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Experimental investigation to analyze the electromagnetic radiation exposure from wireless communication devices☆

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ABSTRACT

Recent advancements in wireless communication technologies have led to the existence of a higher amount of electromagnetic radiation (EMR) in the atmosphere. The intensity of these exposed radiation depends upon the frequency of operation from these communication devices. The paper presents a scientific study on assessing the intensity of electromagnetic waves emitted by different wireless communication devices with human beings based on analyzing the electric field, magnetic field and power density generated from various electronic gadgets and wireless communication devices like smartwatch, laptop, mobile phone, nano-station, headset and mobile towers using an electro-smog meter (Electromagnetic Field (EMF) Meter - PCE-EM 29). The interaction is being studied by placing different wireless communication equipment near to human body. Based on the study, it is identified that a portion of the EMR is absorbed by nearby human beings and is identified by differentiating the field characteristics with and without its presence and is tested in near or far away from the devices. From the test results, it is identified that a portion of the EMR is absorbed by the body parts of the human beings near to the wireless device. This result could act as scientific evidence providing the effects of EMR interactions like electromagnetic hypersensitivity symptoms on humans. Similarly, most of the field exposures from the radiating devices are highly influenced by all the biotic community including human beings based on its interaction. All these field exposures to radiation from various wireless communication devices are direct indications of the Specific Absorption Rate (SAR).

1. Introduction

In the present world, the number of wireless communication devices are increasing day by day. As the number of these devices increases, the amount of EMR emitted to the environment is also increasing. When the excess amount of these electromagnetic radiation creates pollution to the environment. Radiation pollution is highly influenced by the emission of EMR from different wireless communication systems (Zhang, 2016; Zhang et al., 2018; Dhami, 2012). Antennas and related RF components present in the communication and health care systems are the major source of radiation emission (Meenu et al., 2017b; Jayakumar et al., 2021; Cousik et al., 2015; Mekaladevi et al., 2021). Based upon the applications, the performance and the configuration of the antennas used in the wireless communication devices varies (Meenu et al., 2017a,c). The intensity of radiation emitted varies from lower to higher frequency ranges (Sironi et al., 2021; Gholami and Bahari, 2021). The influence of non-ionizing radiation highly leads to the radiation pollution and other subsequent issues. The electric and magnetic field distribution over the entire system should be characterized based on these antenna configurations (Mohammed et al., 2022; Barotte, 2021; Frank, 2021). Thus the amount of the electromagnetic energy that is emitted from these systems changes. This effect is reported to all the living creatures in the environment including human beings (Sivani and Sudarsanam, 2012; Kumar et al., 2021; Impens and Salomaa, 2021; Higley et al., 2021; Meenu et al., 2022). The impact of EMR on the constituents of the ecosystem depends on the physical and electrical characteristics of the particular organism and also the interactions of it with the environment. The variation in the environmental parameters

☆ In this paper, we report a scientific experimental investigation by analyzing the intensity of electromagnetic radiation (EMR) from wireless communication devices on human beings. The experimental results provide an idea about the amount of EMR (E and H fields) that gets absorbed by the human body, which leads to electromagnetic hypersensitivity syndrome in human beings.

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based on the influence of the EMR creates biological issues on living creatures (Voloshyn et al., 2021; Liu et al., 2021; Gautam et al., 2022).

Even if human beings and animals are continually exposed to EMR, it is very difficult to analyze the internal effects on them due to the absorption of EMR. The effects will differ when exposed with different electromagnetic sources and also depends on frequency, modulation methods, SAR specification and exposure time. Variation in the SAR value causes heating of tissues resulting in changes in different species based on the absorption rate. Exposure to low levels of EMR creates electromagnetic hypersensitivity in human beings (Traini et al., 2023). The reported symptoms are headaches, body pain, lethargy, tinnitus (ringing in the ear), nausea, burning sensation, heart arrhythmia and anxiety (Kiziloğlu et al., 2023). These symptoms may differ from individual to individual. These exposure also results in oxidative stress in tissues of the human body. The damage in these tissues is based on the thermal and the non-thermal effects. Thermal effects are based on the rise in the body temperature and thereby creates changes in blood circulation. The non thermal mechanisms result in the production of free radicals in tissues (Benfedala et al., 2023). Along with these, other reported symptoms are chromosomal instability, degeneration in the transitional epithelium, stromal irregularity in bladder tissue, alteration of gene expression, gene mutations, neuropsychiatric effect, abnormal gene formation and can even lead to cancer. These effects are occurring to the human being based on the frequency of the radiation, exposure time and human body characteristics. Advancement and automation in the existing technologies are leading to the development and enhancement in the usage of the wireless communication devices in the institution, industries, hospitals and multinational companies. In these places, the working personnel are in direct or indirect interactions with these wireless communication devices. So they interfere with EMR emitted from these devices. The intensity of exposure may vary based on the specification and frequency of operation of these devices. Also, the influence of EMR on human beings varies based on the specific absorption rate of each person. So the amount of electric and magnetic field distribution and its absorption by human beings are analyzed and based on that the scientific evidence on the hazards of the EMR can be identified. Other than these theoretical concepts and experimental research, studies related to the field exposure from different communication devices are limited. According to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2020 report (Kavet and Tell, 2023), some guidelines are provided for limiting the exposure of EMR against the substantiated health effects for continuous long and short term exposure. The threshold value for limiting the exposure could not be explicitly provided by the generic scenario. It can be made possible only by considering the exposure situations and populations more in conservative manner. These conservative measures typically involve the biological variability, environmental conditions, variability in baseline conditions like tissue temperature, dosimetric uncertainty associated with health science and deriving exposure value. The ICNIRP categories the study group to the occupationally exposed individuals and general public, where the exposure analysis in this article is focused on the general public.

In an academic premise, all the community should have been involved in different activities related to their role in that organization. They have worked over the period of instructed hour which they are focused in the activities related to academics, research and related experimentation etc. After the working hours, they had shown some electromagnetic hypersensitivity syndrome. This motivated us to investigate the influence of each wireless communication device which they continuously interacted with during their working hours. In this research article, a detailed analysis on the exposure of the EMR from different communication devices like mobile phone, laptops, router, smart watches, bluetooth headsets etc. are studied at various scenarios of the usage of the devices in the academic sector. It helps in identifying the amount of field that is being emitted from the communication devices. Finding out the scientific evidence confirming the interaction between EMR and the living community including human beings is one of the promising problems that has to be addressed in this article. This evidence can be identified only by conducting different experimental studies and analyzing those results. For that, there should be a clear understanding about the source of EMR from the available wireless communication devices and the parameters that depend on the variation in the characteristics of these sources. Apart from these, the structural characteristics of the source and field exposure from these devices should be analyzed in the different test environments. For the analysis, the absorption of the field that is emitted from the devices on the living community is being measured using test equipment. This research article is structured as follows. Section 2 describes the characteristics of the wireless communication devices, peculiarities of antennas in these devices and the significance of the structural variation of the antenna and its performance. Section 3 details the EMR exposure from the communication devices and the methodology to identify the field characteristics from different communication devices based on different operational scenarios using electrosmog meter/ triaxial meter. Section 4 describes the interpretation of the field exposure by analyzing field characteristics and power intensity of each device. Section 5 indicates the result and discussion of the methodology validation and experimental analysis.

2. Antennas: Key element of wireless communication devices

Wireless communication devices are communicating among each other without the involvement of any physical medium. So without the existence of any physical medium, the transmission and the reception of signals are established with the help of antennas. These antennas exist in both the transmitter and the reception session of the communication systems. Antennas help in converting the electrical signal to the electromagnetic waves. These waves propagate to free space and exist in the environment. It consists of the varying E field and H-field in mutually perpendicular directions. These fields are also perpendicular to propagation of EM waves. Field distribution of these systems are varied based on the existence of different antenna configurations. Based on the application of each device, the size of the antenna systems are varied. Planar inverted F antenna, Microstrip antenna, Coplanar waveguide fed loop antenna, spiral antenna, planar monopole antenna etc. are the different planar antenna configurations that exist in the handheld devices. But in other related wireless communication systems like cellular base stations are using omnidirectional and directional antennas. Dipole antennas are commonly used for omni directional functionality whereas directional patterns are achieved by the involvement of circular and rectangular type horn antennas, different antenna arrays like yagi-uda antenna and patch antenna array. Along with these, the technologies used in wireless communication devices are also varied from one application to another based on the component size, source and various other features.

3. Methodology - Interaction of electromagnetic radiation on human beings

Electromagnetic radiation is defined in terms of the field that exists while propagating over the medium. The basic qualities involved in the electromagnetic field are power density ‘S’, Electric field strength ‘E’ and Magnetic field strength ‘H’. Power density ‘S’ is the measure of radiation density over an area. The strength of electric and magnetic fields represents the number of field lines that exist within the area under study. While propagating these EM waves, it interacts with each and every object in the space. Based on this, the wave reflection, refraction, interference, attenuation, absorption and scattering occurs. The characteristics of the wave are identified by analyzing the propagated EM wave characteristics. So the intensity of propagation is identified based on analyzing the resulting waves or identifying the changes in the field parameters while propagating over the medium. Propagation

of EM waves is accomplished by the transport of energy. Amount of emitted energy is based on the frequency of the waves. The distribution of EM waves on each component depends on the electrical properties (specific conductivity, dielectric constant) and the magnetic properties (magnetic permeability) of the components. Propagation of the waves is associated with a specific amount of energy. The energy of the EM waves is based on the equivalent amount of individual photons. The combination of these individual photons together constitutes and is referred to as EM radiation. When EM waves propagate, the resulting energy is transferred to all the components that exist in the environment. The intensity of electromagnetic fields in each of the biological systems is based on the distribution of the field inside each component. It is categorized based on the conductivity, dielectric permittivity and the permeability of each of the living components which is dependent on its electric and magnetic properties. The distribution of the electromagnetic radiation over each component is determined based on the energy transmission, chemical composition and the geometry of the physical structures. This physical distribution leads to biological effects on living tissues due to the exposure of the electromagnetic fields. These biological effects can lead to certain diseases or hypersensitive disorders (Electromagnetic Hypersensitivity). Amount of energy that is being absorbed by the living component is based on the specific absorption rate (SAR). The SAR is related to field distribution through Eq. (1) (El Amrani et al., 2020).

$$SAR = \frac{\sigma|E^2|}{\rho} \tag{1}$$

where, σ = Conductivity of tissue ρ = Mass density of tissue E = Electric field

The composition of SAR value of the entire human body of any living creature is complex as it depends on the different parameters like metabolism, blood perfusion etc. So the distribution of EMF on the human body is based on the amount of energy that is being radiated by different wireless communication devices. This electromagnetic radiation interacts with the human body based on the absorption rate. The amount of EMR absorption is categorized depending upon the penetration depth. Based on the experimental studies in literature, it can be identified that a certain amount of the original EMF penetrates below the surface of the tissue and the remaining energy penetrates into the deeper parts of the human body. The energy absorbed mainly depends upon the operating frequency, material properties and water content within the tissues. At 2.45 GHz, the penetration depth is 1.7 cm through muscle, skin and tissues with high water content and is 11.2 cm for fat, bone and tissues with low water content (Johnson and Guy, 1972). The microwave power reduces by a factor of $1/e^2$ ($\approx$ 0.14) when penetrates through the body due to the absorption by the tissues. Based on these experimental studies, it can be identified that 1/7th ($\approx$ 0.14) of the original EMF penetrates below the surface of the tissue and the remaining penetrates deeper into the human body and most of the energy is absorbed by the muscles based on the water content (Johnson and Guy, 1972; Verma et al., 2023). So, on the basis of different study results and on analyzing the scientific evidence, the experimentation for analyzing the EMR from different wireless communication devices in the academic premises, which is a real world environment and not a controlled environment is performed using an electrosmog meter for finding out the intensity between EMR from wireless communication devices and human beings. Experimentation is performed using an electrosmog meter (PCE - EM29) which is able to capture the E field, H field and power density analysis at 2.45 GHz. PCE - EM29 is a portable handheld electromagnetic detector of frequency ranging from 50 MHz to 3.5 GHz with spherical triaxial three-dimensional isotropic sensor used to measure electromagnetic fields (EMFs). This meter is able to detect the electromagnetic pollution generated from different EM sources operating within the frequency range from 50 MHz to 3.5 GHz. Device is calibrated within the frequency range and the selection of frequency is automatic when the experimentation is carried out. The resolution of the E field, H field and power density are 0.1 mV/m, 0.1 μgA/m and 0.01 μgW/m^2. The accuracy of the device depends upon frequency range. The E field and H field strength can be measured in near field and far field area of source, so the equipment works for both near and far fields. The obtained values of the field are instantaneous and the average value. It can be varied based on the orientation. Isotropic measurement can be obtained with three channel measurement sensors. Based on the experimentation, the exposure of EMR from different wireless communication devices operating at 2.45 GHz is analyzed. It is categorized based on the variation in electric field and magnetic field. In this research work, the influence of the field exposure from the communication devices like base station, nanostation loco M2, smart watch, mobile phone, laptop etc. are analyzed. Each device is categorized under different scenarios of operation. For the first scenario, the smart watch with different manufactures like boatstorm, amazefit and boat wireless headset are used. Bluetooth is used as the mode of communication. For scenario 2, the Linksys router and Ubiquity Nanostation M2 configured to 2.45 GHz. For scenario 3, Redmi android mobile phone with different mode of operations. For Scenario 4, Hp laptop with different technology are activated and operated with different modes and also placed in different parts of the human body. For scenario 5, mobile with wired/ wireless headset establishing call. The exposure is analyzed with different modes of operation. For scenario 6, analyze the exposure of the indoor and outdoor environment of the study area. Experimentation is carried out using an electrosmog meter on different operational conditions of each device where the electrosmog meter is placed 5 cm from the human body with the test area distribution of approximately 314.16 square cm. The time average value of E field, H field and the power density of each scenario are captured using the electrosmog meter by placing the equipment in the four different vertical/horizontal locations on individual/location under test for the selected scenarios. The interaction varies depending on the mode of operation, intensity, operating frequency, location and range where the exposure from devices exists. Each of the communication devices operates based on the application in different scenarios and interacts with the human body based on the mode of operation. The study on these specific devices based on its usage in the academic premises is studied in detail.

The distance from the human body to the selected devices are based on the usage of each device for the specific operation in the academic premises. For each of the scenarios, the location of the device from the human body varies from the close contact to far away distances. For scenario 1, bluetooth technology is monitored, where the smart watches and the bluetooth headset are in close contact with the human body. For scenario 2, the router as the source is monitored, where the router and the Ubiquity Nanostation M2 is placed 1 m from the selected location in the academic premics under test. For scenario 3, the mobile phone is monitored, where the mobile phone is closely contacted with different parts of the body like thigh, head and ear and is compared with field exposure of mobile phone which is located 10 cm from the human body. For scenario 4, a laptop connected with and without WiFi and Bluetooth is placed 10 cm apart from the human body whereas for the scenario where laptop is placed on the thighs, there comes close contact between the laptop and the human body. For Scenario 5, combinations of mobile phone with wired and wireless headset are monitored. In this scenario itself, when using the mobile phone with wired headset, it is placed 10 cm from the human body and in the case of using the wired/wireless headset there comes close contact. For Scenario 6, all the indoor wireless communication devices and base stations located in the outdoor environment are considered. For the indoor environment, the combinations of different wireless devices like Laptop, Router, Mobile Phone and Smartwatch are considered. In these cases the usage distance remains the same as that of the above mentioned scenarios. For the outdoor scenario, multiple base stations are located 650 m from the location under test, where the human beings are working. The exposure time of each device is based on

Table 1
Abbreviation for different operational scenarios.

Scenario category	Scenario	Scenario abbreviation
Scenario 1: Bluetooth	Boat Smart Watch	BSW
	Amazefit Smart Watch	ASW
	Bluetooth Headset	BH
Scenario 2: Router	Router	R
	Ubiquity Nanostation M2	UNM2
Scenario 3: Mobile Phone	Mobile Phone	MP
	Mobile Phone Ear Head Contact	MPEHC
	Mobile Phone Leg Thigh Contact	MPLHC
Scenario 4: Laptop	Laptop-WiFi Connected	LWC
	Laptop-WiFi Not Connected	LWNC
	Laptop-Bluetooth Connected	LBC
	Laptop-Bluetooth, WiFi Not Connected	LBWNC
	Laptop on Thighs	LT
Scenario 5: Mobile Phone with Wired/Wireless Headset	Call using Wired Headset - Mobile Phone	CWH-MP
	Call using Wired Headset - Ear Headset	CWH-EH
	Call using Bluetooth Headset - Mobile Phone	CBH-MP
	Call using Bluetooth Headset-Ear Headset	CBH-EH
Scenario 6: Indoor/Outdoor	Indoor - Laptop, Router, Mobile Phone and Smart watch	ILRMPSW
	Outdoor Base Station - Building Fifth Floor	OBSBFiF
	Outdoor Base Station - Building Fourth Floor	OBSBFoF

the scenario of operation. In scenario 1, watches are in continuous usage and bluetooth headset is used for communicating with phones for different purposes over a period of 10 min. In scenario 2, the router is in continuous use for the providing WiFi facility for the entire test location whereas the Ubiquity Nanostation M2 is exposed over the period of 8 h for specific research related experimentation in an indoor environment. In scenario 3, the mobile phone is in the active mode and it is placed closely in contact with different parts of the body like thigh, head and ear and exposed/used over the period of 10 min. In scenario 4, laptops having different modes of operation with Wi-Fi and bluetooth connected and placed on the thighs are used over the period of 10 min. In scenario 5, attending/making calls using the mobile phone with wired and wireless headset over the duration of 10 min. For scenario 6, both the indoor and outdoor exposure are continuous. The equipment used, electrosmog meter, can have the capability to measure the time average value of the observed parameters over the period of 1 - 2 min, as the value is stabilized over this specified time. As the observation and the time averaging of the equipment is considered as 1 - 2 min, all the parameters are captured in this specific time duration. The group of the individuals tested has a significant role in each operational scenario. The physical characteristics are based on the gender and have a significance in the absorption rate. In the location where the experimentation is performed, 80% of the working individuals are women and only 20% are men. The significance of the combined influence of women and men is considered only for scenario 2 and indoor, outdoor conditions in scenario 6. For all the other scenarios, the experimentation is performed within the specified field locations on the female candidate as they are more in number. In this experimentation, the gender is not considered for validation of the observations. Also, the female candidates had reported fatigue in the test location due to the exposure of EMR. The abbreviation of this in different operational scenarios are listed in Table 1 .

Based on the locality of the selected devices, the field orientation towards the human body is varied. In the case of the mobile phone, the field exists when the ongoing calls are active and placed nearer to the head contact and the thighs are analyzed. The analyzed field is characterized based on its placement nearer and far away from the human body. The field characteristics from the mobile phone are analyzed with and without the involvement of wireless and wired headset. It is characterized based on the field analysis nearer to the mobile phone and to the ear where the headset is connected. The field analysis is carried out for the laptop in which both the Wi-Fi and bluetooth are connected and not connected mode and comparing the field variation when placed on the thighs. Nearfield analysis of the smartwatches of different brands is carried out and is compared with the bluetooth connected headset. The electric and magnetic field characteristics of the router in its active mode in indoor room environments where more users are available. This mode of the operation of the router (Linksys) with a nanostation when it is in active mode is analyzed which is place at a distance of 1 m from the observed location. The field analysis in the indoor environment is monitored when the entire devices are active and are connected. This indoor analysis is compared with the outdoor environment field characteristics when the multiple base stations are located within a 650 m distance from the entire building and its effective field analysis is captured for the exposure variation study. Fig. 1 represents the different operational scenarios of the communication devices.

4. Analysis and interpretation

The electric field E (mV/m), Magnetic field H (μ A/m) and power density (μ W/m^2) from the different wireless communication devices are analyzed using an electrosmog meter. This testing is carried out on different modes of operation of wireless communication devices in contact with the human beings in academic premises. Before the experimentation, the field characteristics of the selected area under study is performed using electrosmog meter. The field captured with the influence of the human being is normalized with respect to the pre-experimental field values. So, the obtained results are based on the exposure from selected devices. The analyzed fields are categorized based on fields that exist in the test environment with and without the involvement of the humans. Due to the involvement of the human being or any other biotic components present in the test environment, the

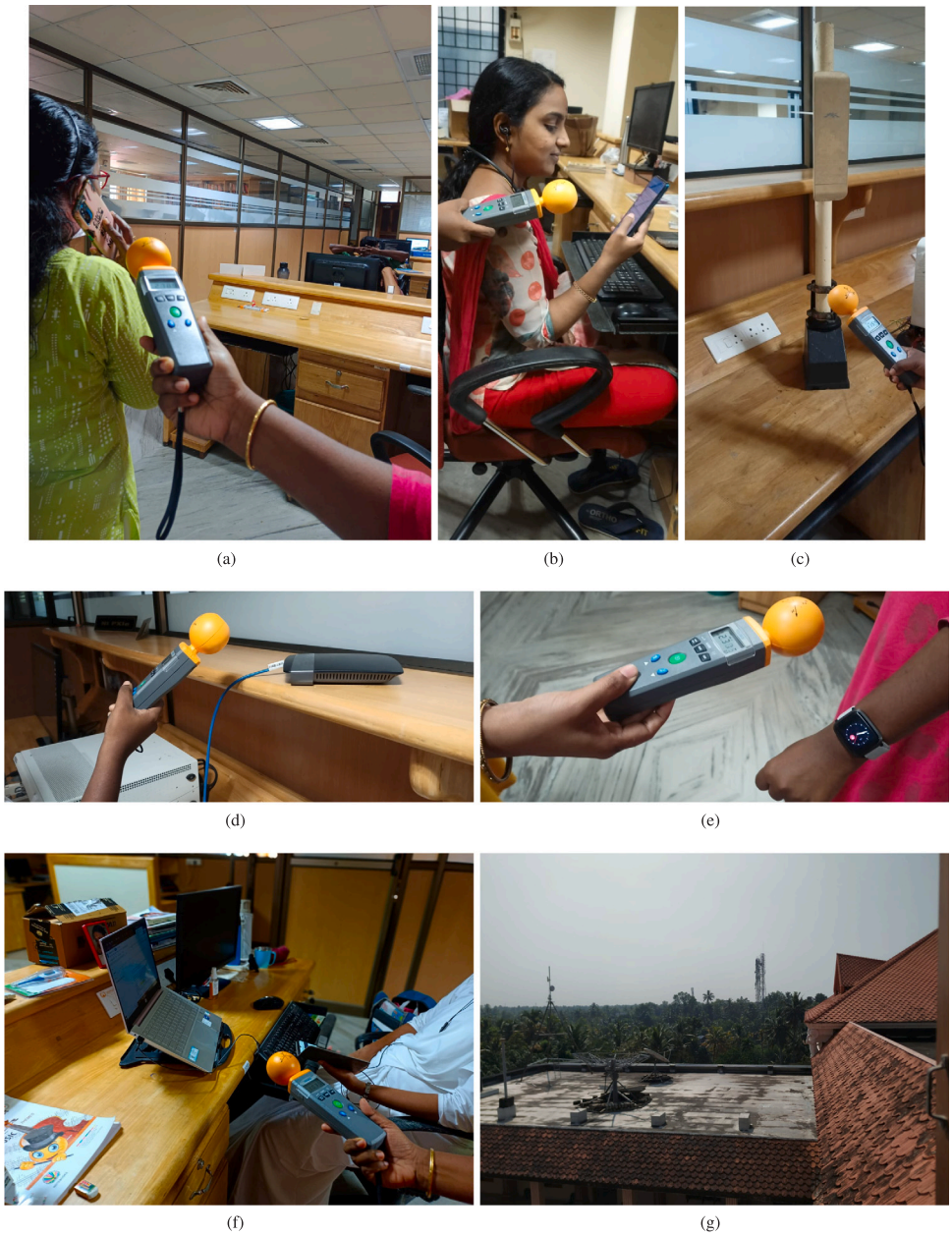

Fig. 1. Experimental trials measuring electric field, magnetic field and power density using electrosmog meter of : (a) Mobile phone (b) Wireless headset & Mobile phone (c) M2 Ubiquiti Nanostation (d) Router (e) Smart Watch (f) Headset and laptop (g) Base station.

analyzed field is the field that exists in the environment after being absorbed by the biotic body. SAR is the measure of the amount of the EMR that is absorbed per unit mass of the tissue. It is directly proportional to the field characteristics of each device when it is in the active mode. So, when the human body is involved, some amount of the EMR is absorbed and the remaining amount is only captured by using the electrosmog meter. The operation of the smartwatch and the headset with bluetooth technology creates a specific amount of field to the nearby region. Smartphones which are in direct contact with the human body leads to a high amount of absorption onto the fleshy surface and thereby results in the limited amount of field that exists in the surrounding region. This result is then compared to the results of absorption by using headset nearer to the head region of the human body. Amount of absorption depends on the characteristics of human body parts. This amount depends on the intensity of the field that exists on the nearby region of the test devices and is represented in Fig. 2. The field exposure from the router is characterized based on the location of the router and where the experiments are carried out. Routers exist on the corner of the room. So the amount of the field on a specified region is higher when it is placed at a longer distance from the human body and is represented in Fig. 3. Radiation effects from the mobile phone are categorized based on its position of exposure to radiation. Field measurements are taken when the mobile phones are nearer to the body organs like head, thighs etc. and compared with the fields generated from mobile phones that are not in contact with the human body. The field characteristics are less in the nearby region where the mobile phone is closer to the ear using the electrosmog meter as represented in Fig. 4. It is due to the higher amount of absorption by the human body. But the absorption on the thighs is less as the amount of the field present in the environment is higher when compared with other two cases. Similarly in the case of the laptop, the field characteristics are very limited in the nearby region because it has close contact to the skin, where the emitted amount of field is absorbed and the remaining amount only exists on the region under

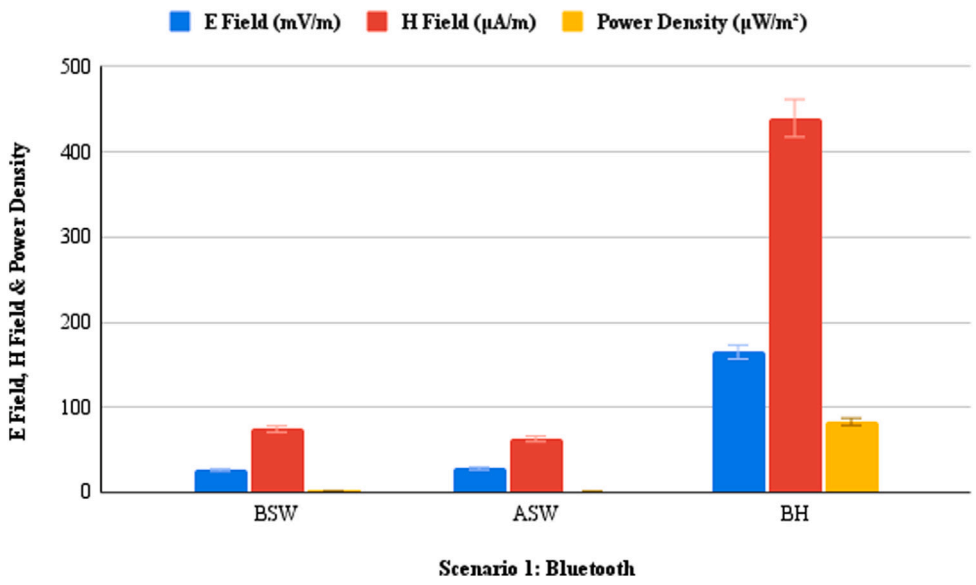

Fig. 2. Variation of Electric field, Magnetic field and Power density for different scenarios of using Bluetooth.

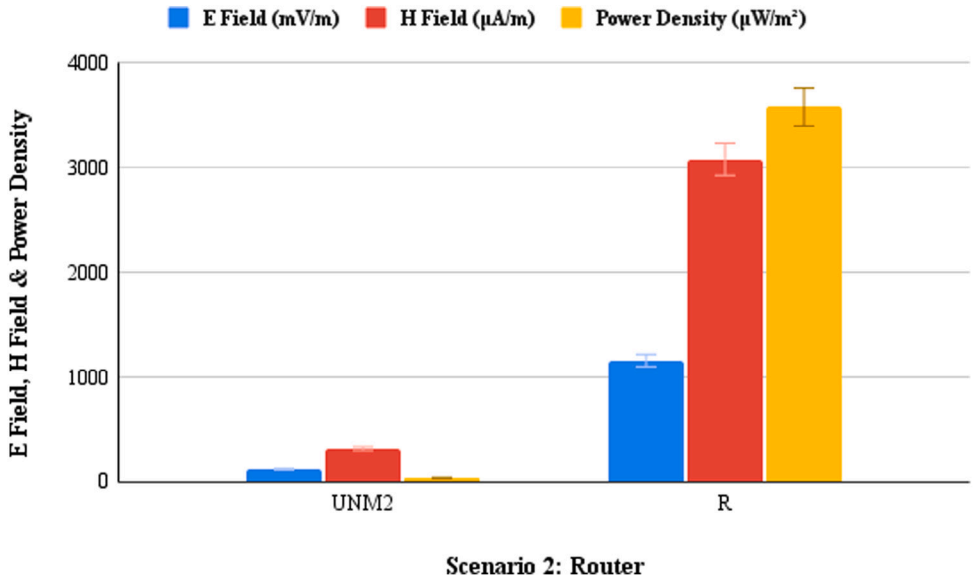

Fig. 3. Variation of Electric field, Magnetic field and Power density for different scenarios of using Router.

test as represented in Fig. 5. When the mobile phone is in active mode all the operation are carried out using the wired and wireless headset. Analysis is performed by measuring the field, using the measuring device electrosmog meter. This measuring device is placed nearer to the headset/ear and the mobile phone is represented in Fig. 6. From these results, it is clear that the wireless and wired headset have variation in the field emission and power intensity and have varying influence on the body. The analysis is carried both in the indoor and outdoor environment where all the communication devices are in active mode and is connected to the wireless network. By the influence of the individuals inside, the field is less in nearby regions and others have a significant role in the absorption. This indoor analysis is compared with the outdoor analysis where the field emitted from the base station is represented in Fig. 7. The cumulative amount of field exists in the academic premises where the multiple base stations are located at equal angular distance. The comparison on the existence of the field and power density in the different floors of the building are being analyzed. This variation is dependent on the absorption of the green environment (vegetation) in the nearby region. The values that are reported in the graph in each scenario is the averaged normalized value of the field exposure at different orientations of the specific scenario of operation. The reproducibility of the experimentation is possible in the different/same location based on the experimentation reported in the methodology section. But if we repeat the experiments in the same location, the observations might not be the same as reported, as the absorption rate depends on the physical and morphological characteristics of the individuals present in the test location. These characteristics of the individuals are not the same as on the day at which the experimentation are performed. So the reported observations are not comparable with any of the experimentation results, if the same experiments are repeated in the test location itself.

In all the above mentioned scenarios the field distributions and power density measured using electrosmog meter are different. This variation in the characteristics are represented in a graphical format depending on the changes in the electric and magnetic fields and power intensity for each operational scenario. The represented field and power density are the measure of specific characteristics that exists in the measured environments. The living things including human beings present

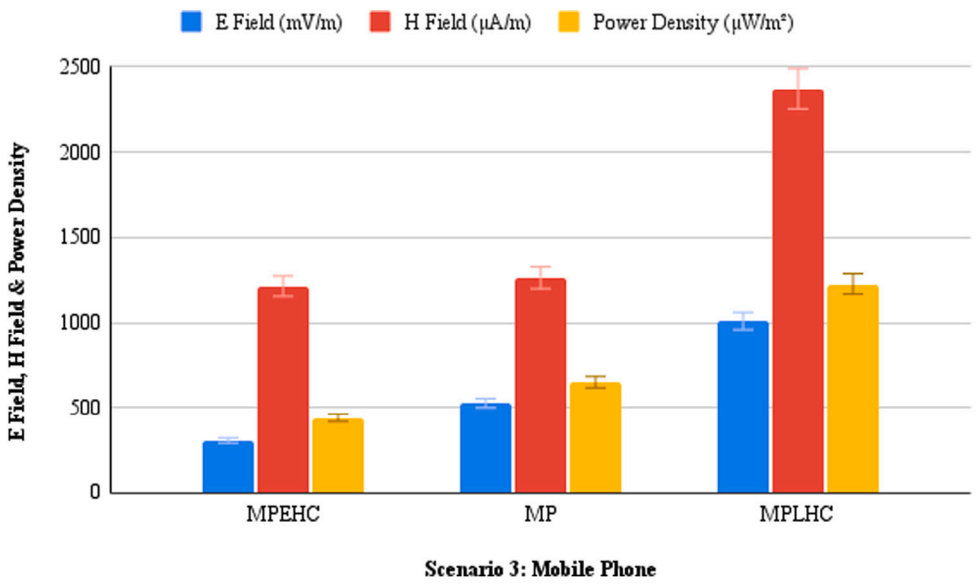

Fig. 4. Variation of Electric field, Magnetic field and Power density for different scenarios of using Mobile Phone.

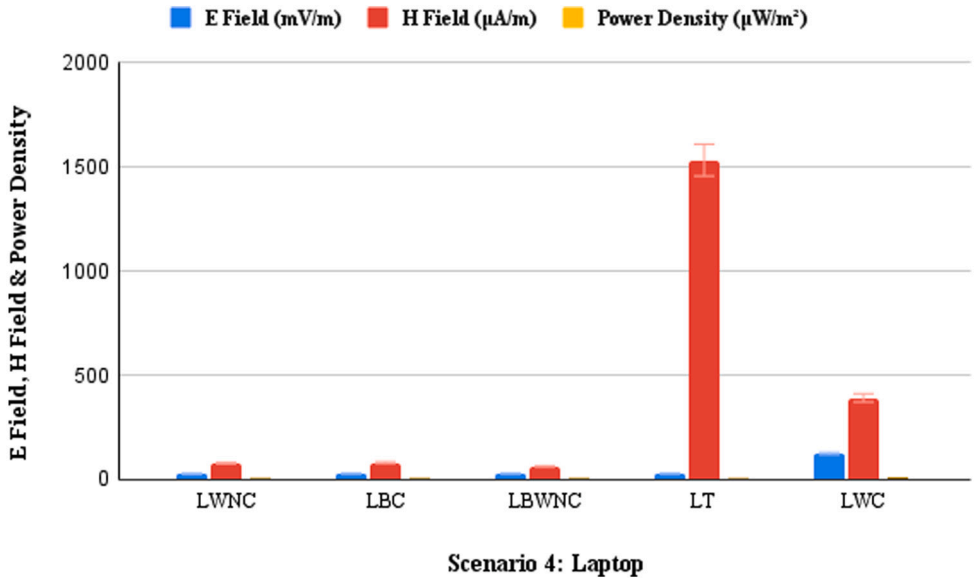

Fig. 5. Variation of Electric field, Magnetic field and Power density for different scenarios of using Laptop.

in the nearby environment will absorb a certain amount of emitted radiation depending upon the material composition. The remaining field that exists in the environment is measured using the triaxial meter. On comparing the results of field intensity with and without the intervention of human beings, the amount of EMR that is absorbed by the human body can be calculated. From the results, significant absorption of radiation by the human body could be confirmed. This is clear evidence of the absorption of EMR on the human being.

5. Results and discussion

Electromagnetic radiation from different wireless communication devices are the source of radiation pollution. This radiation is based on the field characteristics of EMR that is emitted from the devices. It is characterized based on the analysis of electric field, magnetic field and power density. The exposure from the devices are varied based on the frequency of operating technology and the intensity of radiation. For analyzing the effects of radiation on living things, the field that is emitted from different wireless communication devices are analyzed with and without exposing radiation on to living things. For this, the field exposure from each of these devices is analyzed using an electrosmog meter. The field exposure varies from device to device and is different for different scenarios of operation. When it is in close contact with the human body, the amount of radiation that exists in the environment is less. So, the amount of absorption on the human body is based on the rate at which the field variation exists in the nearby region. Based on these, the analysis of all the devices are characterized and the exposure is analyzed. Sometimes, the cumulative amount of field is also captured by the electrosmog meter in the indoor and outdoor area under test. The amount of field is analyzed when the smart watch is in contact with the hand and is compared with the field of the bluetooth headset. The field characteristics are measured when the selected device is operational. The field characteristics vary for each device based on the field of the exposure on specific time span. The field from the mobile phone is categorized based on its mode of operation and the variation in the occurrence of field when the active mobile phone is placed nearer to the head and thighs of

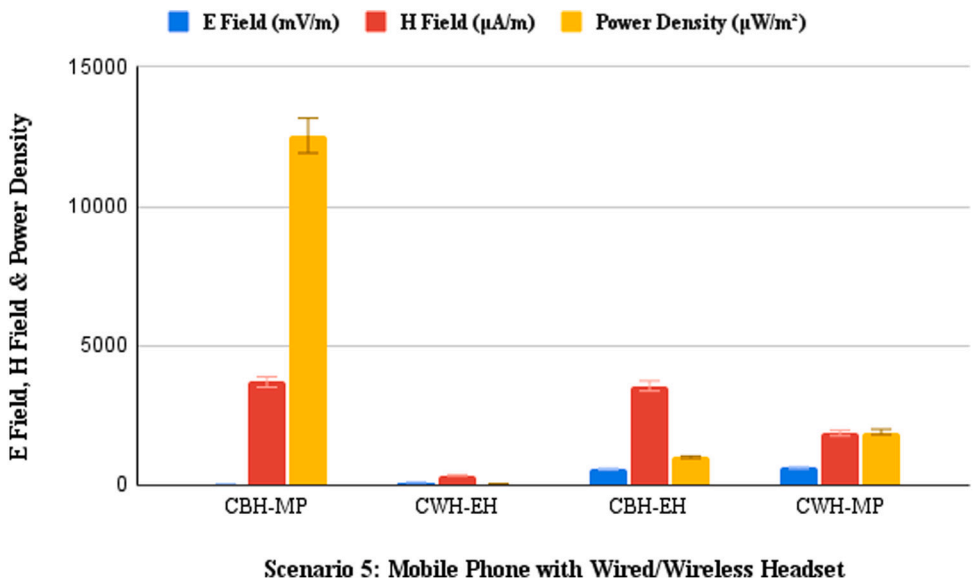

Fig. 6. Variation of Electric field, Magnetic field and Power density for different scenarios of using Wired and Wireless Headset.

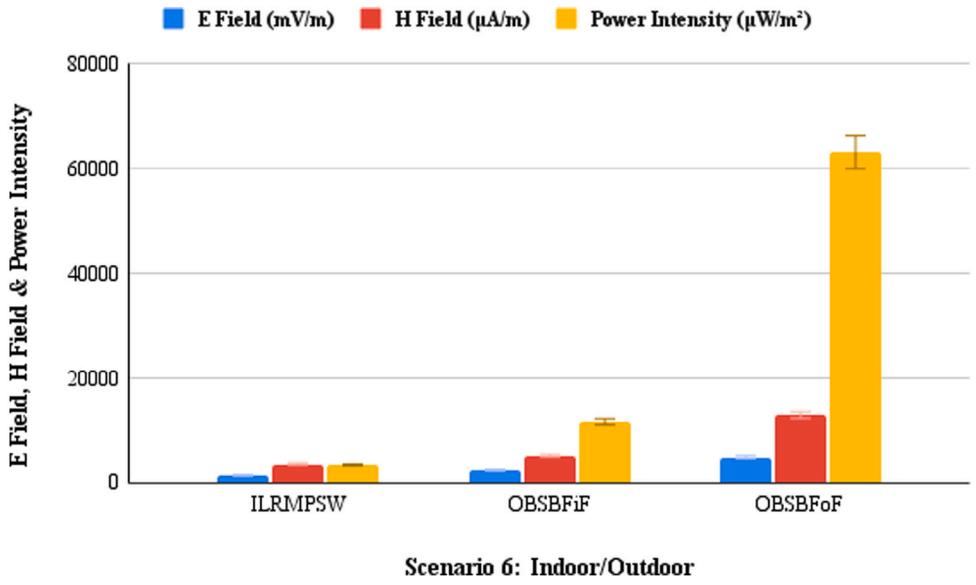

Fig. 7. Variation of electric field, magnetic field and power density for different scenarios of indoor and outdoor experiments.

the body. The comparison in the field is based on the variation in the field that occurred at the location nearer to head and the thighs. The relatively higher amount of absorption happens when the mobile phone is placed near to the head region. The variation in the field is also analyzed for the case of router, laptops and the base station. So, from this it is identified that the field that is emitted from the devices is highly influenced by the absorption of the human body where it is placed nearer to it. The values of E field, H field and power density captured nearer to the human being is relatively less when compared with the guideline of exposure of electromagnetic radiation provided by International Commission on Non-Ionizing Radiation Protection (ICNIRP) (International Commission on Non-Ionizing Radiation Protection et al., 2020). As per the guidelines, the threshold value of E field, H field and power density for the general public are 100 V/m, 1.2 A/m, and 80 W/m^2, whereas, all the measurement values at 5 cm from human beings in this work are in the range of mV/m, μA/m and μW/m^2. One of the reasons for this reduced values of E field, H field and power density could be due to the absorption of EMR by human beings in the test area.

The absorption of EMR is based on the composition of the human body. The oscillating E field and H field that exist in the EMR are the key parameters that interact with the body. This is based on the interactions of EMR with the atoms and molecules that exist in the specified body. When the human body is exposed to EMR, some amount of power is reflected and remaining is absorbed by the body based on its physical properties and the dimensions of the whole body. The influence of this induces an E field inside the body where this induced E field exerts the force in polar molecules and free charged particles. As the result of the movement of polar molecules and charged particles, the field energy is converted to the kinetic energy. This generated kinetic energy is further converted to heat by the interactions of these molecules and particles with other polar molecules and charged particles. As the frequency of the field varies from lower to higher, the induced E field creates nerve stimulation as well as the dielectric breakdown of biological membranes. These interactions can trigger the excitable cells within the human body, which could in turn generate action potentials and may result in rigorous reactions within the body. These changes may not be noticed if the exposure time is less. But

as the exposure time as well as the intensity of exposure increases, observable changes could be noticed. The impact produced by these interactions of EMR is not predictable and depends on the intensity of the stimulus from the field and the power density towards the human body. It varies depending on the exposure time at the specific frequency and penetration based on the physical and the morphological properties of the human body (Adey, 1981, 1993; Cifra et al., 2011; Hossmann and Hermann, 2003).

This study provides scientific evidence for the reason behind electromagnetic hypersensitivity symptoms occurring in an occupational group of individuals when using wireless devices for long duration and when conducting antenna testing and measurements without an anechoic environment. These groups of people have shown the symptoms with higher sensitivity than that of the general public which is beyond the far field of the study.

6. Conclusion

The work is initiated with the background study on the effects of electromagnetic fields on human beings. Even though most of the wireless communication gadgets are inevitable in the present living environment, high intensity EMR or the electric and magnetic fields are generated from these gadgets, which is acting as a pollutant to the environment. An investigation of these non ionizing electromagnetic fields generated from wireless communication gadgets (smartwatch, laptop, mobile phone, nanostation, headset and mobile towers) are carried out using the radiation measuring equipment electrosmog meter. On analyzing the electric field, magnetic field and power density with and without the influence of human intervention, the amount of EMR that is absorbed by the human body can be calculated. As per literature and from the current studies, it is clear that the absorption of these EMR is creating physical, mental or biological changes to the person near to the EMR source. The experimental investigation presented in this paper could act as scientific evidence for the reason behind electromagnetic hypersensitivity reactions within the human body when exposed to EMR. Even though the evidence confirming the influence of EMR on Specific Absorption Rate (SAR) on the living things is less, the damage created by its influence is not repayable. So further studies have to be done in the area for providing stronger scientific proofs for confirming the impact of EMR on living things and need to propose solutions for reducing the effects of EMF exposure.

CRediT authorship contribution statement

Meenu L.: Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Aiswarya S.:** Writing – review & editing, Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **K.A. Unnikrishna Menon:** Writing – review & editing, Validation, Resources, Methodology, Investigation, Conceptualization. **Sreedevi K. Menon:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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