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Full Length Research Article

ESTIMATING RADIO-FREQUENCY RADIATION ABSORBED BY HUMANS AROUND SELECTED BASE TRANSCEIVER STATIONS WITHIN KADUNA METROPOLIS, KADUNA STATE, NIGERIA

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ABSTRACT
This paper is aimed at estimating Radio Frequency (RF) radiation absorbed by humans around Base Transceiver Stations (BTS) within Kaduna metropolis. RF radiation absorbed by humans from forty two (42) selected (BTS) tagged M1 to M42 of the four major network providers (MTN, 9mobile, Airtel and Globacom) within Kaduna metropolis, Kaduna State, Nigeria within radial distance intervals of $20\ m$ to $100\ m$ from the foot of each BTS were estimated. The Average Power Density $(PD_{Ave.})$ and Specific Absorption Rate $(SAR_{Ave.})$ of data obtained from these BTS were computed, and the results indicated that the average amount of SAR for the selected forty two (42) base transceiver BTS facilities were within the range of $16.9 - 331.7 \times 10^{-9}\ W/kg$ and $0.648 - 10.659 \times 10^{-6}\ W/m^2$ respectively. These values are lower than the recommended limit by International Commission on Non Ionization Radiation Protection (ICNIRP) which is $0.08\ W/kg$ for the human body. This study has shown that RF radiation absorbed by people either residing or transiting the study area has negligible effect on their health.

Keywords: Telecommunication, Average Power Density, Average Specific Absorption Rate, Radio frequency radiation, Health Risk, Base Transceiver Stations.

INTRODUCTION
Mobile phone technology has revolutionized the telecommunication scenario in Nigeria. Owing to its numerous advantages, mobile phone technology has grown exponentially in the last decade, with more than 120 base stations built monthly on the average by each of the major network operators (MTN, 9mobile, Airtel and Globacom), with each of these network operators estimated to have approximately 3,000 BTS in cities within Nigeria (Umar, 2017). This growth comes with concerns about the compliance to safety distance from the BTS by the public and network providers, along with associated health risk due to radiation from mobile phones and the BTS.
Generally, radiation effects are divided into thermal and non-thermal effects. Thermal effects are similar to that of cooking in the microwave oven. Non-thermal effects are not well defined but reports has it that non-thermal effects are 3 to 4 times more harmful than thermal effects. Radiation effects from mobile phones and BTS falls under thermal effects (Daniel et al., 2022).
A BTS and its transmitting power are designed in such a way that mobile phone should be able to transmit and receive enough signal for proper communication up to a few kilometers. Majority of these towers are mounted near the residential and office buildings to provide good mobile phone coverage to the users. These cell towers transmit radiation 24×7, so people living within 10's of meters from the tower will receive 10,000 to 10,000,000 times stronger signal than required for mobile communication. In Nigeria, most people reside within these high radiation zones, hence the growing concern of the effects of these radiations to living things residing within these areas where they are mounted.
Related research on analysis and evaluation of specific absorption rate has been carried out within and outside Nigeria. A few of these include, a study on the evaluation of Specific Absorption Rates (SAR) distribution in human head tissues from measured electric field strengths around selected GSM base stations in Benin City, Edo State, Nigeria. Here a total of forty (40) mobile phone base station masts were studied and their electric field strength (V/m) were determined by means of a digital Electrosmog digital meter, model MECO 9810 RF covering the frequency range 10 MHz – 8 GHz with results indicating that SAR values in the different human head tissues evaluated at distances $25, 50, 75$ and $100\ m$ from the mobile base stations are below the United States (US) Federal Communications Commission (FCC) and the International Commission on Nonionizing Radiation protection (ICNIRP) exposure limit for the general public which is $1.6\ W/kg$ in $1\ g$ (Osahon, 2017). In a related study, Promise et al., (2019) presented an analysis and evaluation of specific absorption rate of GSM signal from five (5) BTS in Obio/Akpor Local Government of Rivers State Port Harcourt, Nigeria. Results obtained indicates the average amount of SAR were within the range of $0.0037\ W/kg - 0.0084\ W/kg$ and the power density $1.5183\ W/m2 - 9.5083\ W/m^2$; these were lower than the recommended limit by ICNIRP which is $0.08 w/kg$ for the human body. Finally, Ilaria, (2022) presented a study on the evaluation of SAR induced by RF systems in different usage scenarios involving current and emerging mobile systems at frequencies between 50 MHz to 5.5 GHz. In their study, analytical methods for SAR estimation in several usage scenarios were derived through a large scale numerical study. These include subject-specific characteristics, properties of the RF systems and provide an estimation of the SAR in the whole body, tissues and organs, and different brain regions.
This study is aimed at estimating the radio-frequency radiation absorbed by humans around forty two (42) selected BTSs within Kaduna Metropolis, Kaduna State, Nigeria. The results

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obtained from this study will add to the existing literature and also assuage the concerns usually expressed by people living or transiting the study area.

Study Area

The study area lies between latitude $10°53^{I}0^{II}N$ and longitude $7°43^{I}0^{II}E$ as depicted in Fig. 1 which comprises of Chikun, Kaduna North, Kaduna South and Igabi Local Government Areas of Kaduna State, Nigeria.

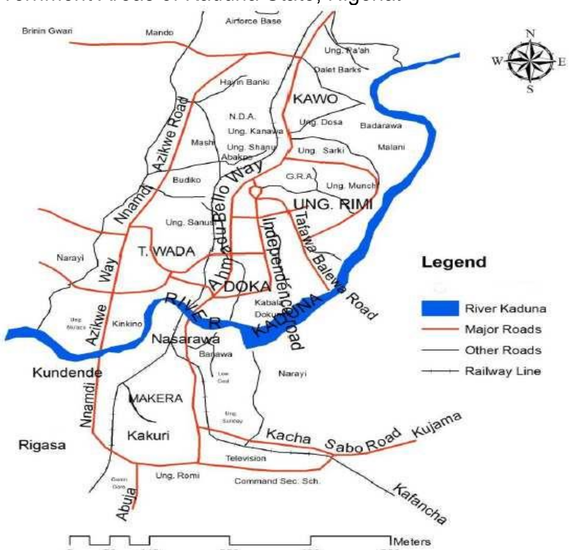

Figure 1 Map of Kaduna metropolis (Abdullahi et al., 2015).

Body surface Area

Values for body-surface area are commonly used in practice of internal medicine, particularly to calculate doses of chemotherapeutic agents and index cardiac output and stroke volume. Generally, the body surface area is computed using the height and weight of an individual. A simplified formula for computing the body surface area proposed by Mosteller, (1987) is given by (1).

$$\left. \begin{aligned} BSA\ (m^2) &= \sqrt{\frac{height\ (cm) \times weight\ (kg)}{3600}} \\ BSA\ (m^2) &= \sqrt{\frac{height\ (in) \times weight\ (lb)}{3131}} \end{aligned} \right\} \qquad (1)$$

Accordingly the average body surface area for adult is $1.7\ m^2$($1.9\ m^2$for adult males and $1.6\ m^2$ for adult females), $1.32\ m^2$ for children of ages 10 to 13years, $1.13\ m^2$ for child of 10 years, $1.08\ m^2$ for a child of 9years and $0.6\ m^2$ for a child of 1 to 2 years respectively (Daniel, 2021).

Body Weight

Body weight is the measurement of weight without items located on the person. Practically though, body weight may be measured with clothes on, but without shoes or heavy accessories such as mobile phones and wallets, and using manual or digital weighing scales. Excess or reduced body weight is regarded as an indicator of determining a person's health, with body volume measurement providing an extra dimension by calculating the distribution of body weight.

Devine, (1974) published an equation for computing lean/"ideal" body weight. Unfortunately, the equations were not referenced to a particular data set, and so created a controversy over their validity. Lean body weight (LBW) has been defined as a combination of body cell mass, extracellular water, and non-fat connective tissue (Moore, 1980). Anthropometric measures and densitometry by underwater weighing are used to measure LBW when a two-compartmental model (fat mass and fat-free mass) is assumed (Heymsfield, 1991). However, this model of measurement has its limitations, which require the use of a four-compartmental model to measure total body potassium, bone mineral density, total body water, and total body carbon (Roubenoff, 1991). The process is undoubtedly complex and is by no means currently applicable in the clinical setting. In contrast, the term ideal body weight (IBW) was coined based on historical data of weights for adult men and women that compared the relative mortality of persons of different height–weight combinations (Knapp, 1983).

The height–weight tables of adult men and women were initially developed to provide a simple means for describing and comparing people with respect to distribution of relative body weight. In addition, height–weight tables were purported to serve as a diagnostic tool for defining under- and overweight (Harrison, 1985). Manjunath and Frank, (2000), discussed the origin of the "ideal" body weight equations, and concluded that any one of these equations given in Table 1, may be used to estimate IBW.

Table 1. Comparisons of ideal weight equations using height (Manjunath and Frank, 2000)

S/N0.	Reference	Equation	
1	(Devine, 1974)	Men	$50\ kg + 2.3\ kg\ /each\ inch\ over\ 5\ feet$
		Women	$45.5\ kg + 2.3\ kg\ /each\ inch\ over\ 5\ feet$
2	(Robinson et al., 1983)	Men	$52\ kg + 1.9\ kg\ /each\ inch\ over\ 5\ feet$
		Women	$49\ kg + 1.7\ kg\ /each\ inch\ over\ 5\ feet$
3	(Miller et al., 1983)	Men	$56.2\ kg + 1.41\ kg\ /each\ inch\ over\ 5\ feet$
		Women	$53.1\ kg + 1.36\ kg\ /each\ inch\ over\ 5\ feet$

Specific Absorption Rate (SAR)

All the wireless devices emit radio waves which can be absorbed by the environment including our bodies. The measure of the rate of absorption, by which this RF energy is absorbed by our body while using a wireless device is called Specific Absorption Rate (SAR).

Specific Absorption Rate (SAR) is a measure of the amount of RF power deposited in the human head or body whenever a mobile phone or other wireless radio device transmits. It is the maximum SAR value (in units of Watts/kilogram) that is measured during SAR compliance testing. Usually, SAR is averaged either over the whole body or over a small sample (for instance, 1 g or 10 g of tissue).

$$SAR = \frac{Power\ take\ in}{unit\ mass} \quad (2)$$

Commonly, the SAR unit is watts per Kilogram (Wkg^{-1}) or milliwatts per gram (mWg^{-1}). Also, SAR value might be achieved in terms of induced electric field (E) in (Vm^{-1}) as in (3):

$$SAR = \frac{\sigma E^2}{\rho} \quad (3)$$

Where E represents the peak electric field strength in the body tissue (Vm^{-1}); σ is the tissue conductivity (Sm^{-1}), and ρ is the mass density of the tissue (kgm^{-3}).

The maximum level of radio frequency energy (SAR) that can be safely absorbed by the entire body is specified in EMF exposure recommendations for radio communications transmitting antennas (Daniel, 2021).

Table 2 presents a summary of the ICNIRP general public safety guidelines for limiting radiation exposure and SAR.

Table 2. Summary of ICNIRP's general public safety guidelines for limiting radiation exposure and SAR (Promise et al., 2019)

Frequency	E-Field (Vm^{-1})	H-Field (Am^{-1})	Power Density (Wm^{-2}	Whole body SAR (Wkg^{-1}	Localized (head) (Wkg^{-1}
400-2000MHz	$1.375f^{½}$	$0.003f^{½}$	f/200	0.08	2
2-300 GHz	61	0.16	10	0.08	2

MATERIALS AND METHODS

Materials

Materials used in this study include a portable hand-held spectrum analyzer model 2658A, linen tape, Global Positioning System (GPS) receiver and an aluminum pointer stick (13 inches).

Methods

1) Data collection

Data were collected near forty two (42) BTS chosen at random, based on their proximity to residential and public buildings, schools, companies/ Industries and organizations, of the four major network operators, namely MTN, 9mobile, Globacom and Airtel within Kaduna metropolis, with the forty two (42) BTS tagged $M1 - M42$ (Daniel et al., 2022). The received power radiation (dBm) and exposure limit (μWm^{-2}) were taken at distance were taken at intervals of $20\ m$ distance for consecutive radii around the mast. Consequently, a computation of the SAR was done.

2) Data Analysis

A simple random sampling was employed for this quantitative research in choosing the BTS. The data utilized for the research are of two types: main and supplementary data. The main data were collected as a result of measurement from the field quantification by physical analysis using the spectrum analyzer and linen tape while the secondary data were obtained from exposure guideline regulations bodies like International Commission on Non-ionizing Radiation Protection (ICNIRP).

The level of radiations emanating from sample base stations were obtained from computation of primary data using eqn. 4.

$$S = \frac{P_{in} \times G}{4\pi r^2} \quad (4)$$

Where S is the power density, P_{in} is the input power of antenna, G, is the gain of antenna, while r is the distance of received radiation from antenna.

The actual power radiated from the transmitting antenna in the base station is given by eqn. 5.

$$Power = power\ density \times Area \quad (5)$$

$$P = \frac{P_{in} \times G}{4\pi r^2} \times Area \quad (6)$$

The power obtained was in decibel relative milli-watts but the acceptable universal standard is in watt/meter- square (W/m^2).

Thus, eqn. 7 was used to convert the power from decibel (dBm) to watt.

$$P(in\ watt) = \frac{10^{\frac{P(dBm)}{10}}}{1000} \quad (7)$$

(Daniel et al, 2022)

RESULTS AND DISCUSSION

Table 3 shows the average power absorbed with body surface area for people on transit or residing around BTS M1 to M42 at distances of $20\ m, 40\ m, 60\ m, 80\ m$ and $100\ m$ within Kaduna metropolis [Daniel, 2021].

Table 3. Average Power absorbed (W) for sample mast M1 to M42.

Distance (m)	Power density (Wm^{-2}) [$\times 10^{-6}$]	Power Absorbed with Human Body Surface Area (W) [$\times 10^{-6}$] Adult Male	Adult Female	Children 11-13 yrs.	Children 9-10 yrs.	Children 4-8 yrs.	Children 1-3 yrs.
20	5.61	10.659	8.976	7.405	6.339	6.059	3.366
40	5.07	9.633	8.112	6.692	5.729	5.476	3.042
60	2.87	5.453	4.592	3.788	3.243	3.099	1.722
80	5.28	10.032	8.448	6.970	5.966	5.702	3.168
100	1.83	3.477	2.928	2.416	2.068	1.976	0.648

Figure 2 shows a plot of power density (P.D) in Wm^{-2}against distance (d) in m. Here, the adult male is expected to absorbed the highest radiation at different distances due to his larger body surface area when compared to other groups of human being as classified by Mosteller, (1987). The classification indicated that the body surface area is 1.9 m^2 for adult males and 1.6 m^2 for adult females, 1.32 m^2 for children of ages 11 to 13years, 1.13 m^2 for children between the ages of 9 to 10 years, 1.08 m^2 for children between the ages of 4 to 8 years and 0.6 m^2 for children between the ages of 1 to 3 years. A child of 1 – 3 years will absorb the lowest radiation according to Figure 3 due to smaller body surface area. The ICNIRP standards state that for any frequency between $400 - 2000\ MHz$ used, it must be divided by $200\ (^{f}/_{200})$ to determine the required limit for power density. The Telecommunication service providers (MTN, Globacom, 9mobile and Airtel) antennas radiate between $900 - 1800\ MHz$; this implies that the limit for power density for this research is:

$$f = 1800 \quad (8)$$

$$f/200 = 1800/200 = 9.00\ W/m^2 \quad (9)$$

From Figure 2, it can be observed that the highest power density that can be absorbed is $10.659 \times 10^{-6}\ W/m^2$ which is much less than $9.00\ W/m^2$.

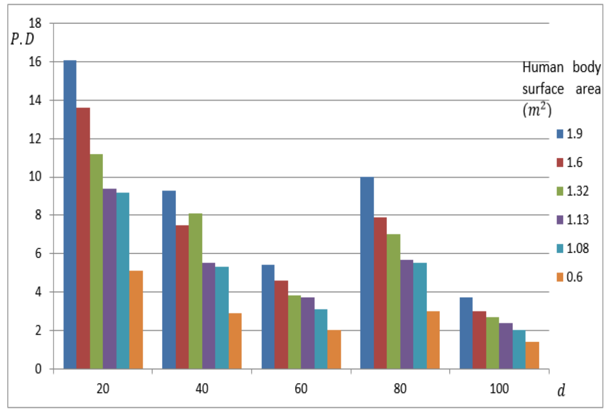

Figure 2 Average Power density versus distance from the 42 selected BTS stations

Table 4 shows the Average Specific Absorption Rate (SAR) for people on transit or residing around the BTS M1 to M42 at different distances of $20\ m, 40\ m, 60\ m, 80\ m, 100\ m$ within Kaduna metropolis [Daniel, 2022]. The body mass of adult male, adult Female, Children 11-13 years, Children 9-10 years, Children 4-8 years and Children 1-3 years computed as 76 kg, 66.9 kg, 32.3 kg, 27.2 kg, 23.6 kg and 14.7 kg respectively.

Table 4. Average Specific Absorption Rate $(\mu W kg^{-1})$ for sample mast M1 to M42.

Distance (m)	Specific Absorption Rate (SAR) $(W/Kg)\ [\times 10^{-9}]$ Adult Male	Adult Female	Children 11-13 yrs.	Children 9-10 yrs.	Children 4-8 yrs.	Children 1-3 yrs.
20	181.3	173.2	296.3	297.8	333.2	289.1
40	80.8	96.9	173.8	173.9	232.0	206.9
60	66.9	70.7	121.5	121.9	131.3	117.1
80	52.0	64.8	128.8	126.7	242.0	215.5
100	30.6	40.7	77.0	73.0	83.7	44.1

A plot of the average specific absorption rate (SAR) in Wkg^{-2} from the selected 42 BTS is depicted in Figure 3. Here, high values of SAR of $296.3 \times 10^{-9}, 297.8 \times 10^{-9}$ and 331.7×10^{-9}, were observed for children between the ages of 11-13, 9-10 and 4-8 years old at a distance of 20 m due to low body mass, compared to the adult male and female. It was observed by Daniel et al. (2022), that the radiation intensity results obtained show diminutive deviation from inverse square law at some points. These deviations could be seen from the average SAR values for children between the ages of 1-3 years with body mass of 14.7 kg. These could largely be attributed to the topography (or elevation) of the area, obstacles constituted by immobile structures placed or erected within the line of sight of measurement, wave interference from other sources of electromagnetic radiation and wave interference from other mobile base stations clustered around a reference base station.
However, when compared with ICNIRP standards as given in Table II, the results can be seen to be relatively lower than the maximum safety standard limit of 0.08 W/kg for whole body exposure, hence unable to generate meaningful health hazard to those people occupying or transiting the regions of the sampled BTS.

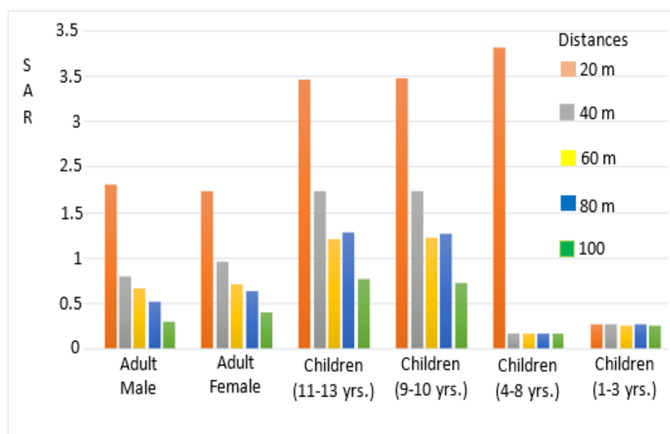

Figure 3 Average SAR from the 42 selected BTS stations

CONCLUSION
The electromagnetic radiation emitted by mobile base stations was measured in terms of electric field strength as a function of distance. The measurements were carried out for 42 BTS stations (M1 to M42) belonging to four different GSM network operators (MTN, Globacom, 9mobile and Airtel)

within Kaduna metropolis. The measured values were used to calculate specific absorption rate of whole-body tissue and power density to assess the potential health risks associated to people residing or transiting the study area. Results obtained show that the values of the SAR and power density for the 42 base stations selected for the study are within the range of $16.9 - 331.7 \times 10^{-9}\ W/kg$ and $0.648 - 10.659 \times 10^{-6}\ W/m$ respectively. These values are quite lower than the limit by International Commission on Non–ionizing Radiation Protection (ICNIRP) which is 0.08 W/kg for the whole-body average SAR. Thus the results obtained from this assessment shows that exposure to RF emissions from the sampled BTS within Kaduna metropolis does not pose health risk to people living within these areas.

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