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Assessment of Output Radiation Density of Cell Phone for Epidemiological Studies: A Pilot Study in Navi Mumbai

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ABSTRACT. In this research, the cell phone radiation output density of 167 different cell phone users has been systematically measured across various scenarios: (i) when no multimedia services were activated, (ii) when all multimedia services were activated (such as WhatsApp, Messenger, Viber, Skype, etc.), (iii) during calls without multimedia services, and (iv) during calls with all multimedia services activated. Through rigorous statistical analysis, the means for each of these four categories were computed. A notable finding is that the radiation output density from cell phones is at its highest during calls with all multimedia services activated (means 11.87 mW/m^2 for 167 cell phones), whereas during calls with no multimedia services active, mean values are found 7.743 mW/m^2. To establish a correlation between the quality of the signal received from the cell phone tower and the radiated power from the cell phone during calls, the output radiation from cell phones was also assessed using the Trifield Electromagnetic field (EMF) meter model (TF2) at different signal quality levels emitted by the towers. These signal quality levels were quantified by measuring Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Received Signal Signal-to-Interference-plus-Noise Ratio (RSSINR). It was observed that the cell phone's radiated power was at its lowest (means 9.428 mW/m^2 for 41 cell phones) when the received signal quality was excellent (RSRP: –70.84 dBm; RSRQ: –12.06 Db; RSSINR: 12.6 dB). Conversely, in areas with the worst received signal quality (RSRP: –82.86 dBm; RSRQ: –17.034 dB; RSSINR: 8.1774 dB), the output radiated power density from cell phones during calls (all multimedia services activated) was recorded at its highest (means 18.336 mW/m^2 for 56 cell phones). Furthermore, the study revealed an inverse correlation between the radiated output power density of cell phones (167) and the quality of the received signal (RSRPr: –0.18456; RSRQr: –0.35026; RSSINRr: –0.6448). This implies that the cell phone's radiated power density is directly influenced by the quality of the received signal from cell phone tower (specifically, its electromagnetic field strength) and the activation of various multimedia services. These findings contribute to improving the indicators of radiofrequency (RF) exposure for use in epidemiological studies. The results highlight that output power density of cell phone increases as the signal level from the cell phone tower decreases. Thus, we can affirm that a low-quality cell phone tower signal during calls leads to increased output radiation of cell phone, consequently resulting in a higher incidence of epidemiological problems.

Keywords: epidemiologist, RF radiation, RSRP and RSRQ, power density

1. Introduction

The impending launch of 5G mobile networks will enable remarkably faster mobile broadband speeds and significantly expanded mobile data usage. Technological advancements encompass diverse transmission systems such as MIMO (employing multiple-input and multiple-output antennas), directional signal transmission or reception (beamforming), and the utilization of different frequency ranges (Wall et al., 2019). The deployment of 5G technology entails the utilization of higher frequencies and denser small-cell configurations, igniting concerns about potential radiofrequency (RF) exposure and its influence on human well-being (Wall et al., 2019). Alongside these innovations, there is potential for alterations in the electromagnetic field of the human body. Consequently, investigating the effects of cell phone tower radiation on humans is crucial for advancing epidemiological epidemiological research (Khurshid et al., 2013; Wall et al., 2019) The World Health Organization (WHO) has highlighted research on RF-EMF exposure as a top priority (Khurshid et al., 2013; Viavi, 2021).

Simultaneously, there is a mounting apprehension regarding the escalating usage of smartphones, wearables, and analogous wireless devices, primarily due to the potential for prolonged exposure to RF radiation. Research is actively exploring the persistent effects of using these devices, with specific emphasis on children (Viavi, 2021; Singh et al., 2023).

Several investigations have explored the potential health consequences of RF exposure, predominantly stemming from earlier wireless technology generations such as 2G, 3G, and 4G (Khurshid et al., 2013; Viavi, 2021). These inquiries have delved into various health aspects, encompassing cancer, neurological impacts, and reproductive well-being (Singh et al., 2023). Re-

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search in epidemiology concerning RF exposure frequently involves extensive population-based studies aimed at examining correlations between RF exposure and health outcome (GSMA Intelligence, 2014; Singh et al., 2023). Epidemiology is the examination of the distribution and determinants of health-related conditions or events in populations, and it holds a pivotal role in evaluating the potential health ramifycations of emerging technologies like 5G (GSMA Intelligence, 2014). Epidemiological studies on RF exposure confront methodological hurdles, including the challenge of precisely gauging individual exposure, establishing causation, and considering potential confounding variables (Cablefree, 2020). Distinguishing the health consequences of RF exposure from those associated with other factors like lifestyle, environmental elements, and genetic predisposition can be a formidable task (Hashem et al., 2009; Cablefree, 2020).

In recent years, there has been a growing focus on histological and physiological examinations to assess the impact of electromagnetic fields on human health (Zare at al., 2007; Al-Gabib et al., 2008; Khaki et al., 2008; Wang et al., 2008; Hashem et al., 2009; Khayyat et al., 2011; Lotfi, 2011; Abo-Neima et al., 2015). These fields may lead to various harmful effects on living organisms, such as chronic fatigue, headaches, cataracts, heart issues, stress, nausea, chest pain, and forgetfulness (Mercola, 2009). They can influence learning, memory, the cardiovascular and reproductive systems (Picazo et al., 1995; Szemersky et al., 2010), as well as the central nervous system, endocrine and immune systems (Ahlbom, 2001; Mohammed, 2015), leading to sleep disturbances, changes in electroencephalographic activity, and alterations in biological functions in both humans and animals (Hossmann et al., 2002; Marzook et al., 2014). The adverse effects of electromagnetic fields have been linked to impacting multiple aspects of human health, increasing the risk of severe conditions like, (Bastuji et al., 1990; London et al., 1991; Savitz et al., 1995; Harrington et al., 1997) brain cancer (Savitz et al., 1995; Harrington et al., 1997), lung and breast tumors (Loomis et al., 1994; Harrington et al., 1997; Ahlbom, 2001), Lou Gehrig's disease (Johansen et al., 1998), genotoxicity, neurodegenerative diseases, infertility, birth defects, higher chances of miscarriage, childhood morbidity, de novo mutations (Gharagozloo et al., 2011; Behari et al., 2012), amyotrophic lateral sclerosis, depression (Verkasalo et al., 1997; Lyer et al., 2003), reproductive anomalies (Blassa et al., 2002), suicide and Alzheimer's disease (Reichmanish et al., 1979).

Utilizing diverse applications and services on a mobile device, such as WhatsApp, Facebook, and multimedia functions, can induce varied implications on the overall radiation output of the cell phone. When cell phones are in operation, they emit RF radiation while transmitting and receiving signals. Engaging in activities like voice calls, text messaging, or mobile data to access applications can heighten the exposure to RF radiation (Savitz et al., 1995; Verkasalo et al., 1997; Johnson et al., 1998; Gharagozloo et al., 2011; Foerster et al., 2018). Engaging in data-intensive services, like streaming multimedia content, such as watching videos on platforms like YouTube or Netflix, may necessitate substantial data consumption. Consequently, this might lead to the phone operating at an increased capacity and, potentially, emitting elevated levels of RF radiation to sustain a stable data connection, albeit the variance is likely minimal. Prolonged utilization of social media apps like Facebook and WhatsApp can result in emotional and psychological consequences, including potential addiction, anxiety, or depression (Khaki et al., 2008; Wang et al., 2008). These effects are not

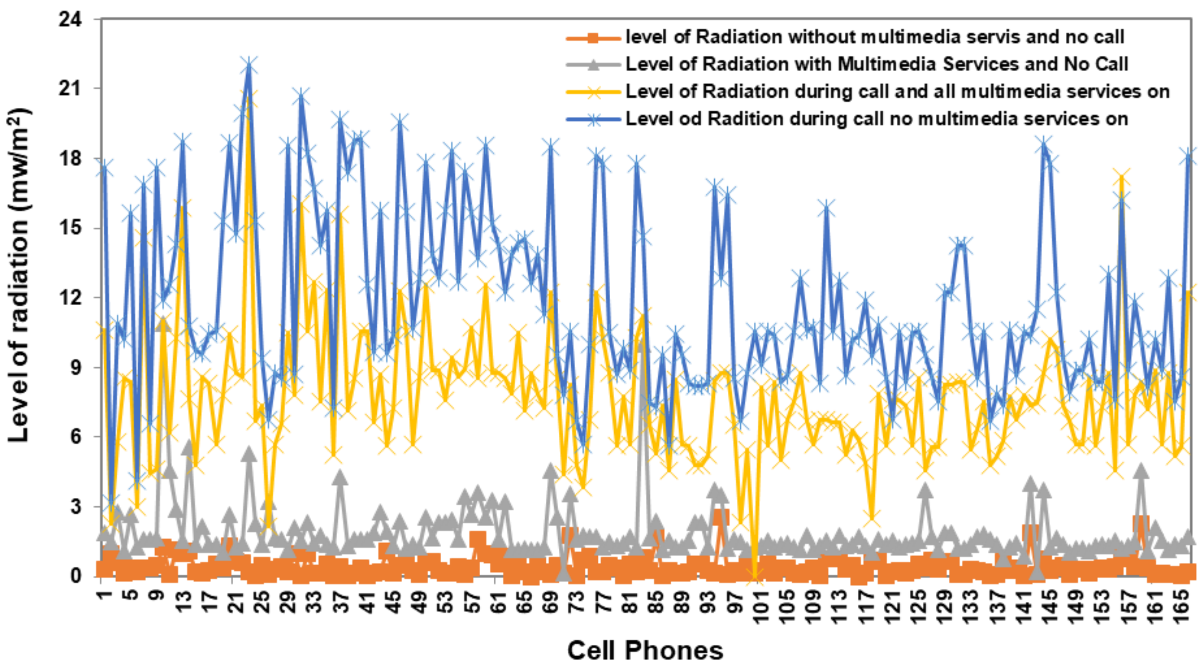

Figure 1. Pattern of level of output power radiation of cell phone in different scenarios: (i) when no multimedia services were activated, (ii) when all multimedia services were activated (such as WhatsApp, Messenger, Viber, Skype, etc.), (iii) during calls without multimedia services, and (iv) during calls with all multimedia services activated.

directly associated with physical exposure but can significantly influence one's overall well-being (Al-Glaib et al., 2008; Abo-Neima et al., 2015).

The potential health effects of radiation emitted by cell phones have been the subject of study and ongoing debate. Current research and investigations persist in exploring and addressing concerns regarding this matter. Here are some of the key points related to this topic (Sobel et al., 1996, Swindlehurst et al., 2014). Output power density of cell phones and the signal quality parameters of cell phone towers, such as Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Received Signal Strength Indicator (RSSI), are interrelated. However, they represent distinct aspects of a mobile network's performance and the potential impact of cell phone usage on a user's health. Let's delve into these concepts and their connections (Ahmad et al., 2016; Huawei et al., 2020; Ericsson et al., 2021; Techtrained et al., 2023).

Low signal quality parameters (lower RSRP, poor RSRQ, or lower RSSI values) can lead to issues such as dropped calls, slow data speeds, and poor network performance. While there isn't a direct link between SAR values and these signal quality parameters, but poor cell phone tower's signal quality may result in the cell phone increasing its RF transmission power to maintain a connection. This, in turn, could potentially increase the SAR values during a call as the phone works harder to communicate with the network (Swindlehurst et al., 2014; Jaber et al., 2016; Singh et al., 2018; Techtrained et al., 2023). In the realm of epidemiological research, these parameters may be considered when scrutinizing the impact of wireless communication networks on health (Yakymenko et al., 2015; Shih et al., 2020). It is imperative to evaluate signal quality and strength across diverse locations and under various conditions to comprehend exposure variations and their potential health consequences (Fernadez et al., 2018; Forester et al., 2018; Russel et al., 2018).

The assessment and correlation among output radiation density of cell phones and cell phone tower signal quality parameters like RSRP, RSRQ, and RSSINR plays a crucial role in epidemiological research, particularly when investigating the potential health implications of RF radiation exposure from wireless communication devices (Techtrained et al., 2023).

Based on the author's knowledge, this type of study has not been conducted before. The research delves into exploring the correlation between different signal quality indicators of cell phone towers (such as RSRP, RSRQ, RSSINR) and the output power density of cell phones. Additionally, the study endeavours to quantify the fluctuations in cell phone output power density across various multimedia services (e.g., WhatsApp, Messenger, Viber, Skype) within the broader Mumbai area.

2. Study Design

The safety from the radiation of cell phone towers in residential or commercial areas and the potential health impacts of excessive cell phone use has sparked significant debate. Studies, including those conducted in various countries, have suggested an association between increased health issues like headaches, sleep disorders, memory problems, seizures, DNA damage, and even tumors. To address these concerns, we propose an enhanced study design integrating a longitudinal aspect for a more comprehensive and objective analysis. This large-scale cohort study aims to examine the correlation between the output power density of cell phones, different signal quality indicators of cell phone towers (such as RSRP, RSRQ, RSSINR), and the varia-tions in cell phone transmission power across diverse multimedia services (e.g., WhatsApp, Messenger, Viber, Skype) within the broader Mumbai region. These investigations aim to shed light on the associations and facilitate the development of interventions, including the establishment of minimum radiation standards for cell phone towers in residential and commercial areas. Additionally, this research intends to inform proper RF planning to mitigate potential epidemiological problems and reduce associated health risks.

3. Methodology

The study has two major components: assessment of output radiation density of cell phones in different scenarios and examination of quality of signal of cell phone towers. (A) Assessment of output radiation density of cell phones: We measured the output power density of cell phones in four scenarios (i) when no multimedia services were activated, (ii) when all multimedia services were activated (such as WhatsApp, Messenger, Viber, Skype), (iii) during calls without multimedia services, and (iv) during calls with all multimedia services activated. In addition, we have also collected information on the cell phone towers in the vicinity of the houses. These included parameters such as 1) height from the ground; 2) The number of antennae in each base station; 3) downtilt of the base stations (mechanical tilt as well as electrical tilt); 4) nature of the tower – whether it is a high gain or a low gain tower; 5) whether the base station is focused in a particular sector or is it omnidirectional; 6) transmitter power and effective radiated power. (B) The quality of the signal of cell phone towers like RSRP, RSSINR, and RSRQ have been collected. Output radiation of cell phones has been measured using a German-made GHz Solution kit and USA-based Trifield meter (covers 20 MHz ~ 6 GHz with range).

Between March 2022 and March 2023, 167 individuals from the rural areas of Greater Mumbai (Navi Mumbai), India, expressed their interest in participating in this study, with data collection conducted at the residences of the participants. Given the experimental design of this study, the meticulous selection of an appropriate sample is crucial for evaluating the output radiation density of cell phones in epidemiological studies, ensuring the validity and thorough analysis of our findings. Various factors have been addressed in the process of collecting samples, outlined as follows: (a) The use of random sampling entails the random selection of participants from the population around the Navi Mum-bai area, ensuring an equal chance of inclusion for every individual. (b) Employing this method helps alleviate bias and increases the likelihood that our samples accurately reflect the entire population in Navi Mumbai. (c) Random sampling is particularly advantageous for analyzing findings on a larger population scale. We also guarantee that the chosen sample size is sufficient for detecting meaningful effects, with a continued emphasis on ethical considerations. Additionally, we recommend consulting with experts in epidemiology and statistics to optimize sample selection under the specific objectives of the study.

The information was gathered through questionnaires that covered various aspects of an individual's phone usage, including details such as the date, time, and duration of each call, as well as the frequency band and output power at fixed intervals throughout each call. More than 167 volunteers with mobile phones from different manufacturers took part in this research. The analysis involved using means, correlations, and linear regression models to investigate the impact of potential explanatory variables on the average output power and the different levels of power emitted by cell phone towers. Participation in the study required volunteers to complete a written consent form, and the research was conducted with the approval of the MGMIHS University research ethics committee.

Research scientists obtained measurement data directly from the handset baseband for several key performance indicators. These indicators included RSRP, RSRQ, and RSSINR. These indicators provide valuable measures of signal strength for the different networks. RSRP was recorded in dBm, while RSRQ and RSSINR were measured in dB. These data reflect the quality of the respective networks. Additionally, the output power density of cell phones in mW/m^2 was documented across various mobile phone data technologies, including High-Speed Packet Access, High-Speed Packet Access+, and 4G network technologies like LTE-Advanced, and Wi-Fi networks.

Spearman's correlations were employed to examine the relationships between the output power density of cell phones, RSRP, RSRQ, and RSSINR across various telecommunications service provider networks. Descriptive statistics, including means and ranges, were computed for the output power density of cell phones under different RSRP, RSRQ, and RSSINR conditions across all telecommunication networks. These groupings were established based on the cellular signal strength for each network. The means of output power density of 167 participants was determined under various conditions, such as with and without multimedia services activated, and during both call and non-call periods.

4. Results

Figure 1 displays the radiation exposure emitted by 167 cell phones across various scenarios: (i) absence of activated multimedia services, (ii) presence of activated multimedia services, (iii) during a call without multimedia services, and (iv) during a call with all multimedia services activated. The highest radiated output power was recorded during phone calls with all multimedia services activated, while the lowest output was noted when there were no multimedia services activated and no calls being made. Additionally, it was observed that the radiation output of cell phones increased as multimedia services increased.

Figure 2 illustrates the means of output power density of all four scenarios mentioned earlier. Notably, it has been observed that the radiation levels in scenario (ii) are four times higher than those in scenario (i). Consequently, it is advisable to disable all unnecessary multimedia services on cell phones to reduce radiation exposure, particularly when placing the phone near the heart or reproductive system. The mean radiation output power density for cell phones is 11.87 mW/m^2 in scenario iv, while it is 7.743 mW/m^2 in scenario (iii). The findings from Figure 2 indicate that the highest radiation emission from cell phones occurs during calls when all multimedia services are active. The cell phone users exposed to this radiation might face potential health issues as identified in previous studies. Thus, it's advisable to disable multimedia services during phone calls and to refrain from making calls through applications such as WhatsApp, Facebook, and Messenger, among others, for precautionary measures.

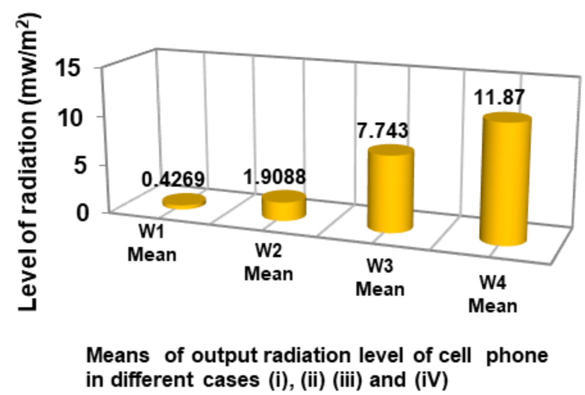

Figure 2. Level of radiation (mean) in different scenarios: (i) W1 when no multimedia services were activated, (ii) W2 when all multimedia services were activated (such as WhatsApp, Messenger, Viber, Skype), (iii) W3 during calls without multimedia services, and (iv) W4 during calls with all multimedia services activated.

The data presented in Table 1 is a graphical representation illustrating the criteria for distinguishing between good and poor quality of signal based on signal strength values radiated by cell phone towers.

In an ideal scenario, where there is no electromagnetic interference and the signal travels from the source to the receiver without any distortion, there would be no need for measuring noise. However, in the real world, the quality of the signal is influenced by various physical obstacles such as mountains, buildings, terrain, and improper antenna installation. As indicated in Table 1, when RSRP is greater than –80 dBm, RSRQ exceeds –11 dB, and RSSINR is above 20 dB, the quality of the signal received from the cell phone tower is considered excellent. When RSRP falls within the range of –90 to –80, RSRQ is between –16 and –11, and RSSINR is between 11 and 20, the quality of the received signal from the cell phone tower is categorized as good, and vice versa (Techtrained, 2021).

Using the received values of signal quality indicators (RSRP, RSRQ, and RSSINR) from cell phone towers, the total number

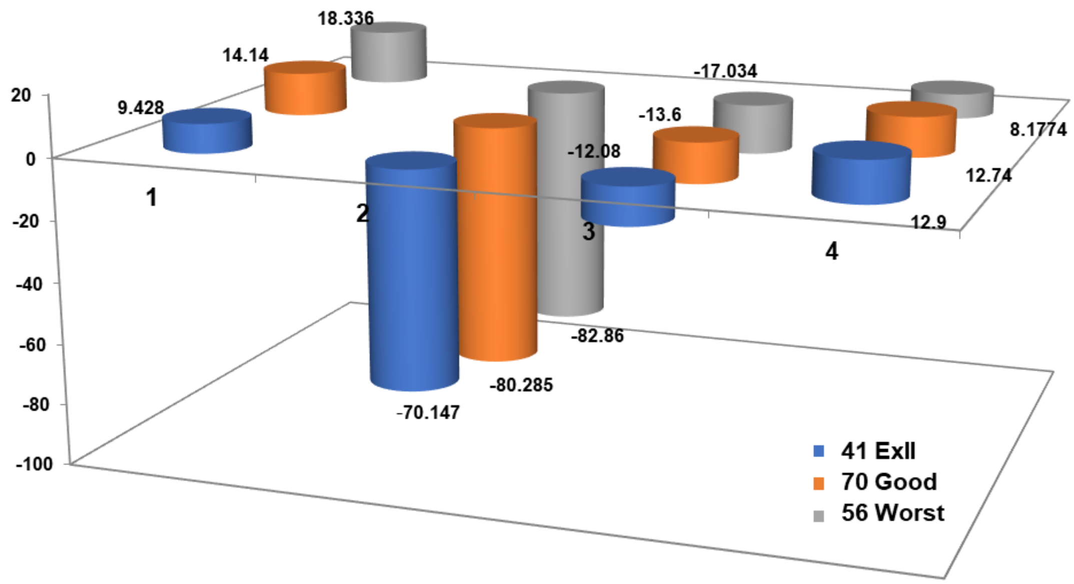

Figure 3. The correlation between cell phone radiation output power density and the levels of RSRP, RSRQ, and RSSINR received from cell phone tower (means).

of users (167) has been categorized into three categories, and their means are presented in Table 2. In category-1 (excellent), this is attributed to the mean values of the signal quality indicators RSRP, RSRQ, and RSSINR, which were –70.147 dBm, –12.08, and 12.9 dB, respectively, and in this category, there are 41 users whose cell phone output mean radiation density has been noted 9.428 mW/m^2. In category-2 (good), 70 cell phone users had a mean output radiation level of 14.140 mW/m^2, with corresponding mean signal quality indicator values (RSRP, RSRQ, and RSSINR) of –80.285 dBm, –17.03, and 8.174 dB, respectively.

Based on the calculated mean values of signal quality indicators (RSRP, RSRQ, and RSSINR, –82.850 dBm, –13.60, and 12.74 dB, respectively), 56 cell phone users were classified into category-3 (worst). This was due to their cell phones mean output radiation density having the highest values (918.360 mW/m^2). Consequently, it was observed that the recorded cell phone output radiation in category-3 was twice as high as in category-1.

Upon analyzing Figure 3, a clear inverse correlation is evident between the cell phone's output power density and the mean values of RSRP, RSRQ, and RSSINR received from cell phone towers. As the signal strength from the cell phone tower decreases, the cell phone's output power density increases, notably when RSRP values indicate poor signal strength. The category-3, characterized as the worst signal quality received from the cell phone tower, registered the highest output power density of the cell phone, which was twice (18.336 mW/m^2) as high compared to the excellent category (9.428 mW/m^2). From the excellent to the worst category, there was an approximate decrease of 17.48, 41.66, and 36.63% in RSRP, RSRQ, and RSSINR values, respectively.

To summarize, based on the data in Figure 3, it can be inferred that the cell phone's radiation output power density reached its peak in category-3, coinciding with the poorest received signal quality from cell phone tower. Hence, it is advisable for users to refrain from making calls when the signal strength from the cell phone tower appears weak on their device. Doing so could lead to increased radiation exposure for the user, potentially causing harmful biological effects on the body.

In Table 3, Spearman's correlation coefficients between signal strength quality indicators and cell phone output power density are displayed. It is noteworthy that a strong negative correlation was observed among RSRP, RSRQ, and RSSINR with cell phone output power density. Importantly, all these correlations were statistically significant.

5. Discussion

This study delved into the correlations among various signal strength quality indicators and the output power density of cell phones, which was measured using the TRI FIELF EMF meter and NARDA SRM-3006 spectrum analyzer. The study highlights that the output power density of cell phones is significantly higher in situations where the signal strength quality indicators are categorized as 'good' and 'poor' (twice as high) in comparison to the 'excellent' category. These findings hold substantial implications for epidemiological research and should be duly considered.

Furthermore, the research underscores that an individual who makes fewer mobile phone calls in areas with poor signal strength of cell phone tower will experience greater RF-EMF exposure compared to someone making more calls in areas with good signal strength. This observation takes into account factors like the density of base stations in urban environments, the distance between the transmitter and receiver (distance between

Table 1. Standard Values of RSRP, RSRQ, and RSSINR Given by Industry (Techtrained et al., 2023)

Type of Quality	RSRP (dBm)	RSRQ (dB)	RSSINR (dB)
Excellent	> –80	⩾ –11	⩾ 20
Good	–80 ~ –90	–11 ~ –16	11 ~ 20
Mid-cell	–90 ~ –100	–17 ~ –22	0 ~ 11
End-cell	–100 onwards	–22 onwards	< 0

Table 2. Means of Output Radiation from 167 Cell Phones and the Quality of the Received Signal (RSRP, RSRQ, and RSSINR)

Types of quality	Radiation (mean) mW/m^2	RSRP (mean) dBm	RSRQ (mean) dB	RSSINR (mean) dB
Excellent (41)	9.43	–70.15	–12.08	12.90
Good (70)	14.14	–80.29	–13.60	12.74
Poor (56)	18.34	–82.85	–17.03	8.174

Table 3. Displays Spearman's Correlation Coefficients (*R*) among Output Power Density of Cell Phones, RSRP, RSRQ, and RSSINR for a Sample Size of 167.

RRSRP	RRSRQ	RRSSINR
–0.185	–0.350	–0.644

cell phone tower and cell phone users), line of sight, reflective surfaces, and building materials that affect the signal between the cell phone tower and the cell phone user. Additionally, the study recognizes the significance of base station attributes such as antenna height, direction, and frequency in determining magnetic field strength. The combination of these factors likely contributes to the wide range of quality of signal levels and output power density values of cell phone observed in this study.

Notably, output power density of cell phone demonstrates a strong correlation with the activation of multimedia services. As evidenced in Figure 1, mean outpower power density of 167 cell phone increases by 53.98% when all multimedia services are activated during a call, compared to when no services are active during the call. In Table 3, the values of Spearman's correlation coefficients between signal strength quality indica-tors and cell phone output power density are displayed. It is noteworthy that a strong negative correlation was observed among RSRP, RSRQ, and RSSINR with cell phone output power density. Importantly, all these correlations were statistically significant (Russel et al., 2018). These strong negative correlations and substantial fluctuations in output power density of cell phone concerning signal strength quality indicators represent potential sources of measurement error uncertainty that have not previously been accounted in epidemiological research.

To minimize exposure misclassification, it is recommended that in future epidemiological studies collect data based on factors that influence cell phone exposure levels, such as the distance between cell phone users and towers, line of sight, building materials, and the frequency used for service. Frequency bands with limited coverage yield weaker connections and result in increased exposure to cell phone output power.

6. Conclusions

An experimental study analyzed the radiation output from 167 cell phone users across various scenarios: no multimedia services, all multimedia services active, phone calls without multimedia services, and phone calls with all multimedia services. Using statistical analysis, the study found that cell phone output power density was highest during calls with all multimedia services, measuring 11.87 mW/m^2, compared to 7.743 mW/m^2 during calls with no multimedia services. The study utilized specific devices to explore the relationship between signal quality indicators and cell phone power density in the Navi Mumbai area. The findings suggest a strong correlation between signal quality and cell phone power density, recommending future epidemiological research to consider signal quality as a proxy for exposure. Additionally, we propose considering the correlation between cell phone power density and multimedia service activation during calls in future epidemiological investigations. To reduce potential risks and exposure to cell phone radiation, the study suggests precautions, which might include: (a) Limiting the activation of multiple multimedia services during phone calls. (b) Use speakerphone or a hands-free headset when making calls. (c) Limit the duration of calls and opt for text messaging when feasible. (d) Keep the phone away from your body when not in use, such as in a bag or on a desk. (e) Adhere to the manufacturer's recommendations and safety guidelines. (f) It is advisable for users to refrain from making calls when the signal strength from the cell phone tower appears weak on their device. (g) It is advisable to disable all unnecessary multimedia services on cell phones to reduce radiation exposure, particularly when placing the phone near the heart or reproductive system.

It is recommended that in future research we need to consider signal quality as a factor in assessing potential exposure and we should further explore the relationship between signal quality, multimedia service activation, and cell phone radiation to better understand and minimize potential health risks associated with cell phone use.

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