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Assessment of Radiofrequency Radiation Level in the Near Field of Selected Mobile Phones in Katsina State, Nigeria

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ABSTRACT
With the rapid advances in mobile communication technology, increase in mobile standards, and the consequent multiple applications of mobile phones in different fields, a higher risk of human exposure to radiofrequency (RF) radiation from the use of mobile phones is speculated. The study focused on the assessment of radiofrequency radiation levels in the near field of common mobile phones of different sizes used in Dutsin-Ma, Katsina State, Nigeria. Real-time measurements of power densities of 50 mobile phones of different sizes, types, and models at varying distances were done in isolated locations using a Cornet Electrosmog RF Meter. The power density was measured when each phone was in standby mode and when dialed at an interval of 10 cm between the RF meter and phone up to a maximum distance of 50 cm. The average power densities of investigated phones, in dialed mode, which range from $0.799 \pm 0.11\,\mathrm{mW/m^2}$ to $182.700 \pm 10.91\,\mathrm{mW/m^2}$, are below the reference level of exposure safety limit set by the International Commission on Non-Ionizing Radiation Protection for the general public. The RF radiation of the phones was found to be independent of the size of the phone. The data presented in this study can be used to promote user awareness, safety considerations, and informed decision-making regarding the safe usage of mobile devices. As long as a mobile phone is operated in the near field region, its power density does not necessarily decrease with distance.

KEYWORDS: mobile phone; near field; power density; radiation; radio frequency

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1. Introduction

Current technological advancement and multiple applications of mobile phones have made them a close companion for all who need to communicate seamlessly. The application of mobile phones in virtually every field of life and its lower cost compared to landlines has drastically increased the number of mobile phone users in Nigeria with the average person having two to three types/models of mobile phones [1–2]. Mobile phones use radiofrequency (RF) waves from the antenna to transmit and receive information in the form of voice, data, or image [3]. Hence, mobile phone users are exposed to RF radiation while the device is turned on, whether the device is in use or not [4]. At the current rate of mobile phone deployment, about 192 million Nigerians and billions from other nations of the world are exposed to radiation from mobile phones [2,5,6].

RF waves are Electromagnetic (EM) waves with frequencies below those of visible light [7]. Though these waves are classified as non-ionizing radiation, since they are incapable of ripping off electrons from an atom, they can penetrate matter to a depth that is equal to their power densities [8]. As a result of this characteristic of non-ionizing radiation, several studies have been devoted to investigating the possible negative effect of exposure to this radiation on humans. It has been reported that radiation from mobile phones causes heating when incident on body tissues [8,9]. The repercussions of this heating and the cumulative RF radiation exposure to human health stirred up great concern in the general public, leading to further research on the subject [5, 8–13]. Reports linked sleep disturbances, loss of appetite, nausea, headaches, fatigue, low blood pressure, slowing of heart contractions, cataracts, and brain cancer to excessive exposure to RF radiations [2,8]. The assessment of determinants of mobile phone output power level in a multinational study reveals that average power levels of mobile phones are higher than the minimum levels that can be achieved in GSM networks theoretically [14]. Determinations of the laterality of mobile phones used in adolescents by comparing hardware-modified phones and self-reported laterality have been studied [15]. The effect of the battery charge level of mobile phones on their RF radiation was reported previously [1]. The maximum electromagnetic wave emission from mobile phones was noticed when the battery was at 1% battery charge and while the battery was being charged with no significant difference observed for the waves emitted at charged levels between 5% and 80%. Examination of call-related factors influencing output power from mobile phones revealed that on average, output power levels used by mobile phones in rural areas with sparse Base Station are higher than those in densely populated areas [16].

To ensure the safety of phone users, different regulatory bodies, such as the Federal Communication Commission (FCC), International Committee on Non-ionizing Radiation Protection (ICNIRP), and Institute of Electrical and Electronic Engineers (IEEE) overseeing occupational and public exposure to non-ionizing radiation have set safety limits to RF radiation based on the four basic quantities for characterizing RF radiation energy, namely, Electric field strength (E), magnetic field strength (H), power density (S) and Specific absorption rate (SAR) [8,17,18]. The reference threshold power density values set by ICNIRP and IEEE for the general public include $4.5\,\mathrm{W/m^2}$, $9.0\,\mathrm{W/m^2}$ and $10.0\,\mathrm{W/m^2}$ for $900\,\mathrm{MHz}$, $1800\,\mathrm{MHz}$, and $2-300\,\mathrm{GHz}$, respectively [17,18]. By implication, exposure to RF radiation estimated by power density greater than the reference levels can affect health adversely.

Assessment of the radio frequency radiation risk from commonly used mobile phones among students reveals that the power density of the 30 mobile phones investigated was below 570.0 $\mu W/cm^2$ [2]. On the other hand, power densities above the ICNIRP reference level have been reported for mobile phones such as Tecno T21 (7.20 W/m^2), Samsung S4 (70.90 W/m^2), Nokia 2700 (6.70 W/m^2) [8]. Others, whose values were obtained within the measurement distance range of 5 cm to 30 cm, Asus (0.5407 mW/cm^2), Infinix 3 (0.5009 mW/cm^2), and Siccoo X100 (0.4506 mW/cm^2) were above the ICNIRP reference level of 0.45 mW/cm^2 [19]. There is every tendency that radiation level of phone models from different manufacturers can vary. Though the limit set by ICNIRP has been adopted in Nigeria, its actual compliance is questionable considering the influx of diverse models of mobile phones from different manufacturers into Nigeria.

Furthermore, as the propagation of radiofrequency waves is dependent on the antenna dimensions and wavelength, there is speculation that RF radiation from mobile phones may increase with the increase in size of the phone [20]. More so, if the description of propagation in the near fields of an antenna is complex because fields change very rapidly in this region, it may be wrong to assume that the power density in this region also decreases with distance as in the case of the far-field region. RF radiation exposure from some phones within the range of 5 cm to 30 cm has been assessed but with the emergence of the 4G network, the near field region has extended to 42 cm. Near field condition for electrically small antenna ($D \ll \lambda$) of size D operating at wavelength λ, at distance r usually employed in mobile phones is $r < \lambda/2\pi$ for reactive near field, $\lambda/2\pi < r < 3\lambda$ for radiating near field and $r > 3\lambda$ for far field [21]. Therefore, this study seeks to investigate the RF radiation level from current phone models of different sizes used by students of Federal University Dutsinma, Katsina State within the near field of mobile phones.

2. Theory of Radiofrequency (RF) Radiation from Mobile Phones

Radio waves that travel at the speed of light comprise magnetic (H) and electric (E) fields, which are at right angles to each other and the direction of travel. Hence, the E and H fields perpendicular to each other generate successive H and E fields which are perpendicular to the previous pair of fields [21]. The combination of these in-phase fields gives rise to a Poynting vector which is perpendicular to both E and H fields and in the direction of propagation [22]. The Poynting vector represents the energy flux (power density) in $Watts/m^2$ of an electromagnetic field. It gives the actual power propagated in space. The magnitude of the power density S is given as [7,8,21,23]:

$$S = E \times H \quad (1)$$

The electric field intensity E and magnetic field intensity H of an electromagnetic wave in free space are related through the characteristic impedance Z_s given by previous researchers [24,25]. Hence, for EM waves:

$$E = Z_s H \quad (2)$$

$$Z_s = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega \tag{3}$$

where μ_0 is the magnetic permeability of free space (1.26 x 10^{-6} H/m) and ε_0 is electric permittivity of free space (8.85 x 10^{-12} F/m) which implies that

$$\mathrm{S} = \frac{E^2}{377} = 377H^2 \tag{4}$$

Equation 4 reveals that the rate at which energy is propagated through a given medium is directly proportional to the square of the magnitude of the electric or magnetic field through that medium.

The strength of the magnetic field (H) produced around a conductor such as an antenna is given by [24]:

$$H = \frac{I}{2\pi r} \tag{5}$$

where r is the radius of the sphere enclosing the antenna. On the other hand, electric field strength (E) is expressed as [21, 24]:

$$E = \frac{q}{4\pi\varepsilon r^2} \tag{6}$$

where E is electric field strength, q is the charge between the antenna and any point on the spherical wavefront, and ε is the permittivity of the medium. Equations 5 and 6 show that the larger the antenna, the lower the E and H.

Omni–directional antennas are commonly employed in mobile stations. This type of antenna closely approximates an isotropic radiator which is a point source that radiates power at a constant rate uniformly in all directions. An isotropic radiator produces a spherical wavefront with radius R and all point distance R from the source lie on the sphere and have equal power intensities. Also, at any instant in time, the total power radiated P_r, is uniformly distributed over the total surface area of the sphere. Therefore, power density S at any point on the surface of a spherical wavefront is [26]:

$$\mathrm{S} = \frac{P_r}{4\pi R^2} \tag{7}$$

Equation 7 shows that the power density is directly proportional to the total power radiated but inversely proportional to the square of the distance from the source R.

3. Materials and Method

The level of RF radiation energy from mobile phones imparted on the exposed part of the body can be estimated by power density measurement. Where frequency selectivity is not a requirement, handheld electromagnetic field meters are usually employed because they are compact, simple, and easy to use [27]. In this study, the power density of 50 mobile phones of different types/models and sizes was measured with the use of an Electro smog RF meter having a frequency range of 100 MHz – 3 GHz, sensitivity range of -55 dB – 0 dB, and three display modes (mW/m^2, V/m, and dBm). The measurements were done in three locations expected to have little interference with other RF sources, namely, the technologists' office in the Physics laboratories (take-off and permanent sites) and a small room in the Katangaru area, all situated in Dutsinma, Katsina State, North Western Nigeria. All of the locations are situated within the academic environment for easy accessibility of current mobile phone models used by students. The phones were collected from willing students during their lecture hours. The size of each phone was measured with the aid of a meter rule. The measurements, which lasted for five days, were done indoors between 9:00 a.m. and 4:00 p.m. each day. This is usually the period of peak activities involving the use of mobile phones by students.

Before the actual power density measurement, the background radiation level for each location was measured for 6 min. The 6-min time was set by ICNIRP to reduce the effect of instantaneous rise and fall of power density on the measured results [1, 17]. The mean value of the background radiation in the locations was calculated and recorded as shown in Table 1. The actual power density measurements were also made within 6 min and the three most stable values were recorded [2]. The power density was measured in the following modes:

(i) Standby mode (S_{off})
(ii) Dialed mode (S_{on})
(iii) Dialed mode at distances from 1.0–50.0 cm, at 10.0 cm interval

The power density of the mobile phones was measured by placing the mobile phone and the meter on the table, 1 cm apart, when the phone was on standby, and when the phone was dialed. The range of measured mean power density values for each phone type is shown in Table 2. In its dialed state, the reading was taken with each phone placed at a 10 cm interval from the meter until 50 cm was reached. One of the measurement setups is shown in Figure 1. The 10 cm spacing was marked on the table with the meter rule before measurements. The measurements were repeated three times for each determination and the mean values were calculated and recorded. The actual values (S_{off}) and (S_{on}) of the mobile phone power densities were obtained by subtracting the background values (S_0), Table 1, from measured values. The plots of variation of measured power density with distance are presented in Figures 2–7.

To correlate the dimensions (L, B, H) of mobile phones to the actual power densities (S_{on}) for the investigated phones, Pearson correlation coefficients were calculated. The correlation coefficients provide insights into how strongly and in what direction (positive or negative) the dimensions (L, B, H) are related to the actual power densities (S_{on}) for the investigated phones. The magnitude of the coefficient indicates the strength of the relationship, with values closer to 1 or -1 indicating a stronger

Figure 1. Power density measurement set-up.

relationship. Values closer to 0 suggest a weak or no linear relationship. The formula for calculating the Pearson correlation coefficient $(r)$is given by [28]:

$$r = \frac{n\sum xy-\sum x\sum y}{\sqrt{(n\sum x^2-(\sum x^2)(n\sum y^2-(\sum y^2)}} \tag{8}$$

where:

- x and y are the values of the two variables being correlated (in this case, dimensions L, B, or H and power density).
- n is the number of data points.

The phones used for investigation are Samsung phones – 6, Infinix phones – 13, Tecno phones – 10, Nokia phones – 7, Gionee phones – 6, Itel phones – 3, LG phones – 2, Vivo phones – 1, iPhone – 1 and Kgtel phone -1.

4. Results

Results of background power densities (S_0) of the locations used (Table 1) and the actual power densities (S) of different sizes and models of phones measured when ON but inactive (S_{off}) and when dialed (S_{on}) at different distances from the meter (Figures 2–7) are presented. The range of measured power densities of the different phones investigated when on standby and when dialed is presented in Table 2 while the phones with maximum power densities when dialed are shown in Table 3.

Table 1. Measured background power density (S_0) of the three locations used.

S/No.	Locations	S_0 (mW/m²)
1	New physics laboratory	0.006
2	Kadangaru area	0.027
3	Physics departmental laboratory (permanent site)	0.448

Table 2. Range of measured power densities of different phones investigated when standby (S_{off}) and when dialed (S_{on}).

S/N	Phone name	Number of phones investigated	Range of S_{off} (mW/m^2)	Range of S_{on} (mW/m^2)
1	Samsung	6	0.014 – 0.016	0.799 ± 0.11 − 160.150 ± 3.69
2	Infinix	13	0.012 – 0.693	1.277 ± 0.02 – 46.505 ± 2.64
3	Tecno	10	0.005 – 0.321	1.884 ± 0.37– 68.770 ± 0.77
4	Nokia	7	0.001 – 0.041	12.521 ± 0.32– 182.7 ± 10.91
5	Gionee	6	0.002 – 0.021	2.906 ± 0.72 – 18.270 ±1.46
6	Itel	3	0.032 – 0.041	3. 572 ± 0.14 – 15.432 ± 0.77
7	LG	2	0.036 – 0.037	1.275 ± 0.42 – 10.132 ± 0.48
8	Others	3	0.015 – 0.112	3.039 ± 0.97– 162.979 ± 0.57

Table 3. Size and model of phones with maximum power density when dialed (S_{on}).

S/N	Phone model	L (cm)	B (cm)	H (cm)	S_{off} (mW/m²)	S_{on} (mW/m²)
1	S1	14.000	7.000	0.600	0.060	160.15±3.69
2	In4	15.000	7.800	0.700	0.018	46.51±2.64
3	T5	15.000	7.000	0.400	0.016	68.77 ±0.77
4	N7	8.700	6.500	1.000	0.003	182.70 ±10.91
5	G3	14.500	5.500	1.000	0.005	18.27 ±1.46
6	It2	7.100	4.200	0.900	0.041	15.43 ±0.77
7	Ip1	13.600	6.600	0.700	0.112	3.57 ±0.48
8	L2	7.200	4.500	0.700	0.036	10.13 ±0.15
9	V1	13.000	6.600	1.000	0.015	3.04 ±0.33
10	K1	11.000	4.500	0.700	0.027	162.98 ±0.57

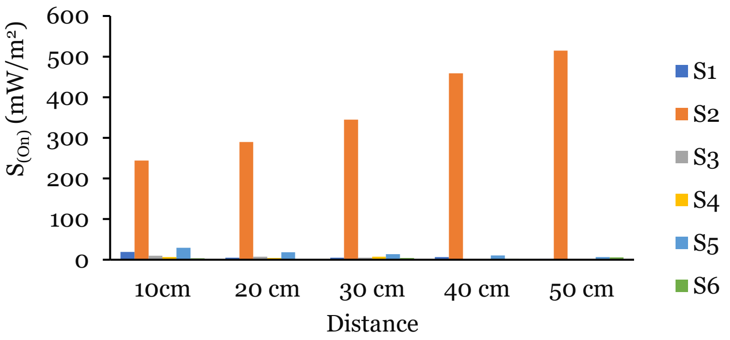

Figure 2. Power densities of dialed Samsung phones at varying distances.

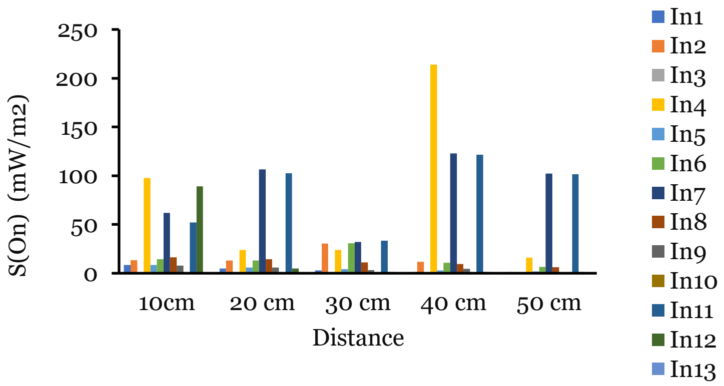

Figure 3. Power densities of dialed Infinix phones at varying distances.

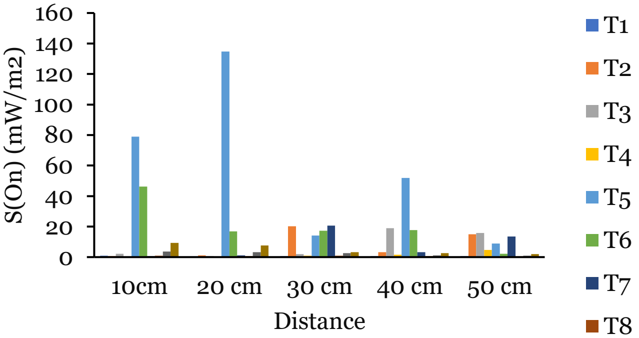

Figure 4. Power densities of dialed Tecno phones at varying distances.

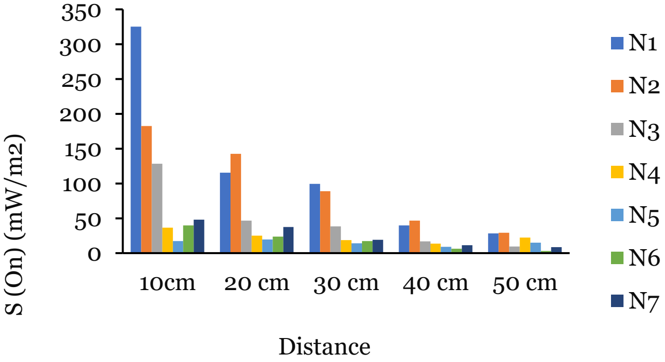

Figure 5. Power densities of dialed Nokia phones at varying distances.

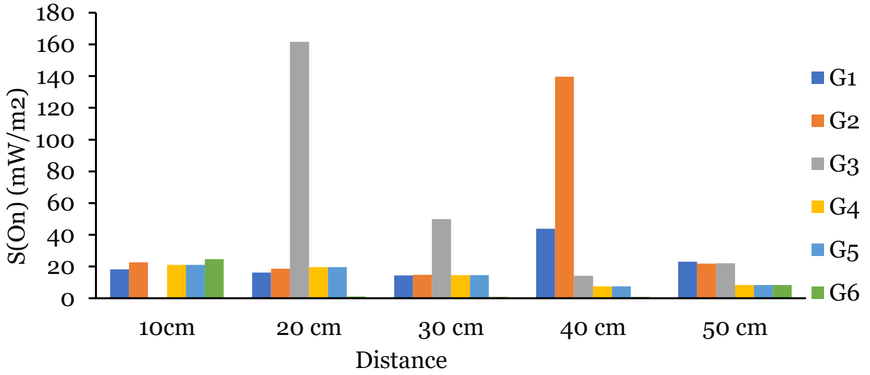

Figure 6. Power densities of dialed Gionee phones at varying distances.

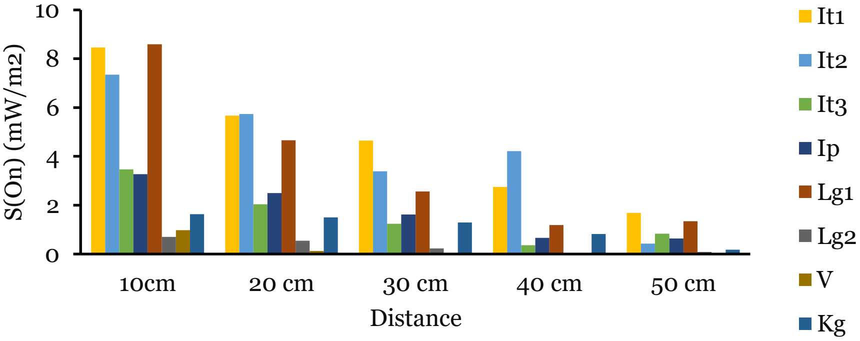

Figure 7. Power densities of dialed other phones at varying distances.

5. Discussion

In line with work done by previous authors, Table 2 reveals that the power radiated by the phones when dialed is significantly higher than when the phones were in standby mode [1,2]. This is because when dialed, a phone utilizes power to connect to the mobile network as it makes an effort to overcome interference from other devices and effects of parameters in the practical environment in which the transmission and reception of information take place [18]. On the other hand, in standby mode, a phone only sends a signal to the nearby base station at regular intervals, to register its presence and position [1]. This increase in power density when the phone is dialed suggests that phone activity, such as making a call, leads to a higher level of radiation emission.

The power density of 49 out of the 50 phones investigated, with a length of 6.00 cm–16.00 cm, breadth of 4.00 cm-9.10 cm, and height of 0.40 cm–1.00 cm, did not show any regular trend. It was observed that some phones with relatively small dimensions produced higher power density than the ones with larger dimensions as depicted in Table 3. For instance, phone model N7 has a notably high power density when dialed (S_{on}) of $182.700 \pm 19.91\,\text{mW/m}^2$ despite its compact size; while phones such as Ip and V1, with relatively higher sizes have lower power densities (S_{on}) values of $3.039 \pm 0.97\,\text{mW/m}^2$ and $3.572 \pm 0.48\ \text{mW/m}^2$, respectively. However, a Samsung phone (S6) with dimensions $25.00\text{ cm } \times 15.00\text{ cm } \times 1.00\text{ cm}$ showed a remarkable low value of power density ($0.799 \pm 0.11\,\text{mW/m}^2$). Pearson correlation coefficient was calculated to further validate the relationship between phone dimension (L, B, H) and the actual power densities (S_{on}), reveal that only the length, breadth, and height of Nokia phones have a positive correlation(0.899, 0.204, and 0.290, respectively) with S_{on}. Dimensions of other phones have a weak negative correlation (< -0.3) with S_{on} indicating a weak nonlinear relationship between them. These findings show that the size of the phone alone may not necessarily impact its power density when active/dialed. Other factors, such as internal components and design, can significantly affect the level of RF radiation emissions.

As shown in the results of variation of actual power density with distance presented in Figures 2–7, out of the 50 phones investigated, 19 (38%) obeyed the inverse square law strictly, and 31 (62%) had no distinct relationship with an increase in distance in the near field (≤ 50 cm) of the mobile phones. This implies that the RF radiation of most mobile phones does not have any specific trend with an increase in distance in this zone. This may be attributed to variations in the position/direction of the meter during measurement. Measurements made in the direction of the main lobe will be high compared to those captured at the side lobes. Other contributory factors include network signal level (which may be impacted by the distance between the base station and the mobile station and the nature and weather conditions of the host environment) and phone battery level at the period of measurement [12].

The analysis of the correlations between the dimensions (L, B, H) of phones and the actual power densities (S_{on}) at different distances (10 cm, 20 cm, 30 cm, 40 cm, 50 cm) can provide insights into how these physical attributes relate to the emitted radiation levels. The correlations between the dimensions (L, B, and H) of all phones and S_{on} at different distances are inconsistent, with some positive and some negative. Overall, the correlations are weak (ranging from -0.016 to 0.368), indicating that there is little or no linear relationship between the size of the phones and power density in the near field. The weak correlations suggest that the size and shape of the phone, as represented by its length, breadth, and height, do not strongly predict the emitted radiation levels at these specific distances. The analysis of phone models' power density at varied distances serves to promote user awareness, safety considerations, regulatory compliance and informed decision-making regarding the safe usage of mobile devices. It should be pointed out that RF radiation from all 50 phones is lower than the reference level of exposure limit of 4.5 W/m^2 , 9.0 W/m^2 and 10.0 W/m^{2}set by ICNIRP and IEEE for the general public using 2G, 3G, and 4G mobile phones, respectively. This is in contrast with the results obtained by previous research [8, 19]. The lower values obtained in this study may be a result of efforts made by mobile phone manufacturers to improve the safety of their products.

6. Conclusion

The assessment of RF radiation from 50 mobile phones of different types, models, and sizes within a 50.0 cm (at 10 cm intervals) distance was conducted by the measurement of the incident power density of each phone. Based on the data obtained in this study, it is challenging to draw concrete conclusions about the relationship between phone size and power density. To establish correlations, more data points covering a broader range of phone models and dimensions would be needed.

Estimated RF radiation from 19 phones (38%) obeyed the inverse square law while others (62%) did not have any definite trend within the near field of the mobile phones. The variations in power density at different distances highlight the importance of maintaining a safe distance from mobile phones, especially when they are in active use.

The study established that the RF radiation from all 50 phones is lower than the reverence level of exposure limit set by ICNIRP and IEEE for the general public, thereby ruling out the anticipated increase in the risk of exposure due to the increase in mobile standards in current phones used by students in Federal University Dutsinma, Katsina State, Nigeria.

However, it is worth noting that the study is limited by the inability to measure the power densities of the phones in the same location, day, and period. Hence, the data may have been influenced by variations in network traffic, phone battery levels, weather conditions, and distance from base stations. These factors not considered in the investigation, may have a more significant impact on radiation levels. Further research and analysis may be needed to better understand the factors influencing power density in mobile phones.

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Conflict of Interest Statement

The authors declare that this research was not funded by any external body that can attract any conflict of interest.

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References

1. Javad, S.; Parvin, N.; Mohammed, R. M.; Mansour, S.; Rami, R. The effect of battery charge levels of mobile phones on the amount of electromagnetic wave emission. *J Environ Health Sci Eng* **2019**, *17*, 151–159.
2. Oyero, O.P.; Oladosu, I.A.; Adeleke, D.K.; Akande, I.O.; Ajayi, A.P.; Oni, A.A.; Oni, E.A.; Ajani, A.S. Measurement of radiofrequency level from commonly used mobile phones among the students of Adeleke University Ede. *Adeleke Uni J Sci* **2022**, *1*, 31-37.
3. Mousa, A. Electromagnetic radiation measurement and safety issues of some cellular base stations in Neblus. *J Eng Sci Tech Review* **2011**, *4*, 35–42.
4. Vijayalakshmi, L.; Davi, P.N. Impact of RF radiation from mobile phones on human health and its remedies. *J Appl Res Tech* **2020**, *18*, 269–278.
5. Miller, A.B.; Sears, M.E.; Morgan, L.L.; Davis, D.L.; Hardell L.; Oremus, M.; Soskolne, C.L. Risk to health and wellbeing for radio frequency radiation emitted by cell phones and other wireless devices. *Front Pub Health* **2019**, *7*, 223.
6. Olukunle, O.O.; Olatunde, M.O.; Abraham, A.A.; Olaoluwa, P.O.; Mustapha, K.L.; Oluseye, D.D. Evaluation of power density radiation from selected mobile phone base stations in Ogbomoso, South Western, Nigeria. *Int J Health Sci Res* **2020**, *10*.
7. Kennedy, G.; Davis, B; Prasanna, S.R.M. *Kennedy Electronic Communication System*, 5th ed.; Tata McGraw Hill Education Private limited: New Delhi, India, 2011; pp. 265–287.
8. Akpolile, A.F; Ugbede F.O. Assessment of radiofrequency radiation levels of mobile phones and evaluation of specific absorption rate to tissues of human head layer. *FUW Trends Sci Tech J* **2019**, *4*, 643–650.
9. National Cancer Institute; Cell Phone and Cancer Risk Fact Sheet. Available online: https://www.cancer.gov/aboutcancer/causesprevention/risks/radiation/cell-phone-fact-sheet (accessed on 25 September 2022)
10. Cell Phones Radio Frequency Radiation: A report of National Taxicology Program (NTP) US Department of Health and Human Services. Available online: https://ntp.niehs.nih.gov/go/cellphone (accessed on 29 September 2022)
11. Cardis, E.; Varsier, N.; Bowman, J.D.; Deltour, I.; Figuerola, J.; Mann, S.; Moissonnier, M.; Taki, M.; Vecchia, P.; Villegas, R.; Vrijheid, M.; Wake, K.; Wiart J. Estimation of RF energy absorbed in brain from mobile phones in interphone study. *Occup Environ Med* **2011**, *68*, 686–693.
12. Oluwafemi, I.B.; Adeoye, J.O.; Faluru, D.M.; Obasanya, D.D. Investigation of factors affecting power density radiation of mobile phones. *Int J Eng Tech* **2020**, *9*, 223–228.
13. Koppel, T.; Ahonen, M.; Carlberg, M.; Hedendahl, L.K.; Hardell, L. Radiofrequency radiation for nearby mobile phone base stations in a case

comparison of one low and one high exposure apartment. *Onco Lett* **2019**, *18*, 5383–5391.

14. Vrijheid, M.; Mann, S.; Vecchia, P.; Wiart, J.; Taki, M.; Ardoino, L.; Armstrong, B.K.; Auvinen, A.; Bédard, D.; Berg-Beckhoff, G.; Brown, J. Determinants of mobile phone output power in a multinational study: Implications for exposure assessment. *Occup Environ Med* **2009**, *66*, 664-671.
15. Inyang, I.; Benke, G.; McKenzie, R.; Wolfe, R.; Abramson, M.J. A new method to determine laterality of mobile telephone use in adolescents. *Occup Environ Med* **2010**, *67*, 507–512.
16. Hillert, L.; Ahlbom, A.; Neasham, D.; Feychting, M.; Jarup, L., Navin, R.; Eliot, P. Call-rated factors influencing output power of mobile phones. *J Expo Sci Environ Epidemiol* **2006**, *16*, 507-514.
17. International EMF Exposure Guideline. Report by GSM Association (GSMA). Available online: https://www.gsma.com/publicpolicy/wp-content/uploads/2021/10/GSMA_ (accessed on 15 September 2022)
18. ITU EMF Guide. Available online: https://www.itu.int>net4>mob>ituemf. (Accessed on 15 September 2022)
19. Oluwafemi, I.B.; Adeoye, J.O. Mobile phones radiofrequency radiation assessment based on call related factors and physical conditions from selected mobile phones. *European J Eng Tech Res* **2020**, *5*, 343–347.
20. Pranas, B.; Raimonds, B.; Saulius, V. Research and evaluation of intensity parameters of electromagnetic fields produced by mobile communication antennas. *J Environ Eng Landscape Mgt* **2012**, *20*, 273–284.
21. Huang, Y.; Boyle, K. *Antennas from Theory to Practice*, 1st ed.; John Wiley and Sons Ltd: West Sussex, UK, 2008; pp. 35–125.
22. Power and energy in electromagnetic fields. Available online: http://Www.Ece.Ksu.Edu/~Khc/Notes/Emt/Poynting.Pdf. (accessed on 9 October 2021)
23. Electromagnetic fields and radiations in antennas. Available online: http://Www.Em- Fields_in_Antennas.Pdf. (accessed on 15 February 2022)
24. Branislav, M.N. *Electromagnetics*; Pearson Education Inc: Upper saddle River, New Jersey, USA, 2011; pp. 426–451.
25. Fraser, W. *Telecommunications*; CBS Publishers and Distributors PVT Ltd: New Delhi, India, 2003; pp. 691–731.
26. Wayne, T. *Electronics Communication System: Fundamental Through Advanced,* 6th ed.; Dorling Kindersley: India, 2007; pp. 101–156.
27. Measurement of electromagnetic radiation in urban environment. Available online: https://www.researchgate.net/publication/350238802 (accessed on 15 March 2023)
28. Field, A. *Discovering Statistics Using IBM SPSS Statistics*, 4th ed.; Sage: New Delhi, India, 2013; pp. 272–275.