TITLE OF ARTICLE

Investigating the Specific Absorption Rate of Four Mobile Phones in Nigeria for Compliance with Electromagnetic Compatibility (EMC) Standard

AUTHORS

MAIN AUTHOR: Enoh F. Akpojotor

AFFILIATION: Department of Computer Engineering, School of Engineering, Delta State Polytechnic, Otefe, Oghara, Delta State.

EMAIL: speak2faustina@yahoo.com

PHONE NUMBER: **+2348035397247**

CO-AUTHOR

Onoriode Oyiborhoro

AFFILIATION: Department of Biochemistry, Faculty of Basic Medical Sciences, University of Medical Sciences, Ondo City, Ondo State, Nigeria.

EMAILS: doconos2013@gmail.com; ooyiborhoro@unimed.edu.ng

PHONE NUMBER: +2348168257357

CORRESPONDING AUTHOR: Onoriode Oyiborhoro

EMAILS: doconos2013@gmail.com; ooyiborhoro@unimed.edu.ng

ADDRESS: Department of Biochemistry, University of Medical Sciences, Ondo City, Ondo State, Nigeria.

Investigating the Specific Absorption Rate of Four Mobile Phones in Nigeria for Compliance with Electromagnetic Compatibility (EMC) Standard

Enoh F. Akpojotor and Onoriode Oyiborhoro

Abstract

The widespread use of mobile phones has initiated research regarding the possible adverse effects of exposures to radiofrequency radiation (RFR). Poor implementation of laws aimed at regulating the import and sale of sub-standard mobile phones in developing countries results in the proliferation of products that are potentially non-compliant with laws on electromagnetic compatibility (EMC) standards. Consequently, individuals in these countries are potentially exposed to dangerous levels of electromagnetic radiations emitted from fake mobile phones. In the present study we measured the electromagnetic field (EMF) strengths of four mobile phones in Nigeria, including Itel 1409, Tecno T349, Nokia T05 and Gretel A80, at distances of 0 cm, 2 cm, 4 cm, 6 cm, 8 cm, 12 cm and farthest distances away from a TM-192 Tri-axial Magnetic Field Meter, where there were no longer detectable changes in magnetic field strength readings and determine their Specific Absorption Rates (SARs) for compliance with the recommended maximum of 2.0 W/kg. Results revealed average EMF strengths of 1.04 ± 0.250 μT, 3.32 ± 0.677 μT, 3.15 ± 0.451 μT and 5.73 ± 0.997 μT at 0 cm from the magnetic field meter; and SAR values of 0.769 W/kg, 7.846 W/kg, 7.063 W/kg and 23.373 W/kg for Itel 1409, Tecno T349, Nokia 105 and Gretel A80, respectively. Investigations also revealed that SAR values were quoted in the operation manual of Itel 1409 and TecnoT349 but none for Nokia 105 and Gretel A80 mobile phones, suggesting that these phones might be sub-standard. Results of this study suggest that only the Itel 1409 mobile phone met the recommended SAR of 2.0 W/kg maximum and that majority of the cheap phones in Nigeria such as Nokia 105 do not meet the required EMC standards on SAR hence, might be causing more harm than good, with regards to the potential health hazards associated with excessively high levels of electromagnetic radiations.

Key Words*:* Electromagnetic Fields, Mobile Phones, Specific Absorption Rates, Tenmars Triaxial Magnetic Field Meter

1. INTRODUCTION

The rapid advancement in the field of telecommunication within the last few decades has led to the introduction of highly sophisticated electronic communication gadgets, including multi-functional mobile phones into the global market. Although these powerful electronic devices have greatly improved the ease of communication and dissemination of information across the so called "global village", they however, have presented the world with a new set of challenges.

For example, widespread availability of these mobile phones have encouraged the development of several social media platforms, including Facebook, WhatsApp, Twitter and Instagram, through which various news items, including fake news, are rapidly disseminated.

Enoh F. Akpojotor is an Assistant Lecturer in the Department of Computer Engineering, Delta State Polytechnic, Otefe-Oghara, Delta State, Nigeria. Email: speak2faustina@yahoo.com

Onoriode Oyiborhoro is a Lecturer in the Department of Biochemistry, Faculty of Basic Medical Sciences, University of Medical sciences, Ondo City, Ondo State, Nigeria.
Email: ooyiborhoro@unimed.edu.ng; doconos2013@gmail.com,

Apart from dissemination of fake news, these platforms are also often used by fraudsters to defraud the unsuspecting and gullible public, including foreigners of their valuables. This is in addition to the global problem of terrorism, which has become widespread, since the advent of these sophisticated mobile devices and social platforms.

Beyond the negative social impact of powerful mobile phones, there is also the potential damaging health effects associated with use of these 21st century devices. For example, the WHO's International Agency for Research in Cancer had observed in May, 2011 that electromagnetic fields generated during prolonged use of mobile phones could potentially increase the risk of developing brain tumors (WHO, 2014). This finding is in consonance with previous observations of Shalagwa *et al.* (2011), which reported that the advancement of mobile phone technology and consequent increase in the electromagnetic radiations emitted from them has become a public health issue of great concern. Several other studies have also opined that the electromagnetic radiations emitted from television and radio stations, computers, radars, microwave ovens and Wifi-based systems have the potential of negatively affecting human health (Shalagwa *et al.* 2011). A few studies however, have attempted to counter this claim by suggesting that product standardization, mode of use and adherence to guidelines and instructions are factors that determine the public health safety of mobile phones and similar electronic devices (Akbal *et al.* 2012). These arguments and counter-arguments suggest that the negative health effects of electromagnetic radiations emitted from mobile phones can be greatly minimized, when properly used and all safety guidelines and instructions from regulatory bodies and manufacturers are strictly adhered to (Agarwal *et al.* 2011).

Consequently, the International Commission on Non-ionizing Radiation Protection (ICNIRP) had specified that mobile phones are legally limited to a specific absorption rate (SAR) of 2.0 W/kg and expects all manufacturers of mobile phones to comply with this limit (ICNIRP, 1998). In line with this guideline, Agarwal *et al.* (2011) has observed that most of the mobile phones currently in use have SARs of approximately 1.4 W/kg and are therefore unlikely to ionize atoms. The SAR is defined as the rate at which energy or heat is absorbed by tissues of the body. It is usually expressed in watts per kilogram (W/kg) or milliwatts per gram (mW/g). Experimentally, SAR is defined as the time rate of change of energy transferred to particles in an infinitesimal volume at a particular point, divided by the mass of the infinitesimal volume. (Iortile and Agba, 2014).

The limit of exposure to electromagnetic radiation is usually defined in terms of SAR, since it is closely related to biological impact. In order to simplify testing of mobile phones for compliance with regulatory guidelines, results of SAR are usually converted into external field levels and power densities which can be easily measured. Consequently, international and national standards provide exposure limits in terms of power density S (W/m^2) or electric field strength E (V/m) and magnetic field strength H (A/m). At far-field where the radiation becomes a plane wave, power density can be evaluated from field strengths and the relationship between power density and electric field strength is described by the equation: $\mathbf{S} = \frac{1\, Re(E \times H)}{2}$

Where *E* is the electric field intensity in (V/m), *H* is the magnetic field intensity (A/m). *Zo* is the characteristic impedance of free space and is equal to 377 Ohms.

However, this equation does not hold for the near-field, where the relationship between the fields is no longer linear. Hence, E and H are determined independently. E and H can be determined practically at about 10 m from the base station, and the measurement of the electric field strength is sufficient to get other limits which are frequency dependent. Since electromagnetic field is frequency dependent, exposure limits must also be frequency dependent. To evaluate the contribution by the radio frequency field exposure from base station antennae, frequency-selective measurement must be employed.

The second method for specific absorption rate (SAR) determination is to measure the electric field inside the body with implantable electric field probes and then calculate the SAR, using the equation:

$$\mathbf{SAR} = \frac{\sigma|E|^2}{\rho} \quad \mathbf{W/kg}$$

Where σ is the tissue conductivity (S/m), E is the electric field strength induced in the tissue (V/m) and ϱ is the mass density (kg/m^3).

This method is suitable only for measuring SAR at specific points in the body and for low values of SAR where the absorbed energy is insufficient to cause a detectable change in temperature. Instrumentation for this type of SAR measurement usually includes an implantable electric field probe, a phantom and a computer controlled system for positioning the probe. The SAR depends on the incident fields intensity (or equivalent power density), tissue properties, geometry, size, orientation of the exposed object, frequency of the incident fields, and exposure time. In the far field region of an electromagnetic wave, transmitted power density is given by the equation:

$$\mathbf{St} = \frac{PtG}{4\pi R^2}$$

Where P is the power radiated by the antenna in watts (w), *G* is the antenna gain with no units, *R* is the effective distance from the antenna to the receiver in meters (m)

Power density is defined as the power per unit area normal to the direction of propagation. Due to the simple relationship between the electric and magnetic fields in this region, the power density can be expressed based on electric field only, through the characteristic impedance:

$$\mathbf{S} = EH = \frac{E^2}{Zo} = \frac{E^2}{377}$$

Where E and H denote the electric and magnetic fields respectively and Zo represents the characteristic impedance.

The possible biological effects arising from the use of mobile phones can be considered to result from energy absorbed by the head, which may affect the brain and tissues of the nervous system. The radio frequency (RF) fields emitted from mobile phones penetrate the exposed tissues producing heat. This thermal effect can cause harm by increasing body temperature, and damaging biological tissues, particularly those of the head and brain. The depth to which radio waves penetrate exposed tissues depends on the frequency of the source, and the electrical properties of the tissue. It is given as $\boldsymbol{\delta} = \sqrt{(\frac{1}{\pi\mu\sigma f})}$

Where δ is the penetration depth (m), μ is the tissue magnetic permeability (H/m), σ is the tissue electric conductivity (S/m), and f is the RF of the source (Hz).

In some developing countries like Nigeria, laws on electromagnetic compatibility (EMC) standard are either non-existent or not strictly adhered to. There is therefore a high possibility of importing mobile phones without EMC certifications into such countries, with consequent negative health implications. The mere labeling of such sub-standard phones with low SAR of less than 2.0 W/kg usually does not translate into lower SAR in the real world, as a result of widespread corruption in these countries. For example, the influx of so-called "China Phones" into the Nigerian market connoted low quality and cheap products that were specifically manufactured for developing countries.

Furthermore, it is believed that electromagnetic radiations emitted under conditions of low network signal from mobile phones usually increase above the standard, yet, such low network signal strengths are prevalent in Nigeria and most other countries of Africa. Finally, as mobile phones age and depreciate, their emission rates increase. The high poverty rate in developing countries translates into a huge number of very old and obsolete phones in circulation. The aim of the current study therefore is to measure the electromagnetic field strengths and power densities of selected mobile phones at varying distances from the phones and determine their SAR values and consequent compliance with electromagnetic compatibility standards.

2. MATERIALS AND METHODS

Four different brands of GSM phones, including Itel 1409, Tecno T349, Nokia T05 and Gretel A80 (Plates 1 and 2) were purchased from an open market (Oba Market) in Benin City, Edo State, Nigeria. The Itel 1409 phone is a dual Subscriber Identity Module (SIM) phone, with SARs of 0.506 W/kg and 0.704 W/kg for head and body tissues, respectively, as indicated in its manual. The Tecno T349 also uses dual SIM cards, with SARs of 1.154 W/kg and 1.184 W/kg for head and body tissues, respectively, also indicated on the user's manual. The Nokia T05 and Gretel A80 are single and dual SIM card phones, respectively, with both phones lacking any information on their SARs, both on their user's manual and websites.

A magnetic field meter (Tenmars Triaxial Magnetic Field Meter), TM-192D (Plate 2) was also purchased from Test Meter Group Ltd, United Kingdom and used for measuring electromagnetic field strengths of mobile phones. The Tenmars Triaxial Magnetic Field Meter is capable of measuring electromagnetic radiations of extremely low frequencies (ELF) of 30 Hz to 2000 Hz, generated around transmission equipment, power lines, microwave ovens, air conditioners, refrigerators, computer monitors, audio and video devices. The meter can also test a wide range of magnetic fields with ELF, using three internal inductor orthogonal sensors that are independent of measurement angles. These sensors are aligned at right to one another, thereby allowing simultaneous recording of three single axis readings, which can either be displayed independently or combined to give a single result. The instrument is cost effective, hand-held and has the following function keys, as shown in plate 2(left): data hold (HOLD) key, maximum hold and minimum hold (MAX/MIN) key, auto range or manual range select mode key, power ON/OFF key, SET key, RANGE key, record (REC) key, READ key and Gauss or Telsa (G/T) key. It also has time and calendar functions, low battery indicator, overload display and a memory size of 500 datasets. The unit of measurement of magnetic field is the Telsa (T) or Gauss (G), where 1T = 10,000 G.

2.1 Procedure for Measurement of Electromagnetic Radiation

A 9 V dry cell battery was purchased and inserted into the magnetic field meter. Meter was powered on and the G/T button pressed to select micro-Telsa (μT) as unit of measurement. Following selection of unit of measurement, all memory of any previous data was cleared by continuously pressing the 'SET' key, until it reaches mode 5, where all previous data memory are cleared (Plate 3). Next, the 'REC' key was pressed in order to clear all data logger memory for previous records and store up the new set up. After clearing the meter of all previous data and data logger memory, the 'SET' key was continuously pressed again until mode 3 was displayed on the screen (Plate 4). This sets the data logging unit for continuous acquisition of new data during the current experiment. The length of time (in hours, minutes or seconds) used for continuous data acquisition can be displayed on the screen by pressing the 'READ' key, which displays readings as HH: MM: SS. Similarly, readings recorded can be displayed in either Gauss (G) or Telsa (T) by pressing the 'G/T' key which changes the measurements between Gauss and Telsa units, whether for hourly, minutes or seconds readings. This function can also be performed using the 'RANGE' key. In the present study, electromagnetic radiation was measured and recorded in Telsa (T) units.

After complete data acquisition, the 'enter' key was pressed to stop operation, after which readings were recorded. The default reading displayed by the TM-192D Triaxial Magnetic Field Meter is triaxial total magnetic field radiation, not the independent three single-axis magnetic field radiation. However, the individual single-axis magnetic field reading for the y, z and x - axes can also be displayed by pressing the 'enter' key, which alternates the readings displayed on the screen between independent y, z or x – axis magnetic field readings and Triaxial total magnetic field reading. Tests were performed at different locations, including rooms with minimal electronics, in order to avoid interference by emissions from electronic gadgets. Most tests were also carried out at night time, when there was minimal human interference. All phones were connected with the Global Communication (GLOBACOM) Subscriber Identity Module (SIM) cards and experiments carried out initially with phones placed at a distance of 5 mm away from the Triaxial Magnetic Field Meter. This was followed by further experiments with phones placed at distances ranging between 0 cm and 12 cm and at 'farthest' distances away from the Triaxial Magnetic Field Meter, where there was no longer detectable changes in magnetic field strength readings.

The experiments carried out with phones placed at a distance of 5 mm from the Triaxial Magnetic Field Meter were done when phones were not engaged in active calls. Further readings obtained at distances of between 0 cm and 12 cm and 'farthest' distances were obtained while phones were actively engaged in making calls. Maximum magnetic field strengths for the x, y and z axes of the meter were taken and averaged for the different phones under study. Readings were taken weekly for a total period of 12 weeks for each of the phones studied and results recorded in micro-Telsa (μT). Calls were made for durations lasting between 6 and 8 seconds with no conversation and no pick up of calls. The minimum distances of 5mm and 0cm range were considered because they represented distances where the most effect of radiation is usually felt by the head or head tissues. A total of 19 to 20 readings were recorded for each brand of mobile phone during this study.

2.2 Estimation of Localized Specific Absorption Rate (SAR) and Standard Body Tissue Dielectric Parameters

The localized SAR of a body tissue is estimated at a point on the tissue and not the whole human body. Localized SAR is related to the internal electric field by the equation:

$$\textbf{SAR} = \frac{S}{\rho} \qquad \textbf{W/kg}$$

$$\textbf{SAR} = \frac{\sigma|E|^2}{\rho} \qquad \textbf{W/kg}$$

Where S is the absorbed power density in watts per square meter (W/m^2)
$\boldsymbol{\sigma}$ is the conductivity of brain tissue in per Ohms per meter ($\Omega^{-1}m^{-1}$)
$\boldsymbol{\rho}$ is the mass density of the human brain in kilograms per square meter (kg/m^2). For a given transmitting frequency, $\boldsymbol{\sigma}$ and $\boldsymbol{\rho}$ are obtained using the standard values given below:

Human brain tissue dielectric parameters

Tissue	**Mass Density (kg/m^2**	**Radius (cm)**	**Specific Heat (J/K.kg)**	**900 MHz**		**1900 MHz**	
				Dielectric Constant	**Conductivity 0 (S/m)**	**Dielectric constant Er**	**Conductivity 0 (S/m)**
Skin	1010	9.00	3662	40.7	0.65	37.21	1.25
Fact	920	8.90	2378	10.0	0.17	9.38	0.26
Bone	1810	8.76	1590	20.9	0.33	16.40	0.45
Brain	1040	8.10	3640	41.1	0.86	43.22	1.29

Frequency (MHz)	**Conductivity (o) (ʊ 1m-1)**	**Mass density (omd) (Kg/m3)**

900	0.7665	1030
1800	1.1531	1030
2100	1.3102	1030

The specific allowable absorption rate SAR value over the body at any 6 minute period is 0.08W/kg and that for the head is 2W/kg (ICNIRP Guidelines, 1998).

The velocity of propagation of electromagnetic waves through human tissue is lower than that in free space, since the impedance of tissues is low, compared with that of free space.

The impedance of the human head tissues (η) can be determined by the formula: $\eta = \eta_o\sqrt{(\frac{\mu r}{\varepsilon r})}$ Where ηo is the free-space impedance **(ηo=Zo = 377Ω).**

The power density (S), the medium impedance (η), the electric field strength (E), and the magnetic field strength (H) are related by the equation: $S = \frac{E^2}{\eta} = H^2.\eta$

2.3 Data Analysis

The Itel 1409 android phone with SAR of less than one was taken as a standard against which the SARs of other phones were analyzed, using Graph Pad Prism, version 8. Data are presented as mean ± SEM and statistically significant differences between Itel 1409 and other individual phones were calculated using one way ANOVA, followed by Brown-Forsythe test, where $P \leq 0.05$ was considered statistically significant.

3. RESULTS

ISSN 2229-5518

Plate 1: Photographs of NOKIA T05, GRETEL A80, TECNO T349 and ITEL 1409

Plate 2: Photographs of Tenmars Triaxial Magnetic Field Meter (alone and when in use)

Plate 3: Photograph of 'All Memory Clear' to Clear All Previous Data Memory

Plate 4: Photograph of 'Data Logging Screen' For Continuous New Data Acquisition

3.1 Total Magnetic Field Strengths of ITEL 1409, TECNO T349, NOKIA T05 and GRETEL A80 at 5 mm from a Triaxial Magnetic Field Meter (When Phones Were Not Engaged)

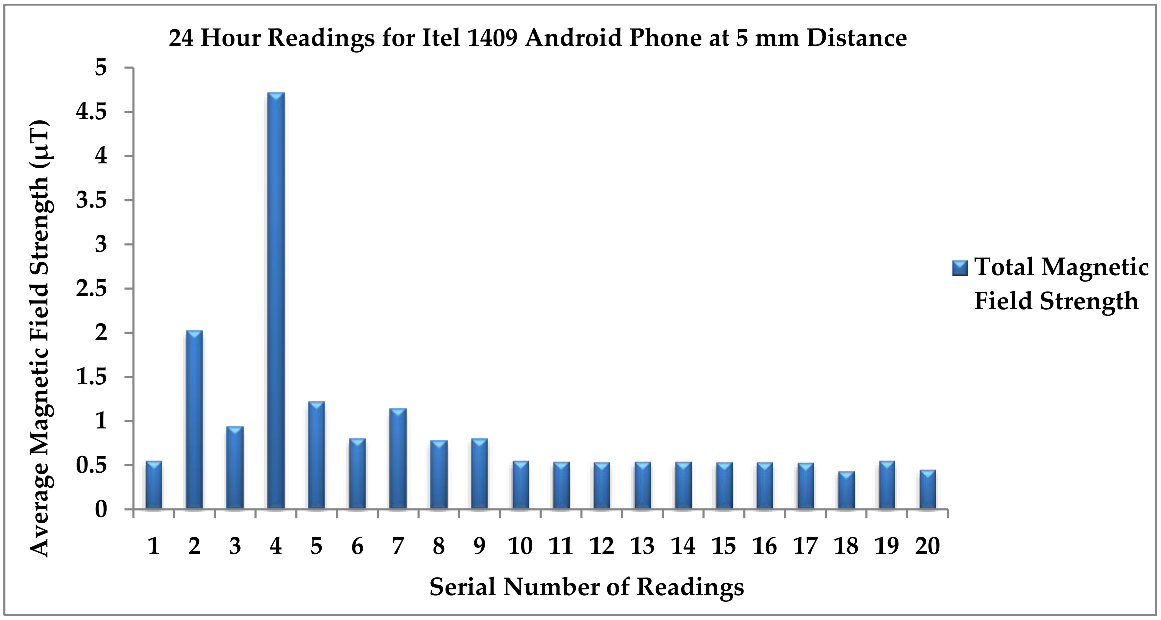

Figure 1: 24 Hour Magnetic Field Strengths (μT) for Itel 1409 Android Phone at 5 mm Distance.
Mean = 1.04 ± 0.250

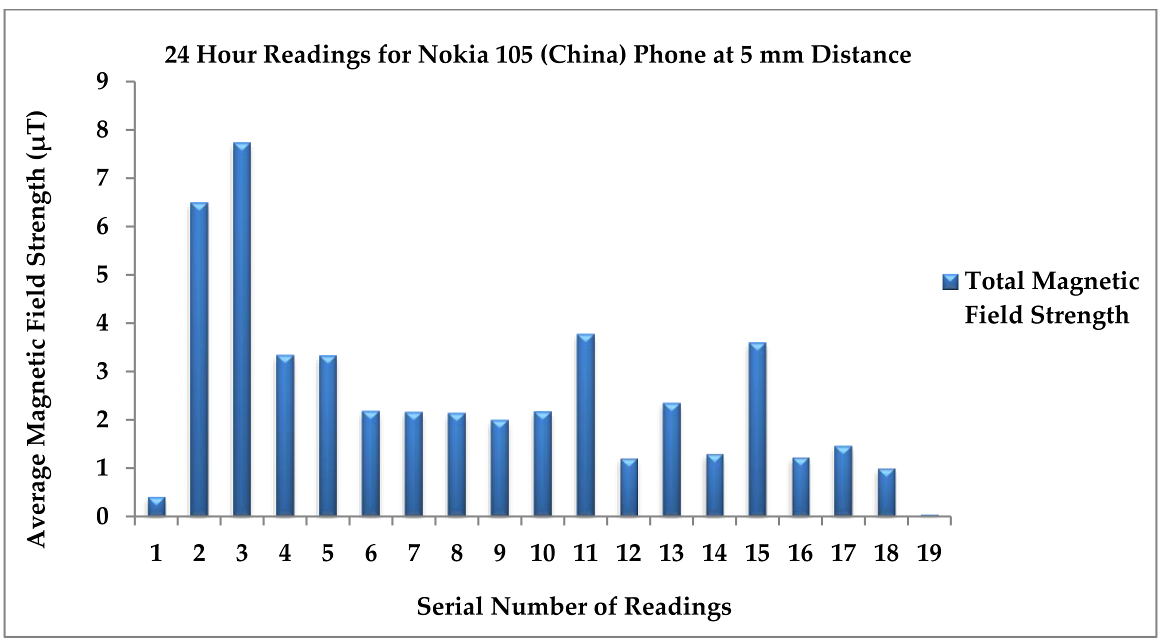

Figure 2: 24 Hour Magnetic Field Strengths (μT) for Nokia 105 (China) Phone at 5 mm Distance.
$P < 0.05$; Mean = 3.15 ± 0.451

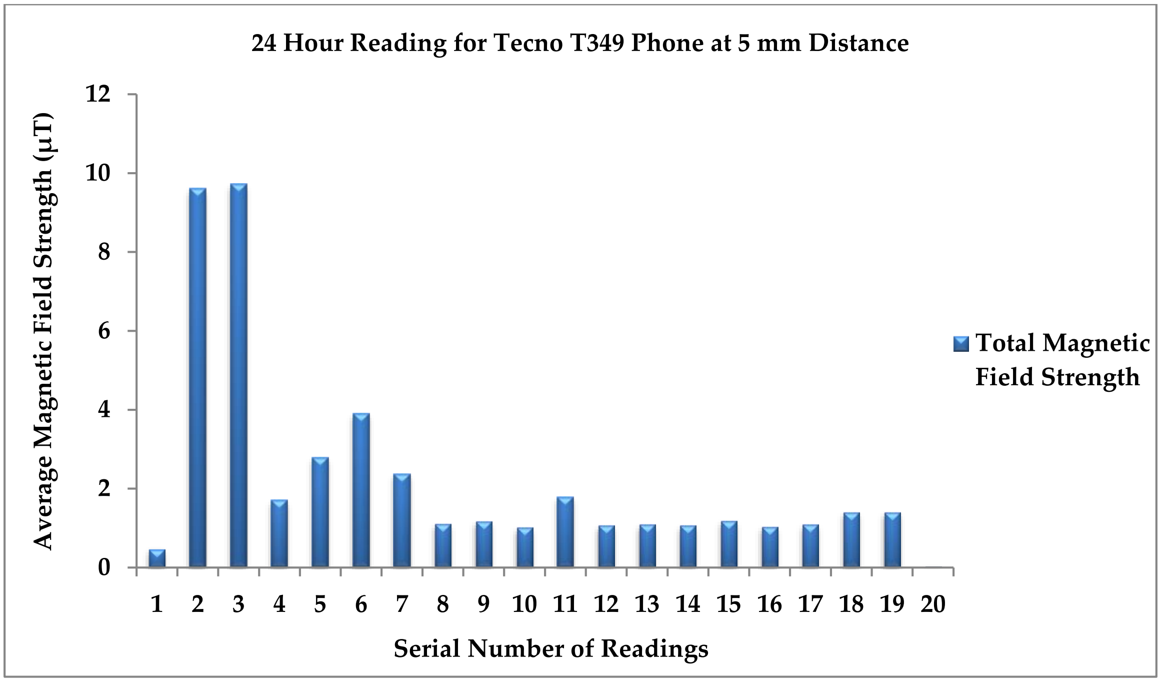

Figure 3: 24 Hour Magnetic Field Strengths (μT) for Tecno T349 Phone at 5 mm Distance.
Mean = 3.32 ± 0.677

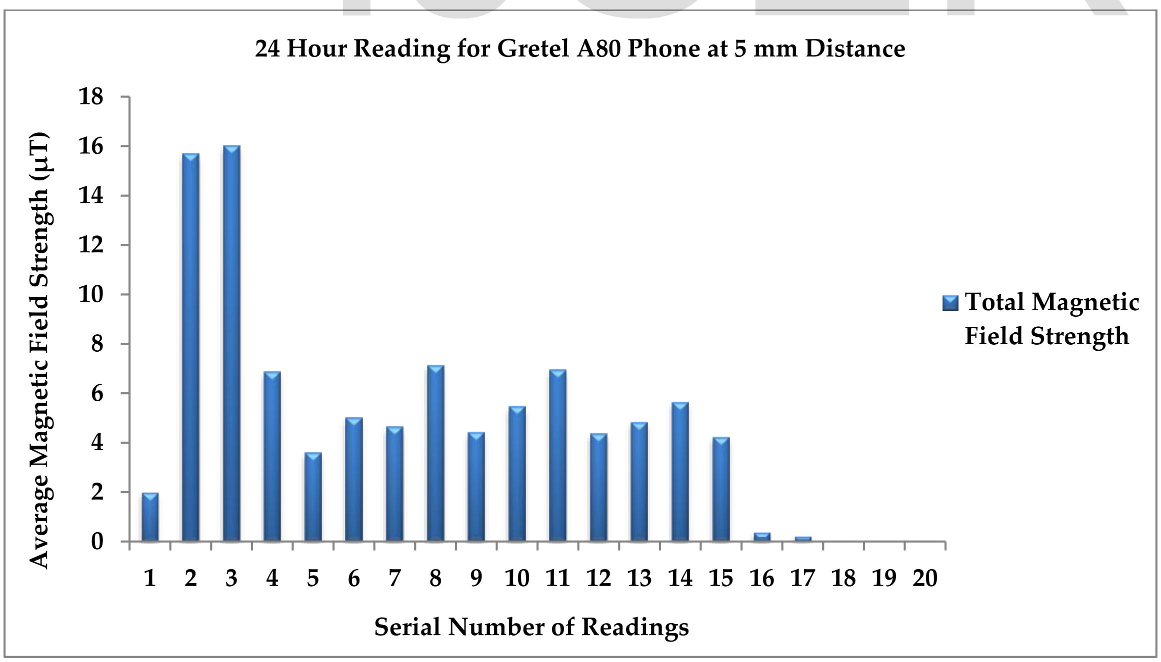

Figure 4: 24 Hour Magnetic Field Strengths (μT) for Gretel A80 Phone at 5 mm Distance.
$P < 0.05$; Mean = 5.73 ± 0.997

3.2 Total Magnetic Field Strengths of ITEL 1409, TECNO T349, NOKIA T05 and GRETEL A80 at 0 cm, 2 cm, 4 cm, 6 cm, 8 cm, 10 cm, 12 cm and 'Farthest' Distances from a Triaxial Magnetic Field Meter (When Phones Were Engaged)

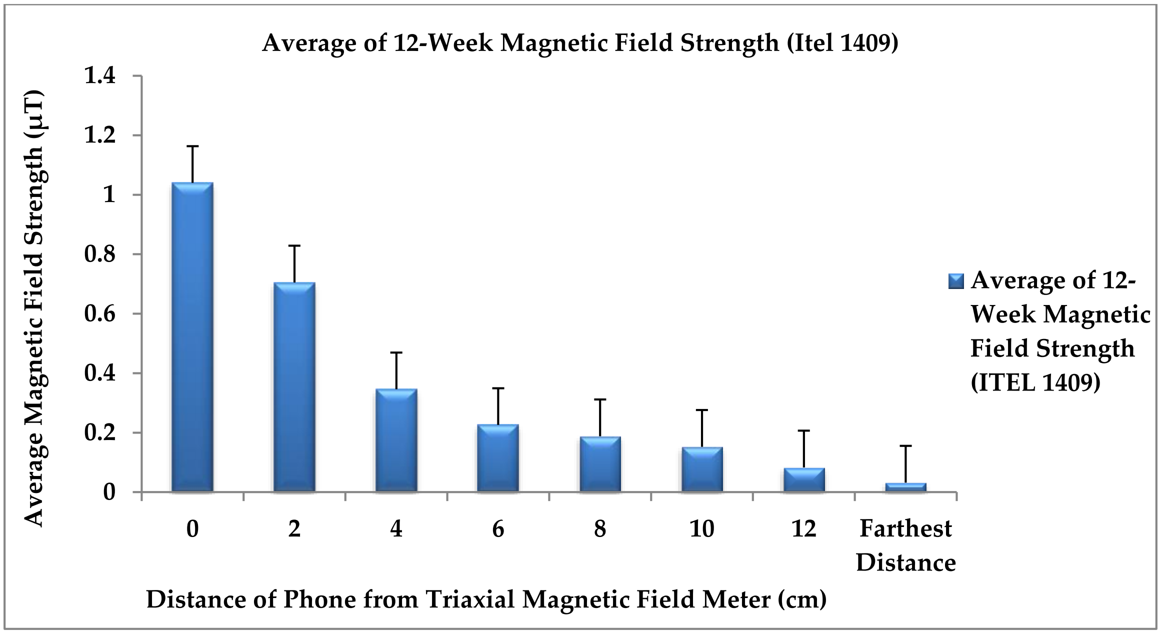

Figure 5: 12-Week Average Weekly Magnetic Field Strength for Itel 1409 (μT)
Average Magnetic Field Strength at 0 cm is 1.04.

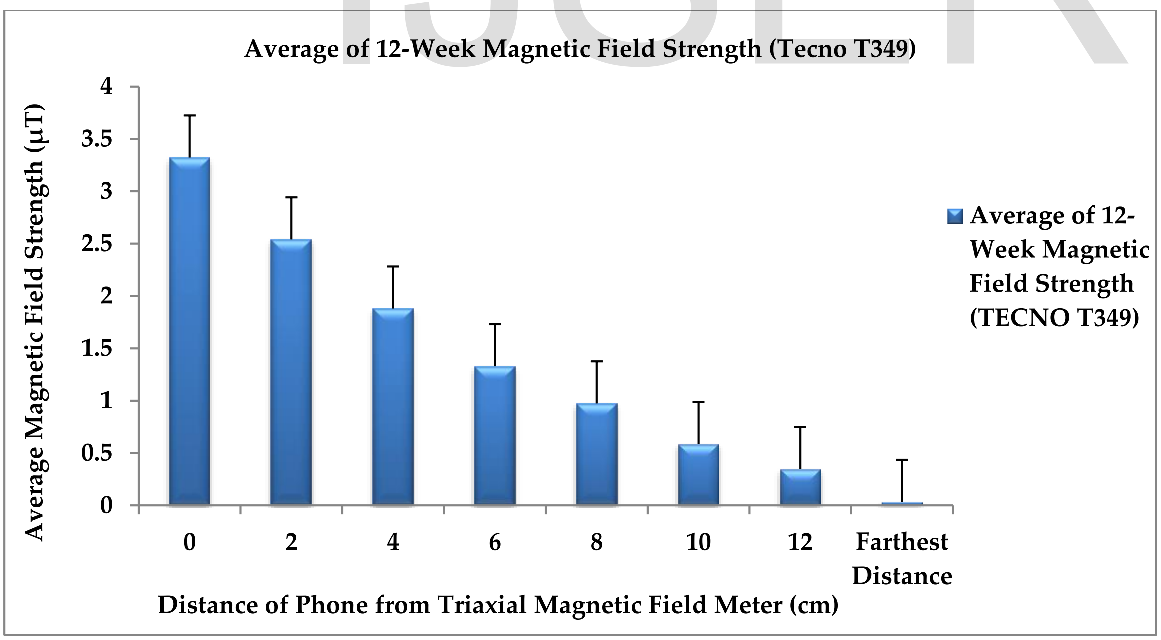

Figure 6: 12-Week Average Weekly Magnetic Field Strength for Tecno T349 (μT)
Average Magnetic Field Strength at 0 cm is 3.32. $P < 0.05$

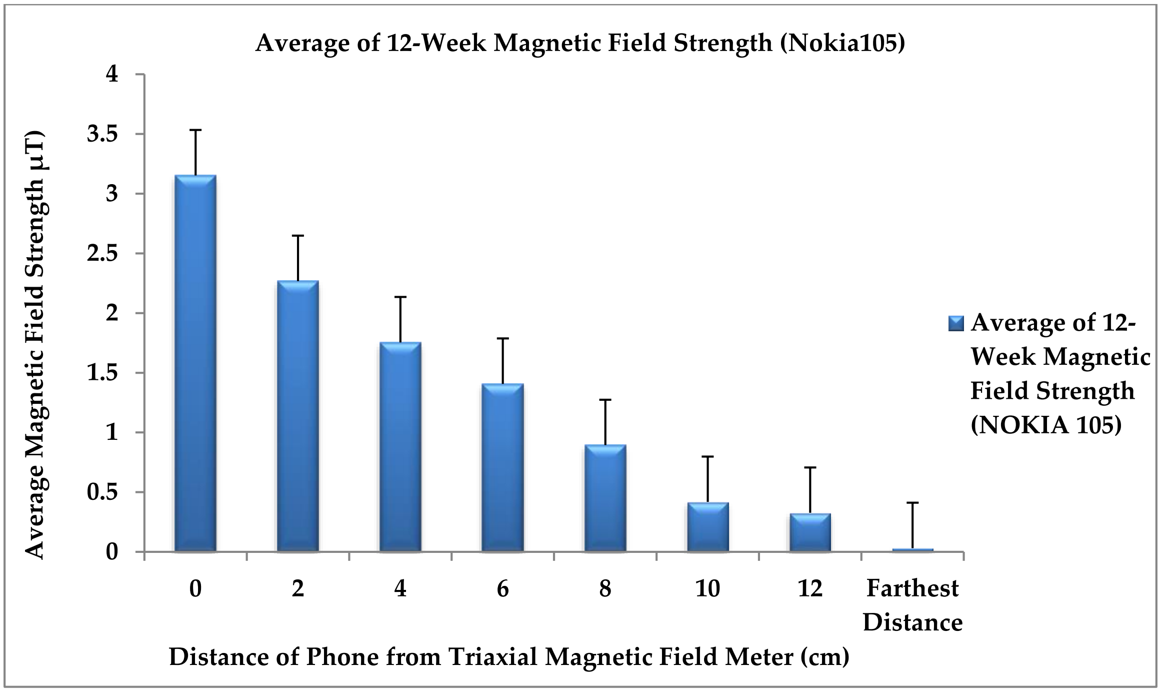

Figure 7: 12-Week Average Weekly Magnetic Field Strength for Nokia 105 (μT)
Average Magnetic Field Strength at 0 cm is 3.15. ***P < 0.05***

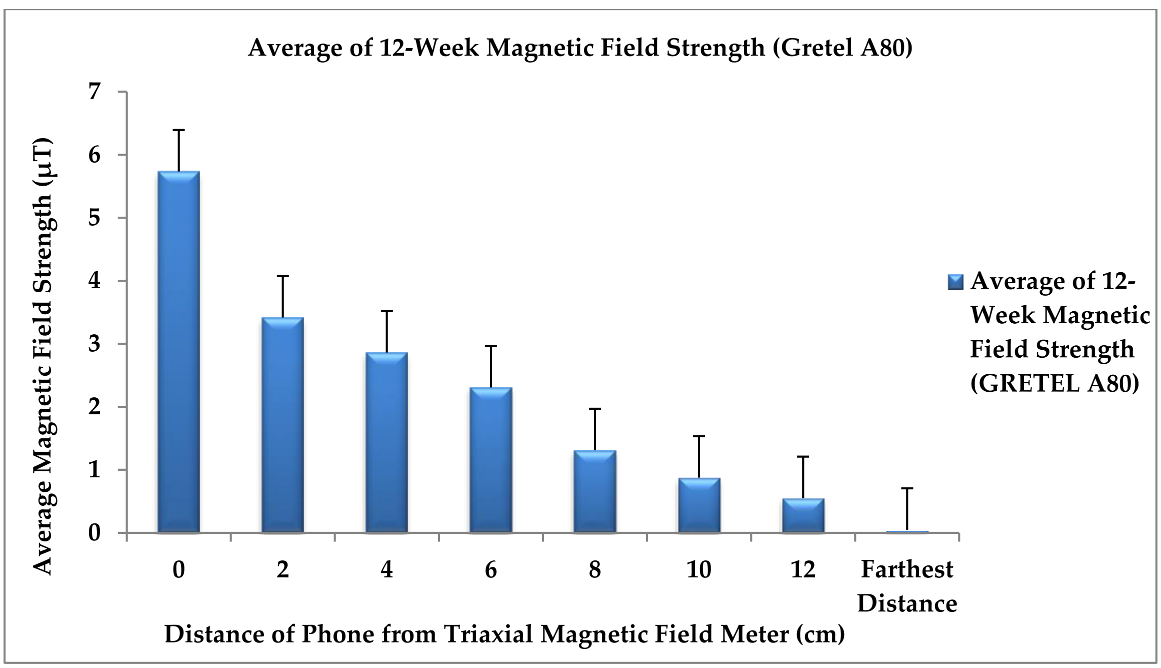

Figure 8: 12-Week Average Weekly Magnetic Field Strength for Gretel A80 (μT)
Average Magnetic Field Strength at 0 cm is 5.73. ***P < 0.05***

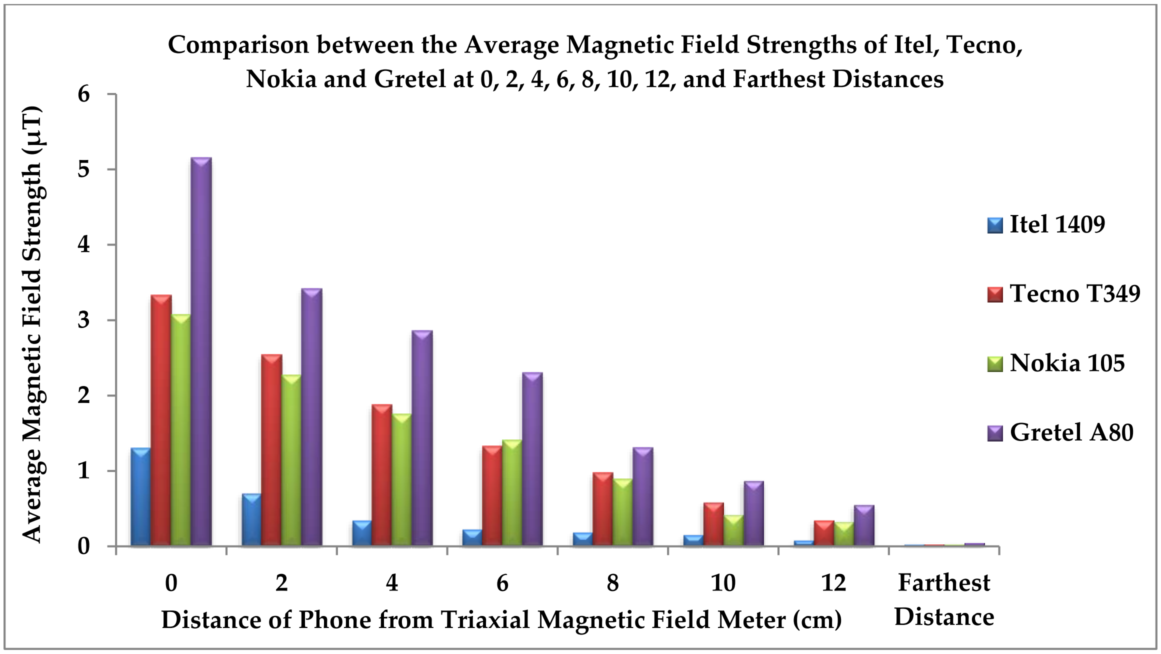

Figure 9: Comparison between the Average Magnetic Field Strengths of Itel, Tecno, Nokia and Gretel

3.3 Estimation of Specific Absorption Rates for ITEL 1409, TECNO T349, NOKIA T05 and GRETEL

At 0cm, the average magnetic strengths for the phones studied are:

Itel 1409 = 1.04 ± 0.250 µT
Tecno T349 = 3.32 ± 0.677 µT
Nokia 105 = 3.15 ± 0.451 µT
Gretel A80 = 5.73 ± 0.997 µT

For Itel 1409;
Magnetic field strength H = 0.796 x 1.04 = 0.8278 (A/m)
Skin impedance η = 377√($\frac{1}{40.7}$) = 59.09Ω
Power Density S = H^2 x η = $(0.8278)^2$ x 59.09 = 40.49 W/m^2
Electric field strength E = √ S x η = √(40.49 x 59.09) = 48.917 V/m
SAR = $\frac{0.65 x (48.917^2)}{2 x 1010}$ = **0.769 W/kg**

For Tecno T349;
Magnetic field strength H = 0.796 x 3.32 = 2.6427 (A/m)
Skin impedance η = 377√($\frac{1}{40.7}$) = 59.09Ω
Power Density S = H^2 x η = $(2.6427)^2$ x 59.09 = 412.68 W/m^2
Electric field strength E = √ S x η = √(412.68 x 59.09) = 156.15 V/m
SAR = $\frac{0.65 x 156.15^2}{2 x 1010}$= **7.846 W/kg**

For Nokia 105;
Magnetic field strength H = 0.796 x 3.15 = 2.5074 (A/m)
Skin impedance η = 377√($\frac{1}{40.7}$) = 59.09Ω
Power Density S = H^2 x η = $(2.5074)^2$ x 59.09 = 371.50 W/m^2
Electric field strength E = √ S x η = √(371.50 x 59.09) = 148.16 V/m
SAR = $\frac{0.65 x 148.16^2}{2 x 1010}$= **7.063 W/kg**

For Gretel A80;
Magnetic field strength H = 0.796 x 5.73 = 4.5610 (A/m)
Skin impedance η = 377√($\frac{1}{40.7}$) = 59.09Ω
Power Density S = H^2 x η = $(4.5610)^2$ x 59.09 = 1229.27 W/m^2
Electric field strength E = √ S x η = √(1229.27 x 59.09) = 269.51 V/m
SAR = $\frac{0.65 x 269.51^2}{2 x 1010}$= **23.373 W/kg**

These set of calculations show the relative SAR values. The safe distance is pegged at a point with a magnetic field strength of 1.5 µT which is estimated as follows, based on the SAR values obtained:
Itel 1409: A few millimeters between the phone and body tissues
Tecno T349: 4 - 6 cm between the phone and body tissues
Nokia 105: 4 – 6 cm between the phone and body tissues
Gretel A80: 6 – 8 cm between the phone and body tissues

4. DISCUSSIONS

The use of mobile phones has long been associated with adverse health effects, which has necessitated the issuance of guidelines to manufacturers, in order to maintain standards aimed at minimizing the negative health impacts of mobile phones. There are generally three types of cellular phones, categorized based on the radiofrequency at which they transmit and receive signals, including analog phones, digital phones and digital personal communication system (PCS). From a health perspective, the signals from each of these technology types are more similar and different in terms of potential biological impact. For example, analog phones operate at frequencies between 824MHz and 894MHz. As energy hogs, analog phones beam up to eight times more of energy into the user's head, when compared with digital phones. Digital phones operate at frequencies between 800 and 900MHz, while digital PCS phones operate in the range of 1850MHz to 1990MHz.

Phones have evolved dramatically, just as their use has increased. Electronics companies are in tight competition to produce profitable and trend-setting phones, which has led to the design and introduction of multiple types of phones into the telecommunications market. Most phones can be placed into one four categories, including cell phones, feature phones, smartphones and tablets. Some common features found on all phones include a battery, an input mechanism which comes in the form of a keypad for feature phones or touch screens for most smartphones and allows the user to interact with the phone; a screen which displays text messages, contacts, and more and basic mobile phone services to allow users to make calls and send text messages. All GSM phones use a SIM card to allow an account to be swapped among devices. Some CDMA devices also have a similar card called an R-UIM. Individual GSM, WCDMA, IDEN and some satellite phone devices are uniquely identified by an International Mobile Equipment Identity (IMEI) number.

Mobile phones are used for a variety of purposes, such as keeping in touch with family members, conducting business and to have access to a telephone in the event of an emergency. Some individuals carry more than one mobile phone for different purposes, such as business and personal use. Multiple SIM cards may be used to take advantage of the benefits from different telecommunication companies and different calling plans. For example, a particular company or tariff plan might offer cheaper rates for local calls, international calls, text messages or roaming.

4.1 Emission Issues from Mobile Phones

The widespread use of mobile phones has initiated research regarding the possible biological effects of exposure to radiofrequency radiation (RFR). This issue is of particular relevance, since a huge percentage of the global population is exposed to cellular RFR emitted in close proximity to the head. Some modern cellular systems operate in a pulsed mode in which data are accumulated and transmitted in short bursts. This is of great significance, since some studies have shown that modulated RFR may cause neurological effects even at low average power (Bawin *et al.*, 1975; Foster, 1996]. Other studies have however, not been able to demonstrate such effects (Green *et al.*, 2005; Platano *et al.*, 2007]. For example, a study by Koivisto *et al.* (2001) compared subjective symptoms such as headaches, dizziness, fatigue, itching, tingling of the skin, redness and feelings of warmth in a group that was exposed to RFR for 30–60 minutes with a non-exposed control group. Results obtained did not reveal any significant differences between these groups. Consequently, it is still quite controversial, whether mobile phone exposures can cause significant biological changes and effects that may lead to adverse health effects in humans. At a distance of about 2 cm from a user's head, mobile phones can radiate radiofrequency (RF) pulsed signals in the range of 450 to 2500 MHz at specific energy absorption rates (SARs) of no more than 2 W/kg (as measured over 10 grams of tissue), which is a recognized general public limit.

4.2 Phone Exposure and Human Health

Mobile phone usage around the world is enormous and is still on the rise. Currently, it is estimated that there are over 1.7 billion mobile phone users globally. Consequently, if there were to be adverse health implications due to exposures from mobile phones, the effects could be widespread amongst vast populations. It is therefore important that all valid possibilities of adverse biological effects due to mobile phone radiation fields be examined and resolved. Various studies on the biological effects of exposures to mobile phones have included the investigation of potential connections to cancer, cell division, blood pressure alteration, induction of epilepsy, depression in melatonin levels, DNA strand breaks, effects on the eyes, and human cognitive alteration, to mention a few. Although many of these studies continue to provide plausible leads for further research, a few others have questioned any possible association between the use of mobile phones and observed adverse effects.

Some of the studies that have reported negative health effects of mobile phones include those by Hardell *et al.* (2000) and Repacholi *et al*. (1997), both of which reported risks of developing brain tumor due to exposures to electromagnetic field (EMF) radiation generated by cell phones. One of the earlier studies by Salford *et al.* (1994) also demonstrated that blood brain barrier function could be affected by cell phone radiation, while Caprani *et al*. (2004) observed that environmental electromagnetic field significantly increases the thromboembolic risks in endothelial cell lines.

4.3 Genotoxic Effects

The photon energy of radiation from mobile phones is much lower than the energy necessary to break chemical bonds. It is therefore generally accepted that RF fields do not directly damage DNA. However, it is possible that certain cellular constituents altered by exposure to EMF, such as free radicals, indirectly affect DNA. In most studies, the genotoxic effects have been investigated after short-term exposures (Vijayalaxmi and Obe, 2004).

The REFLEX study performed by twelve research groups in seven European countries also investigated basic biological effects induced by EMF using toxicological and molecular technologies at cellular and sub-cellular levels in vitro. The REFLEX investigators (Diem *et al.* 2005) reported DNA strand breaks (measured by both the neutral and alkaline versions of the "comet" assay) in human diploid fibroblasts and cultured rat granulosa cells after RF field exposure of 1800 MHz; SAR 1.2 or 2 W/kg; different modulations; during 4, 16 and 24 hours; intermittent 5 minutes on/10 minutes off or continuous wave). Statistically significant increases in micronucleus formation and chromosomal aberrations were also observed in fibroblasts. Nicolova *et al.* (2005) also reported a low and transient increase in DNA strand breaks in embryonic stem cell-derived neural progenitor cells, after a 6-hour but not a 48-hour exposure to RF field.

4.4 Reproductive and Developmental Effects

Epidemiological studies on adverse pregnancy outcomes following exposure to RF fields have been reviewed by Verschaeve and Maes, (1998), Heynick and Merrit (2003) and Feychting (2005). The evidence on possible effects of RF fields on pregnancy outcomes is virtually limited to occupational exposures among physiotherapists. The possible effects investigated included spontaneous abortions, birth weight, gender ratio, and congenital malformations. Although results suggested some associations with the conditions studied, none of such adverse effects has been consistently reported. Some of these studies have also reported that women who use mobile phones regularly during pregnancy are more likely to give birth to children with behavioral problems, development of hyperactivity and difficulties with conduct, emotions and relationships by the time they reach school age.

4.5 Effect on Brain Development

Several studies in the past had suggested that between 20% and 60% of the energy emitted from a mobile phone is absorbed by the user's head. The percentage absorbed depends on the design of the phone, type of aerial or antenna (the stubby ones which cannot be extended are worse because they concentrate energy into the user's brain), and proximity to the nearest base-station (the weaker the base station signal, the more the phone will power up to maintain contact with the network). Electromagnetic waves alter electric activity of the brain, causing disturbances in sleep, lack of concentration, fatigue, headache and mental sluggishness. Other possible effects include increase in resting blood pressures, reduction in the production of melatonin and DNA strand breaks. Radiation from mobile phones could also damage key brain cells and trigger an early onset of Alzheimer's disease.

Findings have also suggested that radiation from mobile phones damages areas of the brain associated with learning, memory and movement; and that users of cell phones were two and a half times more likely to have a temporal brain tumor on the side of the head where they held their phone. In the case of tumors of the auditory nerve, which connects the ear to the brain, the risk increased to more than three times for mobile phone users.

4.6 Effects on Sleep (Insomnia)

Fairly low levels of electromagnetic radiation have been shown to alter the human body's sleep rhythms. In a study, Mann, (1996) demonstrated among volunteers who were fast asleep, that exposure to cellular phone radiation could shorten the stage of rapid eye movement (REM) during sleep. In a similar study, Borbely *et al.* (1999) exposed healthy young men and women to alternating 15-minute on and off intervals of digital frequency cellular radiation during an overnight sleep after which they were observed for REM. Results obtained revealed an increase in non-REM sleep and reduction in the waking time after sleep. These findings suggest that cellular phone radiation modifies the brain patterns associated with sleep. Such alterations may impact learning, given that the loss of REM sleep and increase in non-REM sleep may reduce attention and increase fatigue. Other studies have also reported that using cellular phones just before going to sleep could disturb the normal sleeping EEG patterns.

4.7 Effects on Memory and Cognitive Functions

A number of studies have also associated mobile phone radiation with impaired cognitive functions and memory.

One of such studies had observed that signals from mobile phones could disrupt the part of the brain that controls memory and learning emphasizing that such signals made no difference in their measurements during the short term but potentially caused sudden memory loss and confusion in the long run. In a similar study, microwaves that are similar to those emitted by cellular phones were found to impair long term memory. In this study, a hundred rats were subjected to a swimming maze, where they learned to find hidden safety platforms in a pool of cloudy water. Some of the rats were later exposed to short bursts of low-level microwaves and challenged to navigate the maze for a second time. The exposed rats were observed to have forgotten the location of the safety platforms, while the unexposed rats retained their spatial memories. These findings suggested that "the long-term memory of virtually all the exposed rats appeared to have been affected. Kraus *at al.* (2000) also observed that high-frequency cellular phone radiation significantly modified several aspects of brain responses during a memory task. Other studies by Lebedeva and colleagues (20000 reported that exposure to RF radiation typical of cellular phones could cause direct stimulation of the cerebral cortex, the region of the brain responsible for consciousness and complex thinking processes in humans. This stimulation was observed to have continued even after exposure was stopped, with increased risks of developing cancers of the brain and alterations in cognitive functions.

4.8 Findings and their Significance

In view of the numerous negative health effects that have been observed in mobile phone users, the current study was aimed at examining the SAR of some selected mobile phones in Nigeria and assessing their compliance with recommended international standards. Following estimation of magnetic field strengths, the SARs of these phones were calculated, using standard formulas.

Findings revealed that only one mobile phone, the Itel 1409 android phone, complied with the internationally acceptable standard maximum SAR of 2.0 W/kg. The other phones studied were observed to possess magnetic field strengths that produced very high SARs with Gretel A80 producing the highest magnetic field strength of 4.5610 A/m and consequent SAR of 23.37 W/Kg, while the Itel 1409 had a magnetic field strength of 0.8278 A/m and SAR of 0.769 W/Kg. The Nokia 105 and Tecno T349 mobile phones produced magnetic field strengths of 2.5074 A/m and 2.6427 A/m; and SARs of 7.063 W/Kg and 7.846 W/Kg, respectively. These findings suggest that roughly 75% of mobile phones available in Nigeria, especially the cheaper phones popularly referred to as "China phones" could be causing more harm than good. Also, the absence of information on the SARs of Nokia 105 and Gretel A80 from their respective user's manual and websites suggested at the onset of this study that these phones were substandard and fell under the so-called 'cheap China phones category, which are produced in China and illegally exported to poor developing countries like Nigeria.

The 24-hour magnetic field strengths for the four phones studied showed similar wave patterns at 5 mm from the Triaxial Magnetic Field Meter (Figures 1 - 4), with an initial surge in magnetic field strengths, especially during the second and third readings. These readings corresponded with the first few minutes after the mobile phones started ringing, suggesting that engaging mobile phones immediately after they start ringing could expose users to large doses of electromagnetic radiations. Consequently, it is advised that mobile phone calls should be received at a safe distance away from the head, immediately after they start ringing. Such safe distances are usually clearly indicated by mobile phone manufacturers and could range between 5 mm and 10 mm. Also, the wave patterns for Itel 1409 and Tecno 349 phones remained consistently low after the sixth and seventh readings, unlike those for Nokia 105 and Gretel A80 phones, which were mostly inconsistent, even beyond the sixth and seventh readings. These observations are consistent with earlier suspicion of the potential substandard nature of these two phones, based on absence of information concerning their SARs on both their user's manuals and websites.

Measurement of magnetic field strengths for the different phones at distances between 0 cm and 12 cm also revealed a reduction in electromagnetic radiations with increases in distance between phones and Triaxial Magnetic Field Meter. This finding suggests that phones should be kept away from body tissues as far as possible, while receiving calls, which is facilitated by use of hands-free mobile phones. Among the four mobile phones studied, the Itel 1409 android phone showed the lowest magnetic field strength at all distances, while Gretel A80 produced the greatest field strength, also at all distances. Again, these findings suggest that Itel 1409, an android phone, produced the least electromagnetic radiation hence, is potentially safer to use, when compared to Gretel A80. The conspicuous absence of essential information on SAR is enough to identify fake and substandard mobile phones and other similar products, but for the widespread corruption and inaction on the part of appropriate regulatory bodies in these countries. Simple market surveys and researches could also potentially identify fake and substandard mobile phones in developing countries and bring same to the attention of regulatory bodies such as the Standard Organization of Nigeria (SON) and the Consumer Protection Commissions (CPCs) established in some states of Nigeria. Considering the huge size of the Nigerian population and widespread use of mobile phones across the nation, there are potentially large numbers of other substandard "China" mobile phones in Nigeria that are yet to be identified. Consequently, one major limitation of this study was the small sample size studied, which was mainly due to financial challenges occasioned by lack of funding for this research.

The consequences of these findings on the health of the average Nigerian is far-reaching. The country Nigeria is the most populous black nation of the world, with an estimated population of over two hundred million people, majority of who are poor, with an estimated daily income of less than one dollar per day. Consequently, these ordinary Nigerians are unable to afford the sophisticated android phones that probably have better compliance with international standards. They are also largely ignorant of the negative health effects associated with use of substandard mobile phones and are therefore the immediate victims of these negative health impacts. Unfortunately, the adverse health effects of electromagnetic radiation emitted from these substandard phones are usually subtle and occur at the sub-acute to chronic levels, making it difficult or almost impossible to directly associate them to use of mobile phones. Indeed, a huge number of Nigerians living below the poverty line continue to suffer from most of the conditions that have been associated with use of mobile phones, even though there are currently few or no research findings that directly associate the current increase in these adverse health conditions to use of cheap and oftentimes, worn-out mobile phones. Consequently, more research on the adverse health effects of radiation from mobile phones, especially the very cheap ones, is urgently needed, to characterize their impact on health. More importantly, the relevant authorities in Nigeria must become more result oriented, not only in the establishment of guidelines, but also enforcement of laws aimed at ensuring that only mobile phones that meet the international standards in terms of electromagnetic radiation and SAR, are imported into the country. This will go a long way in not only safeguarding the health of its citizens, but also eliminating the adverse social impacts of associated neurological and mental effects.

5. CONCLUSION

As new data become available, our understanding of the role of mobile phone emissions in human health will improve. However, the explosion in utilization of this technology creates a unique necessity for ongoing monitoring and regulation, especially in developing countries such as Nigeria, which often serve as dumping grounds for substandard products. The huge number of current and potential future cellular phone users creates a great cause for worry. Even if only a small percentage of cellular phone users are adversely affected, that could still equate to a public health issue of epidemic proportions. It is very important for manufacturers to provide mobile phone users with information on the potential adverse health effects of using them, so as to make informed choices concerning their use. Millions of cellular phone users worldwide are now exposed daily to radiofrequency and microwave radiation under prolonged and physically close conditions. It is necessary for mobile phone users to become more responsible in their use. They are also encouraged to become familiar with the possible biological effects of cellular phone radiation, a segment of which has been reviewed in this article.

REFERENCES

Agarwal A., Singh A., Hamada A and Kesari K (2011). Cell Phones and Male Infertility: A review of Recent Innovations in Technology and Consequences. *International Brazilian Journal of Urology, 37: 432–54.*

Akbal A., Kiran Y., Sahin A., Turgut-Balik D and Balik H. (2012). Effects of Electromagnetic Waves Emitted by Mobile Phones on Germination, Root Growth, and Root Tip Cell Mitotic Division of *Lens culinaris Medik. Poishl Journal of Environmental Studies, 21(1): 23−9.*

Bawin S.W., Kaczmarek L.K and Adey W.R (1975). Effects of Modulated VHF Fields on the Central Nervous System. *Annals of New York Academy of Science, 247:74–80.*

Borbely A.A., Huber R., Graf T., Fuchs B., Gallmann E and Achermann P (1999). "Pulsed High Frequency Electromagnetic Field Affects Human Sleep and Sleep Electroencephalogram." *Neuroscience Letters, 275(3): 207-210.*

Caprani A., Richert A and Flaud P (2004). Experimental Evidence of a Potentially Increased Thrombo-embolic Disease Risk by Domestic Electromagnetic Field Exposure. *Bioelectromagnetics, 25:313-315.*

Diem E., Schwarz C., Adlkofer F., Jahn O and Rudiger H (2005). Non-thermal DNA Breakage by Mobile Phone

Radiation (1800 MHz) in Human Fibroblasts and in Transformed GFSH-R17 Rat Granulosa Cells in vitro. *Mutation Research, 583: 178-183.*

Feychting M. (2005). Health Effects of Static Magnetic Fields – A Review of the Epidemiological Evidence. *Prog Biophys Mol Biol*., 87: 241-246.

Foster K.R (1996). Interaction of Radiofrequency Fields with Biological System as Related to Modulation, Proceedings of the International Seminar on Biological Effects of Non-thermal Pulsed and AM RF EMF and Related Health Risks, *Munich, Germany, (WHO/ICNIRP 3:97).*

Green A.C., Scott I.R., Gwyther R.J., Peyman A., Chadwick P., Chen X., Alfadhl Y and Tattersall JEH (2005). An Investigation of the Effects of TETRA RF Fields on Intracellular Calcium in Neurones and Cardiac Myocytes. *International Journal of Radiation Biology 81: 869–885.*

Hardell (2000). Case-Control Study on Radiology Work, Medical X-ray Investigations, and Use of Cellular Telephones as Risk Factors for Brain Tumors. *Medscape.com.*

Heynick L.N and Merritt J.H (2003). Radiofrequency Fields and Teratogenesis. *Bioelectromagnetics, Suppl 6: 174-186.*

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.*

ICNIRP (1998). Guidelines for Limiting Exposure to Time-varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz). Health Physics, 74: 494–522.

Koivisto M., Haarala C., Krause C.M., Revonsuo A., Laine M and Hämäläinen H. (2001). GSM Phone Signals does not Produce Subjective Symptoms. *Bio-electromagnetic, 22, 212-215.*

Krause C.M., Sillanmaki L., Koivisto M., Haggqvist A., Saarela C., Revonsuo A., Laine M and Hamalainen H (2000). Effects of Electromagnetic Field Emitted by Cellular Phones on the EEG During a Memory Task. *Neuroreport, 11(4):761-4.*

Lebedeva NN, Sulimov AV et al. "Cellular phone electromagnetic field effects on bioelectric activity of human brain." Crit Rev Biomed Eng, Vol. 28, No. 1-2, pp:323-337, 2000.

Mann K and Röschke J (1996). Effects of Pulsed High Frequency Electromagnetic Fields on Human Sleep. *Neuropsychobiology 33:41–47.*

Nikolova T., Czyz J., Rolletschek A., Blyszczuk P., Fuchs J., Jovtchev G., Schuderer J., Kuster N and Wobus A.M (2005). Electromagnetic Fields Affect Transcript Levels of Apoptosis-Related Genes in Embryonic Stem Cell-Derived Neural Progenitor Cells. *FASEB Journal, 19(12): 1686 – 1688*

Platano D., Mesirca P., Paffi A., Pellegrino M., Liberti M., Apollonio F., Bersani F and Aicardi G (2007). Acute exposure to Low-level CW and GSM-Modulated 900 MHz Radiofrequency does not Affect Ba^{2+} Currents through Voltage-gated Calcium Channels in Rat Cortical Neurons. *Bioelectromagnetics 28:599–607*

Repacholi (1997). Lymphomas in Mice Exposed to 900MHz Pulsed EMFs. *Radiation Research, 147 (5): 631-640*

Salford L.G., Brun A., Sturesson K., Eberhard J.L and Persson B.R (1994). Permeability of the Blood-Brain Barrier Induced by 915 MHz Electromagnetic Radiation, Continuous Wave and Modulated at 8, 16, 50, and 200 Hz. *Microsc. Res. Tech. 15: 535-542*

Shalangwa D.A., Vasira P.G and Waba A.S (2011). Health Risk of Using Global System for Mobile Communication (GSM) Mobile Phone. *International Journal of Electromagnetics and Applications, 1(1): 16-18*

Verschaeve L and Maes A (1998). Genetic, Carcinogenic and Teratogenic Effects of Radiofrequency Fields. *Mutation Research 410: 141-165.*

Vijayalaxmi, O.G (2004). Controversial Cytogenetic Observations in Mammalian Somatic Cells Exposed to Radiofrequency Radiation. *Radiation Research, 162: 481-496.*

WHO (2014). Electromagnetic Fields and Public Health: Mobile Phones. *Accessed Online on who.int. On 08-03-2020*