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Temporal variation of exposure from radio-frequency electromagnetic fields around mobile communication base stations

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A B S T R A C T

Radiofrequency electromagnetic fields (EMF) are subjected to a public perceived risk of adverse effects, and results from many epidemiology studies were largely inconclusive. Results of EMF measurements vary among researchers due to co-varieties of factors among which are temporal variations. This study assessed temporal variation of exposure from radiofrequency electromagnetic fields from some selected MCBSs in Kuje Area Council, in Nigeria. The Mobile phone frequencies band considered in the study area are GSM 900 MHz, GSM 1800 MHz, and Wi-Fi 2400 MHz. Using a selective radiation spectral analyzer HF- 2025E, measurements of peak power densities and their corresponding time of occurrence were made. The result shows that the RF fields vary with time in different locations for various power densities. When the aggregate of maximum exposures was compared with the international commission on Non – ionizing Radiation Protection (ICNRP) guidelines, they were found to be below the recommended limit.

Introduction

The proliferation of the number of mobile communication base stations (MCBSs) has benefited the way of living which allows easy communications with comfort, providing them opportunities to remain connected to near and far distances [1]. However, the public was concerned about possible effects that were connected with this type of radiation emanating from the mast. This phobia has cause arguments on both proposed or existing siting of base stations, most especially closed to residential and school environments [2]. Most of the concerns arise from controversial popular press reports linking radia-

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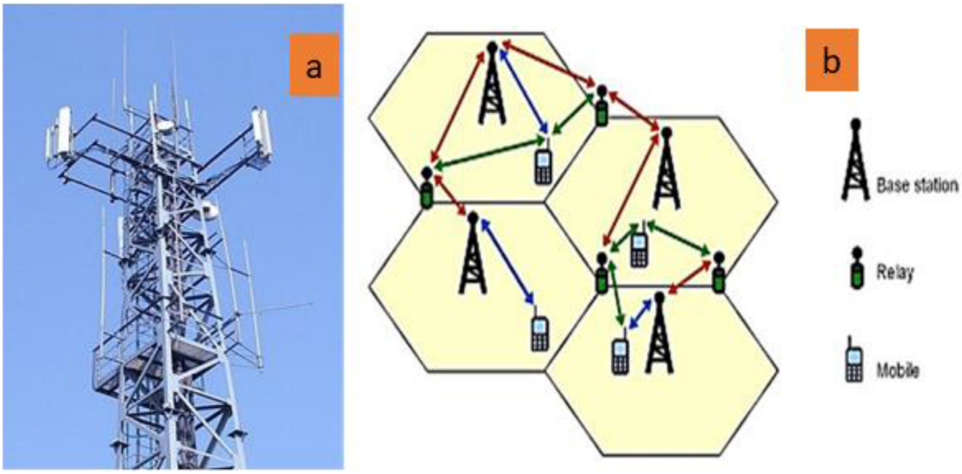

Fig. 1. (a) Mobile communication base stations (b) Showing interconnectivity between the base stations and Mobile phones.

tion from base stations with scientific research to cancer. [3,4]. In the scientific community, various studies have attempted to determine a correlation between non-ionizing radio-frequency (RF) radiation and adverse health effects on humans, of particular concern is the public's perceived health risk from RF fields. Researchers have extensively studied various indicators of human health [5,6]. Victor & Dada [7] noted that there has been a significant increase in the usage of wireless communication devices over the past decade, as well as an increase in the possible health hazards that emanated with the use of these devices, nevertheless, these devices are still important in modern society. It is often argued that handsets posed more exposures to humans compared to the base stations as a result of continuously exposing people for 24 – hours per day. In addition to the scientific reports, these concerns may also due to the baseless assumption from the public that as demand for cellular is increasing, so also the emission radiation levels from the mobile communication base stations increases [8]. There is always a misconception between cellular systems operation and broadcasting radio. Revenues are related to the coverage area at a particular time in radio broadcast either Medium Wave or Frequency Mode transmitter (AM or FM), which make their stations to intensifies the effective radiated power of the transmitter. Unlike cellular systems, the principle is based on the allocation of frequency within the limited available number of cells that can be used and reuse within a geographical area [1,9,10]. The cellular system is, therefore, requires a limited level of radiation power to operate and control radiofrequency interference. To minimize interference with other cells operating at the same frequencies, system capacity can be accomplished by increasing the number of cells in the system and decreasing the number of users with low power transmitters in the cell accordingly [11,12]. One area that is not well understood about base station pollution, except for system planners and engineers, is that of the effects of signal power exposure from a single spot on the ground that temporarily differs (over time) as a result of the systemic radiation energy propagated in complex environments (i.e. urban areas) based on the cellular call traffic of the base-stations. These effects are usually unpredictable and can cause irregular varying or undulated fluctuations in the level of exposure [13]. They also cause variation in exposure conditions from point to point on the ground surface. Two or more closely spaced points may indeed differ by a small amount or have the same exposure levels [10]. But the exposure effect on the person's around the mobile communication base stations may be high or variable irrespective of the person is moving or not. Broadband measurement of electromagnetic radiation around the base stations has been reported using exposimeter [14]. However, these assessments are not reliable due to the limitation of exposimeter. For accuracy and reliability data, narrowband measurement of temporal variation from the different environment was assessed to examine whether RF fields power density varies over time(i.e. temporally), so we can compare RF fields power density times to human activity peak time, assuming the intensity levels of RF fields power density varies temporally [15]. Also, repetitive standardized was design to measure daily in the same area and time, so conclusions were able to draw about temporal variations, being the first time in that area [16].

This research is therefore examined the temporal (i.e. time) variability of RF fields of GSM frequency band 900 MHz, GSM Frequency Band, 1800 MHz, and Wi-Fi frequency band 2400 MHz. And a long time evolution for 24 h at different outdoor is presented. The pictorial representation of the mobile communication base station is as shown in Fig. 1

Related works

The level of exposure of radiofrequency radiation and power distributed around different mobile base stations in Keffi town, Nasarawa state was reported [28]. In their report, fifteen mobile base stations were randomly selected from four major mobile phone operations in Nigeria. Measurement of electromagnetic radiation level was recorded at a distance of 50 to 190 m away from each mobile station using a Radiofrequency meter (Electqosmog ED-155A). The results show that different base stations have different average power density and the average value for power density contribution to RF was 0.0287872 W/m ^{2} which complies with the exposure safety limit set by ICNRP.

The level of exposure to radiofrequency radiation of selected mobile base stations in Obio, Akpor local Government areas in River State, Nigeria was reported [29]. Specific absorption rate (SAR) was used to determine the level of exposure to electromagnetic radiation. Data were obtained using EMF meter and electric field intensity for selected mobile base stations. Data were recorded up to a distance of 300 m away from each of the base stations of different phone operators mast for GLO, MTN AIRTEL in Nigeria. The power density and specific absorption rate were assessed from electric field strength. The results revealed that the mean amount of power density is from 1.5183 W/m^2 to 9.5083 W/m^2 and SAR is in the range of 0.0037 W/mg to 0.0084 W/kg and the results were compared with that of ICNIRP guideline which was found to fall below ICNRIP recommendation. This showed that the public is safe from these radiations.

Gertrude et al. [30], report the temporal variation of radiofrequency electromagnetic field exposure from mobile base stations in a sensitive environment. In their report, five sensitive environments were selected and a narrow band of radiofrequency of electromagnetic exposure was performed. They investigated indoor micro-environments such as schools, residential areas, hospitals, and commercial areas all in Kapala in Uganda. Measurement was set up at every location with calibrated Aaronia OmniLOG70600 antenna and installed MCS software while allowing the set up to run for 24 h for three days in a week to sweep the signal of a narrow-band frequency of power density of that area. Maximum exposure was recorded at every measurement location for each signal of GSM 900, GSM 1800, UMTS 2100, and LTE 2500 and was compared with the international commission on non-ionizing radiation (ICNRP) guidelines and they were found to be relatively lower than the guideline. Hence assured public safety.

Broad and measurement of the electromagnetic field were carried out at different regions of Ijebu- Igbo in Ogun State, Nigeria [31]. In this study, ten (10) MBTS sites at GSM 900 and 1800 WCDMA bands were measured and recorded. Data were obtained from 20 cm to 100 cm away from each mobile station at intervals of 20 m. Power density and electric field intensity were assessed using handheld broadband 3 axis RF field meter operation at a frequency of 50 MHz to 3.5 GHz. Electric field strength and power density data were recorded at each point. The results revealed that the maximum exposure level of power densities measured at different MTS was found to be in the range of 0.001188 W/m^2 to 0.0021735 W/m^2 which was found to fall below the ICNIRP guideline, therefore, it is safe for public use.

Mobile phone technology has grown rapidly in the last decade due to its advantages and it has become a necessary and omnipresent part of our everyday life. As these technologies continue to satisfy our desire for connectivity so does the electromagnetic radiation range that carries signals become diverse and complex. Although exposure levels from radiofrequency generally remain below the standard limit (ICNIRP, 1998). The continuous exposure from transceiver stations concerning its proximity to the public and residential areas was of great concern in our society today. Peoples perceived that exposure signals from base stations may be associate with various non-specific physical symptoms and ecological effects.

Numbers of research have been conducted on these over decades where spot and personal measurements are performed aimed at characterizing the temporal and spatial variation of exposure of radiofrequency exposure during the day. However, exposures to electromagnetic vary temporally over time due to variation of active users and the changes in environments this tend to neglect the spatial variation dimension. Despite various research published on monitoring radiation signals from mobile stations installed in some cities. The available information is scarce and there is a need for more data to educate the populace. More importantly, the results are yet to be satisfactory. It is imperative that we must assess the situation about the health issue that the public may be exposed to. In this paper time-dependent (Temporal variation) of the electromagnetic field was analyzed in order to evaluate radio-frequency exposure level by measuring power density and to determine whether or not the radio frequency exposure from the region exceeds the maximum permissible exposure limits.

Method

This survey was carried out at the Kuje local government area (LGA) of Abuja, FCT in the North Central of Nigeria (See Fig. 2). The Spectran HF- 2025E Spectrum analyzer was in spectrum analysis mode and set to measure RF fields power density of narrowband cell phone frequency band GSM 900 MHz, cell phone frequency band GSM1800 MHZ, and WiFi frequency band 2400 MHz every second. Meanwhile, the GPS was set to record temporal data every second as well along the roadsides of the area of interest. Five sensitive areas were investigated which are Pasali, Low cost (LC), Secretariat road (SR), Market road (MR), and Tipa garage (TG). The equipment was set up at every location of measurement. The equipment was calibrated Aaronia spectran HF-2025E spectrum analyzer, hyperLog measurement antenna, Spectran HF analyzer, and communication software (Aaronia Software) installed in a Laptop. The Spectrum Analyzer was connected to the Laptop via Aaronia USB for data logging. The sample was collected within the 7 h to 19 h of the day which were divided into Six two-hour block times. Data were collected around the mobile communication base station following the designed path during the fieldwork. Besides, the study design repetitive standardized measurements daily, at the same time, and are based on time- block which enables us to conclude temporal variations, in the area of study. Data collected were store in a computer for further processing. Table 1 shows the geographical location/Coordinate of the survey area and Fig. 3 shows the equipment used for measurement.

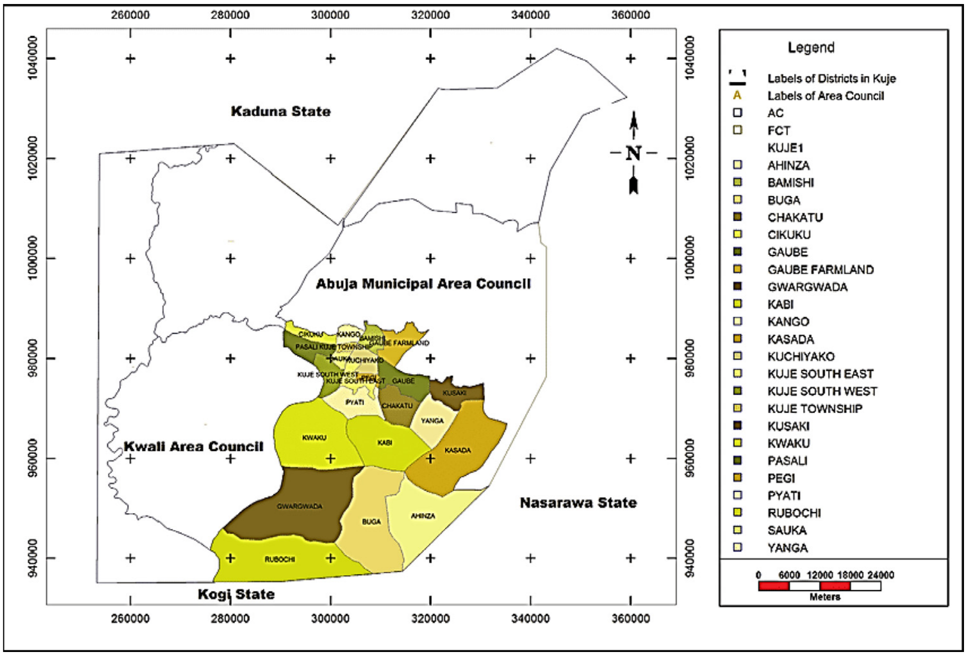

Fig. 2. Geographical location of the study showing the survey area in Kuje LGA of Abuja.

Table 1
Geographical location/ Coordinate of survey Area in Kuje, FCT Abuja.

AREAS	COORDINATES	
	NORTHING	EASTING
Pasali	8.882514	7.232670
Low cost	8.883395	7.230686
Secretariat Road	8.882596	7.232567
Market Road	8.882795	7.232301
Tipa Garage	8.883351	7.230740

Table 2
Sample of Raw RF Data, per second of Entire Sampling Period.

Local Time	Lat N	Long E	900 MHz Power Density (μW/m^2)	1800 MHz Power Density (μW/m^2)	2400 MHz Power Density (μW/m^2)
12:01:05	8.883578	7.231248	38.91	41.12	13.12
12:02:08	8.883554	7.231277	42.93	42.56	3.19
12:03:16	8.883529	7.231309	49.84	12.34	1.43
12:04:04	8.883507	7.231309	67.91	44.91	0.98
12:05:21	8.883475	7.231381	74.24	26.41	4.72
12:06:10	8.883458	7.231411	70.73	46.34	1.26
12:07:14	8.883435	7.231433	21.15	41.02	2.33
12:08:22	8.883405	7.231461	12.62	22.37	1.16
12:09:13	8.883394	7.231489	18.57	48.61	0.7

Results and discussion

To make the work more feasible and practical, 8 h was divided into 4 (two-hour time block) and each of three (3) time- blocks were randomly assigned to a day for four weeks of data collection. The starting time for which the data was collected began within a given time block. The United Environment Programme warns against a failure to control for temporal variability in human exposure assessment e.g. the bias of a single "random–day" sample and suggests a sample period of several days [15]. Therefore, this study is characterized by the entire 7 h of data sampling. Table 2 displayed samples of raw RF data per second of the entire sampling period

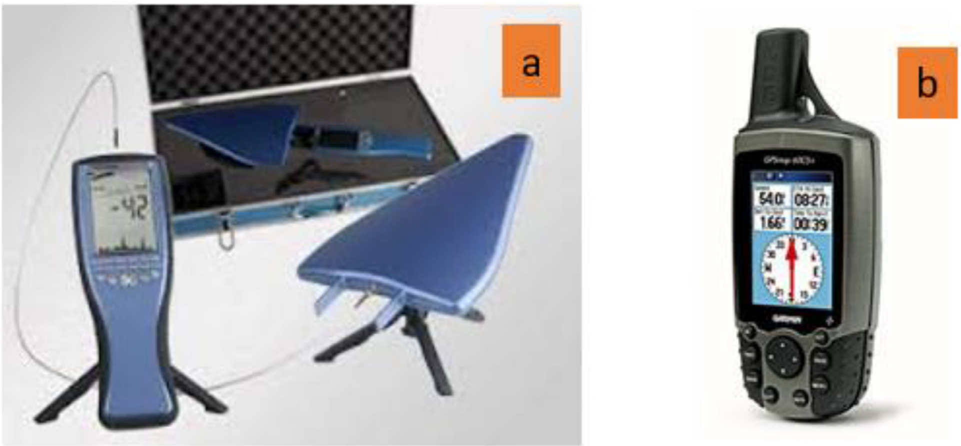

Fig 3. (a) SPECTRAN HF – 2025E RF Handheld Spectrum analyzer (b) GPSMAP 60CSx.

Temporal variation of RF frequency band GMS 900 MHz

Fig. 4 shows the temporal variation of the RF field signal of GSM 900 MHz from five measurement area for 7 h. Temporally there were definite variations that were visible in Fig. 4. These can be seen clearly where some of the five superimposed power density signals taken at the various time are different; some shifted towards larger or smaller. Tipa garage experience high exposure signal of 900 MHz frequency band within 12.00 to 13.00 h as well as 15.00 to 16.00 h in the day with an exposure peak of 278 μW/m^2. Compliance tests need to be carried out during this period. Market road exposure power density was slightly high most especially in mid-day around 12.00–13.00 h and also late hour. Around 17.00–18.00 h, signal strength was noticed to be higher within this period and closed to 285 μW/m^2. Compliance tests need to be carried out in those periods.

Secretariat road experience low signal strength during the data collection as it can be seen from the plot, it as clearly seen that most of the signal fell below 220 μW/m^2 except some spike that showed around 13 h and between 14–15 hour with the highest peak of 320 μW/m^2 that need to be tested for compliance.

The best time to test for compliance in Pasali for 900 MHz frequency field band is around 13 h of the day with the highest peak about 400 μW/m^2 while the remaining hours of frequency signal appear to be uniform and below 200 μW/m^2 in that area.

In Low-cost exposure signal to 900 MHz frequency band signal area was slightly high throughout the day except for around 13 h and 14 h that appeared to be 420 μW/m^2 while other hours fall within 0–220 μW/m^2 and those two hours that was the high need to be tested for compliance. Generally, exposure to the 900 MHz frequency band was higher in Low cost and Pasali as we can see in Fig. 4. It falls within the range of 0–420 μW/m^{2,} while Secretariat road signal exposure is slightly high and falls within the range of 0–330 μW/m2 about signal strength, appeared to be low at Tipa garage and the Market road which fall within the range of 0–279 μW/m^2. All these values fall below the ICNIRP value for the 900 MHz frequency signal limit which is 4.5 μW/m^2.

Temporal variation of rf frequency band gms 1800 MHz

Fig. 5 shows the temporal variation of the RF field signal of GSM 1800 MHz from five measurement areas in Kuje- Abuja between 11.00–18.00 h of the day. Temporally there were definite variations that were visible in Fig. 5. These can be seen clearly where some of the five superimposed signals of power density taken at the various time are different; some shifted towards larger or smaller. The following observation can be deduced from the figure. Tipa garage temporal variations of GSM 1800 MHz power signal were slightly high. Maximum exposure was observed between 12.00–14.00 h with a signal strength of about 270 μW/m^2. Therefore, compliance tests should be performed during this period while other hours fall below 180 μW/m^2. At market road from Fig. 5 exposure signal of 1800 MHZ appear to be constant but slightly high between 12.00–13.00 and 13–14 h and the spike also rose toward 17.00–18.00 h of the day with the highest peak of 279 μW/m^2. A compliance test is necessary at this period. The secretariat exposure signal has its signal peak in 12.00 h with a power density of 320 μW/m^2. Therefore, the need for compliance tests while remaining hours appear to be constant with signal strength falling below 200 μW/m^2. Pasali exposure to 1800 MHz frequency band was below 200 μW/m^2 apart from 11.00 h that have its' peak of signal strength of about 410 μW/m^2 which needs to test for compliance. At Low cost, exposure to GSM 1800 MHz was relatively low between 11.00–14.00 h within signal strength below 184 μW/m^{2,} and signal began to rise between 14.00–15.00 h and fall again between 15.00–16.00 h. The peak signal exposure power density was noticed within 14.00–15.00 h and 16.00 h with a power density of 276 μW/m^2. Compliance tests need to be carried out around

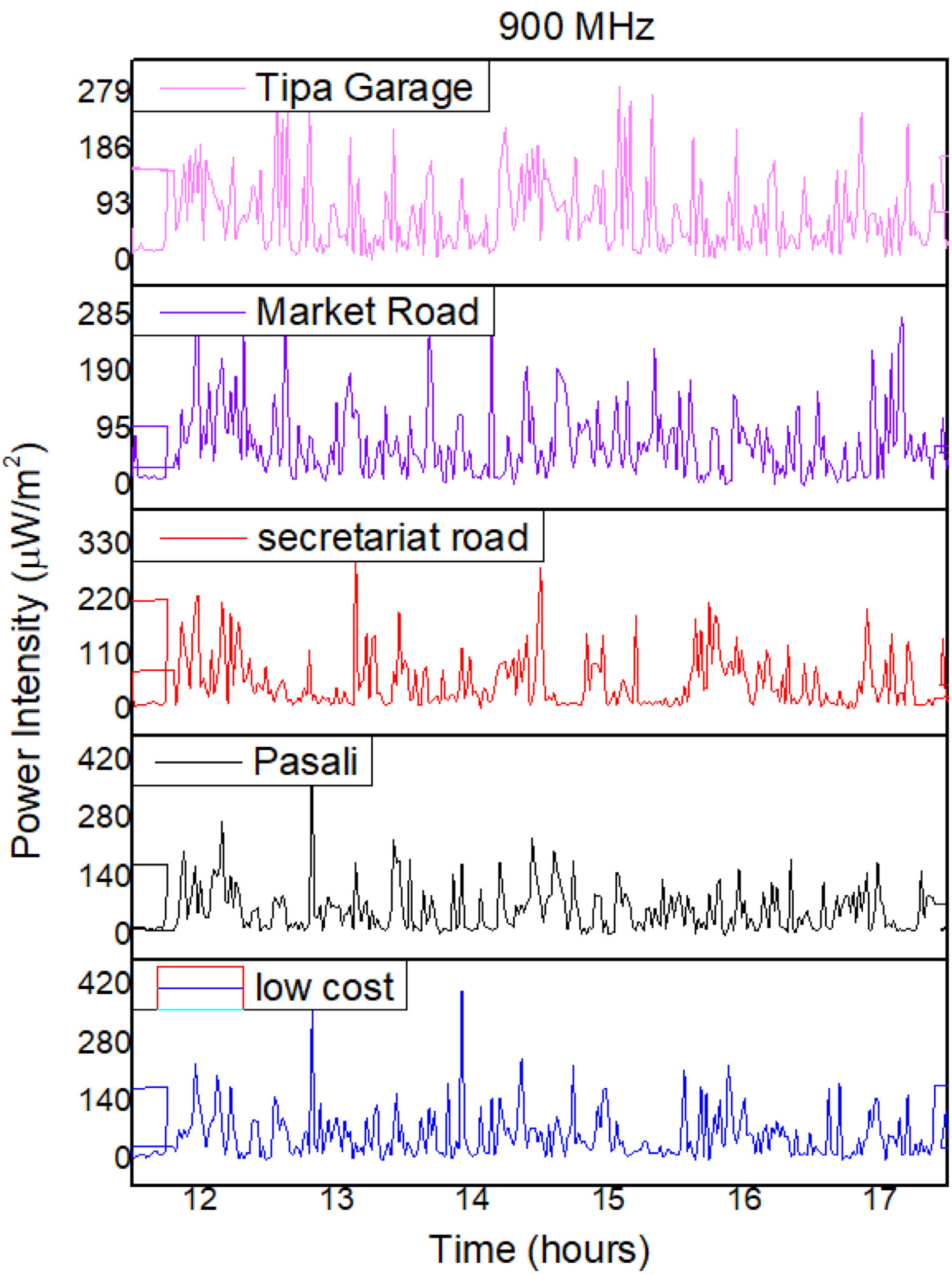

Fig 4. Temporal variation of RF frequency band GMS 900 MHz.

these periods. Generally from the plot, the highest exposure was signal seems to be low generally in Secretariat road and Tipa garage.

Temporal variation of RF frequency band Wi-Fi 2400 MHz

Fig. 6 shows the temporal variation of the RF field signal of Wi-Fi MHz from five measurement areas between 11.00–18.00 h of the hours day. Temporally there were definite variations that were visible in the figure. These can be seen clearly where some of the five superimposed signals of power density taken at the various time are different; some shifted towards larger or smaller. The following can be deduced from Fig. 6, exposure of temporal variation due to Wi-Fi 2400 MHz was slightly high in Tipa garage within 11.00–14.00- hours of the day but was below 190 μW/m^2. compliance test needs to be called out within this period. The signals fell drastically below 90 μW/m^2 for the rest of the hours of measurements. Market road experience high exposure signal of power density 12.00–13.00 h and has its' peak value of exposure signals at 15.00 h

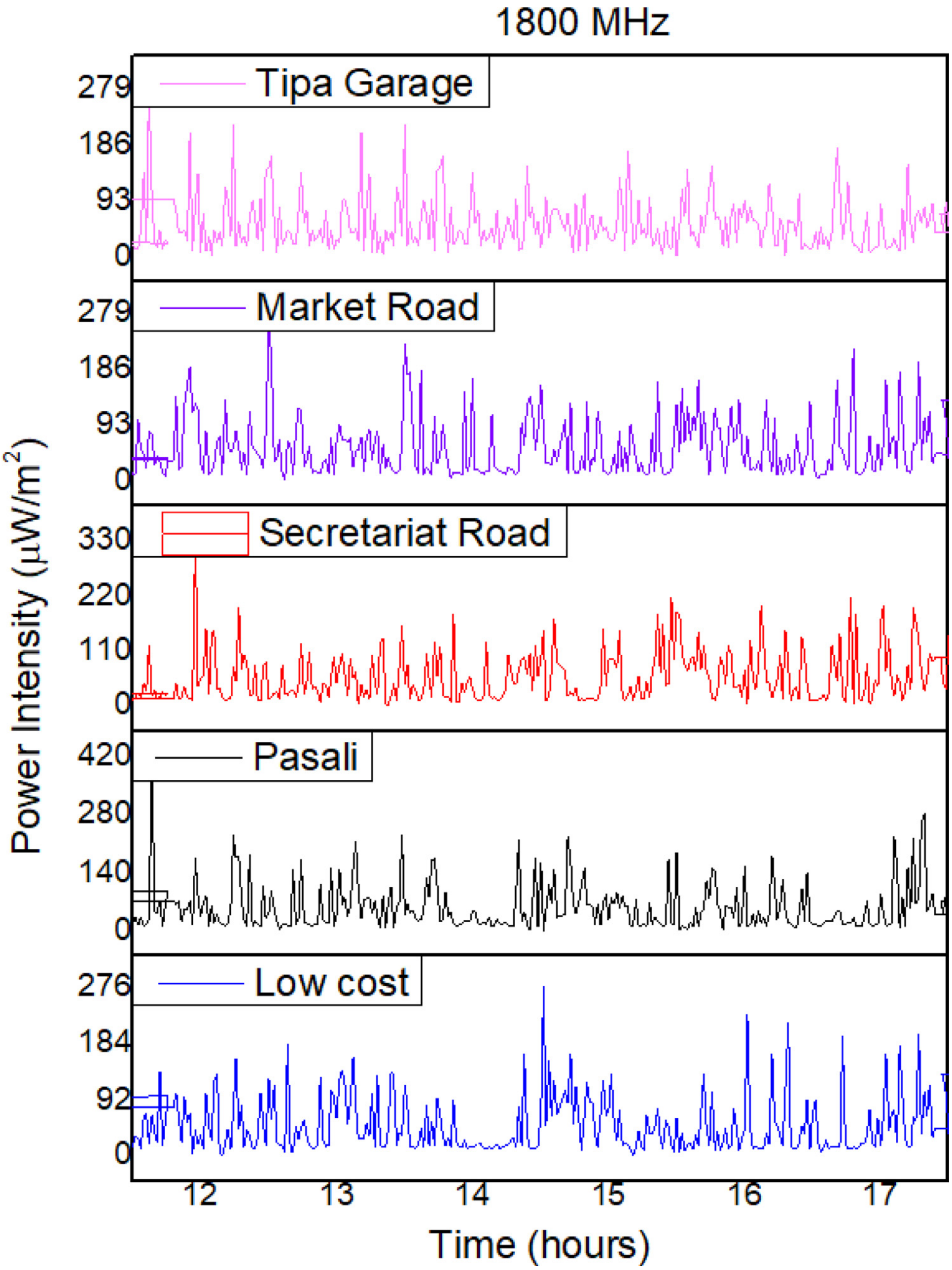

Fig 5. Temporal variation of RF frequency band GMS 1800 MHz.

of 294 μW/m^2 that need compliance test in this period. Secretariat road showed low signal power density exposure signal to 2400 MHz frequency band between 14.00 to 18.00 h of the day which falls below 90 μW/m^2 but slightly highs at 12.00–13.00 h and 14.00 h of the day that needs to test for compliance. Pasali has the highest exposure signal to 2400 MHz around 12.00 h with 250 μW/m^2 and a low signal within 14.00–16.00 h with an exposure signal below 50 μW/m^2. Compliance test needs to be carried out within 12.00–14.00 h and 15.00 h at low cost, but exposure signal falls between 15.00–17.00 h of the day. Generally, compliance tests may need to be carried out within the 12.00–14.00 h of five places measured but during the periods unlike 14.00–17.00 h, exposure was noticed to fall below 100 μW/m^2 all from the five places.

General observation

Temporally, some variations were visible from the plots as evidence in Figs. 4, 5, and 6. These can be accounted for by the different land uses in the study area or variation may due to the period in which the peoples around the place were

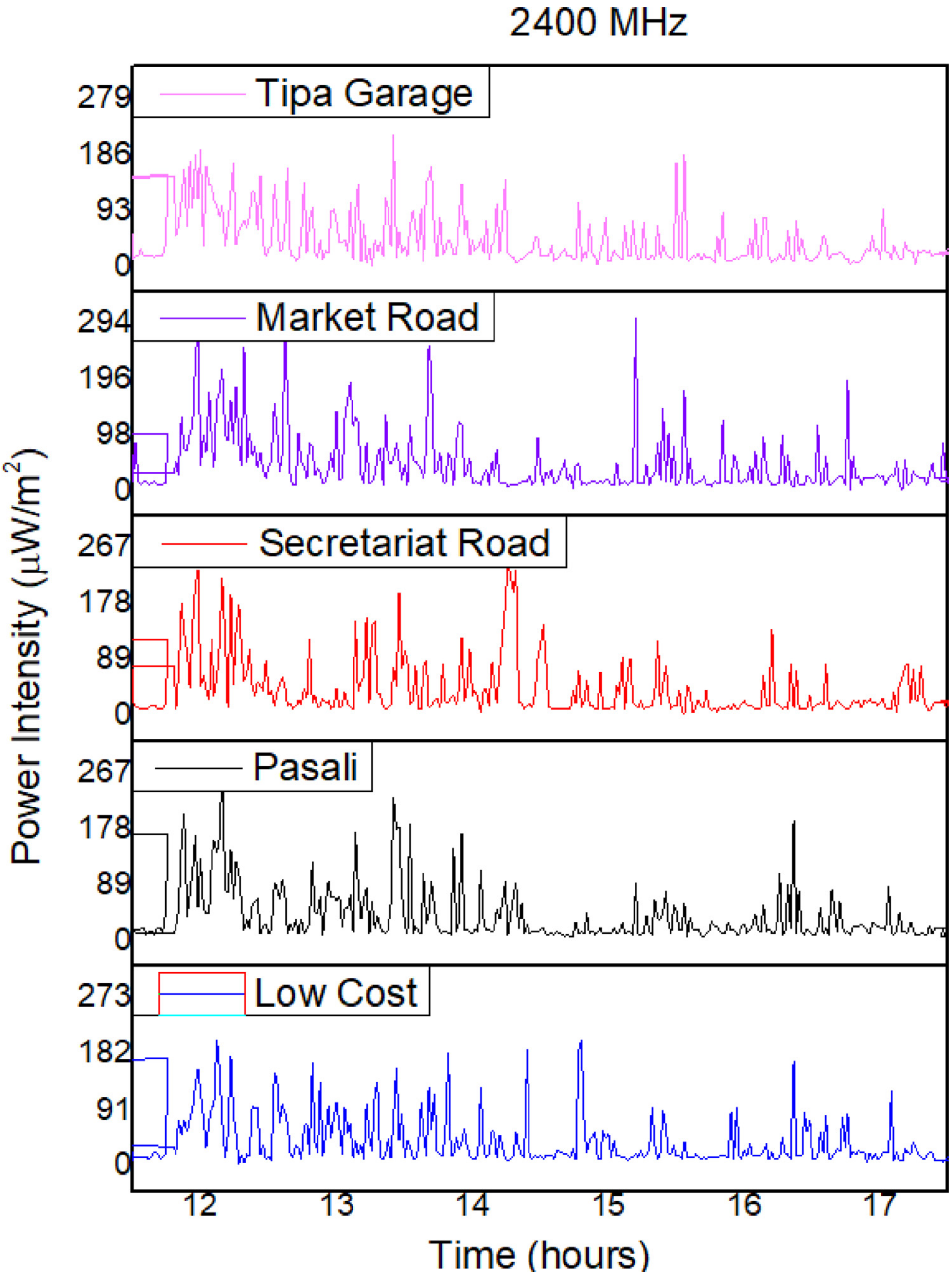

Fig 6. Temporal variation of RF frequency band Wi-Fi 2400 MHz.

busy with their phone call (uplink and downlink). The temporal variation from GSM 900 MHz, GSM 1800 MHz, and Wi-Fi 2400 MHz may also result from the total number of incident rays from electromagnetic radiations which are equal to the power density from that antenna and this summation is known as multipath effects, they emanated from the source (base station) and propagate isotropically over a different path, transversing through a building and passes through trees to get to the receiver. As its moves through different directions, is statistically fluctuated as a result of the motion of vehicles or peoples e.t.c, as the propagated rays arrived at the receiver, the sum of power densities may add or subtract from each other based on the power distribution [27]. It can be observed that level does necessarily fall – off regularly concerning distance from the source (tower). This implies that two spaces that are closely located may have different power densities by some factor [17]. This results from the radiation pattern of the antennas itself are due to the direction of the line of sight rays or blockage of the by building, trees, and other structures.

Table 3
Comparison of Maximum Exposure of the Study Area with that of ICNRP Value.

Area of Measurement	RF Fields Power Density W/m^2		
	900 MHz cell Phone Frequency Band	1800 MHz Cell Phone Frequency Band	2400 MHz Wi-Fi Frequency band
ICNIRP Values	4.5	9.0	10.5
Pasali	0.00046	0.00056	0.00019
Low cost	0.00043	0.00053	0.00022
Secretariat Road	0.00040	0.00055	0.00021
Market Road	0.00049	0.00060	0.00024
Tipa Garage	0.00047	0.00057	0.00020

Comparison of radio frequency fields to human exposure of phone band (900 MHz and 1800 MHz) and wi-fi 2400 MHz with icnirp exposure limit

RF fields power density of each cell phone radiofrequency band (900 MHz and 1800 MHz) and Wi-Fi band 2400 MHz was calculated using a spatial average formula which is the average of the value obtained at each point as shown in the measurement of non- Ionizing radiation (NIR) as shown in Eq. (1) [32].

$$S_{spatial-average} = \frac{\Sigma_i^n s_i}{N} \quad (1)$$

Where S_i = power density
N = Number of count

Based on the report from Vitor et al., [7]. The results were compared with the international commission of Non – Ionizing Radiation Protection (ICNIRP, 1998) [2] recommendation. See Table 3

During the time of measurement, the weather was variable. These metrological variations could account for the lowest RF field strength values. It was found that the RF field from 900 MHz, 1800 MHz, and 2400 MHz frequency bands was below the ICNIRP limit(ICNIRP,1998) using Eq. (1) to calculates the total power density of each area, the results of each area measured were displayed in table 3. These results are similar to that of an urban study in Malaysia which found that the highest power recorded value for power densities for narrowband cell base station measurement value was below the International Commission on Non- ionizing Radiation Protection (ICNIRP) guidelines [25, 27]. Another similar study was found that most RF field strengths were within international limits [5, 14, 17–20]. Patrizia et al., [21] examine levels of exposure and the importance of different RF-EMF sources and settings in a sample of volunteers living in a Swiss city in Switzerland with an expository meter. He found that the mean value was below the recommended limit using the robust regression on order statistics (ROS) and discovered that exposure level to RF-EMF varies considerably between persons and locations. Various research published on monitoring radiation signals from mobile communication stations installed in some cities in Italy [1,12,22–24], maximum exposure from the electromagnetic field were recorded below the standard limits. A survey in Europe on RF field strength levels concluded that such levels are well below those established by current regulations by various international organizations for safe exposure to electromagnetic radiation and that it does not appear that there are founded reasons for public consideration [23]. Long-time exposure to RF may likely lead to possible health damage such as cancer, particularly leukemia as a result of dose accumulation depending on the individual susceptibility to a specific situation. Nevertheless, no study has been established that exposure to RF fields below the ICNIPRP from base stations, increases the risk of cancer or any other disease.

Conclusion

This study presents the temporal variation of RF radiation around mobile communication base stations and suggests that further research is required to improve the representation of such environmental characteristics that may adversely impact human health. i.e. area of maximum exposure. This study also aimed to include implications for future research and legal standards to reduce health risks. Therefore, the study considered temporal variation in daylight, and have not taken into account the variation with RF field during the night also small areas were considered for data collection and analysis, hoping that the results of this study can be extrapolated for a larger context. The results from the findings may not be applied to other regions due to unique variations in environmental characteristics such as geographical or land use and development. In addition to the results obtained in this work, some points could be further improved, such as further research using a spectrum analyzer to cover a wider frequency range and more research to cover all seasons or climate weather condition for 24 h, most area of a higher value of power density on the plot that shows high signal should be continually monitoring to enhance the safety of the populace. Based on the precautionary principle, these non – ionizing RF electromagnetic radiation could be considered as –potential polluting agents and dealt with in a similar manner as air, water and, noise pollutions [26]. However, field strength levels from mobile telephone and wireless local area network RF bands in the Kuje area in Abuja, Nigeria are currently well below Internation Commission for Non – Ionizing Radiation Protection (ICNIRP,1998) limit. Consequently, there is little cause for public concern.

Declaration of Competing Interest

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

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