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Comparative Analysis of SAR and Temperature Rise within Head Tissues Exposed to RF Radiation from GSM Transceiver Base Station in South-South Nigeria

[1]O.D. Osahon,
[1]Department of Physics, Faculty of Physical Sciences, University of Benin, Benin City, Edo State, Nigeria.
okhuomaruyi.osahon@uniben.edu
[2*]P.O. Ushie,
[2]Department of Physics, Faculty of Science, Cross River University of Technology, Calabar, Cross River State, Nigeria.
patushie98@gmail.com
[3]O. A. Ojo
[3]Department of Physics, Faculty of Science, Osun State University, Osogbo, Osun State, Nigeria.
dotun4realoj@gmail.com

Abstract

In this study, measurement of radiofrequency exposure due to cellular transceiver base station antennas was carried out. Both far and near field measurements of electric field and magnetic field level were made around selected transceiver base station antennas in selected South-South States Nigeria, with the aid of frequency-dependent equipment (CORNET, Electrosmog meter ED78S EMF RF/LF Dual mode model). The results obtained were analysed using thermal related indices such as specific absorption rate (SAR) with peak value in cerebrospinal fluid-CSF (0.095358W/kg), temperature rise with peak also in CSF (0.008381 ^{o}C). These results were compared with threshold values of 2 W/kg and 0.08 W/kg for SAR (over the head and whole body respectively), and 1^{o}C for temperature rise as set by International Commission of Non Ionizing Radiation Protection (ICNIRP). The results indicate that none of the network operators in the study area have SAR above the recommended threshold value with the worst case observed in Calabar.

Key Words

SAR, Temperature Rise, Thermal Indices, GSM, Radiofrequency Radiation.

ACADEMIC DISCIPLINE

Bio/Medical/Biomechanics Physics

SUBJECT CLASSIFICATION

Applied Physics

TYPE (METHOD/APPROACH)

Theoretical: Mathematical Methods in Physics and Medical Physics- Structural or Metric derivatives.

1.0 Introduction

Radiofrequency fields penetrate the body to an extent that decreases with increasing frequency. To understand the effects this might have on biological tissue, the magnitude of the fields needs to be determined within the various parts of the body that are exposed. This requires knowledge of the electrical properties of the different types of tissue and, once this has been determined, it is possible to calculate E and B at every part of the body caused by a particular source of radiation such as a mobile phone. The rate, at which the energy is absorbed by a particular mass of tissue m, is $m\sigma E^2/2\rho$, where σ and ρ are, respectively, the conductivity and density of the tissue and E is the rms value of the electric field. The quantity $\sigma E^2/2\rho$ is called the specific energy absorption rate or specific absorption rate (SAR) and is measured in watts per kilogram (W/kg). It varies from point to point in the body both because the electric field changes with position and the conductivity is different for different types of tissue (The density is much the same for all tissues apart from bone). Since the average values of the conductivity at 900 MHz and the density of body tissue are 1 S/m and 0.001 kg/m^3, respectively, the typical value of electric field needed to produce a SAR of 1 W/kg is about 30 V/m. (The average value of conductivity is somewhat higher at 1800 MHz, so lower electric fields, about 25 V/m, are needed). The SAR produced by a particular value of electric field is somewhat larger in children than in adults because their tissue normally contains a larger number of ions and so has a higher conductivity [5]. We understand that an internationally agreed standard testing procedure that will allow the SAR from mobile phones to be compared has being developed by the International Commission for Non Ionising Radiation Protection (ICNIRP) and National Radiological Protection Board (NRPB).

It is important to stress that these are the electric fields inside the body. The fields outside the body that correspond to these internal fields are typically around three times larger. It is very well established that electromagnetic radiation can only be absorbed in quanta of energy h, where h is Planck's constant. Now the energy needed to remove an electron from (ionise) an atom or molecule is a few electron volts (eV) (an eV is the energy needed to move an electron of charge e from an earthed plate to one at a negative voltage of one volt). So if the quantum of energy is less than about 1 eV, it is essentially impossible for ionisation to occur. The quantum of energy of RF radiation is in fact many thousand times less than 1 eV so RF radiation cannot ionise atoms or molecules and is described as non-ionising radiation (NIR). However, higher frequency radiation, such as far-ultraviolet radiation and X-rays, has energy quanta bigger than 1 eV and so can readily ionise atoms and molecules, and produce some damage to biological tissue even at very low intensities. This is referred to as ionising radiation. The intensity determines the number of quanta striking the body per second and, even though this is small at low intensities, each quantum still has a certain probability of ionising and so damaging biological molecules such as DNA. Non-ionising electromagnetic radiation, however, is believed to be harmless at very low intensities, although it can be damaging at high intensities. For example, light at modest intensities produces useful biological effects which allow us to see illuminated objects. However, if the intensity of the light becomes too large, the eye can be seriously damaged. Very high intensity RF radiation can also be damaging as is clear from the strong heating effects produced in a microwave oven. So we need to know at what intensity the radiation starts to produce damage; this might usually be expected to be higher than the lowest intensity at which biological effects can be detected. There are current guidelines that are in force to protect people from harmful exposures.

The possible biological effects arising from the use of mobile phones can be as a result of energy absorbed by the head that may affect the brain and nervous system tissue [10]. The ICNIRP (1998) [6] guidelines specify basic restriction on SAR which are analogous to the NRPB (1998) [9] basic restrictions and state that ‘protection against adverse health effects requires that these basic restrictions are not exceeded’. The basic restrictions on SAR that apply to frequencies within the range 10 MHz to 10 GHz for occupational and public exposure are given in Table 1. All restrictions are to be time-average over a six minute period. The restrictions on localised SAR permit averaging over a 10 g mass of tissue.

Table 1: ICNIRP basic restrictions on exposure to electric and magnetic fields in the frequency range 10 MHz to 10 GHz for occupational and general public exposure [6].

Exposure quantity	Occupational (W kg^{-1})	General public (W kg^{-1})
SAR averaged over the body and over 6 minutes period	0.4	0.08
SAR averaged over any 10 g in the head and trunk and over any 6 minutes period	10	2
SAR averaged over any 10 g in the limbs and over any 6 minute period	20	4

The SAR value depends on the incident fields intensity (or equivalent power density), tissue properties, geometry, size, orientation of the exposed object, frequency of the incident fields, and exposure time. The principles of modern dosimetry have recently been reviewed in the frequency range of approximately 100 kHz to 10 GHz. The specific absorption rate (SAR) is the important dosimetric quantity and is defined as the mass averaged rate of energy absorption in tissue [7].

$$\text{SAR}=\left[\frac{dW}{dm}\right]=\frac{d}{dt}\left[\frac{dW}{\rho dV}\right] \quad (1)$$

Also, in terms of physical and electrical parameter of the absorbing object SAR can be calculated by;

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

where W is the absorbed energy (Joule), E is the amplitude of electric field (V/m), is the conductivity of the material/tissue (S/m), ρ is the mass density of the tissue (kg/m^3), m is the tissue mass (kg).

The depth of penetration of RF radiation into the skin is dependent on some dielectric parameters of the tissue as shown in Table 2.

Table 2: Data of various tissues in the human head for 1800 MHz [3]

S/N	Air/Tissue	Mass Density ρ(kg/m^3)	Conductivity (S/m) 1800MHz	Itis, 2016 C(J/^{o}C.kg)	Tissue Thickness (mm)
1	Air	1.225	-	3513	-
2	Skin	1100	1.18	3391	2.0
3	Fat	920	0.078	2348	0.16
4	Skull Bone	1850	0.28	2274	6.5
5	Dura Matter	1050	1.32	3364	0.3
6	Cerebrospinal Fluid (CSF)	1060	2.92	4096	4.0
7	Brain	1040	1.15	3630	2.5

In the healthy human body, the thermo-regulatory system will cope with the absorbed heat until it reaches the point at which it cannot maintain the body temperature satisfactorily. Beyond this point, the body may become stressed. Excessive exposure Radiofrequency Radiation (RF) can give rise to hyperthermia, sometimes referred to as heat exhaustion, an acute, treatable condition which, if neglected could have serious results. Excessive heating can also cause irreversible damage to human tissue if the cell temperature reaches about 43ºC. A rise in body core temperature of about 2.2ºC is often taken as the limit of endurance for clinical trials [11]. For RF radiation purposes, a limit of an increase of 1ºC in rectal temperature has often been postulated as a basis for determining a specific absorption rate (SAR) limit for human exposure. Most Western occupational standards are based on a SAR of 4 Wkg^{-1} divided by ten to give a further safety margin; thus the general standard is 0.4 Wkg^{-1}. From temperature perspective, a specific increase of rectal temperature 1ºC will require a much higher SAR at low relative humidity than is needed at high humidity. A particularly interesting paper on the thermo-regulatory mechanisms of the human body is that of Adair, (1987) [1]. It notes experimental work done to establish the thermal equivalence of heat generated in the body during physical exercise and passive body heating such as that from High Frequency (HF) physiotherapy equipment. It also made reference to the radical difference between the thermal responses of man and various animals and the consequent difficulty in extrapolating animal exposure data to human beings on this account, quite apart from any resonance differences. It has been shown that SAR and temperature are related by the heat equation Eq.(4) [2]. An energy balance equation of a body for time interval dt can be express as [8];

$$H = (mc)\left(\frac{dT}{dt}\right) \quad (3)$$

and

$$SAR = C\frac{\Delta T}{\Delta t} = C\frac{dT}{dt}\Big|_{at\ t=0} \quad [2] \quad (4)$$

where, t is the time in seconds, C is specific heat capacity of tissue ($Jkg^{-1}.^{o}C^{-1}$), T is the temperature in ^{o}C and m the tissue mass in kg.

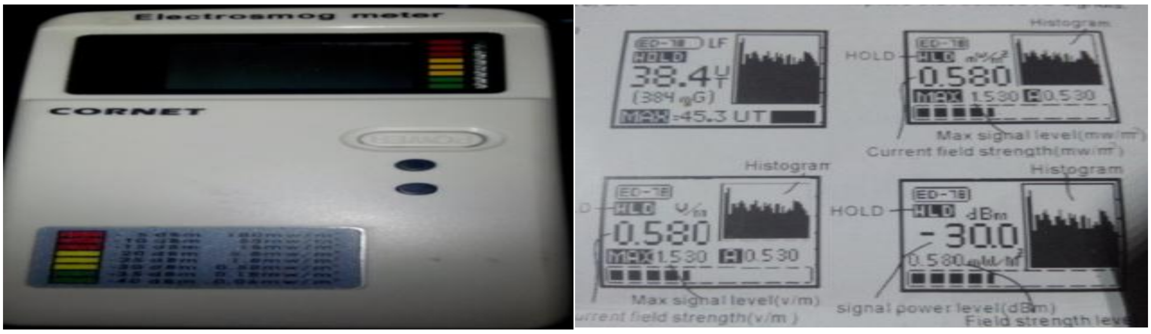
SAR is a measure of the electric field, and indirectly the magnetic field at the point under study, and also a measure of the local heating rate *dT*/*dt* [3].

Geographically**, t**he South-South region of Nigeria comprises the area covered by the natural delta of the Niger River defined by its geology and hydrology. Its approximate northern boundaries are located close to the bifurcation of the Niger River at Aboh, while the western and eastern boundaries are around the Benin River and the Imo River, respectively. The area is approximately 25,900 square kilometers with longitude ($5^{o}0^{'}0^{"}$E – $9^{o}0^{'}0^{"}$E) and latitude ($4^{o}0^{'}0^{"}$N – $7^{o}0^{'}0^{"}$N). It consists of six States; Akwa-Ibom, Bayelsa, Cross River, Delta, Edo, and Rivers. The region is extremely important due to its oil reserves and biological diversity.

2.0 MATERIALS AND METHOD

This study involves site specific measurement of electric and magnetic field strength from GSM base stations of selected States in South-South Nigeria.

The distance from the foot of the BSA to point of interest (POI) was measured by means of a tape rule (50 m long). A broadband survey Meter (Cornet Electrosmog Radiofrequency Meter) Model: ED-78S; Frequency range: 100 MHz -8 GHz; Sensitivity: 0.5 µW/m^2 to 10.8 W/m^2 and sensitivity of 0.1 µT to 60 µT [4] was used to measure electric and magnetic field strength around the Base Transceiver Station (BTS).



(a) (b)

Fig. 1: (a) Electrosmog Meter ED-78S (b) Display mode after survey

The microcell base stations studied cover the four major network provider (MTN, GLO, Etisalat and Airtel) base stations in Nigeria. Selection of base station was done base on transmission frequency (1800MHz), residential area, office area, open market area and nearness to other radiofrequency antennas (e.g. TV and Radio antennas). Wherever possible, measurements were made in axis that permits measurements in line of sight to the directional antennas or antenna beam.

The electric and magnetic field strength at each of the sites in near field was measured at 25 m interval from the foot of the mast at the front direction of the sector antenna and at about 1.67 m above sea level i.e height of an average man.

The electrosmog meter was used vertically as recommended in the user's manual. The readings were taken after every 100 seconds of scanning by the equipment at the various points (25 m, 50 m, 75 m, 100 m 125 m and 150m) from the foot of the base station. The broadband survey meter is frequency dependent; it therefore provides relatively simple and convenient means for measuring electric and magnetic field in microcell base stations sites where space is limited and in busy towns and city centres where many microcells and picocells base stations are sited. This data was recorded for sixty (60) base stations in the study area. In order to investigate the degree of consistency of field measurement with existing models, specifically for the near field measurement, a transmitting cell phone was placed 2 cm from the spectrum analyser to measure the electric and magnetic field in the near field region. This is the distance between the cell phone and human head when on call without kits.

In the same near field condition, a typical human head was modeled (Fig. 2) showing the different tissue thickness (parameters are shown in Table 2) and direction of propagation of the EM waves.

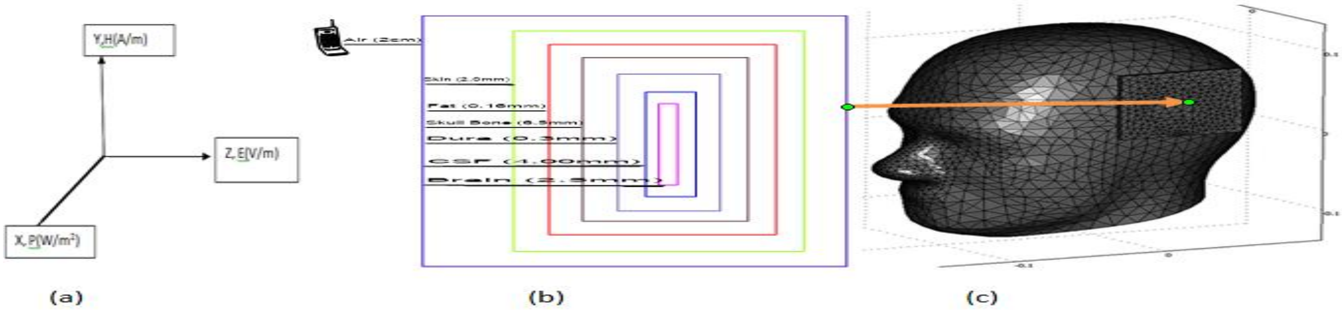


Fig. 2: (a) Direction of EM wave propagation (b) Section of the head showing the different tissue layers (c) A three-dimensional (3D) finite element mesh of human head model showing different layers.

3.0 Results

The results obtained in this study are presented in Figs. 3-5 and mean values of SAR and Temperature Rise in Table 3.

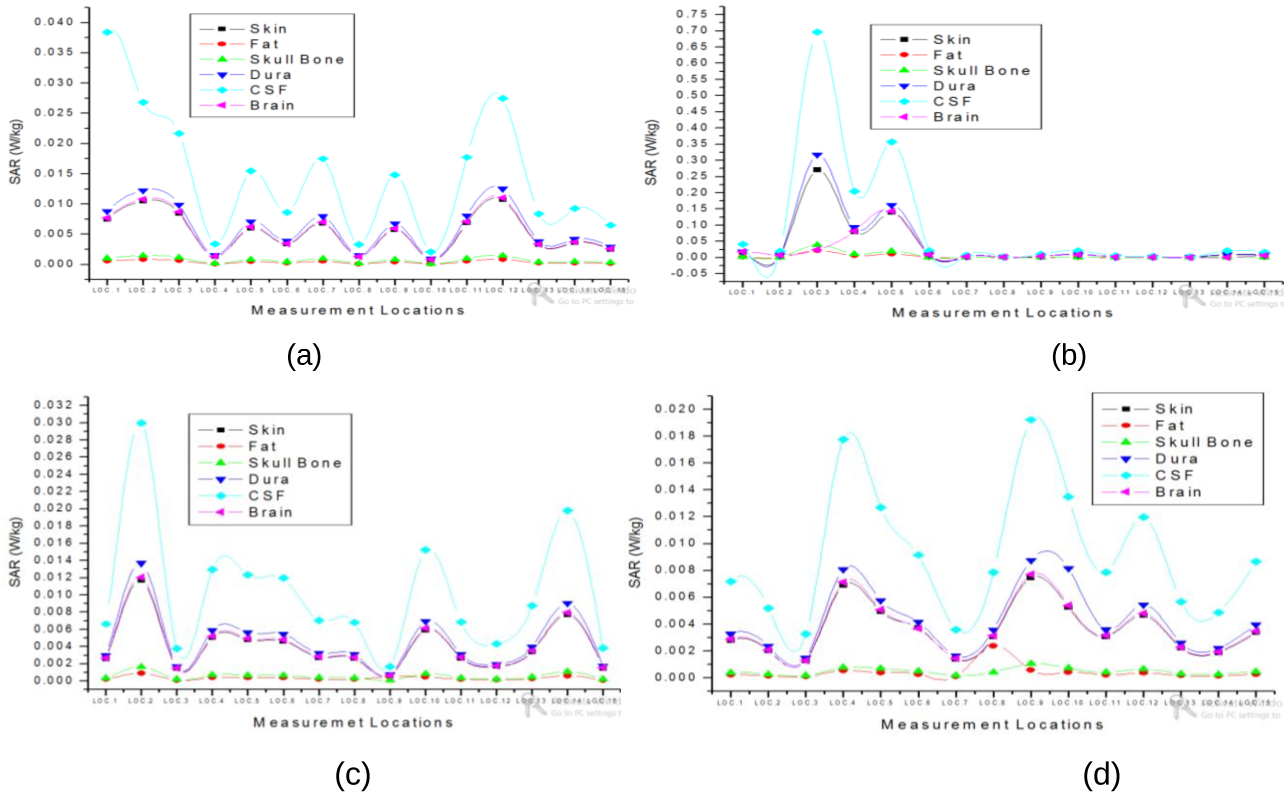
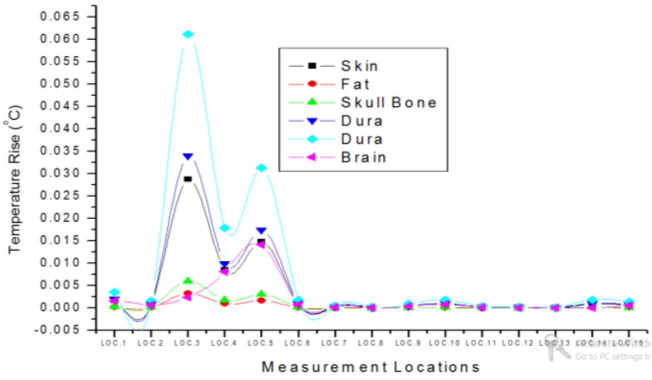
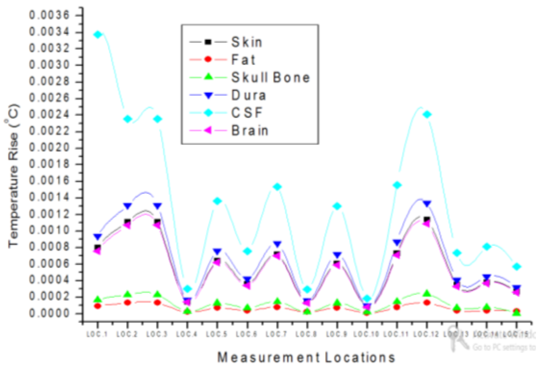
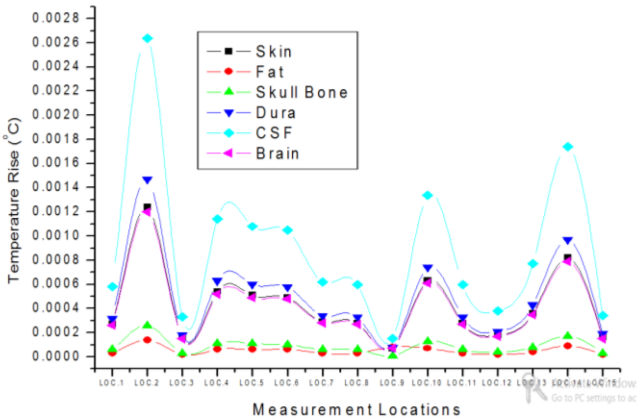


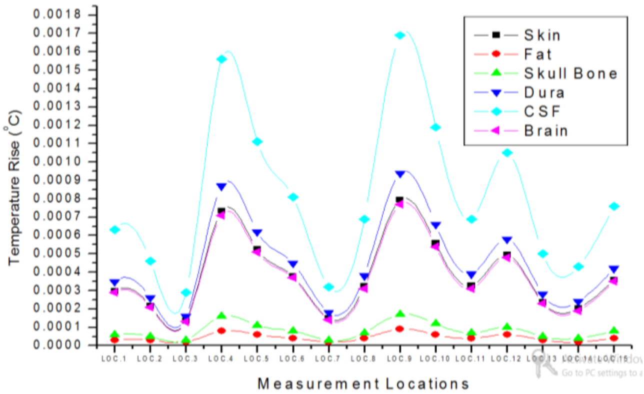
Fig. 3: Rate of Energy Absorption (SAR) of the different Head Tissues versus Measurement Locations in (a) Benin City (b) Calabar (c) Port-Harcourt and (d) Yenagoa based on ICNIRP standard.





(a) (b)





(c) (d)

Fig. 4: Temperature variation of the different Head Tissues versus Measurement Locations in (a) Benin City (b) Calabar (c) Port-Harcourt and (d) Yenagoa based on ICNIRP standard.

Table 3: Mean values of SAR and Temperature rise showing the same trend in the different head tissues (Calabar).

Quantities	Skin	Fat	Skull Bone	Dura	CSF	Brain
Mean SAR(W/Kg) ± 0.034	0.037134	0.002933	0.005241	0.043485	0.095358	0.02088
Mean Temperature rise(°C) ± 0.003	0.003942	0.00045	0.00083	0.004657	0.008381	0.002058
Statistical Correlation	0.99					

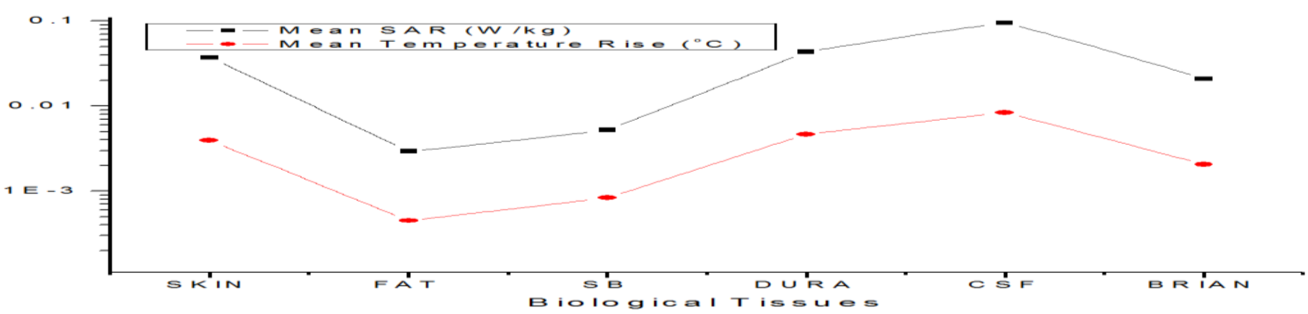


Fig. 5: Relationship between SAR and Temperature rise versus Head Tissues in Calabar

4.0 Discussion

Using Eq. (2) where E is the measured electric field (V/m), ρ is the mass density of the tissue (kg/m^3), σ is the electric conductivity of the tissue layers at 1800MHz, the values of SAR from the sixty (60) Locations in the selected States covered in South-South Nigeria were evaluated and plotted against the various measurement locations. As presented in Figs. 3(a-d), these shows that maximum SAR value is observed in the cerebrospinal Fluid (CSF) with highest electrical conductivity but least in the fat tissue with least conductivity, mass density and tissue thickness (Table 2). Similar trend was observed across the four States covered. It also indicates that no network operates above the ICNIRP recommended threshold across the selected States.

The solution of Eq. (4) was used in a time dependent field to evaluate the temperature rise in every tissue of human head over a six minutes (360 seconds) exposure to RF. The six minute period adopted was to allow for proper comparison with the threshold value of ICNIRP. These yields;

$$T = \frac{SAR\ x\ t}{C} \tag{5}$$

where, T is the temperature rise in ^oC, t is the time in seconds and C is specific heat capacity of tissue ($Jkg^{-1}.^oC^{-1}$).

Using tissue parameters in Table 2, temperature rise for different human tissues was evaluated as presented in Figs. 4(a-d). They indicate that the maximum temperature rise value is observed in the CSF with highest electrical conductivity but least in the fat tissue with least mass density and thickness, exhibiting the same trend as SAR. Therefore, a perfect thermal relationship between SAR and temperature rise is observed. It also indicates that the recommended thresholds of ICNIRP (1998) are not exceeded. Figs. 3 and 4 equally show that Calabar has the highest SAR and temperature rise across the study locations followed by Port Harcourt, Yenagoa and least in Benin.

Considering the worst case in Calabar as indicated in Figs 3b and 4b, for which the mean SAR and Temperature rise were evaluated and correlated as in Fig. 5 establishing a good relationship between SAR and temperature increase in biological tissue with strong correlation coefficient (0.99) as shown in Table 3.

5.0 Conclusion

The results of this study were compared with threshold values of 2 W/kg and 0.08 W/kg for SAR (over the head and whole body respectively), and 1^oC for temperature rise as set by International Commission of Non Ionizing Radiation Protection (ICNIRP), it is obvious that all the network operators in the study area have SAR less than the recommended threshold value with the worst case observed in Calabar. A good thermal relationship between SAR and temperature rise was also in this study. Thermal conductivity, mass density and thickness of biological tissues are key parameters that define the extent of the effect induced by SAR and temperature rise when these tissues (Skin, Fat, Skull Bone, Dura, CSF and Brain) are exposed to RF radiation.

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