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Electromagnetic Radiation and Spatial Proximity of Mobile Communication Base Stations: Analysis of Compliance in Sagamu Metropolis

ONALAJA OLABISI OLAYINKA[1], BADRU RAHMON ARIYO[2], AWOSOLA ADEOLUWASAMUEL[3]
[1, 3]*Dept. of Computer Science, Gateway ICT Polytechnic, Saapade, Ogun-State.*
[2]*Dept. of ICT, Cooperative Information Network (COPINE), National Space Research and Development Agency (NASRDA), Obafemi Awolowo University's Campus, Ile-Ife, Nigeria*

Abstract- Electromagnetic radiation emanating from randomly selected 113 GSM Mobile Base Transceiver Stations (MBTSs) in different regions of Sagamu, Ogun State, Southwest, Nigeria, was assessed according to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, National Communication Commission (NCC), National Environmental Standards and Regulations Enforcement Agency (NESREA). This was to determine the exposure level at these MBTS and their compliance to setback distance in relation to the specification in the guidelines. Measurements of the maximum Power Density of radio signals were taken for sites operating in GSM 900MHz, GSM 1800MHz, WCDMA 2100MHz and correlated with the ICNIRP, NCC and NESREA specifications. The result indicated that only 23.9% (27) of the entire MBTSs complied with NCC regulations (5m) set back to the closest infrastructure, while majority 76.1% (86) do not comply. 62.8% (71) complied with the NESREA standard of 10 metres set back to the closest infrastructure while 37.2% (42) do not comply with the regulations as they do not observe 10 meters set back from the nearest infrastructure. Only 6.2% (7) of the total MBTSs in the study area, violated the recommended E(V/m) for 900MHz, GSM 1800MHz, WCDMA 2100MHz rates having a peak value of 85V/m. Also, 25.7% (29) violated the recommended power density levels for 900MHz, GSM 1800MHz, WCDMA2100MHz rates having highest value for power density which is (47.75mW/m2) while others also showed high values ranging from 9.966 to 29.73mW/m2. These findings suggest that many MBST's complies with NESREA (10m) setback regulation but violated the NCC (5m) regulation.

Indexed Terms- Electromagnetic waves, Mobile Phone, Base Stations, power density, radiation level

I. INTRODUCTION

With the introduction of the Global System for Mobile Communication (GSM) in 2001, Nigerian telecommunications got a significant boost. Econet (now Airtel) was the first telecommunications service to begin in Nigeria on August 8, 2001, competing with MTN, which also started operations in August of that year. They were granted renewable GSM licenses with a 5-year expiration period, allowing them to operate in the 850 MHz and 1900 MHz spectrum bands. The operators were given basic goals by the NCC. A minimum of 100,000 subscribers in each of the country's geopolitical states in the first year of operations, 1.5 million subscribers in the next five years, and a minimum of 5% regional penetration within each of the country's geopolitical states were among the goals (nairametrics, 2019).

There are 4 million telecoms towers in use around the world, with a 4.1 percent annual growth rate projected through 2020. In 2014, the worldwide demand for tower building was projected to be worth $20.3 billion. The estimated installed base will have increased from 4 million to 5 million towers by 2020. As of 2016, there were 25, 396 towers in Nigeria, with individual tower firms owning or operating 85 percent of the BTS6. In Nigeria, the number of third- and fourth-generation (3G and 4G) base transceiver stations (BTS) has increased from 30,000 to 53,460 (NCC, 2021). Cell towers are being positioned haphazardly adjacent to schools, creches, public playgrounds, industrial structures, hospitals, universities, campuses, and terraces in heavily populated urban residential areas because there is no regulation on their placement Consequently, the public is vulnerable to constant, low intensity radiation from these towers. Because electromagnetic radiation cannot be seen, smelled, or felt, its potential harm over long periods of exposure would go unnoticed until it manifested in the form of biological disorders. Various experiments have demonstrated the ill-effects of Radio frequency electromagnetic field (RF-EMF) on bees, fruit flies, frogs, birds, bats, and humans, but the long-term studies of such exposures remain incomplete and limited. The International Commission on Non-Ionizing Radiation Protection (ICNIRP), the Institute of Electrical and Electronics Engineers (IEEE), and the Federal Communication Commission (FCC) have all issued recommendations. These groups provide rules that limit the amount of electromagnetic radiation that can be dissipated in the human body. These restrictions apply to both the general public and on-site staff, i.e. occupational (Al-Hamdany & Al-Ahmady, 2022). In Nigeria, NCC and NESREA which are the regulatory bodies also have recommended guidelines for base station.

1.1 Electromagnetic Waves and Mobile Phones

Electromagnetic waves, also known as electromagnetic radiation or energy, are used by mobile phones and their base stations to transmit and receive signals. Many natural and man-made sources emit electromagnetic radiation, which plays an important role in our lives (Batool et al, 2019). An electromagnetic field or wave is made up of two fields: an electric field € and a magnetic field (H) that oscillate in phase perpendicular with each other and with the direction of energy propagation. The peak value (positive or negative) of an electric or magnetic field measured in units of V/m or A/m respectively may be used to indicate its strength, though the root mean square (RMS) value is more commonly used (the square root of the average of the square of the field). This is equivalent to the peak value divided by square root of two (√2) for a sinusoidally varying field.

1.3 Statement of Research Problem

The Nigerian Communications Commission (NCC) and National Environmental Standards and Regulations Enforcement Agency (NESREA) set the setback standard for the proximity of Mobile Communication Base Station to the nearest infrastructure as5.0 m and 7.5m.Also, the International Commission for Non-Ionizing Radiation Protection ICNIRP (2020) stipulate that the average level of incident electric field strength E_{inc} (V/m), magnetic field strength H_{inc} (A/m) and power density S_{inc} $(W/m^2)$of the electromagnetic spectrum over the whole body in 30 minute should not exceed $3{f_m}^{0.5}$, $0.008{f_m}^{0.5}$ and $f_m/40$ respectively for occupational exposure scenario while general public exposure scenario should be$1.375{f_m}^{0.5}$, $0.0037{f_m}^{0.5}$ and $f_m/200$ respectively. Thus, the E_{inc} (V/m),H_{inc} (A/m) and S_{inc} (W/m^2) for occupational and public exposure scenario of electromagnetic source operating at 200MHz (for example) would respectively be $42.426\ kVm^{-1},\ 113.137Am^{-1} and\ 5.0\ MWm^{-2}$, $and, 1.945\ kVm^{-1}, 52.326\ Am^{-1} and\ 1.0\ MWm^{-2}$. Despite these regulations, there has being surge increase in the number of base stations (to reduce traffic congestions) due to increase in the use of mobile phones which are been installed in farmlands, green fields, on top of homes and within houses without application of these guidelines. To evaluate the implementation status of these regulations in Sagamu area of Ogun state, hence, this study.

1.4 Aim and Objectives

The aim of this research is to analyze the compliance level of the required electromagnetic radiation emission levels and spatial proximity of selected mobile communication base stations to nearest infrastructure in Sagamu Metropolis, Ogun State, Nigeria.

The Specific Objectives include:

1 To carry out the radio frequency radiation measurements at different frequency bands (GSM 900MHz, GSM 1800 MHz, WCDMA 2100 MHz) at selected base stations within Sagamu Metropolis.
2 Carry out spatial proximity measurement of base stations to residential settlements at selected base stations in Sagamu Metropolis.
3 Comparatively analyze the RF levels and spatial proximity measurement of each base station with ICNIRP, NESREA, NCC regulations for public limiting exposure.

1.5 Research Question

1. What is the radio frequency radiation measurements at different frequency bands (GSM 900MHz, GSM 1800 MHz, WCDMA 2100 MHz) at selected base stations within Sagamu?
2. What is the spatial proximity measurement of base stations to residential settlements at selected base stations in Sagamu?
3. Does the RF levels and spatial proximity measurement at each base station conform to with the ICNIRP, NESREA, NCC regulations?

II. LITERATURE REVIEW

Base Stations

Base stations are fixed radio transmitters equipped with antennas installed on freestanding masts or on structures (see figure 1). The biggest base stations supply the network's primary infrastructure and may be located up to several kilometers apart18. Their antennas are typically positioned high enough to allow a clear view of the surrounding geographical region. Smaller base stations are often installed closer to the ground and provide extra radio capacity in densely populated areas, such as cities and towns. Base station radio waves are radiofrequency electromagnetic fields (EMFs), a kind of non-ionizing radiation with frequencies in the microwave portion of the electromagnetic spectrum (Agency, U. K. H. S. 2021). Mobile phone base stations are also referred to as base transceiver stations or telecommunications buildings. They are two-way radios with a low power consumption and a large number of channels. Antennas generate radio frequency radiation and are often installed on transmission towers or roof-mounted structures. These buildings must have a specific height in order to provide a certain amount of covering. When a mobile phone communicates, it is connected to a nearby base station. Your phone call is routed through that base station to the traditional fixed-line phone infrastructure. Due to the fact that mobile phones and their base stations are two-way radios, they generate RF radiation in order to communicate and so expose those in close proximity to RF radiation. However, because both phones and base stations have low-power (short-range) transmitters, RF radiation exposure levels are often rather modest. Base stations vary in size and coverage area. Some span many kilometers, while others encircle only a few city blocks. While the majority of stations transmit in all directions, directional antennas are also available. While base stations are typically controlled by a single carrier, they may also provide roaming coverage for other networks (Agency, U. K. H. S. 2021).

Nigerian telecommunications operators have built 34,033 base stations to date19. The infrastructure was built by MTN, Airtel, Glo, Ntel, 9mobile, and Smile Communications, according to industry data recently released by the Nigerian Communications Commission (NCC). As of 2019, the number of base stations had increased by 11.1 percent from 30,637 at the end of 2018. This showed that operators were able to add 3,396 base stations last year19. According to the NCC, the number of existing base stations in a nation inevitably impacts the quality of service (QoS), therefore favorably affecting the degree of telephone penetration. According to a breakdown of infrastructure ownership, MTN held the most base stations (16,796), while Airtel owned 8,924. Globacom had 7,516 base stations, whereas Ntel had 675. As of the end of 2019, 9mobile and Smile communications had built 120 and two base stations, respectively (Sarker & Islam, 2019). In addition to their own infrastructure, the operators are permitted to mount their radios on masts built by others through a process called collocation, which requires rent payment to the infrastructure owner. Non-payment of this rent is a component of the industry's massive debt, which has prompted conflict among operators. Lagos State, which has 9,860 base stations as of December 2019, gained the most from the operator's investment in base stations, according to the NCC study. Other states in the top five beneficiaries are Ogun, with 3,398 beneficiaries; Rivers, with 3,329 beneficiaries; the Federal Capital Territory, Abuja, with 3,034 beneficiaries; and Oyo, with 2,842 beneficiaries. The top three states accounted for 49% of all base stations in the country, while Jigawa had the fewest: 316; Yobe had 422; Zamfara had 434; Gombe had 521; and Kebbi had 561(Sarker & Islam, 2019).

Cellular mobile systems for mobile phones are classified into three generations: the first generation operates between (450-900) MHz, the second generation (GSM) operates between 900 MHz, 1800 MHz, or 1900 MHz, and the third generation operates between 2000 MHz20. The GSM 900 system operates on two frequency bands: uplink 890-915 MHz (transmitted from mobile devices), and downlink 2000 MHz (transmitted from base stations to mobile phones). The GSM 1800 system operates on the 1710-1785 MHz uplink and 1805-1880 MHz downlink frequency bands.

Figure 1: Base Station

2.2 GSM Network

Global System for Mobile Communications (GSM) is an acronym for Global System for Mobile Communications (Hanzo, L. 2008). It is the world's most commonly utilized digital mobile network. GSM is the most extensively utilized technology among TDMA, GSM, and CDMA as shown in figure 2. GSM is the most commonly utilized of the three digital wireless telephony technologies: TDMA, GSM, and code-division multiple access (CDMA) (Chindhe et al. 2019). GSM digitizes and compresses data before sending it down a channel with two other user data streams, each with its own time slot. It is capable of operating in the 900 megahertz (MHz) or 1,800 megahertz (MHz) frequency bands(Chindhe et al. 2019). The limitations of these systems underscored the importance of developing a more efficient cellular technology that could be utilized worldwide. The GSM network is comprised of four distinct components that operate in concert to ensure its overall functionality: the mobile device itself, the base station subsystem (BSS), the network switching subsystem (NSS), and the operation and support subsystem (OSS) (Chindhe et al. 2019).

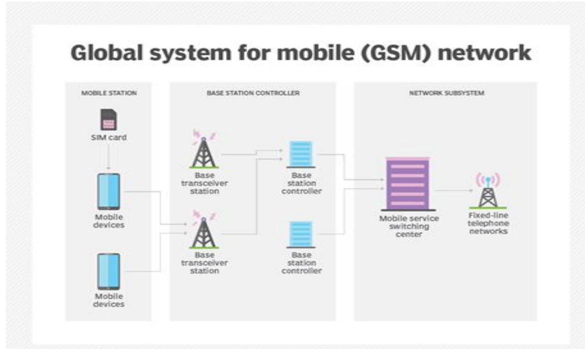


Figure 2: GSM Network (Dipak, 2019)

2.3 Radiation

2.3.1 Electromagnetic Radiation

Electromagnetic radiation is described as a form of radiative energy that propagates over space as waves and also as photon particles. It propagates at a characteristic speed, the speed of light, in a vacuum, and often in straight lines(Norgard & Best, 2017). Charged particles emit and absorb electromagnetic radiation. As an electromagnetic wave, it consists of both electric and magnetic fields that oscillate in phase with one another, perpendicular to one another, and perpendicular to the direction of energy and wave propagation, as seen in Figure 3 (Ahmed & Fadel, 2018). Where E, H, and Z denote the electric, magnetic, and free space impedances, respectively.

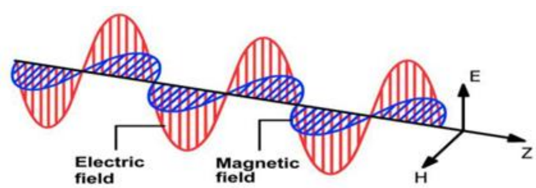


Figure 3: E.M Wave Propagation (Saleh. 2017)

Ionizing Radiation

Ionizing radiation is defined as high frequency ultraviolet radiation, Xrays, and gamma rays that contain enough energy to remove electrons from atoms or molecules. Non-ionizing radiation is defined as radio waves, microwaves, infrared radiation, visible light, and low frequency UV radiation (Al-Tamer & Al-Ahmady, 2020). Due to the low energy of these radiations, they excite electrons to a higher energy state rather than ionize them. Both the strength and frequency of EMR have an influence on the biological consequences. Although non-ionizing radiation at its highest frequency is capable of non-thermal biological effects comparable to those of ionizing radiation, for lower frequencies of EMR up to those of visible light (i.e. radio, microwave, infrared), the damage to cells and also to many common materials is primarily determined by heating effects, and thus by the radiation power (Al-Tamer & Al-Ahmady, 2020). By contrast, for higher frequency radiations at ultraviolet and above (i.e. X-rays and Gamma rays), the damage to chemical materials and living cells caused by EMR is significantly greater than that caused by simple heating, due to the ability of individual photons in such high frequency EMR to chemically damage individual molecules(Al-Tamer & Al-Ahmady, 2020).

Non-Ionizing Radiation

Non-ionizing radiation is a kind of electromagnetic radiation that does not include ionized particles. Non-ionizing electromagnetic radiation particles have a low energy, and instead of generating charged ions as they travel through matter, they have enough energy to modify the rotational, vibrational, or electronic valence configurations of molecules and atoms (Barnes &Greenebaum, 2018). Thus, unlike ionizing radiation, it has sufficient energy to cause an electron to shift to a higher energy state. The boundary between what is termed 'ionizing' radiation and non-ionizing radiation is not clearly defined, as various molecules and atoms ionize at different energies. NIR is the part of the electromagnetic spectrum with a large wavelength (> 100 nm) and a low photon energy (12.4 eV), spanning the frequency range of 1 Hz to 3 1015 Hz (Parasuraman, et al. 2018)

2.4 Electro Magnetic Field (EMF)

The term "electromagnetic field" refers to the physical field generated by electrically charged objects. The electromagnetic field is infinitely long in space and is used to describe electromagnetic interaction. According to Sironi, et al (2021), It is one among nature's four basic forces (the others are gravitation, weak interaction, and strong interaction). This field may be thought of as a hybrid of electric and magnetic fields. The electric field is generated by static charges, whereas the magnetic field is generated by moving charges (currents); these two are sometimes referred to as the field's origins. The electric field is denoted by the letter 'E' and its unit is the volt per meter [V/m], whereas the magnetic field is denoted by the letter 'H' and its unit is the ampere per meter [A/m]. The combined impact of these two fields is represented by the symbol S and is expressed in watts per square meter [W/m^2] (Renke & Chavan, 2018).

Maxwell's equations and the Lorentz force law describe how charges and currents interact with an electromagnetic field. EMF has several critical parameters: amplitude, frequency, phase, and wavelength. The electromagnetic wave and its various parameters. Frequency 'f' is the number of times per second that the wave changes direction and is measured in hertz [Hz]. Amplitude is the amplitude of the displacement shift relative to the start of the EMF wave. The wavelength() of an EMF wave is the distance between its peaks and is measured in meters [m]. It is equal to the speed of light (c) divided by its frequency (f), as indicated in Equation 1 (Renke & Chavan, 2018).

$$\lambda = \frac{c}{f} \qquad 1$$

Electromagnetic fields are utilized to transmit signals in wireless communication systems. Radio waves enable communication signals such as mobile telephones, television, radio transmitters, and radar to be sent across great distances[1].

2.5 Cellular Networks and Base Station in Nigeria

The huge expansion of mobile communications technology over the previous decades, particularly in Nigeria, has generated serious concerns about the safety of the people exposed to radiofrequency (RF) radiation emitted by either cellular phone terminals or base transceiver stations (BTS) (Yuan, 2021). Due to the numerous advantages of cell phone technology, it has changed the world's telecommunications landscape, particularly in developing nations like Nigeria. Around 1.6 billion mobile phones and cell towers are being added without regard for their disadvantages (Al-Hamdany & Al-Ahmady, 2022).

2.6 International and National Standards and Guidelines

With the increased usage of wireless technology, there is growing worry about the health risks associated with RF radiation (Renke & Chavan 2018). To research the radio frequency field, its effects on human health, and to monitor the radiation level, several international organizations such as the WHO, ICNIRP, FCC, and

IEEE provide global safety recommendations and procedures. These recommendations are based on the thermal effects of radio frequency radiation. These guidelines provide safe exposure limits for the general population and occupational, i.e., workers. WHO is the first body to express worry about the health risks associated with RF fields, but it is the first to recognize ICNIRP's work in the field of non-ionizing radiation and its impact. Europe and North America were the first to express worry about the potential dangers of RF exposure on public and professional health. Since 1985, the FCC has accepted and has been using these internationally acknowledged safety recommendations for evaluating RF environmental exposure in the United States, whereas the majority of Europe has followed ICNIRP guidelines. IEEE standards were created by experienced scientists and engineers following comprehensive studies of the scientific literature on the health effects of radio frequency radiation. Federal health and safety agencies, such as the Environmental Protection Agency's (EPA) Safety Code 6 Regulations: Canada, the National Institute of Occupational Safety and Health (NIOSH), and the Occupational Safety and Health Administration (OSHA), have also been monitoring and investigating issues related to RF exposure(Renke & Chavan 2018).

Numerous adverse health effects have been documented at doses lower than those recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), including altered white blood cells in children; childhood leukemia; impaired motor function, reaction time, and memory; headaches, dizziness, fatigue, weakness, and insomnia, among others (Al-Hamdany & Al-Ahmady, 2022). The total average power radiated, is determined by integrating the power flow over the source's sphere of radius, r. Antennas radiate in two directions: horizontally and vertically. There is a single primary lobe and many secondary lobes. The half-power beam-width (HPBW – defined as the angular range within which maximum power is reduced to half its value) of the primary lobe is 65 degrees in the horizontal direction and 6 degrees in the vertical direction.

2.7 The National Environmental Standards and Regulations Enforcement Agency (NESREA) and the Telecommunications Sector

The National Environmental Standards and Regulations Enforcement Agency was formed in 2007 by the National Environmental Standards and Regulations Enforcement Agency Act. The Federal Government formed the Agency as a parastatal of the Federal Ministry of Environment in accordance with section 20 of the 1999 Nigerian Constitution, as amended. The Agency is charged with the responsibility of enforcing environmental standards, rules, laws, policies, and recommendations (Oruonye, 2021). In accordance with its purpose, the Agency drafted the National Environmental (Standards for Telecommunications and Broadcast Facilities) Regulations, 2011. The Regulations' primary objective is to guarantee uniform implementation of environmental laws, regulations, and standards throughout all sectors of the Nigerian telecommunications and broadcast industries.This describes NESREA's entrance into the telecoms industry. As a result, rule 5(4)(1)(b) of the NESREA Regulations, 2011 requires that all new facilities have a minimum setback distance of ten metres from the perimeter wall of any property to the base of the mast/tower. This is where NCC and NESREA diverge. In the majority of cities, including Sagamu, mobile phone towers are located near residential areas, with some on the roof tops of big business buildings. Although the antenna emits less power vertically downward, the distance between the antenna and the top floor is often only a few meters, ensuring that the radiation intensity in top floors remains extremely high. The antennas linked to the base station are often positioned high above ground level to avoid interference from buildings and other objects. Antennas for macro cellular base stations are typically mounted between 15 and 50 meters above ground level, as they are meant to deliver communications over many kilometers(Osahon, et al. 2017). Microcellular base stations, on the other hand, have their antennas positioned closer to the ground since communications are limited to a few hundred meters. Osahon, et al. (2017) affirmed that, antennas are installed directly on existing structures, such as buildings, although ground-based lattice towers, shorter masts put on rooftops, and lamp-post systems are also utilized. An antenna for a GSM900 base station broadcasts at a frequency of 935 – 960 MHz. This 25 MHz frequency range is split into twenty 1.2 MHz sub-bands that are assigned to separate operators. A single operator may be assigned several carrier frequencies (1 to 5), with a maximum bandwidth of 6.2 MHz. Each carrier frequency is capable of transmitting between 10 and 20 W of electricity. Thus, one operator may send 50–100 W of electricity and three–four operators may be located on the same roof top or tower, resulting in a total sent power of 200–400 W. Additionally, directional antennas are employed, which generally have a gain of approximately 17 dB, allowing for the effective transmission of several kW of power in the main lobe direction (Osahon, et al. 2017). This can be related to the study frequency band (1800 MHz) with a few exceptions, as illustrated in Table 1

Table 1 NCC Frequency Spectrum Allocation at 1800MHz.

Operators	GLO	MTN	IRTEL	ISALAT
Transmitting Frequency	1820 - 1835	1835-1850	1850-1865	1865-1880

III. REVIEW OF EMPIRICAL STUDIES

Oruonye, (2021) assessed of the level of compliance of GSM mast location to environmental standard regulations. ArcGIS 10.1 was used to create a geo-database depicting the study area's base stations and their distribution in space. Using the buffer Tool found in ArcGIS's Geo-Processing Tool Box, the authors were able to set up buffer zones of 5 and 10 metres around GSM Base Stations. Throughout the city, 59 GSM masts were located. The research found that only 10.2% of the masts complied with the regulatory setback while 89.8% did not. Clustering of houses around GSM masts indicates a violation of the 5m and 10m NCC/ NESREA regulations because the environmental effects of GSM masts locations, such as oil spillage into wells, mast falling, building cracks/collapse, are more severe in areas closer to the masts and decrease as the distance increases away from the masts.

In a work by Musa, et al. (2016) on the assessment of spatial distribution of telecommunication base stations and compliance level of the operators to the regulations in Federal Capital City Abuja, Nigeria. Their research aimed to ascertain the density of Abuja's cellular towers and whether or not the various service providers were in accordance with the rules set forth by the Nigerian Communication Commission (NCC). They used the preexisting base stations in Abuja to collect both secondary and primary data. The research included both geographical analysis using satellite imagery and field surveys. According to the findings of the research, 92 base stations within the metropolitan area are not compliant with NCC standards (26.1 percent). Researchers found that 17 overlapping base stations could be turned off without affecting service provided by the operators. The NCC standards were found to play a smaller role in base station placement than economic considerations. In order to get in line with NCC regulations, it was suggested that 17 base stations be turned off.

Mohammed (2019) used the descriptive-observational research design method to figure out how the placement of mobile phone towers in Minna, Nigeria affects the environment. The Global Positioning System (GPS), the Testo 815 sound metre, and the Rasi-700 air quality metre were used to find out where the GSM mast was, how loud it was, and how much pollution there was. The collected data was put through descriptive statistics (frequency, percentage, mean, and standard deviation) and spatial analysis (Nearest Neighbourhood Analysis). The study found that there were a total of 74 network antennas from four different network operators (MTN, GLO, Airtel, and 9Mobile) on 58 GSM masts all over Minna. Seventy-two (72%) of the 58 GSM masts are used by only one network operator, while only 22 (28%) are used by more than one. The study also found that all of the GSM masts in Minna, except for those belonging to MTN mobile, have a clustered distribution pattern. All of the GSM operators also did not follow the 10m setback regulation by NESREA or the 1000m tower-tower regulation. So, the study comes to the conclusion that there are a lot of GSM masts in Minna, but most of them don't follow NCC and NESREA regulations.

IV. RESEARCH METHODOLOGY

This consists of research approach, requirement specifications and research method.

4.1 Research Approach

The study measured RF radiation from different frequency bands at selected base stations. Spatial proximity measurement of base stations to residential settlements at selected base stations will also be geospatially measured by running proximity analysis in ArcGIS environment. The RF levels and spatial proximity measurement at each base station was analyzed with respect to ICNIRP, WHO, NESREA, NCC regulations to identify the compliance level.

4.2 Requirement Specifications

Hardware Minimum Requirements: This include a hand held broadband 3 axis RF Field meter operating in the frequency range of 50 MHz to 3.5 GHz, GPS (Global Positioning System) for recording location coordinate, digital camera, tape rule, laptop with at least 250 GB HDD, 4 GB RAM, and an Intel Pentium Dual-Core processor

Software Requirements: Microsoft Windows operating system, ArcGIS 10.41 for spatial analysis and interpretation, Microsoft office (Word, excel)

4.3 Research Method

Sampling/Data Collection Technique

The research took place in and around the city of Sagamu Metropolis. For the purposes of this study, the condition of RF radiation in Sagamu and its surrounds would be assumed to be indicative of RF radiation expectations in underdeveloped nations, notably Nigeria, the cellular base stations for this study was chosen at random.

Description of Research Instrument

The instruments used in this study are:

1. A hand held broadband 3 axis RF Field meter operating in the frequency range of 50 MHz to 3.5 GHz for monitoring frequency radiation, electromagnetic field value of the Radio - Frequency, isotropic measurements of electromagnetic fields with three-channels measurement sensor.
2. Laptop/PC with the relevant sftware to process the measured results.
3. GPS (Global Positioning System) recording location coordinates.
4. Digital camera

4.4 System Design

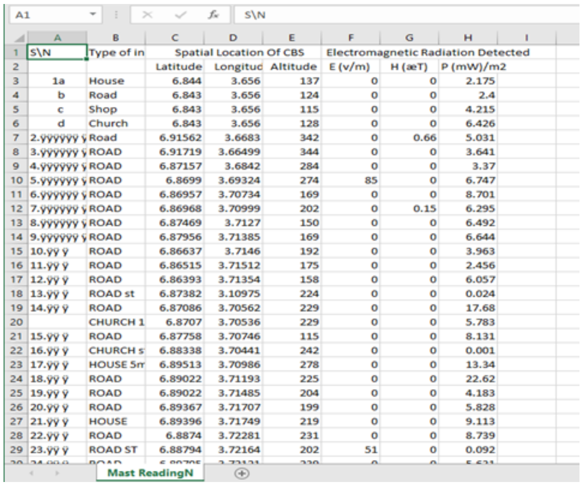
System design entails data capturing, data cleansing preparation and Data Processing and Analysis.

Data Capturing

In this phase, a handheld GPS device was used to record the location of the Central Base Station. Going out to various Base Station locations to record their coordinates constituted the fieldwork for this exercise (longitude and latitude). This fieldwork was conducted to discover where each Base Station in Sagamu is located. To locate the area with the highest RF field strength, an RF Field metre was used to measure the spatial variation of RF fields in the area (Yussuff, & Adewole, 2020). Details about the locations, including GPS coordinates, were recorded. Between 20 and 200 metres were measured from the base of each base station mast. After surveying and scanning the entire MBTS to obtain the highest possible readings, the optimal measurement points were determined. A portable broadband three-axis RF field metre operating from 50 MHz to 3.5 GHz was used to measure the electric field strength and power density. Electric field strengths and power densities were measured and recorded at each location. In addition, a measuring tape was used to record data on how far away these base stations were from various residential areas.

Data Cleansing and Preparation

This stage involved the addition and subtraction of necessary information to the data collected on the field. This was done to avoid repetition and redundancy of the collected data. In addition, the preparation of the data was carried out by the use of Microsoft Excel (as shown in figure 3.1). The coordinates (longitude and latitude) were plotted in rows and columns against the name of the adjoining land use.



S\N	Type of in	Spatial Location Of CBS			Electromagnetic Radiation Detected		
		Latitude	Longitud	Altitude	E (v/m)	H (æT)	P (mW)/m2
1a	House	6.844	3.656	137	0	0	2.175
b	Road	6.843	3.656	124	0	0	2.4
c	Shop	6.843	3.656	115	0	0	4.215
d	Church	6.843	3.656	128	0	0	6.426
2.ÿÿÿÿÿÿ ÿ	Road	6.91562	3.6683	342	0	0.66	5.031
3.ÿÿÿÿÿÿ ÿ	ROAD	6.91719	3.66499	344	0	0	3.641
4.ÿÿÿÿÿÿ ÿ	ROAD	6.87157	3.6842	284	0	0	3.37
5.ÿÿÿÿÿÿ ÿ	ROAD	6.8699	3.69324	274	85	0	6.747
6.ÿÿÿÿÿÿ ÿ	ROAD	6.86957	3.70734	169	0	0	8.701
7.ÿÿÿÿÿÿ ÿ	ROAD	6.86968	3.70999	202	0	0.15	6.295
8.ÿÿÿÿÿÿ ÿ	ROAD	6.87469	3.7127	150	0	0	6.492
9.ÿÿÿÿÿÿ ÿ	ROAD	6.87956	3.71385	169	0	0	6.644
10.ÿÿ ÿ	ROAD	6.86637	3.7146	192	0	0	3.963
11.ÿÿ ÿ	ROAD	6.86515	3.71512	175	0	0	2.456
12.ÿÿ ÿ	ROAD	6.86393	3.71354	158	0	0	6.057
13.ÿÿ ÿ	ROAD st	6.87382	3.10975	224	0	0	0.024
14.ÿÿ ÿ	ROAD	6.87086	3.70562	229	0	0	17.68
	CHURCH 1	6.8707	3.70536	229	0	0	5.783
15.ÿÿ ÿ	ROAD	6.87758	3.70746	115	0	0	8.131
16.ÿÿ ÿ	CHURCH s	6.88338	3.70441	242	0	0	0.001
17.ÿÿ ÿ	HOUSE 5m	6.89513	3.70986	278	0	0	13.34
18.ÿÿ ÿ	ROAD	6.89022	3.71193	225	0	0	22.62
19.ÿÿ ÿ	ROAD	6.89022	3.71485	204	0	0	4.183
20.ÿÿ ÿ	ROAD	6.89367	3.71707	199	0	0	5.828
21.ÿÿ ÿ	HOUSE	6.89396	3.71749	219	0	0	9.113
22.ÿÿ ÿ	ROAD	6.8874	3.72281	231	0	0	8.739
23.ÿÿ ÿ	ROAD ST	6.88794	3.72164	202	51	0	0.092

Mast ReadingN

Figure 4: Screenshot of Data Captures Showing Type of Infrastructure, Spatial Location, EM Radiation Detected and Nearest Distance.

Source: Field Survey 2022

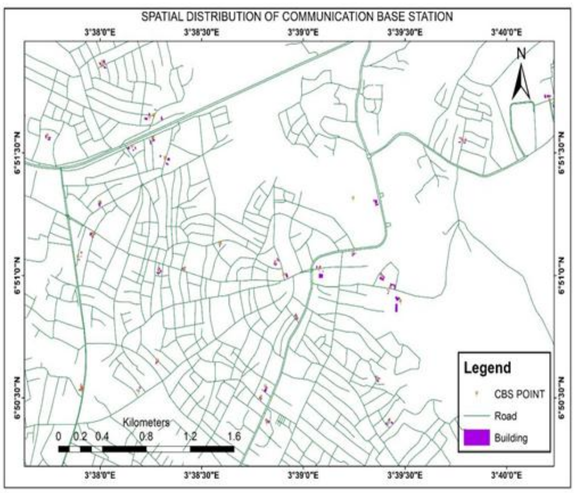


Figure 5: Spatial Distribution of Base Stations

Source: Field Survey 2022

Data Processing and Analysis

The data processing and analysis were done by using ArcGIS 10.41. it involves the following steps:

1. Importation of the excel file into ArcMap environment.

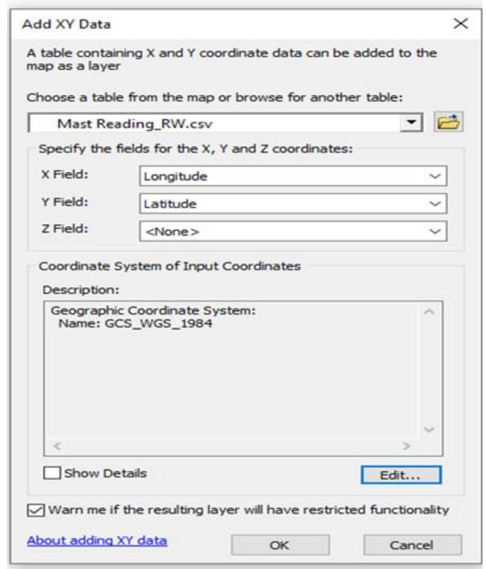


Figure 6: Importation of the Excel File into ArcMap Environment

Source: Research Design 2022

2. Downloading of satellite imagery of Sagamu. This was done by the use Universal Map Downloader, it involved the provision of the latitude and longitude of the study area (top/bottom & right/left)

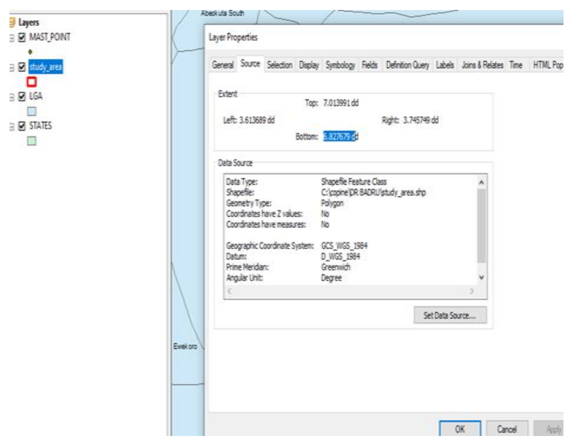


Figure 7 (a)

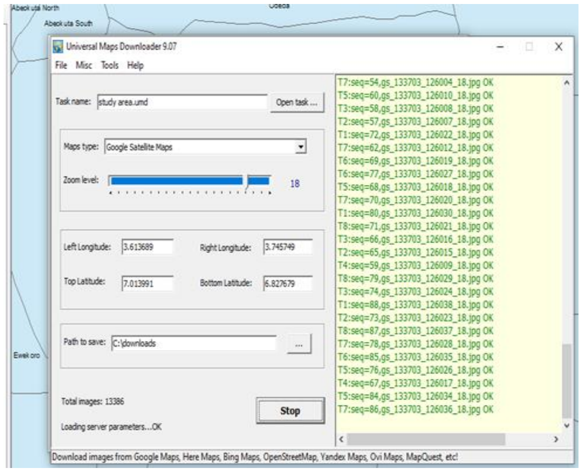


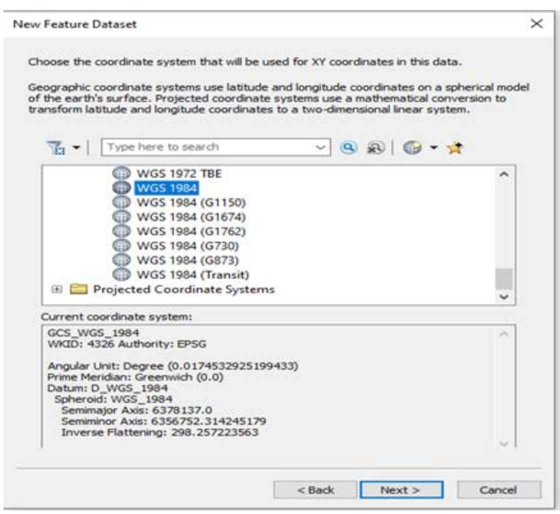
Figure 7 (a) and (b): Screenshot of Satellite Imagery Download of Sagamu

Source: Field Survey 2022

Spatial Proximity Measurement of Base Stations to Residential Settlements at Selected Base Stations in Sagamu.

3. Vectorisation of the satellite imagery

The buildings located close to each Central Base Station were digitized, in order to be to measure the distance between them and the CBS.



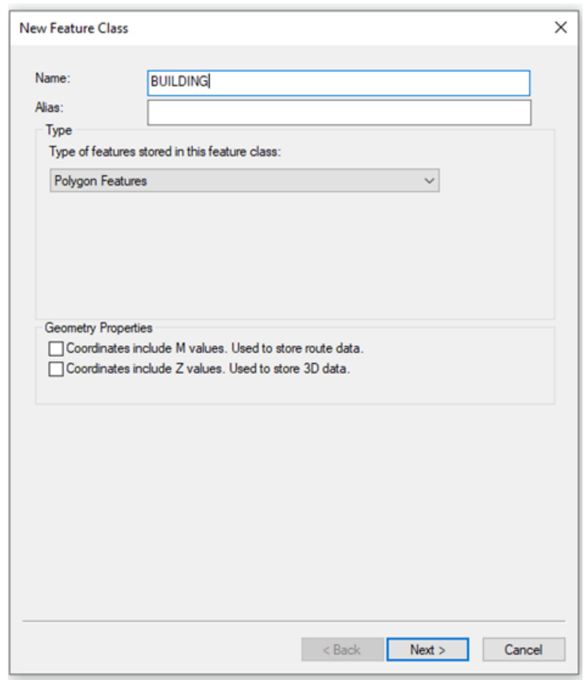


Figure 8 (a) and (b): Screenshots of Vectorisation of the satellite imagery

Source: Research Design 2022

4. Between the buildings and Central Base Station: The distance between the central Base Station and the surrounding were measured by using a tool from the ArcMap toolbox called NEAR. The tool measures the distance between two features in the ArcMap environment.

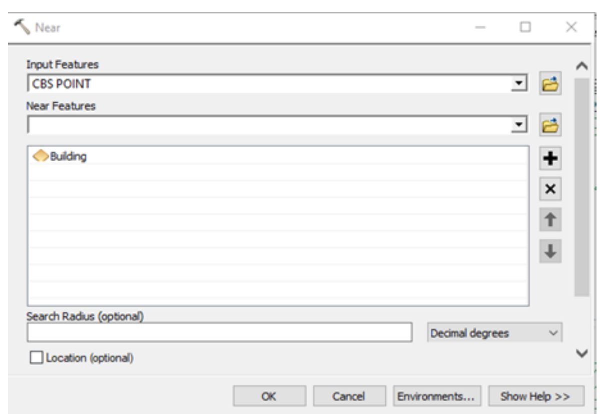


Figure 9: Screenshot of Tools Used to Measure the Distance between the Central Base Station and the Surrounding

Source: Research Design 2022

4.5 Investigation of RF Levels and Spatial Proximity to Base Stations

The data was comparatively analyzed with the international regulations (ICNIRP) for RF exposure levels, and local regulatory bodies in Nigeria (NESREA, NCC) regulations for proximity measurements. Any one that is higher or less than or equal to the normal exposure level will be recorded as non-compliant and the complaint respectively.

4.6 Method of Data Analysis

Data collected from the RF levels and spatial proximity measurement at each base station was tabulated based on GPS of site location, distance from mast (m), electric field (V/m) and power density (W/m^2). The data will be comparatively analyzed with the ICNIRP, NESREA & NCC regulations for public limiting exposure and closeness. The GPS location was analyzed using ArcGIS for the spatial information of the area of study.

V. RESULTS

Result on Spatial Proximity Measurement of Base Stations to Residential Settlements at Selected Base Stations In Sagamu Metropolis

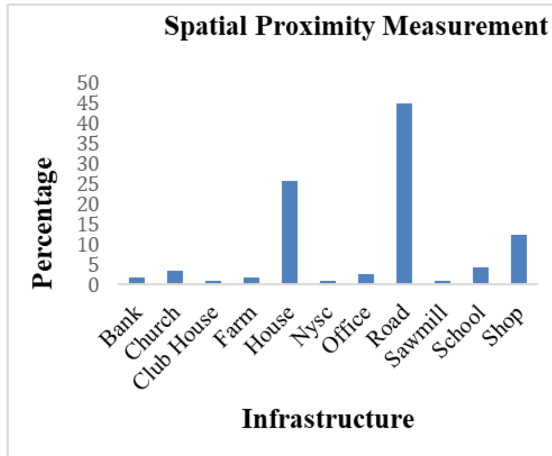
Table 2 Frequency Table of Type of Infrastructure Close to MBST's

Type of Infrastructures	Frequency	Percentage
Bank	2	1.8
Church	4	3.6
Club House	1	.9
Farm	2	1.8
House	29	25.7
Nysc camp	1	.9
Office	3	2.7
Road	51	45.1
Sawmill	1	.9
School	5	4.4
Shop	14	12.4
Total	113	100.0

Source: Field Survey, 2022

Figure 8: Chart Showing Type of Infrastructure and Percentage

The study revealed that the study area had about 113 CBS distributed around the over 200 km^2 aerial extent of the study area. Those base stations were noticed to be located around



the city centre with very few located around the peri-urban areas of the study area. This implies that most of the base stations are located within the activity areas and the residential neighborhoods. One major characteristic of the base station was its location along the major route within the study area. In other word only 88.5% were in operation. From Table 2, it can be observed that road infrastructure has the highest frequency which represent 51 (45.1%) of the entire infrastructure while the residential houses have 29 (25.7%), shop 14 (12.4%). Other infrastructure frequencies are presented on the table.

Only 23.9% (27) of the MBST's complied with NCC regulations (5m) set back to the closest infrastructure, while majority 76.1% (86) of the measured MBST's do not comply. However, majority 62.8% (71) of the MBST's complied with the NESREA standard of 10 metres set back while 37.2% (42) do not comply with the regulations as they do not meet the 10 meters set back from the nearest infrastructure.

Table 3: ICNIRP Reference Levels for Different GSM Frequency Bands

Frequency Band (MHz)	Electric Field (V/m)	Power Density (W/m^2)
900	41	4.459
1800	58	8.923
2100	61	9.870

The reference to ICNIRP in Table 3 displays the maximum permissible power density limits for GSM networks operating at various frequency bands (ICNIRP, 2009). These limits, which will be used in this study to analyze the compliance levels of base stations located within the study area, can be found in ICNIRP's table.

Table 4: Infrastructures that Violates ICNIRP Recommended E (v/m) for 900Mhz, GSM 1800 MHz, WCDMA 2100 MHz

Type of infrastructure nearest to CBS	Latitude	Longitude	Altitude	E (V/m)	Distance
ROAD	6.8699	3.69324	274	85	0
ROAD ST	6.88794	3.72164	202	51	0
ROAD	7.00436	3.66544	562	45	0
HOUSE	7.00432	3.66552	560	61	0.02
CLUB HOUSE	6.85793	3.63866	281	54	0
ROAD	6.84225	3.63187	133	60	0.04

Source: Field Survey, 2022

Table 4 shows infrastructures that violates the recommended E (v/m) for 900MHz, GSM 1800 MHz, WCDMA 2100 MHz rates. The BST at location lat/long/Alt (6.8699/3.69324/274) has the peak value for electric field strength (85 V/m) which violated the ICNIRP standard for 900Mhz, GSM 1800 MHz, WCDMA 2100 MHz. This is followed by the BST at lat/long/Alt (7.00432/3.66552/560) at 61 V/m. Others include, lat/long/Alt (6.84225/3.63187/133) at 60 V/m; (6.85793/3.63866/281) at 54 V/m; (6.88794/3.72164/202) at 51 V/m; (7.00436/3.66544/562) at 45 V/m. This shows that 6.2% of the total MBTSs in the study area, violated the recommended E (V/m) for 900MHz, GSM 1800 MHz, Wcdma 2100 MHz rates. However, these CBS's complied with NCC and NESREA regulations on base station proximity to the nearest residence (5m and 10m set back respectively)

Table 5: Infrastructures that Violates ICRIP Recommended Power Density for 900MHz, GSM 1800 MHz, WCDMA 2100 MHz

Type of infrastructure nearest to CBS	Latitude	Longitude	Altitude	P (mW/m^2)	Distance
ROAD	6.87086	3.70562	229	17.68	7.55531
HOUSE	6.89513	3.70986	278	13.34	9.259123
ROAD	6.89022	3.71193	225	22.62	20.91693
HOUSE	6.89396	3.71749	219	9.113	39.53444
ROAD	6.89159	3.72064	237	10.07	16.67173
ROAD	6.88334	3.72627	288	10.55	5.327683
ROAD	6.88328	3.72642	270	15.45	10.27098
ROAD	6.8832	3.72707	269	12.5	3.739173
ROAD	6.89895	3.71791	248	11.66	10.08787
ROAD	6.90835	3.68185	347	10.31	5.273474
ROAD	6.91758	3.66139	343	14.92	4.645231
SHOP	6.91757	3.66137	356	9.471	26.35039

ROAD	6.9409	3.63561	319	13.34	15.34428
SHOP	6.9908	3.68112	421	9.113	11.47519
HOUSE	6.99078	3.68118	418	15.27	9.456221
ROAD	6.8577	3.63857	252	12.99	4.041859
ROAD	6.85957	3.62899	270	12.94	16.64315
HOUSE	6.86083	3.63773	294	11.05	5.162242
ROAD	6.86756	3.63844	157	10.63	18.42812
ROAD	6.86425	3.63351	289	12.03	2.314915
CHURCH	6.85207	3.64319	140	16.12	50.03267
SHOP	6.85217	3.64324	169	10.6	24.31804
ROAD	6.85929	3.63769	255	47.75	16.67173
ROAD	6.85039	3.63806	198	29.73	3.605990
HOUSE	6.85086	3.6477	236	9.996	9.174485
HOUSE	6.85521	3.65408	128	9.996	7.273484
ROAD	6.85184	3.65281	127	11.39	12.08719
SHOP	6.84236	3.63181	139	16.37	9.259527
HOUSE 1	6.84208	3.6365	198	14.81	4.738676

Source: Field Survey, 2022

Table 5 shows different MBTS's that violates the power density recommended level by ICNIRIP. From the table, the MBTS on the road at lat/long/Alt (6.85929/3.63769/225) has the highest value for power density which is (47.75mW/m^2). Other also showed high values ranging from 9.966 to 29.73 mW/m^2 which are higher than the power density recommended level by ICNIRIP for 900MHz, GSM 1800 MHz, WCDMA 2100 MHz. Also, majority of the MBTS on the Table 4 didn't comply with the power density standards also didn't comply the NCC and NESREA proximity standards (5m and 10m respectively). This accounts for 25.7% of the total MBTS in the study area that violated the recommended power density levels for 900MHz, GSM 1800 MHz, Wcdma 2100 MHz rates

4.5 Discussion of Findings

The power densities measured at various CBS were analysed. From Table2, it can be observed that road infrastructure has the highest frequency which represent 51 (45.1%) of the entire infrastructure while the residential houses have 29 (25.7%), shop 14 (12.4%). Other infrastructure frequencies are presented on the table. Only 23.9% (27) of the entire MBTSs complied with NCC regulation complied with NCC regulations (5m) set back to the closest infrastructure, while majority 76.1% (86) of the measured MBTSs do not comply. However, majority 62.8% (71) of the MBTSs complied with the NESREA standard of 10 metres set back while 37.2% (42) do not comply with the regulations as they do not 10 meters set back from the nearest buildings. Road infrastructure close to MBTSs presented maximum exposure to electric field, with a peak at around 85 V/m , while all the other measured values are 61 V/m, 60 V/m, 54 V/m, 51 V/m, 45 V/m which show high electric field strength (E).

Also form Table 4 which shows the MBTSs with high power density with a peak value of 47.75 mW/m^2. This accounts for 25.7% of the total MBTSs in the study area. Other also showed high values ranging from 9.966 to 29.73 mW/m$^{2.}$. It can be observed that the power density at t4ese MBTSs is quite high. Since it accounts for 25.7% of the total CBS in the study area. The remaining 74.3% accounts for MBTSs that complied with recommended power density levels for 900MHz, GSM 1800 MHz, Wcdma 2100 MHz rates($P_t/4\pi R^2$). It however increases gradually as one move away from the base station and decreases at greater distance. This suggests that the base station antennas were not particularly directional, which would explain the diffuse nature of the power densities. The data also showed substantial fluctuations while being measured. Although it was predicted that power density would decrease as the square of the distance (Pt /4R2), the opposite appeared to be true in most cases. There were five factors noticed during measurement that could account for fluctuations: I immovable structures erected in the field of view that obstruct the view (ii) electromagnetic radiation (EMR) interference from nearby radio and television antennas, receivers, etc., at the reference base station. (iii) disruption due to electromagnetic radiation or outside noise from passing vehicles, motorcycles, etc. iv) the relative elevation of the land around the reference base station in relation to the distance from the base station, and v) the presence of wave interference from other mobile base stations in close proximity to the reference base station. As the distance from an object increased, the power density typically decreased.

CONCLUSION

The minimum average power density from individual base station (surveyed) in the town was about 9.113 mW/m^2 while the mean maximum was about 47.75mW/m^2.Therefore, RF exposure hazard index in the town of Sagamu was below the permitted RF exposure limit to the general public recommended by ICRNIP this is because, 74.3% of the CBS complied with recommended power density levels for 900MHz, GSM 1800 MHz, WCDMA 2100 MHz rates. The majority of the MBTSs do not comply with NCC (5m) set back regulation. Most of the MBTSs complied with the NESREA standard of 10 metre set back.

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