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Research Article

Assessment of Radiofrequency Exposure Levels in a University Campus in South-western Nigeria

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ABSTRACT
Objective: This study examines the level of radiofrequency exposure measured in a university campus in South-western Nigeria.
Methods: The study locations were grouped into three: Hostel, Lecture Rooms/Offices and the base of mobile phone telecommunication mast. Measurements were carried out using Electrosmog (TES-92 Electrosmog, Anhui, China (Mainland)).
Results: Results of mean radiofrequency power densities (S) of hostels range between 42.9 and 217.6 $\mu W/cm^2$ and the corresponding electric field strengths (H) range between 100.6 and 325.4 mV/m. The range of mean power density measured in the classrooms/offices of Faculty of Sciences complex is 2.3 (Basement) and 106.9 $\mu W/cm^2$ (2nd floor) with the mean value of 32.5 $\mu W/cm^2$. Meanwhile, the corresponding mean value of electric field strength measured is 204.1 mV/m. In addition, the mean power density and electric field strength measured at a distance of 1-2 m from the base station perimeter fence is 4.7 $\mu W/cm^2$ and 231.4 mV/m respectively. The mean values of measured power densities at Ajayi Crowther University fall within the acceptable limit of 1.2mW/cm^2 for antenna operating in the 1800-2000 MHz range and antenna operating at 900 MHz (0.57 mW/cm^2) as recommended by IEEE and America National Standard Institute-ANSI). Correspondingly, the mean electric field strengths fall below the restriction and reference levels of 5 V/m.
Conclusions: Both mean power densities and electric field strengths recorded in this study are below the restriction and reference levels indicating that RFR exposures are within the acceptable limit and do not pose any danger to the public health.

INTRODUCTION

Electromagnetic waves (e-m) are generated by accelerating or oscillating charges. They are transverse in nature and travel through space at the speed of light. This family of waves are disturbances in a field rather than in a medium. When electromagnetic waves encounter a material medium, they can interact with it and transfer energy to the medium. An electromagnetic wave such as radio waves and x-rays possess energy which is characterized by its frequency (f) and wavelength (λ). The frequency range of 0.5 MHz – 100 GHz consists of all the frequencies that serve as significant sources of medical, occupational and public exposures. Examples include: radiofrequency heater and sealer, AM, FM, cell phones, amateur radio, UHF and VHF television, telecommunication and traffic control radar.[1]

Radiofrequency waves occupy the frequency range of 3 kHz and 300 GHz. Microwaves are specific category of radio waves that cover the frequency range of 1 GHz to approximately 100 GHz. Although radiofrequency range (RFR) has a wide application, it has attendant effects on human health. The effects of RFR are of major concern to the general public all over the world.[2] Literature review has shown that thermal changes appear to account for all of the reported behavioural effects of microwaves radiation absorption in the frequency range of 300 MHz to 300 GHz.[1,3]

Mode of Interaction of Radiofrequency with a Biological System

It is evident that radio and microwaves fields have the tendencies of causing changes in biological materials by applying forces to the constituents or by changing the energy states of their constituent molecules and ions.[4,5] Maxwell equations expressed in the form shown in equations (1) to (4) describe the nature of non-ionising radiation and its interaction with biological material.

$$\nabla x H = J + \frac{\partial D}{\partial t}, \quad (1)$$

$$\nabla x E = -\frac{\partial B}{\partial t}, \quad (2)$$

$$D = \epsilon_0 E + P, \quad (3)$$

and

$$B = \mu_o (H + M), \quad (4)$$

Where E is the electric field, H is the magnetic field, D and B are the electric and magnetic displacement vectors, E_o and μ_o are the dielectric constant and magnetic permeability for the free space, P and M are the electric and magnetic polarizabilities and J is current density.
By carrying out some vector algebra and integrating over the volume to obtain Poynting'sTheorem for the power flow into or out of volume, we get.[6]

$$-\int(ExH).ds = \int_v \left[J.E + \frac{\partial}{\partial t}\left(\frac{\epsilon_o}{2}E\right) + \frac{\partial}{\partial t}\left(\frac{\mu_o}{2}H.H\right) + E.\frac{\partial P}{\partial t} + \mu_o H.\frac{\partial \mu}{\partial t}\right] dv \quad (5)$$

where ds is the element of surface surrounding the volume v. The equation gives a picture of separation of power dissipated by the flow of free charges in the $J.E$ term from that dissipated by the motion of bound charges as depicted by $E.\delta p/\delta t$ term
In biological materials, the dominant conduction mechanism is by the transport of ions. At low and moderate electric fields, the current density is given by

$$J = \sigma E = qn\mu^l \mathrm{E} \quad (6)$$

where n is the carrier density and μ^l is the mobility.

Both microwaves and radiowaves affect biological materials. This is observed when biological tissues are heated. The two mechanisms are (1) induced current density (ion motion) power is dissipated in the tissue by this source (2) loss through damping of the dipole moments which may be associated either with the molecules or with larger bodies such as cells or block of tissues. The rate of energy loss in a biological system due to ion motion and damping of dipole moment could be represented by equations (7) and (8) respectively.

$$P_{2J} = \frac{J^2}{2\sigma} \quad (7)$$

where P_{2J} is the rate of energy loss due to ion motion, σ is the conductivity of the medium

$$P_{2D} = \frac{w-\epsilon^{ll}}{2}|E|^2 \quad (8)$$

where $E(t)$ is defined as $E(t) = Ecos\ wt$ and w is the angular frequency. Equations (7) and (8) can be measured by estimating the rate of temperature rise in the biological system. The temperature rise could be determined by balancing the rate at which it flows to the tissue with the rate at which energy flows out. Generally, heat energy is transferred away from biological tissue, where it is absorbed by conduction, convection and radiation. However, in a biological system, conduction is the dominant heat transfer mechanism and is by ions transport. In such a biological system, the rate of change of temperature can be expressed as

$$\frac{\partial T}{\partial t} = \frac{P_2}{\rho c} - \frac{T-T_o}{\tau} \quad (9)$$

where T is the temperature, and T_o is the initial temperature, t is time, P_2 is the power absorbed, t is the thermal time, ρ is the density, and c is the specific heat capacity of the medium. The thermal time constant τ is dependent on the geometry of the medium.

For short pulses, all the losses can be neglected, such that the change in temperature may be expressed as

$$\Delta T = \frac{P_2 t}{\rho c} \quad (10)$$

The temperature rise could lead to changes in chemical reaction rates, fluid velocity, thermal conductivity, diffusion coefficient, conductivity and dielectric constant.[4] A biochemical reaction rate is the most important of these changes arising from temperature rise. These changes in biochemical reaction rates can in turns affect a large number of biological functions.

Asides, the magnitude of temperature change, the rate of temperature dT- rise can induce current flow across membranes, thus leading to the firing rates of nerve cells. Other effects are changes in growth rate, increase in metabolism and sweating.

Other effects of high frequency field are seen in the alignment of molecules as measured by changes in birefringence in liquid containing long chain molecules and in the formation of pearl chains. Shift in birefringence of blood plasma upon the application of slowly varying electric fields in the range of $3x10^3$ and 2×10^4 Vm^{-1} has been observed.[4] Another aspect of orientation phenomenon is the conductivity of a liquid containing a long chain polymers which become anisotropic if large fields are applied.

In addition, there is a time dependence of conductivity of those field associated with the time that it takes to orient the long chain molecules and the change in the distribution of ions and large molecules. With an applied field, long chain molecules are expected to be oriented at random. However, upon the application of a significant field, these particles are either rotated or distorted with the reduction of conductivity in one direction and an increase in the other.

Earlier Studies on Health Effects of RFR

Except for a study in which rats showed questionable increase in endocrine cancers [7] and acceleration of cancer development in mice,[8] RFR-induced cancer has not been reliably shown in medical surveillance studies [9] that investigated the question systematically did not show an excess in any form of cancer that could be interpreted as microwave related.[10] It is also clear from investigation that low intensities of microwaves can modify behaviour. Radiofrequency energy absorption can influence behavioural thermoregulation.[11]

Literature contains much evidence that absorption of microwave energy has led to behavioural changes in man and laboratory animals. The changes include simple perturbation or outright stoppage of on-going behaviour. Extreme absorption of microwave can result in seizures followed by death.[3] Some researchers have shown behavioural effects during chronic exposures to low- level microwave frequency, but controversy exists over threshold and mechanism of action. In all cases, however, behavioural disruptions ceases when chronic microwave exposure is terminated. Thermal changes in man and animal during microwaves exposure appear to account for all reported behavioural effects.

Other Studies on Health Effect of RFR

In the recent times, there are has been rapid growth in the telecommunication industries that use RFR (service provider of cell phone communication). Medical effects of application of RFR in modern world in telecommunication and other related fields have generated a great deal of debates and controversies. Concerns about this issue stem from the fact that new technology are often made available without providing the necessary background information about their nature and health effects on the users (public).

The possible harmful effects on human health are not adequately discussed in academic circles.[12] However, in an investigation carried out on 1000 patients in Germany, it was concluded that the proportion of newly developing cancer case was significantly higher among the patients who lived up to ten years at a distance of 400 m from cell phone base station as compared to patients who lived farther away.[13]

Similar study carried out in a different part of Germany involving 575 inhabitants showed statistically significant increase of the cancer incidence within 400 m radius of a base station five years after it was sited.[14]

In Australia, a study involving self-declared base station neighbours (DBS $\leq$ 100 m) shows that people who rated the distance from their home to the next base station as 100 m or less had higher scores in psychological strain scales with significantly higher concentrations of alpha amylase in their saliva; they also experienced obsessive-compulsive anxiety, and so on. The mean power density measured in rooms of persons rating DBS 100 m or less for GSM-900 MHz and GSM-1800 MHz was 856.75μWm^{-2} for DBS $\leq$ 100 m was 223.80 μWm^{-2}.[15] In addition, Hutter et al. [16] indicate a significant relationship between observed symptoms and measured power density. He also showed that the average power density measured in rural area within a radius of 24-60 m was 0.05 mWm^{-2}, and in urban areas within 20-250 m from the base stations the power density measured was 0.02 Wm^{-2}.

As mobile phone finds its way into global market, there are greater concerns of the host communities on the danger posed by telephone masts and base stations sited near the living quarters. Earlier studies have extensively discussed the possible effects of RFR on human health.[17-20] As a result of the increase in the use of RF in mobile communications, it is pertinent to understand the level of RFR exposure in a community such as a University campus. This study aims at assessing the level of radiofrequency radiation exposures at Ajayi Crowther University, Oyo.

MATERIALS AND METHODS

The Study Site

The study was conducted at Ajayi Crowther University, Oyo. The private University is located along Ogbomosho-Ilorin Road. The study examined power density (S) and electric field strength (H) of some offices and student hostels within the premises of Ajayi Crowther University. The measurement was carried out using Electrosmog meter. The data were collected from hostel rooms, staff offices, and lecture rooms as well as beside a base station (measured at distance of 1m and 2m).

Description of Electrosmog Meter

An electrosmog meter is a portable device designed for safe measurement of electromagnetic field characteristics by isotropic method. The device is equipped with 3- channel sensor which allows measurement simultaneously on X,Y,Z axes. The device can be used to measure the radiation produced by wireless communications (CW, CDMA, DECT, GSM), radio stations, wireless Wi-Fi, microwaves, televisions and monitors, hidden signal sources and other sources of high frequency electromagnetic radiation. It has frequency range of 50MHz to 3.5GHz, and it is used for isotropic measurements of electromagnetic fields. Electrosmog has non-directional measurements capability with three-channel measurement probe. It has high dynamic range due to three- channel digital results processing, configurable alarm threshold and memory functions. This equipment measures RFR in terms of power density, S ($Wm^{-2}$and the associated electric field strength, H (Vm-1) in TEM cells and absorber rooms. Both of these parameters were measured simultaneously during this investigation.

The Electrosmog used in this study was factory calibrated and the calibration was still valid at the time the measurement was carried out. This equipment was obtained from Radiation and Health Physics Laboratory, Department of Physics, University of Ibadan.

At high frequency, the power density is of particular interest because it provides a measure of the power absorbed by a person exposed to the field. This power level must be kept as low as possible at high frequency. Elecrosmog is used to ensure that public/workers are not exposed to high level of e-m radiations by taking regular measurements. Measurements were taking at different locations (at least three points within a room) on the same floor of buildings investigated (depending on the length of the floor or width). The Electrosmog used for the measurement was kept at a height of about 1.5m from the floor during measurement of radiofrequency radiation (RFR). Data collected were analysed using descriptive and inferential statistics. An attempt was made to compare the mean electric field strengths and power densities measured using one way analysis of variance (ANOVA) at confidence interval (CI) of 95%.

RESULTS

The following are the results of power density (S) and field strength (H) obtained and recorded during the measurement of the level of RFR exposures.

The result of power densities (S) and electric fields (H) are shown in Tables 1-3. Results shown in Table1 are those of measurement carried out at the University Female Hostel (UFH). The results indicate that the mean and range of power density and the corresponding electric field strength are 42.9 (10.8-70.2) $\mu W\ cm^{-2}$ and 100.6 (47.1-143.3) mV/m respectively. The results in Table 2 of mean and range of power density (S) and electric field strength (H) are 217.6 (88.3-417.5) $\mu\ W\ cm^{-2}$ and 221.8 (108.9-403.6) mV/m respectively for the four floors of Joseph Adetiloye Hall (JAH-male hostel). Results of Lagos male hostel (LMH) are shown in Table 3. The results indicate that the mean power density and the range are194.3 (117.9-339.9) $\mu W\ cm^{-2}$ and the mean electric field strength measured was 325.4 (240.4-339.9) mV/m. Table 4 is the result of Diocese of Lagos West female hostel (LWDF). The mean power density of the hostel was 141.2 (9.1-327.9) µ W cm-2 and the corresponding electric field strength was 173.0 (16.2-382.4) mV/m.

Additionally, the value of power density shown in Table 5 and 6 were measured at the Faculty of Natural Sciences (FNS-32.5 µ W cm^{-2} or 0.0325 mW cm^{-2}), and at about 1-2 metres away from the bottom of the mobile telephone base station (4.7 µ W cm^{-2} or 0.0047 m W cm^{-2}).The mean electric field strength and the corresponding range measured in the Faculty of Natural Sciences are shown in Tables 5 as 204.1 (1.1- 482.3) mV/m. The results in Table 6 are the mean electric field strength measured at a distance of between 1- 2 m from the perimeter iron fence of telephone base station in the campus is 231.4 mV/m.

Figures 1 and 2 show results of mean and standard deviations of Electric field strength measured in each hall of residence and a faculty complex.

Table 1: Power density and electric field strength at University Female Hostel- UFH- three floors [Hall of Residence]

Parameters Measured	Power density (µW/cm²)		Electric field Strength (mV/m)	
Floor	Mean	Range	Mean	Range
Ground Floor	47.7± 23.39	0.007 - 111.7	143.3± 40.92	10.3-233.5
First Floor	10.8 ± 5.71	0.3 - 29.3	111.4±54.64	26.5-297-1
Second Floor	70.2 ± 38.79	0.9 - 193.2	47.1±12.23	16.1-84.4
Mean±SEM	42.9 ± 17.3	10.8 - 70.2	100.6 ± 28.3	47.1-143.3

SEM = Standard Error of Mean

Table 2: Power density and electric field strength at Joseph Adetiloye Hall-JAH- four floors [Hall of Residence]

Parameters Measured	Power density (µW/cm²)		Electric field Strength (mV/m)	
Floor	Mean	Range	Mean	Range
Ground Floor	234.4±42.81	98.2 - 332.4	258.9 ±80.70	0.4 - 421.4
First Floor	88.3±62.62	0.4 - 302.4	108.9 ±85.90	4.8 - 406.4
Second Floor	417.5 ±147.26	55.6 - 710.2	403.6 ± 87.06	164.5 - 636.3
Third Floor	130.1± 110. 45	3.0 - 512.7	115.9 ± 98.63	1.6 – 457.6
Mean± SEM	217.6 ±73.40	88.3 - 417.5	221.8 ± 69.80	108.9 – 403.6

SEM= Standard Error of Mean

Table 3: Power density and Electric Field strength of Lagos Hostel (Male Hostel) LHM -Three Floors [Hall of Residence]

Parameters Measured	Power density (µW/cm²)		Electric field Strength (mV/m)	
Floor	Mean	Range	Mean	Range
Ground Floor	117.9 ±45.832	2.3 - 228.5	240.4±64.95	82.5 - 414.6
First Floor	339.9 ±144.41	1.4 - 725.4	470.5±110.95	209.6 - 818.5
Second Floor	125.1± 68.14	1.3 - 256.3	265.3±77.40	75.5- 468.1
Mean (SEM)	194.3 ±72.90	117.9 - 339.9	325.4 ±51.60	240.4 - 470.5

SEM= Standard Error of Mean

Table 4: Power density and Electric Field Strength of Diocese of Lagos West (Female Hostel)-LWDF (Four Floors) [Hall of Residence]

Parameters Measured	Power density (µW/cm²)		Electric field Strength (mV/m)	
Floor	Mean	Range	Mean	Range
Ground Floor	18.2 ± 13.62	0.1- 65.1	16.2 ± 9.21	1.7- 47.8
First Floor	9.5 ± 4.28	0.5-19.3	45.3± 17.07	14.7-102.2
Second Floor	209.6 ± 105.19	0.004 - 506.2	271.2 ± 97.83	15.6 - 517.9
Third Floor	327.9 ± 143.83	61.2 -778.9	382.4 ± 76.78	147.1 -572.8
Mean ± SEM	141.2 ±77.50	9.1- 327.90	173.0 ±91.70	16.2-382.4

SEM= Standard Error of Mean

Table 5: Power Density and Electric Field Strength of Faculty of Natural Sciences- FNS (Five Floors) [Offices and Lecture Rooms]

Parameters Measured	Power density (µW/cm²)		Electric field Strength(mV/m)	
Floor	Mean	Range	Mean	Range
Basement	2.3 ± 0.71	1.3-3.3	337.0 ±237.44	1.2-672.8
FNLT*	1.6	–	1.1	–
Ground Floor	11.7± 5.87	1.5-42.1	118.9 ± 57.7	81.9-293.5
First Floor	40.0 ± 37.01	1.9-114.0	81.2 ± 64.81	1.7-237.0
Second Floor	97.2 ± 67.29	1.1-287.5	482.3 ± 185.62	1.7-905.6
Mean± SEM	32.5± 19.90	1.6-106.9	204.1±89.05	1.1-482.3

* FNLT =Faculty of Natural Sciences Lecture Theatre (located beside the Basement)
SEM= Standard Error of Mean

Table 6: Power density and Electric field strength at different distances from the base station-BSA- within University Campus (Side A)

Parameters Measured	Power density (µW/cm²)		Electric field Strength (mV/m)	
Distance From Base Station(m)	Mean ± SEM	Range	Mean ±SEM	Range
		Side A		
1	6.0 ±1.98	2.1 – 12.4	1.2±0.11	1.0 – 1.6
2	3.3±0.61	2.2 – 5.3	1.3± 0.19	1.0 – 936.6
Mean	4.7	–	1.25	–
		Side B		
1	22.3 ± 5.42	7.5-35.8	2.9 ± 0.63	1.1-4.3
2	35.2 ± 7.91	20.4-58.1	3.7± 0.37	2.5-4.5
Mean	28.8	–	3.3	--

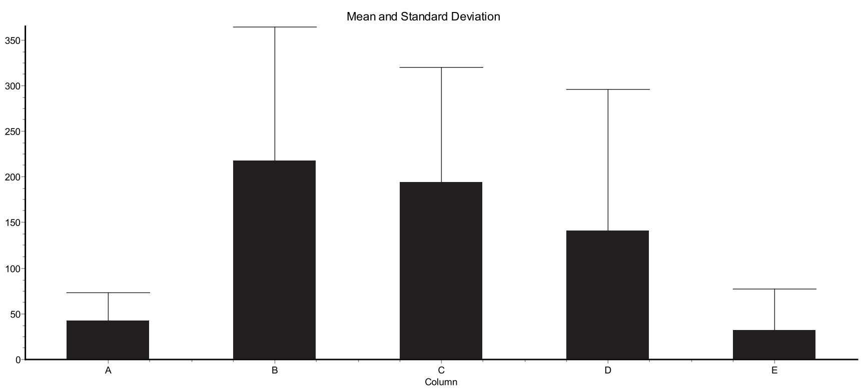

Figure 1: Power density (µW/cm²) for UHF(A), JAH (B), LHM (C), LWDF (D) and FNS (E

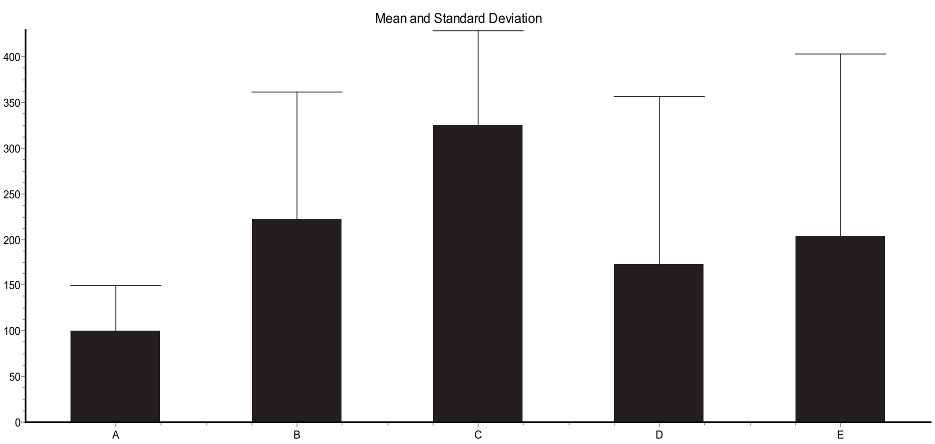

Figure 2: Electric field strength (mV/m) for UHF(A), JAH (B) LHM (C), and LWDF (D) and FNS (E)

DISCUSSION

Among the four halls of residence examined, the one where the highest mean power density of 217.6 μW cm^{-2} (0.217 m W cm-2) was recorded was JAH. This could be attributed to the proximity of the hostel to some base station in the neighbourhood. However, the mean value of power density obtained in JAH fall within the acceptable safe limit of exposure recommended by the Institute of Electrical and Electronics Engineer (IEEE) and American National standard Institute (ANSI) for general public (1.2 mW cm^{-2}) for antenna operating in the 1800- 2000 MHz range. This also falls below the limits for the antenna operating in 900 MHz range - 0.57 mW cm^{-2}.[21]

The results in Tables 5 and 6 (for FNS and a Base Station) are also within the safe limit of 1.2 mW cm-2 or 0.057 mW cm-2 recommended by the regulatory bodies. The results presented in this study show that power densities measured at Ajayi Crowther University (ACU) fall within the acceptable safe limit. The results of the present study are lower than the earlier investigation carried out in Nigeria [22] at a distance of 200 m radius from a base station (1.32 mWcm^{-2}).

Earlier studies carried out reported some symptom resulting from the power density of 1100 μWm^2 at a distance of 150 m radius of the base station. The symptoms recorded include fatigue, irritability, headache, and nausea. Another study carried out showed that there was an association between irritability, depression, dizziness, tiredness and living within 100-300 m radius of the base station.[23] The study suggested that a residential apartment should be sited at a minimum distance of 300 m (0.3 km) radius away from a base station. It is important that Nigerian Nuclear regulatory Authority (NNRA) and Nigerian Communication Commission (NCC) should both prevent erection of telephone base stations near a residential area through legislation.

The results of the present study (for both halls of residence and FNS offices) are well below the basic restriction level for all tissues of head and body (occupational exposure-0.8 V/m, and general public-0.4V/m). The mean values of the electric field fall within the reference level (occupational exposure and general exposure of 5kV/m).[24] There are no significant differences in mean electric field strengths and power densities measured among the halls of residence investigated in this study.

This study indicates that the campus environment is within the acceptable RF exposure safety limits. This implies that the RF exposure level within Ajayi Crowther University does not pose any danger to the campus community.

CONCLUSION

In this study radiofrequency exposure levels were measured in four different halls of residence (two males and two females) and in the Faculty of Natural Sciences complex at Ajayi Crowther University, Oyo. Results obtained fall within the acceptable safety and restriction limits recommended by International Regulatory bodies.

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