Paper

PERSONAL EXPOSURE TO RADIOFREQUENCY ELECTROMAGNETIC FIELDS AMONG PALESTINIAN ADULTS

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Abstract—**This work deals with the assessment of personal exposure to radiofrequency electromagnetic fields and the study of temporal and spatial daily variations in a group of 24 adults from the West Bank, Palestine. Exposure was measured using a personal exposure meter EME SPY 140. Mean values of exposure levels from different radiofrequency sources were calculated using both naive and robust regression on order statistics approaches. The total daily exposure from all radiofrequency electromagnetic field sources varied widely among participants depending on their location, the mobile network they use, their activities, and their mode of transportation, ranging from about 0.2 V m^{-1} to 0.9 V m^{-1}. The average total daily exposure of all participants was about 0.48 V m^{-1}. The main contribution to the mean exposure was from WiFi 2G (45%), GSM900 uplink (19%), GSM900 downlink, and FM radiobroadcasting (each by 11%). Other sources including GSM1800, UMTS2100, WiFi 5G, DECT, TETRA, WiMAX, and TV bands all together contributed 14%. During different activities, participants were exposed to the highest exposure level while traveling and to the lowest exposure while they were sleeping. During the day, participants received the highest exposure during the time period from 1600 to 2400 h. Based on thermal effect of radiofrequency electromagnetic fields, all evaluated personal exposures comply with guidelines recommended for the general public by the International Commission on Non-Ionizing Radiation Protection.**
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Key words: electromagnetic fields; health effects; radiation, nonionizing; radiofrequency radiation

INTRODUCTION

THE USE of radiofrequency electromagnetic fields (RF-EMF) in wireless telecommunications considerably increases over the years in terms of new emerging technologies and diversity in the used frequency bands. All these developments led to a substantial change of the RF-EMF exposure situation and to concerns about potential adverse health effects in the population (Urbinello 2015). In principle, two different types of RF-EMF exposure sources can be distinguished: sources that are applied close to the body, usually causing high and periodic short-term exposures mainly to the head (e.g., mobile phones), and environmental sources that, in general, cause lower but relatively continuous whole-body exposures (e.g., mobile phone base stations). While exposure from mobile phones can be assessed using self-reported mobile phone use or operator data, valid assessment of exposure to environmental fields is more challenging (Frei et al. 2009; Vrijheid et al. 2009).

In Palestine, the number of people potentially exposed to RF-EMF has dramatically increased in the last two decades. The percentage of mobile phone users increased from 43.1% in the year 2000 to 97.9% in 2015 (59.4% of them are users of smartphones) (PCBS 2015). Internet users increased from 1.1% to 63.2% of the population in the same period (IWS 2018). Furthermore, there are 41 registered radio stations broadcasting in the frequency modulation (FM) frequency band as well as 15 television (TV) stations. Mobile network services are provided by two Palestinian providers operating on global system for mobile (GSM) 900 and GSM1800 frequency bands and provide second generation (2G) services. The Israeli mobile networks and internet provider services represent 20% of the Palestinian market size. Five Israeli providers offer third generation (3G) and fourth generation (4G) services. The internet services in Palestine are provided by 56 companies (40 companies for wireless connection to the internet [WiFi], 6 companies for connections to the internet protocol [IP] telephony [voice over internet protocol or VOIP], and 10 companies for broadband internet connection) (MTIT 2015).

The concern for possible health effects of RF-EMF has increased after the classification of RF as a possible human carcinogen, group 2B, by the International Agency for Research on Cancer (IARC) of the World Health Organization in 2011. In response to public concerns, the Center for Radiation Science and Technology at Al-Quds University

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conducted research over the whole West Bank on the outdoor and indoor environmental levels of RF-EMF from different sources including mobile base stations, FM radio and TV broadcasting, wireless local area network (WLAN), and microwave ovens (Lahham and Hammash 2009; Lahham et al. 2015). All these studies resulted in environmental exposure levels below the limits recommended for the general public by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). These environmental measurements of RF levels (even when some of them were conducted at places where individuals spend most of their time) are neither a good indicator of the mean exposure to environmental fields over the day, nor a good indicator of exposure due to one's own calling pattern (Frei et al. 2010). Measurements in fixed locations do not fully represent the amount of radiation exposure due to factors such as the interaction of electromagnetic waves with matter, and spatial and temporal variations in the electric field.

Therefore, it is of particular importance to find an alternative method for the assessment of mean personal exposure to RF sources during daily life activities. The World Health Organization emphasized the need for evaluation of personal exposures from multiple RF-EMF sources for human epidemiological studies using objective measurements (Van Deventer et al. 2011).

Exposure to radiofrequency RF-EMF in everyday life is highly temporally and spatially variable due to various emitting sources like broadcast transmitters or WLAN. Little is known about the RF-EMF exposure distribution in the general population (Röösli et al. 2010). Personal exposure meters (PEMs) are considered one of the most accurate tools in assessing environmental personal exposure, allowing researchers to capture different sources of exposure, evaluate how this exposure varies over time, and validate exposure prediction models (Bolte et al. 2016; Inyang et al. 2008; Frei et al. 2010). The main advantages of PEM measurements are their convenient handling for study participants and the large amount of personal exposure data which can be obtained for several RF-EMF sources. On the other hand, the use of PEMs has some limitations: their use has been recommended for measuring personal exposure from environmental far-field sources in everyday life (Frei et al. 2010). Measurements taken during calls with mobile or digital enhanced cordless telecommunications (DECT) phones strongly depend on the distance between the emitting device and the PEM and do not reflect maximum exposure at the head of the person making the calls (Inyang et al. 2008). Another limitation is that mobile phone measurements depend heavily on the way the device is used (Neubauer et al. 2008; Bolte and Eikelboom 2012).

Measurement campaigns have confirmed that for a considerable proportion of wireless technologies, EMF values are below the detection limit of PEMs (Hamiti et al. 2016). A common approach, usually called the naive approach, is to substitute a fraction of the detection limit for each censored observation. This naive method produces poor estimates of summary statistics. To resolve the problem of censored data, the robust regression on order statistics (ROS) method is used. ROS is a nonparametric method that fits a normal (or lognormal) distribution to the observed data. The modeled censored values are then combined with the observed values above the detection limit to obtain summary statistics (Röösli et al. 2008; Helsel 2005, 2006).

The aim of this work was to study the personal exposure to RF-EMF in the everyday environment in West Bank, Palestine, in a population sample in different microenvironments such as homes, transportation, and schools. To reach this goal, measurements of personal exposure were conducted in a group of 24 adult volunteers living in different places over the West Bank using a frequency-selective portable PEM (EME SPY 140) over a 24 h period of time.

MATERIALS AND METHODS

Study population

An open invitation was announced by the Center for Radiation Science and Technology to students at the Al-Quds University inviting volunteers to participate in the study. An initial 65 students responded to the center's request. After they were contacted, only 24 students (15 females and 9 males) accepted and committed to carry the PEM for 24 h. The age of participants ranged from 19 to 32 y. Carrying the personal exposure meter for longer periods was rejected in most cases. Fortunately, initial information collected from the participating volunteers provided a wide variety of aspects of individual life in the West Bank including living conditions, transportation, travel time, mobile networks, and internet providers and usage. The volunteers recruited are distributed between seven governorates in the northern, central, and southern parts of the West Bank.

The volunteers were instructed to carry the EME SPY PEM on their belt for 24 h. When sleeping, they were asked to place the PEM close to the bed. They were also instructed to fill out a questionnaire providing data before, during, and after the process of measurement.

Data collected before the measurement process included personal data regarding living conditions (location, type of apartment, number of occupied apartments in the building) and number of RF-emitting devices located in the volunteer's home (network routers, DECT, microwaves, radios, and TVs). Measurements were conducted between September 2015 and July 2016. 8,640 data points of personal RF-EMF exposure for every volunteer were collected and stored while they were carrying an EME SPY 140 PEM for one working day. A diary (activity log) was given to every volunteer to keep track of activities during the measurement period. Daily activities and locations were limited to five major categories: sleep, home, travel, university, and others. Transportation used for traveling was specified in the diary (public transport, private cars, on foot). Data collected after the measurement period included number of mobile phones and WiFi-emitting devices used by the volunteers and their family members during the measurement period, call logs stored in personal mobile phones during 24 h (call start time, call duration, network operator), and mobile phone distance from participants while sleeping.

Instrumentation

Measurements of personal exposure were conducted using tri-axial E-field frequency-selective personal exposure meters EME SPY 140 (Satimo/MVG, Paris, France; www.satimo.fr), enabling measurements of electric field strength in 14 predefined frequency bands in the range from 80 MHz–6 GHz. This PEM offers the possibility of differentiating uplinks and downlinks for cellular technologies. The EME SPY 140 measures exposure from 15 frequency bands: FM (88–108 MHz), TV3 (174–223 MHz), terrestrial trunked radio (TETRA) (380–390 MHz), TV4&5 (470–830), GSM900 uplink (UL) (880–915 MHz), GSM900 downlink (DL) (965–960 MHz), GSM1800 UL (1,710–1,785 MHz), GSM1800 DL (1,805–1,880 MHz), DECT (1,880–1,900 MHz), Universal Mobile Telecommunications System (UMTS) 2100 UL (1,920–1,980 MHz), UMTS2100 DL (2,110–2,170 MHz), WiFi 2G (2,400–2,500 MHz), Worldwide Interoperability for Microwave Access (WiMAX) (3,400–3,800 MHz), and WiFi 5G (5,150–5,850 MHz). The lower detection limit of the used PEM differs from band to band (0.05 V m^{-1} for FM; 0.01 V m^{-1} for TETRA and TV4&5; 0.02 V m^{-1} for TV3, WiMAX, and WiFi 5G; and 0.005 V m^{-1} for the rest), while the upper limit is 6 V m^{-1}. The PEM recorded power density in 14 different frequency bands every 10 s producing 8,640 measurements per person during 1 d. At the end of the measurement period, stored data are exported to the PEM analysis software for postprocessing and backup. The software also enables a real-time display of the field level in selected units (electric field strength or power density) for each frequency band to be displayed as it is measured.

RESULTS AND DISCUSSION

In this study, the software of the EME SPY 140 set each value below the detection limit (censored data) to the value of the detection limit for a specific frequency band. Also, it did not differentiate between exposure due to personal calls (mobile phone calls or DECT) by participants and exposure from mobile calls from other people's phones. Therefore, exposure from mobile telephone uplinks is related to both personal calls and calls from other mobile phones. Exposure to uplinks from DECT phones is exclusively from other people's calls, since not one of the participants reported in the diary that she/he used a DECT phone during the entire time of measurement. Mean values of exposure levels from different RF-EMF sources were calculated using both naive and ROS approaches. All measurements were recorded in power density units of μW cm^{-2} and then converted into electric field strength. ROS was calculated in R Version 3.2.2 statistical software using the Nondetects and Data Analysis for Environmental Data (NADA) package (www.r-project.org). ROS was used when 10 measurements or more were above the detection limit. Daily average exposure levels in terms of mean and median as well as minimum and maximum values and percentage of censored data are presented in Table 1. The average total daily exposure from all sources of RF-EME was about 0.48 V m^{-1}. The main contributors to the average daily total exposure were WiFi 2G, GSM900 uplink, FM, and GSM900 downlink. Fig. 1 shows the relative mean contributions from all sources of RF-EMF. The daily total exposure varied widely among participants depending on their location, the mobile network they used, their activities, and their modes of transportation. The total daily exposure of individuals from all RF sources ranged from about 0.2 V m^{-1} to 0.9 V m^{-1}.

The maximum mean exposure found for all participants from a single RF source was about 0.322 V m^{-1} from WiFi 2G, while the minimum mean exposure was from TETRA (about 0.005 V m^{-1}). Exposure levels from WiFi 2G were high because of the following: participants spent most of their time indoors (at home or in the university) where most spaces include WiFi routers, and the absence of 3G services in the country during our study increased the use of WiFi 2G. TETRA and TV4&5 are considered very weak sources of exposure in our environment as their use is very rare (percentages of censored data from these sources were 99.4% and 95.3%, respectively). Similarly, WiMAX and WiFi 5G were weak sources of exposure. Exposure to WiFi 5G was possible only in a few places on the university campus.

Temporal variations in personal exposure

To investigate the temporal variation in personal exposure to RF-EMF during 24 h, the entire time of measurements was divided into three time intervals (daytime from 0800 to 1600, evening from 1600 to 2400, and nighttime from 2400 to 0800). Mean exposure from different sources for all participants was calculated for every time internal (Fig. 2). The total exposure was highest during the evening time with uplink (the total of GSM900, GSM1800, and UMTS2100 frequency bands) and WiFi 2G sources contributing the largest exposure. A similar situation was found during the daytime from 0800 to 1600. The lowest total exposure was at nighttime. What is interesting is that the mean exposure from WiFi 2G was approximately the same during the three time intervals of the day, which means that people were using their WiFi routers during the late nighttime. TV includes exposure from TV3, TV4, and TV5 as well. FM broadcasting

Table 1. Average exposure in terms of mean and median during total measuring time of 1 d to all participants from different RF sources.

	Electric field strength (V m^{-1})								
	Mean		Median		Minimum		Maximum		
RF source	Naive	ROS	Naive	ROS	Naive	ROS	Naive	ROS	Censored data (%)
FM	0.1601	0.1555	0.1233	0.1238	0.0507	0.0167	0.3300	0.3268	81.4
TV3	0.0209	0.0161	0.0202	0.0149	0.0200	0.0112	0.0251	0.0264	88.2
TETRA	0.0110	0.0048	0.0102	0.0025	0.0100	0.0005	0.0195	0.0168	99.4
TV4&5	0.0143	0.0110	0.0117	0.0069	0.0100	0.0010	0.0304	0.0290	95.3
GSM900 UL	0.205	0.205	0.1242	0.1243	0.0585	0.0583	0.7489	0.7489	73.9
GSM900 DL	0.1558	0.1558	0.0920	0.0919	0.0466	0.0466	0.4851	0.4851	13.8
GSM1800 UL	0.109	0.109	0.0689	0.0688	0.0064	0.0043	0.2640	0.2640	83.6
GSM1800 DL	0.0240	0.0239	0.0194	0.0191	0.0086	0.0074	0.0510	0.0508	51.4
DECT	0.0789	0.0789	0.0537	0.0536	0.0132	0.0129	0.1939	0.1939	54.4
UMTS2100 UL	0.0568	0.0566	0.0124	0.0115	0.0064	0.0043	0.2194	0.2194	93.2
UMTS2100 DL	0.0137	0.0134	0.0122	0.0123	0.0078	0.0070	0.0294	0.0294	67.4
WiFi 2G	0.3224	0.3224	0.1741	0.1741	0.0206	0.0204	0.8881	0.8881	47.5
WiMAX	0.0534	0.0496	0.0244	0.0139	0.0201	0.0032	0.1516	0.1503	99.3
WiFi 5G	0.0901	0.0884	0.0673	0.0650	0.0250	0.0153	0.1818	0.1810	93.7

is nearly constant during daytime with less activity at nighttime. FM radiobroadcasting does not transmit 24 h d^{-1} in our country. The highest change in exposure as a function of time of day was found in uplink, downlink, and DECT. This is because the activity of mobile base stations decreases at nighttime; the use of mobile phone handsets and DECT phones is similar.

Exposure at different locations and activities

Exposure from different RF sources at different locations and activities was also evaluated for all participants.

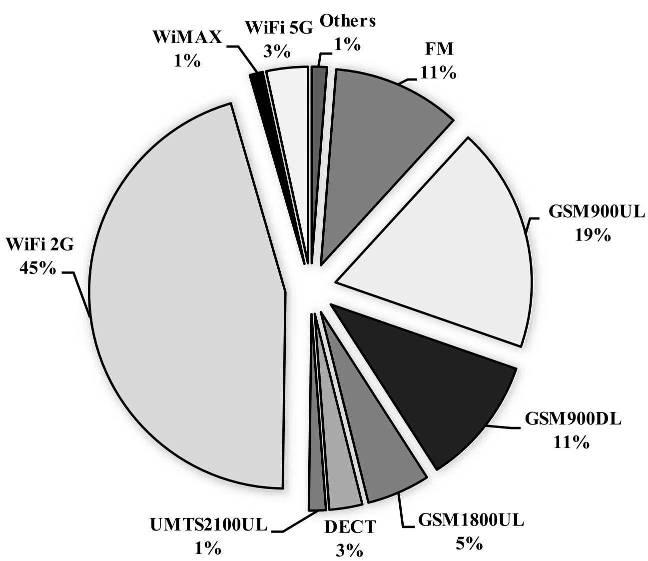

Fig. 1. Mean contributions to the total exposure from all RF sources. Others include TETRA, GSM1800, and UMTS2100 downlinks and TV bands.

Table 2 presents the mean electric field strength while participants are at home, traveling, at the university, or sleeping.

At home, the mean value of exposure from different sources ranges from 0.008 V m^{-1} (UMTS2100 DL) to 0.30 V m^{-1} from WiFi 2G with an average total daily exposure of about 0.377 V m^{-1}. While sleeping, participants are exposed to a mean value of exposure ranging from 0.006 V m^{-1} (again from the UMTS2100 DL frequency band) to about 0.18 V m^{-1} from WiFi 2G with a total average exposure of about 0.3 V m^{-1} representing the lowest exposure due to activity of the participants. While traveling, they are exposed to a mean exposure ranging from 0.01 (TETRA) to 0. 5 V m^{-1} from GSM900 uplink. Participants are exposed to the highest mean exposure from all sources during their travel times (0.7 V m^{-1}). The maximum value of mean exposure measured at any location was about 1.33 V m^{-1} from GSM900 uplink. This level of exposure was measured during travel activity. Most of the participants used public transport where they can be exposed to uplink from phone calls of travel mates. Furthermore, most of participants use

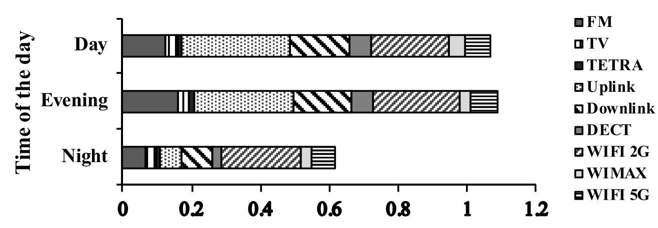

Fig. 2. Mean exposure from different frequency bands during time of day for all participants.

Table 2. Mean and maximum exposure levels at different locations and RF sources.[a]

	Electric field strength (V m^{-1})							
	Home		Sleep		Travel		University	
RF source	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum
FM	0.070	0.261	0.065	0.297	0.330	0.784	0.070	0.214
TV3	0.021	0.030	0.021	0.029	0.022	0.031	0.021	0.024
TETRA	0.010	0.010	0.010	0.011	0.010	0.014	0.011	0.017
TV4&5	0.012	0.030	0.010	0.010	0.016	0.025	0.016	0.063
GSM900 UL	0.135	0.557	0.060	0.184	0.493	1.329	0.269	0.746
GSM900 DL	0.099	0.307	0.159	0.673	0.228	0.333	0.189	0.409
GSM1800 UL	0.062	0.251	0.088	0.367	0.195	0.433	0.154	0.359
GSM1800 DL	0.016	0.036	0.012	0.034	0.057	0.134	0.021	0.034
DECT	0.059	0.265	0.023	0.118	0.120	0.410	0.026	0.058
UMTS2100 UL	0.018	0.252	0.006	0.012	0.053	0.277	0.046	0.241
UMTS2100 DL	0.008	0.016	0.007	0.049	0.021	0.033	0.019	0.038
WiFi 2G	0.305	0.965	0.176	1.023	0.147	0.581	0.234	0.531
WiMAX	0.029	0.193	0.032	0.169	0.057	0.374	0.039	0.130
WiFi 5G	0.082	0.169	0.058	0.234	0.082	0.192	0.086	0.245
Total	0.377	NA	0.279	NA	0.704	NA	0.453	NA

[a]NA: not available.

subscriber identity module (SIM) cards in mobile phones operating at GSM900 which is the oldest and the most used network throughout the country. While they are at the university, participants are exposed to a mean value of electric field strength ranging from 0.01 V m^{-1} from the TETRA band up to 0.23 V m^{-1} from WiFi 2G.

Exposure from fixed outdoor sources during transportation

The outdoor mean exposure from six fixed RF-EMF sources in relation to transportation methods was also investigated for all participants. Participants either use private cars or buses, or walk to the university, with most of them traveling by bus. Fig. 3 illustrates this relationship. The main exposure during all three methods of transportation comes from FM radio broadcasting with the highest exposure to walking participants living nearby the university campus (0.56 V m^{-1}). The second highest source of exposure during all transportation comes from GSM900 DL (0.25 V m^{-1} for walkers) followed by GSM1800 DL (about 0.07 V m^{-1}). Signals from

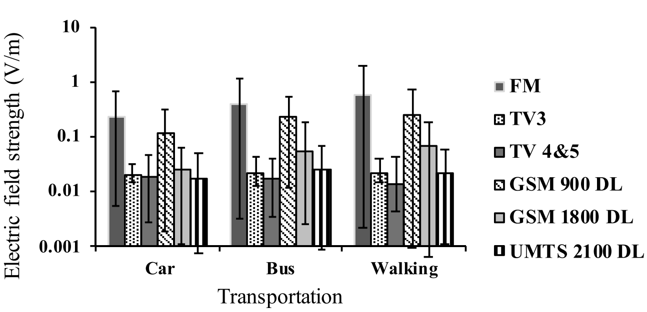

Fig. 3. Mean exposure to 24 participants from fixed outdoor RF-EMF sources during different transportation modes.

FM radiobroadcasting and mobile phone base stations are relatively common across all microenvironments. The lowest exposure levels were from TV4&5, mainly for walkers since there are no TV broadcasting stations in the area where our university is located. The lowest mean average exposure from all six sources was 0.25 V m^{-1} for participants using private cars. This can be due to the lower duration of exposure (shorter travel time). Participants using buses for transport are exposed to higher levels of exposure (0.45 V m^{-1}) due to the longer duration of exposure from fixed sources and because buses are usually moving from the center of the cities where the GSM traffic is high. The highest average mean exposure from all sources was received by participants reaching the university by walking (0.62 V m^{-1}). These results are consistent with our previous study on outdoor sources of environmental exposure to RF-EMF where FM and GSM900 were the main contributors to population exposure (Lahham and Hammash 2009). We can notice from the figure that the differences between exposures from the same source of RF in different transportation modes are relatively small. Differences can be attributed to participants' locations, time spent by participants in different transportation methods, their routes of travel, and the existence of outdoor RF sources across the travel route.

Compliance with ICNIRP exposure limits

To evaluate compliance with ICNIRP guidelines in a multiple-frequency environment, the ratio of measured exposure value at each frequency and the reference level for that frequency (exposure quotient) must be calculated. The total exposure quotient (TEQ) is the sum of all ratios of individual frequencies and their corresponding reference levels as shown in the equation below. Compliance with ICNIRP guidelines is demonstrated if the total exposure quotient is less than or equals unity (ICNIRP 1998; Mann et al. 2000; Alhekail et al. 2012):

$$TEQ = \sum_{i=1}^{n} \left(\frac{Ei}{El,i}\right)^2, \quad (1)$$

where n is the total number of frequencies (RF signals); Ei is the electric field strength at frequency i; and El,i is the electric field reference level for frequency i.

For all participants in this study, the TEQ was calculated for the highest exposure level from all investigated RF sources averaged over any 6 min time interval during the entire time of measurement. The highest TEQ calculated among all participants was about 0.002 indicating compliance of evaluated exposures with ICNIRP guidelines recommended for general public.

Values of specific absorption rate (SAR) depend on the incident field parameters, the characteristics of the exposed body, and ground effects and reflector effects of other objects in the field near the exposed body (Viel et al. 2009). Furthermore, personal exposure measurements do not allow differentiation between uplink from the personal phone producing localized exposure and uplink from other people's phones, which would generally produce a more homogenous whole-body exposure; thus, the whole-body SAR was not determined. Without such differentiation, SAR calculations would not be reliable (Wout et al. 2012). Because of these reasons we have not attempted to calculate SAR in this work.

CONCLUSION

This work was the first attempt in our country to evaluate personal exposure to RF-EMF sources. The mean total daily exposure found was 0.48 V m^{-1}. The major sources of exposure include WiFi 2G, mobile telephony handsets, mobile base station downlinks, and FM radiobroadcasting. Because all study participants are volunteers (students from Al-Quds University), further studies on personal exposure will be needed which include participants from different populations. However, the data obtained in this study (besides the assessment of the amount of exposure to a group of potentially exposed people) provided valuable information in characterizing the temporal and spatial variation of exposure to RF-EMF.

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