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Mobile measurement of radiofrequency electromagnetic field exposure level and statistical analysis

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ABSTRACT

In this study, radiofrequency electromagnetic field exposure levels were measured as mobile on the main streets of Diyarbakır during a week. The measurements were carried out using high precision spectrum analyzer with an isotropic antenna mounted on the top of a car. With this mobile measurement, large areas were measured in a short time and information about characteristics of electromagnetic environment was obtained quickly. Measurement results showed that measurement values were not in normal distribution and variances between independent variables were not homogeneous. According to Spearman's rho correlation coefficient, there was no strong correlation between measurement days. In terms of mean electric field values, contribution of each band to total band was arranged as UMTS DL, GSM900 DL, GSM1800 DL, TV4-5, FM, and TV3 band, respectively. It was determined that all measurement values were below the reference levels of the International Commission on Non-Ionizing Radiation Protection.

1. Introduction

Measurement of radiofrequency (RF) electromagnetic field (EMF) exposure level is crucial for human health and epidemiologic research [1–5]. Limits on the EMF exposure are called basic restrictions. Between 1 Hz and 10 MHz, the basic restriction is current density for preventing adverse effect on nerve and muscle cells. In the frequency range from 100 kHz to 10 GHz, the basic restriction is specific absorption rate (SAR) for prevention of local and whole body heating. Between 100 kHz and 10 MHz, the basic restrictions are both current density and SAR. Finally, in the frequency range from 10 GHz to 300 GHz, the basic restriction is incident power density for preventing excessive tissue heating near or at the body surface [6]. The basic restrictions correspond to the reference levels which are proposed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [7] or the maximum permissible exposure levels which are recommended by the Institute of Electrical and Electronics Engineers (IEEE) [8]. Many countries, including Turkey have adopted the ICNIRP's reference levels.

The basic restriction for Frequency Modulation (FM) broadcast, Television (TV) broadcast, Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) as shown in Table 1 is the SAR. In the far field region, the SAR can be related to electric field strength (E), magnetic field strength (H) and power density. In addition to that, the SAR can be calculated by measuring E values [9].

FM and TV broadcast transmitters, GSM and UMTS base stations are important sources of RF EMF in terms of exposure level. In general, FM and TV broadcast transmitters are installed in places far distance from the city center. It should be noted that the power density of the RF EMF is

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Table 1
Measured RF EMF bands, their frequency range and resolution bandwidth.

RF EMF band	Frequency range (MHz)	Resolution bandwidth (kHz)
FM	87.5–108	50
TV3	174–230	1000
TV4-5	470–862	1000
GSM 900 DL	935–960	50
GSM 1800 DL	1805–1880	50
UMTS DL	2110–2170	1000

DL: Downlink

inversely proportional to the square of the distance in the far field [10].

Transmission from base station to handset (mobile phone) is called downlink. Likewise, transmission from handset to base station is called uplink. UMTS operates at 2100 MHz and GSM operates at 900 MHz and 1800 MHz in Turkey. The maximum output powers of a radio channel used in GSM and UMTS networks are 10–40 W and 20–60 W, respectively [11]. Output powers of FM and TV transmitters are much more then output powers of GSM and UMTS base stations. Unlike the FM and TV broadcast transmitters, GSM and UMTS base stations are installed in places where people live nearby. Furthermore, power control is an effective technique which enables to reduce interference and the output power radiated by handset [12] and base station. Thus, the RF EMF exposure level in the environment is allowed to reduce.

There are several methods to assess the EMF exposure level in literature. One of them is the personal exposure measurement [3,13–18] that volunteers carry exposimeter device during their daily activities. Exposimeter measures and records RF EMF bands. Another method is the stationary measurement [19–31] that instrument takes measurement samples at defined location over a period of time (for example 6 min). Then, collected samples are analyzed.

The objective of the present study was to measure the RF EMF exposure levels as mobile on the main streets in dense urban, urban and suburban areas of Diyarbakır in Turkey. All six RF EMF bands as seen in Table 1 were measured at the same time every day of the week. It was statistically investigated that whether there is a significant correlation between the days of the week. Contribution of the every band to the total band was determined separately. Finally, measurement results were compared with the reference levels of ICNIRP [7].

2. Materials and method

2.1. Measurement

The study was carried out between 10 November 2014 and 16 November 2014 in the city center of Diyarbakır which is one of the most populated cities of Turkey. Six different RF EMF bands: FM, TV3, TV4-5, GSM900 DL, GSM1800 DL and UMTS DL as shown in Table 1 were measured during the whole week between 17:00 and 18:20 h. During the study, busy hour of mobile network operators in Diyarbakır was about 17:00 local time.

The measurement system consisted of selective radiation meter SRM-3006 (Narda Safety Test Solutions, USA) connected to E-field 3501/03 isotropic antenna by RF cable and a laptop for data collection. SRM-3006 is a portable spectrum analyzer measuring high frequency EMF. E-field 3501/03 is the three axis electric field antenna frequency range from 27 MHz to 3 GHz, dynamic range 0.2 mV/m–200 V/m and maximum extended measurement uncertainty +2.6/−3.8 dB for 85–2200 MHz. RF cable is 1.5 m long and contains ferrite to reduce the effects of the external fields [32].

SRM-3006 equipped with isotropic antenna was mounted on the top of the car. Antenna was placed at 1.70 m height above ground. Measurements were taken as mobile on the main streets where people spend much time. Average speed of the car in the route as shown in Fig. 1 was about 40 km/h.

Channel bandwidth for FM broadcast [33], GSM900 DL [34] and GSM1800 DL [34] is 200 kHz, for UMTS DL [35] 5 MHz and for terrestrial TV3 [33] and TV4-5 broadcasts [33] 7 MHz. Resolution bandwidth for each band as shown in Table 1 was calculated by using the relation:

$$\mathrm{RBW} \leqslant \frac{\mathrm{Fspan(narrowest\ service)}}{4} \tag{1}$$

where RBW denotes resolution bandwidth and Fspan denotes frequency span [32]. The frequency span was selected as the channel bandwidth for every individual band. RBW for FM broadcast, GSM900 DL and GSM1800 DL was set to 50 kHz. RBW for TV3, TV4-5 and UMTS DL was set to 1000 kHz.

Measurements considered the worst case were performed. In this way, the maximum instantaneous E values for each band were chosen as a sample at an interval of 10 s and recorded by the program written by us during the measurements. The program obtained information (e.g., date, time, latitude, longitude, E values) from the SRM-3006 and recorded it. Total E value for each sample was calculated by summing of the maximum instantaneous E values (root mean square values) of all six RF EMF bands using the relation:

$$E_{\mathrm{TOTAL}} = \sqrt{E_{\mathrm{FM}}^2 + E_{\mathrm{TV3}}^2 + E_{\mathrm{TV4-5}}^2 + E_{\mathrm{GSM900\ DL}}^2 + E_{\mathrm{GSM1800\ DL}}^2 + E_{\mathrm{UMTS\ DL}}^2} \tag{2}$$

where E_{TOTAL} denotes Total E value and others denote the maximum instantaneous E values for each band.

2.2. Statistical analysis

The number of measurement samples for each RF EMF band was become equal to 472 samples per a day and 3304 samples per a week. FM, TV3, TV4-5, GSM900 DL, GSM1800 DL and UMTS DL bands were considered as independent variables, whereas TOTAL band was considered as a dependent variable for statistical analysis. For each band, summary statistics such as mean, standard deviation, and variance were calculated with 95% confidence interval