TECHNICAL EVALUATION OF LEVEL OF RADIATION EXPOSURE FROM GSM BASE STATIONS TO THE PUBLIC IN NIGERIA

J. J. Popoola[1*], A. C. Obafemi[2]

[1,2]Department of Electrical and Electronics Engineering,
Federal University of Technology, Akure, Ondo State, Nigeria

ABSTRACT

The objective of this paper is to evaluate the hazardous effect of electromagnetic radiation generated by Global System for Communications (GSM) base stations on human health and environment. In carrying out the study, field measurements of electric field emitted from 120 base stations of the four GSM providers in 6 cities in South West Geopolitical zone in Nigeria were carried out using Tri-Axis field strength meter. From the data obtained, the Specific Absorption Rate (SAR) was calculated for 6 body tissues. The calculated SAR values were further analysed statistically. The results of the study show that the maximum average calculated SAR value is about 3% of the set value by the International Commission on Non-Ionizing Radiation Protection recommended guidelines. It was therefore concluded that there was no technical evidence that electromagnetic radiation generated from GSM base stations in the geo-political zone and the whole country at large has potential to cause any adverse effects on human health and environment.

KEYWORDS: *Mobile phone; electromagnetic field and waves; electromagnetic radiation; specific absorption rate*

1.0 INTRODUCTION

Over the last fifteen years, the use of land-based mobile telephony has increased dramatically in Nigeria, especially with the introduction of the GSM 900/1800 systems in early 2000. This increase in use of mobile phone has led to increase in deployment of base stations as well as public perception on adverse effects of radio frequency (RF) radiation from electromagnetic field and waves, which are important media for carrying signals. As reported in Mousa (2011), while electromagnetic field (EMF) is propagated at the speed of light in the free space so that it can be modulated, transmitted and received when carrying the information, the electromagnetic waves consist of both the electric field and the magnetic field, which are perpendicular to each other and both are perpendicular to the direction of their propagation.

Basically, electromagnetic waves are of different types with different frequencies. Each of the frequencies has its own characteristics and applications. Irrespective of the applications, generally whenever electromagnetic field and waves are used for signal transmission, there is generation of electromagnetic radiation which can be ionizing or non-ionizing. While the ionizing radiation has enough energy to remove bound electrons from the orbit of an atom such that it becomes an ionized atom which may cause health hazard and other environmental effects, the non-ionizing radiation (NIR) does not have

[*] Corresponding Email: jidejulius2001@gmail.com

the sufficient energy to ionize the atoms. Generally, NIR originates from both natural and man-made sources. According to Kwan-Hoong (2003), sunlight has been identified as the major example of natural source of NIR, while the wireless communications, industrial and medical application are common examples of man-made sources of NIR.

With wireless communications as one of the sources of NIR, it is obvious that large numbers of people are being exposed to NIR from mobile or cellular phones on daily basis. This is because mobile phone is the major means of transmitting information by majority of populaces nowadays (Rahman, 2013). Similarly, a growing evidence of GSM base stations within and around the residential buildings suggests that environmental levels of RF radiation may increase the risk of infectious diseases and reduce the efficacy of vaccinations. This possible health and environmental risks of mobile communication radiation due to its interface with human has caused a great concern for individuals, researchers, governments and other relevant institutions worldwide.

According to Adejumobi, Orimolade and Omotayo (2015), reviews of the effects of electromagnetic radiation on human beings by both the World Health Organisation and Royal Society of Canada revealed that exposure to EMF can affect the production of the hormone melatonin by pineal gland in the brain aggravating breast cancer, Parkinson's disease and Alzheimer's syndromes. Similarly, as reported in Behari (2010), it was revealed that the electromagnetic radiation from digital mobile phones can cause significant changes in ornithine decarboxylase activity, which is essential for DeoxyriboNucleic Acid (DNA) synthesis. In addition, adverse effects of EMF radiation investigated, as reported by Buckus, Strukeinskiene and Raistenskis (2014), by various clinical trials include the possible link to increased risk of leukaemia, sleep disturbances and tumours. Furthermore, in a survey study conducted by Santini, Santini, Danze, LeRuz and Seigne. (2003) on people living in the vicinity of GSM base stations, the results of these authors' study revealed that series of self reported symptoms were given by people interviewed depending on their closeness to the GSM base station. According to Ozovehe, Usman and Hamdallah (2015), similar experiences are common with peoples living in vicinities of GSM cell towers in Spain, Egypt, Poland and Australia.

On the other hand, some groups such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and mobile manufacturer forum that manufactures mobile equipment and GSM operators across the world insist that there are no discernible effects from the RF radiated from mobile phone base stations (Shalangwa, Vasira, & Shalangwa, 2011; Shalangwa, 2010). This imbalance on effect of electromagnetic radiation generated from cell or mobile phone base stations has generated controversy with some believe that there exists no health effect from cell phone technology probably because of business inclinations while others are saying there are adverse environmental and biological effects of the cell phone technology to people.

Technically, during the process of electromagnetic signal propagation, radiation falls on the population in different ways. Energy or radiation interception during this process can be through reflection, refraction, transmission or absorption depending on the complex conductivity of the exposure body as well as the frequency of the source. Therefore, when using a mobile or cell phone magnetic pulses are being generated. These pulses peak at several tens of micro tesla caused biological effects around $0.2\mu T$ (Behari, 2010). Similarly, during signal propagation and usage of mobile phone, the absorbed RF energy can be converted to other forms of energy that can cause interference with the functioning of the living system. Most of this energy is converted into heat, which can have adverse effects on both the population and environment (Behari, 2010).

Based on these divergent opinions, there is a need to determine the level of radiation absorbed by human body. This motivated the study presented in this paper, which unlike most studies in this area brings in the concept of Specific Absorption Rate (SAR) as a deterministic factor for determining level of radiation absorbed by human body. This will help to technically determine whether or not the radiation generated from GSM base stations in Nigeria has adverse effects on human health and environment. Thus, in providing the required technical solution to the problem on ground, the study presented in this paper determined the SAR value for the some tissues (skin, muscle, nerve, cerebellum, tendon and blood) of the human body so as to determine whether absorbed field or radiation into those tissues has caused or has potential to cause any biological adverse effect on human health. The study further determined whether or not the SAR of the tissue varies with geographical location and operating frequency of the GSM providers.

2.0 THEORETICAL FRAMEWORK

The specific absorption rate is defined as the rate at which electromagnetic radiation or RF energy is absorbed in a body (Adejumobi et al., 2015; Sharma, Gautam & Kumar, 2014). It is therefore the parameter for determining or evaluating the rate at which the amount of electromagnetic radiation or RF energy is absorbed by the human body. The measurement of SAR is based on thermal effect, which is based on the concept that RF energy absorbed within the biological tissues. SAR value is dependent on the separation between the body and the mobile phone (Sharma et al., 2014; Bhat & Kumar, 2013; Kargel, 2005). Hence, the closer the distance of the radiation source to the human head the higher the SAR value. Generally, high values of SAR portend risk for the people's health. This led many international bodies around the world to specify limits the SAR value could reach before it starts getting harmful to the human body.

In human tissue, SAR is proportional to the square of the internal electrical field caused by external device. It is expressed mathematically in Ozyalcin, Akleman and Sevgi (2002) as;

$$SAR = \frac{\sigma}{\rho}|E|^2 \tag{1}$$

where $E\left[V/m\right]$, $\sigma\left[S/m\right]$, and $\rho\left[kg/m^3\right]$ are electric field strength, conductivity and mass density of the tissue at considered point, respectively. Similarly, SAR can be expressed mathematically in term of increase in temperature at a point according to Behari (2010) as;

$$SAR = \left.\frac{cdT}{dt}\right|_{t=0} \tag{2}$$

where $dT\left[{}^{o}C\right]$, dt , and $c\left[J/kg\,{}^{o}C\right]$ are change in temperature, duration of exposure and specific heat capacity, respectively. Also when using the electric field, the dissipated power density, P , in any tissue can be calculated using mathematical expression in Joseph and Divine (2015) as;

$$P = \sigma |E|^2 \quad (3)$$

Substituting (3) in (1) gives (4), which implies that;

$$SAR = \frac{P}{\rho} \quad (4)$$

SAR can be obtained using either laboratory studies or with computer simulations (Ozyalcin et al., 2002). However, the Transmission Line Matrix (TLM) and Finite-Difference Time Domain (FDTD) approaches have become the most important time-domain simulation techniques used in broad range of electromagnetic studies (Ozyalcin et al., 2002). According to these authors, while TLM is based on the networking theory, the FDTD uses the field theory. SAR's measurement according to Adejumobi et al. (2015) is very complex. However, in this study Equation (1) was used because the local SAR at specific point was determined. The ICNRIP, an independent body in charge of providing guidance and advice on the health hazards of non-ionizing radiation exposure gave the standard for SAR and radiation exposure. The guidelines for both occupational and general public exposures as presented in Gandhi (2002) are shown in Table 1.

Table 1. ICNRIP'S Basic Restrictions for time-varying Electric, Magnetic Fields and SAR for frequencies up to 10 GHz (Gandhi, 2002)

Exposure	**Frequency range**	**Current density J for head and trunk (mA/m²**	**Whole body average SAR (W/kg)**	**Localized SAR for head and trunk (W/kg)**	**Localized SAR (W/kg)**
Occupational exposure	Up to 1 Hz	40	-	-	-
	1-4 Hz	$40/f$	-	-	-
	4 Hz-1 kHz	10	-	-	-
	1-100 kHz	$f/100$	-	-	-
	100 kHz-10 MHz	$f/100$	0.4	10	20
	10 MHz-10 GHz	-	0.4	10	20
General public exposure	Up to 1 Hz	8	-	-	-
	1-4 Hz	$8/f$	-	-	-
	4 Hz-1 kHz	2	-	-	-
	1-100 kHz	$f/500$	-	-	-
	100 kHz-10 MHz	$f/500$	0.08	2	4
	10 MHz-10 GHz	-	0.08	2	4

where f is the frequency in Hertz, J is averaged current density over a cross section of 1 cm^2 perpendicular to the direction of induced current, and localized SAR averaged is any 10 g of contiguous tissue.

3.0 METHODOLOGY

In carrying out this study, the activities involved were divided into three phases or stages: Field Measurement or Data Collection, SAR Determination and Data Analysis. Details on the three stages are presented in the following sub-sections.

3.1 Field Measurement

The field measurement for the study presented in this paper was carried out in South-West Geopolitical zone of Nigeria. The zone was chosen as the good representation of Nigeria due to its socio-economic development, the large concentration of industrial activities, and its population size (Popoola, Ponnle & Ale, 2011). It is located between longitude $2^{o}31'$ and $6^{o}00'$ E and Latitude $6^{o}21'$ and $8^{o}37'$ N with a total land area of $77{,}818\, km^{2}$ as shown in Figure 1. These areas have different terrains ranging from mountainous to rocky. The zone, where the field measurements were conducted, comprises of six states: Ekiti, Lagos, Ogun, Ondo, Osun and Oyo.

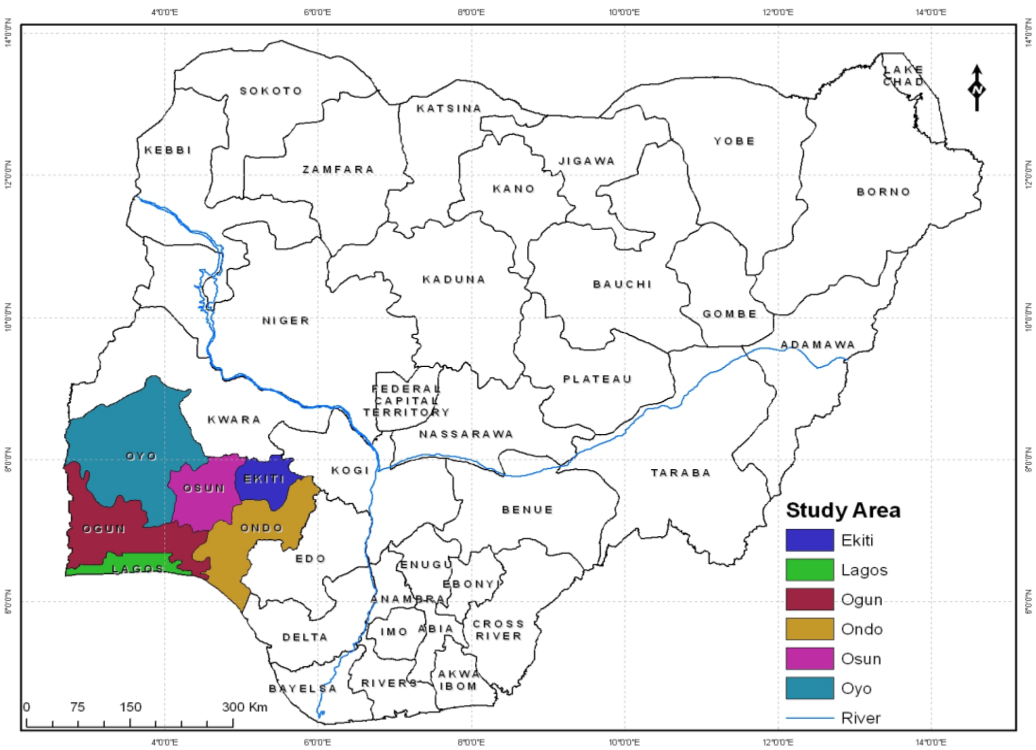

Figure 1. Map of Nigeria showing the study areas

Currently, there are four major GSM operators operating in the zone as well as in the whole country. They all operate at 900 MHz and 1800 MHz. The four GSM operators are Etisalat Nigeria Limited (Etisalat), Globalcomm Nigeria Limited (Glo), Mobile Telecommunication Network (MTN) and Airtel Nigeria Limited (Airtel). The allocated frequencies for the four GSM operators by the Nigerian Communications Commission (NCC) are presented in Table 2. Hence, this study is based on the radiation generated by these four GSM networks. Measurements of the electromagnetic field radiation generated by the four GSM operators were taken in twenty different sites in each state, which implies that five base stations were considered for each GSM operators in each state and a total of one hundred and twenty in all the states. The field measurement or monitoring was conducted in each state capital.

Table 2. Uplink and Downlink frequencies for GSM-900 and GSM-1800 in Nigeria (NCC, 2016)

GSM Provider	**GSM-900**		**GSM-1800**	
	Uplink or Receiver Frequency (MHz)	**Downlink or Transmitter Frequency (MHz)**	**Uplink or Receiver Frequency (MHz)**	**Downlink or Transmitter Frequency (MHz)**
Etisalat	890 - 895	935 - 940	1770 - 1785	1865 - 1880
Glo	900 - 905	945 - 950	1725 - 1740	1820 - 1835
MTN	905 - 910	950 - 955	1740 - 1755	1835 - 1850
Airtel	910 - 915	955 - 960	1755 - 1770	1850 - 1865

The monitoring of the EMF radiation was done using the RF Tri-Axis Meter shown in Figure 2. It is an isotropic measuring device with 3-channel measurement sensor that is designed for a reliable measurement and monitoring RF EMF strength. It has a frequency range of 50 MHz - 3.5 GHz. It indicates the level of electromagnetic pollution generated artificially wherever there is voltage or current, electric and magnetic fields. As shown in Figure 3, the monitoring of the field or radiation strength was taken over distance of $50\ m$ with an interval of $5\ m$ starting from $5\ m$ away from the base stations. The results obtained were recorded and stored for the determination of SAR values for different human tissues in the next stage.

Figure 2. Tri-Axis field strength meter

3.2 Determination of SAR

SAR determination of the six human tissues considered in this study was the focus of this phase. The SAR value of each tissue was calculated using Equation (1). E used to determine the SAR value of each tissue in Equation (1) was obtained from the measured field strength while the conductivity and mass density are obtained from Martinez-Burdalo, Martin, Anguiano and Villar (2004).

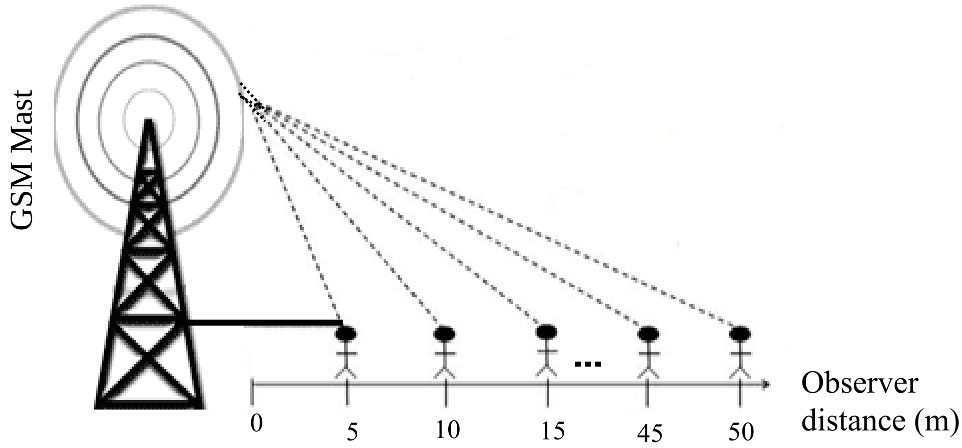

Figure 3. Field strength measurement procudure

The adoption of these authors' conductivity and mass density values for various human tissues was based on these two reasons: usage of FDTD, which is based on field theory employed in monitoring the field strength in this study and availability of corresponding data for GSM-900 and GSM-1800, which were considered in this study. The tissues considered and the corresponding values for conductivity and mass density employed are presented in Table 3.

Table 3. Mass Density and Conductivity of tissues for GSM-900 and GSM-1800 (Martinez-Burdalo et al., 2004)

Tissue		**GSM-900**	**GSM-1800**
	$\rho\left(kgm^{-3}\right)$	$\sigma\left(Sm^{-1}\right)$	$\sigma\left(Sm^{-1}\right)$
Skin	1126.0	0.693	0.999
Muscle	1059.0	1.198	1.840
Nerve	1112.0	0.606	0.867
Cerebellum	1035.5	1.066	1.441
Tendon	1151.0	0.951	1.367
Blood	1057.0	1.868	2.283

3. 3 Data Analysis

This last stage of the methodology involved data analysis. Analysis of Variance (ANOVA) using SPSS software was employed. This was carried out on the calculated SAR values in section 3.2. Furthermore, in analysis of the calculated SAR values obtained, ANOVA was employed in order to check for differences of SAR in the states used as case study. ANOVA analyses were performed using post hoc Duncan method.

4.0 RESULTS AND DISCUSSION

A total of five base stations were considered for each GSM network in each state, which made a total of 120 base stations altogether. The average calculated SAR results from each of the states considered based on the electromagnetic field intensity measured were presented in Figure 4 to Figure 7. The results across the states show that the field diffused at highest rate to the blood tissue follow by the cerebellum tissue and at lowest rate into the nerve tissue. This implies that the blood tissue stands a greater risk and health defect if put under constant exposure to GSM radiation and field. Also, the overall analysis of the results show that the EMF radiation has relatively high adverse effect on the inner tissues of the body compare with the skin, which is an outer part of the body. In addition, the results show that MTN SAR's values are at the highest side while those of the Airtel are the lowest side. In between these two extremists are Glo and Etisalat with Glo values relatively higher than that of Etisalat. The overall result also shows that the SAR value for the tissues varies with GSM networks as well as the distances of observation from the base stations. However, with reference to Table 1 which shows ICNIRP limits guidelines for SAR exposure and Table 4, which shows the calculated minimum and maximum average SAR values obtained from the measurements carried out, it is obvious that none of the SAR values reach the limit of 0.08W/Kg, which shows that the radiations from mobile base stations in Nigeria currently has no environmental and biological adverse effects on those living within the distance measured during the study. From Table 4, the average minimum and maximum SAR values obtained from the study are 0.00025 W/Kg and 0.0023 W/Kg respectively, which are 0.3125% and 2.875% respectively of the ICNIRP SAR limits guidelines. This result shows that the maximum average calculated SAR value is about 3% of the reference level set by the International Commission on Non-Ionizing Radiation Protection recommended guidelines.

Table 4. Summary of maximum and minimum SARs for the various networks

Network	Minimum SAR (W/Kg)	Maximum SAR (W/Kg)
Airtel	0.000209	0.000899
MTN	0.000265	0.004908
Etisalat	0.000304	0.001858
Glo	0.000257	0.001671
Average	**0.00025875**	**0.002334**

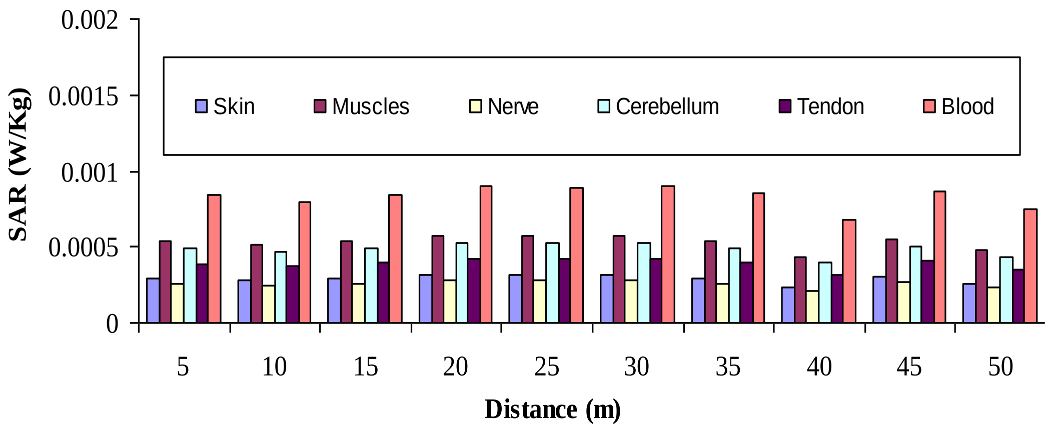

Figure 4. Average SAR value for Airtel network across all the States

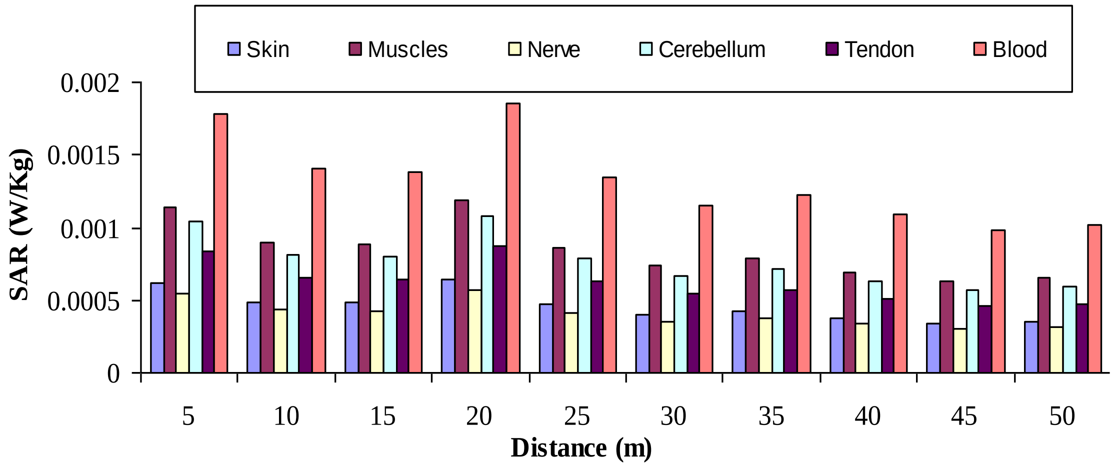

Figure 5. Average SAR value for Etisalat network across all the States

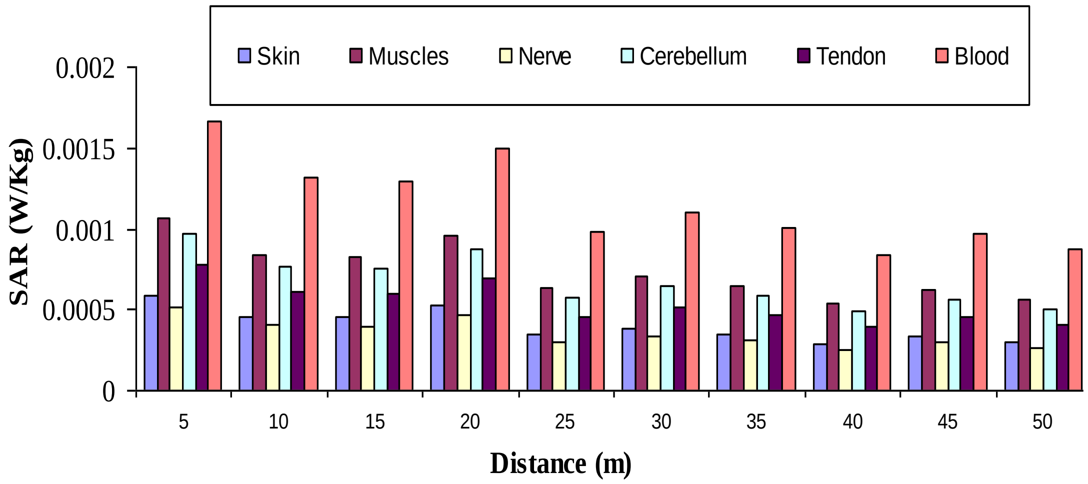

Figure 6. Average SAR value for Glo network across all the States

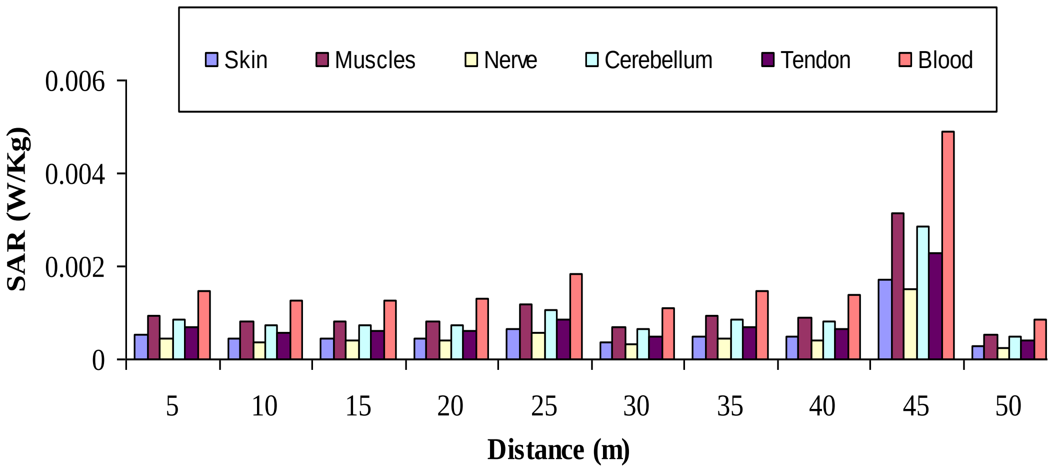

Figure 7. Average SAR value for MTN network across all the States

In order to further justify the findings of this study technically, the obtained SAR values across the states were further analysed using multivariate analysis and post hoc Duncan analysis. The results obtained as presented in Table 5 shows that there is significant difference between the SAR values and the distance of observation from the base stations. However, the multivariate test carried out shows that there is no significance variation on the obtained SAR values across the states. The results show that Glo has the highest SAR value in Ekiti, Ogun and Ondo states while MTN has the highest SAR value in Osun. Airtel was found to have the highest SAR value in Oyo state while Etisalat has the highest SAR value in Lagos state. The result thus shows that Glo telecommunication network has an averagely higher SAR value when compared with other networks. The multivariate test, as shown in Table 6, further shows that the SAR value varies from one state to another. In addition, the multivariate result of the study as shown in Table 7 shows that the SAR value varies with operating frequency of the GSM providers though without any significance effect.

Table 5: Multivariate Tests for Distances from the base stations across all the States

Multivariate Tests	**Pillai's Trace**			**Wilks' Lambda**		
	Value	**F**	**Sig.**	**Value**	**F**	**Sig.**
Ekiti State	.023	.487	.883	.977	.487	.883
Lagos State	.486	9.00	.883	.486	9.00	.883
Ogun State	.005	.116	.999	.995	.116	.999
Ondo State	.008	.180	.008	.992	.180	.008
Osun State	.033	.714	.033	.967	.714	.033
Oyo State	.044	.963	.044	.956	.963	.044

Table 6: Multivariate Tests for Networks across all the States

Multivariate Tests	**Pillai's Trace**			**Wilks' Lambda**		
	Value	**F**	**Sig.**	**Value**	**F**	**Sig.**
Ekiti State	.101	7.372	.000	.899	7.372	.000
Lagos State	.101	7.372	.000	.899	7.372	.000
Ogun State	.107	7.822	.000	.893	7.822	.000
Ondo State	3.142	3.000	.026	3.142	3.000	.026
Osun State	4.687[a]	3.000	.003	4.687[a]	3.000	.003
Oyo State	.057	3.957[a]	.009	.943	3.957[a]	.009

Table 7: Multivariate Tests for Frequency across all the States

Multivariate Tests	**Pillai's Trace**			**Wilks' Lambda**		
	Value	**F**	**Sig.**	**Value**	**F**	**Sig.**
Ekiti State	.219	37.081	.000	.781	37.081	.000
Lagos State	.527	221.451	.000	.473	221.451	.000
Ogun State	.584	278.510	.000	.416	278.510	.000
Ondo State	.262	70.411	.000	.738	70.411	.000
Osun State	.747	584.709	.000	.253	584.709	.000
Oyo State	.606	305.305	.000	.394	305.305	.000

Table 8: Result justification with related studies in Nigeria

Author(s)	Parameter employed	State where the study was conducted in Nigeria	GSM Network used	Conclusion
Shalangwa (2010)	Power density	Adamawa	Glo, MTN and Airtel*	No significant environmental or health effect
Enyinna & Avwir (2010)	Power density and SAR	Rivers	Glo, MTN, Airtel*, Zoom, Starcomm and NITEL	No significant environmental or health effect
Otitoloju et al. (2010)	Hematological biological indices	Lagos	Not specified	No significant environmental or health effect
Shalangwa et al. (2011)	Power density	Adamawa	Glo, MTN and Airtel*	No biological effect on human health
Ahaneku & Nzeako (2012)	Power density	Enugu	Not specified	No significant environmental or health effect
Iortile, Agba & Ujah (2013)	SAR	Benue	Glo and MTN	No significant environmental or health effect
Iortile & Alumuku (2014)	SAR	Benue	Glo and Airtel*	No significant environmental or health effect
Ojuh & Isabona (2015)	Power density	Edo	Glo, MTN and Airtel	No significant environmental or health effect
Ahaneku, Nzeako, & Udora (2015)	Power density	Enugu	Not specified	No significant environmental or health effect
Adejumobi et al. (2015)	SAR	Ogun	Glo, MTN, Airtel and Etisalat	No significant environmental effect
Popoola & Obafemi (2016)	SAR	Ekiti, Lagos, Ogun, Ondo, Osun and Oyo	Glo, MTN, Airtel and Etisalat	No significant environmental or health effect

*Airtel was called Zain in this study

The result obtained from this study was further justified by comparing it with results from similar studies in surveyed literature. The choice of the reference studies is based on the following criteria: (i) use of the same or almost the same network's base stations or masts. (ii) use of specified parameters to authenticate their respective conclusions. (iii) conduct of the reference study in Nigeria. However, the major difference between the study reported in this paper and most of the reference studies is the parameter employed. While most of the reference studies used power density, the study presented in this paper employed SAR. However, the justification of the conclusion of this study with those reference studies that used power density is based on the fact that SAR value employed was calculated from the power density obtained from field measurement conducted in each state or location considered in the study. The direct justification of the result of the present study with the reference studies in surveyed literature is presented in Table 8. On the basis of the available information in surveyed literature presented in Table 8 as well as the result of this study, it is established that there is no existence of any environmental or health hazard(s) from the radiation genrated from GSM base stations in Nigeria

5.0 CONCLUSION

From the field measurements conducted in the one hundred and twenty mobile base stations considered and the calculated SAR values for the six tissues (skin, muscles, nerve, cerebellum, tendon and blood), the minimum and maximum SAR values of 0.00025 W/Kg and 0.0023 W/Kg respectively were obtained. When theses values were compared with the standard guideline limit value of 0.08 W/Kg recommended by ICNIRP for the whole body, it was deduced that there is a no significant risk from radiation generated by mobile base stations on those living within the distance of 5 m to 50 m away from mobile base stations. However, it is important to note that an accumulation of these effects over a long period of time is not considered. But since all non-ionization radiation is accompanied with thermal effects, adequate precaution should be taken to prevent constant or regular exposure to GSM radiation.

The result of the study further shows that the GSM electromagnetic field diffuses into the body tissues at different rates. In addition, the overall analysis of the results show that the GSM radiation has relatively high adverse effect on the inner tissues of the body compare with the skin, which is an outer part of the body. Also, the overall result also shows that the SAR value for the tissues varies with GSM networks. Furthermore, it was found that there is significance variation on the obtained SAR values across the states.

The study also revealed that the SAR values vary with operating frequency of the providers. Furthermore, the result of this study as buttresses the finding of other related studies on the subject that electromagnetic radiation generated from GSM base stations in Nigeria has no significant environmental or health effect. Above all, since the overall minimum and maximum SAR values obtained from this study is significantly lower than the reference level or guideline limit SAR value recommended by ICNIRP, the study has established the fact that there is no technical evidence that electromagnetic radiation generated from GSM base stations in Nigeria has potential to cause any adverse effect on both human health and environment.

ACKNOWLEDGEMENT

The authors acknowledge the financial support received from Israel Obafemi and Frances Obafemi. The principal author also thanks Philip Oguntunde of Agricultural and Environmental Engineering, School of Engineering and Engineering Technology of the Federal University of Technology, Akure, Nigeria for proofreading the manuscript.

REFERENCES

Adejumbi, I. A., Orimolade, J. F. & Omotayo, B. A. (2015). Measurement and analysis of radio frequency energy and specific absorption rate from global system for mobile communications in FUNAAB, Ogun State, Nigeria. *Journal of Natural Science, Engineering and Technology*, 14(1): 117-126.

Ahaneku, M. A. & Nzeako, A. N. (2012). GSM base station radiation level: A case study of University of Nigeria environment. *International Journal of Scientific and Technology Research*, 1(8): 102-107.

Ahaneku, M. A., Nzeako, A. N. & Udora, N. N. (2015). Investigation of electromagnetic radiations by GSM base stations in Nigeria for compliance testing. *Advances in Physics Theories and Applications*, 47: 10-17.

Behari, J. (2010). Biological responses of mobile frequency exposure. *Indian Journal of Experimental Biology*, 48(10): 959-981.

Bhat, M. A. & Kumar, V. (2013). Calculation of SAR and measurement of temperature change of human head due to the mobile phone waves at frequencies 900 MHz and 1800 MHz. *Advance in Physics Theories and Applications*, 16: 54-63.

Buckus, R., Strukeinskiene, B. & Raistenskis, J. (2014). The assessment of electromagnetic field radiation exposure for mobile phone users. *Voinosanitetski Pregled*, 71(12): 1138-1143.

Enyinna, P. I. & Avwir, G. O. (2010). Characterization of the radiofrequency radiation potential of Alakahia and Choba communities, Nigeria. *FACTA UNIVERSITATIS*, 7(1)**:** 25-31.

Gandhi, O. P. (2002). Electromagnetic fields: Human safety Issues. Annual Review of Biomedical Engineering, 4: 211-234

Iortile, J. T., Agba, E. H. & Ujah, F. O. (2013). Impact assessment of radio frequencies field levels of some GSM base stations in Makurdi metropolis. International Journal of Natural Sciences Research, 1(3): 20-25.

Iortile, J. T. & Alumuku, L. (2014). A comparative study of radiofrequencies field levels of some base stations in Makurdi and its environs in Benue state, North Central Nigeria. International Journal of Natural Sciences Research, 2(3): 44-47.

Joseph, I., & Divine, O. O. (2015). Experimental assessment of specific absorption rate using measured electric field strength in Benson Idahosa University and environs. American Journal of Modern Physics, 4(2): 92-96.

Kargel, C. (2005). Infrared thermal imaging to measure local temperature rises caused by handheld mobile phones, IEEE Transaction on Instrumentation and Measurement, 54(4): 1513-1519.

Kwan-Hoong, N. (2003). Non-ionizing radiation – sources, biological effects, emissions and exposures, Proc. of the International Conference on Non-Ionizing Radiation, UNITEN, Malaysia, 1-16.

Martinez-Burdalo, M., Martin, A., Anguiano, M. & Villar, R. (2004). Comparison of FDTD-calculated specific absorption rate in adults and children when using a mobile phone at 900 and 1800 MHz, Physics in Medicine and Biology, 49(2): 345-354.

Mousa, A. (2011). Electromagnetic radiation measurements and safety issues of some cellular base station in Nablus, Journal of Engineering Science and Technology Review, 4(1): 35-42.

NCC (2016). Commercial Frequency Assignment Tables 900 MHz and 1800 MHz. Online: http://www.ncc.gov.ng/index.php?option=com_content&view= article&id= 84&Itemid=98. Accessed on April 8, 2016

Ojuh, O. D. & Isabona, J. (2015). Radio frequency EMF exposure due to GSM mobile phones base stations: measurements and analysis in Nigeria environment, Nigerian Journal of Technology, 34(4): 809-814.

Otitoloju, A. A., Osinkalu, V. O., Obe, I. A., Adewale, O. A. & Akinde, O. R. (2010). Level of radiofrequency (RF) radiations from GSM base stations and its biological effects on Albino Mice, Mus musculus. Journal of Applied Science Management, 14(3): 87-93.

Ozovehe, A., Usman, A. U. & Hamdallah, A. (2015). Electromagnetic radiation exposure from cellular base station: a concern for public health, Nigerian Journal of Technology, 34(2): 355-358.

Ozyalcin, M. O., Akleman, F. & Sevgi, L. (2002), SAR Simulations in Wireless Communication and Safety Discussions in the Society, Turkish Journal of Electrical Engineering and Computer Sciences, 10(2): 411-426.

Popoola, J. J., Ponnle, A. A. & Ale, T. O. (2011). Reliability worth assessment of electric power utility in Nigeria: residential customer survey result, Assumption University Journal of Technology, 14(3): 217-224.

Rahman, M. M. (2013). Mobile phone – A technical evaluation on electromagnetic exposure and specific absorption rate (SAR) for human safety, International Journal of Technology Enhancements and Emerging Engineering Research, 1(4): 106-115.

Santini, R., Santini, P., Danze, J. M., LeRuz, P. & Seigne., M. (2003). Survey study of people living in the vicinity of cellular phone base stations, Electromagnetic Biology and Medicine, 22(1): 41-49.

Shalangwa, D. A. (2010). Measurement of exposure of radio frequency field (RF) radiation from global system for mobile communication (GSM) masts, Journal of Electrical and Electronics Engineering Research, 2(3): 75-84.

Shalangwa, D. A., Vasira, P. G., & Shalangwa, D. (2011), Review of measurement of exposure of radio frequency field (RF) radiation from global system for mobile communication (GSM) masts, The Pacific Journal of Science and Technology, 12(1): 621-627.

Sharma, P., Gautam, A. K. & Kumar, S. (2014). Comparative assessment of SAR under different power density exposure for human eye for near field radiation of electromagnetic wave at wireless communication of 900 MHz and 1800 MHz frequency, Proc. of National Conference on Cloud Computing and Big Data, Bangalore, India, 23-26.