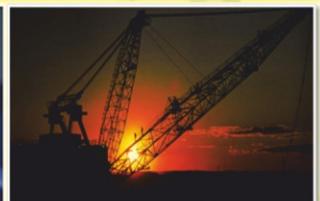


Journal of Engineering and Engineering Technology

ISSN 1598-0271



School of Engineering and Engineering Technology,
The Federal University of Technology, Akure, Nigeria





Assessment of Electromagnetic Radiation Effects and Safety Issues of GSM-900 and GSM-1800 Radio Frequencies – A Case Study of Akure, Nigeria

Popoola, J. J., Akinfenwa, D. O., and Animasahun, I. O.

Department of Electrical and Electronics Engineering, The Federal University of Technology, Akure, Nigeria

A B S T R A C T

Keywords:

Ionizing radiation,
Cellular network,
Cells,
Frequency Re-use,
GSM,
Base Stations

As users of mobile phone are geometrically increasing all over the world, the numbers of Global System for Mobile communications (GSM) base stations and operators are also growing, leading to increase in base stations distribution everywhere in the neighbourhood. This widespread of base stations has increased both the numbers of sources emitting electromagnetic fields, especially radio frequencies, and reactions concerns the effect of Radio Frequency (RF) radiated from GSM masts or antenna on human health. In order to investigate this health issue, measurement of RF emitted from four major GSM Operators' masts in Akure, Nigeria was conducted using RADEX RD1706 radiation monitor. The data measured were analysed and compared to international standards to scientifically establish possible adverse effect of RF radiation on human health. The result obtained shows that the average measured radiation values are approximately 0.002%, 0.0008% and 0.0003% of the standard safe values on the short-term, medium-term and long-term accumulated scales respectively, which implies that there is no convincing scientific evidence that the RF radiation from GSM networks may cause adverse health effects. In addition, the study shows that the radiation generated from the GSM masts or antenna is not directly proportional to the operating frequency.

1. Introduction

In wireless communication, transmissions of signals such as voice, data and images from the sending end to the receiving end require a medium. Radio spectrum is the primary medium for transmitting signals in wireless environment. It is divided into different portions called frequency bands. Each of these frequency bands has its own properties and characteristics which distinguishes them from each others as well as determining their specific application. However, irrespective of their application, whenever the radio spectrum is used for signal transmission, there is generation of electromagnetic radiation which can be ionizing or non-ionizing.

According to Mousa (2011), while ionizing radiation has enough energy to remove bound electrons from the orbit of an atom such that it becomes an ionized atom which can cause health hazard, the non-ionizing radiation does not have the sufficient energy to ionize the atom. This implies that while very high frequency, such as X-ray, are classified as ionizing radiation because of their strong ionization and penetration power, the electromagnetic radiation generated by RF transmitters, which includes radiation from the mobile phone transmitters, is classified as Non-Ionisation Radiation (NIR). Although the radiation from the mobile phone base stations is low, the concerns is

that there may be aggregated NIR levels generated by more than one base stations installed in close proximity in order to enhance high connectivity and reliable information transfer.

In Nigeria, like other parts of the world, the use of mobile phone commonly known as GSM has geometrically increased over the last decade. This increase has equally lead to increase in both the number of base stations and the amount of RF electromagnetic wave people are being exposed to on a daily basis with all sorts of mobile base stations installations and other wireless nodes around and within residential buildings (Agarwal et al., 2009). Thus, there is widespread concern on the potential adverse effects of mobile phones base stations radiation and their associated NIR. These potential effects on human health have stimulated the research community to define more precisely the physical properties of the radiation and to set the thresholds for their possible effects on human health and environment (Yavuz et al., 2008). Some studies conducted according to Iortile et al., (2014) showed that exposure levels of about 3 kHz - 5 MHz generates painful nerves impulses while exposure levels in ranges of gigahertz and megahertz leads to temperature rise of the body and changes in the cellular DeoxyriboNucleic Acid (DNA). Similarly, as previously reported in Agarwal et al., (2009), recent epidemiologic studies have highlighted the role of cell or mobile phone exposure on sperm motility, morphology and viability. The authors reported that cell phone use reduces male fertilization potential. Other known effects of NIR from the mobile phone revealed that exposure of developing

Correspondence:

E-mail address: jidejulius2001@gmail.com;
jjpopoola@futa.edu.ng

rodents to RF electromagnetic fields may lead to an impairment of brain cells depending on variables such as the target-specific absorption rate and the duration and frequency of electromagnetic field exposure (Chen et al., 2014).

However, some groups such as the International Commission on NIR protection and mobile manufacturer forum that manufactures mobile equipment and global systems for mobile communications operators across the world insist that there are no discernible effects from the RF radiated from mobile phone base stations (Shalangwa et al., 2011 and Shalangwa, 2010). Similarly, scientific studies on the possible adverse health effects from low level of RF radiation emanating from mobile phones and mobile base station have not been found to be hazardous even under long term exposure. This controversy on possible health effects has brought about the formation of a number of international and national regulations, standards and recommendations dealing with electromagnetic exposure in the RF range. With this controversy and the increasing numbers of mobile base stations and number of mobile users worldwide, the needed area of research now is not to review the standard level of permissible RF radiation but to scientifically confirm these positions. This motivated the study presented in this paper, which unlike most studies in this area brings in the concept of frequency allocation as a deterministic factor for level of radiation each base station generates.

The study has two primary objectives, which are; (i) to investigate and establish the relationship between the mobile phone frequency allocation and radiation generation, and (ii) to measure radiation from mobile phone base stations of the four main mobile phone providers in Nigeria and compare the obtained data with the standard values. This will help to determine whether the radiation generated from those mobile phones base stations in Nigeria have adverse effects on human health and environment or not. For sequential and logical presentation of the study, the rest of this paper is organized as follows. Section 2 presents brief review on both cellular network and GSM operating frequencies. Detailed information on the methodology employed in carrying out this study is presented in Section 3, while the results obtained are presented and discussed in Section 4. The paper is finally concluded in Section 5 with summary of findings.

2. Cellular Network

A cellular communication system is a mobile network that provides services by using large number of Base Stations (BSs), which maintains the communication between the network and the mobile users through a radio link. The BSs use limited power that covers only a limited area, called a cell. This limited power makes it possible to re-use the same frequency a few cells away from the base station without causing interference (Ahaneku and Chijindu, 2013). In this way, a large geographical area can be covered with only a limited set of frequencies.

The major feature of a cellular communication system is the ability to re-use frequencies to increase both its coverage and capacity. The concept of frequency re-use implies that limited spectrum allocated to the service can be partitioned into N non-overlapping channel sets, which are then assigned in a regular repeated pattern to a hexagonal cell

grid (Rahnema, 1993). The principle of frequency re-use in cellular communication system arises from the fact that each cell is assigned a group of channels, which needs to be properly plan to avoid degradation by co-channel interference.

The cell size determination is usually based on the local traffic distribution and demand (Rahnema, 1993). This implies that the size of a cell varies according to the number of users that are to be served as well as the amount of traffic per user. Hence, in urban areas where there are much traffic the cell size will be smaller than in rural areas where the traffic is relatively small. This means that the more the concentration of traffic demand in an area, the smaller the cell has to be sized in order to avail the frequency set to a smaller number of roaming subscribers and thus limit the call blocking probability within the cell (Rahnema, 1993). However, the smaller the cell is sized, the more equipment will be required in the system as each cell needs the necessary transceiver and switching equipment, known as the base station subsystem, through which the mobile users or terminals access the network over radio links (Adeniran, 2003). Hence, the degree to which the allocated frequency spectrum is being re-used over the cellular service area determines the spectrum efficiency in cellular communication system. This means that the smaller the cell size as well as the smaller the number of cells in the re-use geometry, the higher will be the spectrum usage efficiency.

The cells in cellular networks can be square, hexagonal, circular or any regular shapes. The conventional shape, as shown in Figure 1, is the hexagonal cells (Goldsmith, 2005). This is because the shape in those cells is laid next to each other without any overlapping, so that the signal propagation can cover the entire geographical region without any gaps. Thus, each of the cells is assigned with multiple frequencies, which have its own Base Station (BS). The BS at the centre of each group of cells functions as the hub for those cells. The elements that determine frequency re-use are the re-use distance, D, and the re-use factor (Ahaneku and Chijindu, 2013). The re-use distance, D, is the minimum separation of identical channels that have the same carrier frequency, at which there is acceptable interference. It is defined mathematically as (Ahaneku and Chijindu, 2013):

$$D = R\sqrt{3N} \tag{1}$$

where D is the minimum required distance (re-use distance) between any two co-channel cells in a cellular system, R is the radius of the hexagonal cell and N is the number of individual cells in a cell group or cluster size (Figure 1). However, the frequency re-use factor is the factor that defines the rate of re-using the radio resources. It is the reciprocal of cells which cannot use the same chunk of frequencies/channels for communication.

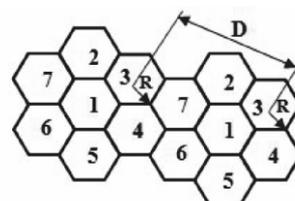


Figure 1: Hexagonal Cellular Structure illustrating Frequency Re-use Principle

The second generation of cellular mobile radio system is GSM. It was developed as a joint initiative by the members of the Conference of European Posts and Telecommunications (CEPT) administration (Adeniran, 2003). The aim of developing GSM was to build a unified Pan-European network as well as to give the users a near uniform service throughout all European countries. It comprises the CEPT defined standardization of the services, functional/subsystem interfaces, and protocol architecture, based on the use of worldwide standards produced by Consultative Committee for International Telephony and Telegraphy (CCITT) and Consultative Committee for International Radio (CCIR), for a Pan-European digital land mobile system primarily to serve users in motor vehicles (Popoola et al., 2009).

GSM consists of several transmitters, called the BSs. It provides terminal mobility with personal mobility provided through the insertion of a Subscriber Identity Module (SIM) into the mobile station or terminal (Rahnema, 1993). The personal number assigned to the mobile user or terminal is carried by the SIM. In operation mode, the RF signal transmitted by mobile terminal is received by the BS, where it will be re-transmitted from the BS to another mobile terminal. The transmitting and receiving are therefore done over slightly different frequencies.

The second generation (2G) GSM was first introduced in 1992 in Nigeria. The generation is the first cellular telephone technology to use digital encryption of conversations. It is also the first generation of GSM to offer data services and Short Message Service (SMS) for text messaging, but their data transfer rates are lower than those of their successors. The third generation, also known as 3G network, succeeded the 2G networks with faster data transfer rates and the first to enable video calls. This capability makes 3G networks suitable for use in modern smartphones, which require constant high-speed internet connection for many of their applications. The 4G, which is the fourth generation of mobile phone communications standards, is a successor of the 3G. It provides ultra-broadband internet access for mobile devices with high data transfer rates capability, which makes it suitable for use in Universal Serial Bus (USB) wireless modems for laptops and even home internet access.

Generally, there are five frequency bands designated by International Telecommunications Union (ITU) for the operation of the GSM mobile phone: GSM-400, GSM-850, GSM-900, GSM-1800, and GSM-1900 (Popoola et al., 2009). In Nigeria, GSM-900 and GSM-1800 are currently being used (Popoola et al., 2009). The radio channels are based on a Time Division Multiple Access (TDMA) structure that is implemented on Multiple Frequency sub-bands (TDMA/FDMA). Each base station is equipped with a certain number of these pre-assigned frequency/time channels. The TDMA structure is applied in both the forward (mobile station to the base transceiver or network station) and reverse (base transceiver or network station to mobile station) directions. On GSM-900, the forward or uplink direction uses 890 – 915 MHz while the reverse or downlink direction is on 935 – 960 MHz, providing 124 radio frequency channels spaced at 200 kHz and duplex spacing of 45 MHz. Also in Nigeria, according to Popoola et al. (2009), 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 at duplex spacing of 95 MHz. Full details on other GSM frequency bands in use across the world is shown in Table 1.

There are five major GSM Operators in Nigeria: Etisalat, MTel, Glo, MTN and Airtel. However, only four (Etisalat, Glo, MTN and Airtel) of them are currently in operation. Hence, this study is based on the radiation generated by these four GSM networks. The details on the methodology employed are presented in section 3.

3. Materials and Methods

The study presented in this paper was conducted in Akure, the capital of Ondo State, Nigeria. The city is situated in the South-Western part of Nigeria, on latitude 7.250°N and longitude 5.195° E to assess the impact of radiation generated from GSM masts/antenna on human and environment. Data for the study were obtained from both primary and secondary sources. While the primary data were obtained from radiation measurement carried out, internet was the source of the secondary data. In carrying out the radiation measurement activity, two materials or tools were used: radiation meter and a measuring tape. The radiation meter shown in Figure 2 was used to determine the non-ionizing radiation density at the GSM mast environment while the measuring tape was used to determine the distance of radiation measurement from the GSM mast. Radiation monitor (RADEX RD1706) was used in detecting and measuring the level of the non-ionizing radiation also referred to as irradiation.

Table 1: World-wide GSM Frequency Bands [Popoola et al. (2009)]

System	Band (MHz)	Uplink (MHz)	Downlink (MHz)
GSM-400	450	450.4 – 457.6	460.4 – 467.6
GSM-400	480	478.8 – 486.0	488.8 – 496.0
GSM-850	850	824.0 – 849.0	869.0 – 894.0
GSM-900	900	890.0 – 915.0	935.0 – 960.0
GSM-900	(E-GSM) 900	880.0 – 915.0	925.0 – 960.0
GSM-900	(R-GSM) 900	876.0 – 880.0	921.0 – 925.0
GSM-1800	1800	1710.0 – 1785.0	1805.0 – 1880.0
PCS-1900	1900	1850.0 – 1910.0	1930.0 – 1990.0



Figure 2: RADEX RD1706 Radiation Metre

The meter evaluates the radiation level by the magnitude of the ambient equivalent of exposure rate of gamma radiation, also known as dose rate, taking into account gamma radiation and the pollution of objects by sources of beta particles. The measurements were taken at ten different points, from 5 m to 50 m, from each mast as shown in Figure 3 so as to determine the radiation generated variation with distance. For each of the operators considered, measurements were taking at five of their respective masts. Secondary data used were gathered from the internet. The data obtained from the two sources were analysed and discussed.

4. Results and Discussions

4.1 Radiation Variation with Distance

The radiation pattern with distance obtained in the study for the four GSM base stations: MTN, Etisalat, Airtel and Glo are presented in Figure 4 (a) – (d) respectively. It is observed that the radiation patterns are similar for all the BSs. However, there are variations in the radiation levels at each distance as shown by the statistical analysis presented in Table 2. Also, it was observed that the radiations at the same distance but different BSs vary. For instance, MTN BS5 in Figure 4(a) seems to have the highest level of radiation when compared to the rest of the other MTN Bss. The same patterns are observed in Figures 4(b), 4(c) and 4(d). Although the radiation obtained vary at random, careful observation shows that it follows the inverse law of antenna radiated power, which states that the radiated power from an antenna is inversely proportional to the square of the distance from the antenna (Kolawole, 2009). In other words, the radiated power from any given antenna reduces as an observer moves farther away from the base station.

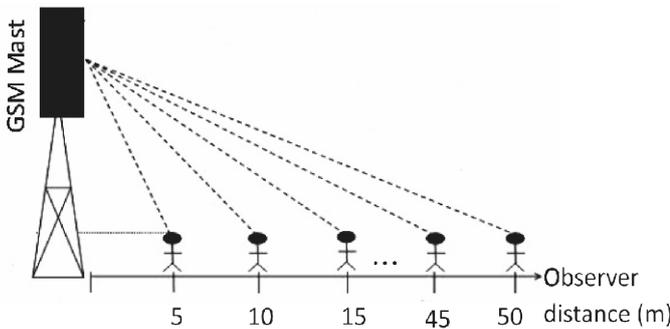


Figure 3: Radiation Measurement Procedure

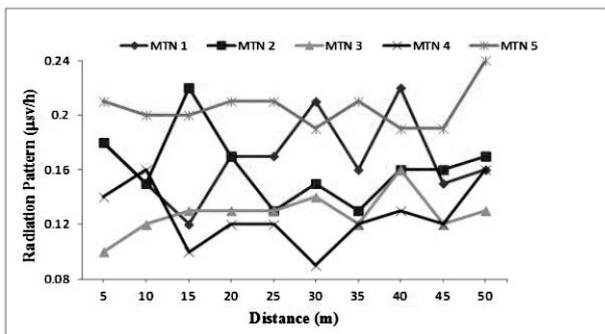


Figure 4(a): Radiation variation with Distance for MTN Service Provider

In addition, the obtained results are in agreement with a report presented in the Office of Utility Regulation (OUR) (OUR, 2005), that there are numbers of factors that contribute to why different BSs produce different radiation values. One of the reasons is as a result of differences in their transmitter powers. Since different GSM providers use different power levels based on the limitations specified by their wireless telegraphy license, this account for usage of different power from one BS to another depending on the configuration of their network so as to optimize their quality of service.

Another factor responsible for the variation in radiation pattern obtained in this study may be as a result of differences in the number of channels transmitting per time at a site. This is because in the process of performing at maximum capacity, both radiation power and radiation generated increased than under normal operating condition when the traffic on the BS is minimal. In addition, tilt and orientation of the antennas can have a significant effect on the measured field strength.

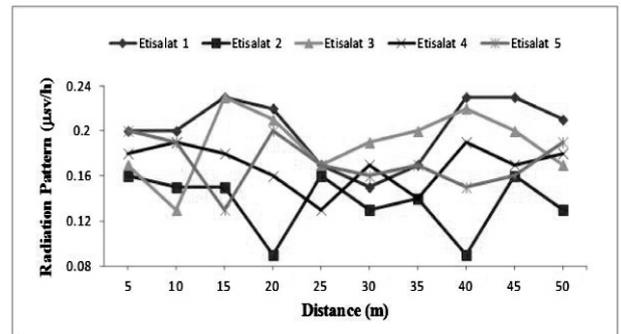


Figure 4(b): Radiation variation with Distance for Etisalat Service Provider

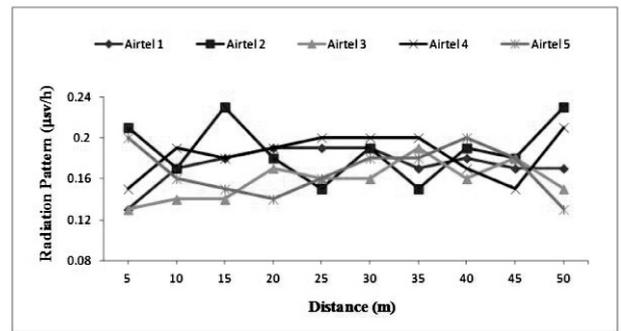


Figure 4(c): Radiation variation with Distance for Airtel Service Provider

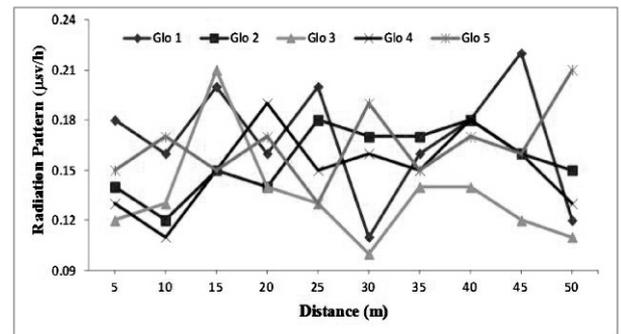


Figure 4(d): Radiation variation with Distance for Glo Service Provider

This is because antenna with high tilt will produce more power in the vicinity of the site than those with low tilt. Hence, in built-up areas, high antenna tilts are generally used by GSM operators to cover hot spots in the close neighborhood of the site.

For better analysis, the comparative radiation pattern with distance for the four GSM networks is presented pictorially in Figure 5. This result shows that the radiation levels obtained for the four GSM networks vary randomly. The overall comparative radiation pattern for the four GSM operators was also evaluated in order to determine which of the GSM operator radiates more NIR to the environment. The result, as shown in Figure 6, shows the radiation pattern for both Airtel and Etisalat are relatively higher while the radiation pattern for Glo is the lowest and radiation pattern for MTN falls between Airtel and Etisalat as a subset and between Glo another subset.

Furthermore, Figure 6 shows variation in the radiation generated by each of the GSM operator. Critical observation of the total radiations obtained from the four GSM networks, when compare with the frequency allocated to each of the GSM operator presented in Table 3, shows that there is no direct relationship between the overall radiation generated by each GSM network and the operation frequency

operator by the Nigerian Communications Commission (NCC). As presented in Table 3, it is observed that the same bandwidths: 5 MHz for GSM-900 and 15 MHz for GSM1800, were allocated to all the four GSM operators in Nigeria but the frequency bands allocation are quite different. For GSM-900 and GSM-1800, the overall result of the radiation measurements conducted shows that the radiation generated by each GSM network is not directed proportional to the allocated frequency. This accounts for the result why Etisalat with the low downlink or transmitter operating frequency band (935 – 940 MHz) in Table 3 generates the highest radiation when comparing with Glo with the high downlink or transmitter operating frequency band (945 – 950 MHz) for GSM-900 MHz. However, for GSM-1800 in Table 2, the result shows that as the downlink or transmitter operating frequency is increasing the radiation generates is also increasing as shown in Figure 6. Thus, it can be inferred from the result of this study that the radiation generated by GSM mast or BS is not directly proportional to the operation frequency but varies with the usage level of each network per time. This implies that the traffic level on the GSM mast or BS determines the radiation level it will generate and not the operational allocated frequency.

Table 2: Measured Average Radiation Pattern Exposure

Observing Distance (m)	Measured Average Radiation Pattern Exposure ($\mu\text{Sv/h}$)			
	MTN	Glo	Etisalat	Airtel
5.0	0.162±0.001 ^d	0.144±0.003 ^b	0.182±0.004 ^d	0.164±0.005 ^a
10.0	0.156±0.003 ^{bc}	0.138±0.002 ^a	0.172±0.002 ^c	0.166±0.002 ^a
15.0	0.154±0.001 ^{bc}	0.172±0.002 ^f	0.184±0.001 ^d	0.176±0.003 ^{bad}
20.0	0.161±0.004 ^d	0.161±0.004 ^{dc}	0.176±0.003 ^c	0.174±0.004 ^{bc}
25.0	0.152±0.004 ^{ab}	0.158±0.004 ^{cd}	0.16±0.002 ^a	0.172±0.002 ^b
30.0	0.156±0.002 ^c	0.146±0.003 ^b	0.16±0.002 ^a	0.184±0.003 ^c
35.0	0.148±0.001 ^a	0.154±0.002 ^c	0.164±0.002 ^b	0.178±0.002 ^{cd}
40.0	0.172±0.002 ^e	0.17±0.002 ^f	0.176±0.001 ^c	0.18±0.003 ^{dc}
45.0	0.148±0.002 ^a	0.164±0.001 ^c	0.184±0.002 ^d	0.172±0.002 ^b
50.0	0.172±0.002 ^e	0.144±0.003 ^b	0.176±0.003 ^c	0.178±0.002 ^{cd}

Table 3: 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
MTel	895 - 900	940 - 945	1710 - 1725	1805 - 1820
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

Table 4: Simplified Hourly Dosage Radiation Rates in Sv/h and mSv/h [(Shoebridge, 2012)]

mSv/h	µSv/h	Health Risk
10,000	10,000,000	Organ failure and death within hours
1,000	1,000,000	Severe: Vomiting/1:20 risk of cancer
100	100,000	Severe: Radiation poisoning
1	1,000	High danger: Evacuate immediately
0.1	100	High danger: Heightened sickness risk
0.02	20	High danger: Sickness risk
0.01	10	Danger: Relocate now
0.005	5	Elevated risk: Relocate as soon as possible
0.002	2	Elevated risk: Take safety precautions
0.001	1	Safe: Short-term habitation only
0.0005	0.5	Safe: Medium to long term habitation
0.00020	0.20	Safe: Long-term habitation (normal levels)

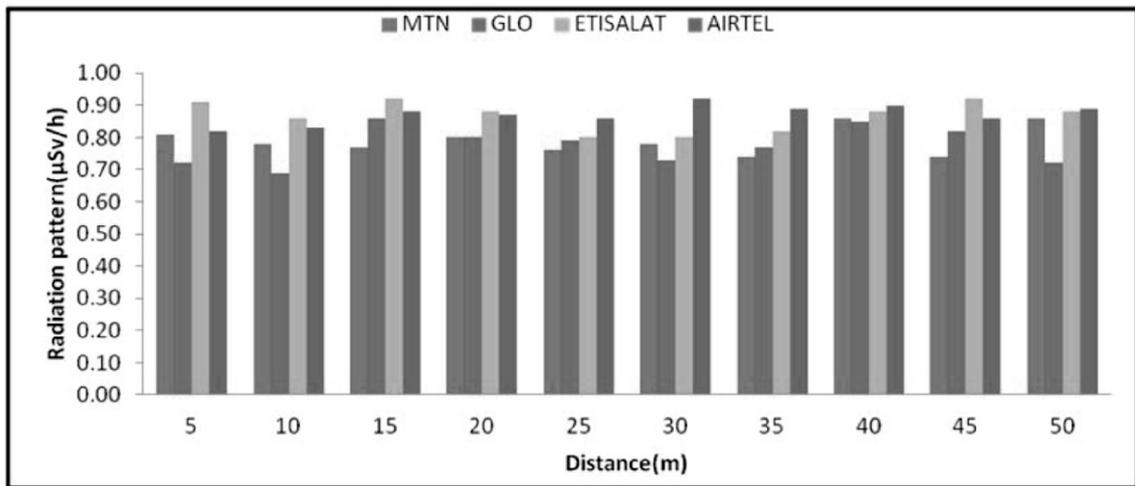


Figure 5: Average Comparative Radiation with Distance for the Four GSM Operators

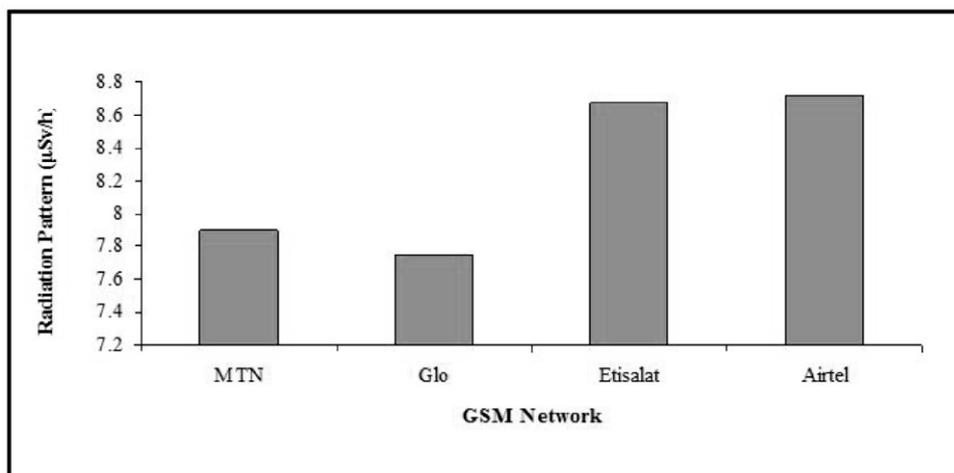


Figure 6: Comparative Radiation Pattern for the Four GSM Operators

4.2 Radiation Effect on Human Health

The statistical analysis of the level of radiation exposure obtained during measurement is presented in Table 2. The analysis result shows that the obtained radiation exposures for the four GSM operators are statistically correlated. Similarly, a simplified hourly

dosage radiation rate obtained from the internet is shown in Table 4. Comparing the statistical measure average radiation exposure shown in Table 2 with the simplified hourly dosage radiation rate in Table 4, it shows that despite the fact that some GSM masts are erected within residential compounds in the studied area, the levels of radiation

from those BSs is still below the minimum recommended safety limit. The comparative study shows that the average measured radiation value is only 0.00165% of the standard value on a short-term scale. Similarly, the comparative study shows that the average measured radiation values are only 0.000825% and 0.00033% of the standard values on a medium-term and long-term scales respectively. The result therefore shows that even under long term or accumulated effects of the radiation generated by GSM masts may not cause any adverse effect on human health. Based on the measurement result, it is obvious that BSs radiation from the four GSM operators in the studied area are well below the international exposure limits and may have no adverse effect on human health and environment. The result therefore shows that there is no convincing scientific evidence that the RF radiation from GSM networks cause adverse health effects. The result also buttress the conclusion made in the study reported in Dasdag et al., (2014) that 900 MHz RF radiation did not have adverse effect on the enamel micro hardness of rats' teeth.

5. Conclusion

In this study, measurement of electromagnetic radiation from four GSM Operators around the city of Akure was carried out in twenty different BSs sites located across the city. The data obtained were analysed and compared to some international standard values. The result obtained shows that the measured value is less than 0.002% of the standard value on a short-term scale. Based on this finding, it is obvious that there is no convincing scientific evidence that the RF radiation from GSM networks may cause adverse effects on human health. Also the result of the study shows that the RF radiation generated from the GSM mast or BS has no direct relationship with the allocated operational frequency.

References

- Adeniran, Y.A. (2003). Two years of GSM services in Nigeria: Issues and Challenges, Paper presented at the Quarterly Lecture Series of the Nigerian Society of Engineers, Minna Branch, at Shiroro Hydroelectric Power Station, Shiroro.1-12. Online [Available]: <https://www.unilorin.edu.ng/publications/adediranya/Two%20Years%20of%20GSM%20Services%20in%20Nigeria%20Issues%20and%20Challenges.pdf>. Accessed on April 2, 2015.
- Agarwal, A., Desai, N.R., Makker, K., Varghese, A. Mouradi, R., Sabanegh, E., and Sharma, R. (2009). Effects of radiofrequency electromagnetic waves (RF-EMW) from cellular phones on human ejaculated semen: an in vitro pilot study, *Fertility and Sterility Journal*, 92(4),1318-1325.
- Ahaneku, M.A., and Chijindu, V.C. (2013). Frequency re-use and the implications of limited network resources in cellular mobile systems, *Global Advanced Research Journal of Engineering, Technology and Innovation*, 2(6),167-172.
- Chen, C., Ma, Q., Liu, C., Deng, P., Zhu, G., Zhang, L., He, M., Lu, Y., Duan, W., Pei, L., Li, M., Yu, Z., and Zhou, Z. (2014). Exposure to 1800 MHz radiofrequency radiation impairs neurite outgrowth of embryonic neural stem cells, *Scientific Reports*, 4,1-10.
- Dasdag, S., Yavuz, I., Bakkal, M., and Kargul, B. (2014). Effect of Long Term 900 MHz Radiofrequency Radiation on Enamel Microhardness of Rat's Teeth, *Journal of Oral Health and Management (OHDM)*, 13(3),749-752.
- Goldsmith, A. (2005). Wireless communication, Cambridge University Press, 1st Edition, New York, 674pp.
- Iortile, J.T., and Agba, E.H. (2014). Assessment of radiofrequency radiation distribution around mobile base stations in Makurdi, Benue State, *International Journal of Natural Sciences Research*, 2(1),1-4.
- 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 February 23, 2016.
- OUR (2005). Audit of Emissions from Radio Mast in Guernsey: Report and Information, 1-2. Online [Available]: http://www.cicra.gg/_files/OUR%200505R.pdf. Accessed on April 14, 2015.
- Popoola, J.J., Megbowon, I.O., and Adeloje, V.S.A. (2009). Performance evaluation and improvement on quality of service of Global System for Mobile Communications in Nigeria, *Journal of Information Technology Impact*, 9(2),91-106.
- Rahnema, M. (1993). Overview of the GSM System and Protocol Architecture, *IEEE Communications Magazine*, 31(4),92-100.
- Yavuz, I., Akdag, M.Z., Dasdag, S., Ulku, S. Z., and Akkus, Z. (2008). Influences of extremely low frequency magnetic fields on mineral and trace elements content of rat teeth, *African Journal of Biotechnology*, 7,3811-3816.
- 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., and 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.
- Shoebridge, G. (2012). Really Simple Guide to Radiation Levels in Sv/h and mSv/h. Online [Available]: <http://www.gavinshoebridge.com/news/basic-guide-to-radiation-levels-in-%C2%B5svh-and-msvh/>. Accessed on April 10, 2015.