

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

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Certification

This is to certify that Olabisi Olayinka Onalaja with matriculation number LCU/PG/001077 carried out this research work titled “Electromagnetic Radiation and Spatial Proximity of Mobile Communication Base Stations” in the Department of Computer and Physical Sciences, Faculty of Basic Medical and Applied Sciences, Lead City University, Ibadan, Oyo State for the award of Master of Science Degree (M.Sc.) in Computer Science, faculty of Basic Medical and Applied Sciences, Lead City University, Ibadan, Oyo State, for the award of Master of Science in Computer Science and that this has not been previously submitted.

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Dedication

This project is dedicated to Almighty God, for his infinite mercy, protection and unending grace that he bestowed upon me, throughout my stay in the institution

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Acknowledgement

Firstly, my sincere appreciation goes to my prestigious institution Lead City University for the opportunity given to me to complete my Master's Program and to the University library for the provision of the materials needed.

I am grateful to the department of Computer Science for giving me the privileged to study and to learn, I say a very big thank you to my supervisor Dr. R.A Badru, whose patience, and encouragement, guidance and time have been dedicated in making this research study a success. May the blessings, mercy and protection of Almighty Allah continue to be with him and his family members. Also I acknowledge Dr.A.A, Waheed my PG coordinator who has always been there anytime I called on him. My profound gratitude of appreciation and special thanks goes to the Head of Department, Dr W. Sapkere.

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“Though the above-mentioned institution and persons have assisted in the process of this research work, I alone stand responsible for errors, if any, found in the work”

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) of the MBTSs do not comply. 62.8% (71) of the MBTSs 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) of the total MBTS in the study area 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. Radiations emanating from the accessed base stations in some vicinity are in safe range specified in the guidelines and as such they do not constitute health risk in the short run. Mobile base stations whose RF radiation intensity is significantly high once identified, the settlers should be advised to relocate away from such base stations.

Keywords: Electromagnetic waves, Mobile Phone, Base Stations, power density, radiation level.

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List of Abbreviations

Abbreviation	Meaning
BTS-	Base Transceiver Stations
CDMA-	<i>Code-Division Multiple Access</i>
EMR-	Electromagnetic Radiation
FCC-	Federal Communication Commission
GSM -	<i>Global System for Mobile</i>
ICNIRP-	International Commission on Non-Ionizing Radiation Protection
IEEE-	Institute of Electrical and Electronics Engineers
IHHP-	Invisible Health Hazard Pollution
IR-	Ionizing Radiation
NCC-	Nigerian Communications Commission
NESREA-	<i>National Environmental Standards and Regulations Enforcement</i> <i>Agency</i>
NIR-	Non Ionizing Radiation
NITEL-	Nigeria Telecommunications Limited
RF-EMF-	Radio frequency electromagnetic field
RMS-	Root Mean Square
WHO-	World Health Organization

Appendix

A: Case Summaries

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Chapter One

Introduction

1.1 Background of the Study

In recent years, the global networking market has experienced exponential expansion, resulting in a drastic rise in the number of wireless devices. For the first time, the overall number of cell phone subscribers in the world is projected to have surpassed eight billion, with 8.3 billion subscriptions in 2019. From 2018 to 2019, the total number of subscribers increased by about 393 million¹. With a world population of 7.7 billion people as of 2020, the number of mobile subscribers now far outnumbers the global population. This follows an incredibly successful era of growth. In 2014, the penetration rate in the United States surpassed 100 percent, and it has been over 100 percent in countries such as the United Kingdom (UK) and Australia for many years¹.

The penetration rate has steadily increased on other continents, such as Africa. Cameroon, for example, saw a 39.3 percent growth in smart phone subscribers from 2010 to 2019, with 81.76 per 100 inhabitants in 2019, and Kenya's average surpassed 100 for the first time in 2019¹. Total active lines (Mobile GSM, Mobile CDMA, Fixed wired/wireless, VoIP) in Nigeria will reach 199 million subscribers in 2020, which is equivalent to the whole population of the world².

Telecommunication in Nigeria dates back to 1886, when the British firm Cable & Wireless Ltd laid telegraphic submarine cable lines connecting Lagos and London during the colonial period. As a result, phone lines were installed to link the renowned commercial center to Jebba, Ilorin, Calabar, Ibadan, and other parts of the region. It's worth noting that telephone lines assisted other means of contact in Nigeria, such as radio, television, and the internet³.

NITEL (Nigeria Telecommunications Limited) was founded in 1985. The government owns NITEL and granted it monopoly status in the communications sector.

The Nigerian Communications Commission (NCC) was established in 1992 as a result of the merger of two government entities: the telecoms arm of the Ministry of Communications' Posts and Telecommunications (P&T) department and the Nigerian External Relations Commission. The NCC decree aided in the liberalization of terminal ends equipment by allowing for innovation and private sector participation. 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 goals³.

GLO has over 45 million subscribers as of December 2018, and it expects to have about 54 million by 2020 making it Nigeria's second-largest network operator⁴. GLO was the first telecommunications company to construct the Glo-1 submarine cable, an \$800 million high-capacity fiber-optic cable connecting the United Kingdom and Nigeria. It is the United Kingdom's first effective submarine cable to Nigeria³. MTN constructed the 3,400-kilometer Yello Bahn cable, which extends its reach throughout Nigeria. In January 2001, the telecommunication company was charged \$285 million for one of four GSM licenses in Nigeria. MTN has gradually deployed its networks across Nigeria since its introduction in August 2001, spending more than \$1.8 billion to improve its mobile telecommunications system. It now serves 223 cities and towns, over 10,000 villages and municipalities, and an increasing number of highways throughout Nigeria, covering 36 states and the Federal Capital Territory of Abuja³. With a presence in 14 African countries, mainly in East Africa, Central

and West Africa, Airtel Africa is a major provider of telecommunications and mobile money services. From Econet to Vmobile, Zain, Celtel, and finally Airtel, it has undergone many rebranding. Airtel had over 99 million customers in Africa as of March 2019. It is a constituent of the FTSE 250 Index and is traded on the London Stock Exchange³. Etisalat Nigeria, which began operations in 2008, was one of the country's first major broadband providers. The organization is known for its groundbreaking goods and services, such as the Eco Sim and the 0809uchoose initiative, which was the first network to sell unique numbers to Nigerians as their mobile numbers.

In the country, mobile telephony is rapidly expanding. In 2017, there were over 148 million active telephony subscribers (148,774,015), which increased to over 172 million by 2018 (172,485,805), and to over 208 million by November 2020 (208,485,805), which is nearly the entire population of the nation². Wireless infrastructure is built on the vast network of base stations that links users via RF signals. Due to the rapid increment in the number of customers for diverse networks, the telecom operators are enticed to raise the number of base stations either on the top of a roof or ground based. The base stations are located on the rooftop of high rise building in the case of urban areas and on the ground in the rural areas. The height of such base stations are usually ranging from 3 to 15 meters in case of rooftop while varying from 15 meters to 50 meters from the ground in case of ground based buildings.

1.1.1 Communication Towers in Nigeria

According to a report, 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 2020⁵. 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 53,460⁷. 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 placement⁸.

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 short-term effects include effects in brain electrical activity, cognitive function, heart rate and blood pressure which contributes to the burning and tingling feeling in the skin of the head, exhaustion, sleep disruption, dizziness, lack of focus, ringing in the ears, loss of memory, headache, nausea, vomiting, disturbance in digestive system etc⁸. In the other hand, despite the lack of conclusive proof of long-term effects, they are linked to epidemiologic effects such as cancer and brain tumors. Cancer, diabetes, obesity, respiratory diseases, infertility, neurodegenerative conditions, are also on the rise in various countries, according to the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO). IHHP (invisible health hazard pollution) is a new environmental danger⁸. Government agencies and international organizations have developed various protocols, practices, and recommendations to research the RF field, its effects on humans, and to track the radiation level.

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. occupational⁸. In Nigeria, NCC and NESREA which are the regulatory bodies also have recommend guidelines for base station.

1.1.2 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 lives⁹. An electromagnetic field or wave is made up of two fields: an electric field (E) 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 ($\sqrt{2}$) for a sinusoidally varying field. The Electric and Magnetic fields are at right angles to each other and also to the direction in which the energy is propagating at a proper distance from the source, where the wave can be represented as a plane wave. The Power density (S), which is calculated in W/m^2 , is the sum of electromagnetic energy flowing through a point per unit area at right angles to the direction of energy flow per second⁹.

Electric and magnetic forces were thought to be two distinct forces. There are four major categories: (a) The attraction or repulsion force between electric charges is inversely proportional to the square of their distance. (b) Much as what electric charges do, magnetic poles come in pairs that attract and repel each other (c) An electric current in a wire generates a magnetic field whose direction depends on the direction of the current. (d) A magnetic field is generated by a moving electric field, and vice versa. To explain these phenomena, Maxwell devised a series of calculations known as Maxwell's equations⁹.

1.1.3 Electromagnetic Waves and Spectrum

This is a continuous range of wavelengths called the electromagnetic spectrum as shown in figure 1.1. Many types of radiations which depending on their frequency and wavelength that occur in different parts of the spectrum have many uses and hazard. Radiation is energy that

moves and extends out as it travels. For example, visible light from a lamp in the home and electromagnetic waves from a radio station are two examples of radiation⁹. EMR can be classified into Ionizing radiation (IR) and non Ionizing radiation (NIR). Microwaves, infrared light, ultraviolet light, X-rays, and gamma-rays are the other forms of electromagnetic radiation (EMR) that make up the electromagnetic spectrum, as seen in the figure 1.2. Ionizing radiation is electric radiation that provides the energy to remove atoms and molecules from tissue, creating a transition in chemicals through contact with the electron.

The ionization of the atom and molecule can trigger DNA damage within cells, which can lead to tumors, birth defects, and genetic defects due to DNA mutations induced by the ionization of the atom and molecule. X-rays and gamma rays are examples of ionizing radiation⁹. For non Ionizing radiation, there isn't enough energy in this kind of radiation to ionize any atoms or molecules. Radio waves, microwaves, radar, visible light waves, TV, stations, wireless telephones, global positioning devices, and FM and AM radio are also examples of non-ionizing radiation⁹. Other types include the earth's magnetic field, as well as magnetic fields that can be seen around power poles, electronic equipment, and home wiring. They are called extremely low-frequency (ELF) waves, although they're not deemed a clear danger to human health. Non-ionizing radiation may have non-mutagenic effects, such as causing burns by inducing thermal energy in biological tissue. Non-ionizing radiation (illustrated in Figure 1.0) does not specifically affect genetic material (DNA) in molecules, according to previous research, and therefore cannot cause cancer⁹.

1.1.4 Microwaves Frequency

Microwaves are electric waves with wavelengths ranging from one meter to one millimeter that we cannot perceive (illustrated in Figure 1.0)⁹. These waves power all the devices humans send to planets using fixed and mobile radio broadcasting, such as radio, television, wireless communications, and navigation to control all the devices humans send to planets, the world of space computer networks, and other applications.

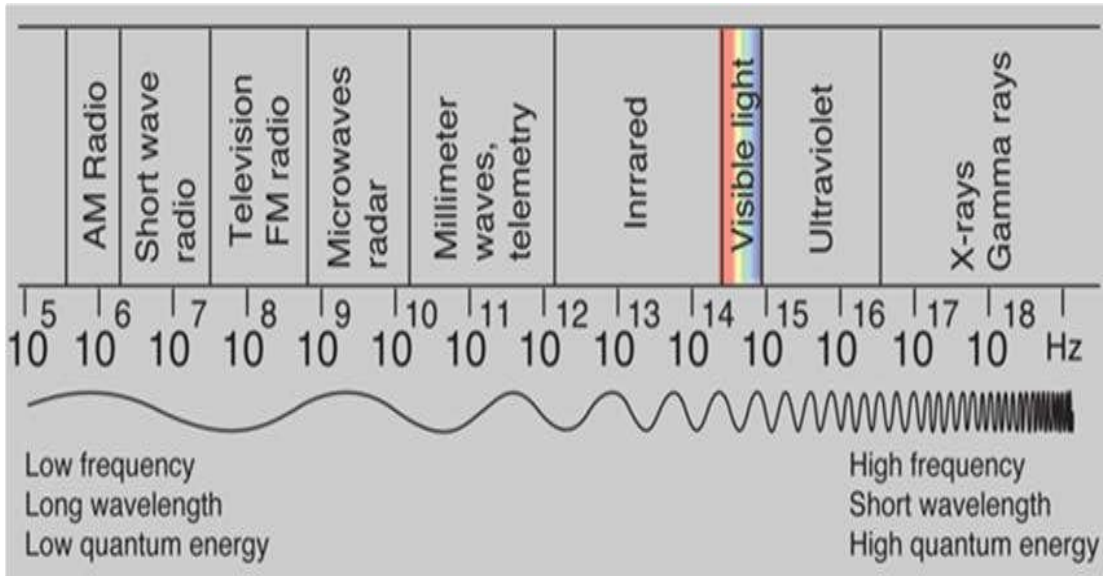


Figure 1.1: Electromagnetic Spectrum⁹

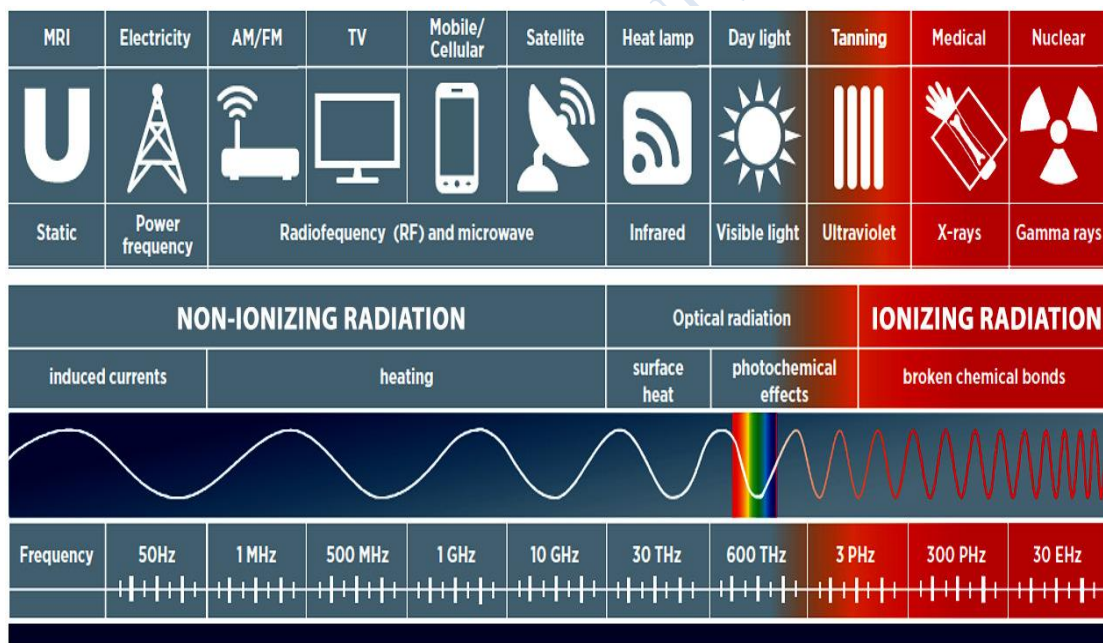


Figure 1.2: Ionizing and Non-Ionizing Radiation¹

The exponential rise of wireless networking has raised concerns about the dangers of microwaves being more common, with microwaves being seen all over us, raising the possibility that certain sources of non-ionizing radiation could have biological consequences which can lead to cancer in some circumstances⁹. Researchers have analyzed the effect of

these waves and their threats to human health in biological experiments. Radiation, which includes radio waves and microwaves, is at the low-power end of the electromagnetic spectrum because it contains less energy than other types of non-ionizing radiation, such as visible light and infrared radiation, which have enough energy to move the atoms in a molecule around or cause it to vibrate but not enough to ionize it. Microwave absorption in large amounts with sufficiently water-containing content, such as food, fluids, and body tissues, has been discovered to generate heat, according to researchers. This will result in skin injury and burns. Although microwave radiation does not induce cancer by disrupting DNA in cells as ionizing radiation does, certain sources of non-ionizing radiation have been linked to cancer in the past⁹.

Exposure to Radio Frequency Radiation (RFR) from both mobile towers and mobile phones can cause thermal and non-thermal effects when held close to the body. Exposure to the thermal effect can result in cataracts, weakness, and a loss of mental focus¹⁰. Many scientists are interested in studying radiation's non-thermal effects, and they've linked it to changes in cell membrane permeability¹¹. Researchers have divided the effects of radio frequency radiation into two categories: thermal and non-thermal effects.

1.1.5 Mobile Phone Base Stations

The use of cellular (mobile) phones has increased dramatically in Nigeria over the years, prompting the expansion of cell phone towers to cover the entire country. Base stations, also known as cell phone towers, are fixed transmission sites that are part of a network's mobile phone grid. They are made up of three antennas, two for receiving and one for transmitting. Two are used on the receive side so that the base station can match signals and choose the right antenna for each customer inside the cell. They are built on a tower and a building with electronics at the base, and their purpose is to receive and transmit radio signals like a mobile phone⁹. The power levels transmitted by mobile phone towers range from a few watts to 100 watts or more, determining the scale of the region that they are designed to serve. Cell phone

tower antennas with a length of about 100 cm and a diameter of about 20–30 cm are often installed on elevated structures or towers at a height of (15–50) meters above ground to communicate with cell phone users who are often near the ground⁹. These antennae emit RF beams that are normally very small in the vertical direction, but the RF field intensity increases significantly as one moves away from the base station and then decreases as one moves farther away from the antenna.

There are many types of existing base stations. Each type has a specific use according to the coverage needed ⁹. Basic transceiver communication base stations are:

- i. **Macro cell:** Used in large areas such as rural areas and highways because it covers the wide distances also its performance can be increased by increasing the efficiency of the transceiver.
- ii. **Micro cell:** Used where a mobile network requires additional coverage to maintain the quality of service to subscribers.
- iii. **Pico cell:** Utilize within homes, when a mobile network needs extra coverage to ensure the level of service to customers.

1.1.6 Base Station Network

A mobile network, also known as a cellular network, is a radio network that is divided into ground stations, each of which is served by at least one stationary site transceiver, also known as a base station. Each cell uses a various range of frequencies from neighboring cells, to obviate interference and provide guaranteed bandwidth within each cell when connected with each other, these cells provide radio coverage over a vast geographic area. This allows a vast number of portable transceivers (e.g., pagers, cell phones, etc.) to connect with each other as well as with stationary transceivers and telephones located within the network via base stations. The antennas receive radio signals, which are then broadcast as radio waves into the field, or cell, surrounding the base station. A larger base station installation will typically have a plant room with electronic devices as well as a mast with antennas⁹.

For transmissions, panel-shaped sector antennas or pole-shaped omni-antennas are used and they communicate with cell phones. Dish antennas are used to link base stations and divide the network into cells using point-to-point microwave connections. Instead of using microwave connections, the base stations are also linked by buried cables. Base stations can be anywhere from a few hundred meters apart in major cities to several kilometers apart in the countryside, depending on the location of the base station and the amount of mobile phone usage to be handled. In areas with low cell phone use, base stations may only have one transmitter attached to their antennas, so they can only broadcast on one frequency¹¹.

Base stations in congested areas can have ten or more transmitters connected to their antennas, allowing them to transmit on many frequencies at once and handle communications from a large number of mobile phones⁹. The power density of each base station transmitter is set to a level that allows a mobile phone to be used within the coverage area for which the base station is designed. Larger cells, as well as cells with rough ground terrain, necessarily require higher powers¹². Individual macro-cellular base station transmitters typically have maximum powers of 5 to 10 watts, but where multiple transmitters are present, the overall radiated power from an antenna will reach up to 100 watts.

The radiated power of a low-capacity base station with just one transmitter does not differ over time or with the number of phone users. A base station like this can handle up to seven phone calls at once. The output power of greater capacity base stations with multiple transmitters can vary over time and with the amount of calls handled⁹. One of the transmitters will transmit constantly at full power, while the others will run occasionally and at differing power levels up to the limit. For example, the power density output of a micro cellular base station with 10 W transmitters could fluctuate between 10 W and 100 W over time. Because of their reduced coverage ranges, micro cellular base stations usually run at lower power levels of 1 to 2W and have fewer transmitters⁹. Hence, electromagnetic radiations from base

stations and their proximity to offices, shops, residences e.t.c need to be investigated and analyzed for effective compliance to the regulatory standards in Nigeria, specifically, Sagamu.

1.2 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 as 5.0 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 $3f_m^{0.5}$, $0.008f_m^{0.5}$ and $f_m/40$ respectively for occupational exposure scenario while general public exposure scenario should be $1.375f_m^{0.5}$, $0.0037f_m^{0.5}$ 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} , 113.137 Am^{-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.

1.3 Aims 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:

- i. 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.
- ii. Carry out spatial proximity measurement of base stations to residential settlements at selected base stations in Sagamu Metropolis.
- iii. Comparatively analyze the RF levels and spatial proximity measurement of each base station with ICNIRP, NESREA, NCC regulations for public limiting exposure.

1.4 Research Question

- i. 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?
- ii. What is the spatial proximity measurement of base stations to residential settlements at selected base stations in Sagamu?
- iii. Does the RF levels and spatial proximity measurement at each base station conform to with the ICNIRP, NESREA, NCC regulations?

1.5 Significance of the Study

This study would be of immense significance to the network providers and to every citizen and residents of Sagamu. This is because, the result of this study will serve as a checklist for compliance of network owners to the regulated exposure levels and spatial proximity, making the environment safer for the residence of the city.

Also, the findings from this study will serve as a mean of awareness to the resident community and also as a compliance information for the regulators. Academically, this research will serve as reference materials for researcher, students in computer science, physics, Electrical Electronics engineering, medical sciences and other related departments.

The findings will also open door for more researches in Sagamu as regard base station ER radiation and spatial distances.

1.6 Scope of Project

The scope of this research study will be based on Mobile Communication Base Stations (MCBS) in Sagamu metropolis. To evaluate the electromagnetic emission and RF exposure level from MCBS towers, review of both local and international standards for EMR safety guidelines would be employed. The analysis of the EMR level used in Nigeria, review of EMR safety guidelines proposed by NESREA and NCC would also be utilized. These research procedures would facilitate the generation of data that would be used to evaluate the level of electromagnetic field emission and their proximity to residence in Sagamu.

1.7 Limitation of the Study

The research study would be conducted within Sagamu metropolis. Measurements of electromagnetic radiations would be carried out at $1.5\text{ m} \leq x \leq 3.0\text{ m}$ where x is the nearest spatial point to communication base stations. Sagamu-Lagos corridor along the express road to Sagamu Local Government boundary along the road would also be investigated. Last but not the least, results of the study may not be completely generalizable because the sample was restricted to only Sagamu Environ and its metropolis.

1.8 Operational Definition of Term

Electromagnetic Field: It's a spatial feature induced by the movement of an electric charge. They are a force field made up of invisible electric and magnetic forces..

Microwaves: Microwaves are a form of electromagnetic radiation that can be used for a variety of purposes, including communications, radar, and, probably most notably, cooking..

Base Stations: Maintains communication between the network and users, as well as among a large number of users. It's a type of radio receiver with one or more antennas.

Telecommunication: Communication for long-distancing electrical signals or electromagnetic waves.

Electromagnetic Waves: They are waves that are produced when an electric field and a magnetic field vibrate together.

Electromagnetic Radiation: Comprises an electrical field (E) that varies in amplitude in a direction perpendicular to the direction of travel of the radiation, and a magnetic field (M) that is directed at right angles to the electrical field.

Radiation: A source of energy or particles that travels through space or other mediums.

Ionizing Radiation: Ionizing radiation is high-energy radiation that causes an atom to become charged or ionized by removing tightly bound electrons from its orbit.

Non Ionizing Radiation: A form of low-energy radiation that is incapable of removing an electron (negative particle) from an atom or molecule.

Endnotes

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Chapter Two

Literature Review

2.1 Conceptual Review

2.1.1 Mobile Network Technology

Mobile networks have been operational for over four decades, and roughly every decade, a new generation of mobile networks is introduced¹. Around 1980 saw the debut of the first commercial mobile network, and since then, several innovations have shaped the mobile communication sector. As a result, there are several terminology, acronyms, and abbreviations used to describe the various technologies developed during the previous 40 years. Mobile communication technology has evolved through multiple generations (G), as shown in figure 2.1 and there are now numerous 2G, 3G, and 4G base stations deployed across the environment, offering services to mobile phone and other device users^{2,3,4}. A fifth generation (5G) of the technology is currently being developed, which will represent the most recent advancements in mobile communications technology⁴. The term "1G" refers to the first generation of mobile networks, which were meant to offer users with basic voice calling capabilities. In the 1980s, 1G networks were launched in many regions of the world using a variety of analogue cellular technology². AMPS (Advanced Mobile Phone System), NMT (Nordisk MobilTelefoni or Nordic Mobile Telephone), TACS (Total Access Communications System), and C-Netz were among these cellular technologies (Funktelefonnetz-C or Radio Telephone Network C)⁵. AMPS were mostly utilized in the United States and certain Asian nations, whilst NMT was primarily used in the Nordic/Scandinavian region, TACS was primarily used in the United Kingdom, and C-Netz was primarily used in Germany. The first generation of wireless networks used the FDMA-Frequency Division Multiple Access technology. AMPS were eventually updated to D-AMPS, a critical second-generation technology⁵.

Additionally, 2G refers to the second generation of mobile networks that succeeded the older 1G network. These networks offered extremely secure phone conversations, text messages (SMS), and a small amount of mobile data^{2,6}. 2G networks began in the 1990s and were implemented throughout the globe using a variety of digital technologies. The Global System for Mobile Communications (GSM) is the most commonly utilized technological standard for the second generation of mobile networks (GSM). Other technologies used to launch second-generation mobile networks include the Digital Advanced Mobile Phone System (D-AMPS) and Interim Standard 95 (IS-95) (2G)⁶. Two new access methods were used in the second generation of mobile networks: Time Division Multiple Access – TDMA – and Code Division Multiple Access – CDMA. The radio component of a mobile network uses access technologies to wirelessly link mobile phones to the network through radio waves. The initial GSM and D-AMPS networks were circuit-switched and were not designed to provide data services efficiently.

GSM networks incorporated a feature called General Packet Radio Service (GPRS) that enabled the addition of new network nodes to the GSM architecture in order to deliver efficient mobile data (internet) services². GPRS is sometimes referred to as 2.5G since it cleared the door for 3G data services, which eventually made use of the same network nodes established by GPRS⁷. These network nodes are referred to as SGSN (Serving GPRS Support Node) and GGSN (Gateway GPRS Support Node), respectively. Another upgrade, EDGE – Enhanced Data for Global Evolution – was released following GPRS but before 3G networks in order to increase peak download rates from 171.2 kbps (with GPRS) to 384 kbps (with 3G) (with EDGE)⁵. More information on the distinction between GPRS and EDGE may be found in our dedicated page. Another critical technology of the 2G period is IS-95, most often referred to as cdma One. IS-95 was the world's first CDMA mobile network, and it was also meant to enable mobile data⁵. IS-95 was released in two versions: IS-95 A and IS-95 B. IS-95 A is capable of downloading data at peak speeds of up to 14.4 kbps. IS-95 B can boost

these data transfer speeds to up to 115 kbps. IS-95 is particularly significant since it developed into CDMA2000 for 3G cellular services⁵.

3G refers to the third generation of mobile networks in wireless communications. There have been two significant 3G migration paths, both of which were based on CDMA technology (Code Division Multiple Access)^{5,8}. The first track was UMTS, which was used to migrate GSM networks to 3G, while the second track was CDMA2000, which was used for IS-95 and D-AMPS. UMTS is an acronym for Universal Mobile Telecommunications Systems and is based on Wideband Code Division Multiple Access – WCDMA – technology. It supports download speeds of up to 2 Mbps at peak times and data transfer rates of up to 384 kbps on average. We have a special article on 3G UMTS that contains information on the technology, frequencies, and bandwidths. Additionally, UMTS serves as the foundation for HSPA (High-Speed Packet Access networks)⁵. HSPA is capable of peak downlink and uplink data transfer rates of up to 14.4 Mbps and 5.76 Mbps, respectively. UMTS was launched as part of the 3GPP Release 1999 and has since been enhanced with the addition of HSDPA (High-Speed Downlink Packet Access), HSUPA (High-Speed Uplink Packet Access), and Evolved High-Speed Packet Access (HSPA+) to enable increased data rates. HSPA+ is capable of downlink data speeds of up to 42 Mbps and uplink data rates of up to 11.5 Mbps⁵. The CDMA2000 track was primarily for IS-95 and D-AMPS. CDMA2000 is capable of downlink and uplink peak data speeds of up to 153 kbps. Later on, the data speeds on CDMA2000 networks were increased via EVDO (Evolution Data Optimized). EVDO has a theoretical maximum download speed of 14.7 Mbps and a theoretical maximum upload speed of 5.4 Mbps⁵.

Additionally, 4G denotes the fourth generation of mobile networks. It is made possible by the use of a technology known as LTE, which stands for Long Term Evolution (of mobile networks). LTE is the 4G migration path for critical 3G technologies such as UMTS and CDMA2000^{2,9}. While another technology, WiMAX (Worldwide Interoperability for Microwave Access), is capable of meeting 4G criteria as well, LTE has been the dominant

technology for global 4G installations. Unlike prior 2G and 3G networks, which were both circuit and packet switched, LTE networks are packet-based⁵. The voice and SMS components of LTE can be enabled via the packet-based technique Voice over LTE (VoLTE). However, LTE networks include a circuit-switched backup capability, which means that even if the device or base station does not support VoLTE, the LTE network can still offer voice and SMS through 2G or 3G networks.⁵ In comparison to 3G networks, LTE can deliver peak downlink data speeds of up to 300 Mbps and reduced latency. In terms of consumer use cases, 4G LTE networks enable the provision of dependable mobile broadband services owing to the average speeds they permit. LTE on a mobile phone may also be used as a mobile hotspot to supplement your home broadband. Following the debut of LTE, improvements in the form of LTE Advanced (LTE-A) and LTE Advanced Pro were released. LTE-Advanced and LTE-Advanced Pro are referred to as LTE+ on mobile phones and can offer theoretical maximum download rates of up to 1 Gbps and 3 Gbps, respectively⁵. The typical speed of 4G LTE is significantly slower than these peak rates. 4G LTE Advanced networks can deliver download rates of up to 65 Mbps on average. LTE is based on Orthogonal Frequency Division Multiple Access – OFDMA – a radio access technology that is significantly more efficient than previous radio access technologies. Additionally, OFDMA offers the modulation technology QAM – Quadrature Amplitude Modulation, which enables greater data rates and more efficient use of available bandwidth^{5,10}.

Finally, 5G refers to the fifth generation of mobile networks, which is now the most advanced cellular generation. It is enabled by the New Radio (NR) technology, which is based on OFDMA¹¹. 5G is distinct from previous generations of mobile networks in that it is capable of supporting a wide variety of use cases due to its inherent flexibility. 5G is extremely fast and capable of supporting a huge number of devices, which can aid in the digitization of several sectors. Additionally, it is capable of operating in a variety of frequency ranges, including both high and low frequencies. The 5G higher frequency bands have a restricted coverage area

but a very low latency (less than 1 millisecond), making them ideal for real-time services⁵. 5G applications fall into three major categories: improved mobile broadband (eMBB), massive machine type communication (mMTC), and ultra-reliable low latency communications (uRLLC). We have a separate piece on eMBB, mMTC, and uRLLC that will assist you in comprehending these three critical foundations of 5G. According to physical principles, lower frequency bands have a larger latency but much better coverage. As a result, widespread deployment of 5G in rural areas can benefit from the lower frequency bands. On the other hand, because the higher frequency bands have a reduced latency, they are suitable for real-time applications such as self-driving vehicles, manufacturing, virtual reality (VR), and other IoT (Internet of Things) services^{5,11}.

In comparison to 4G LTE networks, 5G NR networks may often deliver much greater data speeds. While 5G has a maximum downlink speed of over 10 Gbps, typical downlink rates of 150 Mbps are very uncommon. Currently, the majority of 5G installations are non-standalone (NSA), which implies they are not fully 5G. 5G non-standalone refers to the use of a mix of 4G and 5G networks to enable 5G technologies.

2.1.2 GSM Network

Global System for Mobile Communications (GSM) is an acronym for Global System for Mobile Communications¹³. 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 2.2. You may easily exchange SIM cards and use another GSM smartphone with 12 GSM phones. GSM features include call encryption, data networking, caller identification, call forwarding, call waiting, SMS, and conferencing. ¹³ GSM (Global System for Mobile Communication) is a digital mobile network that is widely utilized in Europe and other areas of the world by mobile phone users. GSM is the most commonly utilized of the three digital wireless telephony technologies: TDMA, GSM, and code-division multiple access¹³. (CDMA). 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 bands¹⁴. GSM, along with other technologies, is a component of the evolution of wireless mobile telecommunications, which also includes High-Speed Circuit-Switched Data (HSCSD), General Packet Radio Service (GPRS), Enhanced Data GSM Environment (EDGE), and Universal Mobile Telecommunications Service (UMTS) (UMTS). GSM's analog predecessors, notably Advanced Mobile Phone Service (AMPS) in the United States and Total Access Communication System (TACS) in the United Kingdom^{13,14}, were developed. However, these telecommunications networks were unable to expand in response to increased user usage. 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)¹³.

The mobile device establishes a hardware connection to the network. The subscriber identity module (SIM) card contains information about the mobile user that the network may use to identify him or her¹⁵. The BSS is responsible for communication between the cellphone and the NSS. It is made up of two major components: a base transceiver station (BTS) and a base station controller (BSC)¹⁶. The BTS houses the hardware that connects with the mobile phones, most notably the radio transmitter receivers and antennas, whereas the BSC houses the intelligence. The base transceiver station controller connects with and controls a set of base transceiver stations¹⁶. The NSS component of the GSM network architecture, sometimes referred to as the core network, records callers' whereabouts in order to offer cellular services. The NSS is owned by mobile providers. The NSS is composed of several components, such as a mobile switching center (MSC) and a home location registry (HLR). These components

provide a variety of services, including call routing and SMS routing, as well as authenticating and storing caller account information via SIM cards¹⁷.

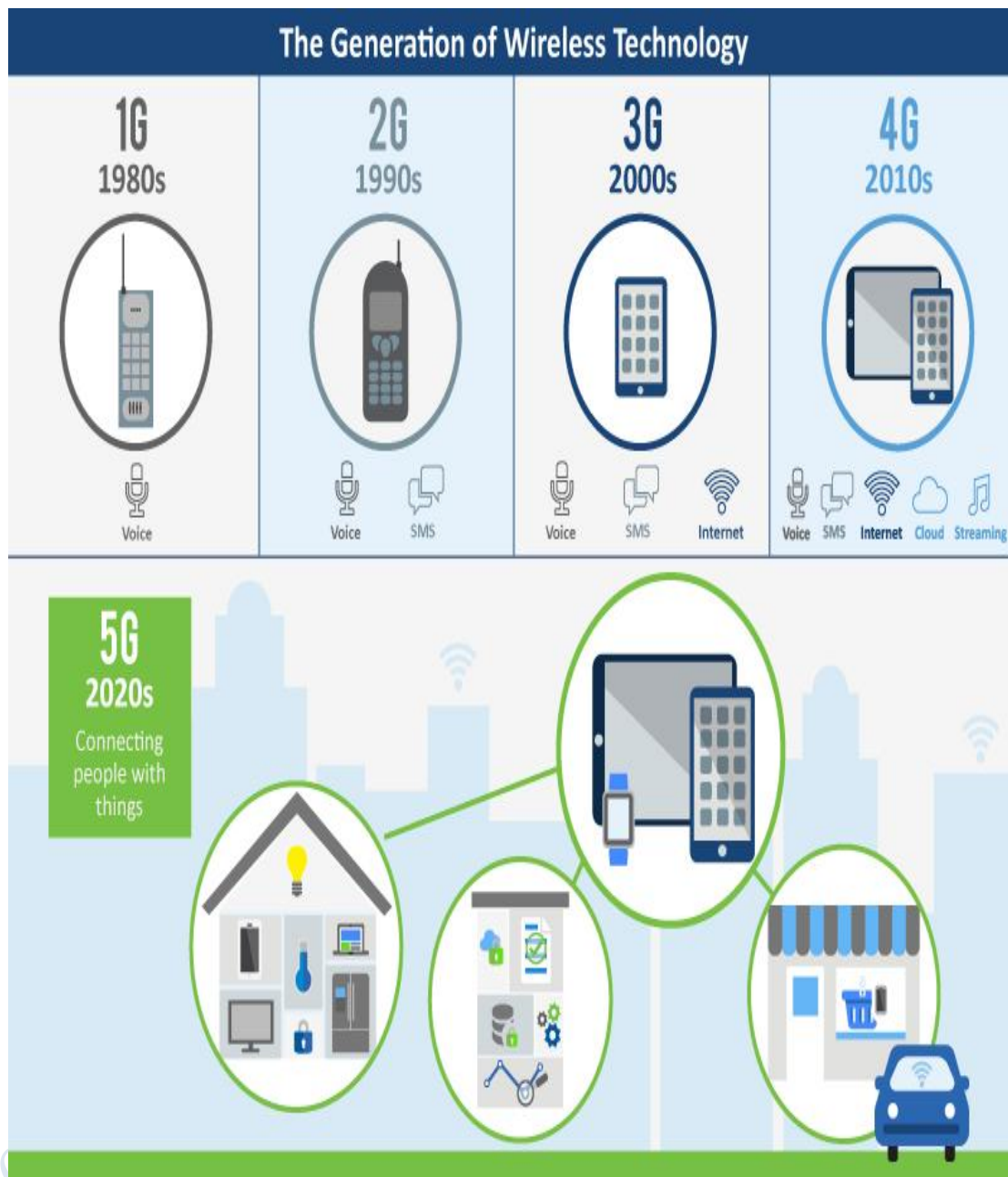


Figure 2.1: Generation of Wireless Technology⁵

Due to the fact that many GSM network providers have roaming agreements with international operators, customers may frequently continue to use their phones while traveling¹⁷.

SIM cards with home network access settings can be converted to those with metered local access, resulting in substantial cost savings while maintaining service. While GSM was meant to be a secure wireless technology, it is susceptible to assault¹⁷. GSM employs authentication mechanisms such as challenge-response authentication, in which the user is prompted to give a correct response to a question, and a pre-shared key in the form of a password or passphrase. Wireless communications refers to data communication that is conducted and transmitted wirelessly. This is a comprehensive word that encompasses all processes and methods for connecting and communicating between two or more devices using wireless communication technologies and equipment.

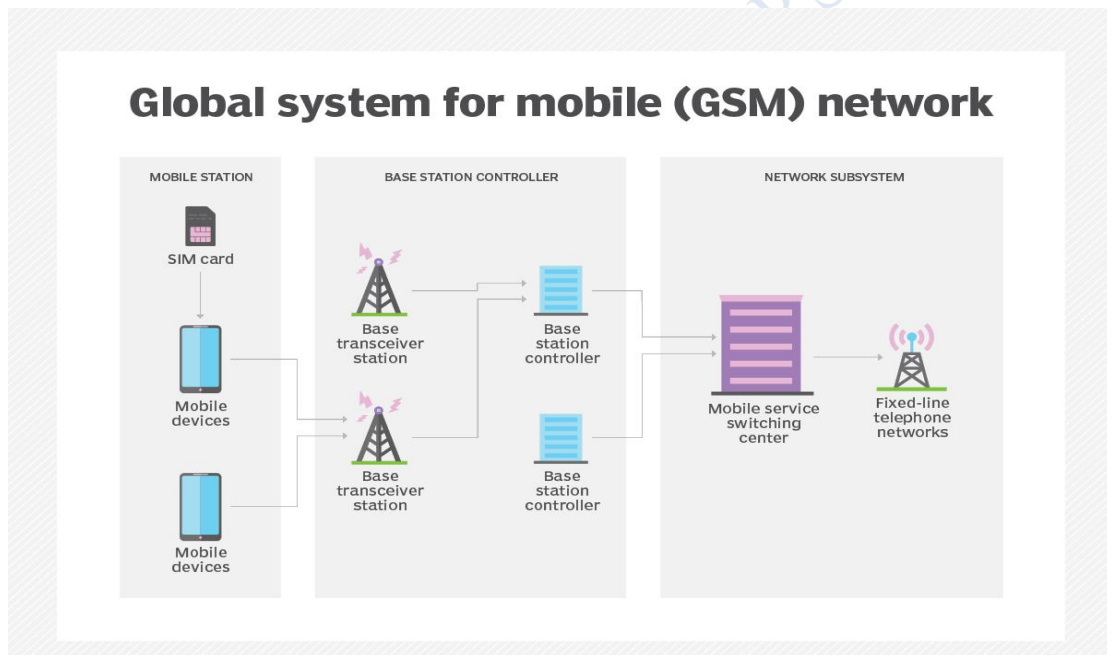


Figure 2.2: GSM Network¹⁷

GSM is utilized in digital cellular and public switched telephone network (PSTN) systems. GSM employs the TDMA method for signal transmission. GSM encrypts phone conversations, offers SMS for text messaging and paging, and enables call forwarding, waiting, and multi-party conferencing. GSM serves over a billion mobile users in more than 210 countries, accounting for more than 70% of the world's digital cellular subscribers.

2.1.3 Base Stations

Base stations are fixed radio transmitters equipped with antennas installed on freestanding masts or on structures (see figure 2.3). 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 spectrum¹⁸. 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 networks¹⁸.

Nigerian telecommunications operators have built 34,033 base stations to date.¹⁹ 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, respectively¹⁹. 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 561¹⁹.

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 bands²⁰.

2.1.4 Radiation

2.1.4.1 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 lines²¹. 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 2.4²². Where E , H , and Z denote the electric, magnetic, and free space impedances, respectively.



Figure 2.3: Base Station¹⁹

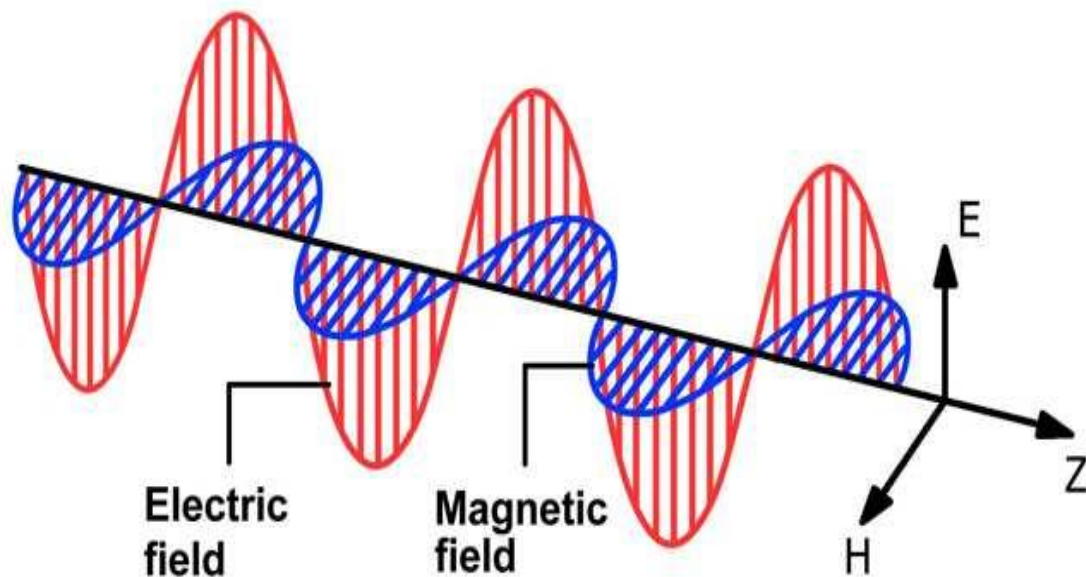


Figure 2.4: E.M Wave Propagation²³

The frequency or wavelength of an electromagnetic radiation is used to explain it. On the basis of the ionizing strength of the radiation, the electromagnetic spectrum is split into two regions: ionizing and non-ionizing as shown in figure 2.5²⁰.

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 radiation²⁰. Due to the low energy of these radiations, they excite electrons to a higher energy state rather than ionize them. The electromagnetic spectrum is depicted in figure 2.6 along with the sources of radiation.

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 ²⁰. 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 molecules²⁰.

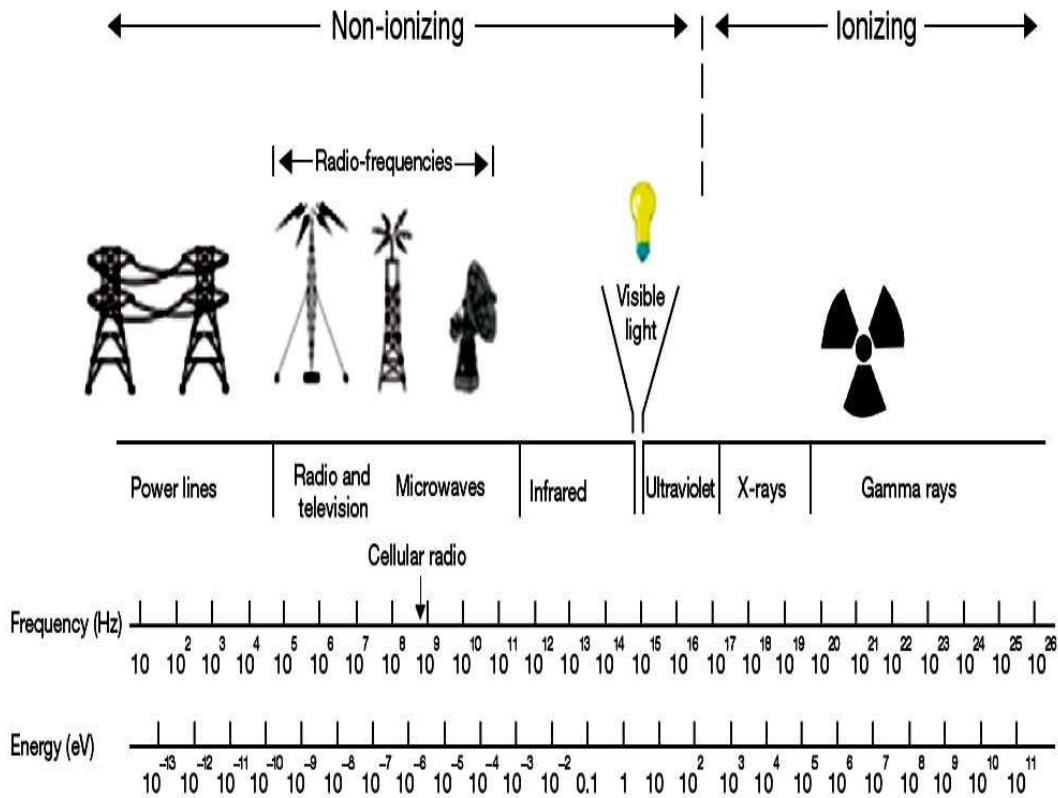


Figure 2.5: Ionizing and Non Ionizing Radiation²⁰

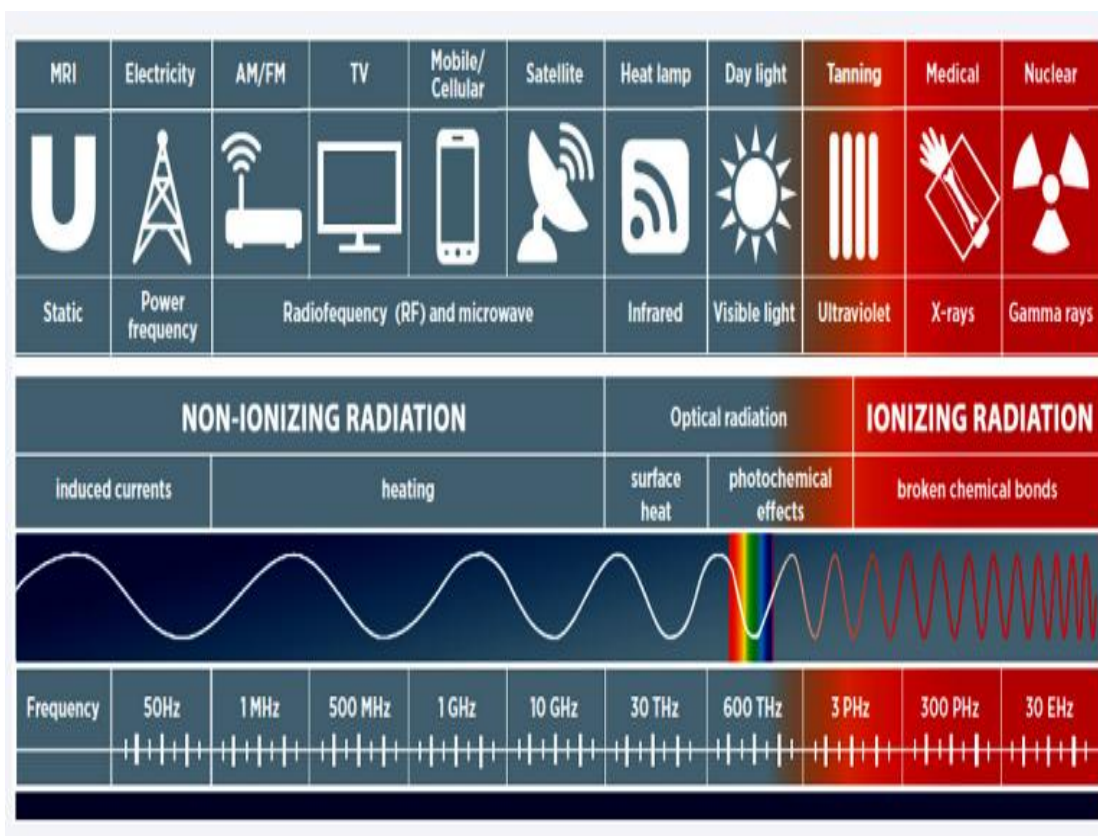


Figure 2.6: The Electromagnetic Spectrum

Radiation and Its Spectrum

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^{20,24}. 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 3×10^{15} Hz^{20,25}. The near-infrared spectrum is composed of four distinct components: optical radiations, static electric and magnetic fields, low frequency fields, and radio frequency fields. The optical radiation spectrum includes ultraviolet, visible, and infrared wavelengths, whereas the radiofrequency spectrum includes microwave and radio waves. This may be demonstrated as follows:

- Static electric and magnetic fields at a frequency of 0 Hz
- Low frequency fields : Frequency - greater than or equal to 0 Hz to 3 kHz
- Radiofrequency (RF) radiation: frequencies ranging from 3 kHz to 300 GHz
- Optical rays: Infrared (IR) spectroscopy : Wavelength 760–106 nm: 400–760 nm, (UV): 100–400 nm

Wireless technology underpins the mobile phone system, which links users via radio frequency transmissions. However, different kinds of non-ionizing radiation have varying biological consequences. The health consequences are highly frequency dependant. There is no doubt that non-ionizing radiation at these energy (most of the UV spectrum and some visible light) is capable of causing non-thermal cellular harm in a manner similar to ionizing radiation. Thus, the health discussion focuses on the non-thermal consequences of considerably lower frequency radiation (microwave, radio wave radiation etc.). Non-ionizing radiation, on the other hand, has been linked to cancer in humans, according to the International Agency for Research on Cancer²⁶.

In terms of biological impacts, the non-ionizing portion of the spectrum may be split into the following categories²⁰: the optical radiation component, in which electrons can be excited (visible light, infrared light); the region in which the wavelength is shorter than the wavelength of the body. Heating can occur as a result of induced currents. Additionally, there are allegations of other severe biological consequences. These effects are poorly understood and are the subject of ongoing research (MW and higher frequency RF); the region where the wavelength is significantly longer than the wavelength of the body and heating by induced currents occurs infrequently (lower-frequency RF, power frequencies, static fields)

Nature is constantly creating non-ionizing radiation. They are produced by people for a variety of reasons or by nature. The sources of NIR may be classified into two categories: Natural (as a result of sunlight or lightning discharges, for example) and man-made (such as wireless communications, industrial, scientific and medical applications). UV radiation is

produced by the sun, arc welding, oxy-gas welding, sun lamps, lasers (UV), low pressure gas discharge lamps, and high pressure gas discharge lamps. IR radiation is thermal radiation that is generated by hot operations such as steel production, glass production, welding, and even by lasers (IR). These rays are not just damaging; they are also employed in a variety of medical applications such as UV and newborn phototherapy, surgical and therapy lasers, and physiotherapy heat lamps. Lasers are increasingly being used as coherent light sources.

RF fields are utilized in wireless communication systems such as mobile phone BSTs, radar/satellite connections, television and FM broadcasting stations, and personal electronic devices like as mobile phones and microwave ovens. Electrical machinery, residential appliances, electrical wiring, and high-voltage electrical transmission lines and transformers are all surrounded by low frequency (LF) electric and magnetic fields (EMFs). Radiofrequency fields are used for a variety of medical applications, including microwave hyperthermia, therapeutic and surgical diathermy, and magnetic resonance imaging (MRI)²⁰.

Wireless Technology

As the name implies, wireless technology does not rely on wires to link people or equipment. This system is built on a vast network of base stations that link users via radio frequency (RF) transmissions. Thus, cellular service in any region is comprised of a transmitter and a receiver referred to as a base station (BS) and a mobile station (MS).¹ Using the coverage provided by other base stations, the mobile station may move freely within the coverage zone and connect to any other mobile station inside the coverage zone. The frequency spectrum is split into several parts for wireless communication systems. Frequencies are critical features because they may be reused by distant transmitters. Each operator has its own dedicated frequency band within the spectrum allotted to mobile phone networks¹.

2.1.4.2 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. It is one among nature's four basic forces (the others are gravitation, weak interaction, and strong interaction)^{1,27}. 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/m²].¹

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 1.¹

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

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 distances¹.

Exposure to Radiation from BSTs

Radiation emitted by BSTs propagates as an EMW, which is defined by its electric and magnetic fields. The extent to which a body is exposed to an RF field is governed by the intensity of the Electric and Magnetic fields (combined effect known as Power density) inside the body, which differ from those outside.¹ However, it is not always feasible to directly measure these intrinsic fields. As a result, investigations evaluating exposure are often conducted either through the use of computational approaches or via the use of physical models of the head or body. For basic exposure settings, the intensity of the electromagnetic field within the body, and therefore exposure, may be estimated to a fair degree by comparing it to the strength of the fields present in the region prior to the body's placement.²⁸ The EMF's characteristics vary with distance from the source. The field may be classified into two types: radioactive and reactive. The radioactive component of the field is the portion of the field that propagates energy away from the source, whereas the reactive component is the portion of the field that stores energy in the region around the source. In the reactive near field area, the reactive component dominates, whereas the radioactive component dominates distant from the source in the far field zone. In the near field zone, the waves are spherical, but in the far field region, they are flat. While the reactive field components do not contribute to energy radiation, the energy they store can be absorbed and so contribute significantly to human exposure in the near-field region¹.

The base station antennas are generally installed on free-standing towers between 10 and 50 meters in height, on short towers atop buildings, or on the sides of buildings. In a common configuration, each tower has three antennas, each of which transmits into a 120-sector area. In BSTs, there are two types of antennas: isotropic and sectoral. Only sectoral antenna were spotted during this observation. In such antennas, a significant amount of the power is concentrated into a roughly horizontal beam that is generally about 60 broad in the vertical direction termed the main beam, while the remainder is directed into a number of weak beams

on each side of the main beam. This distance is dependent on the BST's height, the antenna's tilt angle, and other factors¹.

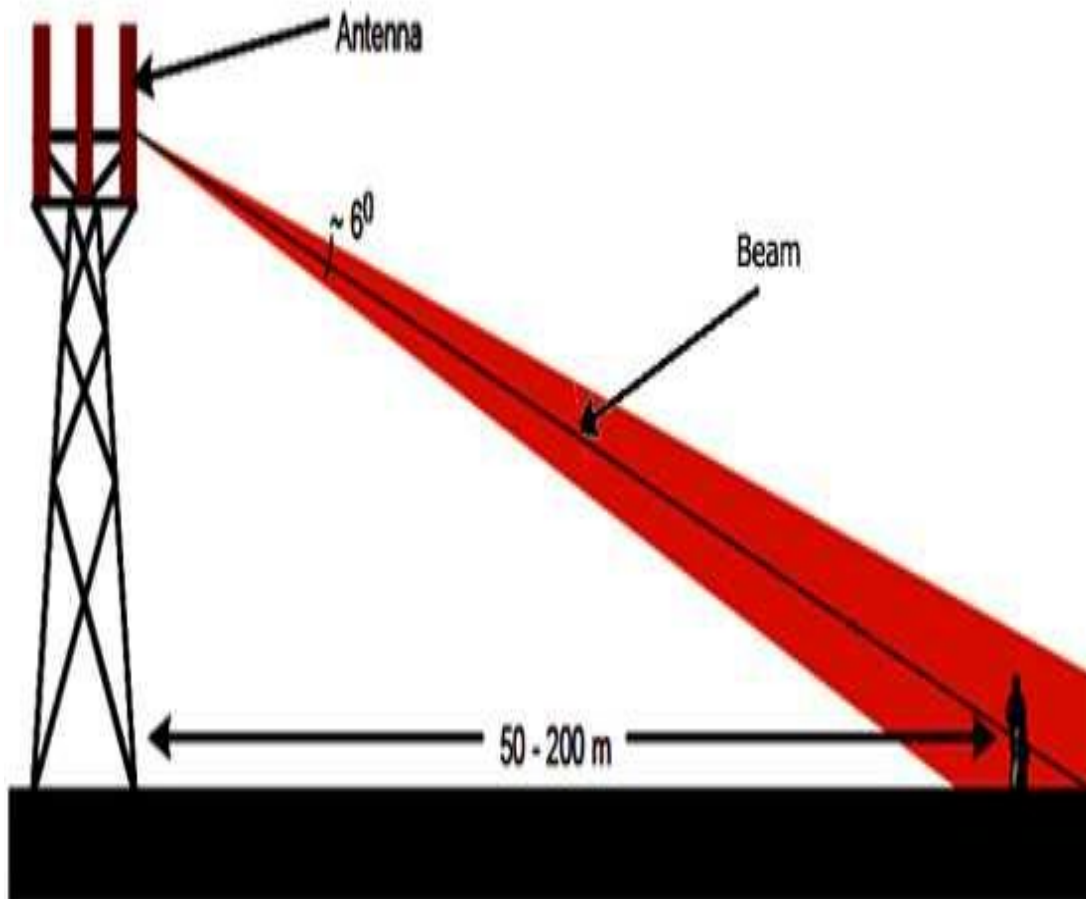


Figure 2.7: Main Beam from an Antenna Mounted on a Tower¹

Radio frequency fields permeate the body to a lesser amount as the frequency increases. To establish the impacts on biological tissue, the size of the fields must be measured in the various exposed areas of the body. This requires an understanding of the electrical properties of various types of tissue; once determined, it is possible to calculate the electric field strength (E) and magnetic field strength (H) at various locations throughout the body caused by a particular source of radiation, such as a mobile phone. The rate at which energy is absorbed by a mass of tissue m is denoted as $m\sigma E^2/\rho$, where σ and ρ are the conductivity and density of

the tissue, respectively, and E is the rms value of the electric field. $\sigma E^2/\rho$ is called the specific energy absorption rate or SAR and is measured in watts per kilogram (W/kg).

Thus, SAR refers to the amount of energy absorbed per mass of tissue. It varies from point to point within the body due to the fact that the electric field changes with position and the conductivity of various types of tissue varies. SAR is calculated by averaging across the entire body or a small sample volume (typically 1 gram or 10 gram of tissue). SAR readings are averaged over a six-minute period using a mass of ten grams as the average. When the SAR value is averaged throughout the entire body, it represents the rate at which electromagnetic energy is absorbed by the body when exposed to a radio frequency electromagnetic field¹.

All electromagnetic waves are represented as self-propagating waves composed of electric and magnetic field components that fluctuate in phase with one another and with the wave's propagation direction. Equation 2.2 shows the relationship between electric and magnetic fields in the far field region;

$$H = \frac{E}{Z} \tag{Equation (2.1)}$$

Where Z denotes the impedance of empty space or vacuum, which has a value of 377Ω . Equation 2.3 illustrates the power density that propagates through a surface. This is the intensity of radio frequency fields and is defined as the quantity of radiated energy that passes through a unit area per second.

$$S = E \times H = E^2/377 = H^2 \times 377 \tag{Equation (2.2)}$$

$$\text{Hence } E = 19.42\sqrt{S} \tag{Equation (2.3)}$$

$$\text{and } H = 0.052\sqrt{S} \tag{Equation(2.4)}$$

Where, 'E' is Electric field strength [V/m], 'H' is Magnetic field strength [A/m] and 'S' is Power density [W/m²]¹.

The waveform of a far field is assumed to be planar, and the exposure to this far field diminishes with the second power of the distance, i.e. obeys the inverse square rule, as indicated in Equation 2.5.

$$S = \frac{P \cdot G}{4\pi r^2} \quad \text{Equation (2.5)}$$

Where, S is the Power density, G is the gain of the antenna, r is the distance from the antenna and P is the transmitted power with unit watt [W]^{1,28}.

Path Loss and Fading

A wireless channel is defined by the following characteristics: Path loss, Fading

Path Loss: Path loss is described as the diminution of an electromagnetic wave's power density (attenuation) as it propagates across space. This term is most frequently used in wireless systems, where it is one of the characteristics used to analyze and develop telecommunications networks^{1,29}. It is dependent on a number of factors, including the loss of free space, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption. Path loss is further affected by the curvature of the terrain, the environment (urban or rural, with plants and foliage), the propagation medium (dry or wet air), the distance between the transmitter and receiver, and the height and position of antennas¹.

Fading: Fading is a term used in wireless telecommunications to describe the deviation or attenuation that a carrier-modulated telecommunication signal suffers when propagating across a particular propagation medium^{1,30}. The fading process is frequently represented as a random process since it varies with time, geographical location, and radio frequency. Fading can occur in wireless systems as a result of multipath propagation, referred to as multipath induced fading, or as a result of shadowing caused by objects interfering with wave propagation, referred to as shadow fading. Fading is classified into two kinds based on the pace at which the signal's amplitude and phase fluctuate. There are two types of fading: rapid or fast Fading and slow fading.

a) Fast Fading: In this type of fading, the amplitude and phase of the wave propagating across the channel change considerably with time. This is sometimes referred to as multipath fading. In other words, due to reflections or other phenomena in the environment, the signal might take multiple distinct paths to reach its destination. Due to the fact that the signals originate from several sources, they would be super positioned in such a way that the amplitude and phase of the signal would be altered³¹.

Due to the many phenomena that occur during the wave's propagation, the amplitude and phase of the signal from one location may differ from those from the other. This phenomena has an effect on mobile phone system power densities. This issue is addressed in wireless communication systems using a technique called 'Frequency Hopping'³¹.

b) Slow Fading: Due to the slow pace at which the amplitude and phase of the signal change, the amplitude and phase of the signal may be regarded approximately constant during the duration of usage. The gradual fading is caused by the wave being shadowed by obstructions. This fading might alter the region covered. If there is an obstruction between the mobile station and the base station, the energy of the signal may fluctuate, affecting the power density in the receiver. It is not feasible to fix it by altering the time. As previously stated, quick fading causes the signal to fluctuate dramatically as the distance changes, but slow fading maintains a more consistent signal³¹.

Frequency Hoping (FH) is a modulation method used in GSM networks. It is the repetitive change of radio frequencies during transmission, frequently to reduce the efficacy of "electronic warfare," i.e. the unlawful interception or jamming of telecommunications. This can be explained by the fact that the calls alternate between different frequency channels in accordance with a plan. The primary objective of FH is to continuously alter the frequency, therefore minimizing signal power loss due to multipath fading. However, certain frequency channels do not hop. These channels are referred to as BCCHs (Broadcast Control Channels) and are devoid of audio. Rather than that, they are used to specify which BS the MS should

interact with. This method minimizes the rapid fading phenomena, therefore avoiding interferences between the various frequency waves³¹.

2.1.5 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)³². 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 disadvantages³³.

2.1.5.1 International and National Standards and Guidelines

With the increased usage of wireless technology, there is growing worry about the health risks associated with RF radiation¹. 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^{1,34}.

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 others³⁴. 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.

Different nations have adopted their own radiation standards, i.e. safety rules, based on the aforementioned international guidelines³⁴. In Nigeria, we have accepted the radiation levels specified in the 1998 ICNIRP guidelines for a safe power density of $f/200$, where frequency (f) is expressed in megahertz. Thus, the power density of the GSM900 transmitting band (935-960 MHz) is $4.7 \text{ W/m}^2 = 4700 \text{ mW/m}^2$, whereas the GSM1800 transmitting band (1810-1880 MHz) is $9.2 \text{ W/m}^2 = 9200 \text{ mW/m}^2$ ³².

The ICNIRP recommendations indicate unequivocally that when several frequency fields are exposed concurrently, the total amount of radiation must be considered. However, in Nigeria, we have applied this restriction to individual carriers, resulting in radiation levels that are many orders of magnitude greater than those allowed by ICNIRP standards, depending on the total number of transmitters in that location. Certain residents (particularly the elderly, housewives, and young children) who live near the towers are exposed to this radiation 24 hours a day³².

Unfortunately, ICNIRP examined only the thermal effects of radiation, but scientists from all over the globe have discovered that the non-thermal impacts of these radiations have substantial health consequences and occur at levels considerably lower than these limits³². Existing public safety regulations are insufficient to safeguard public health, and the proposed $1000 \mu\text{W}/\text{m}^2 = 1 \text{ mW}/\text{m}^2$ threshold for outdoor, cumulative RF exposure is an improvement. The European Parliament recommends a value of $100 \mu\text{W}/\text{m}^2 = 0.1 \text{ mW}/\text{m}^2$ ³⁵. The current threshold in the United States of America for radiation exposure from mobile phone towers is between 580 and 1,000 $\mu\text{W}/\text{cm}^2$, however the government is contemplating changing the guideline. Over 100 physicians and experts at Harvard and Boston Universities' Schools of Public Health have declared that cellphone towers pose a radiation risk. Thirty-three (33) delegate physicians from seven nations have declared a public health emergency regarding mobile phone towers. ³² Numerous nations have implemented far tighter maximum radiation densities of 0.001 - 0.24 W/m^2 , or 1/100th - 1/1000th of the ICNIRP standards, as indicated in Table 2.1. These nations' citizens have conducted considerable research on the health risks associated with cell tower radiation in order to enact tougher radiation limits.

Table 2.1 International Radiation Power Density Limits for GSM1800³²

Power Density (mW/m²)	International Exposure limits adopted by various countries
10,000	FCC(USA) OET-65, Public Exposure Guidelines at 1800 MHz
3,000	Canada (Safety Code 6, 997)
2,000	Australia
1,200	Belgium (Ex Wallonia)
500	New Zealand

240	Exposure limit in CSSR, Belgium, Luxembourg
100	Exposure limit in Poland, China, Italy, Paris
95	Exposure limit in Italy in areas with duration > 4hours
95	Exposure limit in Switzerland
90	ECOLOG 1998 (Germany) Precaution recommendation only
25	Exposure limit in Italy in sensitive areas
20	Exposure limit in Russia (since 1970), Bulgaria, Hungary
1	"Precautionary limit" in Austria, Salzburg City only
0.9	BUND 1997 (Germany) Precaution recommendation only
0.01	New South Wales, Australia

Source: O. D. Osahon, P. O. Ushie, & O. A. Ojo. 2017:

2.1.5.2 World Health Organization (WHO)

The World Health Organization (WHO) is a United Nations (UN) specialized organization dealing with international public health. It was founded on April 7, 1948, in Geneva, Switzerland.¹ It is responsible for global health leadership, driving the research agenda, establishing norms and standards, articulating evidence-based policy choices, assisting nations with technical assistance, and monitoring and analyzing health trends. The WHO's EMF project has established a mechanism for reviewing and evaluating scientific publications on the harmful health effects of human exposure to RF radiation. WHO developed this initiative in response to widespread concern about the effect of radio frequency on health and to ascertain scientifically compelling evidence about radio frequency's harmful health effects. In

1997, that project developed a research agenda to carry out and coordinate research on the probable harmful effects of non-ionizing radiation; however, such agendas have been refined and modified on a recurrent basis in succeeding years. The EMF project is primarily focused with determining the harmful effects of radiation in the frequency range of 0 to 300 GHz and developing guidelines for mitigating such effects. Due to the fact that there were inconsistent evaluations about the health effects of RF radiation, it encouraged study to address knowledge gaps. For this reason, the national government has invested more than \$250 million in EMF research during the last decade¹.

WHO is the first body to do research on the radiofrequency field and its effects on human health. The first breakthrough in radio frequency research occurred as a result of the contribution of an ad hoc committee of invited scientific professionals who convened in June 2002 in Geneva. The committee examined research in the fields of epidemiology and human laboratory investigations, animal and cellular studies, and dosimetry. Additionally, consideration was limited to RF; non-ionizing radiation from static fields, wide-band, and high-power frequencies will be examined individually. It was further refined during the March 2003 WHO workshop on "Adverse Temperature Levels in the Human Body" in Geneva. Although no adverse health effects are predicted from exposure to RF fields from base stations and wireless networks, WHO continues to support research to discover whether there are any adverse health effects associated with the increased RF exposures from mobile phones. The WHO/IARC, on the other hand, categorized radiofrequency electromagnetic fields as potentially carcinogenic to humans (Group 2B), citing an increased risk of glioma, a malignant type of brain cancer, related with cellular phone use. On 31 May, 2011. The IARC examined and evaluated existing literature and research on the carcinogenicity of RF-EMF and concluded that the evidence for carcinogenicity was "limited for RF-EMF, based on positive correlations between glioma and acoustic neuroma and exposure." WHO has authorized ICNIRP to do research in the realm of non-ionizing radiation and its effects.¹

2.1.5.3 International Commission on Non-Ionizing Radiation Protection (ICNIRP)

ICNIRP is a non-profit scientific organization formed in 1992 by the International Radiation Protection Association in Germany (IRPA). ICNIRP's purpose is to screen and evaluate scientific information and current results in order to provide recommendations on protection in the frequency range of up to 300 GHz, i.e. radio, microwave, and far infrared, by investigating the effects of NIR on human health and well-being¹. The commission publishes summaries of its evaluations and studies of current scientific knowledge. The World Health Organization and the International Labour Organization have both formally recognized ICNIRP in the realm of non-ionizing radiation and adhere to its recommendations. ICNIRP maintains tight ties with the many international organizations that operate in this sector. It serves as a scientific analytical tool and a safeguard against the negative effects of non-ionizing radiation¹. The scope and activities of ICNIRP include the following: analyzing the physical properties of NIR and reports of biological effects associated with NIR exposure, recommending appropriate terminology, quantities, units, and methods of measurement, developing protection criteria, recommending protective systems against NIR, including an appropriate exposure limit, and providing guidance for the protection of the world. The ICNIRP exposure limit is stated in Tables 2.2 and 2.3, where f is the frequency in MHz:

Table 2.2 ICNIRP Exposure Limit for Occupational¹

Frequency (MHz)	Electric field (V/m)	Power density (W/m ²)
0.065-1.0	610	
1.0-10.0	610/f	
10-400	61	10
400-2000		f/40

2000-300000

50

Source: A. Renke, & M. Chavan. 2018

Table 2.3 ICNIRP Exposure Limit for General Public¹

Frequency (MHz)	Electric Field (V/m)	Power Density (W/m ²)
0.15-1.0	610	
1.0-10.0	$87/\sqrt{f}$	
10-400	28.0	2.0
400-2000		$f/200$
2000-300000		10

Source: A. Renke, & M. Chavan. 2018

2.1.5.4 Federal Communications Commission (FCC)

The Federal Communications Commission (FCC) is an independent federal organization formed by Congress to permit and license devices, transmitters, and facilities that emit radio frequency and microwave radiation. The Federal Communications Commission works toward six objectives in the fields of broadband, competition, spectrum, media, public safety, and national security¹. The FCC was established by the Communications Act of 1934 A.D. to take over the Federal Radio Commission's radio regulatory duties. It is responsible for all transmission services throughout North America. The FCC does not have control over the health and safety aspects of communication. It consults with other government and non-

government entities regarding this area's norms¹. However, under the American government's NEPA, the FCC is required to demonstrate in particular circumstances whether its judgment would have a major adverse effect on the quality of the human environment or not. The FCC is required to conduct an evaluation of the human exposure to radio frequency radiation generated by the transmitter. The FCC changed its standards for RF exposure in 1996 to comply with the requirements of the American Telecommunications Act. The FCC has mandated that all radio and television broadcast stations, satellite-earth stations, and cellular mobile systems undergo routine RF compliance reviews¹.

At the moment, there is no nationally regulated standard for RF exposure. Several non-governmental organizations, however, including ANSI, IEEE, and NCRP, have published guidelines about human exposure to radio frequency electromagnetic fields. The Commission accepted the NCRP's proposed Maximum Permissible Exposure limits for field strength and power density for transmitters operating at frequencies between 300 kHz and 100 GHz on August 1, 1996. Additionally, the Commission approved the SAR limitations stated in the ANSI/IEEE C95.1-1992 standards for devices operating in close proximity to the body.

The FCC's exposure limit table is given in Tables 2.4 and 2.5, where f denotes frequency in MHz:

2.1.5.5 Institute of Electrical and Electronics Engineers (IEEE)

IEEE is the world's biggest technical professional society, formed in 1963 and based in New York City. It is devoted to fostering innovation and technological excellence for the benefit of mankind³⁶. It is intended for professionals working in all facets of electrical, electronic, and computing engineering, as well as allied fields of science and technology that underpin modern society.¹ In 1966, the first ANSI standard on RF radiation exposure was published, recommending that exposure be confined to field levels of no more than 10 mW/cm^2 . ANSI C95.1-1982 was the world's first SAR-based human exposure standard³⁶. IEEE's exposure limit table is given in Tables 2.6 and 2.7, where f denotes frequency in MHz:

Table 2.4 FCC Exposure Limit for Occupational¹

Frequency (MHz)	Power Density (W/m²)
0.03-1.34	10
1.34-30.0	$90/f^2$
30-300	0.1
300-1500	$f/30$
1500-100000	0.5

Source: A. Renke, & M. Chavan. 2018

Table 2.5 FCC Exposure Limit for General Public¹

Frequency (MHz)	Power Density (W/m²)
0.03-1.34	10
1.34-30.0	$18/f^2$
30-300	0.02
300-1500	$f/150$
1500-100000	0.1

Source: A. Renke, & M. Chavan. 2018

Table 2.6 IEEE Exposure Limit for Occupational¹

Frequency (MHz)	Power Density (W/m²)
------------------------	--

0.1-1.0	9000
1.0-3.0	$9000/f^2$
30-300	10
300-3000	$f/30$
3000-300000	100

Source: A. Renke, & M. Chavan. 2018

Table 2.7 IEEE Exposure Limit For General Public¹

Frequency (MHz)	Power Density (W/m²)
0.1-1.34	1000
1.34-30.0	$1800/f^2$
30-400	0.02
400-2000	$f/200$
2000-100000	10
100000-300000	Increase from 10-100

Source: A. Renke, & M. Chavan. 2018

2.1.5.6 The Nigerian Communications Commission (NCC) and the Regulation of the Telecommunication Sector

In 2001, the Nigerian Communications Commission (NCC) held a GSM license auction, which brought in new entries to the telecommunications industry, including Multilinks, MTN,

Zoom, Visafone, Airtel, Glo, and Etisalat³⁷. The Nigerian Communications Commission is regulated by the Act No. 19, 2003, establishing the Nigerian Communications Commission. It was formed with the mandate of regulating the Nigerian communications sector³⁸. The Commission is responsible for defining and publishing technical standards and specifications for communications equipment and infrastructure used in Nigeria. Among the objectives of the technical code and specifications are the development of network facility safety and the acceptance of technical standards issued by international organizations. Section 136 (3) of the NCC Act, 2003 mandates operators to take all reasonable efforts to ensure the safety of individuals, property, and the environment when installing their respective network facilities³⁸. The NCC has published several guidelines and regulations, one of which is the Guidelines on Technical Specifications for Telecommunications Masts and Towers Installation³⁸. The Guidelines establish criteria for telecommunications service providers/operators and telecoms tower installers to follow in order to ensure environmental safety and sound engineering practices. As a result, section 9(9)(c) of the 2009 NCC Guidelines specifies that towers must be placed back five metres from any demised property, except the fence. Additionally, the 2009 NCC Guidelines require that all generators inside a base station be located five meters from all demised premises, except the fence. All towers located in residential areas must adhere to the setback requirements specified in the Guidelines in order to reduce the effects of heat, smoke, and noise pollution caused by generating units³⁹.

Regulations of the National Communications Commission on the siting of telecommunications base stations According to the Nigerian Communication Commission Act of 2009, the following is said on the siting of telecommunications towers and masts:³⁸

- i. Masts and towers shall be sited in accordance with the Act's provisions and in accordance with the provisions governing collocation and infrastructure sharing in order to limit their number, protect and promote public safety, and lessen aesthetic effect on the community.

- ii. Telecommunications towers greater than 25 metres in height would be prohibited within residential zones.
- iii. Where towers more than 25 metres in height are authorized, they must be setback at least 5 metres from the next demised property, excluding the fence.
- iv. The minimum distance between two or more towers exceeding 55 metres in height is 1 (one) kilometer.

2.1.5.7 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 Act⁴⁰. 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. 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 industries⁴⁰. 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. The former requires a five-metre setback, whereas the latter requires a ten-metre setback. As described at the beginning of this article, it was the execution of this clause in NESREA's Regulation that resulted in NESREA shutting down MTN's base station. The set back of the MTN mast in question was 1.2 metres, which is even less than the distance specified in both Regulations⁴⁰. NESREA's

move resulted in the sealing and shutting down of a number of base stations (22) owned by other telecommunications firms such as Airtel, Glo, and others around the Federation.⁴¹

In the majority of cities, including Ibadan, 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 kilometers³². Microcellular base stations, on the other hand, have their antennas positioned closer to the ground since communications are limited to a few hundred meters. When possible, 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 utilized³². 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 direction³².

This can be related to the study frequency band (1800 MHz) with a few exceptions, as illustrated in Table 2.8

Table 2.8 NCC Frequency Spectrum Allocation at 1800MHz.³²

Operators	GLO	MTN	AIRTEL	ETISALAT
Transmitting Frequency	1820-1835	1835-1850	1850-1865	1865-1880

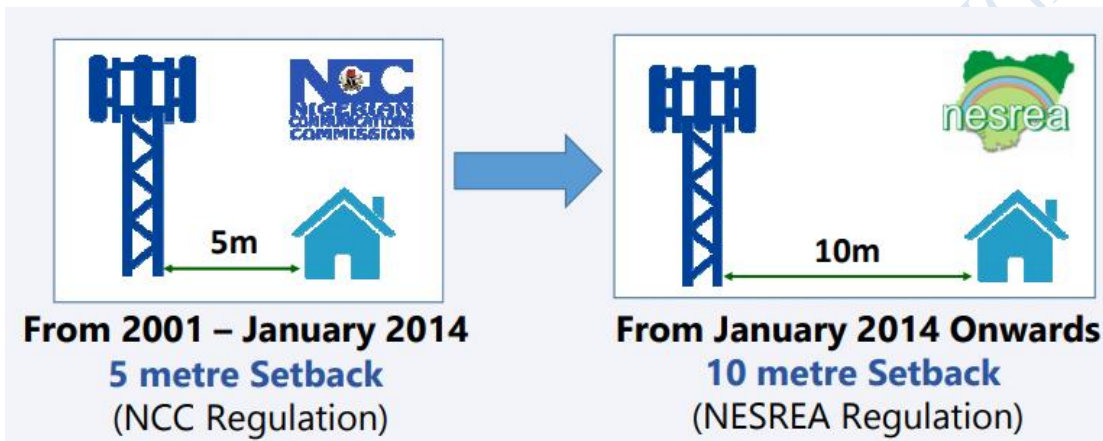


Figure 2.8: NCC and NESREA Base Station Setback Regulations

For time harmonic fields, the time averaging

Instantaneous power density is:³².

$$P_{avg} = \frac{1}{T} \oint (E \times H) dt \quad \text{Equation(2.6)}$$

Where, $E = \text{Re}\{E e^{j\omega t}\}$ and $H = \text{Re}\{H e^{j\omega t}\}$

The instantaneous magnetic field may be rewritten as

$$H = \text{Re}\{1/2[H e^{j\omega t} + H^* e^{-j\omega t}]\} \quad \text{Equation(2.7)}$$

which gives an instantaneous power density of;

$$S = E \times H = \frac{1}{2} \text{Re}\{(EXH) + (EXH^*)\}$$

$$S = [E][H]\sin\theta \quad \text{Equation(2.8)}$$

Where E denotes the intensity of the electric field, H is the strength of the magnetic field, and θ is the angle between E and H (90° for mutually perpendicular angles). BTS servicing macro cells are generally installed on free-standing towers between 10 and 30 meters in height, on short towers atop buildings, or on the side of buildings. Each tower typically holds three antennas, each radiating into a 120° sector³².

A significant amount of the antenna's radiated power is concentrated into a roughly horizontal beam that is generally about 6° broad in the vertical direction, while the remainder is directed into a number of weak beams (referred to as side lobes) each side of the main beam. The primary beam is slightly angled downward but does not reach ground level until at least 10 meters from the tower³². The antennas on the base stations broadcast far more power than the phones. The power limit is legally established by the requirement to avoid RF interference and by a license issued by the Radio Communications Agency. This does not limit the overall power output directly, but does so indirectly by limiting the maximum intensity that an antenna may broadcast into the main beam. This is accomplished by determining the maximum allowable equivalent isotropically radiated power (EIRP). The EIRP is the amount of energy that must be radiated evenly in all directions to attain a certain intensity. Indeed, as previously stated, the antennas employed are far from isotropic, with the majority of the power being radiated into the main beam, and the antenna gain is defined as the ratio of the EIRP to the total power output. For a section of 120° , the gain of the antenna is typically between 40 and 60W ³².

2.2 Review of Empirical Studies

In a study to investigate the main lobe distance of transmitted power density from GSM transceiver base stations in South-South Nigeria³². The authors quantified radiofrequency radiation caused by antennas on cellular transceiver base stations. With the help of frequency dependent equipment (CORNET, Electro smog meter ED78S EMF RF/LF Dual mode model), far field measurements of power density and electric field intensity were conducted around

chosen transceiver base station antennas in selected states in South-South Nigeria. The power density as measured from various states is provided in their study. Additionally, using observed values of electric (E) and magnetic (H) fields as a reference, power density was estimated using a well-known Maxwell's equation. The data indicate that the greatest observed power densities are 8.411 mW/m² in Benin, 4.168 mW/m² in Calabar, 5.520 mW/m² in Port Harcourt, and 12.940 mW/m² in Yenagoa, all of which are less than the ICNIRP limit of 9000 mW/m² (1998) intended for the general public. At 75 and 100 meters from the foot of the BTS, peak power density values of 8.411 mW/m² were found in Benin, 4.168 mW/m² in Calabar, 5.520 mW/m² in Port Harcourt, and 12.940 mW/m² in Yenagoa. These power density levels are less than the ICNIRP limit of 9000 mW/m² (9 W/m²) for public exposure but significantly exceed the EU parliament's threshold value of 0.1 mW/m² (1999)

In another research o Electromagnetic Radiation From Mobile Phone Base Stations in GAZA⁴². The purpose of this study is to highlight pertinent worldwide research and to build computer tools for predicting and monitoring EMF levels in our city. The developed software program saves the characteristics and locations of the base stations in a database and then creates tables and maps illustrating theoretically estimated EMF levels. Additionally, it is capable of communicating with a measuring equipment and storing real measurements in a database, allowing for the generation of maps and tables. According to the author, real-world data corroborate theoretical ones and are far lower than the international health organizations' suggested exposure limit.

A similar research was conducted on the Electromagnetic Radiation Effects From Mobile Phone Base Stations On Human Health⁴³. The research examined the impact of electromagnetic radiation on many areas of health, including an increase in body temperature, cancer incidence, and cellular and DNA abnormalities. All of the information contained in this article can assist readers in comprehending the overall picture of research and research techniques from the past to the present.

Also, in a work on Modeling indoor electromagnetic fields (EMF) from mobile phone base stations for epidemiological studies⁴⁴. The authors evaluated the accuracy of indoor RF-EMF model predictions and the effect of including information about building features on model accuracy. In Amsterdam, the Netherlands, we conducted 15-minute spot measurements in 263 rooms across 101 primary schools and 30 private residences. We collected data at each measurement location on building features that might impact indoor RF-EMF exposure, specifically glass and wall and window frame materials. Following that, we used the 3D radio wave propagation model NISMap to simulate RF-EMF at the measurement sites. They used a mixed effect model to compare model predictions to measured values and to determine if building features altered the connection between simulated and measured RF-EMF. A Spearman correlation of 0.73 was discovered between the modelled and observed total downlink RF-EMF from base stations. The average modelled and measured RF-EMF values were 0.053 and 0.041 mW/m², respectively, with a precision of 0.184mW/m². Incorporating information on the physical features of the structure had no effect on the model's predictions. They found that, despite exposure misclassification, it is possible to accurately rank indoor RF-EMF from mobile phone base stations for epidemiological research.

In a work on Outdoor and indoor sources of residential radiofrequency electromagnetic fields, personal cell phone and cordless phone use, and cognitive function in 5–6 years old children. The authors examined the connection between residential RF-EMF exposure from mobile phone base stations, the presence of indoor sources in the home, personal cell phone and cordless phone use, and cognitive performance in children aged 5–6 years. A cross-sectional research was conducted in the Netherlands (n=2354) on children aged 5–6 years from the Amsterdam Born Children and their Development (ABCD) program. A 3D geospatial radio wave propagation model was used to predict residential RF-EMF exposure from mobile phone base stations. The mother noted the availability of indoor sources (cordless phone base stations and Wi-Fi) in her residence, as well as her children's mobile phone and cordless

phone use. The Amsterdam Neuropsychological Tasks were used to measure information processing speed, inhibitory control, cognitive flexibility, and visuomotor coordination. According to their findings, the presence of RF-EMF indoor sources in the home was related with an increase in the speed of information processing. Increased residential RF-EMF exposure from mobile phone base stations and the presence of indoor sources was associated with improved inhibitory control and cognitive flexibility, whereas increased personal cordless phone use was associated with decreased inhibitory control and cognitive flexibility. Increased residential RF-EMF exposure from mobile phone base stations was linked with decreased visuomotor coordination, but the presence of RF-EMF interior sources and increased personal cell phone use enhanced visuomotor coordination.

In a study on required levels of radiation power of GSM base stations on urban area taking into account attenuation in buildings and intra system EMC⁴⁵. The authors conducted analysis on the basis of a behavior simulation of a fragment of the GSM network in voice communication mode, using the multi beam radio wave propagation model X3D and a topological model of a fragment of the central part of Minsk's urban area, by comparing statistical distributions of signal levels received on various floors of buildings, taking into account have. The results indicate that in typical urban areas with a medium number of storey buildings, high communication quality at BS equivalent isotropic radiated power of $\geq 43-45$ dBm can be achieved in GSM-1800 networks only through diagnostics and improvement of intra system EMC of the cellular network, as well as network optimization, including optimization of spatial structure and frequency sharing.

In another study on clinically defined non-specific symptoms in the vicinity of mobile phone base stations: A retrospective before-after study⁴⁶.

The major goal of this study was to examine any changes in the prevalence and number of NSS associated with MPBS exposure prior to and following an increase in the number of MPBS antennas deployed. We did a retrospective cohort research in which we compared two

time periods with a high contrast in terms of the number of MPBS deployed. The study used electronic health information from 1069 adult individuals who were registered in nine general practices across the Netherlands. All participants lived within a 500-meter radius of the nearest base station. 55 of them reported being susceptible to MPBS at T1. Indoor exposure to RF-EMF from MPBS at T1 was assessed using a propagation model in conjunction with a questionnaire. The exposure at T0 was estimated using the number of antennas at T0 in comparison to T1. According to the authors, the overall number of MPBS antennas increased by more than 30% at T1. At T1, the MPBS-sensitive group had a greater prevalence of the majority of NSS compared to baseline. In the overall sample, exposure estimations were not related with GP-registered NSS. There were many significant interactions between MPBS sensitivity and exposure estimations on the likelihood of symptoms. It was established that RF-EMF exposure to MPBS was not related with the development of NSS using clinically defined outcomes and a time interval of > 6 years. Nonetheless, there was some evidence of an increased risk of NSS in the MPBS-sensitive group, mostly due to UMTS exposure, although this should be taken cautiously. Future longitudinal studies must confirm these findings, with a special emphasis on potentially vulnerable population subgroups, high sample sizes, and integrated exposure assessment.

Similarly, Comparative Analysis of Electromagnetic Field Exposure Levels and Determination of the Minimum Safe Distances from Mobile-Phone Base Stations in Urban Areas⁴⁷. The authors presented software-based and experimental evaluations of the exposure levels to electromagnetic fields generated by GSM 900, GSM 1800, and 3G base stations in urban areas, as well as the determination of the minimum safe distance. They utilized the software program SPECTRAemc in conjunction with the P.1546 propagation wave model and a topographic digital map to determine the electromagnetic field levels at the receiving antenna's height relative to the person. In situ measurements of the electric field strength were made at a few places along the path of greatest radiation intensity. At a few exposure areas,

base station power densities ranged from 0.11 ($\mu\text{W}/\text{cm}^2$) to 6.73 ($\mu\text{W}/\text{cm}^2$). Finally, they compared the results of the experimental survey conducted in Kosovo to those of surveys conducted in 21 nations across five continents. Kosovo's power density levels are greater, but several times less than the safety requirement limits.

In another related study on Radiofrequency electromagnetic field exposure assessment: a pilot study on mobile phone signal strength and transmitted power levels⁴⁸. They noted that assessing RF-EMF exposure from mobile phone use is prone to measurement mistakes, therefore restricting epidemiological studies. A frequently neglected element is the received signal intensity from base stations and its link to the transmit (Tx) power of mobile phones. They utilized an Android phone called a Qualipoc, which is a gadget that displays both signal strength and transmit power. On 3G and 4G networks, the phone simultaneously measures the Received Signal Strength Indicator (RSSI), Reference Signal Received Power (RSRP), Received Signal Code Power (RSCP), and Tx power. In the wider Melbourne area, measurements revealed a wide variety of signal strength levels. Correlations between various signal strength indicators and Tx power were examined, and significant negative correlations were discovered for 3G and 4G data technologies (3G RSSI 0.93, RSCP 0.93; 4G RSSI 0.85, RSRP 0.87). The variation in Tx power was measured across categorical categories of signal strength and revealed significant increases in Tx power as signal level dropped. Thus, future epidemiological studies should account for signal strength or variables affecting signal strength in order to minimize the measurement error associated with RF-EMF exposure.

In a related work on Measurement of Levels of Electromagnetic Energy Density Emitted By Mobile Phone Towers In The City of Mosul, IRAQ⁴⁹. The research examines the energy density levels of mobile phone towers in the city of Mosul for the downlink of GSM 900 and GSM 1800 frequency range signals for the Asiacell and Korek businesses, and compares them to national and international radiation safety regulations. SRM-3006 was utilized to determine the energy density of electromagnetic radiation in this study. Measurements were obtained

from mobile phone towers located inside the municipal humpback sector. The results demonstrate that the constellation antennas' radio frequency radiation levels do not exceed the permitted limits for various radio frequency transmissions. Asiaticell's average power density (PD) in the (900 MHz) frequency band was 0.0872399 W/m², whereas Korek's was 0.0313094 W/m². Whereas Asiaticell's average power density (PD) in the (1800 MHz) frequency band was 0.16183177 W/m², Korek's was 0.0607802 W/m². Although the greatest overall mean density was 0.17914139 W/m², several places in this research were exposed to two levels above 0.1 W/m², which corresponds to the Russian border. The energy density values obtained were greater than those found in other nations' study, owing to certain variations in measuring devices, measurement site standards, measurement equipment settings, survey technique, and urban design. GIS was used to create maps of the location of radio towers and their radiation levels.

Modeled and Perceived Exposure to Radiofrequency Electromagnetic Fields from Mobile-Phone Base Stations and the Development of Symptoms Over Time in a General Population Cohort⁵⁰. The authors examined the relationship between predicted and experienced exposure to radiofrequency electromagnetic fields (RF-EMF) from mobile-phone base stations and the onset of nonspecific symptoms and sleep disruptions over time. A population-based Dutch cohort study, the Occupational and Environmental Health Cohort Study (AMIGO) ($n = 14,829$; ages 31–65 years), was established in 2011/2012 (T_0), with follow-up of a subgroup ($n = 3,992$ invited) in 2013 (T_1 ; $n = 2,228$) and 2014 (T_2 ; $n = 1,740$). They used a three-dimensional geospatial model to simulate far-field RF-EMF exposure from mobile phone base stations near the participants' homes (NISMap). The questionnaire was used to measure perceived exposure (0 = no exposure; 6 = significant exposure), nonspecific symptoms, and sleep disruptions. Cross-sectional and longitudinal analyses were conducted, as well as fixed-effects regression. They discovered minor associations between modeled and felt exposure in baseline AMIGO participants ($n = 14,309$; $r_{\text{Spearman}} = 0.10$). For 222 follow-up

participants, modeled exposure increased substantially ($>0.030 \text{ mW/m}^2$) between T_0 and T_1 for 222 follow-up individuals. This rise in modeled exposure occurred concurrently with an increase in felt exposure during the same time period. In comparison to modeled RF-EMF exposure from mobile-phone base stations, perceived exposure was related with increased symptom reporting scores in both cross-sectional and longitudinal analyses, as well as with sleep disruptions in cross-sectional studies.

In a study on the health effects of electromagnetic radiation (EMR) from GSM base stations in North-Western Nigeria⁵¹. Their work assessed the radio frequency radiation from mobile base stations in some selected states in north western Nigeria. The study's methodology is one of measuring and instrumentation. A handheld spectrum analyzer (Aaronia HF 4040V3) and a wheel meter were used to quantify electromagnetic emissions from selected Airtel, Glo, MTN, and Etisalat base stations in Kano, Jigawa, and Katsina state capitals, respectively. A portable spectrum analyzer (Aaronia HF 4040V3), a wheel meter, and a digital computer were utilized. On-site field measurements were used to determine exposure levels. Microsoft Excel was used to collect and evaluate data on electromagnetic emissions from selected Airtel, Glo, MTN, and Etisalat base stations in Kano, Katsina, and Dutse. The received power (dBm) and exposure limits (mW/m^2) were determined at distances ranging from 20 to 460 meters from the chosen base stations operating in the 100MHz to 4GHz frequency band. We analyzed the net effect of RF emissions and compared it to the ICNIRP standard. The investigation determined that the average electromagnetic radiation released in the study region ranged between 17 and 70 mW/m^2 , indicating complete compliance with the exposure limit by GSM service providers in the area. The findings validated the environmental safety level of radio frequency energy that is maintained within the general population and is reliably low enough to provide no major health risks to humans.

Another research, health disturbances and exposure to radiofrequency electromagnetic fields from mobile-phone base stations in French urban areas⁵². They sought to determine the

relationship between self-reported non-specific and insomnia-like symptoms and measured exposure to radiofrequency electromagnetic fields (RF-EMF) from MPBSs. Between 2015 and 2017, a cross-sectional study of 354 persons living in buildings 250 meters or fewer from an MPBS and within the main transmit beam of the antennas was done in five big cities in France. Environmental worries, anxiety, and non-specific and insomnia-like symptoms were elicited using a telephone questionnaire. Following that, a comprehensive broadband field-meter measurement [100 kHz - 6 GHz] was taken at five sites throughout each residence, followed by a spectrum analysis at the point of greatest exposure, highlighting the contribution of each service, including MPBS. MPBS exposure was 0.27 V/m (0.44 V/m for global field), with a range of 0.03 V/m to 3.58 V/m, with MPBSs being the primary source of exposure in 64% of households. The exposure level measured in this research group was from MPBSs was not related with non-specific or insomnia-like symptoms as self-reported. However, a substantial relationship between RF-EMF exposure from MPBSs and environmental concerns was discovered for insomnia-like symptoms.

Moreover, in another study on Validity of at home model predictions as a proxy for personal exposure to radiofrequency electromagnetic fields from mobile phone base stations⁵³. The study builds on earlier research by examining the feasibility of utilizing NISMap to estimate indoor RF-EMF exposure levels at home as a proxy for human exposure to RF-EMF from mobile phone base stations. The authors used an EME-SPY 121 exposimeter to determine personal exposure to RF-EMF from mobile phone base stations for 93 persons in the Netherlands during a 24-hour period. Each subject kept a journal from which we collected information about their time at home and in the bedroom. They utilized NIS Map to simulate exposure at the participant's home address (at bedroom height). The authors then used the Spearman correlation coefficient (rsp) to compare model predictions to measurements for the 24 hour period, at home, and in the bedroom, as well as to calculate specificity and sensitivity using the 90th percentile of the exposure distribution as a cutoff for high exposure. They

discovered a low to moderate ρ of 0.36 for the 24 hour period, 0.51 for measurements at home, and 0.41 for measurements in the bedroom. Although the specificity was high (0.9), the sensitivity was poor (0.3). These findings show that a meaningful ranking of personal RF-EMF is possible, despite the fact that the correlation between model predictions and 24-hour personal RF-EMF measurements is lower than the correlation between model predictions and at-home data. However, when RF-EMF field estimates from mobile phone base stations are used in epidemiological research, substantial exposure misclassification occurs, resulting in a loss of statistical power to detect health impacts. These data do not support the idea that RF-EMF from MPBSs has an effect on generalized non-specific or insomnia-like symptoms. Further research is needed to elucidate the favorable relationship between MPBS exposure and insomnia-like symptoms in persons expressing environmental concerns.

On a Review on RF Field Exposure from Cellular Base Stations⁵⁴. Their work reviewed the estimation and evaluation of human exposure to electromagnetic fields (EMF); these radiated fields from cellular base stations that aim to verify exposure compliance with human protection guidelines. Numerous publications employed a variety of exposure measuring methods, including single point measurements and spatial averaging approaches, such as 3, 6, 9, 20 points. Selected nations around Europe and abroad conducted an EMF exposure study and compared the results to the International Commission on Non-Ionizing Radiation Protection's recommendations (ICNIRP). Additionally, the study discusses various international regulations for EMF exposure from base stations. Finally, the unfavorable biological consequences of EMF exposure are outlined from several studies.

In an investigation on residential exposure to electromagnetic field from cellular mobile base station antennas⁵⁵. Their research examined how much electromagnetic radiation is emitted by base station antennas in residential areas. Numerous exposure scenarios such as the hallway, kitchen, bedroom, and patio were investigated, and electromagnetic field exposure was quantified in terms of power density and electric field. The typical antenna tower was around

150 feet tall, and the average number of antennas on base station towers was approximately 16. The observed power density values were significantly less than the maximum allowed exposure limits. The exposure to electromagnetic fields was greatest on the patio, moderate in the hallway and bedrooms, and minimal in the kitchens. Residential exposure ranges between 45.92 to 13860 $\mu\text{W}/\text{m}^2$. Residential exposure reached a high of 2797 $\mu\text{W}/\text{m}^2$.

Additionally, in An Assessment of Electromagnetic Field Exposure from Cellular Mobile Base Station Towers in Densely Populated Residential Areas⁵⁶. Their research included measurements obtained near cellular mobile towers in heavily populated metropolitan areas throughout India. The power densities and electric field intensities were determined at distances ranging from 10m to 150m at a height of 1.5m in the radiating direction of the antenna using a three-axis field strength meter KM 195. It was discovered that the majority of cellular base station antenna locations adhered to Indian criteria for measuring cellular phone radiation. The average power density is 3479.65 $\mu\text{W}/\text{m}^2$. Beyond $\mu\text{W}/\text{m}^2$, around 80% of power densities increase. The amplitude of electromagnetic field exposure (EMF) is dependent on the distance between the base station tower and the ground, the height of the base station tower, the number of antennas on the base station tower, and the direction. In heavily crowded residential areas, line of sight distances were accessible up to 100m, beyond which no line of sight distance was allowed. The line of site power density was found to be higher than the nonline of site power density. The results indicate that power densities were higher in some areas near cellular base stations and were too low in others. It was discovered that there was a dramatic change in power density and electric field intensity daily, and that by measuring general electromagnetic field exposure, one can provide this data to the agencies responsible for electromagnetic field regulation.

In an Assessment of Spatial Distribution of Telecommunication Base Stations and Compliance Level of the Operators to the Regulations in Federal Capital City Abuja, Nigeria⁵⁷. Their work aimed to determine the spatial distribution of telecommunication base

stations in Abuja and the operators' compliance with the Nigerian Communication Commission (NCC) regulations. They gathered secondary and primary data from Abuja's existing base stations. The study utilized field surveys and geographical analysis through satellite imagery. According to the study's analysis, there are 92 base stations in the city that are not in accordance with NCC standards (26.1 percent). According to the research, 17 base stations overlap, which may be shut down without affecting the operators' operations. Economic benefit was found to be a significant role in base station siting, rather than the NCC standards. It was proposed that 17 base stations be shut down in order to achieve a high degree of compliance with NCC guidelines.

In an Assessment of the Level of Compliance of GSM Mast Location to Environmental Standard Regulations⁵⁸. The research's particular goals include mapping the position of GSM masts and determining the extent to which environmental standard laws are being followed in the study region. The scientists used ArcGIS 10.1 software to construct a geodatabase that visualized the geographical position and distribution of base stations across the research region. Buffering of 5 and 10 meters around GSM Base Stations was built using the buffer Tool in ArcGIS's Geoprocessing Tool Box. There were 59 GSM masts found across the town. The data indicate that 89.8 percent of the masts breached the regulation setback and just 10.2 percent complied to the regulatory standard. The environmental impacts of GSM mast locations, such as oil spillage into wells, mast collapse, and building cracks/collapse, were observed to be more severe in areas closer to the masts and less severe as distance increased away from the masts, due to house clustering around the masts, which indicates a violation of the 5m and 10m NCC/NESREA regulations. The research proposes that both the NCC and NESREA unify their minimum regulation setback distance policies, as noise risks are still reported from a distance. Additionally, regulatory authorities should increase their vigilance in enforcing prohibited rules and regulations. Additionally, the research advises that regulatory bodies (NCC/NESREA) conduct public awareness and sensitization campaigns on the dangers

associated with living near telecommunications towers. BTS, environmental compliance, environmental rules, environmental standard, and GSM Mast are all terms that refer to the same thing.

In a work titled Telecommunication Masts/Base Transceiver Stations and Regulatory Standards in Abia State, Nigeria⁵⁹. Their study examined GSM service providers' compliance with established guidelines for the installation of BTSs and masts in Abia State, Nigeria. They used a geometric survey approach and mostly depended on primary data acquired by direct observation and measurement. The BTSs/Masts that were surveyed were proportionally selected using cluster and simple random sampling approaches. The data were analyzed using SPSS for Windows, Version 17, with appropriate parametric tests. The study's assumptions were tested using the t test for paired samples and Analysis of Variance (ANOVA). The findings indicate a substantial discrepancy between the mean number of BTSs/Masts surveyed and the mean number that met regulatory criteria. Additionally, the study discovered that there were no major variations in how telecommunications networks applied environmental regulations. The authors thus proposed that both the NCC and NESREA be required to delegate their supervisory and monitoring functions to Town Planning Authorities at the local government level in order to guarantee efficient enforcement of regulatory requirements.

In the Analysis Of The Spatial Distribution Of Global System Of Mobile Communication Base Stations In Zaria Urban Area, Kaduna State, Nigeria⁶⁰. The authors identified and mapped existing base stations (masts) in accordance with World Health Organization (WHO) (2007) criteria for GSM base station location, which stipulates that the Mast should be constructed ten (10) metres away from residential areas. The study analyzed spatial data from GSM base stations (masts), a Quickbird satellite picture of metropolitan Zaria, field survey data, the Geographic Positioning System (GPS), several service providers, and the Nigeria Communication Commission (NCC). The 10m buffer zone tests were also used to evaluate the requirements for the position and distribution of base station masts. The research region

had 116 GSM Base Stations, of which only 16 masts met WHO standards, while the rest 100 did not. Finally, the geographical distribution of these facilities inside residential areas subjected to electromagnetic radiation. According to their proposal, regulatory bodies should monitor service providers that breach the ten-meter rule for GSM base station placement away from residential areas and remove incorrectly located masts. Additionally, the public media and schools should be adequately informed about the potential health risks associated with electromagnetic radiation exposure for those residing near GSM base stations.

2.3 Summary of Gaps in Literature

Various researchers have worked and contributed to the existing literature RF and power densities generated on distribution of base stations and their compliance to regulations. Some also worked on exposure to radio frequency electromagnetic fields from mobile-phone base stations and the development of symptoms, electromagnetic radiation (EMR) and human health both in Nigeria^{32,33,51,57}. Researches were also done outside the country on transmitted power density from GSM transceiver base stations and their effects on human health and compliance levels^{34,42,43,45,48}. However, most of this investigations are in some cities of the nation and other countries, the study can be carried out in major cities like Sagamu metropolis Nigeria, where there is complex, sophisticated and highly congested traffic base stations. Also, some of the study provided power density measurements for the GSM 900 and GSM 1800 frequency range signals only. This study also tend to analyze power densities for GSM 900MHz, GSM 1800 MHz, WCDMA 2100 MHz frequency range signals.

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Chapter Three

Research Methodology

3.1 Research Approach

The study will measure 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 will be analyzed with respect to ICNIRP, WHO, NESREA, NCC regulations to identify the compliance level.

3.2 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)

3.3 Research Method

3.3.1 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.

3.4 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 software to process the measured results.
3. GPS (Global Positioning System) recording location coordinates.
4. Digital camera

3.5 System Design

RF Radiation Measurements at Different Frequency Bands (GSM 900Mhz, GSM 1800 Mhz, Wcdma 2100 Mhz) at Selected Base Stations.

3.5.1 Data Capturing

This stage involved the capturing of the Central Base Stations coordinates by the use of hand GPS. It involved the carrying out of field of exercise by going to different locations of the Base Stations to take their coordinates (longitude and latitude). This field exercise was done in order to know the spatial distribution of all the Base Station in Sagamu. The RF Field meter was used to determine the spatial variation of RF fields in the vicinity of the site in order to pinpoint the location of maximum field strength¹. GPS coordinates were recorded, as well as any other pertinent information about the locations. Measurements were collected at intervals of 30m between about 20m and 200m from each base station mast. The whole area of the MBTS was surveyed and scanned until maximum readings are acquired, and these points was identified as the locations for measurements. The electric field strength and power density

was measured using a hand-held broadband three-axis RF field meter working in the frequency range of 50 MHz to 3.5 GHz. At each site, data on the electric field strength and power density was collected and recorded. Also, spatial proximity of these base stations to residential settlements was measured and recorded using a measuring tape to know the proximity of base stations to residences.

3.5.2 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.

1	S\N	Type of in	Spatial Location Of CBS			Electromagnetic Radiation Detected		
2			Latitude	Longitud	Altitude	E (v/m)	H (æT)	P (mW)/m2
3	1a	House	6.844	3.656	137	0	0	2.175
4	b	Road	6.843	3.656	124	0	0	2.4
5	c	Shop	6.843	3.656	115	0	0	4.215
6	d	Church	6.843	3.656	128	0	0	6.426
7	2.yyyyyyy y	Road	6.91562	3.6683	342	0	0.66	5.031
8	3.yyyyyyy y	ROAD	6.91719	3.66499	344	0	0	3.641
9	4.yyyyyyy y	ROAD	6.87157	3.6842	284	0	0	3.37
10	5.yyyyyyy y	ROAD	6.8699	3.69324	274	85	0	6.747
11	6.yyyyyyy y	ROAD	6.86957	3.70734	169	0	0	8.701
12	7.yyyyyyy y	ROAD	6.86968	3.70999	202	0	0.15	6.295
13	8.yyyyyyy y	ROAD	6.87469	3.7127	150	0	0	6.492
14	9.yyyyyyy y	ROAD	6.87956	3.71385	169	0	0	6.644
15	10.yy y	ROAD	6.86637	3.7146	192	0	0	3.963
16	11.yy y	ROAD	6.86515	3.71512	175	0	0	2.456
17	12.yy y	ROAD	6.86393	3.71354	158	0	0	6.057
18	13.yy y	ROAD st	6.87382	3.10975	224	0	0	0.024
19	14.yy y	ROAD	6.87086	3.70562	229	0	0	17.68
20		CHURCH 1	6.8707	3.70536	229	0	0	5.783
21	15.yy y	ROAD	6.87758	3.70746	115	0	0	8.131
22	16.yy y	CHURCH s	6.88338	3.70441	242	0	0	0.001
23	17.yy y	HOUSE 5m	6.89513	3.70986	278	0	0	13.34
24	18.yy y	ROAD	6.89022	3.71193	225	0	0	22.62
25	19.yy y	ROAD	6.89022	3.71485	204	0	0	4.183
26	20.yy y	ROAD	6.89367	3.71707	199	0	0	5.828
27	21.yy y	HOUSE	6.89396	3.71749	219	0	0	9.113
28	22.yy y	ROAD	6.8874	3.72281	231	0	0	8.739
29	23.yy y	ROAD ST	6.88794	3.72164	202	51	0	0.092
30	24.yy y	ROAD	6.88705	3.72131	220	0	0	5.631

Figure 3.1: Screenshot of Data Captures Showing Type of Infrastructure, Spatial Location, EM Radiation Detected and Nearest Distance.

Source: Field Survey 2022

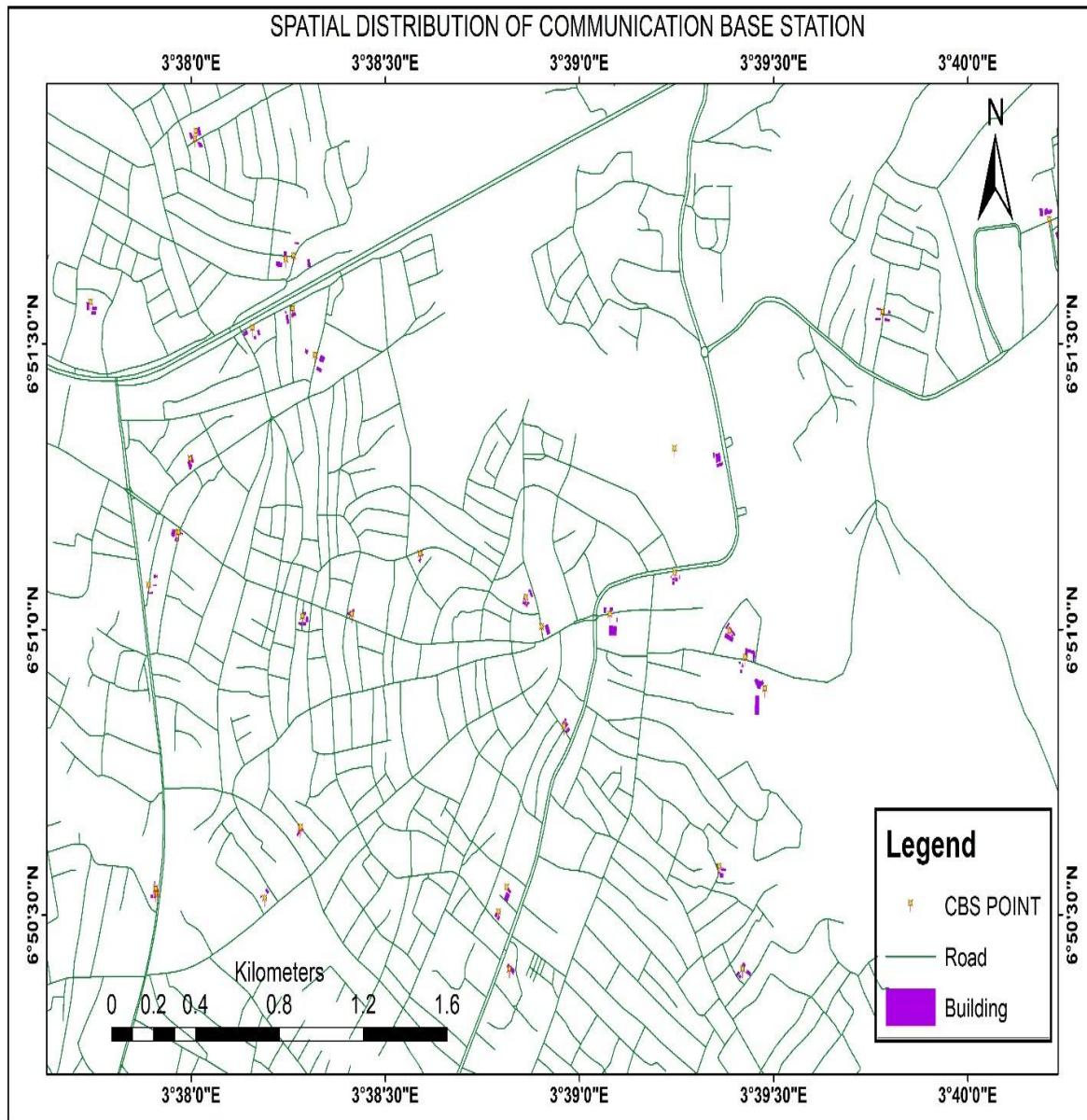


Figure 3.2: Spatial Distribution of Base Stations
Source: Field Survey 2022

3.5.3 Data Processing and Analysis

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

- i. Importation of the excel file into ArcMap environment.

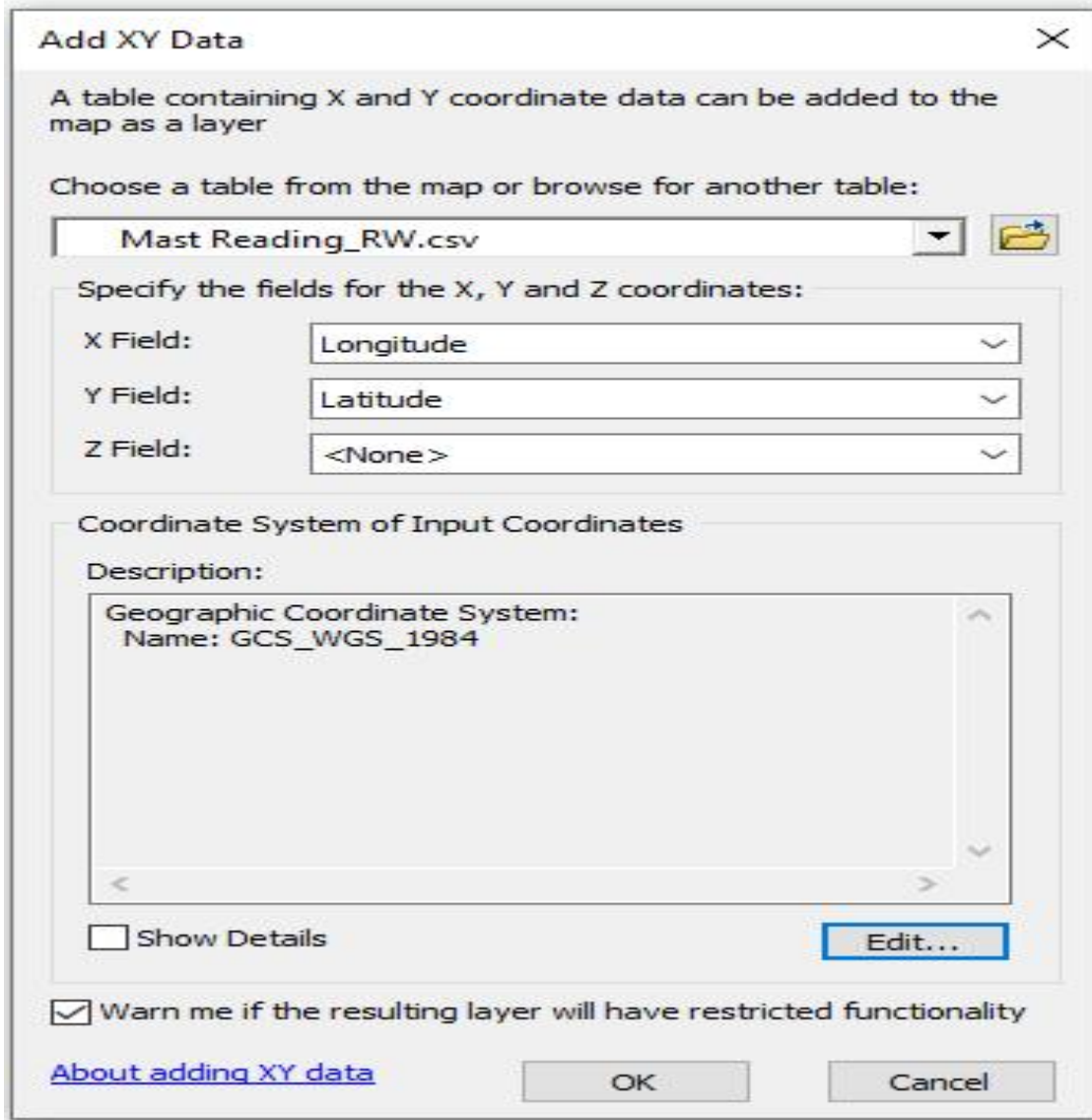


Figure 3.3: Importation of the Excel File into ArcMap Environment

Source: Research Design 2022

- ii. 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)

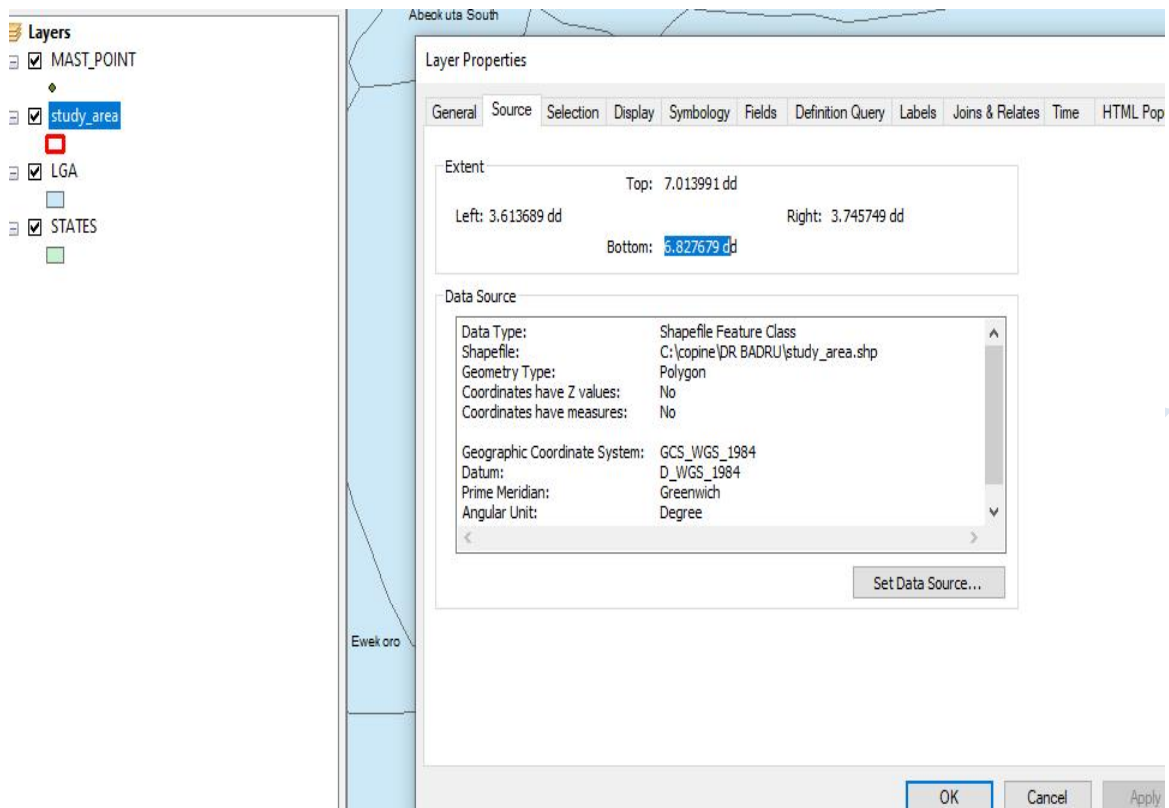


Figure 3.4 (a)

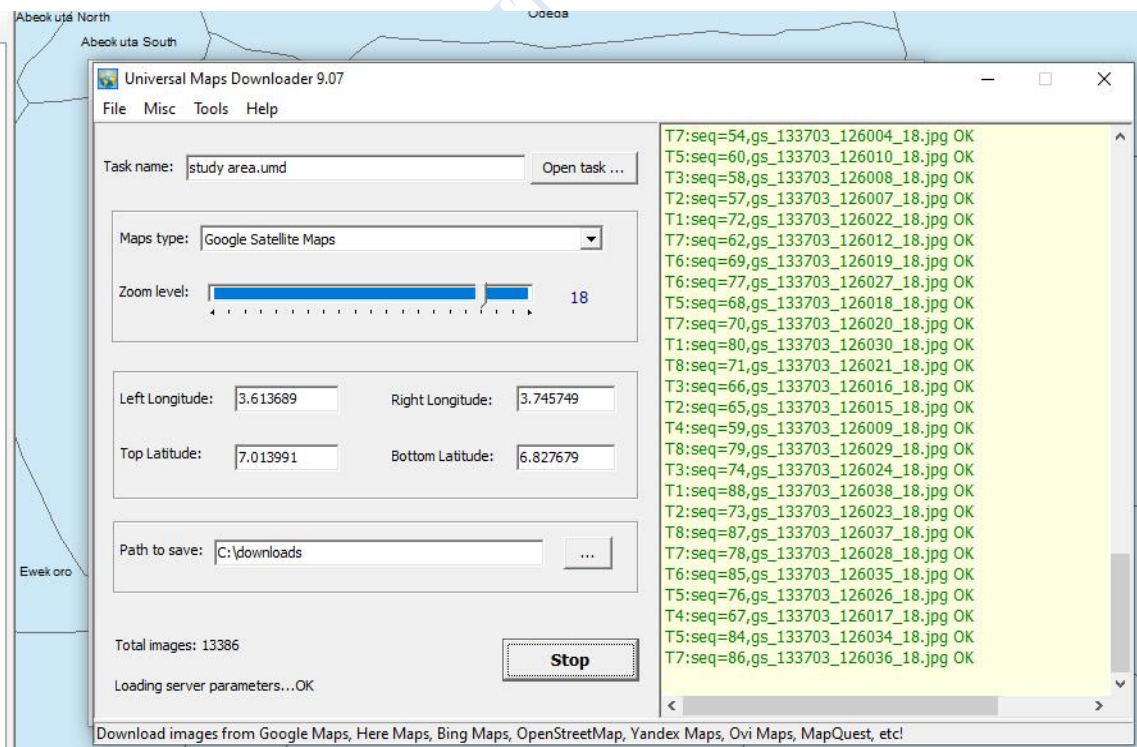


Figure 3.4 (a) and (b): Screenshot of Satellite Imagery Download of Sagamu
Source: Field Survey 2022

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

iii. 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.

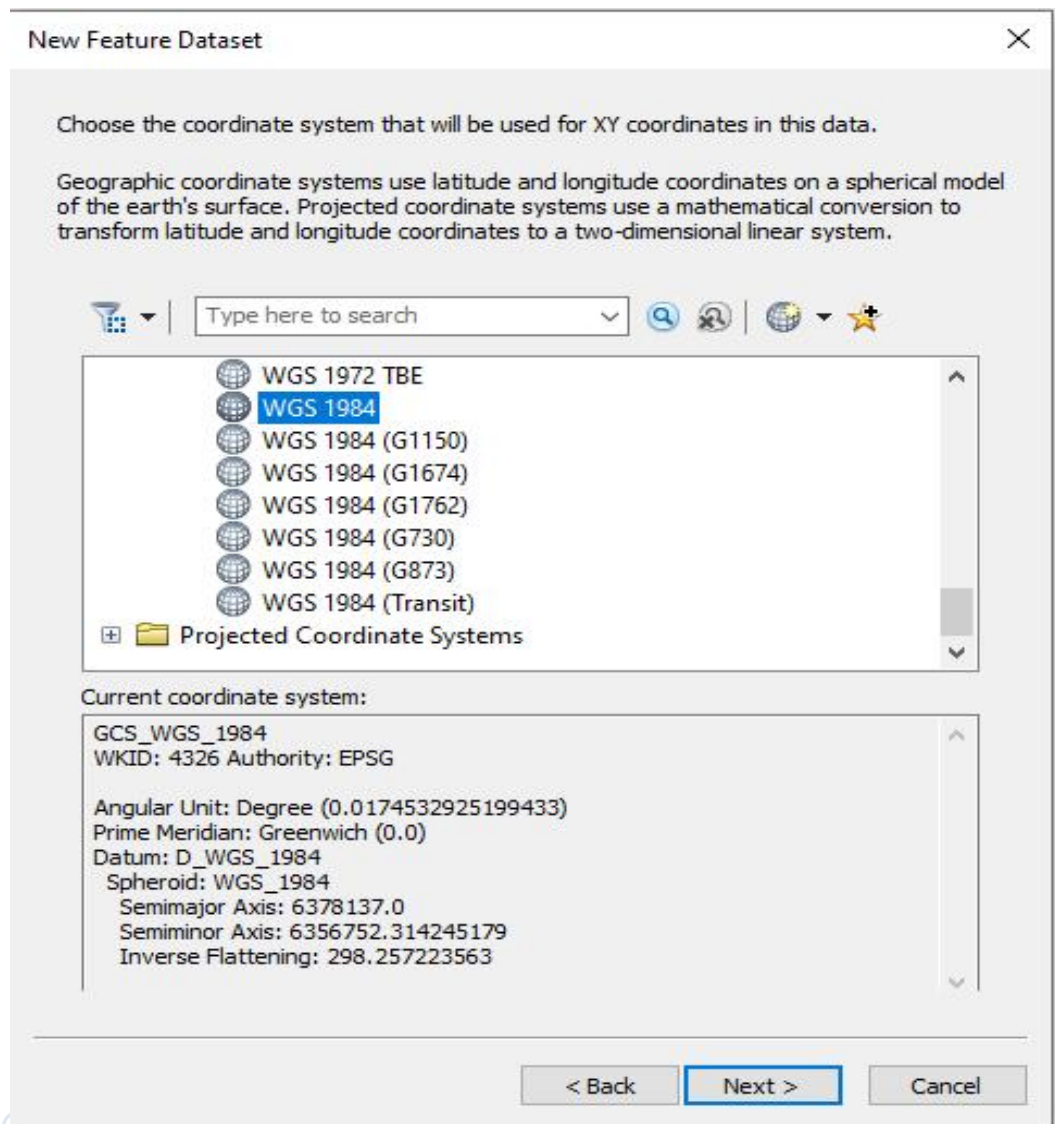


Figure 3.5 (a)

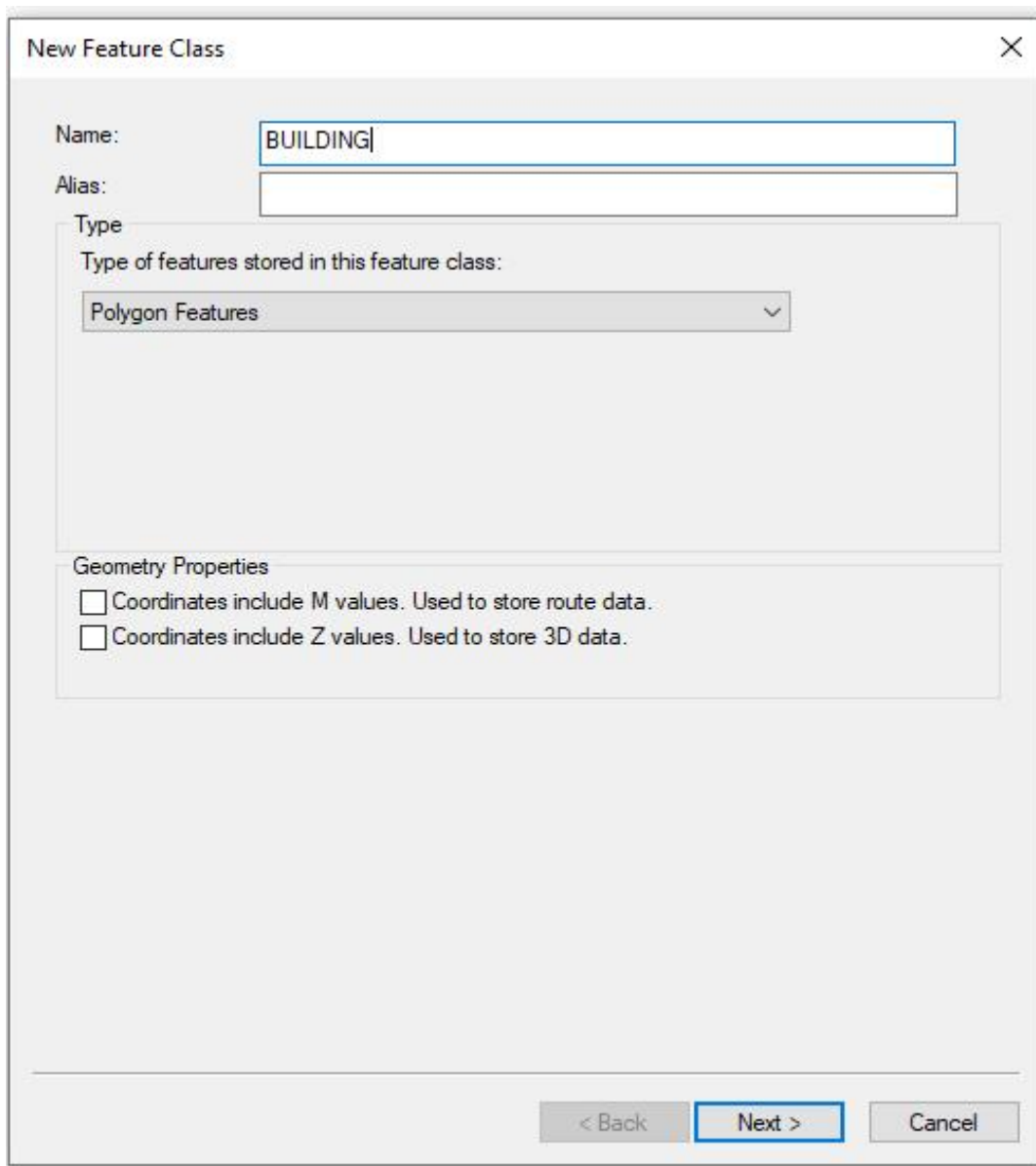


Figure 3.5 (a) and (b): Screenshots of Vectorisation of the satellite imagery

Source: Research Design 2022

- iv. 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.

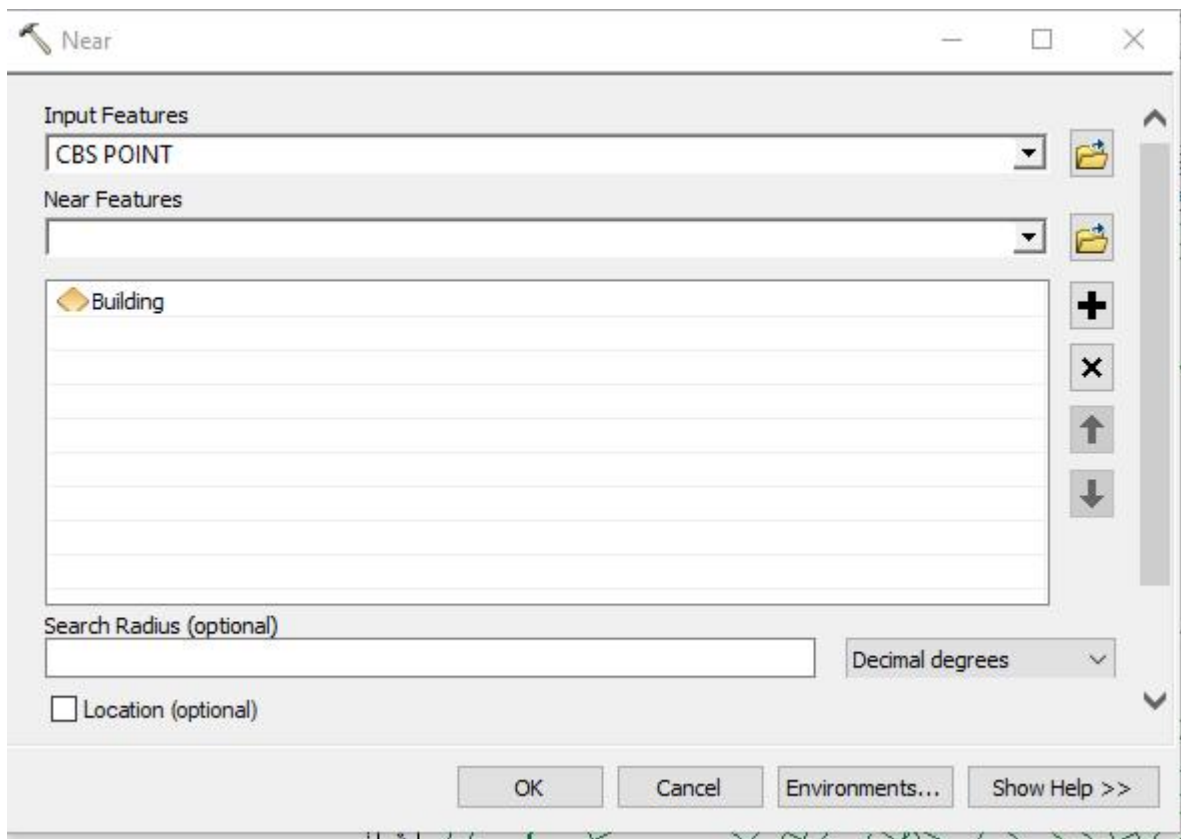


Figure 3.6: Screenshot of Tools Used to Measure the Distance between the Central Base Station and the Surrounding
Source: Research Design 2022

3.6 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.

3.7 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.

Endnotes

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Chapter Four

Result and Discussion of Findings

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

Table 4.1 Frequency Table of Type of Infrastructure Close to MBST's

Type of Infrastructure	Frequency	Percent
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

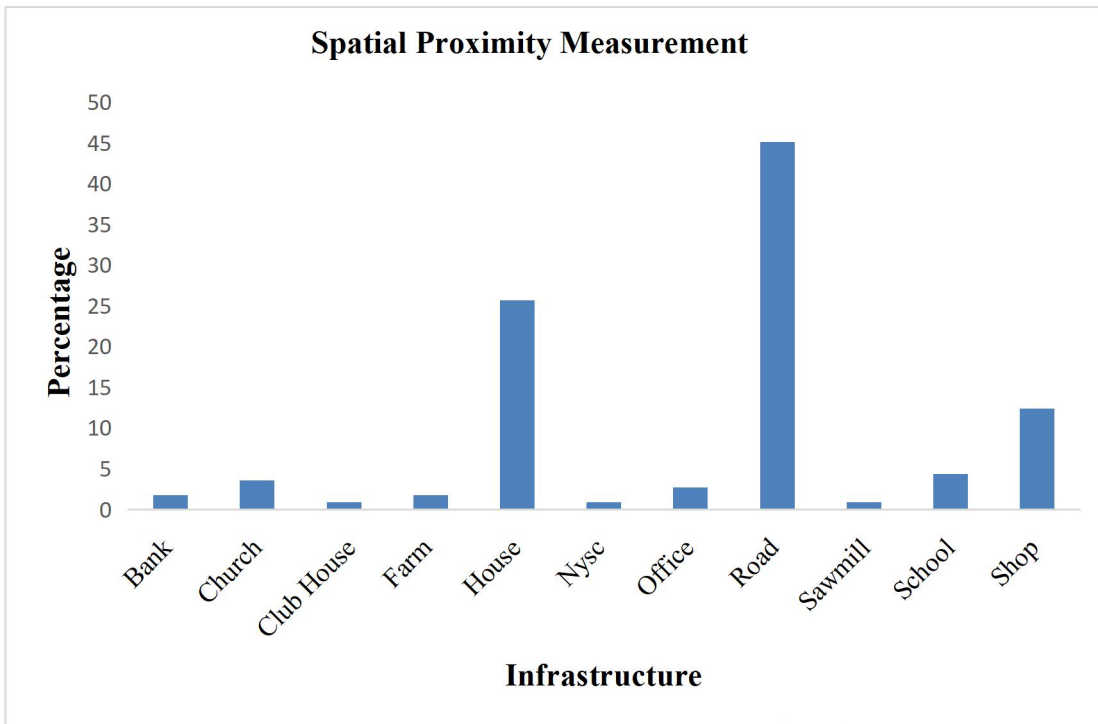


Figure 4.1: Chart Showing Type of Infrastructure and Percentage

The study revealed that the study area had about 113 CBS distributed around the over 200 km² 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 4.2, 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.

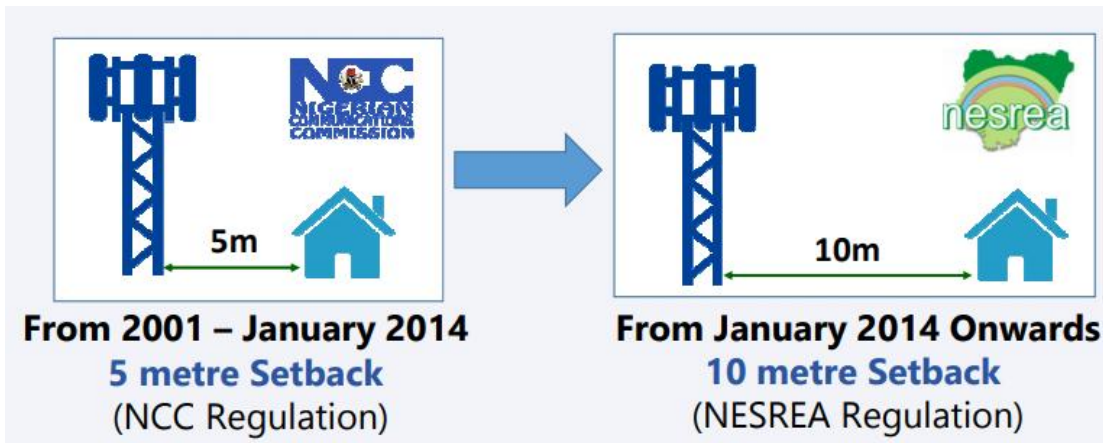


Figure 4.2 NCC and NESREA regulations on base station proximity to the nearest residence.

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 (see Appendix A).

4.1.1 RF Radiation Measurements at Different Frequency Bands (GSM 900MHz, GSM 1800 MHz, WCDMA 2100 MHz) at Selected Base Stations.

4.1.1.1 Power Density

By applying the Poynting theorem, Power Density, or P.D., is connected to the E-field and H-field vectors as given in Eq. 1¹.

$$PD = \frac{1}{2} \text{Re} [\vec{E}] \times [\vec{H}] \quad \text{Equation (4.1)}$$

Mathematically, the Power Density of an antenna can be expressed as:

$$P. \quad D = \frac{|E_{rms}|^2}{Z_0} = Z_0 \cdot |H_{rms}|^2 \quad \text{Equation (4.2)}$$

where, \vec{E} and \vec{H} represent the electric and magnetic field intensity of the electromagnetic waves.

$$Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} \quad \text{Equation (4.3)}$$

Z_0 is the characteristic impedance

$$\mu_0 = 4\pi \times 10^{-7} \text{ H/m, and } \epsilon_0 = \frac{10^{-9}}{36\pi}$$

$$\text{Then, } |E_{\text{rms}}|^2 = \sqrt{\frac{30NP_{\text{rad}}}{R}} \quad \text{Equation (4.4)}$$

Where, N is the number of carriers (antennas), P_{rad} is the radiated power, G is the radiation gain for the antenna, and R is the distance from the base station. Eq. 4.4 into Eq. 4.2 gives power density (Eq. 4.5).

$$\text{PD} = \frac{30P_{\text{rad}}G}{R} \quad \text{Equation (4.5)}$$

The equivalent Power Density,

$$\text{PD} = 0.0769N \frac{P_{\text{rad}}}{R^2} \times 10^{\frac{G}{10}} \quad \text{Equation (4.6)}$$

Hence, for a single human being exposed to a single base station antenna, N=1 in Eq. 4.6¹.

Table 4.2: 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 4.2 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.

Because of its close relationship to the effects of electromagnetic radiation on living things, the specific absorption rate (SAR) is typically used to define safe levels of electromagnetic

radiation exposure². These physiologically effective amounts are transformed into external field levels and power densities so that compliance testing can be carried out in a more straightforward manner. The external fields consist of a free electric field and the magnetic field intensity, both of which are easily measurable in terms of their exposure to real-life conditions. As a result, international and national standards both give exposure limitations expressed either in terms of power density S (W/m²) or in terms of electric field strength E (V/m) and magnetic field strength H (A/m).

Table 4.3: Infrastructures that Violates ICNIRP Recommended E (v/m) for 900Mhz, GSM 1800 MHz, WCDMA 2100 MHz

Type	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 4.3 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 4.4: Infrastructures that Violates ICRIP Recommended Power Density for 900MHz, GSM 1800 MHz, WCDMA 2100 MHz

Type infrastructu nearest CBS	Latitude	Longitude	Altitude	P(mW)/n	Distance
ROAD	6.87086	3.70562	229	17.68	7.55531159
HOUSE	6.89513	3.70986	278	13.34	9.25952751
ROAD	6.89022	3.71193	225	22.62	20.9169231
HOUSE	6.89396	3.71749	219	9.113	39.5344362
ROAD	6.89159	3.72064	237	10.07	16.6717266
ROAD	6.88334	3.72627	288	10.55	5.32768283
ROAD	6.88328	3.72642	270	15.45	10.2709807
ROAD	6.8832	3.72707	269	12.5	3.73917263
ROAD	6.89895	3.71791	248	11.66	10.0878688
ROAD	6.90835	3.68185	347	10.31	5.27347362
ROAD	6.91758	3.66139	343	14.92	4.64523175
SHOP	6.91757	3.66137	356	9.471	26.3503901
ROAD	6.9409	3.63561	319	13.34	15.3442803
SHOP	6.9908	3.68112	421	9.113	11.4751959
HOUSE	6.99078	3.68118	418	15.27	9.45622118
ROAD	6.8577	3.63857	252	12.99	4.04185949
ROAD	6.85957	3.62899	270	12.94	16.6431511
HOUSE	6.86083	3.63773	294	11.05	5.16224212
ROAD	6.86756	3.63844	157	10.63	18.4281154
ROAD	6.86425	3.63351	289	12.03	2.31491506
CHURCH	6.85207	3.64319	140	16.12	50.0326726
SHOP	6.85217	3.64324	169	10.6	24.3180449
ROAD	6.85929	3.63769	255	47.75	16.6717266
ROAD	6.85039	3.63806	198	29.73	3.60598964

HOUSE	6.85086	3.6477	236	9.996	9.17448524
HOUSE	6.85521	3.65408	128	9.996	7.27348460
ROAD	6.85184	3.65281	127	11.39	12.0871948
SHOP	6.84236	3.63181	139	16.37	9.25952751
HOUSE 1	6.84208	3.6365	198	14.81	4.73867696

Source: Field Survey, 2022

Table 4.4 above 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/m²). Other also showed high values ranging from 9.966 to 29.73 mW/m² 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 4.4 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

4.2 Discussion of Findings

The power densities measured at various CBS were analysed. From Table 4.2, 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 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. Table 4.3road 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 from Table 4.4 which shows the MBTSs with high power density with a peak value of 47.75 mW/m². 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/m². It can be observed that the power density at these 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. It however increases gradually as one moves away from the base station and decreases at greater distance. This indicates that the power densities were not concentrated within any particular area, which could be due to the directivity of the antennas used in the base stations. Also there was a significant fluctuation in data during measurement. One would have expected a decrease in power density by the square of distance ($P_t / 4\pi R^2$) as you move farther away from reference base station; this was however not so in most cases as could be observed. Fluctuations could be attributed to one or more of the five factors observed during measurement: (i) obstruction constituted by immobile structures placed or erected within the line of sight of measurement (ii) wave interference from other sources of electromagnetic radiation around reference base station such as radio and TV antennas, receivers etc. (iii) interference from radiation and/or noise from moving objects such as vehicles, motorcycles etc. (iv) topography (or elevation) of the land area around reference base station with respect to distance away from base station and (v) wave interference from other mobile base stations clustered around a reference base station. In general, the power density decreased with increase in distance.

Endnotes

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Chapter Five

Conclusifon

5.1 Summary of Findings

This study examined the compliance level of the required Electromagnetic Radiation (RF) emission levels and spatial proximity of selected mobile communication base stations in Sagamu Metropolis, Ogun State, Nigeria. According to the results of this research, the average power density of base stations dropped as distances (away from the base stations) rose, and the intensity of radiation differed from one mobile base station to the next (even at the same distance away). It was found that mobile base stations that experienced little to no fluctuation (in power density with distance) experienced little to no interference from external sources, whereas mobile base stations that experienced noticeable data fluctuations experienced significant interference from external sources. Fluctuations were caused by one or more of the following five factors that were observed during measurement: (i) obstruction constituted by immobile structures placed or erected within the line of sight of measurement (ii) wave interference from other sources of electromagnetic fields around reference base station, such as radio and TV antennas, receivers, etc. (iii) interference from radiation (wave) and/or noise from moving objects such as vehicles, motorcycles, etc. (iv) topography (or elevating features). The majority of the MBTSs do not comply with NCC (5m) set back regulations while majority 76.1% (86) of the measured infrastructure 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. This implies that most of the MBTSs complied with the NESREA standard of 10m set back.

The minimum average power density from individual base station (surveyed) in the town was about 9.113mW/m^2 while the mean maximum was about 47.75mW/m^2 . Therefore the 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.

5.2 Conclusion

The minimum average power density from individual base station (surveyed) in the town was about 9.113 mW/m² while the mean maximum was about 47.75mW/m². 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 regulations. Most of the MBTSs complied with the NESREA standard of 10 metre set back.

5.3 Recommendations

In line with the above findings, the study recommends that;

- i. Providers of mobile network services shall locate mobile base stations at least 150 metres away from residential areas and other potential sources of electromagnetic radiation.
- ii. Mobile base stations whose RF emission/radiation intensity is significantly high should be identified, and settlers (around such MBS) should be forced to relocate further away from such base stations. This will reduce the amount of exposure that people have to potentially harmful levels of radiation.
- iii. The government should enact and enforce a law that ensures service providers adhere strictly to set precedence and guidelines for installation of mobile base stations, particularly in relation to their proximity to residential areas. This law should ensure that service providers adhere strictly to set precedence and guidelines for installation of mobile base stations.
- iv. In light of the potential dangers of long-term exposure, national regulatory agencies should, in collaboration with other government agencies (at both the state and federal level), establish

and launch an enlightenment campaign to regularly sensitize the general public on the implications of RF radiation exposure and safety measures. This should be done in light of the fact that the public should be made aware of the potential dangers of long-term exposure.

- v. The government at both the state and the federal level should enforce and insist on town planning as a matter of the utmost importance in Sagamu town and its environs, while also ensuring an environment that is conducive to the construction of buildings that are in accordance with the town plan.
- vi. The Nigerian Communication Commission (NCC) needs to begin the same campaign in Nigeria and build a data bank for RF radiation from diverse network providers in order to facilitate risk management and improved standards of safety for everyone.

5.4 Contribution to Knowledge

The result of this study gave a checklist for compliance of network owners to the regulated exposure levels and spatial proximity, making the environment safer for the residence of the city. The results also served as means of awareness to the resident community and also as a compliance information for the regulators.

5.5 Suggestion for Further Studies

The following are the suggestions for further research:

- i. Additional research be conducted on the effects of RF power levels on health in adolescent and pregnant women.
- ii. This study was only carried out in Sagamu, Ogun State and thus implying that the findings are only limited to CBS in the State.

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Appendix

Type infrastructu nearest CBS	Spatial Location Of CBS			Electromagnetic Radiation Detected			
	Latitude	Longitude	Altitude	E	H	P	Distance
				(v/n)	(μ l)	(mW)/n	
House	6.844	3.656	137	0	0	2.175	3.75846363
Road	6.843	3.656	124	0	0	2.4	9.33302938
Shop	6.843	3.656	115	0	0	4.215	55.9670298
Church	6.843	3.656	128	0	0	6.426	47.9040775
Road	6.91562	3.6683	342	0	0.6	5.031	11.8822243
ROAD	6.91719	3.66499	344	0	0	3.641	4.43252016
ROAD	6.87157	3.6842	284	0	0	3.37	46.9581300
ROAD	6.8699	3.69324	274	85	0	6.747	16.0589550
ROAD	6.86957	3.70734	169	0	0	8.701	9.57926985
ROAD	6.86968	3.70999	202	0	0.1	6.295	4.31704436
ROAD	6.87469	3.7127	150	0	0	6.492	3.08176872
ROAD	6.87956	3.71385	169	0	0	6.644	13.1231863
ROAD	6.86637	3.7146	192	0	0	3.963	29.9081356
ROAD	6.86515	3.71512	175	0	0	2.456	14.2026977
ROAD	6.86393	3.71354	158	0	0	6.057	5.15502860
ROAD	6.87382	3.10975	224	0	0	0.024	19.9625120
ROAD	6.87086	3.70562	229	0	0	17.68	7.55531159
CHURCH	6.8707	3.70536	229	0	0	5.783	10.9007671
ROAD	6.87758	3.70746	115	0	0	8.131	52.4082255
CHURCH	6.88338	3.70441	242	0	0	0.001	59.8297461
HOUSE	6.89513	3.70986	278	0	0	13.34	9.25952751
ROAD	6.89022	3.71193	225	0	0	22.62	20.9169231
ROAD	6.89022	3.71485	204	0	0	4.183	26.7860338
ROAD	6.89367	3.71707	199	0	0	5.828	36.5562126
HOUSE	6.89396	3.71749	219	0	0	9.113	39.5344362
ROAD	6.8874	3.72281	231	0	0	8.739	50.0326726
ROAD ST	6.88794	3.72164	202	51	0	0.092	24.3180449
ROAD	6.89705	3.72121	239	0	0	5.631	10.4052235
ROAD	6.89159	3.72064	237	0	0.0	10.07	16.6717266
ROAD	6.89359	3.7185	224	0	0	5.522	81.1813995
ROAD	6.89126	3.72102	239	0	0	4.484	4.73867696

ROAD	6.88334	3.72627	288	0	0	10.55	5.32768283
ROAD	6.88328	3.72642	270	0	0	15.45	10.2709807
ROAD	6.8832	3.72707	269	0	0	12.5	3.73917263
ROAD	6.8832	3.72718	272	0	0	4.347	3.60598964
ROAD	6.90097	3.71138	274	0	0	5.522	8.34696989
ROAD	6.89895	3.71791	248	0	0	11.66	10.0878688
ROAD	6.89647	3.72462	281	0	0	4.449	3.96291990
ROAD	6.90835	3.68185	347	0	0	10.31	5.27347362
ROAD	6.93009	3.66666	377	0	0	2.239	25.2957516
SCHOOL	6.93012	3.66669	378	1	0	3.268	25.2957516
HOUSE	6.93001	3.66674	378	0	0	2.933	9.17448524
ROAD	6.91758	3.66139	343	0	0	14.92	4.64523175
SHOP	6.91757	3.66137	356	0	0	9.471	26.3503901
HOUSE	6.91756	3.66149	369	0	0	7.458	13.5768280
HOUSE	6.9311	3.63933	341	0	0	3.319	26.7176146
ROAD	6.93152	3.63867	353	0	0	3.449	30.4612107
SHOP	6.93154	3.63862	352	0	0	4.151	2.96606140
HOUSE	6.94	3.63142	186	0	0	1.475	7.27144938
ROAD	6.9399	3.6314	276	0	0	3.641	16.9330850
HOUSE	6.94084	3.63566	311	0	0	2.121	13.9255559
SHOP	6.94091	3.63561	329	0	0	1.789	5.73327771
ROAD	6.9409	3.63561	319	0	0	13.34	15.3442803
ROAD	6.93165	3.63484	287	0	0	2.933	4.13242961
BANK	6.93432	3.63559	325	0	0	2.437	7.27348460
FARM	6.92532	3.64285	288	0	0	2.121	1.75794042
OFFICE 1	6.92532	3.64285	288	0	0	2.187	12.0871948
OFFICE 2	6.92442	3.64144	276	8	0	3.641	6.64435000
ROAD	6.9157	3.6637	354	0	0	5.479	8.00767152
SHOP	6.91573	3.66364	358	0	0	4.415	11.7585555
ROAD	6.90383	3.66595	298	0	0	3.319	7.40740159
ROAD	6.8689	3.65816	245	0	0	2.757	4.56796813
ROAD	6.85919	3.66301	117	0	0	6.198	8.79592245
NYSC	6.86189	3.67015	259	0	0	11.48	14.5049316
ROAD	6.86243	3.67162	241	0	0	3.169	23.1543538
ROAD	6.86423	3.67154	258	0	0	7.401	1.28983852

HOUSE	6.86427	3.67152	261	0	0	13.6	15.4912094
CHURCH	7.0038	3.66684	574	0	0	4.881	19.9251843
ROAD	7.00376	3.66677	579	0	0	4.732	- 7.14393039
ROAD	7.00436	3.66544	562	45	0	5.347	17.1020380
HOUSE	7.00432	3.66552	560	61	0.0	8.836	34.6830942
ROAD	6.99096	3.68117	429	0	0	8.634	5.53568461
SHOP	6.9908	3.68112	421	0	0	9.113	11.4751959
HOUSE	6.99078	3.68118	418	0	0	15.27	9.45622118
ROAD	6.99202	3.68046	440	0	0	3.613	1.64571946
SHOP	6.99195	3.68047	442	0	0	4.025	4.46092170
HOUSE	6.99186	3.68047	442	0	0	2.437	34.6443787
ROAD	7.00189	3.68464	533	0	0	2.911	17.4504637
ROAD	7.00198	3.68438	531	0	0	4.553	17.6011124
SHOP	7.00209	3.6844	562	0	0	5.151	2.43394538
HOUSE	7.00209	3.68439	557	0	0	5.479	16.9701454
HOUSE	7.00229	3.68463	536	0	0	2.553	6.04088468
ROAD	7.00235	3.68435	560	0	0	5.151	4.93240374
ROAD	7.00286	3.68364	546	0	0	3.169	5.27659818
HOUSE	7.0028	3.68354	531	0	0	5.073	19.8383203
SHOP	6.98351	3.68326	372	0	0	2.8	5.74006846
HOUSE	6.98363	3.68337	376	0	0	8.372	10.1000932
ROAD	6.98347	3.68324	334	0	0	3.613	9.47713116
ROAD	6.98178	3.68325	354	0	0	3.577	16.6747188
HOUSE	6.98183	3.68349	330	0	0	8.905	3.85682478
ROAD	6.96718	3.68031	479	0	0	3.697	16.7958984
HOUSE	6.96716	3.68036	475	0	0	2.572	8.46229529
HOUSE	6.9684	3.67906	459	0	0	5.479	8.63800363
ROAD	6.96926	3.6697	464	0	0	7.692	7.94200400
FARM	6.96923	3.66957	443	0	0	1.845	9.01717512
HOUSE	6.93432	3.66774	404	0	0	4.215	21.4693746
ROAD	6.93422	3.6677	389	0	0	2.82	5.45123598 7.03364168
ROAD	6.85308	3.63676	194	0	0	5.873	180.703608
SHOP	6.85301	3.63672	193	0	0	3.933	3.88051934

HOUSE	6.85316	3.63668	205	0	0	7.574	9.31839464
HOUSE	6.8549	3.6333	213	54	0	0.394	6.06851081
HOUSE	6.85131	3.63166	203	0	0	2.256	2.35461301
ROAD	6.85122	3.63152	167	0	0	5.694	7.50289319
CLUB HOUSE	6.85793	3.63866	281	54	0	8.631	11.3301542
ROAD	6.8577	3.63857	252	0	0	12.99	4.04185949
ROAD	6.85957	3.62899	270	0	0	12.94	16.6431511
HOUSE	6.85948	3.62902	273	0	0	2.866	13.9019679
CHURCH	6.86073	3.6374	300	0	0	6.442	5.16224212
HOUSE	6.86083	3.63773	294	0	0	11.05	5.16224212
SHOP	6.8675	3.63836	154	0	0	5.763	2.50217021
ROAD	6.86756	3.63844	157	0	0	10.63	18.4281154
ROAD	6.86425	3.63351	289	0	0	12.03	2.31491506
HOUSE	6.86447	3.63355	280	0	0	4.415	7.55531159
ROAD	6.84411	3.63801	170	0	0	5.272	10.9007671
SHOP	6.84413	3.63804	174	0	0	5.151	52.4082255
ROAD	6.86895	3.65468	390	0	0	3.55	59.8297461
HOUSE	6.869	3.65498	245	0	0	3.669	9.25952751
SCHOOL	6.98707	3.67022	501	0	0	3.503	20.9169231
HOUSE ST	6.98994	3.66665	510	0	0	0.005	26.7860338
ROAD	6.85037	3.65131	183	0	0	4.995	36.5562126
SHOP	6.85037	3.64023	202	0	0	4.347	39.5344362
CHURCH	6.85207	3.64319	140	0	0	16.12	50.0326726
SHOP	6.85217	3.64324	169	0	0	10.6	24.3180449
HOUSE	6.85214	3.64342	151	0	0	7.121	10.4052235
ROAD	6.85929	3.63769	255	0	0	47.75	16.6717266
SHOP	6.85927	3.63753	248	0	0	8.702	81.1813995
SHOP	6.8588	3.63596	239	0	0	6.644	4.73867696
HOUSE	6.85873	3.63596	247	0	0	8.056	5.32768283
ROAD	6.85274	3.63272	203	0	0	2.239	10.2709807
SHOP	6.85276	3.6328	205	0	0	2.553	3.73917263
ROAD	6.85039	3.63806	198	0	0	29.73	3.60598964
SHOP	6.8503	3.63811	205	2	0	5.151	8.34696989
HOUSE	6.85027	3.63803	207	0	0	6.905	10.0878688

SHOP	6.85	3.64838	233	0	0	2.17	3.96291990
SHOP	6.85095	3.64806	251	0	0	6.295	5.27347362
ROAD	6.85096	3.64772	248	0	0	3.169	25.2957516
CHURCH	6.851	3.6477	239	0	0	3.613	25.2957516
HOUSE	6.85086	3.6477	236	0	0	9.996	9.17448524
SHOP	6.85054	3.62464	263	0	0	4.025	4.64523175
ROAD	6.85065	3.62457	193	0	0	6.295	26.3503901
HOUSE	6.85065	3.62462	184	0	0	3.53	13.5768280
SHOP	6.84713	3.64927	208	0	0	6.057	26.7176146
ROAD	6.84708	3.64928	182	0	0	5.437	30.4612107
HOUSE	6.8471	3.64934	190	0	0	8.244	2.96606140
ROAD	6.84874	3.65461	121	0	0	1.313	7.27144938
WALKWAY	6.8487	3.6546	88	0	0	4.087	16.9330850
SCHOOL	6.84911	3.65711	180	0	0	5.607	13.9255559
SCHOOL	6.8482	3.65795	157	0	0	3.503	5.73327771
ICT OFFICE	6.84988	3.65643	99	0	0	2.888	15.3442803
ROAD	6.85158	3.65409	105	0	0	8.437	4.13242961
HOUSE	6.85521	3.65408	128	0	0	9.996	7.27348460
HOUSE	6.85197	3.65286	124	0	0	3.344	1.75794042
ROAD	6.85184	3.65281	127	0	0	11.39	12.0871948
ROAD	6.83313	3.63796	132	0	0	3.144	6.64435000
HOUSE	6.83293	3.63818	142	0	0	3.268	8.00767152
SCHOOL	6.83285	3.63819	149	0	0	3.963	11.7585555
HOUSE	6.83405	3.63534	174	0	0	4.449	7.40740159
ROAD	6.834	3.63522	155	0	0	4.198	4.56796813
ROAD	6.83657	3.63619	177	0	0	2.437	8.79592245
HOUSE	6.83673	3.63633	173	0	0	2.437	7.55531159
SHOP	6.83667	3.63625	169	0	0	2.592	10.9007671
ROAD	6.84225	3.63187	133	60	0.0	3.963	52.4082255
HOUSE	6.8422	3.63182	142	3	0.0	4.046	59.8297461
SHOP	6.84236	3.63181	139	22	0	16.37	9.25952751
HOUSE 1	6.844	3.652	177	0	0	2.363	20.9169231
HOUSE 2	6.844	3.652	160	0	0	4.314	26.7860338
ROAD	6.844	3.652	156	0	0	2.933	36.5562126
SHOP	6.844	3.652	222	0	0	6.057	39.5344362

BANK	6.84	3.657	180	0	0	2.911	50.0326726
HOUSE	6.84	3.657	197	0	0	2.437	24.3180449
ROAD	6.84	3.647	180	0	0	3.669	10.4052235
SAWMILL	6.84	3.647	189	0	0	1.726	16.6717266
ROAD	6.84168	3.64653	172	0	0	4.119	81.1813995
HOUSE 1	6.84208	3.6365	198	0	0	14.81	4.73867696
HOUSE 2	6.8424	3.64688	188	0	0	1.963	5.32768283

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Case Summaries

		V7	Electromagnetic Radiation Detected
Type of infrastru	1	P (mW)/n	E (v/m)
nearest to CBS	2		
	Total N	2	2
BANK	1	2.437	0
	2	2.911	0
	Total N	2	2
Church	1	6.426	0
	Total N	1	1
CHURCH	1	4.881	0
	2	6.442	0
	3	16.12	0
	4	3.613	0
	Total N	4	4
CHURCH	1	5.783	0
	Total N	1	1
CHURCH	1	0.001	0
	Total N	1	1
CLUB HOU	1	8.631	54
	Total N	1	1
FARM	1	2.121	0
	2	1.845	0
	Total N	2	2
House	1	2.175	0
	Total N	1	1
HOUSE	1	9.113	0
	2	2.933	0
	3	7.458	0
	4	3.319	0
	5	1.475	0

6	2.121	0
7	13.6	0
8	8.836	61
9	15.27	0
10	2.437	0
11	5.479	0
12	2.553	0
13	5.073	0
14	8.372	0
15	8.905	0
16	2.572	0
17	5.479	0
18	4.215	0
19	7.574	0
20	0.394	54
21	2.256	0
22	2.866	0
23	11.05	0
24	4.415	0
25	3.669	0
26	7.121	0
27	8.056	0
28	6.905	0
29	9.996	0
30	3.53	0
31	8.244	0
32	9.996	0
33	3.344	0
34	3.268	0
35	4.449	0
36	2.437	0
37	4.046	3

	38		2.437	0
	Total	N	38	38
HOUSE 1	1		2.363	0
	2		14.81	0
	Total	N	2	2
HOUSE 2	1		4.314	0
	2		1.963	0
	Total	N	2	2
HOUSE 5m	1		13.34	0
	Total	N	1	1
HOUSE ST	1		0.005	0
	Total	N	1	1
ICT OFFICE	1		2.888	0
	Total	N	1	1
NYSC	1		11.48	0
	Total	N	1	1
OFFICE 1	1		2.187	0
	Total	N	1	1
OFFICE 2	1		3.641	8
	Total	N	1	1
Road	1		2.4	0
	2		5.031	0
	Total	N	2	2
ROAD	1		3.641	0
	2		3.37	0
	3		6.747	85
	4		8.701	0
	5		6.295	0
	6		6.492	0
	7		6.644	0
	8		3.963	0
	9		2.456	0

10	6.057	0
11	17.68	0
12	8.131	0
13	22.62	0
14	4.183	0
15	5.828	0
16	8.739	0
17	5.631	0
18	10.07	0
19	5.522	0
20	4.484	0
21	10.55	0
22	15.45	0
23	12.5	0
24	4.347	0
25	5.522	0
26	11.66	0
27	4.449	0
28	10.31	0
29	2.239	0
30	14.92	0
31	3.449	0
32	3.641	0
33	13.34	0
34	2.933	0
35	5.479	0
36	3.319	0
37	2.757	0
38	6.198	0
39	3.169	0
40	7.401	0
41	4.732	0

42	5.347	45
43	8.634	0
44	3.613	0
45	2.911	0
46	4.553	0
47	5.151	0
48	3.169	0
49	3.613	0
50	3.577	0
51	3.697	0
52	7.692	0
53	2.82	0
54	5.873	0
55	5.694	0
56	12.99	0
57	12.94	0
58	10.63	0
59	12.03	0
60	5.272	0
61	3.55	0
62	4.995	0
63	47.75	0
64	2.239	0
65	29.73	0
66	3.169	0
67	6.295	0
68	5.437	0
69	1.313	0
70	8.437	0
71	11.39	0
72	3.144	0
73	4.198	0

	74		2.437	0
	75		3.963	60
	76		2.933	0
	77		3.669	0
	78		4.119	0
	Total	N	78	78
ROAD	1		0.024	0
	Total	N	1	1
ROAD	1		0.092	51
	Total	N	1	1
SAWMILL	1		1.726	0
	Total	N	1	1
SCHOOL	1		3.268	1
	2		3.503	0
	3		5.607	0
	4		3.503	0
	5		3.963	0
	Total	N	5	5
Shop	1		4.215	0
	Total	N	1	1
SHOP	1		9.471	0
	2		4.151	0
	3		1.789	0
	4		4.415	0
	5		9.113	0
	6		4.025	0
	7		5.151	0
	8		2.8	0
	9		3.933	0
	10		5.763	0
	11		5.151	0
	12		4.347	0

	13		10.6	0
	14		8.702	0
	15		6.644	0
	16		2.553	0
	17		5.151	2
	18		2.17	0
	19		6.295	0
	20		4.025	0
	21		6.057	0
	22		2.592	0
	23		16.37	22
	24		6.057	0
	Total	N	24	24
WALKWAY	1		4.087	0
	Total	N	1	1
Total	N		113	113

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TYPE_OF INFRASTRUCTURE		NEAREST_DISTANCE
BANK	1	5.273473624
	2	13.901967900
	Total N	2
CHURCH	1	3.081768726
	2	17.102038060
	3	4.932403746
	Total N	3
CHURCH st	1	29.908135610
Total N	1	
CLUB HOU	1	19.925184320
Total N	1	
FARM	1	25.295751680
	2	8.795922454
	Total N	2
HOUSE	1	14.202697790
	2	10.900767120
	3	10.270980740
	4	3.739172639
	5	3.605989644
	6	10.087868840
	7	3.962919903
	8	16.933085030
	9	1.757940420
	10	8.007671526
	11	7.407401599
	12	4.567968137
	13	14.504931610
	14	1.289838526
	15	7.143930396
	16	34.683094290

	17		9.456221186
	18		17.450463760
	19		19.838320360
	20		3.856824788
	21		8.638003637
	22		7.942004001
	23		180.703608600
	24		9.318394649
	25		2.354613012
	26		4.041859499
	27		18.428115460
	28		2.314915068
	Total	N	28
HOUSE ST	1		2.433945383
	Total	N	1
ICT OFFICE	1		5.451235987
	Total	N	1
NYSC	1		26.717614670
	Total	N	1
OFFICE 1	1		25.295751680
	Total	N	1
OFFICE 2	1		9.174485246
	Total	N	1
Road	1		3.758463632
	Total	N	1
ROAD	1		9.333029385
	2		55.967029820
	3		47.904077540
	4		11.882224380
	5		4.432520165
	6		46.958130030
	7		16.058955070

8	9.579269856
9	4.317044367
10	13.123186340
11	5.155028608
12	19.962512080
13	7.555311597
14	52.408225540
15	59.829746130
16	9.259527518
17	20.916923180
18	26.786033860
19	36.556212650
20	39.534436200
21	50.032672600
22	24.318044950
23	10.405223520
24	16.671726670
25	81.181399520
26	4.738676966
27	26.350390160
28	13.576828010
29	30.461210720
30	2.966061404
31	7.271449383
32	13.925555900
33	15.344280300
34	12.087194820
35	6.644350002
36	11.758555520
37	23.154353850
38	15.491209460
39	11.475195940

	40		1.645719464
	41		34.644378740
	42		16.970145430
	43		5.276598188
	44		5.740068465
	45		8.462295296
	46		7.033641688
	47		6.068510812
	48		11.330154200
	49		5.162242121
	50		2.502170214
	Total	N	50
SAWMILL	1		5.162242121
	Total	N	1
SCHOOL	1		5.327682833
	2		17.601112460
	3		9.017175123
	4		21.469374650
	5		3.880519342
	Total	N	5
SHOP	1		8.346969898
	2		4.645231755
	3		5.733277716
	4		4.132429615
	5		7.273484603
	6		5.535684617
	7		4.460921701
	8		6.040884687
	9		10.100093220
	10		9.477131164
	11		16.674718890
	12		16.795898480

	13	7.502893191
	14	16.643151120
	Total N	14
Total	N	113

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This is to certify that this thesis by Onalaja Olabisi Olayinka with Matriculation Number LCU/PG/ 001077 in the Department of Computer Science, Faculty of Natural and Applied Sciences, Lead City University, Ibadan is in full compliance with the approved University's Format and Style.

Signature

Date

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