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Evaluation of Specific Absorption Rate Distributions from GSM Base Stations in Benin City, Nigeria

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Abstract
This study is aimed at evaluating the 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. 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. Measurements were made at the base of the masts and at distances 25, 50, 75 and 100 m respectively from the base of the masts. The measured values of the electric field strength along with the human head tissues properties were used to compare the SAR values. The result showed that the SAR values in the different human head tissues evaluated at different distances from the mobile base stations are below the United States (US) Federal Communications Commission (FCC) and the ICNIRP exposure limit for the general public which is 1.6 W/kg in 1 g of tissue.

1. Introduction

For about two decades now, mobile communication devices in Nigeria have completely changed the way we connect with the entire world and our community. There is no exaggerating the fact that modern civilization thrives on our ability to communicate easily using the Internet and mobile devices. Nonetheless, most of these communication techniques use radio frequency (RF), which exposes us to a lot of biological and non-biological entity. These entities interact with RF electromagnetic radiation from cellular towers and mobile devices. It suffices to state here that at every frequency possible, we are exposed to electromagnetic radiation [1].

Global System for Mobile Communications (GSM) is an open digital cellular technology used for transmitting mobile voice and data services. GSM differs from first generation wireless systems in that it uses digital technology and Time Division Multiple Access (TDMA) transmission methods. GSM is a circuit switched system that divides each 200kHz channel into eight 25kHz time slots. GSM-900 and GSM-1800 are used in most parts of the world. GSM-900 uses 890-915MHz to send information from the mobile station to the base transceiver station (uplink) and 935-960MHz for the other direction (downlink) providing 124RF channels (Channels numbers 1 to 124) spaced at 200kHz. Duplex spacing of 45MHz is used. GSM-1800 uses 1710-1785 MHz to send information from the mobile station to the base transceiver station (uplink) and 1805-1880 MHz for the other direction (downlink) providing 374 channels (channel members 512 to 885).

With the increasing demand for better communication through good network coverage and quality service, more and more base stations are been installed throughout the world. Recent studies have highlighted the health hazards caused by electromagnetic fields (EMF) and they reported that despite the tremendous benefits of GSM and other related technologies, significant exposure to RF radiation from base stations and GSM handsets could be detrimental to health [2], [3], [4], [5], [6] due to interactions with biological tissues as a result of either the forces exerted on the biomolecules, ions or by changing their energy states. These health issues have been of concerned to many professionals and the health-conscious public. This concern spurred many researchers to study the effects of electromagnetic fields on biological materials, particularly the absorption rate of electromagnetic radiation when human body or other biological objects are exposed to such radiation [7], [8], [9], [10], [11].

The awareness of the potential health hazards has led to the development of guidelines on the exposure limits to RF radiation by the Institute of Electrical and Electronic Engineers (IEEE)/American National Standard Institute (ANSI), International Commission on Non – ionizing Radiation and Protection ICNIRP) and National Radiological Protection Board (NRPB). Presently in Nigeria, there is no known regulatory agency for non–ionizing radiation protection, as we have for the ionizing radiation which is the Nigerian Nuclear Regulatory Authority (NNRA). As at date, there is unavailability and inaccessibility of data to the public for comparison with the recommended international safety limits. Most persons perceive the radiation risks from RF exposure as likely or even possibly severe. Several reasons for public fear include media announcements of new unconfirmed scientific findings leading to a feeling of uncertainty [3]. There have been reports on the thermal and non–thermal effects of RF interactions with biological tissues which produce toxic physiological effects [12].

There is an induction of internal electric and magnetic fields when biological materials are exposed to radio waves which can be solved using Maxwell's equations for given boundary conditions [13]. It has been observed that a temperature gradient arises due to EM because the biological materials absorbs significant amounts of energy due to electromagnetic radiation. The term "Specific Absorption Rate" (SAR) is used to define this rate of energy absorption in biological objects. Government regulations and radiation exposure guidelines use the SAR to define safe limits of exposure to high-frequency EM fields for occupational workers as well as the general public. Specific absorption rate has been standardized as Watts per kilogram [14]. However, the guidelines and regulations mainly revolve around the thermal effects of microwave radiation. There is sufficient evidence to prove that non-thermal effects also deteriorate our health and well-being; unfortunately, current regulations are not effective enough to prevent non-thermal health hazards of electromagnetic radiation [15]. Numerous dosimetric studies have intensively used numerical SAR calculations to evaluate the effects of exposure to EM radiations from communication towers and other mobile devices on human tissues [16], [17]. A study on EM radiations and its effects on water has also been carried out [18].

In other to avoid the adverse health effects of electromagnetic radiation, several standard organizations such as the Institute of Electrical and Electronic Engineers (IEEE), United States (US) Federal Communications Commission (FCC), the National Council on Radiation Protection and Measurements (NCRP) and the International Committee on Non- Ionizing Radiation Protection (ICNIRP) and the National Radiation Protection Board (NRPB) have adopted exposure guidelines/standards for the general public as well as for RF workers in the course of their regular duties. According to FCC standards, the safe level of SAR is 1.6 W/Kg in 1 g of tissue for the general public. [19]

Thus in this paper, we will measure and analyze the Specific Absorption Rates (SAR) around some GSM base stations in Benin City and hence compare the values obtained with the values recommended by FCC.

2. Materials and Methods

The RF power density, S, magnetic field strength, H, and electric field strength, E, around selected GSM antenna base stations in Benin City were determined by means of a portable Electrosmog digital meter model 9810 RF manufactured by MECO, USA. The meter is a broad band device for measuring RF radiation in the frequency range of 10 MHz to 8 GHz. It is a triaxial isotropic measurement meter with three channel measurement sensor, high dynamic range configurable alarm threshold and memory function.

SAR for electromagnetic energy can be calculated from the electric field within the tissue as:

$$SAR = \frac{1}{V}\int_V \frac{\sigma(r)\left|E(r)\right|^2}{\rho(r)}dr \text{ (W/kg)} \tag{1}$$

where σ is the sample electrical conductivity, E is the RMS electric field, ρ is the sample density and V is the volume of the sample.

SAR measures exposure to fields between 100kHz and 10GHz (known as radiowaves) [20]. It is commonly used to measure power absorbed from mobile phones and during magnetic resonance imaging (MRI) scans.

Specific Absorption Rate (SAR) is a measure of the rate at which energy is absorbed by the human body when exposed to a radiofrequency (RF) electromagnetic field, although, it can also refer to absorption of other forms of energy by tissue, including ultrasound [21] It is defined as the power absorbed per mass of tissue and has units of watts per kilogramme (W/kg) (Jin 1998) SAR is usually averaged either over the whole body or over a small sample volume (typically 1g or 10g of tissue).

Depending on the distance from the source, near- and far-field conditions to RF-EMF occur in everyday life. Near-field sources are for example mobile and cordless phones, whereas far-field sources include mobile phone base stations, broadcast transmitters, or base stations of cordless phones. Far-field sources can also be called environmental far-field sources. Near-field sources are generally responsible for highly localized exposure, for example, in the head area, and exposure is in general limited to short time periods. Exposure from environmental far-field sources results in a more homogeneous whole-body exposure that is lower than the maximum exposure due to an operating mobile phone on the head, but occurs usually over prolonged time periods.

Under far-field conditions, we can convert between electrical field strength (V/m) and Power flux density (W/m^2) using the formula.

$$S = \frac{E^2}{z_o} \text{ or } E = \sqrt{S \times z_o} \quad (2)$$

Where z_o is the free space impedance of 377 Ω. Conversion into the magnetic field (H) is also possible for far-field conditions using the formula.

$$H = \frac{E}{z_o} \quad (3)$$

In the near-field range, the Specific Absorption Rate (SAR) is the most common measure of intensity. Because measuring SAR in living persons is impossible, the electrical field strength (V/m) or the power density (W/m^2) measured outside of the human body is instead used for regulating far-field RF-EMF. Above 2 GHz, the ICNIRP recommends a field strength of 61 V/m or a power flux density of 10 w/M^2. Below 2 GHz, the values are decreasing with decreasing frequency, although constant between 10 and 400 MHz (28 V/m) [22].

A total of forty (40) mobile base stations in ten locations (Fig. 1) were covered with four base stations considered from each location.

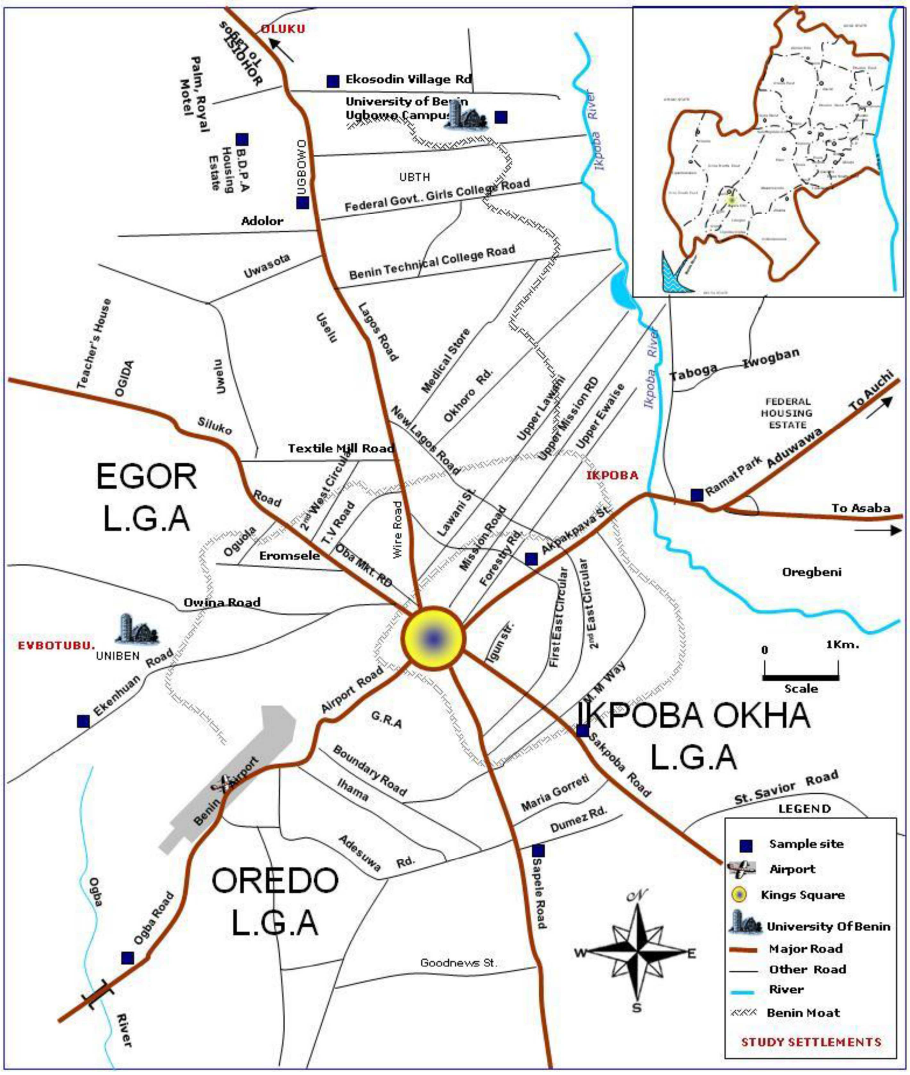

Figure 1. A sketched map of Benin City showing the location of the base station masts in this study.

The ten different locations were further divided into five zones with zone one consisting of masts located in Ekosodin Village and University of Benin, Benin City, Ugbowo campus. Zone two housed the masts in Bendel State Development Property Authority (BDPA) Ugbowo. Zone three consists of the masts in Ekenhuan and Oko/ Ogba roads. Zone four comprised of masts around Akpakpava road, Ikpoba Slope and Ikpoba Hill by Ramat Park while zone five has masts around Sapele and Sakponba roads. Measurements were made at the base and at distances 25, 50, 75 and 100 m from the mobile base stations. The base stations were randomly selected and the measurement sites were spread to cover a good part of Benin City metropolis. The readings were taken between the hours of 9 a.m. and 11 a.m. for the purpose of uniformity in time and when calls or network traffic is high.

3. Results and Discussion

Table 1. *Mean values with standard deviation of Electric field intensity E(V/m) in study locations.*

Distance (m)	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
0	2.542±0.053	3.839±0.355	1.820±0.068	3.626±0.599	8.757±5.464
25	2.567±0.367	3.790±0.054	1.305±0.450	2.963±0.716	11.745±8.143
50	3.074±0.955	1.950±0.099	0.934±0.139	3.529±0.954	2.531±0.791
75	1.749±0.773	1.416±0.523	2.604±0.739	2.132±0.672	4.228±1.472
100	1.549±0.389	1.371±0.474	3.183±1.132	2.031±0.507	2.547±0.484

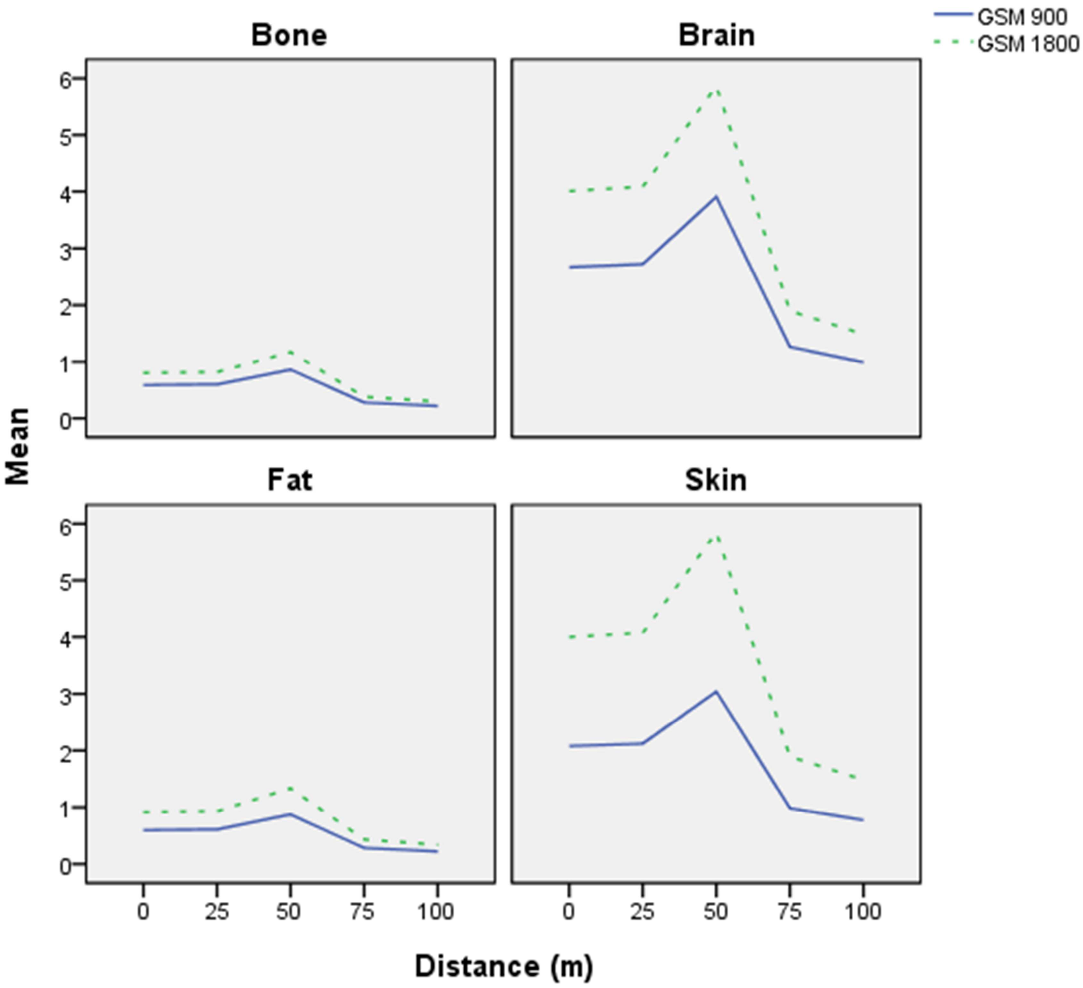

Figure 2. *Mean SAR (mW/kg) of GSM 900 and GSM 1800 for the different Human Head Tissues at different distances from the Base Stations in Zone 1.*

Figure 2 shows that the SAR value reduces exponentially over distance, except at 50 m from the mobile base station, where it showed higher value. In all the points of assessment (distance measured), it was observed that the Brain had the highest SAR value, followed by the skin, fat and bone had significantly lower SAR values.

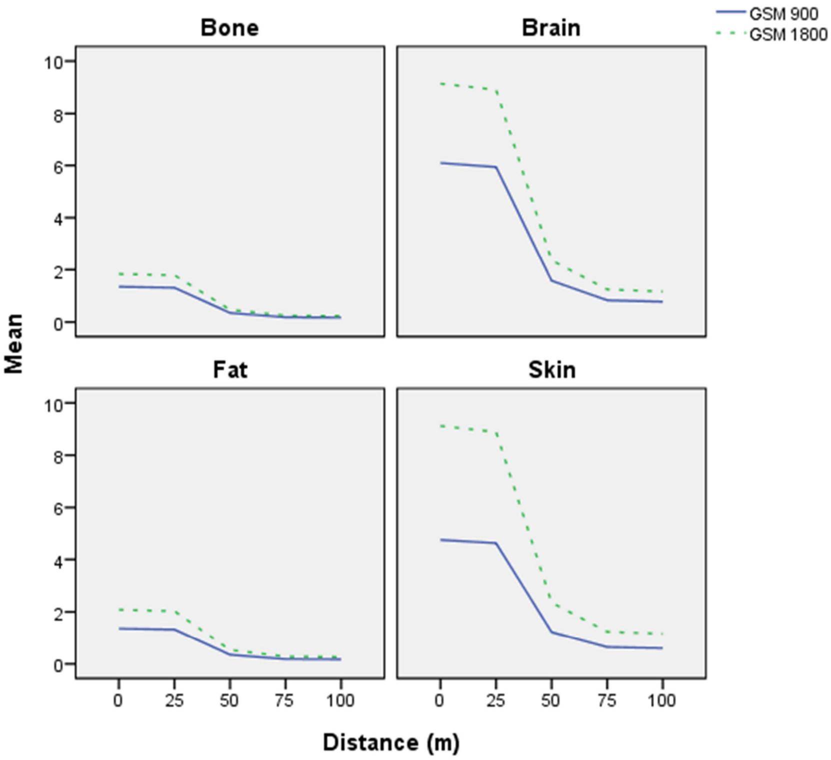

Figure 3. *Mean SAR (mW/kg) of GSM 900 and GSM 1800 for the different Human Head Tissues at different distances from the Base Stations in Zone 2*

Figure 3 shows that the SAR value reduces over distance from the mobile base station. In all the points of assessment (distance measured), it was observed that the Brain had the highest SAR value, followed by the skin, fat and bone had significantly lower SAR values.

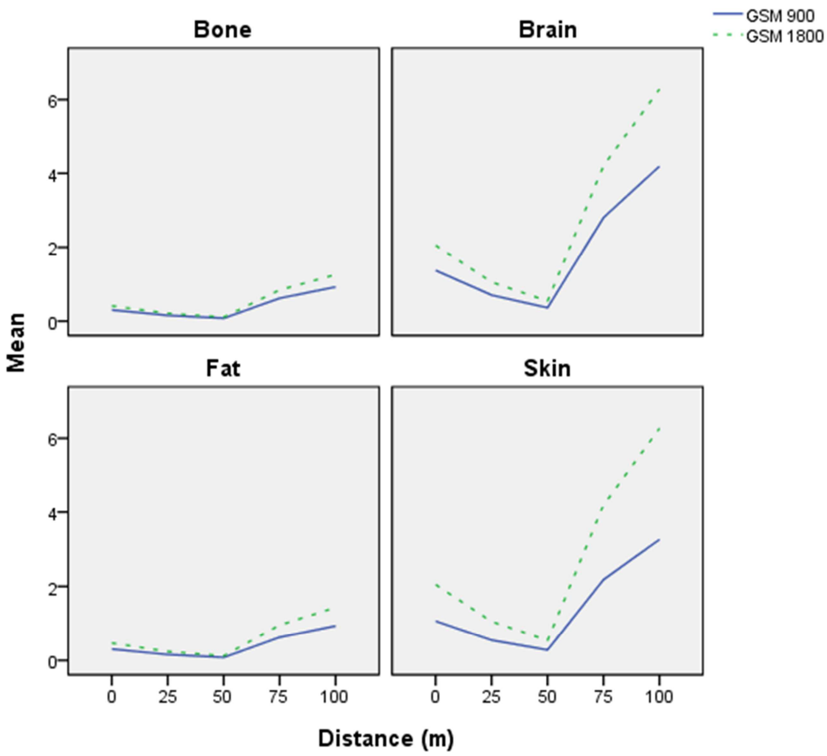

Figure 4. *Mean SAR (mW/kg) of GSM 900 and GSM 1800 for the different Human Head Tissues at different distances from the Base Stations in Zone 3.*

Figure 4 shows that the SAR value reduces over distance up to 40cm from the mobile base station, where it began to rise. In all the points of assessment (distance measured), it was observed that the Brain had the highest SAR value, followed by the skin, fat and bone had significantly lower SAR values.

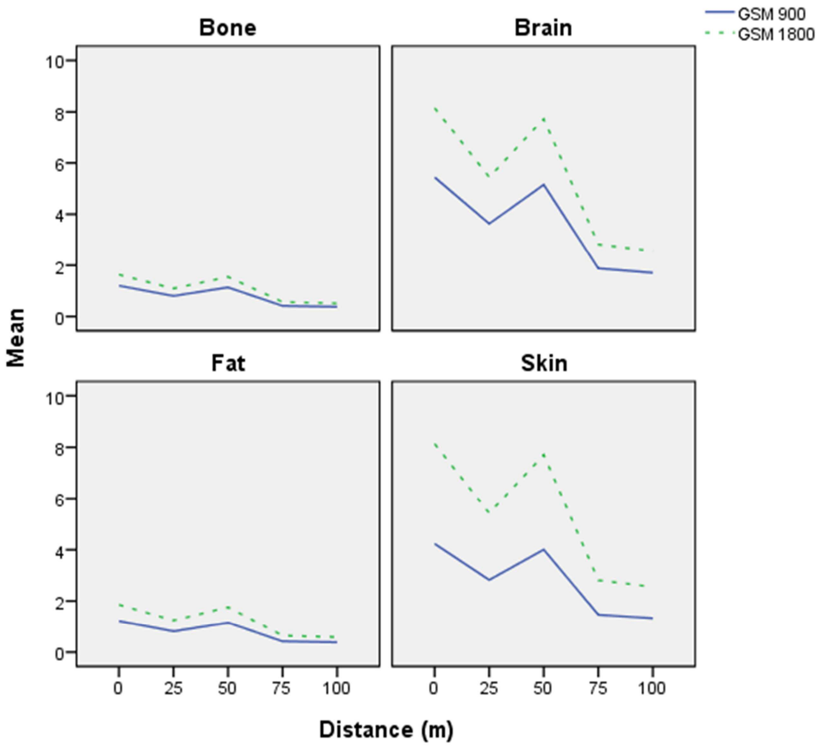

Figure 5. *Mean SAR (mW/kg) of GSM 900 and GSM 1800 for the different Human Head Tissues at different distances from the Base Stations in Zone 4.*

Figure 5 shows that the SAR value reduces over distance, except at 50cm from the mobile base station, where it peaked and dropped afterwards. Making the curve looking like a typical Gaussian curve. In all the points of assessment (distance measured), it was observed that the Brain had the highest SAR value, followed by the skin, fat and bone had significantly lower SAR values.

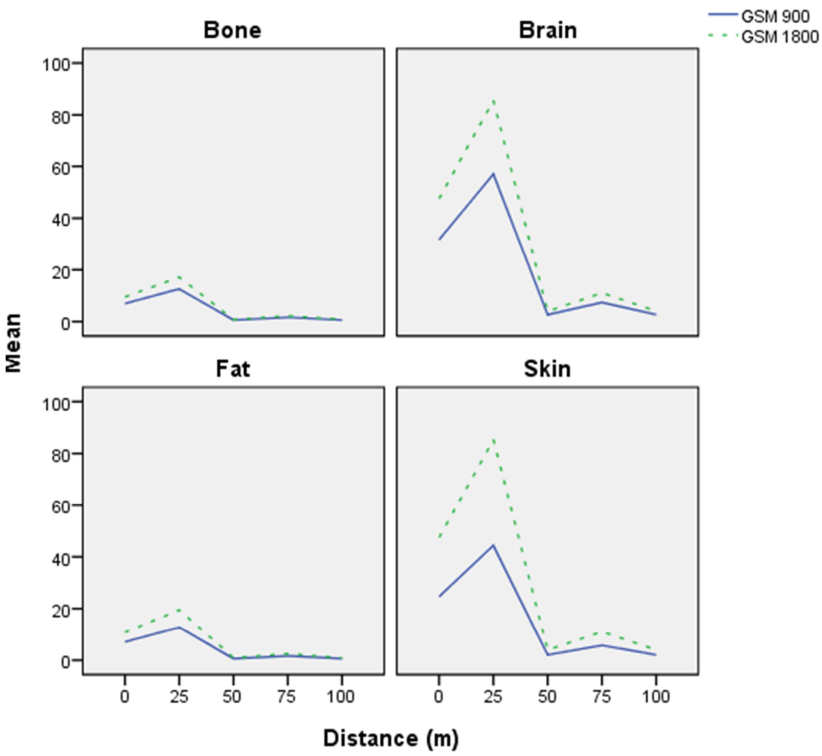

Figure 6. *Mean SAR (mW/kg) of GSM 900 and GSM 1800 for the different Human Head Tissues at different distances from the Base Stations in Zone 5.*

Figure 6 shows that the SAR value undulates over distance from the mobile base station, with several crest and trough. In all the points of assessment (distance measured), it was observed that the Brain had the highest SAR value, followed by the skin, fat and bone had significantly lower SAR values.

4. Discussion

The finding from this study shows that in Zone 1, Zone 2, Zone 3, Zone 4 and Zone 5 the maximum SAR values were at 50, 0, 100, 0 and 25 m respectively. That is to say that inhabitants living around these distances from the mobile base stations are highly exposed to electromagnetic radiation from the masts.

Also from the finding of this study, it was revealed that one can not exactly adopt the inverse square law for variation of radiation over distance. This is shown by the irregularity of the SAR values over distance; which didn't show a typical exponential decaying graph as expected; rather at certain points it increases and at other points decreases with distance. It could be said here that in an ideal situation SAR decreases over distance, but due to interference of radio waves from other sources around the point of assessment, it has biased the outcome effect. Although, certain RF measuring devices can help select specific frequency range to be specific on the outcome, the value will not be representative of the cumulative effect on humans.

The brain was reported to have the highest SAR value in the human head tissue followed by the skin, next is the fat and last is the bone. This trend is in good agreement with [23] who carried out similar study using radiofrequency radiation from mobile phones. Although the SAR values measured in their study were higher than what was obtained in this study, this could be likely due to the fact that they evaluated SAR at the near field (0 – 1 cm); while ours is at far field (0 – 100 m). Comparing the values of SAR in this study with that of [24], this study shows higher SAR values, although [24] employed a theoretical approach.

5. Conclusion

In this study, the distributions of specific absorption rates in Human Head tissues from measured Electric field strengths selected GSM Base Stations in Benin City, Edo State, Nigeria has been carried out successfully. It is observed that the higher the frequency, the greater the specific absorption rates. This is more pronounced in the tissues with higher water contents such as the brain and the skin. However, the SAR values in the different human head tissues evaluated at different distances in this study from the mobile base stations are below the Federal Communication Commission (FCC) and the ICNIRP threshold value of 1.6 W/kg in 1 g of tissue.

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