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Case Study

Comparative analysis of electromagnetic field exposure in a higher educational institution: a study before and after the COVID-19 pandemic

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Abstract

The advancement and improvement of telecommunication technology has created worries about the effects of electromagnetic (EM) radiation on biotic systems. The COVID-19 pandemic has made extensive use of smartphones and other technologies that were both essential and unavoidable. In addition, this has resulted in humans being exposed to excessive microwave radiation from smartphones, particularly youngsters who have early access to these devices. In higher educational institutes, such as the Dayalbagh Educational Institute, the dependency on wireless communication has increased during the pandemic. In this work, we used SRM-3006 to evaluate the electric field, magnetic field, and power density for broad public exposure and compared the results to ICNIRP and FCC safety standards. Results of the measurements taken in the year 2023 have been compared with those of the pre-COVID measurements recorded in 2019, and their analysis has been performed. The findings indicate a significant increase in radiation levels in the post-COVID-19 scenario.

Keywords Electromagnetic spectrum · Radiation exposure · COVID-19 · SRM-3006

1 Introduction

Smartphones have become an indispensable element of daily life for most people. The frequency of the radiation used for communication has increased as mobile communication has developed from 1 to 5G. The communication frequency of mobile phones ranges from 900 MHz to 2.5 GHz [1]. With the rapid growth of information technology, more and more electronic devices/gadgets are produced, and the electromagnetic radiation of electronic devices/gadgets is receiving more and more aid in this modern era of technology. Over the past ten years, there has been a rapid increase in mobile phone users around the world, prompting widespread worry about the harmful effects of electromagnetic radiation emitted by cell phones on health. In India, there are around 80 crore cell phone customers and 4.5 lakh cell phone towers established to offer communication [2]. However, the speedy and universal adoption of this technology has raised concerns about potential negative health consequences. Sources of radio-frequency electromagnetic fields are expanding at an exponential rate to make human life more comfortable. Radio broadcasting, BTS, television transmitters, mobile handsets, microwave, and so on are some examples [3]. Mobile phones are the most commonly used of these sources [4]. The most common wireless systems include FM radio, television broadcast stations, mobile and cellular phones,

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radar, and microwave systems. The electromagnetic (EM) spectrum covers a broad spectrum of electromagnetic waves, including Infrared (IR) light, Visible Light, Ultraviolet (UV) light, X-rays, and Gamma rays, with frequencies ranging from Extremely Low Frequency (ELF/VLF) to Radio Frequency (RF) and Microwaves [5]. GSM/CDMA phones use frequencies ranging from 900 to 1900 megahertz (MHz). The energy from these rays is absorbed by the human body, causing biological tissues to distort. This increase in tissue temperature has the potential to affect one's health and capacity to function normally [4, 6–8]. The influence of mobile phone radiation on human health is a source of great concern due to the rapid expansion of mobile phone users around the world. Over the last two decades, numerous research has been conducted to determine the health concerns presented by mobile phone radiation [9, 10]. Despite numerous research, information on the harmful effects of radiofrequency and microwave radiation on human health, as well as biological reactions to their exposure, remains restricted [11, 12].

Both thermal and non-thermal effects of electromagnetic radiation exposure have been extensively studied due to their potential biological impact on human health. Thermal effects occur when absorbed energy raises tissue temperature, causing cellular damage through protein denaturation and membrane changes, with higher SAR values increasing this risk [13, 14]. Non-thermal effects, occurring at lower energy levels, involve interactions with cellular membranes and ion channels, leading to altered cell signalling and oxidative stress [15, 16]. The thermal effects of high-frequency (HF) electromagnetic radiations have been suggested by international organizations such as ICNIRP, FCC, IEEE, and the World Health Organization (WHO) [17–21]. As a result of the thermal impacts of HF radiations, our body temperature rises, potentially affecting our stomach, pancreas, liver, eyes, brain, and heart [13, 21–24]. Non-thermal effects are also caused by RF radiation over a long period, regardless of whether the amplitude of the radiation is below or equivalent to international guidelines [25, 26].

In this paper, we have raised the concern of high exposure to EM radiation in human lives. The unavoidability of digital technology and wireless communication can be seen in pre and post COVID-19 scenarios. In the aftermath of the COVID-19 outbreak, it's critical to understand people's perspectives on their reliance on digital technology and how they're dealing with it. In the following section, we have discussed the pros and cons of virtual education among students. As a result, children's long-term exposure to mobile microwaves during e-learning during COVID-19 is a significant and indirect corona health risk that parents, health policymakers, and governments should consider. In the third section, ICNIRP and Government of India guidelines and limitations for general public exposure have been discussed. Then the following section describes the measuring instrument (SRM- 3006) description. The results and measurement section gives details of the investigation site, Dayalbagh Education Institute, Agra, Uttar Pradesh. A comparison has been shown based on pre-COVID and post-COVID-19 scenarios. The conclusion section summarises the findings and responds to the research issue of whether dependency on technology during lockdown has greater negative health consequences than during normal times.

2 Status of education during COVID-19 shutdown

The coronavirus outbreak affected schools and universities in India and around the world. In-person classes were replaced by online learning. In March 2020, the Indian government closed all schools and colleges and imposed a nationwide lockdown to control the spread of the virus. The University Grants Commission (UGC), along with the Ministry of Education, issued a notice recommending the use of Information Communication Technology (ICT) for teaching and learning [27]. As a result, people earn a living by working from home, teaching, and learning online, conducting online meetings, handling business, and processing transactions using their mobile phones. Online classes, webinars, seminars, and conferences have all benefited from software solutions like Zoom, Webex, Skype, Google Meet, GoTo Meeting, and others. Therefore, during the lockdown, mobile phones have become essential in everyone's life. To avoid boredom during the lockdown, some people spend long hours on their phones watching videos, playing games, or browsing social media, which can negatively affect healthy brain function [27–31]. Roy et al. [30] aimed to assess knowledge, attitude, anxiety experience, and perceived mental healthcare needs among adult Indians during the COVID-19 outbreak. An online survey used a method called snowball sampling and a semi-structured questionnaire. Sleep problems, concern of contracting COVID-19, and distress associated with social media were all noted by 12.5%, 37.8%, and 36.4% of those surveyed, respectively. More than 80% of those polled said they required mental health treatment.

During the current global crisis, virtual education and e-learning offer several benefits compared to traditional teaching methods. These include being more cost-effective, providing regular updates, offering flexibility in time and location, ensuring easy access to instructional materials, helping to navigate lockdown restrictions, and reducing shyness in students when asking questions and interacting [32, 33]. The transition to digital and remote learning happened swiftly, and by promoting social distancing, it helped enhance safety, comfort, and a sense of control while also reducing the spread of the coronavirus. In this context, the use of smartphones and tablets for e-learning became essential and unavoidable, leading to children being exposed to high levels of microwave radiation from mobile phones at an early age [34]. On the other hand, the necessity of using the Internet for social networks and virtual education exposes children to higher frequency microwave radiation. Since it is uncertain when the COVID-19 crisis will end and many virtual and e-learning systems may continue to be used, it is essential to create a scheduled health program to monitor children's health.

3 ICNIRP and Indian guidelines

Several international organizations, including the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the Federal Communications Commission (FCC), and the Institute of Electrical and Electronics Engineers (IEEE), are dedicated to establishing guidelines on electromagnetic radiation (EMR) exposure [35]. Electromagnetic radiation can be found in much different public and professional environments. It can constitute a significant health danger to the general public and workers if it is not properly regulated. The ICNIRP and the Indian government have established some guidelines and limitations for general public exposure as part of their objective to enhance non-ionizing radiation protection for the benefit of people and the environment [9, 19, 25].

Although India is a tropical country with hot and humid weather, the maximum radiated EMR that can be tolerated should be substantially lower than in colder nations [25]. The Indian government approved the adoption of ICNIRP guidelines for reducing electromagnetic field (EMF) exposures, which were tightened to 1/10th of the prescribed level [28]. According to the ICNIRP standards, Table 1 displays reference levels for several frequency bands.

4 Electromagnetic fields and their biological impacts: understanding specific absorption rate (SAR)

Electromagnetic (EM) fields are omnipresent in modern environments, originating from devices such as mobile phones, Wi-Fi routers, microwave ovens, and other electronic equipment. While these fields facilitate technological advancements, they also raise concerns about their potential effects on biological systems [36]. Research suggests that exposure to EM fields can lead to adverse impacts, which depend on several factors. The frequency of the EM field determines how it interacts with tissues, with radiofrequency waves penetrating deeper and higher-frequency waves primarily affecting surface tissues. The field strength significantly influences the extent of energy absorbed, with stronger fields leading to greater energy deposition. Prolonged exposure increases the cumulative energy absorbed by tissues, which may heighten potential risks. Additionally, the signal characteristics, such as whether the signal is continuous or pulsed, also affect the biological response.

The Specific Absorption Rate (SAR) is a key metric used to measure the rate at which electromagnetic energy is absorbed by biological tissues. Expressed in watts per kilogram (W/kg), SAR provides a standardized measure to evaluate the safety of devices emitting electromagnetic radiation [37]. It represents the amount of energy absorbed by one

Table 1 ICNIRP radiation levels for different bands

Band name	Frequency range (MHz)	E-field strength (V/m)	H-field strength (A/m)	Equivalent plane wave power density S_{eq} (W/m^2)
FM Radio	87.5–108	28	0.073	2
GSM R	876–880	40.7	0.109	4.4
GSM 900	890–960	42.6	0.11	4.8
GSM 1800	1710–1880	59.6	0.16	9.4
UMTS DL	2110–2170	61	0.16	10
LTE (TD)	2300–2400	61	0.16	10
WLAN	2400–5000	61	0.16	10

kilogram of tissue and is critical in assessing the biological impact of EM fields [38]. The calculation of SAR involves the energy absorbed per unit mass of tissue and is determined using the formula:

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

In this equation, σ refers to the electrical conductivity of the tissue, which varies based on tissue type and frequency of the EM field. *E* represents the electric field strength, indicating the intensity of the EM field, and ρ denotes the density of the tissue, reflecting its physical characteristics. Direct measurement of SAR is challenging due to the complexity of biological tissues and the non-uniform interactions with EM fields. Instead, SAR is often determined indirectly by measuring parameters such as the electric field strength, power flux density, or magnetic field strength.

To protect humans from excessive exposure to EM fields, regulatory bodies have established SAR thresholds based on extensive scientific studies. These thresholds aim to limit both thermal and non-thermal effects of electromagnetic radiation. SAR values exceeding 1.0 W/kg are generally considered to pose significant health risks. In the United States, the Federal Communications Commission (FCC) has set the maximum allowable SAR limit at 1.6 W/kg, averaged over 1 g of tissue. In Europe, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has set a slightly higher limit of 2.0 W/kg, averaging over 10 g of tissue [17, 38–40]. These limits are designed to ensure public safety while accounting for differences in exposure scenarios and regulatory standards.

5 Measuring instrument: selective radiation meter

The investigation required equipment that could simultaneously measure electric and magnetic fields. The SRM3006 (Selective Radiation Meter) made by Narda is used to assist us. The SRM-3006 (Selective Radiation Meter) is a frequency selective measuring equipment for high-frequency electromagnetic field safety study and measurement in the environment in the frequency range 9 KHz to 6 GHz [22, 41]. There are operating modes tailored to the main applications: Safety Evaluation, Spectrum Analysis, Level Recorder, Scope, and Universal Mobile Telecommunication System (UMTS). For measuring electric fields (E-fields) and magnetic fields (H-fields), Narda offers a wide range of three-axis and single-axis antennas. It can also detect absolute and limit values of high-frequency electromagnetic fields such as broadcast radio (AM, FM), television (TV), mobile telecommunications (GSM, UMTS), radar, and wireless communications (WiMax, WLAN) [41]. It's difficult to tell which field belongs to which service provider when many mobile telephone service providers share a single antenna location. The SRM-3006 may show absolute values as well as percentages of the authorised limit level for the entire field level and specific services [41]. The SRM-3006 Basic Unit, RF cable, and three-axis and single-axis measurement antennas for E-fields and H-fields constitute the entire instrument. The fundamental unit of the SRM- 3006 devices is shown in Fig. 1.

6 Measurements and methodology

Agra (27°10′N, 78°05′E, 169 m.s.l.) lies roughly 204 km south of Delhi in India's north-central region. It is home to the Taj Mahal, a world-famous historical site. Measurements of the electric field, magnetic field, and power density were made in various locations of the Dayalbagh Educational Institute (DEI) in Agra to evaluate the levels of high-frequency electromagnetic radiation created by BTS towers. Dayalbagh Educational Institute is located on the northern outskirts of Agra, roughly 2 km from the city centre. Every day, over 4,000 students attend this institute. There are three BTS towers, all of which are located outside of the campus. There are also numerous Wi-Fi routers on campus. Each measurement was six minutes long, as required by ICNIRP regulations [42]. Multiple measurements were conducted at each of the four selected locations (ML1, ML2, ML3, and ML4). The measurement setup of the SRM-3006 which is placed at a height of 1.5 m from the ground. At each site, measurements were repeated three times during the specified peak hours (12:00 PM to 2:00 PM) on different days. This time frame was selected as it represents the period of maximum activity on campus, with the institution operating in its regular mode. The density of people and environmental conditions during these times were typical of usual college days. The average values of electric field strength, magnetic field strength, and power density were calculated and reported as the final results. This approach ensures that the data represent normal conditions at the measurement sites and minimizes the impact of any anomalies or transient variations during a single measurement. The

Fig. 1 Basic Unit of SRM-3006

measurement locations (ML1, ML2, ML3, ML4) and their distances from BTS towers (BTS1, BTS2, BTS3) are depicted in the layout plan as shown in Fig. 2. As mentioned in ref. [22], there are two types of towers around the institution. The two of them are Roof Top Towers (RTTs): BTS1 and BTS2. The BTS3 tower is Ground Base Tower (GBT). Figure 3 shows a satellite view of Dayalbagh Educational Institute, the BTS towers (red circles), and the measurement sites (yellow squares) where the measurements were obtained. The distance between the BTS towers was taken into consideration when selecting these locations. The average values of the electric field, magnetic field, power density and SAR value were recorded for each measurement. For calculating SAR value, the values of conductivity and density considered were $\sigma = 0.8$ S/m and $\rho = 1000$ kg/m^3, respectively (for muscle tissue). The duration of each measurement was six minutes, as specified in ICNIRP regulations. Table 2 shows the average values of electric field strength, magnetic field strength, power density and SAR value obtained from a variety of measurements taken at various sites in the year 2023. Figure 4 shows one of the frequency selective EMR measurements made with the SRM-3006 for several frequency bands.

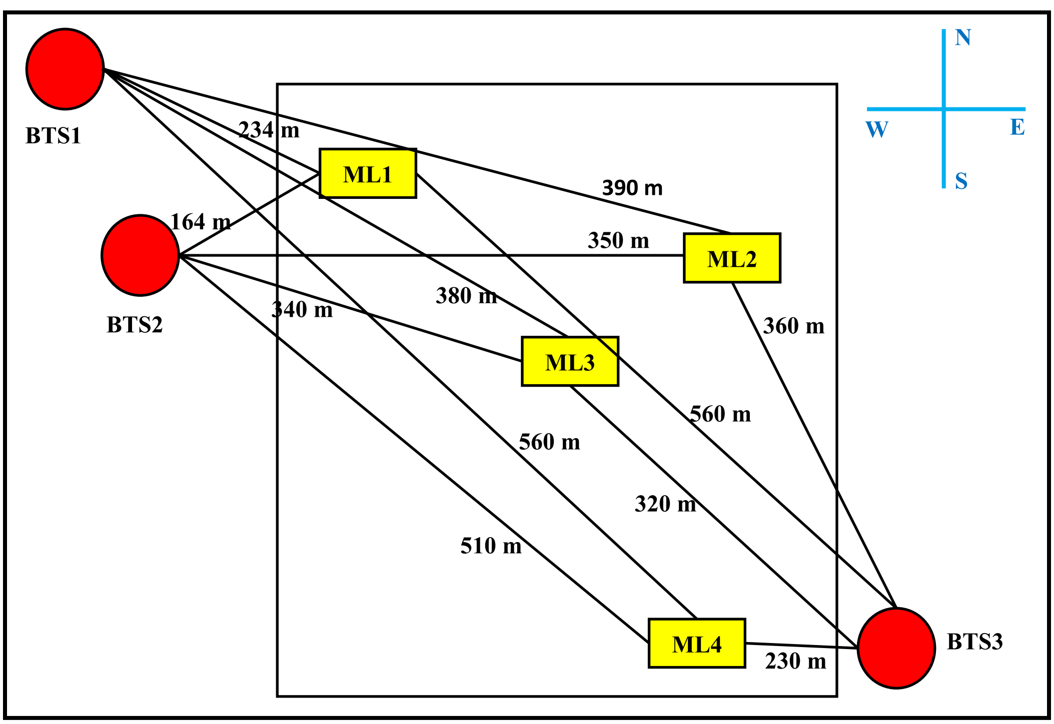


Fig. 2 Measurement Layout Plan

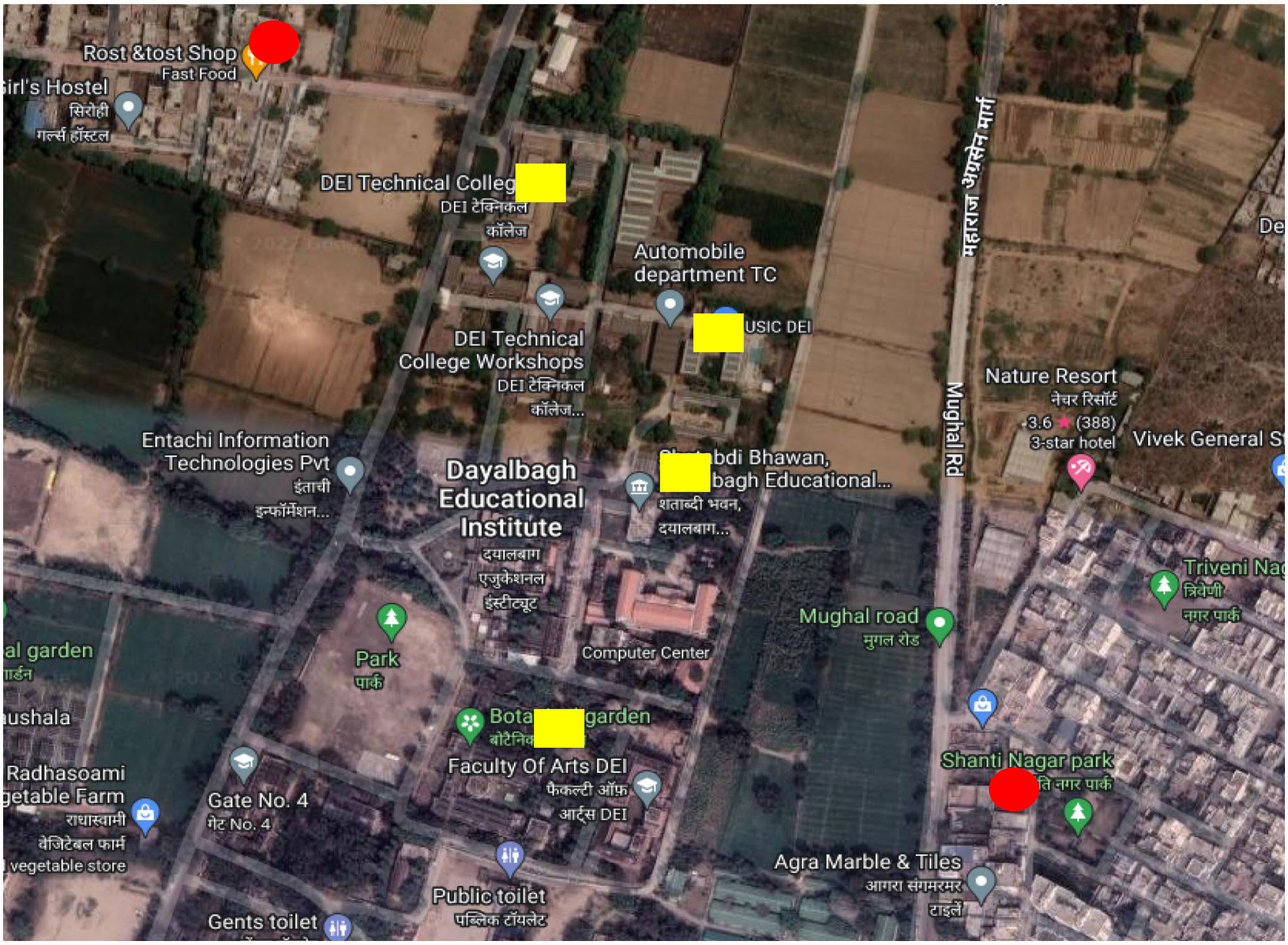


Fig. 3 Measurement Locations and Base Stations (Satellite View)

To determine the impact of the technology on children's health, a survey was undertaken and data was collected from residents of 64 cities in India's various states. The survey was conducted entirely online in order to maintain social distance during the Pandemic. A self-designed questionnaire was prepared in the form of Google Form which was composed of 19 questions. The link of the questionnaire was forwarded to people e-mail, Whatsapp, and Facebook to the contacts of researchers. Participants were asked to reach out to as many people as possible with the questionnaire. Participants came from a variety of backgrounds and ages.

7 Discussion

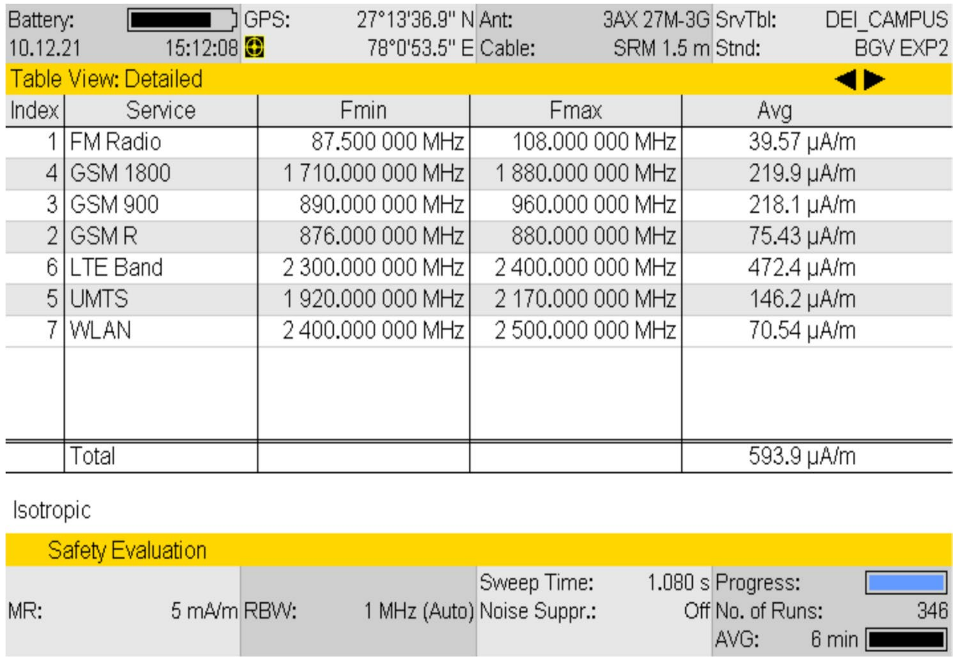
The highest recorded average values for LTE (TD), GSM 900, WLAN, and GSM 1800 bands are recorded at measurement locations ML1, ML2, ML3, and ML4, respectively, when all measurement results are taken into account. Coloured Pie charts illustrating the proportion of distributions of all frequency bands for measurements obtained at different measurement locations in the year 2023 are shown in Fig. 5 to help determine the dominance of all bands at different locations.

At measurement locations, ML1 and ML2, the maximum average values for LTE (TD) band were recorded. This may be due to the additive effect of both the nearest BTS towers at ML1 and ML2. Similarly due to the BTS tower 3 highest values were observed at ML4 since they have a small distance of 230 m between them. The high values for the WLAN band are recorded at positions ML1 and ML2, which could be due to the presence of a Wi-Fi router. The EM radiation measurements taken at four separate places fall below the ICNIRP and Indian guidelines and limits.

Table 2 Average value of electric field strength, magnetic field strength, and power density measured at different measurement locations in the year 2023

Band name	Frequency (MHz)	Avg. E. field strength (mV/m)	Avg. M. field strength (μA/m)	Avg. Power density S_{eq} (μW/m^2)	SAR value (W/Kg) $\times 10^{-4}$
Measurement Location 1 (ML1): Faculty of Engineering					
FM Radio	87.5–108	32.48	86.90	2.804	0.01
GSM R	876–880	181.9	488.6	98.3	0.26
GSM 900	890–960	52.04	141.1	7.712	0.02
GSM 1800	1710–1880	814.3	2092.0	1690.0	5.30
UMTS DL	2110–2170	556.8	1377.0	539.1	2.48
LTE (TD)	2300–2400	827.0	2023.0	1615.0	5.47
WLAN	2400–5925	21.61	58.30	1.395	0.00
Measurement Location 2 (ML2): USIC					
FM Radio	87.5–108	34.28	89.91	3.098	0.01
GSM R	876–880	52.69	133.9	6.397	0.02
GSM 900	890–960	279.8	841.7	220.2	0.63
GSM 1800	1710–1880	184.7	514.1	92.1	0.27
UMTS DL	2110–2170	403.1	1059.0	436.2	1.30
LTE (TD)	2300–2400	622.1	1360.0	703.7	3.10
WLAN	2400–5925	26.72	68.67	1.298	0.01
Measurement Location 3 (ML3): Boys Canteen					
FM Radio	87.5–108	32.21	85.34	2.779	0.01
GSM R	876–880	7.603	20.12	0.134	0.00
GSM 900	890–960	50.79	143.1	6.570	0.02
GSM 1800	1710–1880	76.85	87.17	2.596	0.05
UMTS DL	2110–2170	32.23	84.16	2.838	0.01
LTE (TD)	2300–2400	33.54	91.65	3.483	0.01
WLAN	2400–5925	22.98	60.16	1.363	0.00
Measurement Location 4 (ML4): Girls Canteen/Herbal Garden					
FM Radio	87.5–108	32.87	86.99	2.854	0.01
GSM R	876–880	27.65	75.43	2.145	0.01
GSM 900	890–960	83.51	218.1	17.89	0.06
GSM 1800	1710–1880	81.96	219.9	17.11	0.05
UMTS DL	2110–2170	58.71	146.2	10.28	0.03
LTE (TD)	2300–2400	200.5	528.2	107.7	0.32
WLAN	2400–5925	27.32	70.54	2.225	0.01

The above results that were obtained in the year 2023 are compared with the previous study which was done in 2019 at Dayalbagh Educational Institute [43] and analysis is done based on these comparisons. It was noticed that there is a rapid increment in radiation exposure. Figure 6 shows the comparison of our results measured in the year 2023 and the results from the previous study in the year 2019 [43]. It has been recorded that there is a high variation in electromagnetic radiation at ML1 and ML2. The university allowed students to bring their mobile phones after the pandemic to scan their assignments and submit their soft copies on Google classroom. That is the reason we can observe a rapid increment in electric field strength, magnetic field strength, and power density of LTE and GSM 1800 bands at ML1 and ML2 as shown in Figs. 5b and 6a. At ML1, the LTE band's electric field strength, magnetic field strength, and power density increased by 50.96%, 37.52%, and 99.08% respectively in 2023 as compared with readings of 2019. For GSM 1800, electric field strength, magnetic field strength, and power density increased by 310.84%, 285.48%, and 1504.94% respectively. A similar increment can be seen at ML2, where electric field strength, magnetic field strength, and power density increased by 339.02%, 254.72%, and 1015.56% respectively for the LTE band. There is a small increase in GSM 1800 band i.e., by 15.87%, 22.34%, and 52.64% in electric field strength, magnetic field strength, and power density respectively. At ML3 there is not a high variation in radiation exposure, since as per university guidelines Boy's canteen is temporarily closed as a result we can observe a fall in WLAN service as depicted in Fig. 6c. The electric field strength, magnetic field strength, and power density fall by 83.52%, 83.36%,



Battery:		GPS: 27°13'36.9" N	Ant: 3AX 27M-3G	SrvTbl: DEI_CAMPUS
10.12.21	15:12:08	78°0'53.5" E	Cable: SRM 1.5 m	Stnd: BGV EXP2

Table View: Detailed

Index	Service	Fmin	Fmax	Avg
1	FM Radio	87.500 000 MHz	108.000 000 MHz	39.57 μA/m
4	GSM 1800	1 710.000 000 MHz	1 880.000 000 MHz	219.9 μA/m
3	GSM 900	890.000 000 MHz	960.000 000 MHz	218.1 μA/m
2	GSM R	876.000 000 MHz	880.000 000 MHz	75.43 μA/m
6	LTE Band	2 300.000 000 MHz	2 400.000 000 MHz	472.4 μA/m
5	UMTS	1 920.000 000 MHz	2 170.000 000 MHz	146.2 μA/m
7	WLAN	2 400.000 000 MHz	2 500.000 000 MHz	70.54 μA/m
	Total			593.9 μA/m

Isotropic

Safety Evaluation

MR: 5 mA/m	RBW: 1 MHz (Auto)	Sweep Time: 1.080 s	Progress:
		Noise Suppr.: Off	No. of Runs: 346
			AVG: 6 min

Fig. 4 Frequency selective EM Radiation values

and 97.23% respectively at ML3. The ML4 is surrounded by four faculties as Faculty of Science, Faculty of Arts, Faculty of Architecture, and Multimedia Building. Before the COVID-19 pandemic, mobile phones were restricted at these premises but after the pandemic, the students were allowed to give their tests in the open field areas of these faculties keeping social distance to maintain the COVID-19 Guidelines. As a result, we can observe the highest increment in electric field strength, magnetic field strength, and power density by 318.84%, 426.10%, and 2731.96% respectively as shown in Fig. 6d. Similarly, the electric field strength, magnetic field strength, and power density for GSM 1800 increased by 41.09%, 78.06%, and 197.41% respectively. The threshold of 1000 $\mu W/m^2$ for pulsed EMR power density for non-thermal biological impacts is proposed in ref. [21], but our measurements at measurement location ML1 for LTE (TD) and GSM 1800 bands, were larger than this value. The EM radiation measurements taken at four different locations are much below the limits and guidelines set by the ICNIRP and India. Table 3 provides the ratios of the highest measurement and ICNIRP limits ratios for different locations. Table 4 shows the t-statistics and p-values computed for the electric field measurements at four different locations (ML1, ML2, ML3, and ML4), comparing the pre- and post-COVID scenarios. The t-statistics are negative at most locations, indicating that the mean electric field value in the pre-COVID scenario is lower than in the post-COVID scenario. The p-values associated with each t-statistic indicate the statistical significance of the observed differences. Since all p-values are greater than 0.05, the differences in electric field measurements between the pre-COVID and post-COVID scenarios at each location are not statistically significant. However, it is noteworthy that, although the measured values are small, there is a significant increment in these ratios when compared to measurements taken in the pre-COVID scenario, i.e., 2019. This increment is a matter of consideration, as it reflects a potential rise in EM radiation exposure due to the proliferation of emerging technologies. Additionally, the survey conducted alongside the measurements highlights growing health concerns associated with these advancements, warranting continued monitoring and evaluation.

In the survey, there were a total of 678 responses, including people of various ages and from various cities. The participants ranged in age from 5 to 30 years old. Age groups and education level were broken down into subgroups and narrow ranges in order to achieve a more precise analysis. Out of the total participants, 91% participants were students and 6% were parent of student while the remaining belonged to the guardian of student category as shown in Fig. 7. The age group of 16–20 years had the highest participation rate, accounting for 54% of the total participation, followed by the age group of 21–25 years, which accounted for 33% of total involvement. Figure 8 illustrates the percentage involvement of each category. Most of the responders were from under graduation with the percentage of 66.1%, followed by post-graduation accounting for 16.2% and then senior high school with 5.8% of total participation. The ratio of responders based on education level is shown in Fig. 9. The majority of individuals are using Vodafone-Idea, Airtel, Reliance Jio, and BSNL 4G Internet connectivity via mobile networks, Wi-Fi, and broadband connections. Figure 10 shows the proportion of respondents who used different service providers.

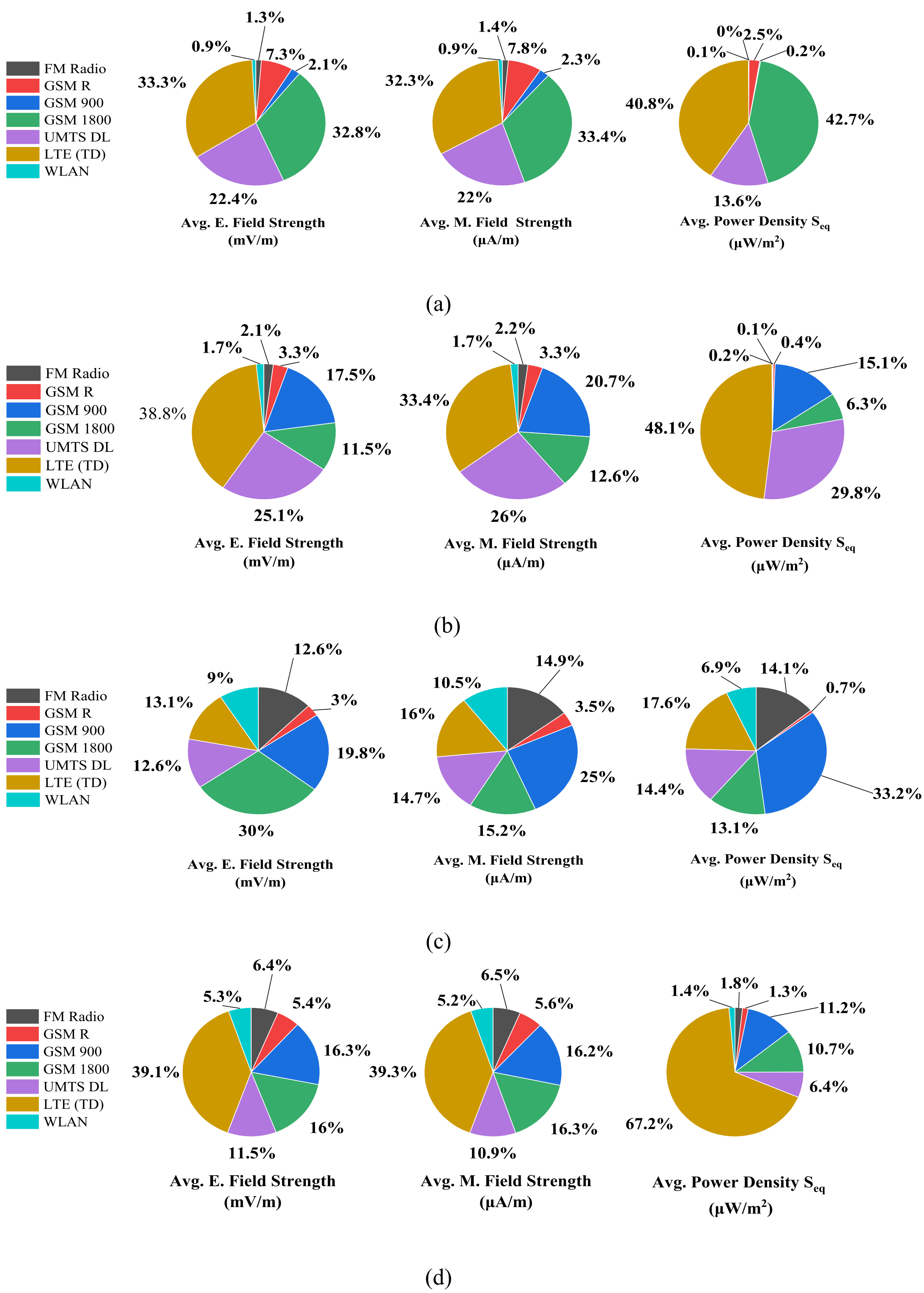


Fig. 5 Pie Chart of Measurements taken at different locations in the year 2023 **a** ML1 **b** ML2 **c** ML3 **d** ML4

The use of mobile phone technology has increased as a result of lockdown circumstances. According to the survey, around 84% of participants have reported that student's screen time is more than 2 h per day. Only 16% of the responders have their screen time less than 2 h per day, as shown in Fig. 11. The reasons for using the internet range from online education and learning to interacting with family and friends. It was also observed that there was an increment in number

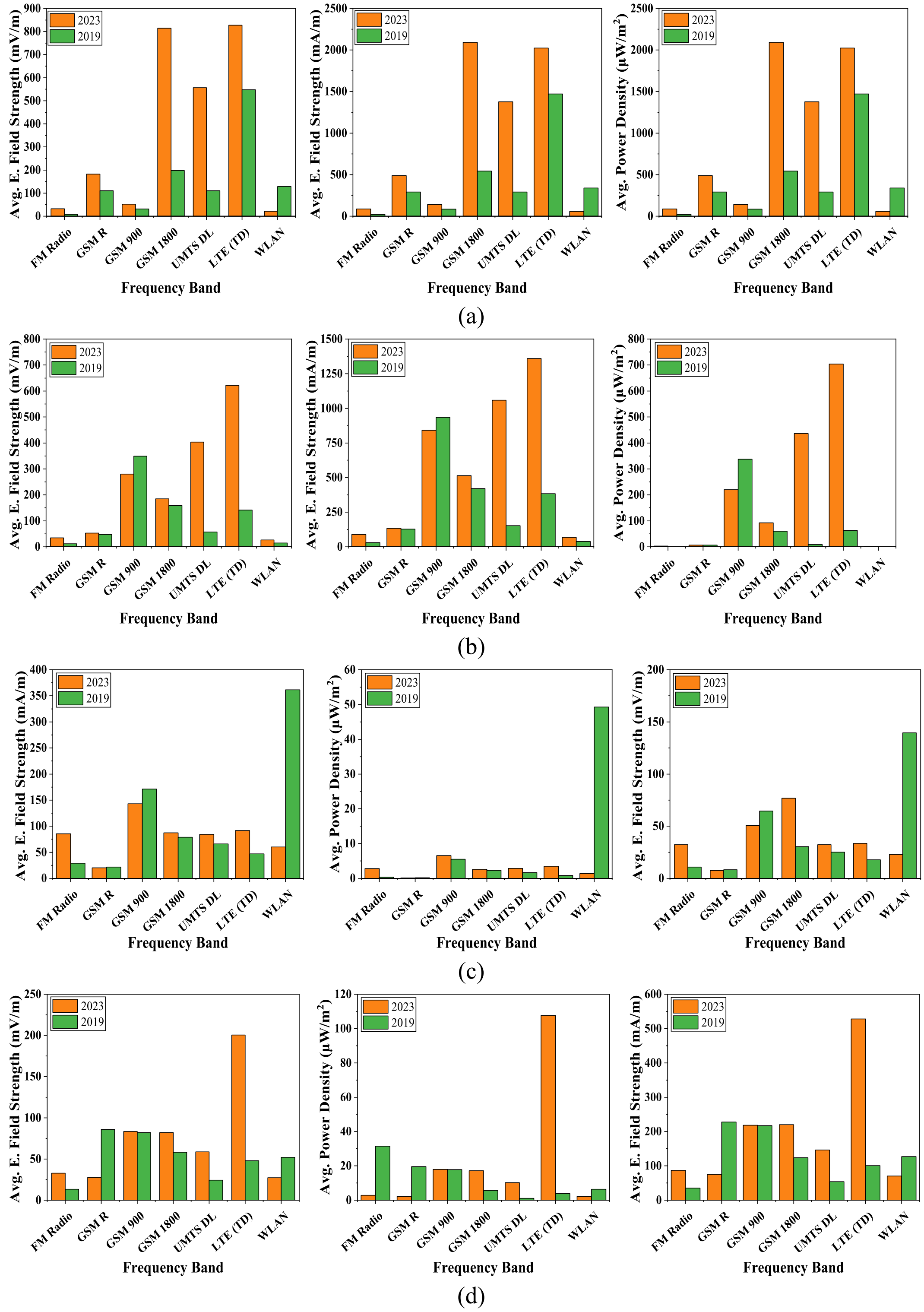


Fig. 6 Comparison between our results measured in the year 2023 and previous study [28] in the year 2019 of measurements taken at different locations **a** ML1 **b** ML2 **c** ML3 **d** ML4

of mobile phones in one's family. The ratio of participants based on the number of mobile phone in each responder's house is shown in Fig. 12. Out of all participants 41% reported that they have more than 3 mobile phones at their house.

Headache, eyestrain/itchy eyes, hearing loss/tinnitus, sleep disorders, obesity, mental stress—cognitive behaviour and emotional changes, musculoskeletal (neck/back/shoulder/chest, etc.), depression, anxiety discomfort in face to

Table 3 Ratios of highest measurements to the ICNIRP limits for 4 measurement locations

EMR	Ratio (Measured/ICNIRP)			
	ML1 (GSM-1800)	ML2 (LTE-TD)	ML3 (GSM-900)	ML4 (LTE-TD)
Max. Avg. E. Field Strength (mV/m)	0.01366	0.01019	0.00119	0.00328
Max. Avg. M. Field Strength (µA/m)	0.01308	0.00850	0.00130	0.00330
Max. Avg. Power Density S_{eq} (µW/m^2)	0.00018	0.00704	0.0000013	0.00108

Table 4 T-statistic and p-value computed for the electric field for 4 measurement locations, comparing pre- and post-COVID scenarios

Locations →	ML1	ML2	ML3	ML4
t-statistics	− 1.2454	− 1.2252	0.2943	− 0.8445
p-value	0.2367	0.2439	0.7735	0.4149

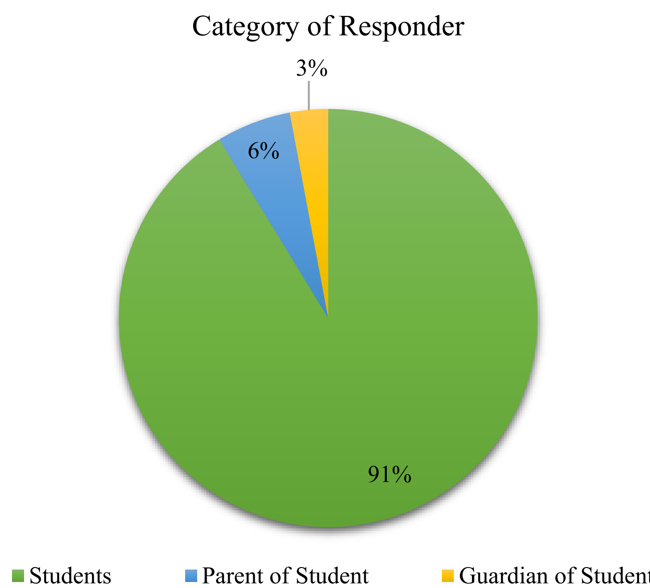


Fig. 7 Ratio of responder based on category

face communication, and smartphone addiction are among the various discomforts experienced by students while using mobile phone technology for an extended period of time. Out of all participants, 36% confirmed headache issue, 39% have confirmed Eye irritation Problem and 32% are facing sleeping disorder due to excessive usage of mobile phones and technology as shown in Fig. 13. Short temper, obesity, anxiety, and low concentration have all been mentioned by a large number of individuals.

To mitigate EMF exposure in educational institutions, practical measures should be implemented to ensure both safety and efficiency. Optimizing Wi-Fi router placement is one such measure, with routers positioned in areas that minimize human interaction, such as ceilings or designated spaces away from high-traffic areas. Additionally, awareness campaigns for students, faculty, and staff regarding safe technology usage can help reduce unnecessary exposure. Encouraging the use of wired connections where possible, limiting screen time, and promoting regular breaks from electronic devices are further strategies to minimize potential health risks. Integrating these measures into the daily routines of educational institutions can create a healthier learning environment while still benefiting from technological advancements.

Fig. 8 Ratio of responders based on age

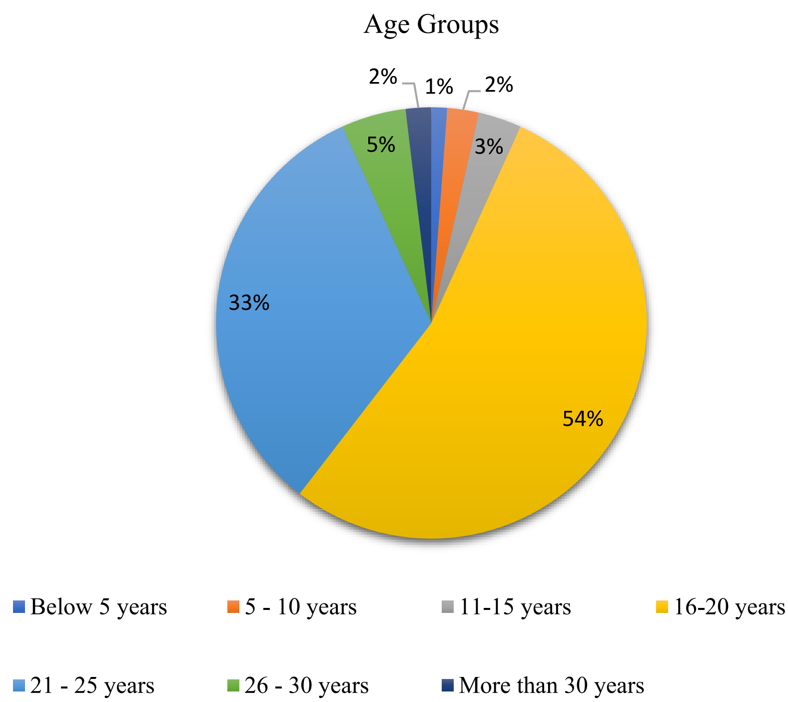
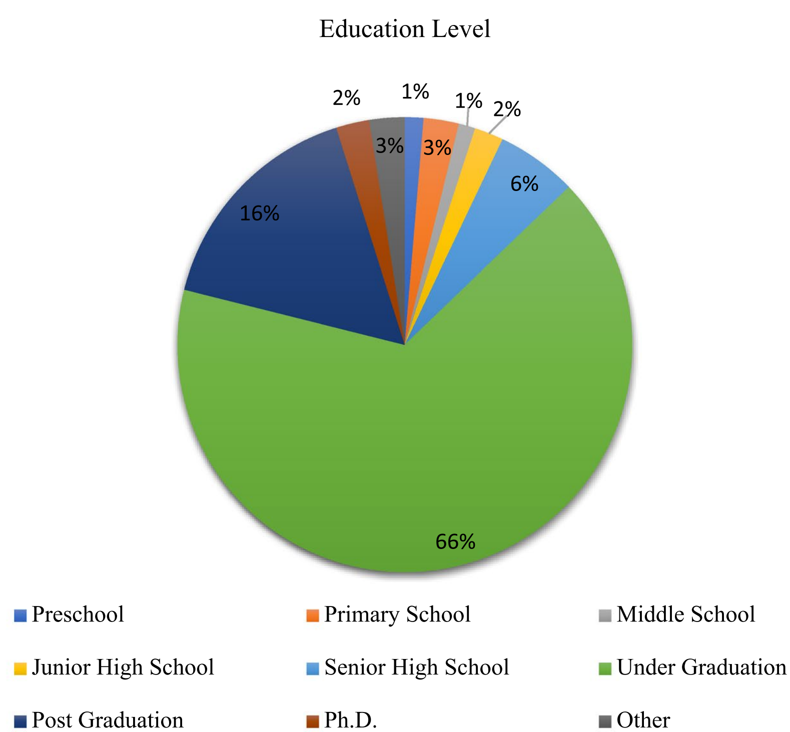


Fig. 9 Ratio of responders based on education level



8 Conclusion

The COVID-19 lockdown forced people to adapt to remote working methods heavily reliant on technology. Numerous studies have highlighted the negative health impacts of excessive technology use. This study aimed to examine these impacts, focusing on electromagnetic exposure, measured in terms of the electric field, magnetic field, and power density at four locations on the Dayalbagh Educational Institute campus. The results, when compared to ICNIRP

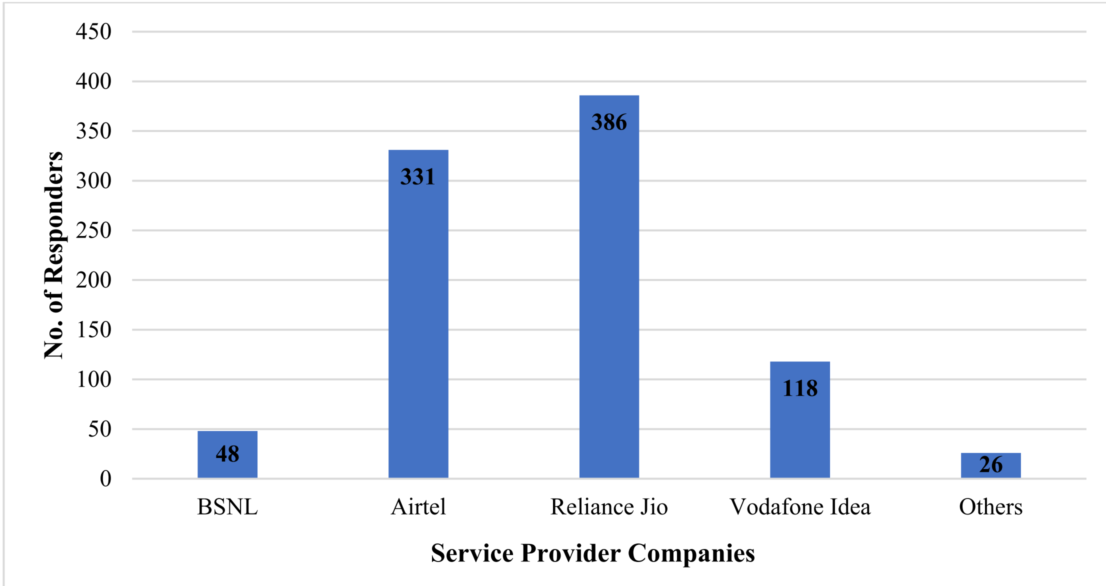


Fig. 10 Ratio of Responders based on using different service providers

Fig. 11 Ratio of Student's Screen Time

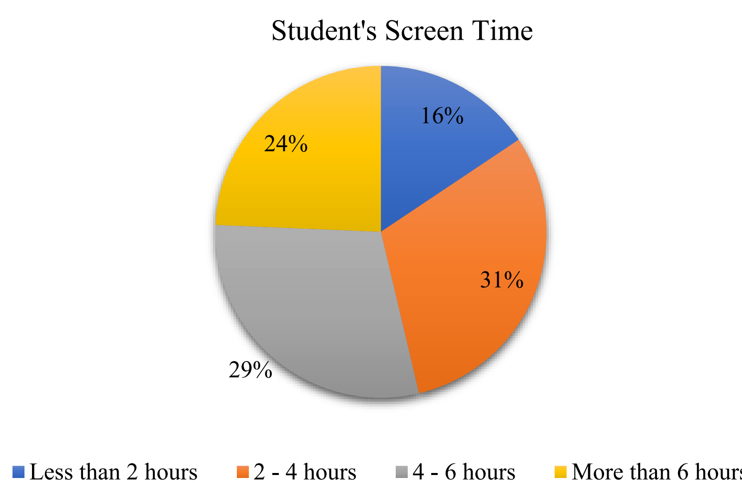
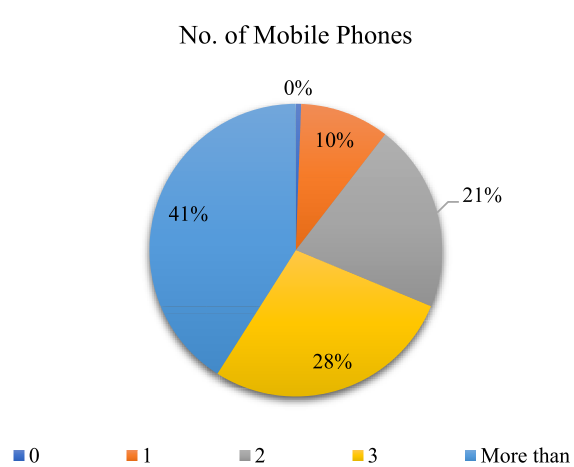


Fig. 12 Ratio of Responders based on No. of Mobile Phones in each house



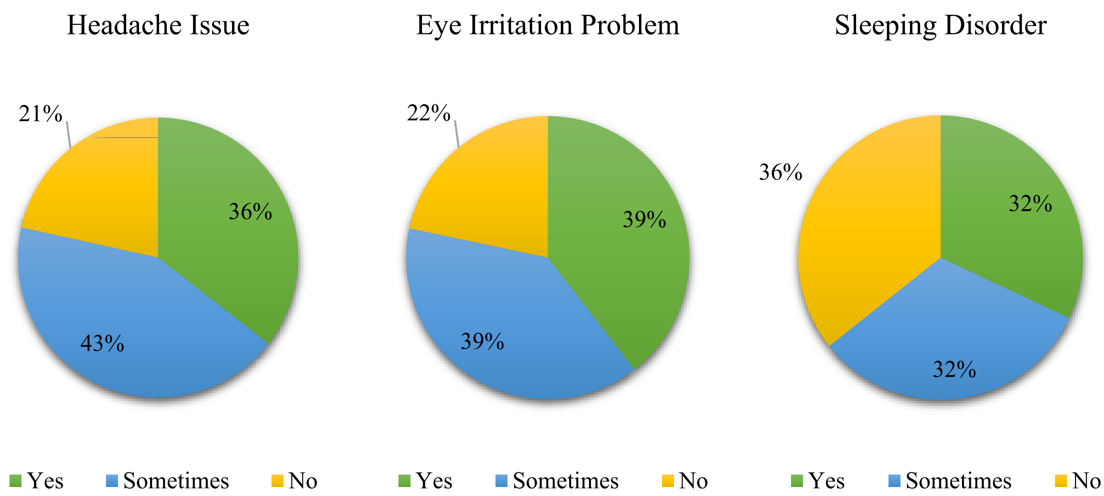


Fig. 13 Ratio of responders based on different health issues

and Indian guidelines, confirmed that the measured values were well below permissible exposure limits. However, the significant increase in values between 2019 and 2023 raises concerns about potential thermal and non-thermal effects due to prolonged exposure.

The survey conducted as part of this study provided critical insights into public health concerns arising from increased reliance on technology during the lockdown. It underscored the urgent need for awareness campaigns and policy interventions to address these risks. Governments and organizations must implement effective strategies to reduce excessive screen time and promote healthier work and learning environments. Work-from-home arrangements should prioritize balanced schedules to avoid extended working hours, and academic institutions should restructure online programs to minimize the negative health impacts of prolonged screen use on students.

As the pandemic subsides, there should be a conscious effort to reduce dependency on technology and encourage greater human-to-human interaction. Additionally, exposure to electromagnetic radiation (EMR) must be minimized whenever possible, as continuous exposure can have adverse effects on human health depending on frequency, distance, and duration. While technology enhances convenience, it often comes at the expense of health, making it essential to prioritize preventive measures and establish national health guidelines to mitigate these risks. The findings of this study and the associated survey highlight the importance of addressing these issues to safeguard public health in an increasingly technology-dependent world.

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Author contributions R.S. conceptualized the study, conducted the data collection in 2023, and drafted the main manuscript text. A.S. contributed to the comparative analysis of the 2019 and 2023 data, ensuring consistency with ICNIRP and FCC standards, and provided critical revisions to the manuscript. A.J. supervised the study, assisted with methodology refinement, and prepared Figs. 1, 2, 3. All authors reviewed and approved the final manuscript.

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Declarations

Competing interests The authors declare no competing interests.

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