, the report also revealed that Nigeria had 3 million new mobile phone subscriptions in the first quarter of 2018, compared to China, India and Indonesia that had 53 million, 16 million and 6 million, respectively. Moreover, as shown in figure 2, the report predicted the number of mobile smartphone subscriptions will reach 7.2 billion in 2023, and nearly all which will be for mobile broadband. The report added that mobile broadband subscriptions will grow by 8.3 billion, accounting for almost 95% of all mobile subscriptions. Finally, the report projected that the number of special cellular mobile subscribers will reach 6.1 billion by the end of the prediction period.

This increasing continuous use and proliferation of cellular mobile phones including other handheld communication devices has in turn steered the increased deployment of base station (BS) antennas. This is to provide a robust support for radio signals coverage and good service quality provision to the connected loads (i.e. mobile users). The main concern of these BS antennas and their cellular phone devices is the possible adversehuman and public health effect of the amount of electromagnetic (EM) wave radiations that emanate from them, especially at proximity during usage.The exposure to EM waves emanating from BSs is a continuous process, and it irradiates the entire body parts and tissues exposed to themat different levelsbased on position and separation distance. According to prominent public environmentalists, the EM wave irradiation occupies the fourth major pollution source besides air pollution, water pollution and noise pollution in our immediate surroundings.

With the above adverse health hazard concern, there have been considerable number of research investigations exploring differentmethodology to probe the intensity level of EM radiation from the BS antennas around us in the past 50 years. This includes the use analytical, simulation and field measurements based investigations techniques.

In this work, a combination of both analytical calculation and field strength measurement approach is proposed to the amount EM waves radiation from a randomly selected BS antennas operating in a typical urban residential area of Benin City.

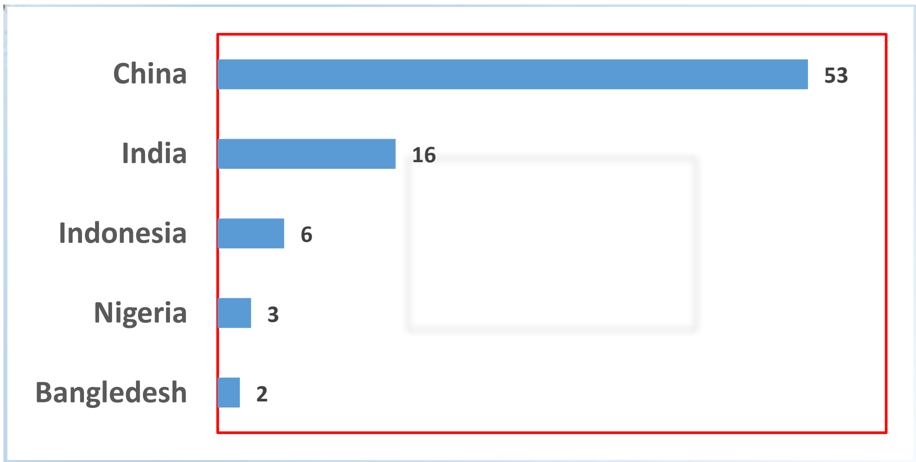

Figure 1: Mobile subscriptions in Millions of Top Five Countries, Ist Quarter 2018

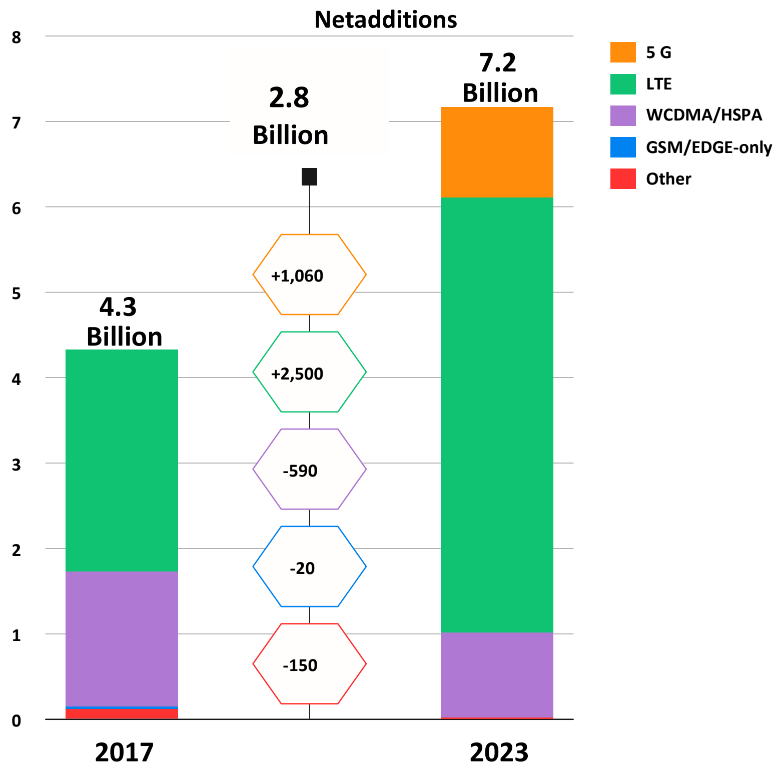

Figure 2: Predicted Global Smartphonesubscriptions by 2023 [1]

A. Base Station

Base stations (BSs), also calledbase transceiver stations (BTS), are multi-channel two-way radio frequency (RF) transmitters or telecommunications structures in which antennas are positioned on either self-supporting masts or roof-mounted structures such as buildings and towers to communicate with cellular mobile phones. Typical methods of positioning BS and their antennas are presented in figures 3 (a) and 3 (b). RF signals are fedby means of cables to the transceiver antennas before beingtransmittedas radio electromagnetic waves into the intended cell (i.e. coverage area) around the BS. The BS antenna system works as a network connecting the mobile phones within each cell. Thus, the transmission structures and towers must to be of a particular height so as to serve a wider radio signal coverage.

A standard largeBSsetting up would comprise of a plant room enclosing the mast with the antennas and other supporting electronic equipments. Often times, the BSs are connected together through the microwave linksorwith buried cables as a replacement for microwave links.

There exist numerous ranges of antennas used for the RF transmissions, such of which are pole-shaped omni antennas, panel-shaped sector antennas, etc., all for communicating with the cellular mobile phones.

(a) A Transmission Tower **(b) A Roof top Structure**

Figure 3 (a) and (b): Mobile phone base stations

B. Electromagnetic Radiation

Electromagnetic (EM) wave radiation can described as a propagating radio waves wherein the electric and magnetic constituents oscillates and moves in the direction of propagation in space as shown in figure 1. The electric and magnetic constituents that form the EM wave is referred to as radiofrequency (RF) fields. A radio signal is generally described as a wave that spread-out from its originating source (the antenna) to the propagating direction.

As the cellular mobile phones and their BSs are dual way interacting radios, they produce EM radiation especiallyduringtransmissionand thereby exposing the people near them to radiated EM waves.The propagated EM waves propagate at the speed of light in vacuum, air, or free space at $3.0x10^8$m/s); thus, waves can be modulated, demodulated, transmitted, received and at same time carries the necessary information

C.EM Wave RadiationExposure RegulationGuidelines

At different locations where humans and general public are exposed to the EM waves broadcast from BS antennas, the amount of exposure is considerably greater and more constant on the entire human body compared to when they interconnect pliably to a mobile phone. In this condition, an appropriate restriction in the recommendations of the ‘‘International Commission on Non-Ionizing Radiation Protection (ICNIRP)’’ is in placed in terms of the specific absorption rate (SAR), power density level, electric field strength level and magnetic field strength level over which the whole body should not be exposed to. For example, the ICNIRP specifies that SAR level average on the whole body this must not exceed 0.08 W kg^{-1} for the general public and 0.4 W kg^{-1} for workers. In terms of power density level, the ICNIRP specifies that it should not be more 2 W/ m^2 to 10 W/m^2 for human and the general public. Details of the ICNIRP recommended guidelines is given in figures 4 and 5 and table 1 over 10 to 300 gigahertz (GHz) RF range.

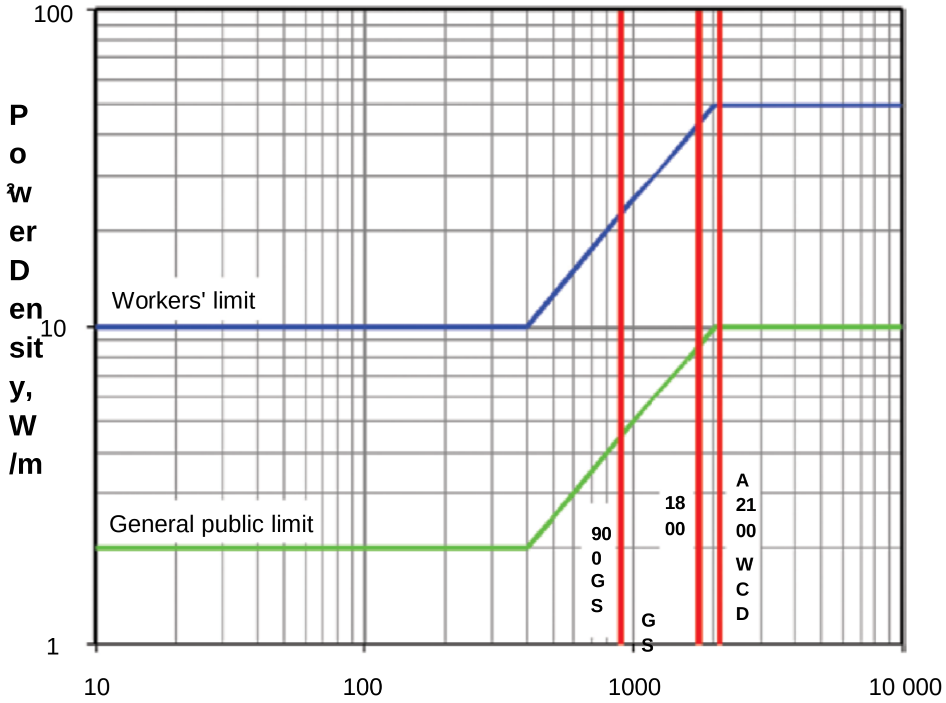

Figure 4: ICNIRP Exposure Limits for Human (source: ICNIRP, 1998)

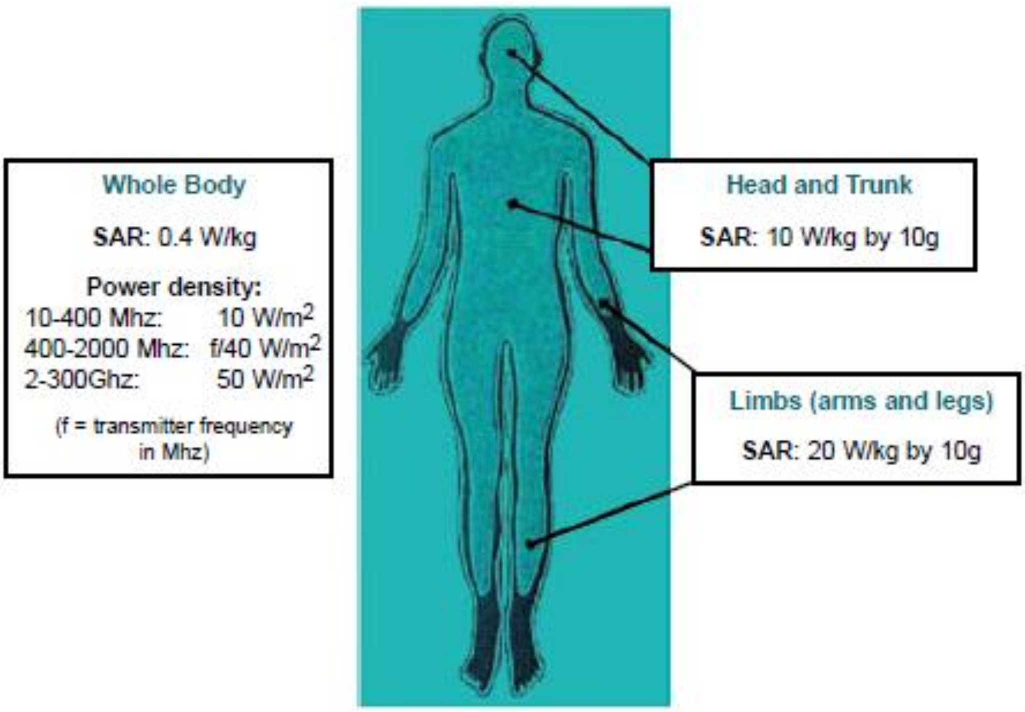

Figure 5: ICNIRP Exposure Limits for Human (Source: MMA, 2012)

Table 1:ICNIRPGuidelines for Human EMF Exposure (source: ICNIRP, 1998)

Frequency	Power Density (W/m^2)	Electric Field (V/m)	Magnetic Field (A/m)
10MHz-400MHz	2	28	0.73
400MHz-2GHz	f/200	$1.37f^{0.5}$	$O.003f^{0.5}$
2GHz-300GHz	10	61	0.16

DEM Radiation Exposure Zones

Base on ICNIRP reference level, the compliance distance from a broadcasting BS antenna can classified as highlighted in tables 2 in the direction of the maximum gain of the antenna.

Table 2: Different EM Wave Radiation Exposure Zones

	Exposure Zone	Description
(i)	Compliance Zone	Zone where possible of EM radiation level is below the recommended reference limits for both occupational and general public exposure
(ii)	Occupational Zone	Zone where possible of EM radiation level is below the recommended reference limits for occupational exposure but exceeds the limits for general public exposure.
(iii)	Exceedance Zone	Zone where possible of EM radiation level exceeds the recommended reference limits for both occupational and general public exposure

II. RESEARCH METHODOLOGY

A. EM waves Radiation Evaluation Methods

Assessment of radiated EMwaves from cellular transmitting telecommunication devices can be accomplished using the key three following methods:(i) Analytical Calculation Method(ii) Electromagnetic mapping by means of software simulation technique and (iii) Field Measurement Method.

In this research work, our focus will be on the first and third EM waves radiation assessment methods which are by calculation and field measurement.

B. Analytical Calculation Method

One of the philosophical perceptions of Albert Einstein says ‘‘a novel kind of analytical thinking is essential if mankind is to survive and move towards higher levels.

Theanalytical calculation method explored here deals with application of mathematical framework to analyze possible EM wave radiation level from cellular phones and their BS transceivers.

Generally, the amount of EM wave radiation can be estimated using four main indicators. They are power flux-density, S (W/m^2), electric field strength, E (V/m), S (W/m^2), and magnetic field strength H (A/m), and specific absorption ratio, SAR (W/kg). For the sake of brevity, this work only considered the use of power flux-density indicator for EM radiation assessment.

C. Power Flux Density

Power flux density, S (W/m^2),can be defined as the quantity of power passing through a unitsphere area from an antenna. If a certain antenna transmit power,P_T (W)to the receivernetworked to its output terminals per square distance meter, the antenna's power densitycan be calculated by:

$$S(W/m^2) = \frac{P_T G_T}{4\pi d^2} = \frac{EIRP}{4\pi d^2} \qquad (1)$$

where G_T is the transmitting antenna gain, and d expresses the communication distance with the load (i.e. the receiver).Specifically, Antenna gain, G_T articulates the measure of the antenna’s capability to direct its input power into a specified radiation direction and is measured at the uttermost radiation intensity. EIRP (Effective Isotropic Radiated Power), also called Equivalent Isotropic Radiated Power defines the grand radiated power of the antenna in a particular direction. Generally, the EIRP is calculated to take into account the gain of the antenna plus the transmit power, including the losses in transmission line and its connectors.

In terms of plane waves, the power density of equation (1) is related to its electric field strength, E (V/m) and magnetic field strength H (A/m) counterparts by:

$$E = \frac{Z_o P_T G_T}{4\pi d^2} = \frac{1}{2d}\sqrt{\frac{Z_o P_T G_T}{\pi}} \qquad (2)$$

$$H = \sqrt{\frac{P_T G_T}{4\pi d^2 Z_o}} = \frac{1}{2d}\sqrt{\frac{P_T G_T}{\pi Z_o}} \qquad (3)$$

where Z_0 indicates the free space intrinsic impedance.

Using the power density model of equation, the compliance distance for EM radiation to the general public can be calculated as:

$$d = \sqrt{\frac{P_T G_T}{4\pi S}} = \frac{1}{2}\sqrt{\frac{EIRP}{\pi S}} \qquad (4)$$

D. EIRP Calculation Method

Close to a particular BS antennas, the power density can go above the recommended ICNIRP reference levels. Cellular network operators estimate compliance distances in different directions from their BS antennas using the EIRP parameters to delineate a borderline outside which the reference levels for public exposure shouldat no time be exceeded. Total EIRP can be obtain various GSM channels as:

$$EIRP_T = EIRP_{BCCH}(W) + EIRP_{BCCH}(W) \times A \qquad (5)$$

where:

$$A = 0.9 \times 0.9 \times \left({Carriers}/{Sector} - 1 \right)$$

$$EIRP_{BCCH}(W) = P_T - \left(Co_L \times Ca_L \right) + G_T,$$

Co_L =combiner loss, and

Ca_T =cable length

E. Field Measurement Method

Apart from analytical calculation method described above, EM waves radiation from BS can also be also be assessed using realistic measurement equipment. There exist a number of handheld equipments attainable for carrying out field measurements of EM radiation waves. The one employed for this work is the Extech EM meter. As displayed diagrammatically in figure 3.4, the EMExtechmeter is a distinctive three dimensional radio wavesexploringtooland it can measure EM radiation intensity in terms electric field strength, power flux density and magnetic field strength

Here, in terms of power flux density, theEM radiation exposure measurement from the investigatedGSM BSs were performed at different measurement distances, in the interval of 5m using the Extech RF meter. The meter was placed facing each investigatedBS in tri-axis planes, at 5m measurement slits, up until a distance of 100m. The measurement were conducted using three GSM wireless network service providers.

III. RESULTS AND DISCUSSION

The following graphs of figures 6 to 13 and tables 3 to 4 displays the intensity of electromagnetic radiations in terms of power density from the assessed Base station antennas, with fitted moving average.

From the graphs and tables, we can see that the power density values obtained from the studied six base station antennas are irregular. In some cases, at the same point, values of power density become very low, while in some cases, it become really very high. This can be attributed to different natural and manmade obstructions blocking the base station and the measurement meter.

In cases where these base stations are covered or blocked by buildings, vegetation or even human beings, the power density will drop. This is because, these elements of obstructions can absorb, scatter, reflect, refract, diffract or transmit the radiated electromagnetic energy.

The tables 3 and 4 contain the measured calculate and measured power density datasets from the base station antennas. The tables reveal that values of the calculated power density are quite higher than the measured ones. This is because, the model used in calculation did not take into consideration of multipath terrain obstructions into consideration when the designing it. This calls for the use of measurement based techniques in assessing the amount of electromagnetic radiation from the antennas in order to avoid over estimation in using the theoretical power density models.

The ICNIRP stated that the intensity of radiation from base station antennas in term of power density should not be higher that 9W/m2 for when it is operating at 900MHz, otherwise, it will affect human health. Accordingly, with calculation method, highest power density values for operator A and B are 2.34 and 1.17W/m^2. By means of field measurement, highest power density values are 0.0016 W/m^2, 0.0024 W/m^2, 0.0021 W/m^2 for operator A and 0.0019 W/m^2, 0.0021W/m^2, 0.0004 W/m^2 for operator B, all which are lower that the 9W/m2 internationally recommended ICNIRP standard for human safety. This also clearly implies that the level of electromagnetic radiations from the assessed base station antennas are not dangerous to human health.

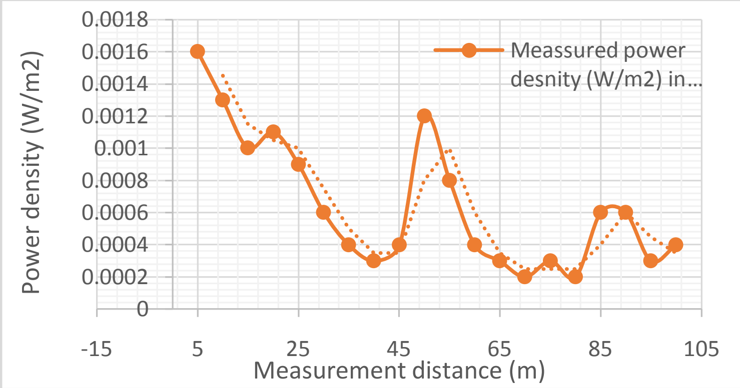

Figure 6: Measured Power density versus distance in Operator's A site 1

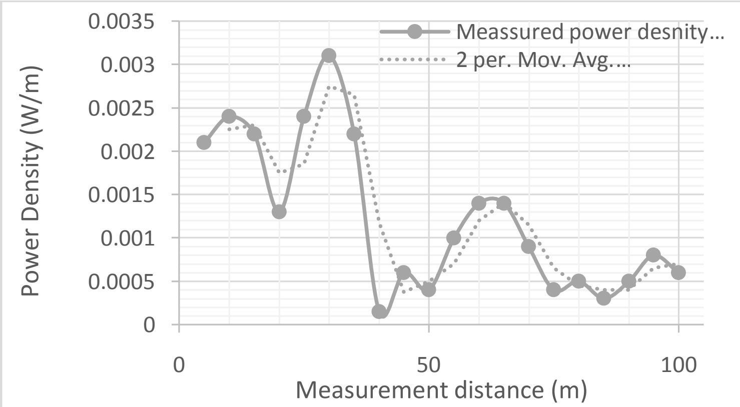

Figure 7: Measured Power density versus distance in Operator's A site 2

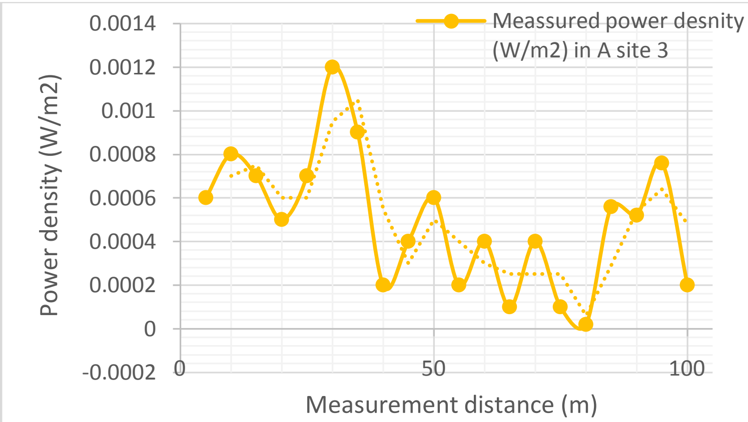

Figure 8: Measured Power density versus distance in Operator's A site 3

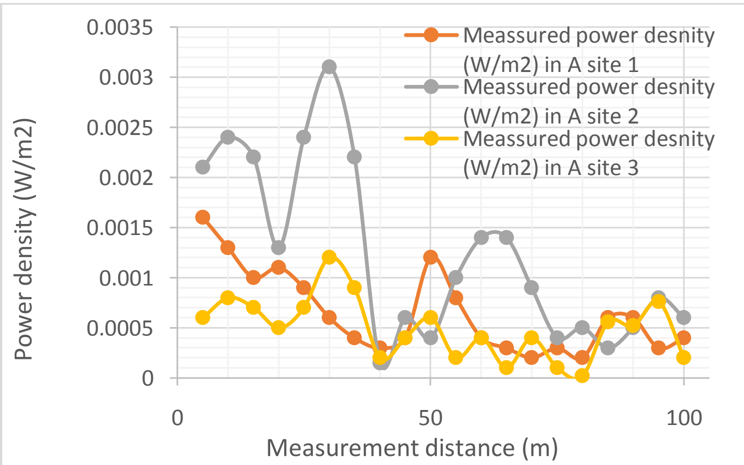

Figure 9: Combined plots of Measured Power density versus distance in Operator's A site 1, 2 and 3

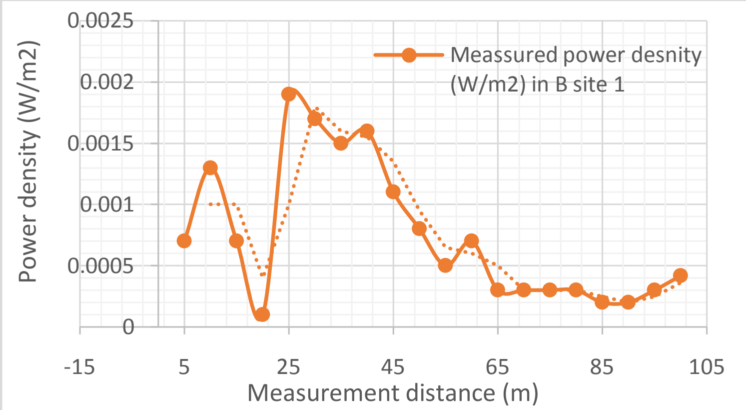

Figure 10: Measured Power density versus distance in Operator's B site 1

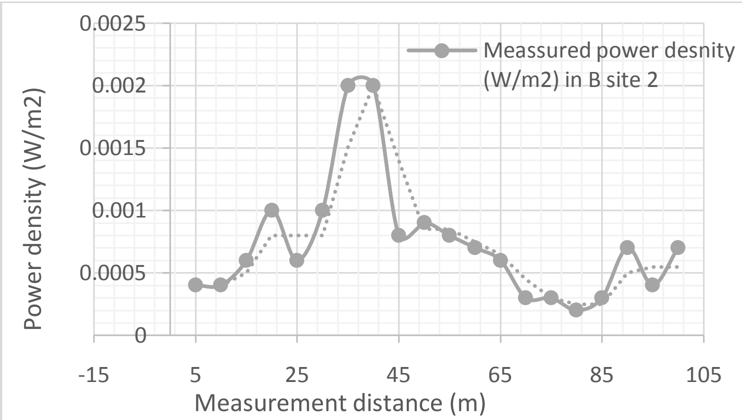

Figure 11: Measured Power density versus distance in Operator's B site 2

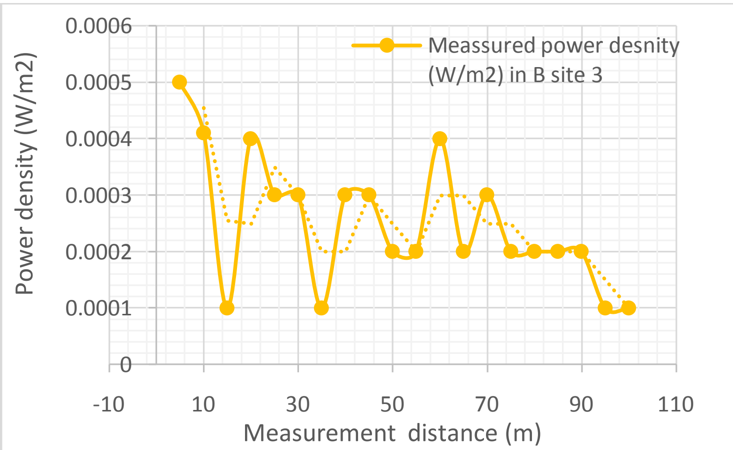

Figure 12: Measured Power density versus distance in Operator's B site 3

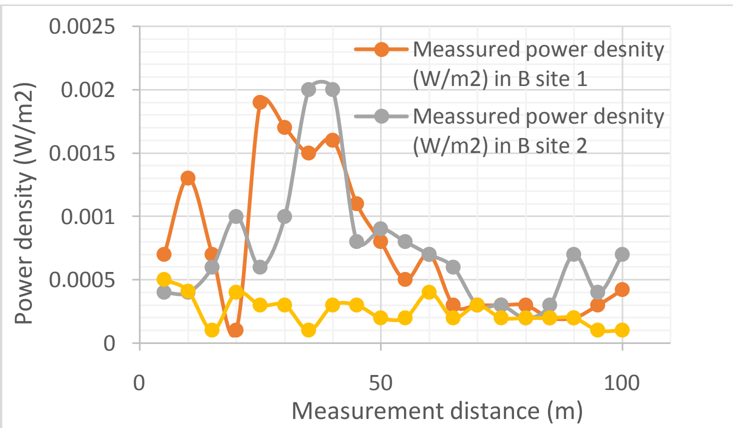

Figure 13: Combined plots of Measured Power density versus distance in Operator's B site 1, 2 and 3

Table 3: Calculated and Measured Power density versus distance in Operator's A BS sites

Distance (m)	Calculated power density (W/m^2)	Measured power density (W/m^2) in operator's A site 1	Measured power density (W/m^2) in operator's A site 2	Measured power density (W/m^2) in operator's A site 3
5	2.348822	0.0016	0.0021	0.0006
10	0.587206	0.0013	0.0024	0.0008
15	0.26098	0.001	0.0022	0.0007
20	0.146801	0.0011	0.0013	0.0005
25	0.093953	0.0009	0.0024	0.0007
30	0.065245	0.0006	0.0031	0.0012
35	0.047935	0.0004	0.0022	0.0009
40	0.0367	0.0003	0.00015	0.0002
45	0.028998	0.0004	0.0006	0.0004
50	0.023488	0.0012	0.0004	0.0006
55	0.019412	0.0008	0.001	0.0002
60	0.016311	0.0004	0.0014	0.0004
65	0.013898	0.0003	0.0014	0.0001
70	0.011984	0.0002	0.0009	0.0004
75	0.010439	0.0003	0.0004	0.0001
80	0.009175	0.0002	0.0005	0.00002
85	0.008127	0.0006	0.0003	0.00056
90	0.007249	0.0006	0.0005	0.00052
95	0.006506	0.0003	0.0008	0.00076
100	0.005872	0.0004	0.0006	0.0002

Table 4: Calculated and Measured Power density versus distances in Operator's B BS sites

Distance (m)	Calculated power density (W/m^2)	Measured power density (W/m^2) in operator's B site 1	Measured power density (W/m^2) in operator's B site 2	Measured power density (W/m^2) in operator's B site 3
5	1.177594	0.0007	0.0004	0.0005
10	0.294398	0.0013	0.0004	0.00041
15	0.130844	0.0007	0.0006	0.0001
20	0.0736	0.0001	0.001	0.0004
25	0.047104	0.0019	0.0006	0.0003
30	0.032711	0.0017	0.001	0.0003
35	0.024033	0.0015	0.002	0.0001
40	0.0184	0.0016	0.002	0.0003
45	0.014538	0.0011	0.0008	0.0003
50	0.011776	0.0008	0.0009	0.0002
55	0.009732	0.0005	0.0008	0.0002
60	0.008178	0.0007	0.0007	0.0004
65	0.006968	0.0003	0.0006	0.0002
70	0.006008	0.0003	0.0003	0.0003
75	0.005234	0.0003	0.0003	0.0002
80	0.0046	0.0003	0.0002	0.0002
85	0.004075	0.0002	0.0003	0.0002

90	0.003635	0.0002	0.0007	0.0002
95	0.003262	0.0003	0.0004	0.0001
100	0.002944	0.00042	0.0007	0.0001

IV. CONCLUSION

For about a decade, the general public has been raising a lot of concern on the issue of cellular base station antennas proliferation and possible health hazards the electromagnetic wave energy they emits may have negative impact on human health. This work appraise the intensity electromagnetic wave radiation intensity from operational telephone base stations deployed typical residential urban environments, Benin City, Edo state Nigeria, using calculation and field power density measurement techniques. This is to provide some basic answers with regard to the general public concern on the level of safetyof human close to the base stations radiations. With calculation method, highest power density values for operator A and B are 2.34 and 1.17W/m^2. By means of field measurement, highest power density values are 0.0016 W/m^2, 0.0024 W/m^2, 0.0021 W/m^2 for operator A and 0.0019 W/m^2, 0.0021W/m^2, 0.0004 W/m^2 for operator B. By comparing the above results with the recommended safety limit of 9W/m^2 by ICNIRP for the public, it is clear that the level of electromagnetic radiation in terms of measured and calculated field strength values were below the ICNIRP regulation and safety limits are safe for human health.The results also revealed that the six assessedoperators A and B base station antennas are operating based on the ICNIRP regulation and safety limits.

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