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RESIDENTIAL EXPOSURE TO EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS IN THE CITY OF RAMALLAH-PALESTINE

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This study was focused on the measurement of residential exposure to power frequency (50-Hz) electric and magnetic fields in the city of Ramallah-Palestine. A group of 32 semi-randomly selected residences distributed amongst the city were under investigations of fields variations. Measurements were performed with the Spectrum Analyzer NF-5035 and were carried out at one meter above ground level in the residence's bedroom or living room under both zero and normal-power conditions. Fields' variations were recorded over 6-min and some times over few hours. Electric fields under normal-power use were relatively low; ~59% of residences experienced mean electric fields <10 V/m. The highest mean electric field of 66.9 V/m was found at residence R27. However, electric field values were log-normally distributed with geometric mean and geometric standard deviation of 9.6 and 3.5 V/m, respectively. Background electric fields measured under zero-power use, were very low; ~80% of residences experienced background electric fields <1 V/m. Under normal-power use, the highest mean magnetic field (0.45 µT) was found at residence R26 where an indoor power substation exists. However, ~81% of residences experienced mean magnetic fields <0.1 µT. Magnetic fields measured inside the 32 residences showed also a log-normal distribution with geometric mean and geometric standard deviation of 0.04 and 3.14 µT, respectively. Under zero-power conditions, ~7% of residences experienced average background magnetic field >0.1 µT. Fields from appliances showed a maximum mean electric field of 67.4 V/m from hair dryer, and maximum mean magnetic field of 13.7 µT from microwave oven. However, no single result surpassed the ICNIRP limits for general public exposures to ELF fields, but still, the interval 0.3–0.4 µT for possible non-thermal health impacts of exposure to ELF magnetic fields, was experienced in 13% of the residences.

INTRODUCTION

In modern life conditions, where electricity-based technologies have become an integral part of our lives, the demand for electricity has enormously increased to maintain modern conveniences. And hence, has brought public concern about residential exposure to power frequency (50 Hz) fields, or the so called extremely low frequency electric and magnetic fields (ELF EMF)[1, 2]. ELF electric and magnetic fields can induce small currents (and hence, induced electric fields) inside the human body which at very high level cause nerve and muscle stimulation[3]. Furthermore, the association between elevated ELF magnetic fields and the risk of childhood leukemia has been given a great deal among much of the scientific researches over the past few decades[4–7]. In 2002, the International Agency on Research on Cancer (IARC) published a monograph addressing ELF magnetic fields as possibly carcinogenic to humans[8]. IARC stated that there is a link between childhood leukemia and ELF residential magnetic fields (above 0.3–0.4 µT)[8]. Exposure to ELF EMF was limited by guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). These guidelines, relying on scientific data, provide the safe levels of exposure to power-frequency electric and magnetic fields[9]. In Palestine, the public concern about the possible health effects of electromagnetic fields in general has increased mainly after the wide spread of sources emitting electromagnetic energy as for example radio frequency (RF) sources which is well investigated in the country, both indoor and outdoor[10, 11], on contrary to ELF sources, which has not been studied before in the country. So, this work aims to provide information about the residential exposure to ELF fields and the ambient levels of magnetic and electric fields originated from power frequency sources in our houses in the city of Ramallah-Palestine.

MATERIALS AND METHODS

Study area

A group of 32 residences were chosen in the study for investigations of indoor ELF fields, these residences were distributed randomly among different locations inside the city of Ramallah which is considered as the commercial and political center of Palestine with more than 40 000 inhabitants currently living in this city[12]. The majority of these 32 homes were apartments within buildings, while the rest were detached homes and few were in buildings where indoor power substation exists.

Power conditions

The measurements were conducted at two distinct power uses, zero-power use and normal-power use. When zero-power use, the switchboard was turned off in view to record the background of ELF fields from surroundings or internal wirings. On the contrary, when normal-power use, most of the household appliances were turned on (just as normal day conditions)[13]. For both of these power conditions, measurements of ELF fields were performed at the same points.

Data collecting

The Spectrum Analyzer NF-5035 from Aaronia was used to measure both electric and magnetic fields inside residences. This device which measures fields of the frequency range 1 Hz–30 MHz[14] was adjusted to record fields at the frequency 50 Hz. A laser distance meter (HILTI)[15] with accuracy of 1 mm, was used to maintain the distance 1 m above ground level and other important distances as displacement from operating appliances and electrical facilities. Spot measurements[13, 16, 17] were used in order to record ELF field levels over short-period of time (6 min). Variations of ELF fields over few hours were recorded only in one of the residences (where the author lives) because of the inconvenience of asking random house owners to stay for hours at their residences. Measurements were taken at one meter above ground level[12] (where the human genitals are) inside the residences living rooms or bedrooms, where a significant amount of time is usually spent (in the middle of the living room and by the bedside or sometimes where the people sleep in the bedroom). For each measurement one location was considered inside the room and attention was given to any electrical appliance in vicinity to the measurement location. Furthermore, existence of any close electric facility, as power lines or indoor substations was taken into consideration.

ELF fields from certain appliances were measured inside few residences to assign the fraction of exposure to ELF fields coming from appliances inside homes.

With Minitab 17 statistical software[18] and Microsoft Excel, the data collected from different measurements carried indoor, were programmed and tested to display some important features of ELF fields:

- Variations of measured ELF fields over time.
- Arithmetic means and standard deviations of measured ELF fields.
- Ranges of measured ELF fields showing the minimum and maximum points.
- Correlation between ELF fields and distance from nearest operating appliance.
- Probability density functions[19], geometric means and geometric standard deviations of overall fields.

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma x}\exp\left(-\frac{(\ln(x) - \mu)^2}{2\sigma^2}\right) \tag{1}$$

where, $f(x)$ is the probability density function (PDF), and x is the variable that follows a log-

Table 1. Ranges, arithmetic means and standard deviations of indoor ELF fields under normal-power uses.

	E-field (V/m)			B-field × 10^{-3} (μT)		
Residence	Range	AM	SD	Range	AM	SD
R1	2.1–8.1	4.1	1.7	32–53	44	9
R2	8.1–16.6	13.1	2.5	28–42	35	4
R3	11.9–13.0	12.5	0.4	111–127	118	4
R4	17.8–33.8	27.6	7.2	49–87	67	14
R5	3.7–4.9	4.2	0.3	218–635	386	176
R6	18–30.5	25.3	3.2	26–37	31	4
R7	8.2–9.1	8.8	0.3	75–132	94	18
R8	2.1–2.7	2.6	0.16	16–40	23	6
R9	2.6–3.1	2.8	0.18	2–9	6	2
R10	2.5–2.9	2.8	0.10	22–47	36	7
R11	1.7–3.0	2.4	0.41	16–22	19	2
R12	16.9–41.5	31.3	6.88	314–588	448	90
R13	7.1–7.7	7.4	0.18	5–16	12	3
R14	57.2–77.3	64.1	7.33	76–105	84	9
R15	0.5–0.7	0.62	0.06	9–16	12	2
R16	56–76.5	63.8	5.0	18–42	36	8
R17	3.7–5.7	4.3	0.49	9–14	12	2
R18	8.9–17.8	11.9	2.69	15–22	18	3
R19	4.2–5.7	5.0	0.57	5–15	10	3
R20	1.6–2.1	1.8	0.16	6–62	18	15
R21	7.3–8.3	7.9	0.27	26–39	31	4
R22	31.3–38.7	36.7	2.08	165–425	306	87
R23	6.2–7.6	6.8	0.54	25–31	28	2
R24	30.1–39.8	35.4	2.68	24–40	32	5
R25	3.4–4.4	3.7	0.28	11–21	15	3
R26	2.3–3.2	3.0	0.24	432–555	489	39
R27	57.9–78.7	66.9	7.18	177–210	196	12
R28	6.0–6.4	6.1	0.11	76–91	82	4
R29	2.3–3.9	3.1	0.45	3–10	7	3
R30	0.98–1.2	1.1	0.06	1–7	4	2
R31	27.1–38.1	32.2	3.27	67–92	78	6
R32	18.7–22.9	21.1	1.08	14–29	22	6

normal distribution (magnetic or electric field). The parameters μ and σ are the mean and standard deviation of $\ln(x)$ values, respectively[19].

RESULTS

In normal conditions, the power use inside the residence was considered to be just as normal daily conditions without applying any restrictions on turning or shutting any particular electric source. Results of electric and magnetic fields recorded in each residence are presented in Table 1. Variations of ELF electric and magnetic fields over 2.5 h at night time in the bedroom of residence R10 are displayed in Figures 1 and 2. Fields strength were recorded at 1 m above ground level by the bedside with TV and AC operating. As Figure 2 shows, the peak experienced around 11:30 pm might be due to operating electrical sources from neighboring apartments, or other unknown sources.

Table 2 presents the results of background ELF fields measured when no electric sources were applied (shutting down of the switchboard).

Except for few residences, the background fields were very low. Figures 3 and 4 show a comparison between mean fields under the normal and zero-power conditions.

During the study, a number of commonly used household appliances were under investigations of field's intensities. The results are summarized in Table 3.

The values of electric fields were distributed in a log-normal fashion with geometric mean, geometric standard deviation and median of 9.6, 3.5 and 7.9 V/m, respectively (Figures 5 and 6). Magnetic fields, also, were log-normally distributed, with geometric mean,

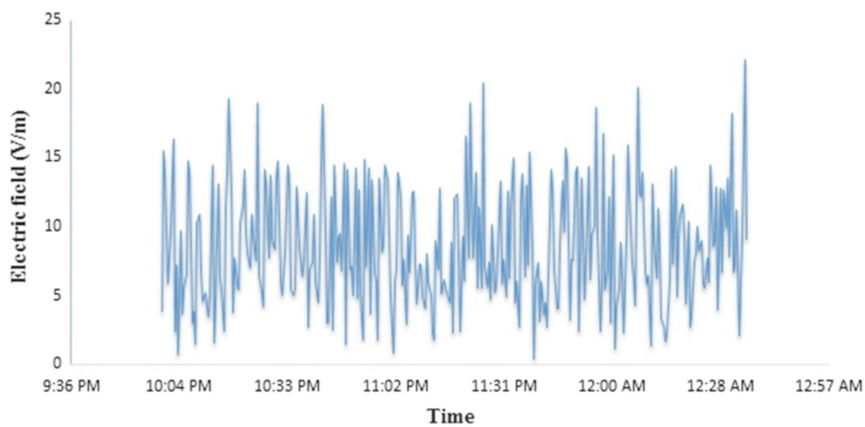

Figure 1. Variations of ELF electric fields over 2.5 h period, and 1 m above ground level at residence R10.

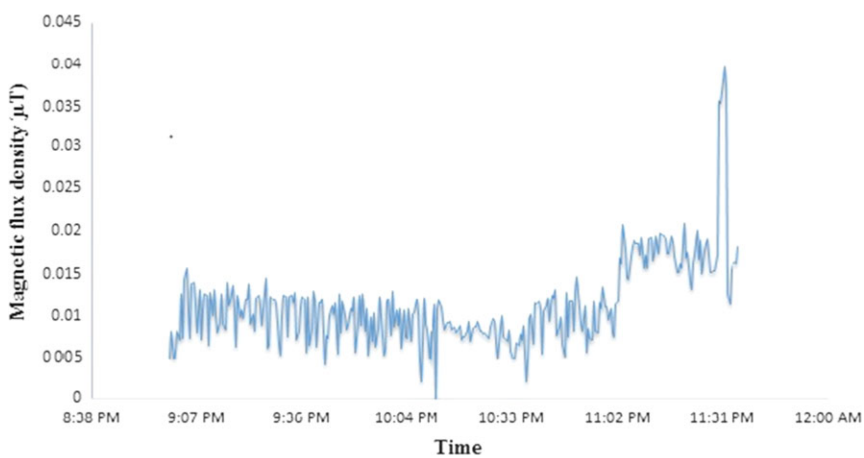

Figure 2. Variations of ELF magnetic flux densities over 2.5 h period, and one meter above ground level at residence R10.

Table 2. Arithmetic means of indoor ELF fields under zero-power uses (background fields).

Residence	AM of E-field (V/m)	AM of B-field × 10^{-3} (μT)
R1	0.14	19
R2	0.26	11
R3	0.39	68
R4	9.33	31
R5	1.24	427
R6	9.83	18
R7	3.58	80
R8	0.19	0
R9	0.17	0
R10	0.17	0
R11	0.12	6
R12	0.12	5.5
R13	0.35	0
R14	0.18	0
R15	0.14	4
R16	0.14	4
R17	0.16	6
R18	0.19	18
R19	0.17	8
R20	0.34	2
R21	0.18	4
R22	0.20	0
R23	0.22	0
R24	0.6	5
R25	Not identified[a]	Not identified[a]
R26	Not identified[a]	Not identified[a]
R27	7.96	148
R28	0.3	29
R29	0.18	0
R30	0.18	0
R31	30.78	6
R32	0.29	0

[a]At residences R25 and R26, the zero-power fields were not identified for technical reasons.

geometric standard deviation and median of 0.04, 3.18 and 0.04 μT, respectively (Figures 7 and 8).

The relation between ELF fields (as dependent variables) and distance from closest operating appliance (as independent variables) was investigated showing a strong negative correlation between mean electric field and distance with coefficient of correlation of –0.8 and *p*-value of 0.000 (Figure 9). On the other hand, a moderate negative correlation was found between mean magnetic fields and distance with coefficient of correlation of –0.41 and *p*-value of 0.020. However, these correlations between indoor ELF fields and distance from operating appliances are in consistence with the physical facts that state diminishing of ELF fields with increasing distances from point sources[20].

DISCUSSION

High ELF fields inside a residence can be attributed to different causes. In accordance with the literature[21–27], these are: proximity to working appliances, proximity to outdoor power lines, existence of indoor power-substation (HV transformer) or type and location of house (flat, detached or in a camp).

ELF magnetic fields

Magnetic fields that were >0.1 μT under normal-power use were found at the residences R26, R12, R5, R22, R27 and R3. With average field intensities 0.49, 0.45, 0.39, 0.31, 0.20 and 0.12 μT, respectively. Back to the characteristics of residences, there is a fair explanation for the high fields; R26 was one floor away from an indoor substation, furthermore, the distribution board was 1 m away from location of measurement. At R12, the measurement was carried in close vicinity (0.4 m) to working electric

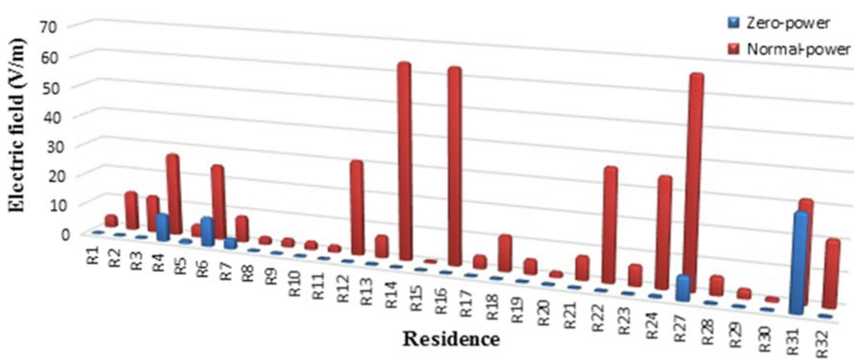

Figure 3. Comparison of average ELF electric fields under zero and normal-power uses.

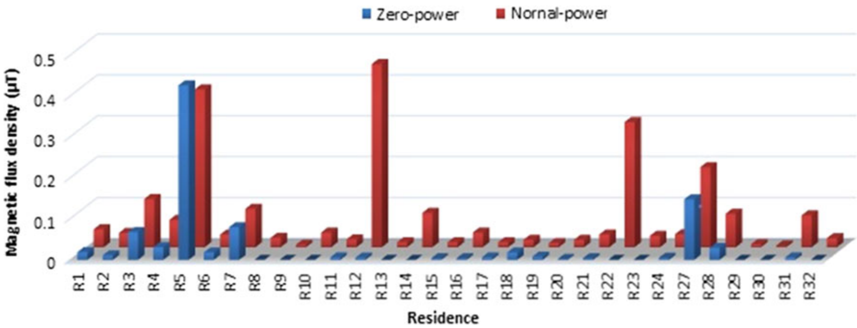

Figure 4. Comparison of average ELF magnetic flux densities under zero and normal-power uses.

Table 3. Average ELF electric and magnetic fields from certain appliances.

	E-field (V/m)		B-field (μT)	
Appliance[a]	Range	Average	Range	Average
Food processor	56–73	64.2	3.2–5.5	3.66
Laptop charger	59.1–73.7	65.5	7.6–8.4	7.86
TV (LCD)	53.3–71.9	60.8	0.06–0.07	0.06
Microwave oven	52–76	65.3	9.9–15.1	13.67
Electric heater	43–48.3	45.9	5.6–9.9	7.63
AC	49.2–68	53.9	0.13–0.87	0.44
Phone charger	48.8–71.7	62.8	0.03–0.04	0.03
Hair dryer	57–77	67.4	0.81–2.0	1.32
Vacuum cleaner	57.2–74.5	66.3	4.8–8.06	6.48
Meter board	62.2–67.2	64	4.84–5.6	5.16
Refrigerator	2.2–3.8	2.9	0.20–0.25	0.23
Toaster	59–78.3	66.8	1.73–3.41	2.82

[a]For the appliances, toaster, hair dryer, vacuum cleaner, food processor, refrigerator and microwave oven the measurements were carried at normal distance of use. For the TV, chargers, AC, electric heater and meter board the measurements were carried at their front surfaces. The average represents different field intensities recorded over 6 min.

heater. R5 was an apartment at Qadourah camp, which is known as a highly populated area with houses very close to each other. At R22, the measurement was performed in proximity to working AC (0.3 m). R27 was at the same floor level of an indoor power substation. The high field at R3 might be attributed to some wire faults within the home. In accordance, the average background fields within these residences were relatively high. Finally, ~33 and 7% of residences experienced average magnetic fields at zero-power conditions of 0 and >0.1 μT, respectively.

ELF electric fields

In accordance with the low-voltage electricity for domestic uses, the majority of ELF electric fields under normal-power conditions were in order of few volts per meter. The highest means of electric fields 66.9, 64.1, 63.8, 36.7, 35.4, 32.2 and 31.3 V/m were found at R27, R14, R16, R22, R24, R31 and R12, respectively. Proximity to working electrical appliances was the main reason for most of these elevated fields; at R14, R16, R22, R24 and R12 the measurements were in close vicinity (<1 m) to laptop charger, AC cable, AC cable, phone charger and electric heater, respectively. R27, as stated earlier was in a building with indoor power substation. R31 was in close vicinity to an outdoor power line. However, the means of background electric fields were relatively very low (<1 V/m in 80% of residences) except at R31 with average background of 30.8 V/m.

For fields from appliances, levels of electric fields varied within the same range which is reasonably justified by the same low-voltage (0.24 KV)[28] electricity inside all homes. On contrast, the strength of magnetic fields from appliances showed different variations and were not within a certain range of

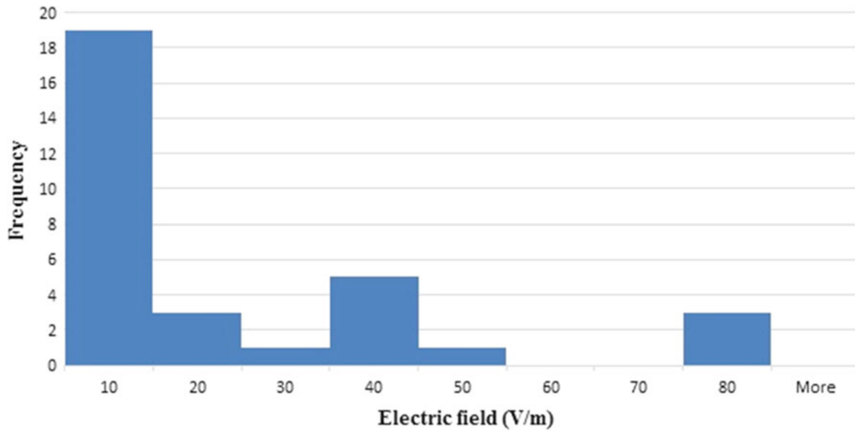

Figure 5. A histogram of ELF electric fields based on maximum recorded intensities at the 32 residences.

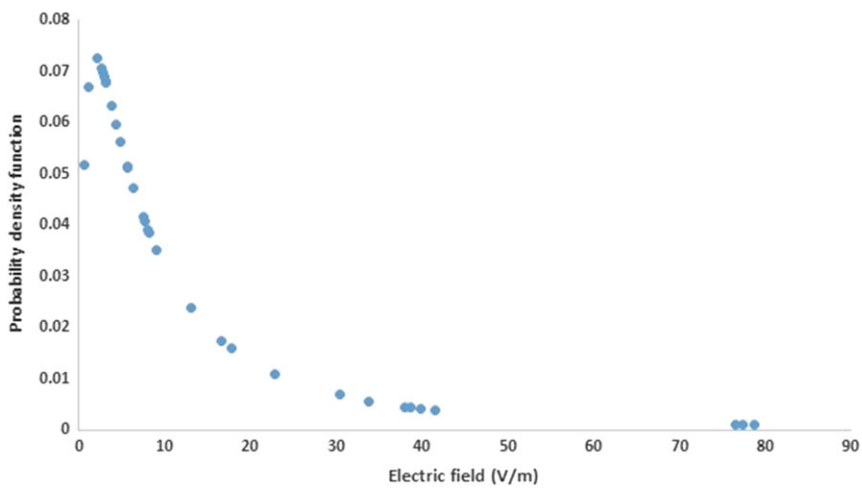

Figure 6. The log-normal distribution of maximum ELF electric fields from the 32 residences (based on the values of parameters $\mu = 2.26$ and $\sigma = 1.25$ V/m).

measurement. A possible explanation for this could be the electrical power of electrical devices; where the power is directly proportional to the electric current.

CONCLUSION

Exposure assessment is more complicated than thought; residents do not spend all their time within bedrooms or living rooms. An average person is exposed to ELF fields from the environment too. Passing underneath power lines, or even, by the sides of near-street distributors would definitely add a fraction to our exposure. Furthermore, as a part of our daily life, we spend not less than an hour (on average) in very close vicinity to operating appliances which, per contra, contributes in a big portion of the exposure.

Numerous previous studies were focused on the effect of ELF fields, and mainly magnetic fields, on health[29–32] and whether they were possible human carcinogenic[4–8]. For this exact reason, international guidelines for exposure to ELF fields have been established. Thus, it is worth mentioning by the end of study to give an approximate assessment for residential exposure to ELF fields in Ramallah city.

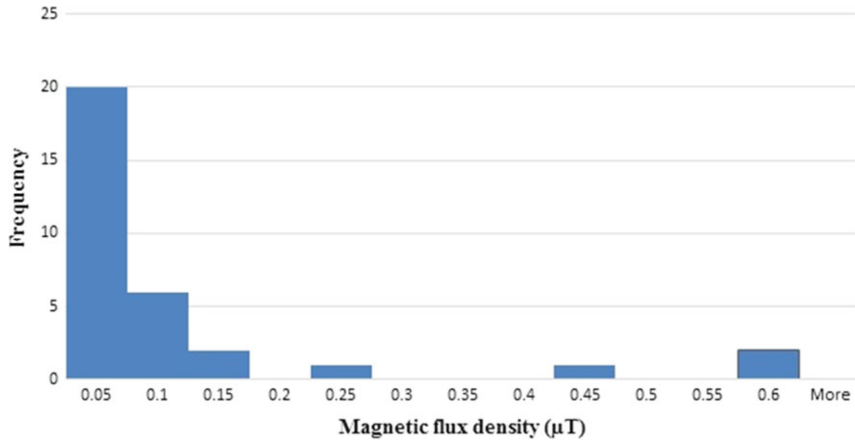

Figure 7. A histogram of ELF magnetic flux densities based on maximum recorded fields at the 32 residences.

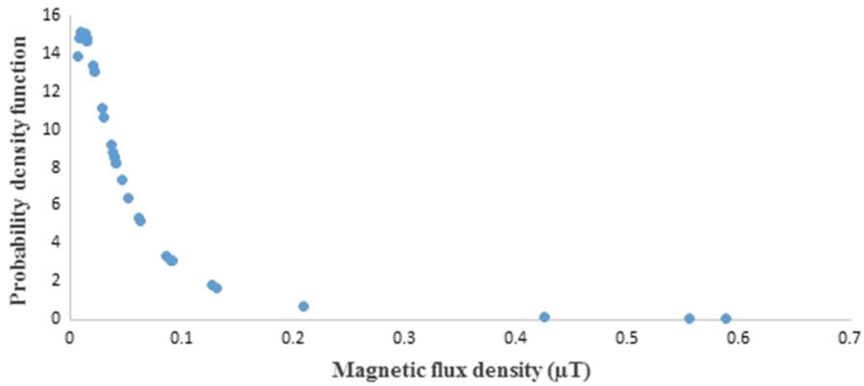

Figure 8. The log-normal distribution of maximum ELF magnetic flux densities from the 32 residences (based on the values of parameters $\mu = -3.12\,\mu T$ and $\sigma = 1.16\,\mu T$).

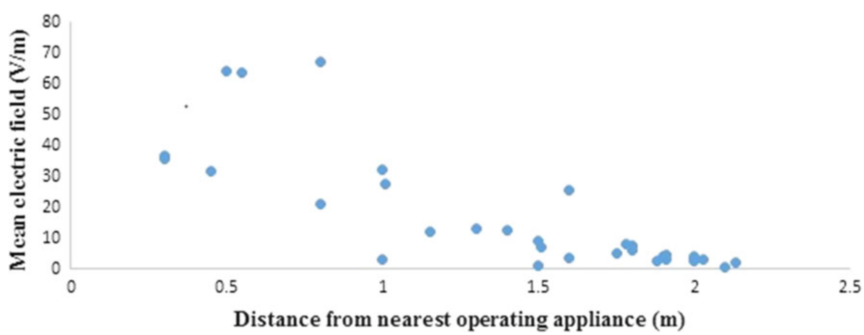

Figure 9. A scatter plot showing the strong negative correlation between mean electric fields measured among the 32 residences and distance from nearest operating appliance.

Table 4. Indoor residential exposure to ELF magnetic fields based on average values.

Exposure to B-field (μT)	Estimated percent of residences experienced the field (%)
<0.1	81
>0.1	19
0.3–0.4	13

Table 5. Indoor residential exposure to ELF electric fields based on average values.

Exposure to E-field (V/m)	Estimated percent of residences experienced the field (%)
<10	59
10–30	19
>30	22

Tables 4 and 5 summarize the data of these indoor exposures.

During the study, no single result surpassed the ICNIRP safety guidelines (100 μT and 5000 V/m for general public exposures to ELF fields)[(9)]. All the measured fields were well below these guidelines. Anyway, if non-thermal effects were considered, the assessment would be different and so would be the risks; since some residences (~13%) experienced fields in the range 0.3–0.4 μT, which is an interval stated by IARC[(8)] for long-term exposures that might be linked to non-thermal possible health impacts as childhood leukemia.

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