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COLLEGE OF SCIENCE
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Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

**A study of Electromagnetic Radiation Absorption on the Human
Head. Case Study of Mobile Phone.**

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A Dissertation Submitted to the Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE), University of Rwanda as partial fulfilment of the requirements for the Master's Degree in Biomedical Engineering.

Supervised by Dr. Gerard RUSHINGABIGWI and Dr. Omar GATERA

DECLARATION

I **MUKANGIRINSHUTI CLOTILDE** declare that this dissertation entitled “**A study of Electromagnetic Radiation Absorption on the Human Head. Case Study of Mobile Phone**” is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

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CERTIFICATE

This is to certify that the project entitled “**A study of Electromagnetic Radiation Absorption on the Human Head. Case Study of Mobile Phone**” is a record of original work done by **MUKANGIRINSHUTI CLOTILDE** (Reference number: **221031144**), a MSc. Degree student in Biomedical Engineering.

This work has been submitted under the guidance of **Dr. Gerard RUSHINGABIGWI** and **Dr. Omar GATERA**.

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ABSTRACT

Mobile phones emit radiofrequency signals, raising concerns about potential health effects on the human brain due to prolonged exposure. This project related to Comprehensive study of the Electromagnetic radiation emitted by mobile telephones and their effect on the human head when mobile phones are held closer (5Cm) from the user's head and away from the user's head (10 Cm). In this work the primary objective was to conduct a survey for determining the most used mobile phones' brand Nyarugenge district located in Kigali city. Second was measurement of electric field (EF) strength emitted from different types of mobile phones that are mostly used in Nyarugenge district. Third assessment of mobile phone radiation level across different overcrowded areas in Kigali city is conducted such as Nyabugogo parks, Nyarugenge Markets, Kimirongo Markets. 3 Axis Radio Frequency Electromagnetic Field Meter, Model: Emf-839, Iso-9001, Ce, Iec1010 has been used in the measurement of electric field strength of mobile and at the chosen areas. To know the effect of such electromagnetic waves emitted by mobile telephones, the specific absorption rate (SAR) of the human head caused by those radiations had been mathematically calculated.

According to the survey done the feature phones are most used than the smartphone. the measurement of electric field emitted by the different phones, the results show that feature phones emit higher than smartphone this means that SAR of the feature phone is greater as compared to the smart phones. The measurement of the electric field has been taken in the three different location, the results shows Nyabugogo parks has high electric field strength as compared to other places, and cause high absorption rate on human head compared to the place chosen in the Kigali city.

The comparison of obtained values of specific absorption rate with the standard value approved by international radiation exposure ICNIRP indicate that they are within the standards limits. That means there is no negative effect on human health from the exposure to these radiations because the SAR measured from mobile phones and at different locations in Kigali city are less than the limit SAR of 2kg/W.

KEYWORDS: Radio frequency, SAR, cell phone E-field, H-field, human head

LIST OF ACRONYMS

E: Electric field strength

EEE: The Institute of Electrical and Electronics Engineers

EMF: Electro-Magnetic Field.

EMF: Electro-Magnetic Field.

FDTD: Finite-difference time-domain

GSM: Global System of Mobile Communications.

H: Electromagnetic field strength

IARC: The International Agency for Research on Cancer

ICNIRP: International Commission on Non-Ionizing Radiation Protection

INIRC: International Non-Ionizing Radiation Committee

RF: Radio Frequency.

RF: Radio Frequency.

SAR: Specific Absorption Rate.

UHF: Ultra High Frequencies.

LIST OF FIGURES

Figure 3.1: Research Process	22
Figure 3.2: Mobile phone users.	24
Figure 3.3: Measurement of electric field strength.	25
Figure 4.1: Specific Absorption Rate and Mobile phones with varying head to mobile phone distance. ..	28
Figure 4.2: Places and SAR (Left) Varying SAR with Distance (Right).....	29

LIST OF TABLES

Table 3.1: Data collected of mobile telephone trends in Rwanda.....	23
Table 3.2: Obtained results at electric field strength and power density of electromagnetic radiations at different places.....	24
Table 3.3: Tissue properties and thickness of six-layer human head.....	26
Table 4.1: Specific Absorption Rate (SAR) when a mobile phone is held 5 cm from the user's head.....	27
Table 4.2: Specific Absorption Rate (SAR) when a mobile phone is held 10 cm from the user's head.....	27
Table 4.3: Specific Absorption Rate (SAR) when a mobile phone is held 10 cm from the user's head.....	28

TABLE OF CONTENTS

DECLARATION	i
CERTIFICATE	ii
ACKNOWLEDGMENTS.....	iii
ABSTRACT.....	iv
LIST OF ACRONYMS.....	v
LIST OF FIGURES.....	vi
LIST OF TABLES.....	vii
CHAPTER 1: GENERAL INTRODUCTION	1
1.1. INTRODUCTION	1
1.2. Problem statement.....	3
1.3. Objectives	4
1.3.1. General Objectives.....	4
1.3.2. Specific objectives	4
1.4. Study of scope.....	4
1.5. Significance of the study.....	4
CHAPTER 2. LITERATURE REVIEW	6
2.1. Introduction.....	6
2.2. Overview of electromagnetic radiation.....	7
2.3. The mechanism of electromagnetic field.....	8
2.4. The Relation between SAR and electric field.....	9
2.5. The relation between electric field strength and SAR	9
CHAPTER 3: RESEARCH METHODOLOGY	22
3.1. Research Process.....	22
3.2. Research Design Process	23
CHAPTER 4: PROJECT'S RESULTS.....	27
CHAPTER 5: CONCLUSION AND RECOMMENDATION.....	31
5.1. CONCLUSION.....	31
5.2. RECOMMENDATIONS	32
REFERENCES.....	33

CHAPTER 1: GENERAL INTRODUCTION

1.1.INTRODUCTION

Mobile phones have become an integral part of our life, providing services that range from phone calls, Bluetooth connections, internet connections, and information sharing via online media. Global data on mobile telephones trends shows in 2019 they were 5.07 billion of mobile users and users of mobile telephone increase every year[1]. The development and use of mobile phones and other telecommunication devices, in general, are associated with relaying information via electromagnetic waves or signals [2], The device that operates on wireless technology use of the electromagnetic field that is in the range of radiofrequency (RF) radiations [3].

The intensity of radiofrequency pollution in the environment has increased in recent years due to new technological improvements in wireless devices and the ease of access to mobile phones. The rise and widespread use of mobile phones and the consequent exposure to electromagnetic RF radiation have continued to generate deep interest in the radiation science community. The possible side effects of RF radiation on living organisms have caused some measures of concern[4]. Radiofrequency radiation has less energy but high-time exposure to the human brain can cause brain cancer and exposure to high levels of RF can cause damage to tissue [5].

Over the years, mobile communication has evolved from the first generation (1G) to the fourth generation (4G) mobile systems and now 5G Technology of Mobile Communication is already developed [6]. Recently GSM mobile phones have dominated the telecom market around the world due to their small size, and ease of use [7]. With the current state of mobile phone deployment and the annual increase in the number of people who are using them, billions of people are exposed to radiation from mobile phones around the world. Radio frequencies are part of the Ultra High Frequencies (UHF) spectrum, which designates a range of electromagnetic waves with frequencies ranging from 300 MHz to 3 GHz. In particular, those used by the global system for mobile communication (GSM) start from the 900 MHz band. In different parts of the world, mobile phone networks utilize different frequency bands and different forms of RF signal modulations that enable phones to carry information [8]. To minimize the effects of the electromagnetic waves on human there are international organization that are in charge of setting the standards on electromagnetic waves which is called International Non-Ionizing Radiation Committee (INIRC) [9]and The Institute of Electrical and Electronics Engineers(IEEE) [10]. Countries can change the

rules about how much electromagnetic radiation devices can emit to keep people safe. But sometimes, a mobile phone might send out too much radiation, which can happen if the phone is broken, has a bad signal, or is set to a high power level. So, it's important to check how much radiation phones give off to make sure they don't hurt people.

Research on how electromagnetic waves from mobile cell phones are absorbed by the human head is important for understanding potential health risks associated with prolonged cell phone use. This type of research typically involves studying the amount of electromagnetic energy absorbed by the tissues of the head when a cell phone is in use, particularly focusing on the brain. This is achieved by collecting the sample of most used mobile telephones in Rwanda and measuring their electromagnetic radiation properties such as electromagnetic field strength and power density by using 3 axis rf electromagnetic field meter therefore the measured parameter used to calculate specific absorption rate of the brain tissue, and the result indicate how much a user is safe when using such mobile telephone brands.

1.2.Problem statement

Mobile phones have become an integral part of modern society, and their antennas emit electromagnetic radiation in the form of radiofrequency (RF) signals. With the widespread use of mobile phones, there is a growing concern about the potential health effects of prolonged exposure to RF radiation, particularly in the context of the human brain. The piece of work by Suhag et al [11] investigated the problem and found that the use of mobile phones can cause brain tumors, male infertility, heart diseases, affect fetus, far hearing function, Alzheimer's diseases, and Parkinson's diseases as illustrated. 150 medical doctors were interviewed about the effects of mobile phone devices on human health, Figure page 8 illustrates the percentage of doctors who believe that mobile telephone can cause such diseases.

The main cause of that disease is due to using mobile telephones that emit high electromagnetic radiation and long exposure time. To reduce the effect of electromagnetic radiation, this research aims to investigate the emitted electromagnetic radiation of mobile telephones and determine the Specific Absorption Rate (SAR) then evaluate potential health risks associated with these exposures.

1.3.Objectives

1.3.1. General Objectives

The main aim of this study is to investigate the levels of electromagnetic radiation emitted by mobile phones and their impact on humans by analyzing the specific absorption rate on the human head.

1.3.2. Specific objectives

The general objective of this study will be achieved through the following specific objectives:

- To conduct survey for determining the most used mobile phones' brand in Rwanda.
- To conduct laboratory, measurement, electric field strength, magnetic field strength of the electromagnetic radiations emitted by mostly used mobile phones' brand in Rwanda.
- To determine the Specific Absorption Rate (SAR) in different regions including the human brain when exposed to electromagnetic radiation from mobile phones.
- To analyze radiation effects based on Specific Absorption Rate.

1.4.Study of scope

This research is focusing on measurement of the electromagnetic radiation absorbed in human head emitted by the cell phone and analysis its effects

1.5.Significance of the study

- **Understanding Mobile Phone Usage Trends:** By conducting a survey to determine the most commonly used mobile phone brands in Rwanda, the study can provide insights into the prevalent technology choices among the population. This information can be valuable for various stakeholders, including policymakers, telecommunications companies, and public health authorities.
- **Assessing Electromagnetic Radiation Levels:** Measuring the electric field strength emitted by popular mobile phone brands when mobile phone is used to make a call and when the phone is at a certain distance from the users for an assessment of the exposure levels experienced by mobile users. This data can inform regulatory standards, technological advancements, and consumer awareness efforts related to electromagnetic radiation safety.
- **Evaluating Specific Absorption Rate (SAR):** Determining the Specific Absorption Rate (SAR) in different regions of the human body, including the brain, when exposed to electromagnetic radiation from mobile phones provides crucial information about the potential health risks associated with mobile phone usage. This can contribute to evidence-based guidelines for safe mobile phone usage and the development of mitigation strategies to reduce exposure levels.
- **Analyzing Radiation Effects:** By analyzing radiation effects based on Specific Absorption Rate (SAR), the study aims to elucidate the relationship between electromagnetic radiation exposure and potential health impacts. This analysis can inform risk assessment

frameworks, public health policies, and educational initiatives aimed at promoting safer mobile phone usage practices.

CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

Mobile phones have changed communication and are now an essential part of everyone's everyday life worldwide due to their widespread use. Mobile phones have many advantages, but there have also been rising worries about possible health hazards related to their use. Specifically, extensive scientific research has been conducted on the effects of prolonged exposure to electromagnetic fields (EMFs) emitted by mobile phones. Research and worry have centered on how these EMFs are absorbed by the human skull, in particular, when using a phone. When assessing the safety and impact of mobile phones in particular, it is essential to comprehend the implications of electromagnetic absorption on human health.

The goal of this chapter is to present a thorough summary of the body of knowledge on electromagnetic absorption in the human cranium, with a focus on the use of mobile phones. The chapter aims to clarify the scope and possible impacts of electromagnetic field (EMF) exposure on human physiology by exploring a number of topics related to this subject, such as the mechanisms of electromagnetic field strength (H), electric field strength (E), and specific absorption rate (SAR). In-depth analyses of these fundamental components and their interactions with biological tissues, as well as possible consequences for prolonged mobile phone use, are provided in the sections that follow.

- **Electromagnetic Fields and Human Exposure**

The area surrounding electric charges and magnetic fields is home to invisible forces known as electromagnetic fields. Extremely frequencies ELF and higher frequency bands, such as microwaves and radio waves, are the categories for these fields based on their frequency and wavelength. The electromagnetic spectrum's radiofrequency (RF) band, which is normally between 800 MHz and 2.5 GHz, is where mobile phones function. A mobile phone, when in use, produces magnetic (H) and electric (E) fields that can interact with the human body; this is especially true when the phone is held close to the head while on a call.

The complicated relationship between electromagnetic fields (EMFs) and biological tissues is dependent upon various elements, including the field's frequency and intensity, the distance from the source, and the characteristics of the implicated tissues. The Specific Absorption Rate (SAR), an essential indicator for evaluating the possible health impacts of electromagnetic fields (EMFs), assesses the speed at which the body absorbs energy from these fields. Typically expressed in watts per kilogram (W/kg), SAR offers a consistent method for assessing exposure levels.

- **Specific Absorption Rate (SAR) and Its Significance**

One important factor in determining how safe it is to use a mobile phone is the Specific Absorption Rate, or SAR. The device's power output and the phone's closeness to the body both affect SAR readings. To guarantee that mobile phones don't exceed safe exposure levels for humans, regulatory bodies like the International Commission on Non-Ionizing Radiation Protection

(ICNIRP) and the Federal Communications Commission (FCC) in the US have set SAR limitations. Since this position results in the highest levels of electromagnetic absorption in the skull, SAR values for mobile phones are typically evaluated with the device held next to the ear. Studies have indicated that SAR levels can differ according on the phone's model, antenna type, and network technology (e.g., 3G, 4G, 5G). The user's age, the size of their head, and the presence of metallic objects (like jewelry or eyeglasses) can also affect how electromagnetic radiation is absorbed and distributed.

- **Mechanisms of Electromagnetic Absorption in the Human Head**

Multiple complex structures are involved in the human head's absorption of electromagnetic energy. The RF waves released by a mobile phone can enter the skin and deeper tissues, where they can interact with cellular structures and cause both thermal and non-thermal effects. The transformation of electromagnetic energy into heat is known as a thermal effect, and it can raise tissue temperatures locally. On the other hand, non-thermal impacts are less well-known and could involve modifications to DNA connections, membrane permeability, and even cellular functioning.

Skin, bone, muscle, and brain tissue are among the numerous tissues that make up the human skull, and each has a unique set of dielectric characteristics. The way electromagnetic radiation travels and absorbed inside the brain is influenced by the tissues' dielectric characteristics. For example, tissues like the brain that contain more water tend to absorb more energy than denser structures like bone.

2.2. Overview of electromagnetic radiation

The energy carried by electromagnetic waves, which are made up of fluctuating electric and magnetic fields, is referred to as electromagnetic radiation. The broadening electromagnetic spectrum consists of these fields, which are perpendicular to each other and to the direction of wave transmission. This spectrum includes a wide range of wavelengths and frequencies, from high-frequency gamma rays to very low-frequency radio waves, each with unique characteristics and uses. Radio waves, which are frequently employed in communication technologies like television, radio broadcasting, and mobile phones, are found at the lower end of the spectrum. Moving up the spectrum, microwaves are used in microwave ovens, wireless networks, and radar systems. Moreover, warm items generate infrared radiation, which is used in thermal imaging and remote controls, among other things.

Visible light is the little portion of the spectrum that is visible to humans. It is essential to many technologies, such as display screens, lighting, and photography. UV radiation is more energetic than visible light and causes sunburns in addition to being used in fluorescence and sterilizing. X-rays are produced at even higher frequencies. They are very useful for security screening and medical imaging because they contain enough energy to pierce soft tissues. Gamma rays, which are released by radioactive materials and other heavenly incidents, are the highest energy radiation

at the extreme high-frequency end. Because of their ionizing potential, they must be handled carefully when being employed in scientific research and cancer therapy.

Ionizing radiation, including X-rays and gamma rays, possesses sufficient energy to extract electrons from atoms or molecules, possibly leading to cellular harm and a higher chance of developing cancer. However, non-ionizing radiation lacks the energy necessary to ionize atoms. Examples of this type of radiation are microwaves, radio waves, infrared, and visible light. Rather than causing atomic structural disruption, non-ionizing radiation can cause molecules to vibrate or heat up. Though it is thought to be less dangerous than ionizing radiation, this kind of radiation is nonetheless utilized extensively in everyday technology and can still be harmful to health in some situations, such as extended exposure to high-intensity sources.

Non-ionizing radiation can cause health effects, but the risks are generally considered to be low at the levels that people are typically exposed to. Some potential health effects of non-ionizing radiation include tissue heating, which can result in burns, pain, and other related symptoms [5]. This is most likely to occur with exposure to high-power sources of non-ionizing radiation, such as microwave ovens and industrial lasers. Some studies have suggested that exposure to non-ionizing radiation may increase the risk of cancer, but the evidence is not conclusive. The International Agency for Research on Cancer (IARC) has classified radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B), based on an increased risk for two types of tumors (glioma and acoustic neuroma). Some studies have suggested that exposure to non-ionizing radiation may affect fertility and increase the risk of birth defects, but the evidence is not conclusive. Some studies have suggested that exposure to non-ionizing radiation may increase the risk of neurological disorders, such as Alzheimer's disease and Parkinson's disease, but the evidence is not conclusive. The risks of developing any of these health effects from exposure to non-ionizing radiation are generally considered to be low. However, the risks may be higher for people who are exposed to high levels of radiation or who are exposed for long periods of time.

2.3. The mechanism of electromagnetic field

The mechanism of electromagnetic fields (EMFs) is rooted in the fundamental principles of electromagnetism, as described by Maxwell's equations. These equations form the basis of classical electromagnetism and provide a comprehensive framework for understanding the behavior of electromagnetic fields and Maxwell proved that an electromagnetic disturbance that originated from one charged body would travel out as an electromagnetic wave with velocity of light in free space. A time-varying electric field induced magnetic field and vice versa. This mutual relationship between electric and magnetic fields results in the phenomenon of wave propagation. [3]. Maxwell's equations for a time-varying EM field are:

$$\nabla \times E = -\mu \frac{\partial H}{\partial t}, \nabla \cdot E = \frac{\rho}{\epsilon}, \nabla \times H = J + \epsilon \frac{\partial E}{\partial t}, \nabla \cdot H = 0 \dots \dots \dots (1)$$

Where E and H are electric and magnetic field strengths, respectively, $J (= \sigma E)$ is the current density, ρ is charge density, σ is conductivity, ϵ and μ are permittivity and permeability, respectively. The manipulations of these equations give the EM wave equation. H-field strengths are vector quantities Ampere per meter (A/m).

2.4. The Relation between SAR and electric field

There has been a lot of interest in and research on the possible health effects of high SAR (Specific Absorption Rate) levels and how they may affect mobile phone users. SAR is a measurement of the rate at which radiofrequency (RF) energy from cell phones and other wireless devices is absorbed by the human body. The power that a unit mass of tissue absorbs is known as the SAR value. One way to determine a local SAR value is shown below.

$$SAR = \frac{\sigma E^2}{\rho} \dots \dots \dots (2)$$

Where σ is conductivity of the tissue (S/m), ρ is mass density of the tissue (kg/m³) and E is rms electric field strength in tissue (V/m). The conductivity varies for different tissues and different field frequencies

2.5. The relation between electric field strength and SAR

SAR is defined as the amount of electromagnetic energy used by an organization within a given time period. Tissue internal electric field can be utilized to compute the local surface area ratio (SAR) because it is correlated with the SAR[12].

$$SAR = \frac{\sigma |E_{in}|^2}{2\rho_m} \dots \dots \dots (3)$$

where E in represents the local electric field induced in human tissue under electromagnetic radiation. σ represents the local electrical conductivity of human tissues. ρ_m refers to the local mass density of human tissues.

2.6. Related works on determining Specific Absorption Rate of mobile telephone.

There are a lot of pieces of work related to determining the specific rate of mobile telephone on the human body. A piece of work by K. Ali et al[13] measures levels of SAR near the human head for different types of mobile phone devices. In their research, the aim was determining the Specific Absorption Rate of different mobile telephone on human head and compare those value with the acceptable range of Specific Absorption Rate which does not affect human lives published by international radiation exposure which is charge of setting the standard limit of electromagnetic radiations[9]. The researchers conducted research on Nokia mobile brands such as Nokia x6, Nokia

95, Nokia 93, Nokia 7230 and Nokia 73. In their methodology, the electric field of a mobile telephone is measured at three different positions from the human head, the positions are 0cm, 10cm, 20 cm from the head then by mathematical calculation specific absorption rate is calculated in those ranges and finally the temperature of head is calculated based on exposure time. To measure the electric field of the emitted electromagnetic radiation, the survey meter model (Radio frequency EMF tester (480846) with digital display was used. That meter measures the electric field in three axes and has the frequency range between 50 MHz and 3.5 GHz with high sensitivity of 20mV/m. In mathematical calculations the specific absorption rate from measured electric field, was obtained using the formula defined as;

$$SAR = \omega \cdot \epsilon_o \cdot \epsilon_r \frac{E^2}{2\rho} \dots \dots \dots (4)$$

Where:

ω : is the angular frequency

ϵ_o : is the permittivity of free space

ϵ_r : is the Imaginary part of the relative complex permittivity.

E: is the peak value of the total field inside the tissue material and

ρ : is the tissue density in kg/m³

SAR value varies from point to point in the body because the electric field changes with the position and density of tissue

The specific absorption rate is calculated with regarding to the position of the mobile phone with referring to the human head and also the head temperature is calculated. Results shows that Nokia n73 has high electric field than other mobile telephone's brands, the electric field at 0cm,10cm and 20 cm are 15.4V/m, 8.2V/m and 2.8V/m respectively. On other hand specific absorption ratio at 0 cm,10 cm and 20 cm are 0.42, 0.27 and 0.22 respectively. From the obtained results it is concluded that both electric field and specific absorption rate on human body decrease as distance between human head and mobile telephone increase, but the temperature of the head increase with increase of the exposed time. Based on the results researchers recommend the public to use mobile telephone in hands-free and reduce time on calls and also the children less than 16 years old and pregnant women are advised to avoid using mobile phone.

Another work by R. Buckus et al[14] conducts the assessment of electromagnetic field radiation exposure for mobile phones users. The aim was to assess electromagnetic field radiation exposure for mobile phone users by measuring electromagnetic field strength in different settings at the distance of 1 cm ,20 cm and 30 cm from the mobile user. To determine the effect of electromagnetic radiation researchers based on the electric field strength of the electromagnetic radiation emitted by mobile telephone. The electric field strength of the stationary mobile and moving phone were measured and results have been compared. In their studies the mobile telephone with Global System for Mobile Communications (GSM) 900 and GSM 1800 were used, randomly different kinds of mobile phone models were used. By using electromagnetic field meter NBM-550 with isotropic probe EF 0392 (electronic field, flat) whose operating frequency range

of the 100 kHz – 3000 MHz used to measure electric field strength, it measures electric field strength, magnetic field strength, electromagnetic field energy and flux density. During measurement, data are taken on outgoing mobile telephone when mobile telephone placed in different settings (urban/rural area, indoor/outdoor setting and moving/stationary) and varying distance as and each parameter takes six minutes to be taken.

Based on the obtained results, the authors concluded that the electric field strength of a mobile phone depends on a brand of the phone, geographical factors, electromagnetic signal intensity from the antenna of the base station, shadowing, specific absorption rate, operating frequency and distance. Authors found that mobile phones in rural area emit high electric field strength than in urban area and mobile phones with high specific absorption rate have higher maximum power output than phones with low specific absorption ratio and calls made from a phone in a moving car emit electric field strength two times more than that of calls in a stationary position. Based on findings the authors advise users of mobile telephone to use safe distance to avoid biological effects.

Another piece of work by D. Azra [15] conducted the visualization and analytical measurement of Electromagnetic radiation from Handheld mobile phones. In their methodology, analysis was carried on human phantom and 45 volunteers while MATLAB is used to do a simulation to show the radiation emitted by mobile telephone on other hand thermal imaging is used to describe the temperature distribution on phantoms and human head. Two different models of the mobile phone were used, one with GSM of 900 MHz and other of 1800 MHz, the setting of the conducted experiment.

The results from the experiments show that the different body tissues absorb electromagnetic radiation at different rates. And the absorption rate is depending on the time operation as time increases the effect of electromagnetic radiation on the human body increases.

Piece of work by S. Khalatbari et al[16]calculating specific absorption ratio in two models of the human head Exposed to mobile phones radiations at 900 and 1800 MHz, researchers described that by using experimental measurements and finite-difference time-domain (FDTD) computation, the specific absorption rate of generated by cellular phones can be calculated. In methodology, two models of mobile telephone of 900MHz and 1800MHz were used and tested on the head phantom and the results were compared with the realistic head model constructed by using resonance magnetic imaging scans. To calculate the specific absorption rate of head numerical method and modeling techniques were used, firstly the head model of a layered sphere is modeled 2.3 and monopole antenna was used to absorb the electromagnetic radiation.

The simulation was conducted on both telecommunication carrier frequencies of 900 MHz and 1800 MHz by using a software sourced from the Utah University of Technology and therefore Mur's second-order absorption boundary conditions was used to compute the computational domain. To calculate specific absorption rate was based on the electric field distribution. At the end of the experiment, total absorbed power, the maximum SAR (1 g), the SAR (10 g) and local SAR values are presented. The results indicate that homogeneous sphere has high specific absorption rate than the layered sphere and this illustrates that due to the head is made by different

layers of tissues like skin, bone, muscle and brain experiences lower SAR compared to the uniform head model. Authors concluded that the maximum local SAR is located at the outermost part of skull while maximum change in dielectric properties is at the boundary between muscle and skull because the maximum reflection takes place at the boundary of muscle and bone and a handset antenna plays an important role in preventing the human head to be affected by electromagnetic radiations.

K. H. Chan et al conducted experimental study of the SAR characteristics of mobile phones [17]

, the experiment is conducted on one hundred eight mobile phone grouped in forty-eight model manufactured by alcatel, ericsson, Gvc, Kyocera, Motorola, NEC, Nokia, Nokia, Nokia, Sam Sung, Siemens, Sony Ericsson and Sony. The objective was to know whether all of these mobile phones have SAR that fall in the safety range when they are used at distance near head.

The setting is made by E-field probe pointing to point ear or cheek position while the SAR is measured by programmed software in computer and data transmission sealed glass spheres (head mickming) are transferred through optical fiber. The distance between head and mobile phone GSM tester was kept constant and to be 50 Cm for all testing on mobile telephone and transmission power of mobile telephone is set to be 2 W. A total of 108 mobile phone samples, including 48 models from 13 manufacturers, have been measured the performance is compared based on maximum SAR values of the measured mobile phone, comparison of the SAR at different transmission frequencies, a comparison of the mobile phones' SAR at ear and cheek, SAR with internal or external antennas and comparison of the SAR for flip and non-flip phones. The result shows that all mobile phone's fall in safe limit with average SAR of 0.888 W/kg. By comparing the SAR at different transmission the three frequencies are taken 890, 902, and 915 MHz, results show that generally SAR distribution is not affected by the transmission frequencies. The comparison of the Mobile Phones' SAR at "Ear" and "Cheek" Position, the value of SAR on all mobile phones when held near ear or cheek is measured, results shows that SAR value at cheek is 98.4% higher than of the ear. Comparison of the Mobile Phones' SAR with Internal or External Antennas shows that the value is very closer

A piece of work by lee et al [18]measures the SAR characteristics of the human brain by different mobile phones. Authors described that based on the operating frequency, outer shape, and form and location of the antennae can affect the level of electromagnetic absorption in the human head or brain. During the experiment 11 mobile phone model were used with different characteristics therefore the effect of the phone type, phone position, operating frequency, and age of head models on the brain SAR were comprehensively determined. Used mobile telephones have Internal and external antenna type located at bottom and top and have operating frequency ranging between 835 and 1850 MHz Test is conducted on human modals (phantoms) of different size and age. To calculate the SAR, Authors based on the finite-difference time-domain method and to study carefully the brain size of each individual is also determined.

Due to the quick advancements in technology in recent years, there has been a daily rise in the use of mobile phones and, with it, in health issues. Not taking a timely note could result in a serious issue. In order to safeguard humanity from excessive exposure to electromagnetic radiation, established organizations like the FCC, IEEE, and ICNIRP have previously established guidelines for the radiation power limits emitted by various electronic gadgets. The majority of earlier research has examined and demonstrated the connection between prolonged and frequent usage of cell phones and an increased risk of biological adverse effects on human health. The health effects of electromagnetic radiation from wireless devices, particularly mobile phones, are reviewed in this research[19] .

The EM radiations the human body absorbs play a major role whenever biological harm to human health is a significant concern. To determine if mobile phone radiation poses a risk to human health or not, comprehensive research on past studies must be conducted and published so that the public, who is literate, may learn the truth. Numerous prior research investigations have examined and demonstrated the connection between long-term, frequent usage of mobile phones and an elevated risk of biological negative impacts on human health. The commonly used metric Specific Absorption Rate (SAR) is used to quantify the amount of electromagnetic radiation that is exposed to or amplified enough to be absorbed by human organs. There are several ways to measure SAR: local peak SAR, whole-body averaged SAR, etc. There are numerous techniques for assessing SAR; two well-known techniques are thermographic approaches and compliance with certain SAR requirements via electric field strength assessment[20].

The rate at which the tissue-equivalent liquid's temperature is rising. Either the human head or perhaps a different portion is used. According to the basic safety, limitations for cell phones set by the IEEE and ICNIRP, 2 W/kg. Which, for 10 grams (g) of tissue, was assessed in specific absorption rate (SAR) on average. Using the Similler parameters of cell phone orientation, the maximum SAR (10 g) values in an adult's skull were compared to an adult's SAR values. The effect of the maximum SAR (10 g) for the human head's brain layers and the total absorbed powers for children of varying ages, while an elderly person is viewing from the same mobile phone position, are observed by comparing the various frequency values the outcomes attained with the head.

Using age-dependent adult and child head models, the measurement and analysis of electromagnetic radiation exposure in human heads has been conducted. Among these, some research has suggested that children are found to have substantially higher levels of electromagnetic radiation than adults. Numerous well-established techniques exist for analyzing electromagnetic radiation absorption in humans; yet, selecting the most appropriate approach that yields dependable and consistent data remains a challenge for humanity. The goal of this study is to recognize and condense the earnest work that has been done by earlier research in relation to accurate assessment of electromagnetic energy absorption in the entire body, a particular body component, and its analysis. Focus in particular on an adult or child's head that has been subjected to a variety of techniques to examine electromagnetic field exposure in the body or head. Nonetheless, this work places more of an emphasis on the FDTD age-dependent SAR measurement technique in adult and younger child heads [21].

A piece of work [22] evaluated the potential health risks associated with mobile phones by examining the amount of power absorbed by the brains, skulls, and skin of four-, eight-, and adult-

year-olds. The half wave dipole antenna (length -147 mm, radius - 1.8 mm, operating frequency - 900 to 1500 MHz) that was used to radiate on the heads of the two children and adult subjects under EM exposure was simulated using General Electromagnetic simulator software, which was based on the FDTD technique. In this study, SAR values are simulated in two ways: first, a mobile device is positioned closer to an adult's head without the use of a resistive sheet, and then the mobile device is subjected to an application of a resistive sheet (50 ohm) to measure SAR. discovered a significant decrease in absorbed power while using a resistive sheet with a mobile phone. The study's findings demonstrate that children absorb power slightly more than adults do because children's cranial tissue layers are thinner and adult skull bones are thicker. With resistive sheets instead of mobile phones, this work may aid humanity in having safe mobile communication.

In a piece of work[23] , SAR values and temperature distribution were obtained, Teerapot Wessapan et al. used three-dimensional numerical human head model tissue layers at frequencies of 900 MHz and 1800 MHz. The impact of the operating frequency, the temperature profile inside the skull, and the separation between the head and the mobile phone during a call are all carefully examined. The temperature distribution in the various human head tissues and the propagation of electromagnetic waves in the human head are computed using Maxwell's equations and the bioheat transfer equation, respectively, when the human head is subjected to electromagnetic waves. The human head's SAR distribution computed at three distinct distances The SAR values for the gaps of 2.0, 1.0, and 0 cm between the human head and the handset with 1.0 W of radiated power for 30 minutes at 900 MHz are 0.4, 0.8, and 1.6 W/kg. This also applies to 1800 MHz. According to the results reported in [9], the SAR value is higher at 1800 MHz close to the skin, however these values are still below the ICNIRPA limit.

While the temperature increase in the brain is lower at 1800 MHz than it is at 900 MHz, the temperature increase in the skin is higher at 1800 MHz. This study may have found that there is a direct correlation between a person's head size and their mobile phone's SAR, electric field intensity, and temperature generation. The study focused on the interaction between human head and mobile phone antennas, and the evaluation of SAR distribution in one and six layers (Skin, Fat, Bone, Dura, CSF, Brain) of the human head model created by Asma Lak and Homayoon Oraizi. This study used a one-and six-layer human skull with a dipole antenna length of 149 mm, radius of 1.8 mm, and operating frequency of 900 MHz. The results reveal that the e-field intensity decreases with distance, or from the skin to the brain. First computed e-field absorption in two iterations, The study of e-field strength in one and six layer human heads was then conducted using PIFA (Planer Inverted F Antenna) at the same frequency and 7.5 mm height from the ground plane. The results are similar in that e-field strength diminishes with distance. However, e-field strength data are displayed using PIFA. Both scenarios' local and averaged SAR calculations reveal that the human head's six layers have higher SAR than a single layer due to changes in the layer-by-layer permeability, permittivity, and conductivity.

Guy et al [24]. conducted a study and extended the research of Gandhi et al [25]. By utilizing downscaling and a similar scaling factor to determine the SAR in children aged five and ten. A phone model with a monopole antenna that simulates an 835 MHz operating frequency and a dielectric coated pinna exposed to electromagnetic radiation is being considered.

Guy et al. came to the conclusion that there were no appreciable variations in EM power absorption. used a dipole antenna as a model for a mobile phone antenna at various distances from the head under test—between 10 and 50 mm—with antenna frequencies of 900 and 1800 megahertz. The specific absorption rate in the heads of children and adults was then determined using the FDTD method. With the small child's head at 22 mm from the ear, they saw results with both frequencies that indicate a drop in SAR (Peak and Average). However, the brain of the smaller head may have a greater averaged SAR with a closer distance between the brain and antenna model. It is examined averaged SAR in the heads of children and adults using a dual-band phone model at frequencies of 900 MHz and 1800 MHz to compare SAR across a head mass of 10 grams. FDTD technique USD and discovered that, although there is no discernible difference in dosimetry, the brain power absorption in two youngsters, ages five and ten, is somewhat more significant than in adults.

Dim by low and Mann developed the FDTD approach for SAR calculation, which uses a dipole antenna at frequencies of 900 and 1800 megahertz to closely couple to a human child and adult head model. Three different radiation source positioning geometries were used in this study: vertical placement in front of the eye, vertical positioning in front of the ear, and horizontal orientation of the headset in front of the ear. found that children's eyes had a higher SAR at short distances. SAR analysis requires, at the very least, careful study of the intricate electrical characteristics of the skin, ears, nose, bones, and skull [26].

The FDTD method [27] has been used to investigate the electromagnetic energy absorption at 835 and 1900 Megahertz in the human neck and head. Monopole antennas with lengths of $\lambda/4$ and $3\lambda/8$ were used for adult and pediatric heads over 1g and 10g averaged SAR. It was discovered that this team had recorded a notable increase in SAR in children's heads. Using the FDTD approach, head models of children aged five to fifteen were generated. The SAR of each model was examined, and the results were compared with the SARs of six adult-made head models. Using a dipole antenna, the operating frequencies have been 900, 1800, 2100, and 2400 megahertz.

According to the study's final findings, youngsters between the ages of 5 and 8 are absorbing more electromagnetic energy [28] because their skin, cranium, and pinna are so thin. Since the obtained results are based on a small dataset, they should be confirmed using a different technique. The SAR distribution in the human skull is age-dependent, according to a large body of research on electromagnetic energy absorption in the head; yet, relatively few of these investigations have produced an approximation of a solution. A few articles complain that children's heads absorb power at a faster pace than adults. control by the head of a children, the idea that children absorb more electromagnetic energy than adults is disputed by certain study.

A child's SAR value may be marginally higher than an adult's, according to a few research studies, but this is still within the safety range established by IEEE rules. The authors concluded that It may be said for now that there is still disagreement over children's increased absorption of electromagnetic radiation. Our poll yielded no meaningful results that may resolve the age-old debate over whether children or adults consume more or less energy. When possible, people should use their mobile phones and other wireless devices in moderation to prevent negative health effects. Further studies yielding meaningful findings are required to confirm that humans, both adults and children, can absorb electromagnetic radiation. Given its resilience and analytical

precision, the Finite Difference Time Domain (FDTD) method might be recommended for additional research. A researcher recommend the next researchers to do Research can be done in the future to determine whether or not electromagnetic radiation from wireless devices, particularly mobile phones, is detrimental to people. However, there might be room to study the SAR in the human body as a whole by taking a temperature shift into account, particularly in a realistic human head. Many studies just computed the surface area of SAR, therefore careful consideration of the intricate electrical properties of the skin, nose, ears, bones, and skull must be made while conducting SAR analysis. The best safety precaution going forward will be the development of a resistive sheet for mobile phones.

Public worry about human exposure to radio frequency (RF) electromagnetic radiation has grown recently due to the quick rise in the use of wireless communication technologies. This is especially clear when it comes to cell phones. The researchers discovered some evidence linking mobile phone users to an increased risk of glioma and acoustic neuroma brain tumors. High frequencies are used by mobile phones to send and receive signals. Radiofrequency (RF) signals can be emitted by mobile phones up to 1 centimeter from the user's head. Cell phone radiation is determined by the device's Specific Absorption Rate (SAR) value. The SAR limit for cell phones in India is 1.6 W/Kg or six minutes of use per day. In the research by Kumar et al [29]. They used a spectrum analyzer to compute the transmitted power from a mobile phone and assessed how much of the electromagnetic radiation from mobile phones was absorbed by the skin and bone of the human head. In this paper, the transmitted power of different mobiles with different operators is calculated using a spectrum analyzer kit[30]. The tools we used to know the Transmitted power from mobile are a spectrum analyzer, preamplifier, ANT-01 Probe, and BNC Cable. In the experiment, different brand names are collected and their transmitted power is measured. Also, the head model is modeled to mimic the human anatomy, then the transmitted power is applied to the head phantom to obtain results.

Plotting the equations concerning frequency using MATLAB software yields the observed trends. The human skull's skin and bone both act as shields, and their efficiency grows as mobile device frequencies rise. There could be dangers to skin and bone as the absorbed power increases with frequency. As the operating frequency rises, the reflected power from the skin and bone layers falls, with values ranging from -53.6 dB to -54.5 dB. At various frequencies, the effectiveness of shielding, absorbed power, and reflected power are compared. This analysis calculates the amount of power that could pass through the flesh of the brain and assesses how much is absorbed by the skin and bone structure of the human head.

The amount of power transferred by various mobile devices running at various frequencies is calculated in this research. Additionally, it uses shielding technology to measure the amount of electricity absorbed and reflected by the skin and bone during mobile phone use. Skin disorders may result from this absorbed power since skin cells have a tendency to dry out. These findings indicate that 3G mobile devices emit higher radiation than 2G mobile devices. This analysis will be used to lower the radiation intensity levels on the human head to allowable levels. The appropriate shield material for the mobile frequency band will be chosen using this procedure.

A piece of work by Imran et al analyzed the effect of absorption rate of cellular phone radiation on the human body [31]. This study presents research on the effects of mobile phone electromagnetic (EM) radiation on the human skull. The Specific Absorption Rate (SAR) is used to measure the electromagnetic radiation. The frequency ranges used by mobile phones for communication (GSM, CDMA, etc.) typically expose the human head to these signals. The radiation absorption was examined using Comsol Multiphysics software to apply frequency domain simulations. The mobile phone's specific absorption rate (SAR) was evaluated at various positions. The radiation absorption was examined using Comsol Multiphysics software to apply frequency domain simulations. The mobile phone's specific absorption rate (SAR) was evaluated at various positions. SARs showed significantly lower values when the phone was held far away from the user's brain. This measurement indicates that SAR is high at close range, meaning that as the distance decreases, the temperature rises as well. Additionally, comparative investigation reveals that the FR4 substrate exhibits higher temperature rise and SAR in comparison to the Rogers RO3006 and RO4003 substrates.

SAR calculations were made to determine the mobile phone's proximity to and distance from the head. The IEEE, IEC, and CENELEC's standard specification of SAR value measurements uses the same geometry (SAM Phantom) for the human head. The amount of radiation that human tissue absorbs is measured using SAR. Heat loss from the human head occurs as a result of blood flow. The blood's heat capacity, density, and blood perfusion rate all affect this heat loss[32].

The human head is subject to a variety of EM radiation impacts. The topic of human head exposure to cell phone radiation has been covered here. By utilizing a model that ascertains the allocation of absorbed energy into brain areas, we can enhance our comprehension of the detrimental consequences associated with mobile phones. From the SAR distribution and temperature increase following findings can be summarized:

- SAR is high at close range, meaning that when the distance decreases, the temperature rises as well. For instance, the SAR is 837.5% higher (from 0.016 to 0.15) and the temperature is enhanced by 0.218K compared to radiation effects at 15 cm when using Rogers RO3006 at 9 cm.
- The SAR and temperature increase of the FR4 substrate are higher than those of the Rogers RO3006 and RO4003 substrates. For instance, at 9 cm, the temperature increased 63.63% (from 0.36 K to 0.22 K) and the SAR increased 100% (from 0.15 to 0.3) compared to the radiation impacts of Rogers RO3006.

It should be mentioned that because each head and antenna model has a different radiation environment variation, it is not possible to directly compare these results with those of other published work or experimental findings. While the Finite-Difference Time-Domain (FDTD) method has been used in a number of research projects [33] using the XFDTD program from REMCOM INC;[34] using LabVIEW; and [35]using CST Microwave Studio software). Each of these studies produced comparable findings and came to the same conclusion regarding the relationship between SAR and temporal relation with distance.

Numerous circumstances can lead to an unintentional overexposure to non-standard mobile phone radiation. The interaction between the human body and the over-power limit of mobile phone radiation may have a negative impact on people's health. It is anticipated that in sensitive organs or tissues like the eyes, brain, skin, etc., a slight temperature increase may cause a significant physiological effect. The body's thermo-physiological reaction to exceeding the maximum radiation exposure from mobile phones is still not fully developed, though. This study examines how excessive mobile phone radiation exposure affects three-dimensional heterogeneous human head models' specific absorption rate (SAR) and temperature rise [36]. This study examines how excessive mobile phone radiation exposure affects three-dimensional heterogeneous human head models' specific absorption rate (SAR) and temperature rise. The study focuses on the variations in higher power level electromagnetic (EM) absorption properties among various usage patterns. Three distinct usage patterns are examined in detail, including the effects of texting, phone calling, and video calling on temperature distributions and SAR in various head tissue types. This work also examines the impact on SAR and temperature distributions of varying user ages, radiated powers, and gap distances between mobile phone and human heads. The analysis's results, which took safety precautions into account, indicate that mobile phone radiation has a significant influence on voice calls. Thus, for the voice calling position at various gap lengths, comparisons of the absorption of mobile phone radiation are computed between the head models of an adult and a 7-year-old child. Furthermore, the findings show that the skull of a youngster always absorbs more mobile phone radiation than the head of an adult. Depending on their dielectric and thermal characteristics, the rate of absorption in tissue increases as the distance between the head and the mobile phone reduces and the radiated power increases. The data obtained can be useful in establishing exposure limits for the mobile phone's power output as well as the recommended distance between the device and the user in terms of thermophysiological factors [37].

The incredible advancements in smart device technology over the past ten years have led to a great growth in the use of mobile phones, Wi-Fi, and other radio frequency emitting gadgets. As technology advances, there is growing concern for the health of those who overuse these gadgets, reside close to transmission power lines, or operate EM radiation-emitting machinery in the workplace. As technology advances, there is growing concern for the health of those who overuse these gadgets, reside close to transmission power lines, or operate EM radiation-emitting machinery in the workplace. When they contact, the non-ionizing radiation is delivered to the biological system.

Theoretical and experimental evidence suggests that prolonged exposure to low-frequency magnetic fields and relatively weak static can alter the concentration of radicals in the human body, potentially leading to damage to a crucial biological molecule and influencing DNA transcription and translation [38].

The three elements listed below are thought to have an impact on people's health when they use cellphones:

- The radiation level from the phone.
- How long the exposure lasts.
- How old the user is [39].

Certain epidemiological research indicate that youngsters who live close to power lines and who use their phones more frequently have a significantly higher risk of leukemia [40].

Effects from Industrial Machines Emitting Radiation

Numerous sectors have made extensive use of electromagnetic energy. Any surface that is penetrated by electromagnetic waves experiences a volumetric conversion of that energy into thermal energy. Microwave heating is employed in numerous residential applications as well as industry due to its unique properties. Concerns have been raised by the public over the health of those employed in this industry and exposed to radiation on all sides. A piece of work by Wessapan et al examined the temperature distribution and SAR in the human body's various tissue layers when exposed to electromagnetic radiation from industrial machinery [41]. A human model was subjected to frequencies of 1900 MHz and 2450 MHz. The greatest SAR, beyond the limited value, was found in the skin for both frequencies, according to the acquired results. It has been shown that when EM wave propagation is in the TE mode, the SAR and temperature distribution are larger in human tissue.

The effect from the overhead transmission line.

People who live close to EHV transmission lines and are exposed to electric and magnetic fields may have negative health impacts. One explanation for this is that biological bodies experience surface charges from AC electric and magnetic fields, which results in a weak current flowing through human bodies that can be detrimental. To determine the electric distribution on a human body standing beneath a 380 kV 3-phase 50 Hz high voltage overhead transmission line, S.M. El-Makkawy [42] conducted a computational analysis. The increased surface electric field causes a rise in induced current density along the body's length, from the head to the legs, except the neck, according to the results.

Effects from Wi-Fi Radiation

As electronic devices become more wireless, people's lives are becoming easier, smarter, and less disorganized. Mobile phones, portable wireless routers, and other wireless devices release radiation, which might come from nearby or distant sources. Wi-Fi systems are defined as any devices that make use of the IEEE 802.11 standard. It is concerning that these radiations could have a harmful effect. Recently, a study was conducted to determine the temperature distribution, fluid flow, and SAR in biological tissue subjected to near-field electromagnetic radiation.

Natural convection in biological tissue is extensively studied in relation to tissue permeability and the distance to the source of electromagnetic radiation. The findings demonstrated that when the distance between the tissue and antenna reduces, SAR, electric field intensity, heat generation, and temperature all rise within the tissue [43].

Effects from Cellphone Tower

Base station antennas release a lot of electromagnetic radiation, however because mobile phone radiation travels a shorter distance than base station radiation, more SAR is absorbed by human tissue[44].

Severe Effect of Radio Frequency Radiation on Equipment

Within the field of electrical engineering, electromagnetic compatibility addresses the issue of whether a device is compatible with its electromagnetic surroundings and whether the radiations it emits do not negatively impact other nearby devices. The operation of medical devices, radio amateurs, and other devices may be impacted by radiation from base station antennas and cell phones. Wireless base stations situated in medical facilities, close to clinics, and in residential areas may be the source of electromagnetic interference. People have been given some recommendations for lowering their exposure to electromagnetic fields.

1. To shield yourself from electromagnetic radiation, it's best to avoid using cell phones as much as possible. For example, keep them away from you when you sleep.
2. Some people always seem to be near the ovens while something is being cooked or heated. They are also exposed to some electromagnetic radiation from this, which is easily avoidable by keeping your distance from the microwaves when cooking.
3. Some women have been observed tucking their phones close to their breasts, which may induce tissue heating and subsequent tissue damage.
4. To lessen the SAR level from direct cell phone contact, hand-free equipment like earphones is advised.
5. Men might not put their phones in their pants close to their reproductive organs, which could lower sperm motility.
6. It is strongly advised that people abide by mobile phone guidelines. The iPhone recommendation states that the phone should be at least 15 Cm away when conversing.

- **The main findings of this research can be summarized as follows.**

- **Phone positions and SAR.** Flip-type phone models with an external antenna generated higher SAR levels at the left position than at the right position for both frequencies.
- **Frequency and SAR.** SAR are higher at low frequency than at high frequency.
- **Age-related changes in SAR.** The variability in the brain SAR of the four head models in this study did not form a consistent pattern with age.

The authors concluded that the outer shape of the mobile telephone, antenna location, operating and frequency are major parameters that determine the SAR of the head.

- **Identified gaps in the literature review**

Through the reviewed papers on assessing the effects of Electromagnetic radiation absorption on the human head due to mobile phones, there is no assessment conducted in Rwanda regarding the most used mobile telephones and their electromagnetic radiation. In addition, also no research conducted in Rwanda shows the region of highest electromagnetic radiation exposure. To address these issues this work aims to access the most used mobile phones and measure their electromagnetic field and measure the electromagnetic radiation in the busiest place in Rwanda for awareness purposes.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Research Process

The project is related on comprehensive study of the Electromagnetic radiation emitted by mobile telephone and their effect of human head, this is achieved by measuring the electric field strength and power density of the electromagnetic radiation emitted by mobile telephone by using numerical method the Specific Absorption Rate (SAR), Figure 3.1 shows a research process used to achieve the objectives of the project, the research objectives and review of existing literature are shown in previous sections while other remaining part are discussed in next sections.

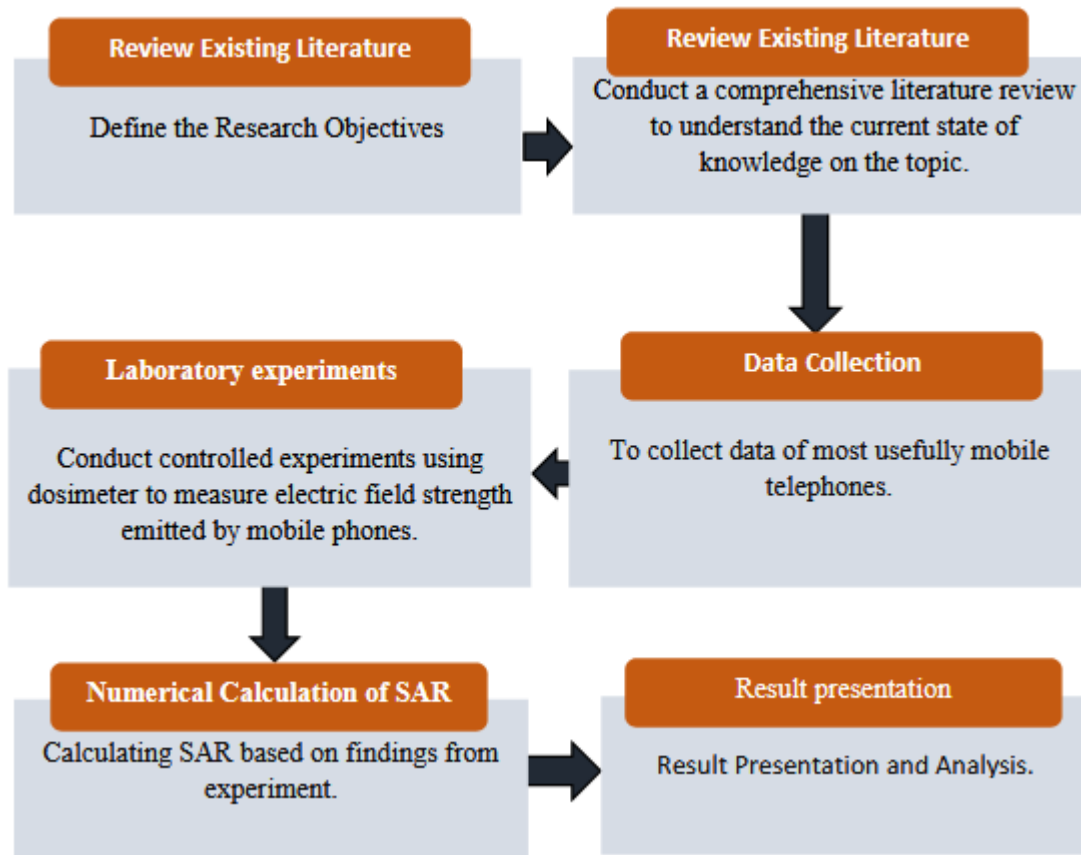


Figure 3.1: Research Process

3.2. Research Design Process

The main objective of this study is to investigate the levels of electromagnetic radiation emitted by mobile phones and their impact on humans by analyzing the specific absorption rate on the human head in Rwanda. To achieve this, firstly is to know the brands of mobile phones used in Rwanda through data collection.

3.2.1. DATA COLLECTION

- **Data collected on the most used mobile telephone.**

Data related to the mostly used brands of mobile telephones in Rwanda, Nyarugenge district is conducted by using the google forms (questionnaire) interview and observation. According to the report of population census in 2022. Nyarugenge districts have a total household of 103,985 and 92.8 % have mobile telephone numbers. The total mobile phones are 96,498 including smartphones and feature phones. Therefore, to know the most used mobile telephone used in Nyarugenge district, sample of 398 have taken to participate in the survey and sample size is calculated based on the formula used to determine sample size at a confidence level of 95% [45]. The results obtained are summarized in Table 3.1.

Table 3.1: Data collected of mobile telephone trends in Rwanda.

SN	Brand Name	Models	Numbers
1	TECNO	TECNO SPARK	45
		INFINIX	37
		T301(feature phone)	22
		T305(feature phone)	87
		T431(feature phone)	18
2	ITEL	Itel IT 2160(feature phone)	68
		IT5310	39
		P505	23
3	SAMSUNG	Galaxy S24	14
4	NOKIA	Nokia C20	22
5	IPHONE	IPhone 15	23

From the data collected on telephone mobile trends in Rwanda, from 398 sample populations, the results show the most used mobile phones are TECNO T301, Itel IT 2160 ,TECNO SPARK and INFINIX as depicted in Figure 3.2. The obtained result indicate that the most popular mobile phone among feature phones are T305 and Itel IT 2160 while Techno Spark and Infix are the most popular among smartphones.

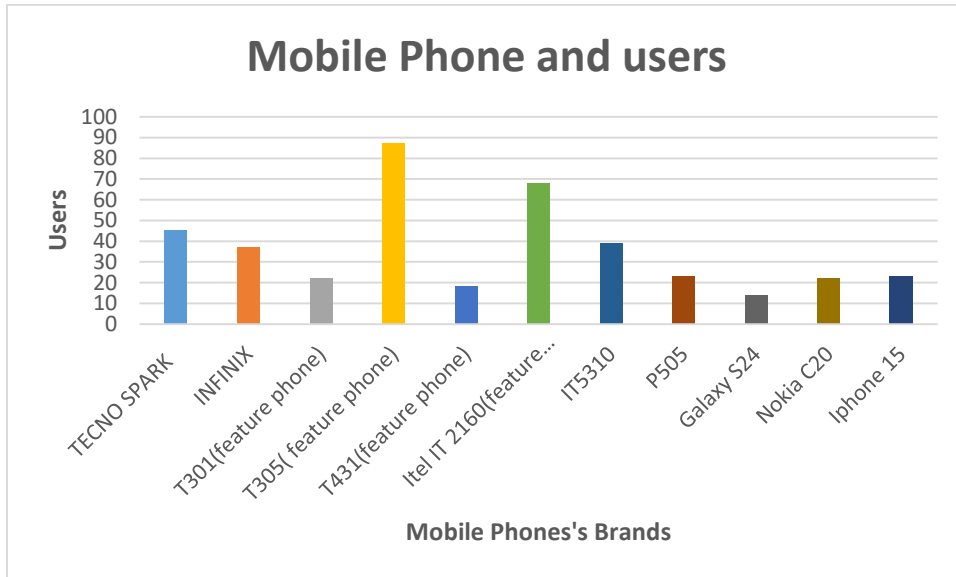


Figure 3.2: Mobile phone users.

- **Collected data by using portable exposure meters to measure mobile radiations in different locations.**

The primary purpose of this data collection is to conduct the exposure assessment of mobile radiation level across different overcrowding locations in Kigali city. To access the effect of those radiations on the people surrounding those place three different places are chosen randomly, Nyabugogo bus park, Nyarugenge market and Kimironko Market by using electromagnetic field meter the intensity of the electromagnetic radiation at those place is measured, the data were taken in two different days at different hours (12:00AM and 17:00 PM). Table 3.2 summarizes the average value of electric field strength at each location.

Table 3.2: Obtained results at electric field strength and power density of electromagnetic radiations at different places.

LOCATION	ELECTRIC FIELD STRENGTH
Nyabugogo bus park	2.1 V/m
Nyarugenge market	1.56 V/m
Kimironko Market	1.5 V/m

3.2.2. LABORATORY EXPERIMENTS

The laboratory experiment aims to measure the electric field strength of the most used mobile telephone. The experiment was carried out by using a dosimeter using a 3 axis radio frequency electromagnetic field meter, Model: EMF-839, ISO-9001, CE, IEC1010. In order to record the

strongest electric field produced, the dosimeter's antenna was moved closer to the cell phone at 5cm, also experiment was repeated when a device and mobile phone with 10 Cm apart to know the how electric field vary with distance. electric field strength was recorded while mobile is either making or receiving a call. Since the emitted frequencies of these mobile phones fell within that range, a high-frequency probe (100 MHz to 3 GHz) was used in accordance with the measurement technique, as shown in the following Figure 3.3.



Figure 3.3: Measurement of electric field strength.

3.2.3. NUMERICAL CALCULATION OF SAR

To calculate the SAR of the human head the method of solving the electromagnetic field equation is used based on Maxwell's equations, to determine the Specific absorption rate of head, firstly head anatomy is disguised.

- **Head anatomy.**

The head is the upper portion of the body consisting of the skull with its coverings and content, including lower jaw, skull protecting the brain [46]. The head has six different tissues considered red as a layer and each layer its own permittivity and conductivity related to electromagnetic radiations. Such layers are skin, fat, bone, dura mater, CSF and brain [47]. The layers of the head from innermost layer (brain) to outermost layer (skin) the dielectric properties of each layer are different from another, quantitative conductivity and permittivity imaging of the human brain using electric properties tomography [48] shows that cerebrospinal fluid have larger permittivity and conductivity than others while fat has smallest electric properties.

- **Permittivity and conductivity of human head layers**

The researchers reported that there is variation in electrical conductivity and permittivity of the human tissue, and variation is caused by tissue type, methodology used, measurement condition, tissue temperature, pathology and age [49].

Due to the variation of the permittivity and conductivities of the human tissue, calculating of SAR was based on the head model in normal health that has the tissue whose conductivity and permittivity are listed in Table 3.3 [47] at the operating frequencies of 900MHz and 1800MHz [50] [19].

Table 3.3: Tissue properties and thickness of six-layer human head.

SN	Tissue	GSM-900 MHz		GSM-1800 MHz		Mass density (kg/m ³)
		Permittivity(f/m)	Conductivity (S/m)	Permittivity(f/m)	Conductivity (S/m)	
1	Skin	40.7	0.65	38.24	1.18	1100
2	Fat	10	0.17	5.01	0.078	920
3	Bone	20.9	0.33	11.5	0.28	1850
4	Dura	40.7	0.65	42.293	1.31	1050
5	CSF	79.1	2.14	66.247	2.92	1060
6	Brain	41.1	0.86	49.247	1.15	1040

Calculating Specific Absorption Rate

- $SAR = \sigma \frac{E^2}{2\rho}$ (5)

Where:

SAR: Specific absorption rate

σ : conductivity of the tissue (S/m),

ρ :Mass density of the tissue (kg/m³)

E: electric field strength

CHAPTER 4: PROJECT'S RESULTS

This chapter highlights the obtained results from the experiment of measuring the electric field strength of most used telephone brands and the electric field strength of the busiest place in Kigali city. The Specific Absorption Rate (ASR) of the head due to each place and mobile telephone's electric field strength is calculated.

4.1.Results presentation

Table 4.1 and Table 4.2 summarize the obtained results from the experiment of measuring electric field strength of mobile telephone and the calculated Specific Absorption Rate of human head by using numerical equations.

- SAR when a device and phone kept 5 Cm apart

Table 4.1: Specific Absorption Rate (SAR) when a mobile phone is held 5 cm from the user's head.

SN	PHONE TYPE		SPECIFIC ABSORPTION RATE(W/Kg)						SAR Of Head
	Model	E	Skin	Fat	Bone	Dura	CFS	Brain	Average
1	TECNO T301	9.28	0.025	0.008	0.008	0.027	0.087	0.036	0.032
2	ITEL IT2160	5.06	0.008	0.002	0.0001	0.008	0.026	0.011	0.0094
3	TECNO SPARK	0.89	0.0002	0.0001	0.0001	0.0002	0.0008	0.0003	0.00029
4	INFINIX	0.92	0.0003	0.0001	0.0001	0.0003	0.0009	0.0003	0.00031
5	TECNO T431	6.2	0.011	0.0036	0.0034	0.0119	0.0388	0.0159	0.01416
6	TECNO T430	5.5	0.0089	0.0028	0.0027	0.0094	0.0505	0.0125	0.01114
7	IT5310	4.8	0.006	0.0021	0.0021	0.007	0.023	0.0095	0.00848

- SAR when a device and phone kept 10 Cm apart

Table 4.2: Specific Absorption Rate (SAR) when a mobile phone is held 10 cm from the user's head.

SN	PHONE TYPE		SPECIFIC ABSORPTION RATE(W/Kg)						SAR Of Head
	Model	E	Skin	Fat	Bone	Dura	CFS	Brain	Average
1	TECNO T301	8.18	0.020	0.006	0.006	0.021	0.068	0.028	0.02464
2	ITEL IT2160	4.00	0.005	0.001	0.001	0.005	0.016	0.007	0.00589
3	TECNO SPARK	0.25	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.00002
4	INFINIX	0.31	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.00004
5	TECNO T431	5.1	0.0077	0.0024	0.0023	0.0081	0.0263	0.0108	0.00958
6	TECNO T430	4.3	0.0055	0.0017	0.0016	0.0057	0.0187	0.0076	0.00681
7	IT5310	3.2	0.0030	0.0009	0.0009	0.0032	0.0103	0.0042	0.00377

Table 4.3 summarizes the obtained results from the experiment of measuring electric field strength of the busiest place in Kigali city and the obtained Specific Absorption Rate of human head by using numerical equations.

Table 4.3: Specific Absorption Rate (SAR) when a mobile phone is held 10 cm from the user's head.

SN	PHONE TYPE		SPECIFIC ABSORPTION RATE(W/Kg)						SAR Of Head
	Place	E	Skin	Fat	Bone	Dura	CFS	Brain	Average
1	NYABUGOGO BUS PARK	2.1	0.001	0.0004	0.0004	0.001	0.004	0.002	0.0016
2	NYARUGENGE MARKET	1.56	0.001	0.0002	0.0002	0.001	0.002	0.001	0.0009
3	KIMIRONKO MARKET	1.5	0.001	0.0002	0.0002	0.0001	0.002	0.001	0.0008

4.2.Data analysis

Data analysis section aims to identify the key finding in the obtained results, showing the mobile telephone that has more and less effects on the human body and also highlight the first place that has most and least effect on humans due to the available electric field strength in that area. Figure 4.1 shows the mobile phone and the Specific Absorption Rate of electric field on the human head when the mobile is kept at 5 Cm and 10 Cm between the user's head.

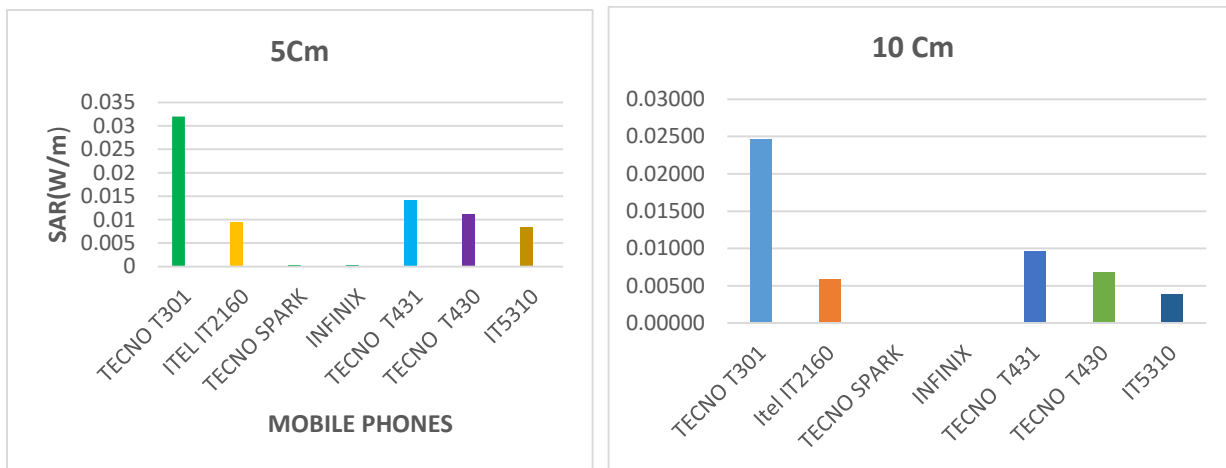


Figure 4.1: Specific Absorption Rate and Mobile phones with varying head to mobile phone distance.

Figure 4.2 (left) shows different places and the Specific Absorption Rate of the electric field on the human head. Figure 4.2 (right) shows the comparison between the measured SAR when the user's head and mobile phones are kept 5Cm and 10 Cm.

The comparison shows that the SAR measured at 5Cm is higher than that of 10Cm, this means that the SAR reduces as the distance between the user's head and mobile phone reduces.

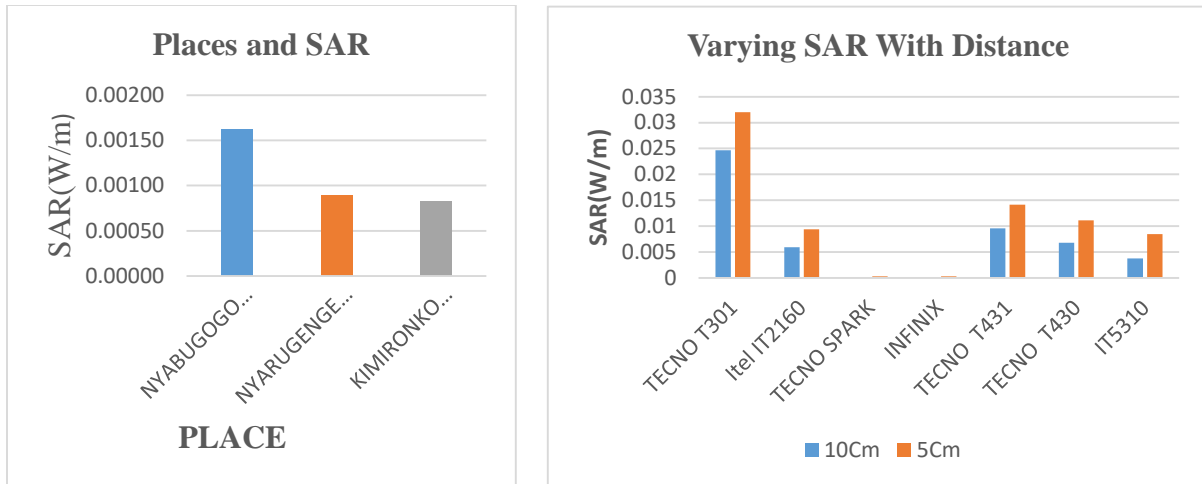


Figure 4.2: Places and SAR (Left) Varying SAR with Distance (Right).

4.3. Results Discussion

This section discusses the analyzed results of the project with referring to specific objectives of the project.

- **Conducting surveys for determining the most used mobile phones' brand in Rwanda.**

The survey is conducted and during setting sample size criteria's all mobile phone users are represented including adults (women and man), youth (boys and girls), employed and unemployed peoples, educated and uneducated people, Kigali city residence and upcountry resident. The results had shown that the most used mobile phone are features phone (2G network) than Smartphones (3G and 4G networks). Among the feature phones the most used is TECNO T301 followed by Tecno T403, while in Smartphones the most used one is TECNO SPARK followed by Infinix.

- **Measurement electric field strength emitted by mostly used mobile phones' brands in Rwanda and the electric field strength available in the busiest place in Kigali city.**

Electric field strength emitted by mostly used mobile phones' brands in Rwanda and the electric field strength available in busiest places in Kigali city are measured by using a dosimeter of 3 Axis Radio Frequency Electromagnetic Field Meter. The results show that feature phones emits higher electric field strength than smart phone where Tecno is leading while Tecno Spark is first smartphone that emit high electric field strength than others. Results also demonstrate mobile phone users experience higher specific absorption rate when mobile phone is closer to the user's head and decreases when the distances increases.

Nyabugogo bus park is the first place that experiences higher emitted electric field strength than other places, this may be because of large numbers of electronic devices users such as Mobile telephone, Radios, television available in Nyabugogo bus park.

- **Determining the Specific Absorption Rate (SAR) in different regions including the human brain when exposed to electromagnetic radiation from mobile phones and different busiest places in Kigali city.**

By using a numerical method, the specific absorption rate of head due to each mobile phone and place is calculated. Results show that TECNO T301 causes higher absorption rate on human head. In the busiest place in Kigali city, Nyabugogo bus park is the leading place that cause high specific absorption rate on human head than other place due to the presence of large electric field strength than other.

- **Analysis of radiation effects based on Specific Absorption Rate.**

According to the guidelines of International Commission on Non-Ionizing Radiation Protection, the safe limit of specific absorption rate on human body is 2 W/Kg, the finding shows that the most of the mobile telephone used in Rwanda emit the electric field strength that cause lower specific absorption rate on human body which range in safe zone.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1.CONCLUSION

Mobile phones are vital instruments that have transformed communication in the current digital era. However, the widespread adoption of such devices has additionally raised concerns over the possible health effects of the electromagnetic radiation they produce. In particular, the Specific Absorption Rate (SAR), is an essential measure of the rate at which radiation is absorbed into the human body, particularly the head. The aim of the research was to evaluate the possible health hazards linked to the use of mobile phones in these urban settings and to offer useful suggestions for reducing exposure and investigating of the electromagnetic radiation levels generated by mobile phones in Kigali's busiest areas. In the areas under study, feature phones which are more common and simpler than smartphones were observed to produce stronger electric fields. These elevated levels are linked to higher SAR values, suggesting that feature phones, as opposed to smartphones, have a larger potential to cause electromagnetic radiation absorption in the human head. This discovery is significant because it raises the possibility that those who use feature phones could be more likely to be exposed to dangerous radiation levels.

One important finding of the study was that when the distance between the user's head and the mobile phone rises, the SAR considerably lowers. The absorption rate is maximum when the phone is held close to the head, as in a phone call. But even a small increase in distance, like when utilizing a hands-free gadget or loudspeaker, can significantly lower the SAR. This finding emphasizes how crucial it is to keep your phone farther away from your head when using it in order to reduce your exposure to electromagnetic radiation. Nyabugogo Bus Park was found to have a noticeably greater level of electromagnetic radiation exposure in the surrounding environment. The park showed increased levels of ambient radiation due to its location as a central transit hub and the high population of mobile phone users. The SAR values determined for the persons in this environment did not exceed safe limits, despite the greater levels of exposure to the environment. This indicates that, under typical usage situations, the specific absorption rates in the human body do not approach unsafe levels.

The results of this study on the Specific Absorption Rate (SAR) that mobile phone use has on the human body are in good agreement with previous research. The data gathered for this study supports the trend of other studies showing that feature phones emit higher levels of electromagnetic radiation than smartphones. Furthermore, SAR values drop with increasing distance between the mobile phone and the user, a finding that is generally accepted. The results of this study are consistent with the well-documented occurrence of an inverse connection between distance and SAR from earlier research.

Moreover, the research supports the idea that electromagnetic radiation levels tend to be higher in urban areas than in rural ones. The significant SAR values found in Nyabugogo, one of Kigali's busiest areas, served as proof of this. According to the statistics, high-traffic urban locations like Nyabugogo are more likely to be exposed to electromagnetic fields, which is consistent with previous research findings. Overall, the study's findings support the accepted knowledge of SAR behavior in relation to distance, environmental context, and mobile phone usage. They also show

that urban areas, with their dense populations and widespread use of mobile phones, are more likely to experience higher electromagnetic radiation levels.

5.2.RECOMMENDATIONS

It is advised that users implement strategies to reduce their exposure to electromagnetic radiation in light of the findings. In particular, when on a call, users should keep as much space as possible between their head and the phone. Bluetooth headsets, hands-free gadgets, and loudspeaker features can all help achieve this. Reducing the length of calls or texting rather than phoning can also help to reduce exposure levels.

Users of mobile phones are recommended to pick smartphones over feature phones due to the significant variation in radiation levels generated by the two types of phones. Owners of feature phones with the Tecno brand in particular are encouraged to monitor their devices closely to ensure that the radiation they emit is kept within acceptable limits. Mobile users should maintain the greatest feasible space between themselves and their phones to be safer.

In addition, people who frequently use Nyabugogo bus park are recommended to restrict their time there to lessen the hazards related to extended exposure to electromagnetic radiation. The purpose of these guidelines is to raise awareness and urge people who use mobile phones and frequent areas with high traffic and potentially heightened amounts of electromagnetic radiation to take preventive steps.

Future research on the effect of exposure duration on radiation levels is advised to help mobile phone users determine the ideal time to use their phones. This study may shed light on the connection between radiation exposure and the amount of time spent using a mobile phone, enabling users to make wise decisions about how much time they spend using them.

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