Journal of Transactions in Systems Engineering
https://journals.tultech.eu/index.php/jtse
ISSN: 2806-2973
Volume 2, Issue 2
DOI: https://doi.org/10.15157/jtse.2024.2.2.235-255
Received: 05.07.2024; Revised: 06.08.2024; Accepted: 26.08.2024

*Research Article*

# Measurement and Analysis of Radiofrequency Radiation Exposure: Impacts on Human Health - A Case Study

**Abdulsalam Alkholidi[1,2*], Shefqet Meda [1], Vasil Mitezi[3] and Anxhela Baraj[1]**

[1] Department of Electronics and Telecom Engineering, Canadian Institute of Technology, Tirana, Albania
[2] Electrical Engineering Department, Faculty of Engineering, Sana'a University, Sana'a Yemen
[3] Director of Spectrum Monitoring, Quality and Inspection at Electronic & Postal Communications Authority, Tirana, Albania

***abdulsalam.alkholidi@cit.edu.al**

**Abstract**

The rapid development of wireless technology, such as the fifth generation (5G) of communication networks, has made radio frequency radiation (RFR) an integral part of our daily lives. However, there is growing concern about the potential harm that 5G might pose to human health. While concerns related to 5G, including those fuelled by rumours during the COVID-19 pandemic and statements by the ITU at that time, have garnered attention, this paper approaches the issue from a scientific perspective. Wireless networks, including data networks and LANs, are ubiquitous in modern life, making it impossible to avoid exposure to RFR. Several international regulatory authorities oversee radio regulation, planning, and standards to ensure that RFR exposure remains within safe limits. By adhering to standards set by the ITU-R, it is possible to minimize risks from radio emissions, thereby protecting both the environment and public health in cases involving mobile service providers (MSPs), multimedia, television and radio broadcasting, radar, and more. The primary goal of this study is to verify that RFR exposure to humans remains within acceptable limits. Additionally, this research aims to conduct a series of RFR measurements in various locations, focusing on densely populated and sensitive areas such as hospitals, public squares, facilities, schools, and kindergartens. The study's key recommendations will support experts and decision-makers in implementing safety measures to protect both the environment and community health.

**Keywords**: Exposure time; transmitted power; frequency; distance; measurements; RF propagation.

## INTRODUCTION

The first wireless telegraphy was successfully carried out by Guglielmo Marconi towards the end of the nineteenth century, which marked the beginning of the radio RFR phenomenon. After that, he was able to demonstrate the viability of this method by transmitting and propagating radio waves across long distances in free space, which led to the development of mobile communications systems. The era of radio frequency radiation began with this. In the early 1800s, Michael Faraday developed the fundamental ideas of electromagnetics. He consequently created the fundamentals of knowing how electricity and magnetism interact. Thus, these tests demonstrated that altering the electric field might increase the magnetic field and vice versa, which prompted the creation of the electromagnetic theories. In the middle of the 19th century, James C. Maxwell developed a system of equations known as Maxwell's equations that mathematically codified the link between the two fields. These formulas anticipated the existence of electromagnetic waves and brought the theories of electricity and magnetism together. Heinrich Hertz conducted the first demonstration and was the first to successfully demonstrate the existence of electromagnetic waves in the late 19th century. He generated and detected radio waves, a type of electromagnetic radiation, in a laboratory setting. His studies supported Maxwell's hypothesis and demonstrated the existence of electromagnetic waves outside of the visible spectrum.

In this research work, we will check the relationship between increasing frequency and its relationship to photon energy, and our focus will be mainly on RFR. The idea is to simplify for the reader the relationship between radio radiation with the following parameters: frequency (f), transmit power (Tx), distance (D) from the antenna, and exposure time (t) and its impact on humans and the environment.

The EMS can be described in terms of wavelength, frequency, or energy. The relationship between wavelength ($\lambda$) and frequency (f) is given by the expression of the equation (1) [1]:

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

where c is the speed of light and correspond to the value 2,998 x $10^8$ m/s.

Figure 1 depict the electromagnetic spectrum [1]. The energy of different components of the electromagnetic spectrum is given by the following expression of equation (2):

$$E = hf = \frac{hc}{\lambda} \tag{2}$$

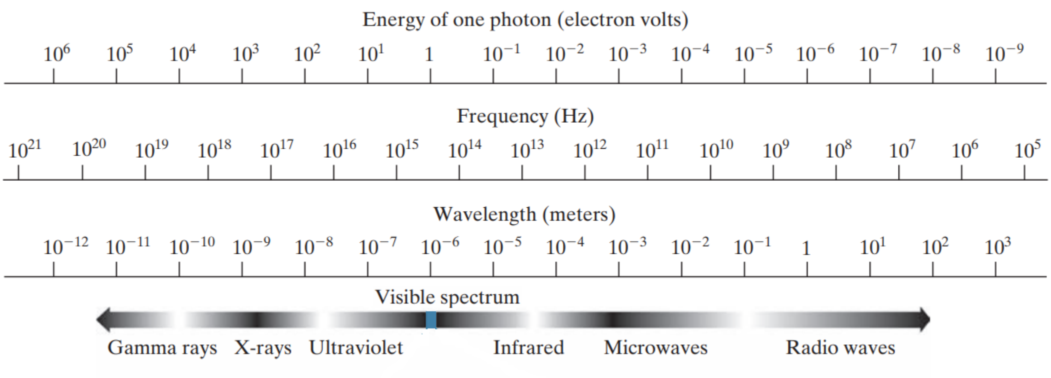


**Figure 1.** The electromagnetic spectrum [1].

As shown in Figure 1, the photon energy in the non-ionizing radio band is smaller compared to the ionizing band, especially starting in the Ultraviolet, where the energy of one photon (electron volts) is 101, then X-rays, and Gamma rays. The energy of a single photon of electromagnetic radiation determines whether the radiation is ionizing or non-ionizing. The energy of the ionizing radiation band is sufficient to free electrons that are firmly attached to atoms, ionizing them and perhaps harming biological tissues. On the other hand, non-ionizing radiation can nevertheless have an impact on biology by heating it, even when it lacks the energy to ionize atoms.

The term "radio frequency radiation" (RF radiation) describes a class of electromagnetic radiation that travels across space at frequencies usually between 3 kHz and 300 GHz and is characterized by oscillating electric and magnetic fields. Many communication technologies, such as wireless networking (Wi-Fi), cellular telephony, television transmission, radio broadcasting, and radar systems, rely on radio frequency radiation (RF radiation).

In order to measure the levels of exposure and enable the comparison of exposure levels across several investigations, all power density measurements were converted to E-field strength (V/m) using the following method, see equation (3):

$$E\ (V/m) = \sqrt{\sqrt{Z_o} * Power\ density\ (W/m^2)} \tag{3}$$

where Z0, equal to 377 Ω, is the impedance of vacuum.

Definitions, the computation of free space, and some presumptions [2].

- pt: the transmitter power (in watts)
- gt : transmitter antenna gain (dimensionless)
- EIRP: Equivalent Isotopically Radiated Power in watts
- d: distance from transmitter (meter)
- e: electric field-strength Volt/metre (V/M) (equation (4)):

$$e = \frac{\sqrt{30E.I.R.P}}{d} \tag{4}$$

For free-space propagation loss (Equation (5)):

$$d = \frac{\sqrt{30E.I.R.P}}{e} \tag{5}$$

Specific Absorption Rate (SAR) is a measurement of the speed at which the body absorbs energy from an electromagnetic field with a radio frequency (RF). Usually, it is stated in watts per kilogram (W/kg) units. The possible health impacts of radiofrequency energy exposure from gadgets like cell phones, wireless routers, and other wireless communication equipment are assessed using SAR [3-4] (Equation (6)):

$$SAR = \frac{\sigma.|E|^2}{\rho} \tag{6}$$

Where:

SAR stands for Specific Absorption Rate, measured in watts per kilogram (W/kg).

σ is the conductivity of the tissue (S/m). The deposited power measurement's geographical distribution increases mostly when there is radiofrequency charging. This equation is relevant to our work since it is used by many countries, including the United States, to determine limitations on exposure to thermal radiation [5].

E, represents the root-mean-square (rms) electric field strength in tissue, measured in volts per meter (V/m).

ϱ is the mass density of the tissue ($kg/m^3$).

Strict criteria are established for peak SAR by numerous nations and organizations. According to experiments, there may be a considerable danger of tissue injury if the head or torso is exposed for 15 minutes to a SAR of 8 W/kg in any gram of tissue indicates the rate at which energy is absorbed per unit mass of the tissue [6].

Usually applied to homogeneous tissues, this equation assumes that the tissue's characteristics won't change. In practice, SAR computations can be more intricate, particularly when interactions with various electromagnetic fields and heterogeneous tissues are considered.

Some of the SAR values of specific mobile phones are presented in Table 1.

**Table 1.** SAR values of specific mobile phones [7-15].

| **Phone model** | **Head SAR (W/kg)** | **Body SAR W/kg** | **Phone model** | **Head SAR (W/kg)** | **Body SAR (W/kg)** |
|---|---|---|---|---|---|
| iPhone 14 | 1.15 | 1.16 | Samsung Galaxy A12 | 1.16 | 0.673 |
| iPhone 14 Plus | 1.14 | 1.15 | Samsung Galaxy S24 Plus | 1.16 | 0.84 |
| iPhone 14 Pro | 1.15 | 1.15 | Samsung Galaxy S22 Ultra | 1.18 | 0.98 |
| iPhone 14 Pro Max | 1.15 | 1.07 | Samsung Galaxy S22 Plus | 1.19 | 1.08 |
| iPhone 15 | 1.12 | 1.09 | Samsung Galaxy S24 | 1.23 | 1.10 |
| iPhone 15 Pro | 1.14 | 1.16 | Samsung Galaxy S24 Ultra | 1.26 | 0.62 |
| iPhone 15 Pro Max | 1.07 | 1.11 | Samsung Galaxy A13 | 1,27 | 0.58 |

Reference values for exposure to non-ionizing radiation, including electromagnetic fields, are established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), see Figure 2. To protect public safety, ICNIRP has set particular reference limits for whole-body exposures lasting six minutes or more. The purpose of these reference values is to guard against the possible harmful effects of electromagnetic field exposure on health [16].

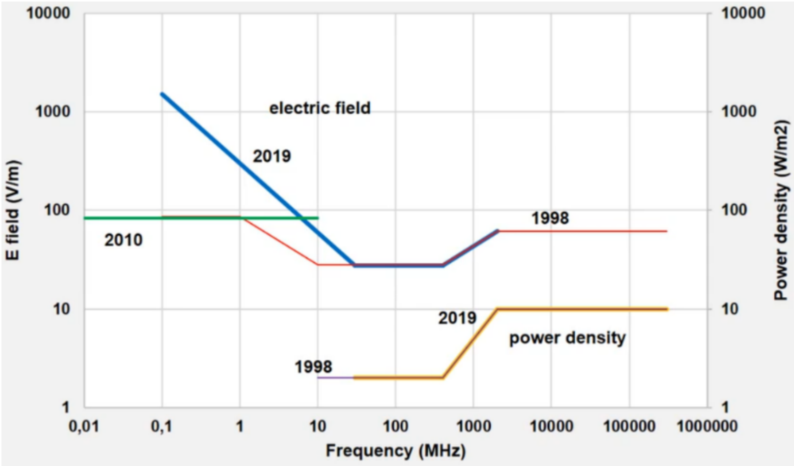


**Figure 2.** Reference levels general public, whole-body ≥ 6 min [17].

Depending on the frequency range of the electromagnetic fields in question, the precise numerical values for the ICNIRP reference levels for whole-body exposure by the general public for periods of 6 minutes or more can change. These reference levels are typically measured in quantities like volts per meter (V/m), tesla (T), or watts per square meter (W/m2) and these values are stated in terms of electric field strength, magnetic field strength, or power density [18].

The aim of this research work is to determine how to protect people and the environment exposed to RFE fields in radio frequency bands: LF, HF, VHF, UHF, and SHF. We conducted numerous measurements in several Albanian cities, focusing on hospitals, schools, crowded areas, and public squares to identify the minimum exposure level needed to produce harm. We will study and analyse the obtained results and compare them with the standards of international bodies regulating radio radiation, such as ICNIRP, the IEEE Standard for Safety Levels, according to the European Conference of Postal and Telecommunications Administrations (CEPT), the International Electrotechnical Commission (IEC), he ITU-R section, etc. The second step of this study is to start with a major literature review.

## LITERATURE REVIEW

During the past twenty years, the number of radio frequency sources has increased significantly, including the development of communications generations all the way to the fifth generation, around which many stories have been woven stating that it was the main source of the global pandemic. COVID-19. Many studies and ITU-T recommendations on human exposure to electromagnetic fields have been published on radio radiation and its impact on humans and the environment. We will discuss the most important research related to this topic, including, for example [19-34].

An article published by Raquel Ramirez-Vazquez et al. indicates that they carried out several measurements by using eighty-three percent of the studies employed personal explosimeters in both Egypt and Belgium, where the obtained results show that the lowest average in Egypt was measured at a value of 0.00100 μW/m2 (1.00 nW/m$^2$) in 2007 and the highest mean was measured in Belgium with a value of 285000 μW/m$^2$ (0.285 W/m$^2$) in 2019. The results of this study support the notion that RF-EMF exposure levels are much below the upper limits recommended by the ICNIRP guidelines [19].

In this study [20], the authors addressed exposure to radio frequency electromagnetic fields in the indoor environment, considering the external environment of radiation emitted from the antennas of radio and television stations and cell phone stations, as well as internal sources, for example, the cell phone and some various wireless communications applications. As the authors note, this study sought to address research efforts over the previous ten years. It was discovered that while measurements in public transportation (0.97 V/m), or homes and apartments, were at their lowest levels, mean values in the range of 0 to 13.43 V/m were found to be the maximum mean levels of the radio frequency range in offices (1.14 V/m). Various RF-EMF source measurements indicate slightly varied patterns for the overall exposure level inside the indoor environment. The measured results should be interpreted as a time-dependent representation of the continuous evolution of exposure to RF-EMF. While Vijayalakshmi L. and Nirmala Devi's published research [21] addresses the issue of the effect of prolonged use of a mobile phone, which has a long-term effect.

The rules have been updated by the ICNIRP. We question the use of surface-only exposure assessments for local exposures above 6 GHz, partly due to the potential for Brillouin precursor pulse formation. Additionally, we briefly assess whether the ICNIRP's new approach effectively prevents heat damage and other adverse biological effects in the context of millimetre-wave 5G [22].

Only thermal effects, or tissue heating, are taken into consideration as potentially detrimental to the existing exposure levels that have been suggested by the ICNIRP and the Federal Communications Commission (FCC). On the other hand, there is growing proof that electromagnetic radiation exposure has non-thermal consequences for human populations and biological systems [23].

The biological sensitivity of developing children has raised widespread concerns about the potential health consequences of radiofrequency electromagnetic radiation on children. We compiled the available information on cancer, birth outcomes, neurocognitive development, and behavioural issues using a search technique and risk-of-bias evaluation [24].

The European Union has not acknowledged the existence of any hazards, despite mounting evidence of the major adverse consequences of radiofrequency radiation on human health and the environment. Seven requests from medical professionals and scientists to the European Union have been made since September 2017, asking for a stop to the introduction of fifth-generation (5G) wireless communication. The intricate waveforms and millimetre waves (MMW) of 5G significantly worsen the already dangerous levels of electromagnetic pollution on Earth. The EU is required by fundamental rights and EU primary law to safeguard its citizens, particularly children, against the various detrimental health impacts of wireless technology. Nonetheless, because of their connections to business, a number of specialists connected to the EU and WHO have conflicts of interest [25].

The impact of the radiofrequency field (RF) produced by 5G communication equipme nt on human health is becoming more widely recognized as a result of the networks' quic k development [26].

A recent publication by the ICNIRP and a report by a Swiss government expert group both overlook the assessment of RF radiation health concerns related to 5G technology [27].

Evidence that a certain frequency band or technology causes health damage must be scientific, proven, extended over time and in different locations, etc. The lack of evidence in some cases has led to wrong conclusions. For example, in the Netherlands, when 5G technology was being tested, some dead birds were found somewhere in an area. The inability to explain the phenomenon and the lack of evidence led some to think that it was an effect of 5G, mainly social websites. But that phenomenon was isolated and did not happen, even though the technology continues to work [28-31].

RF-EMR can hurt the function of the central nervous system (CNS) by changing the blood-brain barrier (BBB), neurotransmitter levels, calcium channel regulation, myelin protein structure, the antioxidant defence system, and metabolic processes. It is important to note, though, that some investigations have indicated that exposure to RF-EMR may have positive effects on cognition for a range of illnesses. Exposure to ELF-EMF has been linked to improvements in CNS function, including better learning and memory retention as well as possible prevention of neurodegenerative disorders. However, it is crucial to recognize that exposure to ELF-EMF has also been connected to changes in hormone regulation, oxidative stress, and the creation of anxiety states. In addition, exposure to ELF-EMR modifies synaptic activity, the antioxidant defence system, notch signalling pathways, and hippocampus function [32].

While some have questioned whether enough research has been done on the health and safety consequences of radio frequency (RF) from 5G systems, standard-setting organizations and health agencies may evaluate the possible effects across this frequency band because RF frequencies up to 300 GHz are widespread. The mode of operation of a 5G radio frequency signal is no different from that of a lower frequency communication signal; both entail heating tissue at high enough field strengths. The primary distinction for 5G frequencies beyond 6 GHz is that the electrical characteristics of the body effectively restrict energy deposition to a shallow depth, primarily limited to the skin's superficial layers [33].

The study by Adedotun T. Ajibare et al. [34] investigates the effects of exposure to radiofrequency (RF) and electromagnetic field (EMF) radiation and examines the implications of reducing this exposure on the specific absorption rate (SAR) and exposure index (EI) for access points (APs) and user equipment (UEs) in fourth-generation (4G) and fifth-generation (5G) wireless technologies. An important problem for research in this field is the time that studies take. While it takes several years to collect and find data to decide whether it constitutes a test for the effect on health or not, the technology moves to another stage. For example, when they started studies on the effects of GSM and 3G technology, in almost two decades, they gave way to 4G and 5G technology, making a scientific conclusion from the studies almost impossible.

## METHODOLOGY AND MEASUREMENT RESULTS

In order to provide a solid study and analyse its results in accordance with international standards, we made a field trip to many cities and made many measurements using the following measuring devices as demonstrated in Figure 3:


**Figure 3.** Wave control SMP2 Field Meter- Rent EMF Measurement Equipment [35-37].

The aims of these measurements were carried out in the framework of the implementation of the standards approved by the ICNIRP in the city of Tirana. Purpose: Monitoring of emissions from mobile phone cells and not only those near buildings and objects with a high density of people, for the effect they may have on public health, as well as monitoring the level of non-ionizing radiation and receiving and processing data collected from field measurements. The type of measurements that this research addresses are non-ionizing radiation level monitoring. This research methodology and measurements focuses on:

- Monitoring the level of radiation in the areas referred to refers to verifying the level of the electric and magnetic fields.
- Graphical and comparative presentation of the values obtained at the 4 points that were measured: Polytechnic University of Tirana, "Koco Gliozheni" Obstetrics and Gynecology University Hospital, "Mother Teresa" University Hospital Center, and ONE Albania D. T. A.

## *Measurements at Polytechnic University of Tirana (PUT)*

We were very careful to take measurements near locations with dense populations, one of which was the PUT. Table 1 shows the obtained results where the electrical field E (V/m) is equal to 0.6096 and the magnetic field H (A/m) is equal to 0.003586. By analysing the results obtained in Table 1, we find that they conform to the standards regulating radio frequency radiation, see Figures 4 until 6.

**Table 2.** Non-ionizing radiation level values were obtained from field data.

| Measurements Location | Realization time | Electric field E (V/m) | Magnetic field H (A/m) |
|---|---|---|---|
| PUT | 26/04/2024 | 0.6096 | 0.003586 |


**Figure 4.** Sequential measurement of field strength E (V/m) and H(A/m).

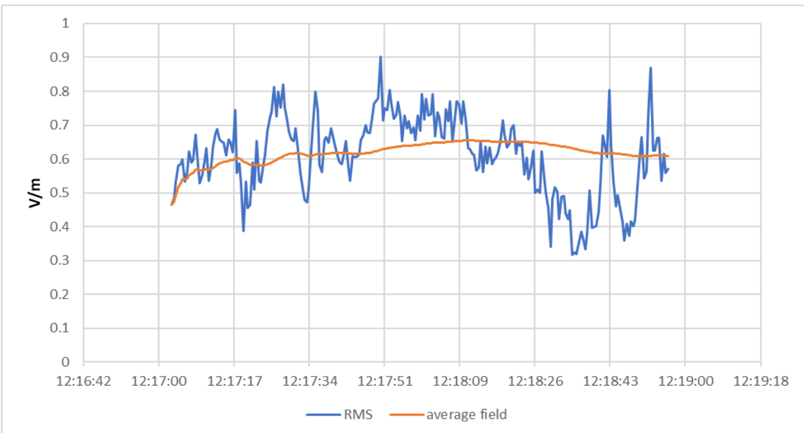


**Figure 5.** Electric field graph E (V/m).

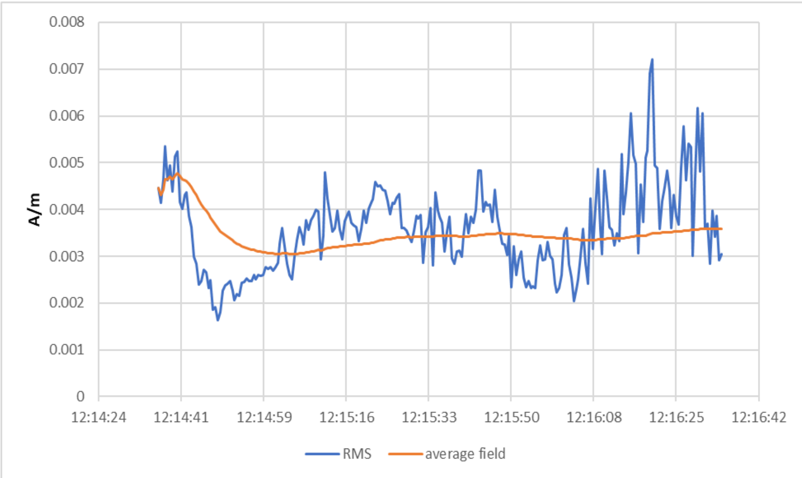


**Figure 6.** Magnetic Field Graph H (A/m).

Figures 4 until 6 illustrate the sequential measurement of field strength E (V/m) and H(A/m), the electric field graph E (V/m), and the magnetic field graph H (A/m), where all results measured are demonstrated in the mentioned above figures.

### *Measurements at Obstetrics and Gynaecology University Hospital "Koco Gliozheni"*

Figure 7 shows the measurements near a hospital in the capital, Tirana, as hospitals were among our priorities in taking radio radiation measurements. Therefore, it was our second destination, the Obstetrics and Gynaecology University Hospital, "Koco Gliozheni."

**Figure 7.** Measurements at the Obstetrics and Gynaecology University Hospital, "Koco Gliozheni".

During the monitoring of the spectrum, measurements were made of the strength of the electric field, E (V/m), and the strength of the magnetic field, H (A/m) as demonstrated in table 3. We found that all measurements respect the standards regulating radio frequency radiation, see table 3 and Figures 8 until 10.

**Table 3.** Non-ionizing radiation level values were obtained from field data.

| Measurements Location | Realization time | Electric field E (V/m) | Magnetic field H (A/m) |
|---|---|---|---|
| "Koco Gliozheni" Obstetrics and Gynaecology University Hospital | 26/04/2024 | 1.516 | 0.004208 |


**Figure 8.** Sequential measurement of field strength E (V/m) and H(A/m).

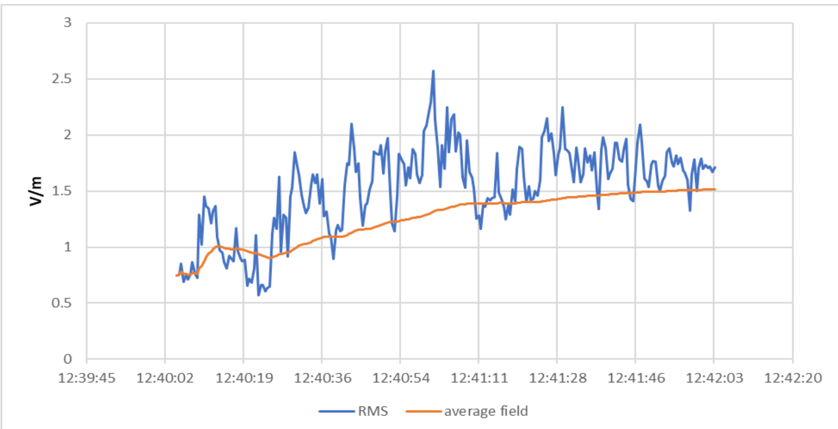


**Figure 9.** Electric field graph E (V/m).

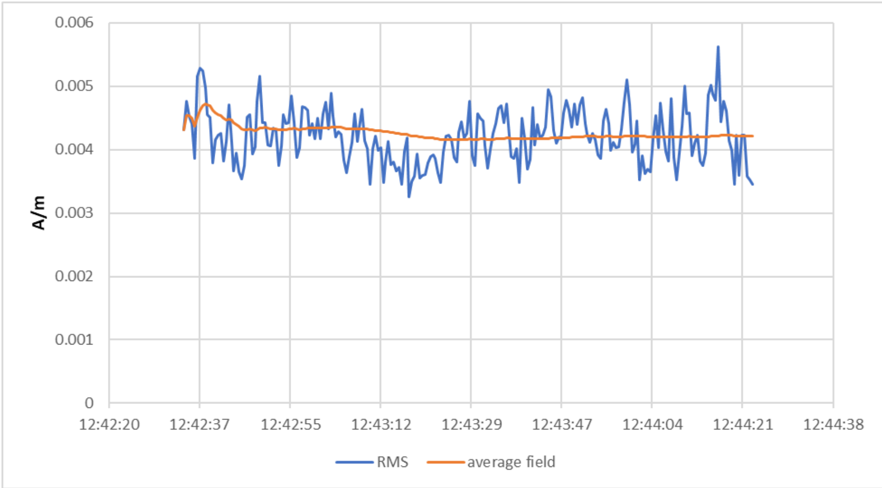


**Figure 10.** Magnetic Field Graph H (A/m).

Figures 8 until 10 present the sequential measurement of field strength E (V/m) and H (A/m), the electric field graph E (V/m), and the electric field graph E (V/m) (see figures 8–10). If we compare the obtained measured results at the PUT with the measurements at the Obstetrics and Gynaecology University Hospital, "Koco Gliozheni," we have found the electric field strength value which is approximately three times greater than the value obtained at the PUT, while the magnetic field strength is slightly higher than it.

### *Measurements at "Mother Teresa" University Hospital Centre*

The next destination was the largest hospital in Albania, Mama Teresa Hospital. The measurements we made showed that the electric field strength was 1.533 E (V/m), while the magnetic field was at a value of 0.004622 H (A/m), as shown in Table 4.

**Table 4.** Non-ionizing radiation level values were obtained from field data.

| Measurements Location | Realization time | Electric field E (V/m) | Magnetic field H (A/m) |
|---|---|---|---|
| "Mother Teresa" University Hospital Center | 26/04/2024 | 1.533 | 0.004622 |

The sequential measurements of the electric field strength are 1.44 E (V/m) and the magnetic field strength is 0.004 H (A/m), as demonstrated in Figure 11.

Figure 12 illustrates the electric field graph E (V/m), where the blue curve shows RMS and the red one presents the average electric field. Figure 13 explores the magnetic field graph H (A/m). The blue curve introduces the RMS value, and the red one depicts the average magnetic field.

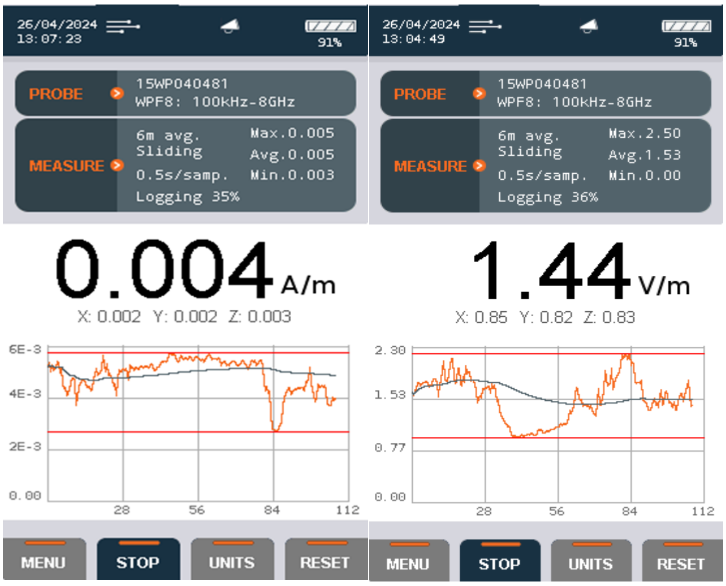


**Figure 11.** Sequential measurement of field strength E (V/m) and H(A/m).

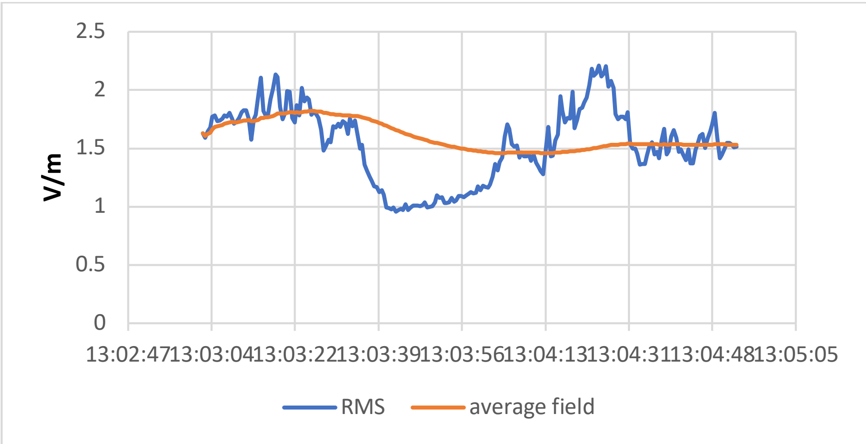


**Figure 12.** Electric Field Graph E (V/m).

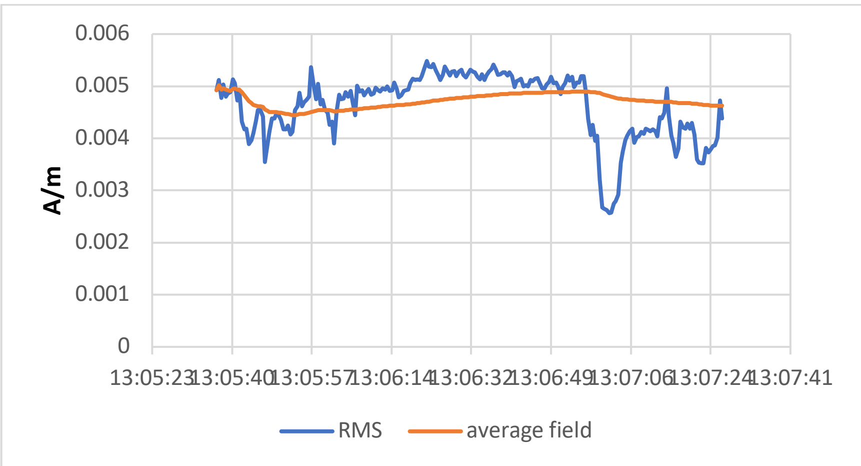


**Figure 13.** Magnetic Field Graph H (A/m).

## Measurements at ONE ALBANIA D.T.A

After we measured RFR near some hospitals, universities, and crowded public areas, our destination this time was a telecommunications and television services company in Albania, "ONE ALBANIA D.T.A." as demonstrated in Figure 14. During the monitoring of the spectrum, measurements were made of the strength of the electric field, E (V/m), and the strength of the magnetic field, H (A/m). The measured results are presented in Table 5.

**Figure 14.** Measurements near ONE ALBANIA D.T.A.

**Table 5.** Non-ionizing radiation level values obtained from field data.

| Measurements Location | Realization time | Electric field E (V/m) | Magnetic field H (A/m) |
|---|---|---|---|
| ONE ALBANIA D.T.A | 26/04/2024 | 1.425 | 0.003589 |

The results show that the electric field measured is equal to 1.425 E (V/m), while the magnetic field is indicated at 0.003589 H (A/m), (see table 5). Both measurements we obtained also respect the standards of radio radiation regulators. The sequential measurement of field strengths is 1.26E (V/m) and 0.004 H (A/m), as illustrated in Figure 15.

Figure 16 illustrates the two blue and red curves. The blue one refers to measuring MRS, where the first point was measured at 1.2 while the last point was measured at 1.23; the highest reading was equal to 1.7 at the midpoint of the curve. As shown in Figure 16, the red curve (average field) began in an oscillating manner, then became as if it were constant or saturated. Figure 17 shows a graph of the magnetic field H (A/m). The red curve shows the MRS, as it appears to oscillate between readings of 0.003 and 0.004. While the blue curve (average field) variates similar to an aperiodic wave, as demonstrated in figure 17, The measured value at the beginning of the measurement point was 0.004, the last reading was 0.0035, and the highest reading was 0.0052.


**Figure 15.** Sequential measurement of field strengths E (V/m) and H (A/m).

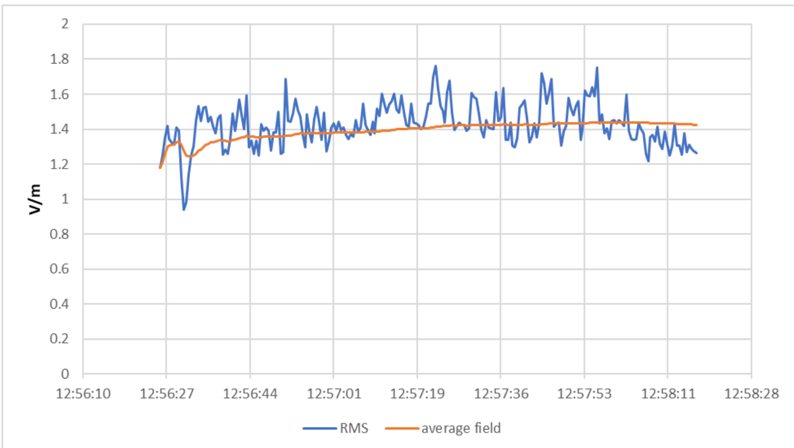


**Figure 16.** Electric Field Graph E (V/m).

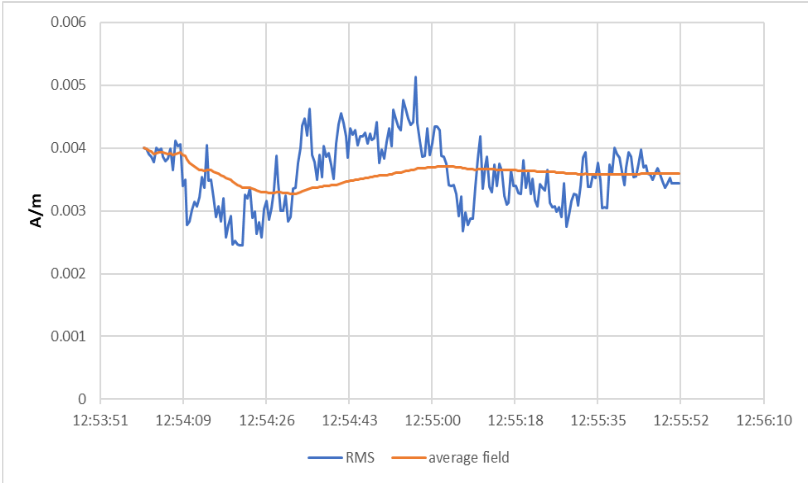


**Figure 17.** Magnetic Field Graph H (A/m).

## ANALYZING AND DISCUSSING

From the measurements performed at the monitored points, it is found that the radiation levels are within the norms defined by the ICNIRP Guidelines for "Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields" [38].

The results of these measurements recorded so far show that the radiation levels emitted by the mobile antenna do not exceed the safety threshold defined by the International ICNIRP. Table 6 shows the limit levels defined in the regulation "On the Protection of the Public from Non-Ionizing Radiation" with which the values obtained in the field can be compared.

**Table 6.** European Recommendation 1999/519/EC—Reference levels for electric, magnetic and electromagnetic fields (0 Hz to 300 GHz, unperturbed RMS values) [40].

| Frequency Range | E-Field Strength (V/m) | H-Field Strength(A/m) | B-Field(μT) | Equivalent Plane WavePower Density $S_{eq}$ (W/m$^2$) |
|---|---|---|---|---|
| 0–1 Hz | — | $3.2 \times 10^4$ | $4 \times 10^4$ | — |
| 1–8 Hz | 10,000 | $3.2 \times 10^4/f^2$ | $4 \times 10^4/f^2$ | — |
| 8–25 Hz | 10,000 | $4000/f$ | $5000/f$ | — |
| 0.025–0.8 kHz | $250/f$ | $4/f$ | $5/f$ | — |
| 0.8–3 kHz | $250/f$ | 5 | 6.25 | — |
| 3–150 kHz | 87 | 5 | 6.25 | — |
| 0.15–1 MHz | 87 | $0.73/f$ | $0.92/f$ | — |
| 1–10 MHz | $87/f^{1/2}$ | $0.73/f$ | $0.92/f$ | — |
| 10–400 MHz | 28 | 0.073 | 0.092 | 2 |
| 400–2000 MHz | $1.375 f^{1/2}$ | $0.0037 f^{1/2}$ | $0.0046 f^{1/2}$ | $f/200$ |
| 2–300 GHz | 61 | 0.16 | 0.20 | 10 |

Note:

- $f$, as shown in the frequency scale bar.
- For frequencies between 100 kHz and 10 GHz, Scq, E2, H2, and B2 shall be averaged every six minutes.
- For frequencies greater than 10 GHz, Scq, E2, H2, and B2 shall be averaged over every 68/$f$1.05 minutes ($f$ in GHz).

Table 7 shows the reference values for electric, magnetic and electromagnetic fields.

**Table 7.** Reference values for electric, magnetic and electromagnetic fields [40].

| Frequency band | Electric field strength - E (V/m) | Value - E (V/m) | Magnetic field strength H (A/m) | Value H (A/m) |
|---|---|---|---|---|
| 1-10 MHz | 87/f½ | 27.53 V/m | 0.73/f | 0.073 A/m |
| 10-400 MHz | 87/f½ | 4.35 V/m | 0.73/f | 0.0018 A/m |
| 400-2000MHz | 1.375f½ | 27.5 V/m | 0.0037f½ | 0.074 A/m |
| 2-500 GHz | 1.375f½ | 61.5 V/m | 0.0037f½ | 0.16 A/m |

The key findings case study draws attention to important health risks linked to radiofrequency (RF) radiation exposure, highlighting possible side effects such as neurological symptoms and discomfort from heat in high-exposure situations. The majority of RF exposure levels meet current safety guidelines, according to analysis of Specific Absorption Rate (SAR) and Exposure Index (EI), but, under some circumstances, suggested limits may be approached or exceeded. There were non-thermal impacts as well, such as oxidative stress, which could have health consequences and call for more research. The results highlight the need for ongoing study to address long-term health effects and updated safety requirements. To reduce potential dangers, precautions and increased public knowledge are advised.

To enhance the accuracy and comprehensiveness of the measurement and analysis of radiofrequency (RF) radiation exposure and its impacts on human health, several additional variables and methodologies could be incorporated into this research work as follows:

- Duration and frequency of exposure: Track both the length and frequency of RF exposure to assess cumulative effects.
- Personal habits and device usage patterns: Examine individual usage patterns and habits with RF-emitting devices to understand their impact on exposure levels.
- Environmental factors: Consider ambient RF radiation levels from various sources to provide a comprehensive view of the exposure environment.
- Biological variables: Include individual differences such as age, sex, and health status to identify variability in health responses.
- Physiological responses: measure physiological markers like heart rate variability and cortisol levels to evaluate the biological impact of RF exposure.

To enhance the accuracy and comprehensiveness of the measurement and analysis of radiofrequency (RF) radiation exposure and its impacts on human health, several additional variables and methodologies could be incorporated into the study:

- Duration and frequency of exposure: Track both the length and frequency of RF exposure to assess cumulative effects.
- Personal habits and device usage patterns: Examine individual usage patterns and habits with RF-emitting devices to understand their impact on exposure levels.
- Environmental factors: Consider ambient RF radiation levels from various sources to provide a comprehensive view of the exposure environment.
- Biological variables: Include individual differences such as age, sex, and health status to identify variability in health responses.
- Physiological responses: Measure physiological markers like heart rate variability and cortisol levels to evaluate the biological impact of RF exposure.
- Longitudinal study design
- Advanced exposure assessment techniques
- Biological monitoring and biomarker analysis
- Controlled experimental studies
- Comparative analysis across different frequencies and modulation patterns
- Enhanced statistical and computational models
- Public and occupational health surveys

Furthermore, some limitations in this research work could be noted as follows:

- Limited measurement accuracy and precision. The limitation of the Wave Control SMP2 Field Meter and similar equipment may not provide the highest level of accuracy or precision in measuring total power density across a broad frequency spectrum. The impact: this restriction may result in less precise evaluations of RF exposure levels, which could compromise the validity of the information and conclusions made regarding the effects on health.
- Power density measurement limitations
- Device Sensitivity and Range Limitations
- Calibration and measurement errors
- Temporal and spatial variability
- Limited number of measurement points
- Subjective health reporting.

## CONCLUSION

In today's connected world, where remote innovation is inescapable, measuring the sum of radio recurrence (RF) radiation is essential. With the widespread use of devices such as smart meters, Wi-Fi routers, and cell phones, understanding and managing RF radiation exposure is essential for public health and safety. By implementing effective monitoring systems and regulations, we can ensure that RF radiation levels remain within safe limits, minimizing potential health risks. Continued research into the long-term effects of RF radiation exposure will help us develop stronger guidelines and protective measures. Ultimately, by staying informed and vigilant about RF radiation, we can create environments that harness the benefits of wireless technology while prioritizing the safety of individuals and communities. Our comprehensive study of radio radiation measurements at some of the busiest sites in Tirana found that all readings were within the limits set by regulatory bodies for electromagnetic field exposure. Moving forward, our future work will focus on monitoring RFR in major cities across Albania. One of the key recommendations from this study is to ensure that the results are published on the relevant Albanian authorities' websites. This will facilitate ongoing monitoring by the appropriate authorities, benefiting the public by providing transparency, assurance, and awareness of RFR levels.

## CONFLICT OF INTERESTS

Authors confirm that there is no conflict of interests associated with this publication.

## REFERENCES


1. Gonzalez, R.C. and Woods, R.E, Digital Image Processing, 4th Edition, Chapter 2, Pearson Education, New York, **2018**; pp. 55-56.
2. International Telecommunication Union. ITU-R, Radiocommunication Sector of ITU, Report ITU-R SM.2452-1, "Electromagnetic field measurements to assess human exposure, SM Series, Spectrum management". Available at https://www.itu.int/pub/R-REP-SM.2452-1-2022. (accessed on 12 June 2024).
3. Tang, Q., Tummala N., Gupta S.K.S., and Schwiebert, L. Communication scheduling to minimize thermal effects of implanted biosensor networks in homogeneous tissue, in *IEEE Transactions on Biomedical Engineering*, **2005**; 52(7); pp. 1285-1294.
4. IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields ", 0 Hz to 300 GHz," in IEEE Std C95.1-2019 (Revision of IEEE Std C95.1-2005/ Incorporates IEEE Std C95.1-2019/Cor 1-2019), vol., no., pp.1-312, 4 Oct. 2019.
5. Garrison, D. (2007). Minimizing Thermal Effects of In Vivo Body Sensors. In: Leonhardt, S., Falck, T., Mähönen, P. (eds) *4th International Workshop on Wearable and Implantable Body Sensor Networks (BSN 2007)*. IFMBE Proceedings, vol 13. Springer, Berlin, Heidelberg.
6. IEC 60601-2-33. Medical electrical equipment, part 2-33, "Particular requirement for the safety of magnetic resonance systems for medical diagnosis. Available at https://webstore.iec.ch/en/publication/67211. (accessed on 10 June 2024).
7. SAR Values of Apple iPhones. Available at https://www.everythingrf.com/community/sar-values-of-apple-iphones. (accessed on 1 March 2024).
8. Samsung Radiation Levels List-2024. Available at https://www.rfsafe.com/list-of-samsung-lowest-to-highest-radiation-phones-actively-carrier-supported/. (accessed on 10 March 2024).
9. Samsung Galaxy S24+ Specifications. Available at https://www.cuit.columbia.edu/sites/default/files/content/Samsung%20Galaxy%20S24+%20Specifications.pdf. (accessed on 2 April 2024).
10. Samsung Galaxy S22 Ultra FCC SAR Levels Specifications. Available at https://www.rfsafe.com/phone-specs/samsung-galaxy-s22-ultra/fcc-sar-levels/. (accessed on 2 April, 2024).
11. Samsung Galaxy S22 Plus Radiation Levels. Available at https://www.rfsafe.com/phone/samsung-galaxy-s22-plus/?sar=usbody. (accessed on 12 April 2024).

12. Samsung Galaxy S24 Specifications. Available at https://www.cuit.columbia.edu/sites/default/files/content/Samsung%20Galaxy%20S24%20Specifications.pdf. (accessed on 9 April 2024).
13. Samsung Galaxy S24 Ultra Specifications. Available at https://www.cuit.columbia.edu/sites/default/files/content/Samsung%20Galaxy%20S24%20Ultra%20Specifications.pdf. (accessed on 9 April 2024).
14. Samsung Galaxy S24 Ultra Radiation Levels. Available at https://www.rfsafe.com/phone/samsung-galaxy-s24-ultra/. (accessed on 26 April 2024).
15. Samsung Galaxy A13 Radiation Levels. Available at https://www.rfsafe.com/phone/samsung-galaxy-a13/. (accessed on 12 April 2024).
16. ICNIRP guidelines for limiting exposure to electromagnetic fields (100 KHZ TO 300 GHZ). Available at https://www.icnirp.org/cms/upload/publications/ICNIRPrfgdl2020.pdf. (accessed on 12 April 2024).
17. ICNIRP, New Statement 2024. Available at https://www.icnirp.org. (accessed on 27 August 2024).
18. RF EMFs, 100 kHz - 300 GHz: https://www.icnirp.org/en/frequencies/radiofrequency/index.html. (accessed on 27 April 2024).
19. Ramirez-Vazquez, R., Escobar, I., Vandenbosch, G.A.E, Vargas, F., Caceres-Monllor, D.A. and Arribas, E. Measurement studies of personal exposure to radiofrequency electromagnetic fields: A systematic review, *Environmental Research*, **2023**; 218; pp. 114979.
20. Chiaramello, E., Bonato, M., Fiocchi, S., Tognola, G., Parazzini, M., Ravazzani, P., Wiart, J. Radio Frequency Electromagnetic Fields Exposure Assessment in Indoor Environments: A Review, *Int J Environ Res Public Health*, **2019**; 16(6); pp. 955.
21. Vijayalakshmi, L. and Nirmala Devi, P. Impacts of RF radiation from mobile phones on human health and its remedies. *Journal of Applied Research and Technology*, **2020**; 18(5); pp. 269-278.
22. Redmayne, M., Maisch, D.R. ICNIRP Guidelines' Exposure Assessment Method for 5G Millimetre Wave Radiation May Trigger Adverse Effects, *Int J Environ Res Public Health*, **2023**; 20(7); pp. 5267.
23. Ishai, P.B., Davis, D., Taylor, H. and Birnbaum, L. Problems in evaluating the health impacts of radio frequency radiation, *Environmental Research*, **2024**; 243; pp. 115038.
24. Lim, H., Choi, J., Joo, H., Ha, M. Exposures to radio-frequency electromagnetic fields and their impacts on children's health – What the science knows? *Current Opinion in Environmental Science & Health*, **2023**; 32; pp. 100456.
25. Nyberg, R., McCredden, J. and Hardell, L. The European Union assessments of radiofrequency radiation health risks – another hard nut to crack (Review). *Reviews on Environmental Health*, **2023**; pp. 1-13.
26. Wang, X., Zhou, G., Lin, J., Qin, T., Du, J., Guo, L., Lai, P., Jing, Y., Zhang, Z., Zhou Y. & Ding, G. Effects of radiofrequency field from 5G communication on fecal microbiome and metabolome profiles in mice, Sci. Rep., **2024**; 14; pp. 3571.
27. Hardell, L. and Carlberg, M. Health risks from radiofrequency radiation, including 5G, should be assessed by experts with no conflicts of interest. *Oncology Letters*, **2020**; 20; pp. 1-11.
28. By Reuters, False claim: Pictures link bird deaths to new 5G mast in the Netherlands. Available at https://www.reuters.com/article/idUSKCN22A3BW/. (accessed on 12 May 2024).
29. Disinformation: Sparrows in PG didn't die because of 5G technology. Available at https://dfc.me/en/disinformation-sparrows-in-pg-didnt-die-because-of-5g-technology/. (accessed on 25 May 2024).
30. Steve Rousseau, Science, No, 5G Radio Waves Do Not Kill Birds. Available at https://www.audubon.org/news/no-5g-radio-waves-do-not-kill-birds. (accessed on 29 May 2024).
31. Shaji George, A. and Hovan George A.S. Exploring the Potential Threats of 5G on Bird Populations: An Ecological Analysis, *Partners Universal International Research Journal*, **2023**; 2(2); pp. 45-67.

32. Eskandani, R. and Zibaii, M.I. Unveiling the biological effects of radio-frequency and extremely-low frequency electromagnetic fields on the central nervous system performance", *BioImpacts,* **2023**; 14(4); pp. 30064.
33. Bailey, W.H., Cotts B.R.T. and Dopart, P.J. Wireless 5G Radiofrequency Technology — An Overview of Small Cell Exposures, Standards and Science, in *IEEE Access*, **2020**; 8; pp. 1-7.
34. Ajibare, A., Oladejo, S.O., Ekwe, S.O., Akinyemi L.A. and Ramotsoela, D. Radiofrequency electromagnetic radiation exposure assessment, analysis, computation, and minimization technique in 5G networks: A perspective on QoS trade-offs", in *SAIEE Africa Research Journal*, **2023**; 114(4); pp. 114-127.
35. WaveControls SMP2 Electromagnetic Field Meter Specification Datasheet. Available at https://www.raecorents.com/amfile/file/download/file/508/product/836/. (accessed on 10 June 2024).
36. Field Strength Meter for EMF exposure, SMP3 Field strength meter, Wavecontrol.com. Available at https://www.wavecontrol.com/rfsafety/images/data-sheets/en/SMP2_Datasheet_EN.pdf. (accessed on 1 July 2024).
37. Wavecontrol SMP2 Rent EMF Meter & Probes. Available at https://transientspecialists.com/products/wavecontrol-smp2-field-meter-rent-emf-measurement-equipment. (accessed on 2 July 2024).
38. ICNIRP GUIDELINES, FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC, MAGNETIC AND LECTROMAGNETIC FIELDS (UP TO 300 GHZ). Available at https://www.icnirp.org/cms/upload/publications/ICNIRPemfgdl.pdf. (accessed on 12 July 2024).
39. European Council recommendation 1999/519/EC of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz). *Off. J. Eur. Communities,* **1999**, L199, pp. 59–70.
40. International Commission on Non-Ionizing Radiation Protection (ICNIRP). ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz). *Health Physics*, **1998**; 74(4); pp. 494-522.