An-Najah National University

Faculty of Graduate Studies

Public Exposure to Extremely Low Frequency Magnetic and Electric fields in Ramallah City-Palestine

By

Falastine Awadallah Ahmad Abuasbi

Supervisor

Prof. Issam Rashid Abdel-Raziq

Co-Supervisor

Dr. Adnan Lahham

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This Thesis was defended successfully on 28/03/2017 and approved by:

Defense Committee Members	**Signature**
- **Prof. Issam Abdel-Raziq /Supersisor**	……………………..
– **Dr. Adnan Lahham /Co-Supervisor**	……………………..
– **Dr. Adnan Judeh /External Examiner**	……………………..
– **Prof. Sami Al-Jaber /Internal Examiner**	……………………..

Dedication

To the memory of my brother, Badran Abuasbi.

Acknowledgements

I am in debted to my beloved family for their endless support. I would like to thank my supervisors Dr. Adnan Lahham and Prof. Issam Abdel-Raziq for their guidance and assistance in making this thesis comes real.

الاقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Public Exposure to Extremely Low Frequency Magnetic and Electric Fields in Ramallah City-Palestine

أقر بأن ما اشتملت عليه هذه الرسالة انما هي نتاج جهدي الخاص باستثناء ما تمت الاشارة اليه حيثما ورد. وأن الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل أية درجة أو بحث علمي لدى أية مؤسسة تعليمية أو بحثية أخرى .

Declaration

I declare that this thesis “Public exposure to extremely low frequency magnetic and electric fields in Ramallah city-Palestine” is entirely a result of my own work, unless otherwise cited or referenced, and it has not previously been submitted for any other degree or qualification.

Name of student: **اسم الطالب:**

Signature: **التوقيع:**

Date: **التاريخ:**

List of Contents

List of Tables

List of Figures

List of Abbreviations

Symbol	Meaning
AC	Air Conditioner
ACGIH	American Conference of Governmental Industrial Hygienists
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
AM	Arithmetic Mean
B	Magnetic Field or Magnetic Flux Density
ELF	Extremely Low Frequency
ELF EMF	Extremely Low Frequency Electric and Magnetic Field
EMF	Electromagnetic Field
CRT	Cathode Ray Tube
D	Electric Displacement Vector
E	Electric Field
F	Force
f	Frequency
FM	Frequency Modulation
H	Magnetic Field Strength
H	Blank’s Constant
HV	High Voltage
Hz	Hertz
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
JDECO	Jerusalem District Electricity Company
KV	Kilo Volt
LV	Low Voltage
MHz	Mega Hertz
mT	Mille Tesla
N	Number of Turns
NF	Nieder Frequenz (in German) Means Low Frequency
NRL	National Radiation Laboratory
nT	Nano Tesla
NIEHS	National Institute of Environmental Health Science
PDF	Probability Density Function
Q	Electric charge
RF	Radio Frequency
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SD	Standard Deviation
T	Tesla
TV	Television
UKCCS	United Kingdom Childhood Cancer Study
V	Volt
WHO	World Health Organization

μ	Micro
$\boldsymbol{\varepsilon}$	Material Permittivity
$\boldsymbol{\mu}$	Magnetic Permeability
$\boldsymbol{\mu}_{\circ}$	Permeability of Free Space
$\boldsymbol{\sigma}$	Conductivity
$\boldsymbol{\varphi}$	Magnetic Flux
λ	Wavelength
$\boldsymbol{v}$	Frequency of a wave
$\boldsymbol{F/m}$	Farads Per Meter
$\boldsymbol{S/m}$	Siemens Per Meter
V/m	Volts Per Meter
$\boldsymbol{A/m}$	Amperes Per Meter
$\boldsymbol{H/m}$	Henrys Per Meter
$\boldsymbol{C/cm^2}$	Coulombs Per Square Centimeter

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Abstract

In this study, the public exposure to extremely low frequency magnetic and electric fields originated from power frequency (50 Hz) was investigated both indoor and outdoor in the city of Ramallah-Palestine. Spot measurements were used to record fields' intensities over six-minute period. Outdoor measurements were performed at one meter above ground level and directly underneath 40 randomly selected power lines distributed fairly within the city. Outdoor electric fields varied depending on the line's category (Power line, transformer or distributor), a minimum mean electric field of 3.89 V/m was found under a distributor line, and a maximum of 769.4 V/m under a high voltage power line. However, results of outdoor electric fields showed a log-normal distribution with geometric mean and geometric standard deviation of 35.88 V/m and 2.81 V/m respectively. Outdoor magnetic fields measured at power lines, on contrast, were not log-normally distributed; the minimum and maximum mean magnetic fields under power lines were 0.894 µT and 3.5 µT respectively.

For indoor measurements, a group of 32 semi-randomly selected residences distributed amongst the city were under investigations of 50-Hz electric and magnetic fields. Measurements were also carried 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 six-minutes and some times over few hours. Indoor electric fields under normal-power use were relatively low; about 59% of residences experienced mean electric fields less than 10 V/m. The highest mean electric field of 66.9 V/m was found at residence R27. However, indoor electric fields were log-normally distributed with geometric mean and geometric standard deviation of 9.6 V/m and 3.49 V/m respectively. Indoor background electric fields measured under zero-power use, were very low; about 80% of residences experienced background electric fields less than 1 V/m. Under normal-power use, the highest indoor mean magnetic field (0.448 µT) was found at residence R26 where an indoor power substation exists. However, about 81% of residences experienced mean magnetic fields less than 0.1 µT. Magnetic fields measured inside the 32 residences showed also a log-normal distribution with geometric mean and geometric standard deviation of 0.044 µT and 3.14 µT respectively. Under zero-power conditions, about 7% of residences experienced average background magnetic field greater than 0.1 µT. Fields from appliances showed a maximum mean electric field of 67.35 V/m from hair dryer, and maximum mean magnetic field of 13.67 µT from microwave oven. However, no single result (of both indoor and outdoor measurements) surpassed the ICNIRP limits for general public exposures to ELF fields.

A strong negative correlation was found between indoor electric fields and distance from closest operating appliance with correlation coefficient and p-value of – 0.8 and 0.000 respectively. On the other hand, a moderate negative correlation was found between indoor magnetic fields and distance from closest operating appliance with correlation coefficient and p-value of – 0.41 and 0.020 respectively.

Chapter One

Introduction

1.1 Background

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. Wherever electricity exists, there exist, as well, electric and magnetic fields. Electric fields arise from electric charges (i.e. potential difference) and are shielded by most common materials, even the human body. Magnetic fields, on the other hand, originate from the motion of electric charges (i.e. currents). On contrary to electric fields, magnetic fields are not shielded by most materials and can easily penetrate them. Both types of fields are highest in proximity to the source producing them, and diminish increasingly as we get further away from the source. Electric power operates at frequency of 50 or 60 Hz (50 Hz in Palestine), this frequency belongs to the range (3-3000 Hz) usually named as extremely low frequency (ELF). Both electric and magnetic fields originated from power frequency (50 Hz) are called extremely low frequency electric and magnetic fields (ELF EMF). (Indira N. et al, 1989; David O. et al, 1994; Palestine travel adaptors, 2017)

Transmission lines, high voltage (HV) power lines and transformers, and distributors are major sources of ELF EMF. Additionally, electric household appliances are significant operators of exposure to ELF fields. (Riadh W.Y., 2002).

The huge demand for electricity in the modern life, resulted in extending HV power lines in rural, sub-urban, urban areas, and sometimes in close vicinity to populated areas, and substantially increasing the public exposure to ELF EMF. However, Electric and magnetic fields underneath a power line vary depending on the voltage and the current carried by the line. Residential exposure to power-frequency fields in homes is much lower, though. Low-voltage (LV) electricity inside homes makes the strength of average electric fields in order of only few tens of volts per meter, while average magnetic fields vary from less than one to several micro tesla near some electrical facilities. (WHO, 2007).

Over time, there have been much concerns about ELF magnetic fields and its potential to assist health risks as childhood leukemia, breast cancer, and other symptoms that might be attributed to long term exposure to this field (Davis et al, 2002; Schuz et al, 2001; Friedman D. et al, 1996; Feychting M. et al, 1996; Pedersen C. et al, 2015).

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. (James C. L., 2009). 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. In 2002, the International Agency on Research on Cancer (IARC) published a monograph addressing ELF magnetic fields as possibly carcinogenic to humans. This classification was based on pooled analysis of epidemiological studies and previous researches. IARC stated that there is a link between childhood leukemia and ELF residential magnetic fields (above 0.3 to 0.4 μT). (WHO, 2002)

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. (ICNIRP, 1998)

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 used for telecommunications (as TV broadcasting, mobile telephony base stations, and FM radio) and other sources located indoor like microwave ovens. These mentioned sources of electromagnetic energy, which is usually, known as radiofrequency (RF) electromagnetic fields, are well investigated in the country, both indoor and outdoor. (Lahham A. et al, 2015; Lahham A. et al, 2011). The public concern regarding the possible health implications of exposure to ELF fields in Palestine has underlined the importance of having accessible and easy to recognize information about ambient levels of ELF EMF in our environment.

1.2 Literature Review

In 1993, Kaune W. discussed (based on published literature) problems related to the assessment of human exposure to power-frequency magnetic and electric fields. (Kaune W., 1993).

The National Institute of Environmental Health Sciences (NIEHS) provided a working group report on the assessment of possible adverse effects from exposure to ELF magnetic fields. Overall, the group reported that ELF magnetic fields are possibly carcinogenic depending on cases of childhood and chronic lymphocytic leukemias. (NIEHS, 1998).

Clinard et al compared between both indoor and outdoor residential magnetic field levels in France. By this work, it was found that only 5% of the dwellings experienced indoor magnetic field levels above 0.120 μT (Clinard et al, 1999).

Intensities of ELF electric and magnetic fields were measured by Havas M. within the 60 Ontario communities. Average magnetic field for the 60 communities was 0.58 μT. In contrast, average electric field was 3.2 V/m. Generally, communities with larger populations experienced higher magnetic flux densities. (Havas M., 2002).

Eskelinen T. and others tested the validity of short-term measurements (20 minutes) in characterizing residential ELF magnetic fields, showing a considerable importance of this approach in giving temporal variations of magnetic field levels. (Eskelinen T. et al, 2003).

Maslanyj and Allen in 2004 investigated sources of residential magnetic field exposures in United Kingdom Childhood Cancer Study (UKCCS).In the homes with exposures greater than or equal to 0.2 μT, it was found that the amount of exposure apparently depends on the type of house and proximity to high voltage power lines. (Maslanji and Allen, 2004).

Paniagua JM. And his group explored ELF magnetic fields in the streets of urban environments in Spain. 30% of streets spot measurements exceeded the level 0.2µT, which is, typically, linked to the risk of adverse health effects. (Paniagua JM. et al, 2004).

Moriyama K., and Yoshitomi K studied the link between residential exposure to ELF magnetic fields and type of house electrical wiring. Measurements took place at 696 points in a room of an apartment building in Japan. The maximum field recorded (1.8µT) was detected at ground level (Moriyama K., and Yoshitomi K, 2005).

In 2005, a pilot study was carried out by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) regarding the 50 Hz magnetic fields in Melbourne residential area. As a result of this work, 12% of the residences experienced levels greater than 0.4 µT. (Karipidis K. and Martin L., 2005).

Safigianni and Kostopoulou measured electric and magnetic fields in an indoor power substation using a three dimensional isotropic prop (EFA-3 analyzer). The maximum magnetic field that was recorded in one of the rooms was 582.2 µT while all measured electric fields were far below the ICNIRP's limits. (Safigianni and Kostopoulou, 2006).

Later in 2007, a study by Paniagua JM and others on exposure to ELF magnetic fields in the city of Cáceres,-Spain showed that detected fields were 7.3% of the ICNIRP limits, additionally, maximum field intensities were found in old neighborhoods. (Paniagua JM. Et al, 2007).

Techniques for evaluating and measuring ELF EMF from HV transmission lines and substations were briefly discussed in a study done by Szuba M. (Szuba M., 2007).

Straume A. and others measured the outdoor variations of ELF magnetic flux densities during two different seasons of the year: summer and winter, in a public environment in Norway. Recorded densities exceeded the value 0.4 μT in 34% of the streets during snowy winter, decreasing to 29% and 4% during cold and summer days respectively. (Straume A. et al, 2008).

Joseph W. et al investigated general public exposure to ELF EMF from different distribution substations. Measured magnetic field intensities ranged from 0.025 to 47.39 μT while the electric field intensities were within the range 0.1 to 536 V/m. The minimum distances from the distribution substations was also determined based on the recorded exposure values. (Joseph W. et al, 2008).

Ilonen K. and others studied the exposure to ELF magnetic fields in indoor power substations. Field intensities were measured inside apartments of thirty different buildings in Finnish cities. Results based on their work apparently showed higher exposure to ELF fields in apartments above the transformer than others in the first and upper floors. About 97% of apartments directly above the indoor transformer experienced exposure of 0.2μT or higher. (Ilonen K. et al, 2008).

Helhel and Ozen assessed the occupational exposure to magnetic fields in HV substations in Antalya city. As a result of their research, operators were exposed to magnetic fields greater than 0.3 μT for 8 working hours per day. (Helhel and Ozen, 2008).

Occupational exposure to ELF EMF during various work jobs at 110 KV substations in Finland was investigated by Korpinen and Pääkkönen. Working from a service platform had the maximum measured electric field (16.6 KV/m) which is above the ICNIRP limits of occupational exposure (10 KV/m). On contrary, the magnetic field did not surpass this limit at any work task. (Korpinen H. and Pääkkönen J., 2010).

A study by Röösli M. and his group was carried out in 39 different apartments in Switzerland. Arithmetic mean of magnetic field was 0.59 μT in 8 apartments that were either directly above the transformer or next to it (touching walls). (Röösli M., et al, 2011).

A study carried out by Schüz J. on the chronic exposure to ELF magnetic fields (≥ 0.4μT) and the risk of childhood cancers (as childhood leukemia and childhood brain tumor). The study based on pooled analyses and epidemiological evidence, updated the classification of ELF magnetic fields as possible carcinogens to humans into still valid. (Schüz J., 2011).

Fard S. and others propped the variations of magnetic fields in various indoor HV substations in Tehran. Maximum recorded magnetic field in one of the rooms was 0.59μT while the minimum was 0.2 μT. Nevertheless, none of the field intensities exceeded the American Conference of Governmental Industrial Hygienists (ACGIH) reference levels of exposure. (Fard S., et al, 2011).

Later in 2012, Yitzhak M. investigated 50-Hz magnetic field levels in buildings with indoor transformers, confirming the previous results of different researches that showed higher average magnetic field in apartments right above the transformer room. (Yitzhak M. et al, 2012).

The relation between residential exposures to ELF magnetic fields in Europe and childhood leukemia was studied in 2013 by Grellier et al. Between 50 and 60 of leukemia cases were estimated to be due to ELF magnetic fields annual exposures, which corresponds to 1.5%- 2% of the total annual leukemia cases in the European Union countries (Grellier et al,2013).

In 2014 Calvente et al characterized indoor ELF magnetic fields in the INMA-Granada cohort, in which 300 boys from 123 different families were subject to long term exposure measurements carried inside bedrooms and living rooms. The arithmetic mean value (± standard deviation) of magnetic fields was found to be 162.30 ± 91.16 nT which is below the reference level recommended by the ICNIRP. (Calvente et al, 2014)

Rachedi B. et al studied, numerically (using comsol multiphysics software) the variations of electric and magnetic fields in vicinity to 220 kilovolts (KV) transmission lines. Numerical analysis of their work showed fields intensities below the safety limits set by the ICNIRP. (Rachedi B. et al, 2014).

The impact of electromagnetic fields originated from HV power lines located in a populated area in Algeria was investigated in a work done by Tourab and Babouri in the year 2015. The intensity of fields was measured to attain the model of the personal exposure, yielding results well below the ICNIRP guidelines. (Tourab and Babouri, 2015).

Recently, in 2015, Nikolopoulos and others probed electromagnetic field levels from ELF and RF sources in certain indoor locations in Greece. Measured power-frequency electric and magnetic fields (ELF) were found, considerably, higher in residences near HV power lines than others. (Nikolopoulos D. et al, 2015).

1.3 Objectives of the Study.

This study aims to assess the public exposure to extremely low frequency magnetic and electric fields in Ramallah city-Palestine, where assessment is based on the following procedures:

1. Measure the ELF electric and magnetic field intensities in the urban environment of Ramallah city. Outdoor measurements are carried out under HV power lines, HV transformers, and their distributors.
2. Measure the ELF electric and magnetic field intensities in some semi-randomly selected residences in the city. Indoor measurements are performed inside the residences living rooms or bedrooms.
3. Compare between variations of field’s intensities from different sources.

Chapter Two

Theoretical Background

2.1 Origin of Extremely low frequency fields.

In the electromagnetic spectrum, the radiation is clearly categorized into two main groups: ionizing and non-ionizing. Ionizing radiation is found at the high frequency end of the spectrum, as gamma rays and x-rays, the associated energy ($E=h\nu$)of such rays is sufficiently enough to ionize atoms and damage tissues. On contrast, non-ionizing radiations including ultraviolet, visible, infrared, radio waves, and extremely low frequency fields, are found at the low frequency end of the spectrum. (Manickavasagan A. et al, 2014; E. Schmid et al, 2007).

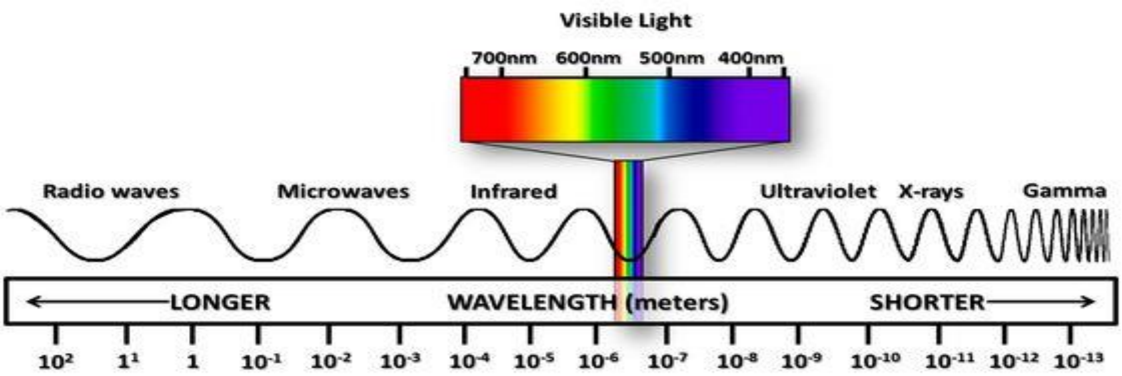

Fig (2. 1): Electromagnetic spectrum (source: Google digital images).

The frequency band (3-3000) Hz at the lower frequency limit of electromagnetic spectrum, is commonly known as extremely low frequency (ELF). In electric power, where time-varying electric currents oscillate at 50/60 Hz, alternating electric and magnetic fields (ELF fields) are produced in two different manners. Unlike the true electromagnetic radiation, as RF radiation, for example, ELF fields are not tightly coupled. However, the radiation becomes dominant if the distances were large compared to the wavelength (i.e. high frequency). In the case of power frequency (50 Hz), the associated wavelength (λ = speed of light/frequency) is very long, about 6000 Km. Consequently, radiation is negligible in the case of ELF fields. (WHO, 2007; SCENIHR, 2009).

2.1.1 Extremely low frequency electric fields.

ELF electric fields, expressed in volts per meter, are originated from the presence of unbalanced electric charges. The force (**F**)* exerted by an electric field (**E**) on a positive electric charge (q) is given by:

$$\boldsymbol{F} = q\boldsymbol{E} \tag{2.1}$$

Regardless of the amount of current, the strength of electric fields depends on the potential difference (voltage) between charge-carrying objects.

Electric flux density or displacement field is related to electric field by:

$$\boldsymbol{D} = \varepsilon\mathbf{E} \tag{2.2}$$

Where $\varepsilon,$ the material permittivity in Farads per meter (F/m), and **D** expressed in Coulomb per square meters (C/m^2) is the displacement vector that characterizes the interaction between electric fields and charges within a dielectric medium. (NIEHS, 1998).

*Vectors are expressed in bold letters.

2.1.2 Extremely low frequency magnetic fields.

ELF magnetic fields arise from the movement of electric charges (i.e. currents), on contrary to electric fields, magnetic fields depend on the amount of current regardless of the voltage. The force exerted by a magnetic field (**B**) on a moving charge (q) is given by:

$$\boldsymbol{F} = q\boldsymbol{V} \times \boldsymbol{B} \qquad (2.3)$$

Where **V** is the velocity of a moving charge, and **F** is the magnetic force. The two descriptions of magnetic fields: magnetic flux density (**B**) and magnetic field strength (**H**) are related through the equation:

$$\boldsymbol{B} = \mu\,\boldsymbol{H} \qquad (2.4)$$

Where μ is the magnetic permeability in Henrys per meter (H/m), **H** is the magnetic field strength in Amperes per meter (A/m), and **B** is the magnetic flux density in Webers per square meter or in Tesla (T). In case of biological tissues, $\mu = \mu_{\circ} = 12.57 \times 10^{-7} H/m$ (permeability of free space). Accordingly, in exposure protection, only one of the two fields' descriptions is needed. (NIEHS, 1998; IARC, 2002).

2.2 Sources of Extremely low frequency fields.

Wherever electricity flows, alternating ELF fields are generated from the flow of time-varying currents. In public exposure, overhead power lines, including HV power lines, transformers, and their distributors are major sources of ELF fields. The strength of magnetic fields underneath power lines can reach 20µT, while electric field can be several kilo-volts per meter. Electrical appliances inside homes and any other facility functions with electric power produces ELF fields, as well. (NRL, 2008; ARPANSA, 2015; WHO, 2007).

2.2.1 Transmission lines.

The lines where electricity is carried from power plants over very long distances into other substations. They are usually located between cities (in non-public areas). Typical voltage of transmission lines is higher than 115 KV. (J. Molburg et al., 2007).

2.2.2 High voltage transformers

Transformers are devices used in power system to change the voltage of electricity. Over very long distances where high voltage is required to minimize the energy loss within wires of transmission lines, stepping up transformers are used. On contrast, in urban and rural areas, stepping down transformers are used to attain the demanded low-voltage electricity.

Fig (2. 2): A transformer in the environment of Ramallah. (Source: Author, 2016).

However, physics of this interesting equipment is based upon Faraday's low of electromagnetism, where two separate coils (with different number of turns) wrapped around an iron core, are the main parts of a transformer. A time-alternating electric current with certain voltage, passing through the primary coil produces an alternating magnetic flux, as well. This flux in turns will be guided by the core into the secondary coil resulting in an induced current with different voltage.

$$V_1 = -N_1 \frac{\partial \varphi_1}{\partial t} \ and \ V_2 = -N_2 \frac{\partial \varphi_2}{\partial t} \qquad (2.8)$$

These relations reduces into:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \qquad (2.9)$$

Where φ_1 ,V_1 ,and N_1 are the flux , voltage, and number of turns of the primary coil, while φ_2,V_2,and N_2 are the flux , voltage, and number of turns of the secondary. (Jerrold T. et al, 2002; Graham D. et al, 1996).

2.2.3 High voltage power lines.

Power lines are cables carrying electrical power supported by pylons or poles, they are also the connection between transmission lines and distributors. (Nicholas J. G., 2010). The typical voltage of power lines (and transformers) in the urban city of Ramallah is 33/11 KV. They are located in different areas in our environment, including rural and urban sides.

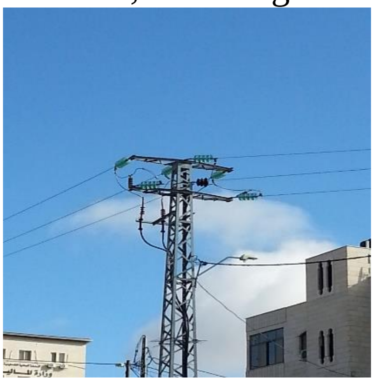

Fig (2. 3): A power line in the environment of Ramallah (source: Author, 2016).

2.2.4 Distributors.

Distribution lines are the last part of power-supply system. They carry low-voltage electricity from stepping down transformers into consumers (houses, companies, etc.). Usual voltage of these distributors is 0.23/0.4 KV. (S. Sivanagaraj et al, 2009).

2.2.5 Household appliances.

ELF fields are produced around electrical equipment in homes. These fields, as stated earlier, are generated from the flow of electric currents. The strength of ELF fields from household appliances varies depending on the sort of appliance, its brand, and its consumption to electric power. However, devices with motors, usually generate higher fields. Strength of ELF fields decrease more rapidly in case of a point source (appliances) than a line source (power lines). (WHO, 2007; Kaune W. T., 1993)

Table (2. 1): Typical magnetic field values from some domestic appliances (at normal user distance).

Source	B-field range of measurement (μT)
Television (TV)	0.02 – 0.2
Refrigerator	0.2 – 0.5
Microwave oven	0.77 – 18.8
Toaster	0.2 – 1.0
hair dryer	1.0 – 7.0

Source: ARPANSA, 2015.

2.3 Coupling between human body and extremely low frequency fields.

At extremely low frequencies, the associated photon energy is quite small, for the power frequency 50 Hz, the energy ($E = hv$) is negligible if compared to that required to damage the weakest chemical bonds. Thus, ELF fields, which are classified as non-ionizing radiation, cannot damage the human cellular function, nor can they raise body temperature. Generally, Exposure to ELF fields results in formation of induced electric fields and current densities. (NIEHS, 1998).

2.3.1 Coupling to extremely low frequency electric fields.

ELF electric fields at relatively high densities, can cause adverse health effects: nerve and muscle stimulation, damage in cell membrane, or even burn injuries. However, effects as these require very high external electric fields (in order of several 100 V/m) that in turns, induce internal electric fields within an exposed human body.

The relation between both fields' intensities (internal and external) and the electrical properties of biological tissues is covered by the equation:

$$\frac{\mathrm{E_{ext}}}{\mathrm{E_{int}}} = \frac{\sigma}{\omega \varepsilon_{\circ}} \qquad (2.5)$$

Where σ is the conductivity of tissue (see table 2.1), ω is the angular frequency $(2\pi f)$, and $\varepsilon_{\circ}$ is the permittivity of vacuum $8.84 \times 10^{-12} F/m$. (NIEHS, 1998).

As the relation implies, a human body that is exposed to typical external electric fields at power frequency (50 Hz), will perturb this field into an extremely small $(10^5 - 10^8 less)$ induced electric fields inside the body. (IARC, 2002).

Table (2. 2): Conductivity of some biological tissues based on power-frequency fields.

Tissue	Conductivity (S/m)
Eye Sclera	0.5
Blood	0.7
Fat	0.02
Heart	0.5
Skin	0.04

Source: (WHO, 2002).

2.3.2 Coupling to extremely low frequency magnetic fields.

The mechanism, in which ELF magnetic fields interact with the human body, is relatively different. The magnetic permeability (μ)of living tissues is the same as that in vacuum, thus, magnetic fields inside and outside the body are nearly the same. According to Faraday's law of induction, magnetic fields induce electric fields within the body:

$$\oint E.dl = \iint \frac{\partial B}{\partial t} \cdot ds \qquad (2.6)$$

Where the integral $\oint E.dl$ represents the electric field integrated over a closed loop, and $\iint \frac{\partial B}{\partial t} \cdot ds$ indicates the time rate of change of magnetic flux density. Considering the human body as a long cylinder of radius r, equation 2.6 reduces into:

$$E = \pi f r B \qquad (2.7)$$

Where f is the frequency, B is the magnetic field strength, and E is the induced electric field. In comparison, these induced fields are much greater than those electrically induced. Nevertheless, they are much smaller than the induced fields required for nerve stimulation. (WHO, 2007; NIEHS, 1998).

2.4 International Guidelines.

The exposure to time-varying (50Hz) electric and magnetic fields cannot be categorized into high or even low level unless we had some reference standards to compare with. Accordingly, the ICNIRP established guidelines for limiting the public exposure to ELF EMF. (See table 1.1).

Table (2. 3): Reference levels for time-varying EMF. (ICNIRP, 1998).

Frequency range	***E-field (V/m)_***	***B-field (μT) __***
1 – 8 Hz	10,000	$4 \times 10^4/f^2$
8 – 25 Hz	10,000	$5000/f$
0.025 – 0.8 KHz	$250/f^*$	$5/f$

*** f is the frequency as indicated in the frequency range.**

As the table shows, 100 μT was recommended as a reference level for exposure to power-frequency magnetic fields, and 5000 V/m for electric field exposures. Higher exposure restrictions were considered in general public exposures than the case of occupational ones (500μT and 10,000V/m), which is, clearly, attributed to the differences in type of exposed individuals and their awareness for EMF exposures. These stated limits were based on short-term instant health effects such as nerves and muscles stimulation and increasing in tissue temperature during exposure to EMF.

Later, the adverse effects (as childhood leukemia) of long-term exposures to ELF magnetic fields were restricted to the interval 0.3-0.4μT or above. (ICNIRP, 1998; WHO, 2002).

Chapter Three

Methodology

3.1 Study area.

Ramallah, where the study measurements were carried, is a Palestinian city in the center of the west bank to the north of Jerusalem and 64 Km from the Mediterranean Sea, with an average elevation of 880 m above sea level. Currently, more than 40,000 inhabitants live in Ramallah city. (Wikipedia; Ramallah Municipality).

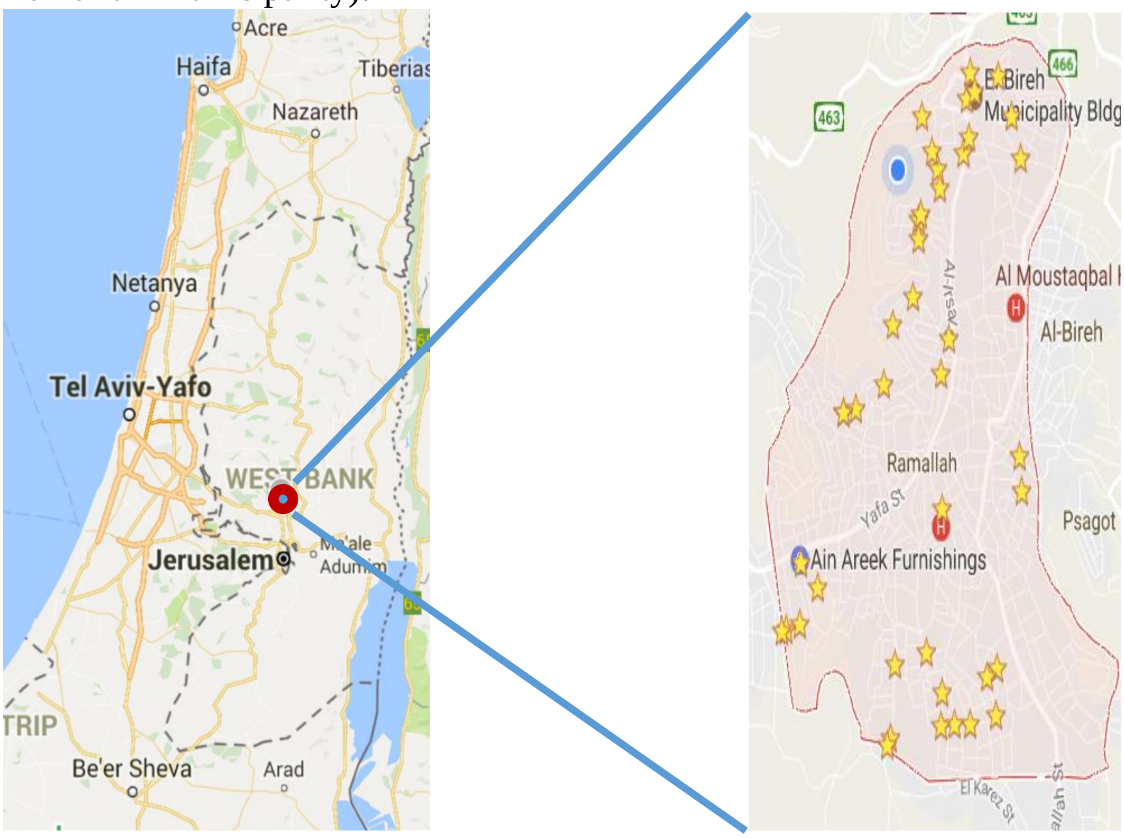

Fig (3. 1): A map of Palestine showing the city of Ramallah in the west bank (left), and a magnified map of the study area showing locations of the 40 power lines (right). Source: Google maps

The study was mainly focused on two distinct surveys: indoor and outdoor. For outdoor measurements, a group of 40 randomly selected power lines in different areas inside the city Ramallah were under investigations of ELF EMF levels. The 40 power lines were fairly distributed in the city environmental locations: Al-Ersal, Al-Balo', Al-Masayef, Al-Tirah, Bitonia, Sateh-Marhaba, Al-Birah, Al-Masyoun, Ein-Menjed, and Ein-Mesbah.

Table (3. 1): Power lines examined during outdoor survey.

Power line	Category	Coordinates* of power line
P1	HV power line	N 31.91212° E 35.20656°
P2	Distributor	N 31.92444° E 35.20833°
P3	HV transformer	N 31.92343° E 35.20521°
P4	HV transformer	N 31.92357° E 35.20528°
P5	HV transformer	N 31.91492° E 35.20216°
P6	HV transformer	N 31.91302° E 35.19973°
P7	HV transformer	N 31.91874° E 35.20288°
P8	HV power line	N 31.91996° E 35.20295°
P9	HV transformer	N 31.92031° E 35.20322°
P10	HV transformer	N 31.92974° E 35.20925°
P11	HV transformer	N 31.93560° E 35.20288°
P12	HV transformer	N 31.92459° E 35.20458°
P13	HV power line	N 31.92683° E 35.20330°
P14	HV transformer	N 31.90748° E 35.19529°
P15	HV power line	N 31.90902° E 35.19866°
P16	HV transformer	N 31.89722° E 35.18853°
P17	HV power line	N 31.89315° E 35.18837°
P18	HV transformer	N 31.89279° E 35.18678°
P19	HV power line	N 31.89264° E 35.18615°
P20	HV transformer	N 31.89562°

		E 35.19056°
P21	HV power line	N 31.90721° E 35.19374°
P22	Distributor.	N 31.89045° E 35.20006°
P23	HV transformer	N 31.19979° E 35.88805°
P24	HV power line	N 31.88561° E 35.19942°
P25	HV transformer	N 31.88508° E 35.19903°
P26	HV power line	N 31.89128° E 35.20386°
P27	Distributor.	N 31.92411° E 35.21541°
P28	HV transformer	N 31.92687° E 35.21429°
P29	HV power line	N 31.92954° E 35.21259°
P30	HV power line	N 31.92801° E 35.20883°
P31	HV transformer	N 31.92846° E 35.20978°
P32	Distributor.	N 31.90714° E 35.22298°
P33	Distributor	N 31.90430° E 35.21531°
P34	HV transformer	N 31.89024° E 35.21253°
P35	HV Power line.	N 31.88958° E 35.21131°
P36	HV power line	N 31.88710° E 35.21238°
P37	Distributor	N 31.88650° E 35.20926°
P38	HV transformer	N 31.88651° E 35.20729°
P39	Distributor	N 31.88643° E 35.20570°
P40	Distributor	N 31.88861° E 35.20584°

*** A GPS devise (hp iPAQ) was used to record the coordinates of power lines.**

For the indoor measurements, a group of 32 semi-randomly selected homes were chosen in the study. These homes were also distributed fairly among different locations inside the city-Ramallah. The majority of residences were apartments within buildings, while the rest were detached homes. See table 3.2

Table (3. 2): Residences examined during indoor survey.

Residence	Residence category	Room category*
R1	Apartment	Living room
R2	Apartment	Living room
R3	Apartment	Living room
R4	Apartment	Living room
R5	Apartment	Living room
R6	Apartment	Living room
R7	Detached	Living room
R8	Apartment	Living room
R9	Apartment	Bedroom
R10	Apartment	Bedroom
R11	Apartment	Bedroom
R12	Apartment	Bedroom
R13	Apartment	Living room
R14	Apartment	Living room
R15	Detached	Living room
R16	Detached	Living room
R17	Detached	Living room
R18	Detached	Living room
R19	Detached	Bedroom
R20	Apartment	Bedroom
R21	Apartment	Living room
R22	Apartment	Bedroom
R23	Apartment	Bedroom
R24	Apartment	Bedroom
R25	Apartment	Living room
R26	Apartment	Living room
R27	Apartment	Living/Bedroom
R28	Apartment	Bedroom
R29	Apartment	Living room
R30	Apartment	Bedroom
R31	Apartment	Bedroom
R32	Apartment	Living room

***The room where the measurement was carried out.**

Table (3. 3): Power conditions at time of measurements.

Residence	Near overhead power lines	Indoor power substation	Operating appliances*	Location of measurement
R1	No	No	Light pulps TV Refrigerator	Middle of the room
R2	No	No	Light pulps TV	Middle of the room
R3	No	No	Light pulps TV Phone charger	Middle of the room
R4	No	No	Light pulps TV	Middle of the room
R5	No	No	Light pulps TV (CRT)	Middle of the room
R6	No	No	Light pulps TV Air conditioner (AC)	Middle of the room
R7	No	No	TV Light pulps	Middle of the room
R8	No	No	TV Light pulps	Middle of the room
R9	No	No	Light pulps AC	Middle of the room
R10	No	No	Light pulps TV AC	Middle of the room
R11	No	No	Light pulps Electric heater	Where the kid sleep
R12	No	No	Light pulps Electric heater (0.4 m) TV	By the bed side
R13	No	No	Light pulps TV	Middle of the room
R14	N0	No	Light pulps Laptop charger (0.5m)	Middle of the room
R15	No	No	Light pulp	Middle of the room
R16	N0	No	Light pulp AC (0.5 m)	By the sofa side
R17	Yes (25 m)	No	Light pulps TV	Middle of the room
R18	Yes (20 m)	No	Light pulp	Middle of the room
R19	No	No	Light pulp	Middle of the room
R20	No	No	Light pulp	By the bed side

R21	No	No	Light pulps TV Phone charger	Middle of the room
R22	No	No	Light pulp AC cable (0.3 m)	Where the kid sleep
R23	No	No	Light pulp AC	Where the kid sleep
R24	No	No	Light AC Phone charger (0.3 m)	By the bed side
R25	No	Yes (3 floors away)	Light pulps TV	Middle of the room
R26	No	Yes (1 floor away)	Light pulps TV Distribution board (1 m)	Middle of the room
R27	No	Yes (same floor)	Light pulp TV Refrigerator Phone charger	Middle of the room
R28	No	Yes (2 floors away)	Light pulps AC	By the bed side
R29	No	No	TV Light pulp	Middle of the room
R30	No	No	Light pulp	By the bed side
R31	Yes (7 m)	No	Light pulp TV (CRT)	By the bed side
R32	No	No	Light pulps TV (0.8 m)	Middle of the room

***Distance was ignored for appliances more than 1 m away. (NRL, 2008)**

3.2 Stages of the study.

Measurements were carried out during autumn of 2016 (September through November). Several stages were implemented to fulfill the points of the study:

- Contacting the Jerusalem District Electricity company (JDECO) and meeting the specialist electric engineers to discuss features of power lines, their locations, and addresses of some indoor power substations inside the city.

- At outdoor power lines, locations were chosen randomly keeping in mind, the fair distribution among the city's different sides. Measurements were taken directly underneath the line and at one meter above the ground level. Variations of ELF fields were recorded over 6-minute period of time for both electric and magnetic field separately.
- At indoor residences, locations were chosen semi-randomly to maintain the distribution and the some existence of homes with indoor power substation (transformer). Measurements were also taken at one meter above ground level inside the residences living rooms or bedrooms, where a significant amount of time is usually spent. Spot measurements were used in order to record ELF field levels over short-period of time (6 minutes). 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.
- For indoor survey, the measurements were performed 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), and measurements of ELF fields took place over short-time as stated earlier. For both of these power conditions,

measurements of ELF fields were applied under the same point within the room.

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

3.3 Study instrumentations.

Field measurements were performed with the spectran analyzer NF-5035. This devise measures fields of the frequency range 1Hz – 30 MHz, with accuracy of 3%. Typical ranges of electric and magnetic fields that can be measured by the spectran at power frequency are 0.1 V/m – 5KV/m and 0.1 nT – 20 mT respectively. Comprising a three dimensional antenna for magnetic field measurements is one important feature of this spectran.

Fig (3. 2): Spectran analyzer NF-5035 (Aaronia, 2013).

A laser distance meter (HILTI) 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.

Fig (3. 3): HILTI laser meter PD 42. (HILTI, 2011)

3.4 Data analysis.

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

- Variations of measured ELF fields over time (displayed on a line chart)
- Arithmetic means and standard deviations of measured ELF fields.
- Ranges of measured ELF fields showing the minimum and maximum points.
- Comparison of ELF fields measured in different residences.
- Comparison of different ELF background fields among the residences.
- Comparison of ELF fields from different household appliances.
- Probability density functions, geometric means, and geometric standard deviations of overal fields.

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma x}\exp(-\frac{(\ln(x)-\mu)^2}{2\sigma^2}) \qquad (3.1)$$

Where $f(x)$ is the probability density function (PDF), and x is the variable that follows a log-normal distribution (magnetic or electric field).The parameters μ and σ are the mean and standard deviation of $\ln(x)$ values respictively. (Millard and Mirchal, 2000).

- Correlation between ELF fields and distance from nearest operating appliance.

Chapter Four

Results

4.1 Results of outdoor measurements.

This section introduces outdoor results of ELF fields measured at power lines locations. Ranges, means, standard deviations, and variations over time are briefly described in the following sub-sections.

4.1.1 Ranges and arithmetic means of outdoor extremely low frequency fields.

Table (4. 1): Ranges, arithmetic means, and standard deviations of ELF fields measured at power lines.

E-field (V/m)				B-field (μT)		
Power line	Range*	AM	SD	Range	AM	SD
P1	5.77 – 45.1	20.48	11.76	3.32 – 3.62	3.5	0.114
P2	1.47 – 2.9	2.62	0.743	2.5 – 2.96	2.76	0.158
P3	15.3 – 60.6	40.72	11.55	1.74 – 3.14	2.54	0.468
P4	21.3 – 35.2	27.7	4.47	2.835 – 2.97	2.935	0.048
P5	26.7 – 43.5	39.26	4.56	2.3 – 3.43	2.75	0.382
P6	51.04 – 71.03	65	5.73	2.06 – 3.23	2.76	0.397
P7	20.9 – 27.1	25.07	1.855	2.95 – 2.72	2.86	0.076
P8	29.3 – 44.6	38.78	6.15	2.897 -2.966	2.94	0.026
P9	32.8 – 47.1	37.86	3.95	2.86 – 2.966	2.93	0.03
P10	4.51 – 8.63	6.58	1.27	2.181 – 2.943	2.66	0.233
P11	37 – 56.7	45.58	5.28	1.84 – 3.17	2.57	0.382
P12	61 – 110.8	75.33	16.88	2.62 – 2.966	2.86	0.114
P13	12.3 – 17.8	14.96	1.64	0.791 – 0.938	0.894	0.058
P14	33.4 – 39	36.28	2.01	2.181 – 2.966	2.879	0.224
P15	115.5 – 136.9	130.45	6.20	1.655 – 2.984	2.83	0.375
P16	21.1 – 28.9	25.61	2.53	2.771 – 2.966	2.877	0.072
P17	41.1 – 58.4	52.68	4.52	2.818 – 2.984	2.91	0.054
P18	49.2 – 57.9	52.68	2.27	2.756 – 2.984	2.869	0.09
P19	400 – 873.3	769.4	140.54	2.867 – 2.966	2.93	0.03
P20	21.2 – 25.9	23.35	1.71	2.733 – 2.966	2.9	0.064

P21	17.6 -25.8	20.52	2.28	2.756 – 2.984	2.89	0.089
P22	12.1 – 17.9	14.91	1.80	2.771 – 2.984	2.898	0.06
P23	20.5 – 24.7	22.87	1.44	2.564 – 3.283	2.823	0.18
P24	85.3 – 110.7	104.1	6.88	2.719 – 2.984	2.882	0.097
P25	25 – 31.5	27.72	1.94	2.792 – 2.984	2.855	0.063
P26	22 – 27.2	24.39	1.67	2.78 – 2.966	2.866	0.06
P27	7.6 – 10.9	9.37	1.19	2.26 – 2.966	2.68	0.237
P28	24.3 – 28.5	26.61	1.43	2.686 – 2.951	2.811	0.095
P29	58.8 – 65.4	61.7	2.07	2.766 – 3.001	2.906	0.084
P30	186.3 – 222.1	202.76	9.90	2.413 – 2.966	2.794	0.148
P31	48.2 – 107	65.68	20.27	2.653 – 2.921	2.748	0.077
P32	21.1 – 23.7	22.47	0.82	3.382 – 3.712	3.463	0.095
P33	3.6 – 5.4	4.4	0.54	3.356 – 3.7	3.499	0.09
P34	18.7 – 24	20.73	1.72	2.679 – 2.966	2.853	0.101
P35	23.8 – 34.3	28.2	3.19	2.823 – 2.984	2.918	0.054
P36	51 – 66.8	58.4	3.88	2.803 – 2.984	2.903	0.062
P37	5.9 – 12.2	9.4	2.02	2.574 – 2.966	2.853	0.133
P38	37.9 – 54.6	46.38	5.92	1.749 – 2.413	2.211	0.205
P39	11.99 – 19.7	16.71	2.26	2.658 – 2.946	2.824	0.104
P40	0.7 – 5.8	3.89	1.52	2.728 – 2.966	2.916	0.073

***The range shows the minimum and maximum recorded fields.**

4.1.2 Variations of outdoor extremely low frequency fields over time.

This sub-section displays the fields' variations of some selected power lines of different categories.

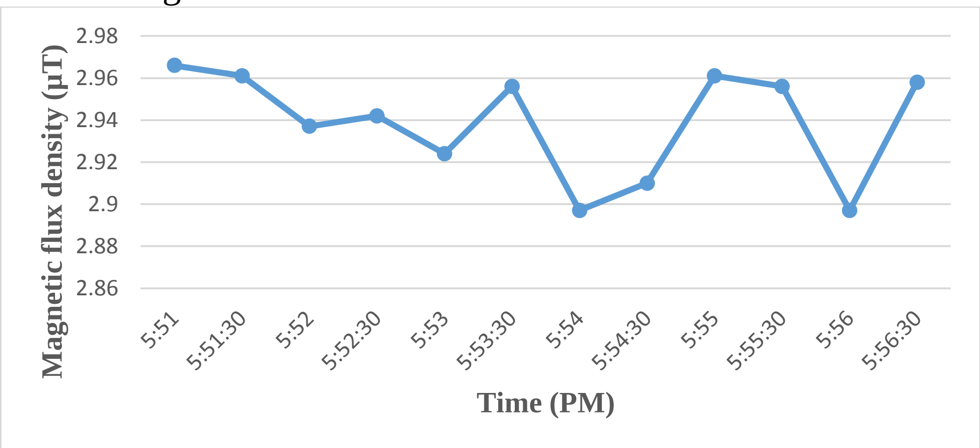

Fig (4. 1): Variations of ELF magnetic flux densities over 6-minute period, and one meter above ground level under power line P8

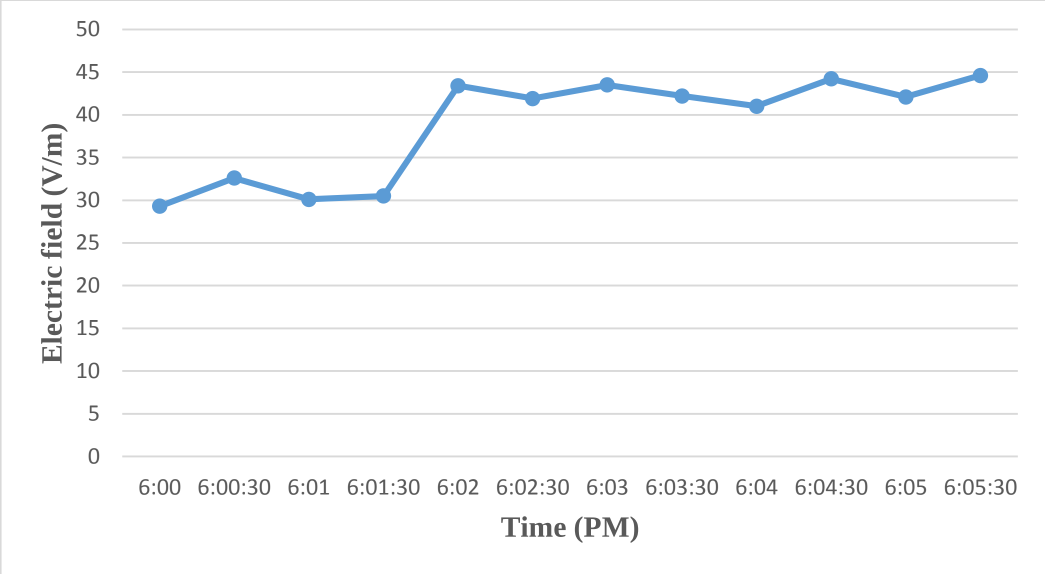

Fig (4. 2): Variations of ELF electric fields over 6-minutes period, and one meter above ground level under power line P8.

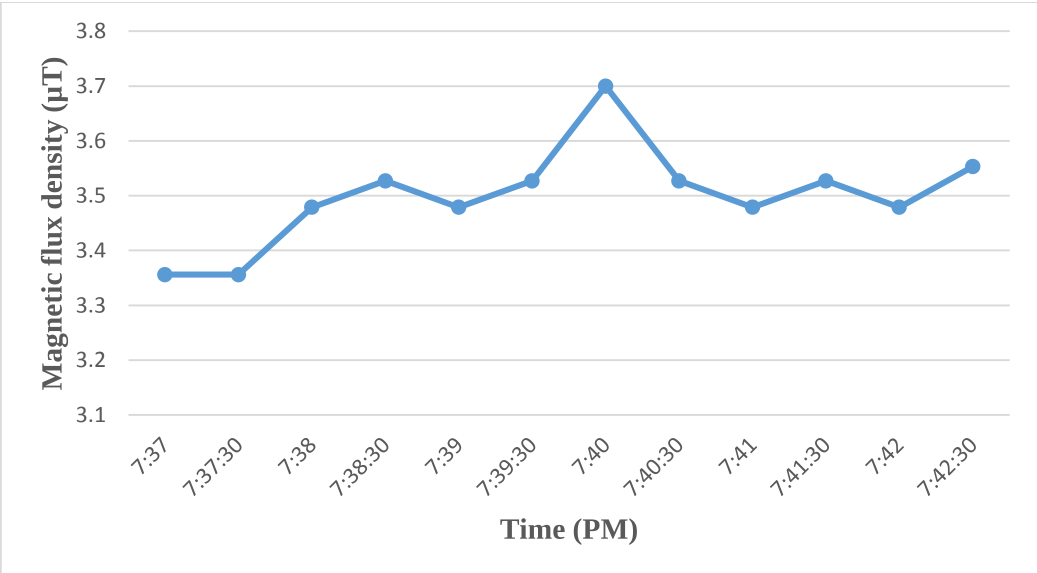

Fig (4. 3): Variations of ELF magnetic flux densities over 6-minutes period, and one meter above ground level under power line P33.

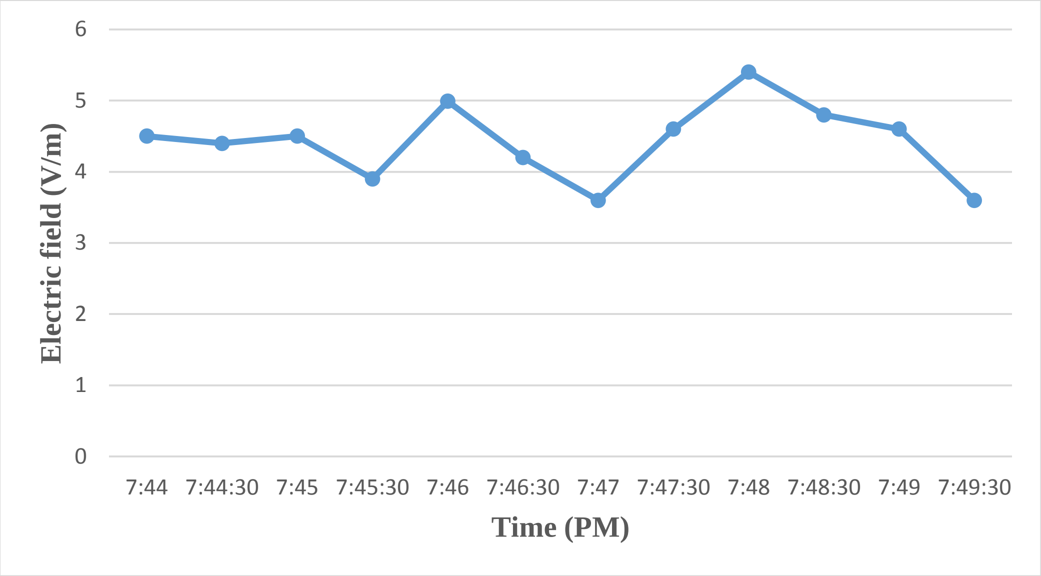

Fig (4. 4): Variations of ELF electric fields over 6-minutes period, and one meter above ground level under power line P33.

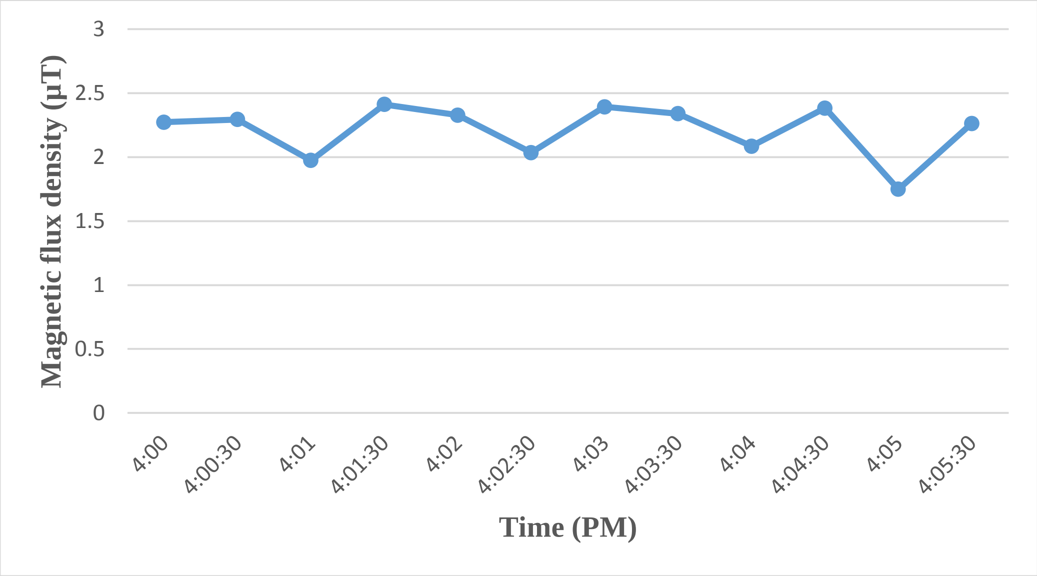

Fig (4. 5): Variations of ELF magnetic flux densities over 6-minutes period, and one meter above ground level under power line P38.

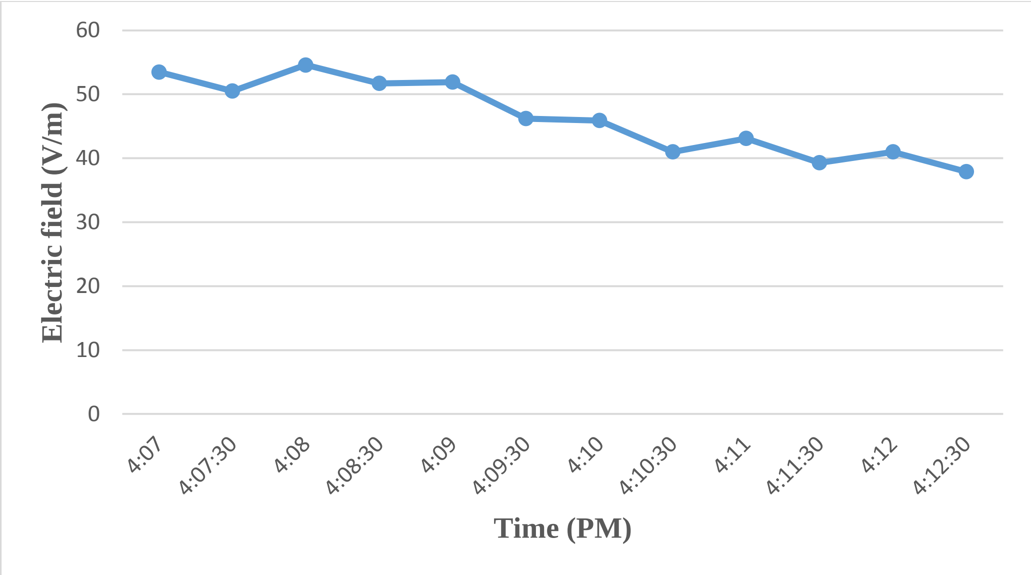

Fig (4. 6): Variations of ELF electric fields over 6-minutes period, and one meter above ground level under power line P38.

4.2 Results of indoor measurements.

This section introduces indoor results of ELF fields measured at the 32 residences in the city of Ramallah. Ranges, arithmetic means, standard deviations, and variations of zero-power use (background) and normal-power use over time are briefly described in the following sub-sections.

4.2.1 Ranges and arithmetic means of indoor extremely low frequency fields.

Table (4. 2): Ranges, arithmetic means, and standard deviations of indoor ELF fields under normal-power uses.

E-field (V/m)			B-field (μT)			
Residence	Range	AM	SD	Range	AM	SD
R1	2.08 – 8.1	4.08	1.69	0.032 – 0.053	0.044	0.009
R2	8.11 – 16.6	13.06	2.47	0.028 – 0.042	0.035	0.004
R3	11.88 – 13.03	12.49	0.35	0.111 – 0.127	0.118	0.004
R4	17.8 – 33.8	27.62	7.22	0.049 – 0.087	0.067	0.014
R5	3.7 – 4.9	4.22	0.31	0.218 – 0.635	0.386	0.176
R6	18 – 30.45	25.34	3.24	0.026 – 0.037	0.031	0.004
R7	8.24 – 9.1	8.79	0.284	0.075 – 0.132	0.094	0.018
R8	2.1 – 2.72	2.57	0.16	0.016 – 0.04	0.023	0.006
R9	2.61 – 3.14	2.83	0.18	0.002 – 0.009	0.006	0.002
R10	2.53 – 2.85	2.76	0.104	0.022 – 0.047	0.036	0.007
R11	1.68 – 3.01	2.35	0.41	0.016 – 0.022	0.019	0.002
R12	16.9 – 41.5	31.3	6.88	0.314 – 0.588	0.448	0.09
R13	7.1 – 7.7	7.38	0.18	0.005 – 0.016	0.012	0.003
R14	57.2 – 77.3	64.1	7.33	0.076 – 0.105	0.084	0.009
R15	0.516 – 0.719	0.617	0.06	0.009 – 0.016	0.012	0.002
R16	56 – 76.5	63.75	4.99	0.018 – 0.042	0.036	0.008
R17	3.7 – 5.7	4.33	0.49	0.009 – 0.014	0.012	0.002
R18	8.9 – 17.8	11.88	2.69	0.015 – 0.022	0.018	0.003
R19	4.22 – 5.74	4.95	0.57	0.005 – 0.015	0.01	0.003
R20	1.57 – 2.1	1.79	0.16	0.006 – 0.062	0.018	0.015
R21	7.33 – 8.26	7.87	0.27	0.026 – 0.039	0.031	0.004
R22	31.3 – 38.7	36.7	2.08	0.165 – 0.425	0.306	0.087
R23	6.19 – 7.56	6.83	0.54	0.025 – 0.031	0.028	0.002
R24	30.05 – 39.84	35.37	2.68	0.024 – 0.04	0.032	0.005
R25	3.4 – 4.42	3.73	0.28	0.011 – 0.021	0.015	0.003
R26	2.32 – 3.19	3.03	0.24	0.432 – 0.555	0.489	0.039
R27	57.9 – 78.7	66.9	7.18	0.177 – 0.21	0.196	0.012
R28	5.998 – 6.4	6.14	0.11	0.076 – 0.091	0.082	0.004
R29	2.33 – 3.89	3.05	0.45	0.003 – 0.01	0.007	0.003
R30	0.986 – 1.21	1.13	0.06	0.001 – 0.007	0.004	0.002
R31	27.09 – 38.05	32.24	3.27	0.067 – 0.092	0.078	0.006
R32	18.66 – 22.91	21.07	1.08	0.014 – 0.029	0.022	0.006

Table (4. 3): Arithmetic means of indoor ELF fields under zero-power uses (background fields).

Residence	AM of E-field (V/m)	AM of B-field (μT)
R1	0.139	0.019
R2	0.259	0.011
R3	0.392	0.068
R4	9.33	0.031
R5	1.24	0.427
R6	9.83	0.018
R7	3.58	0.08
R8	0.191	0
R9	0.174	0
R10	0.173	0
R11	0.123	0.006
R12	0.123	0.0055
R13	0.354	0
R14	0.176	0
R15	0.144	0.004
R16	0.144	0.004
R17	0.156	0.006
R18	0.194	0.018
R19	0.166	0.008
R20	0.338	0.002
R21	0.183	0.004
R22	0.201	0
R23	0.217	0
R24	0.595	0.005
R25	Not identified*	Not identified
R26	Not identified	Not identified
R27	7.96	0.148
R28	0.295	0.029
R29	0.178	0
R30	0.175	0
R31	30.78	0.006
R32	0.286	0

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

4.2.2 Variations of indoor extremely low frequency fields over time.

This sub-section introduces the fields' variations of some selected indoor measurements under normal-power uses.

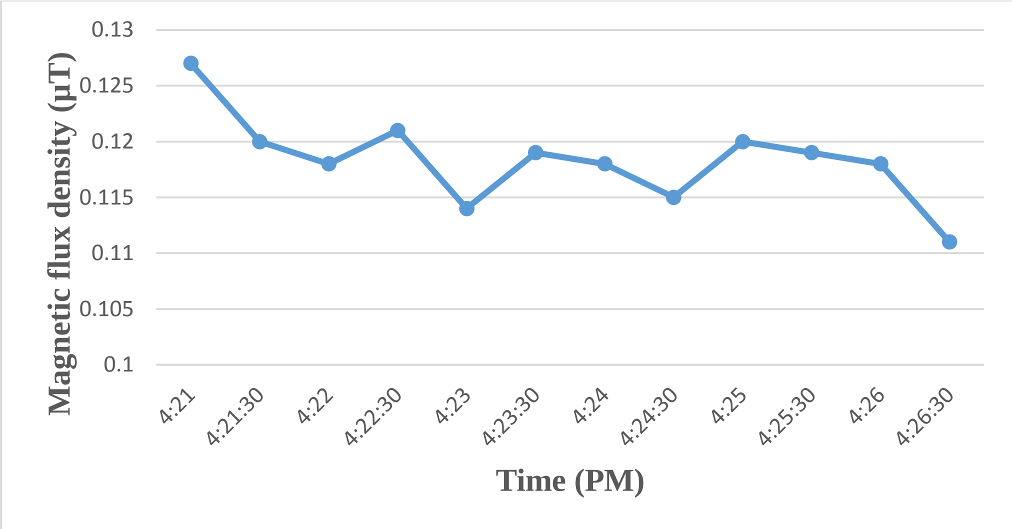

Fig (4. 7): Variations of ELF magnetic flux densities over 6-minutes period, and one meter above ground level at residence R3.

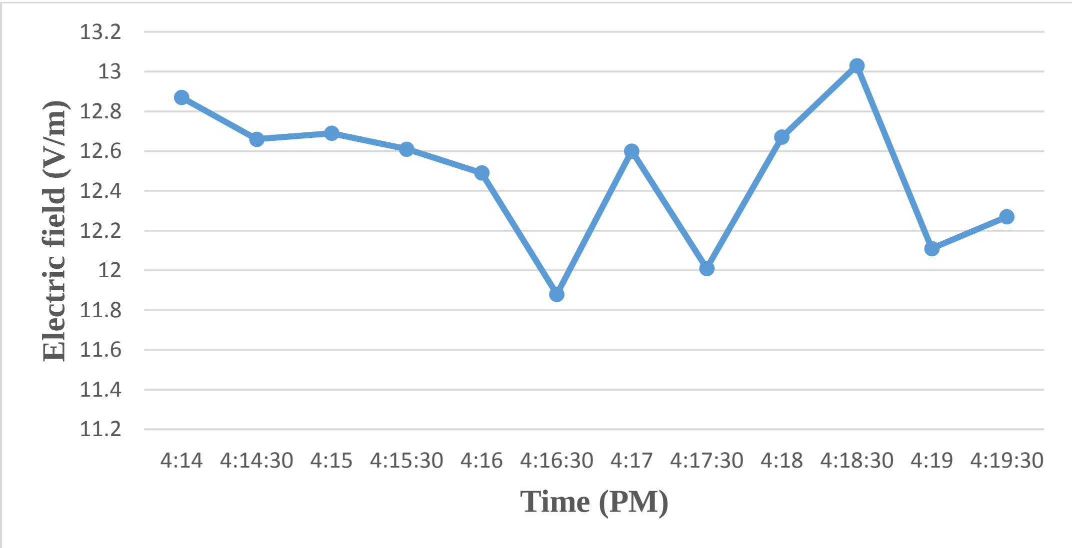

Fig (4. 8): Variations of ELF electric fields over 6-minutes period, and one meter above ground level at residence R3.

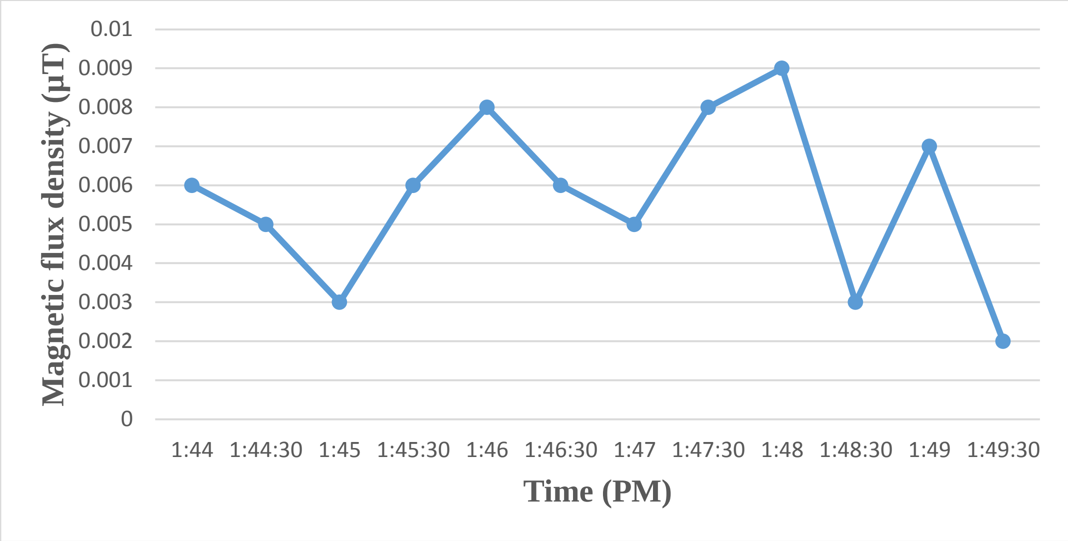

Fig (4. 9): Variations of ELF magnetic flux densities over 6-minutes period, and one meter above ground level at residence R9.

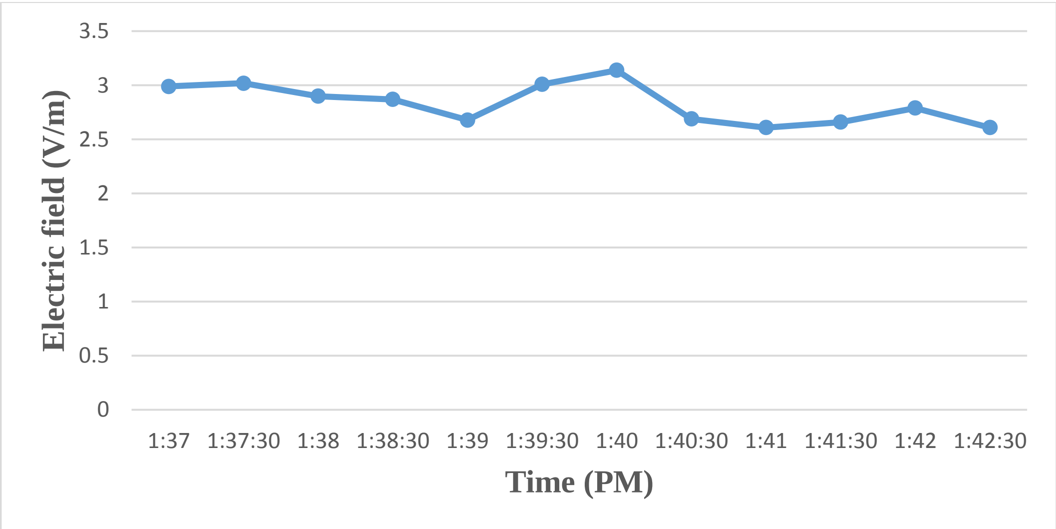

Fig (4. 10): Variations of ELF electric fields over 6-minutes period, and one meter above ground level at residence R9.

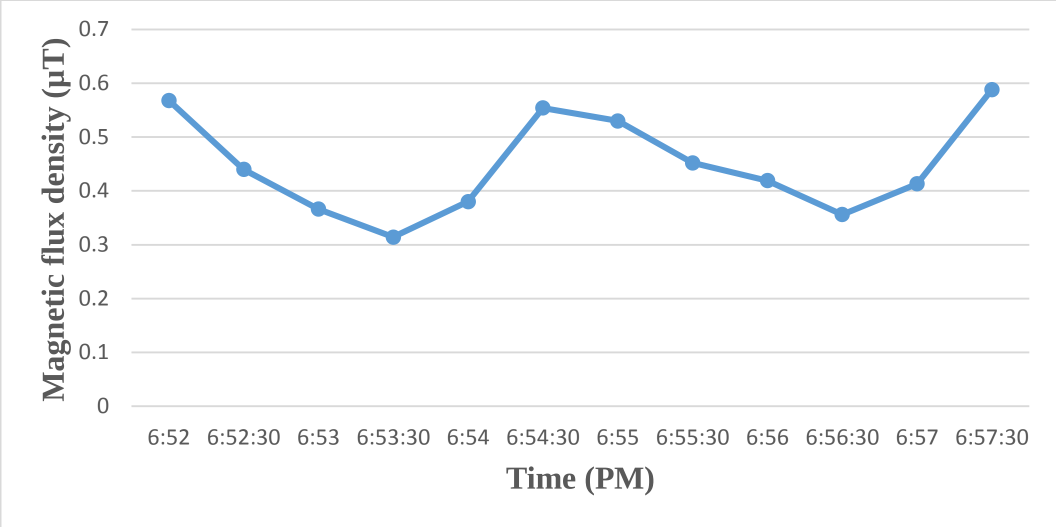

Fig (4. 11): Variations of ELF magnetic flux densities over 6-minutes period, and one meter above ground level at residence R12.

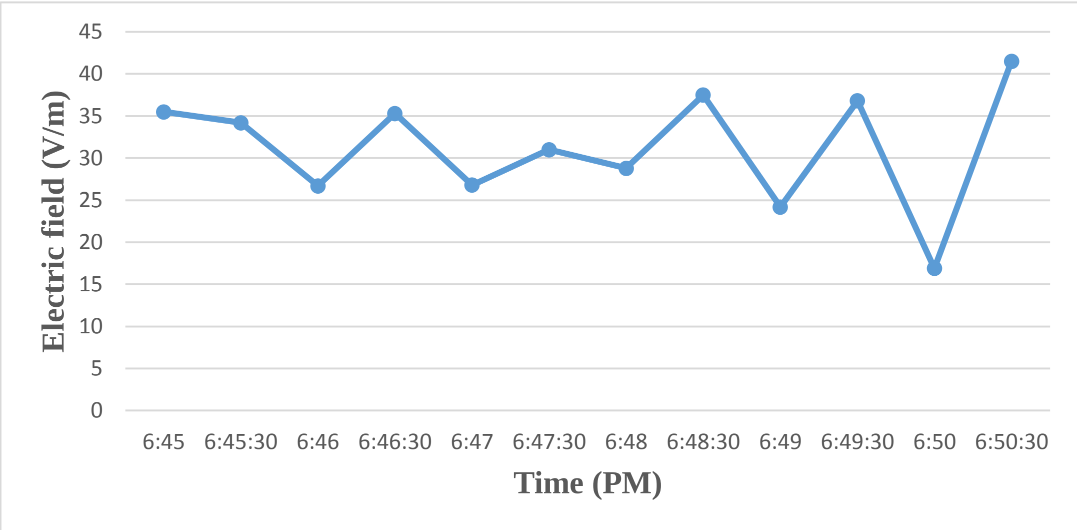

Fig (4. 12): Variations of ELF electric fields over 6-minutes period, and one meter above ground level at residence R12.

The next two figures display variations of ELF electric and magnetic fields over two and half hours at night time in the bedroom of residence R10. Fields strength were recorded at 1 meter above ground level by the bedside with TV and AC operating.

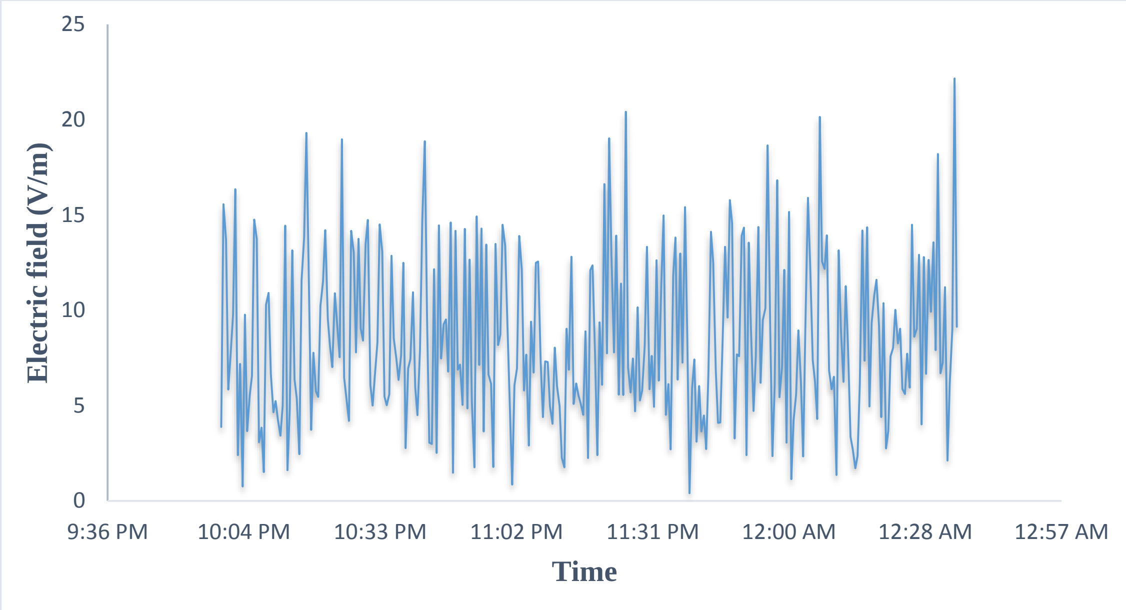

Fig (4. 13): Variations of ELF electric fields over 2.5 hours period, and one meter above ground level at residence R10.

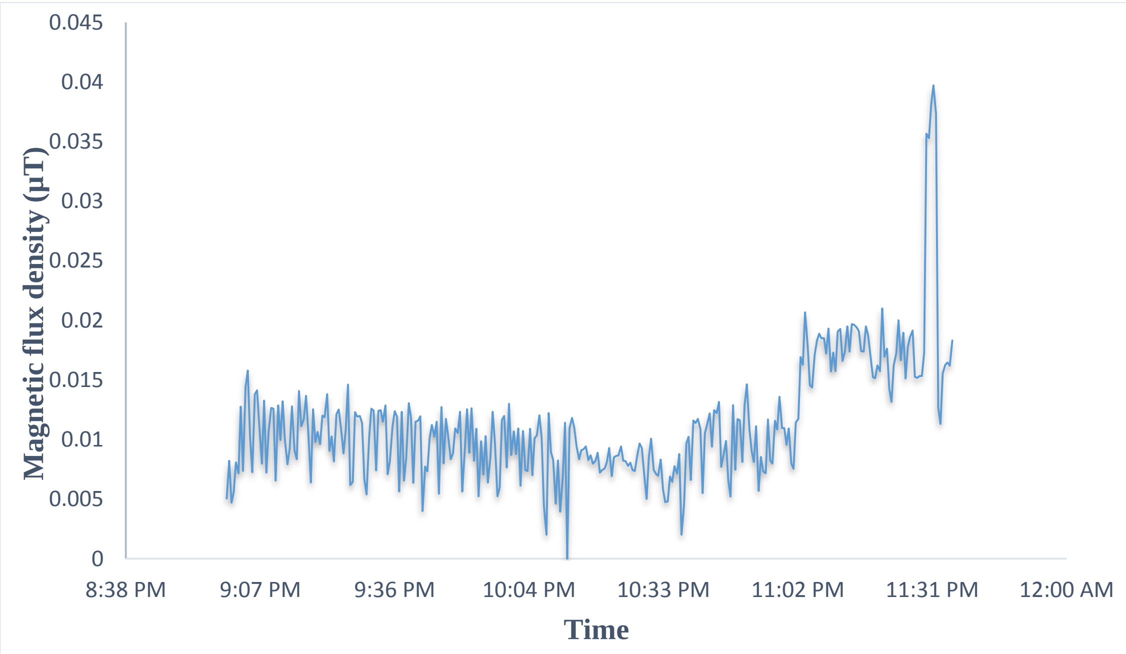

Fig (4. 14): Variations of ELF magnetic flux densities over 2.5 hours period, and one meter above ground level at residence R10.

As the figure shows, the peak experienced around 11:30 PM might be due to operating electrical sources from neighboring apartments, or other unknown sources.

4.2.3 Variations of indoor background extremely low frequency fields over time.

Residences experienced different background field levels (under zero-power uses). This sub-section displays the variations of some background fields that were relatively, higher than other residences.

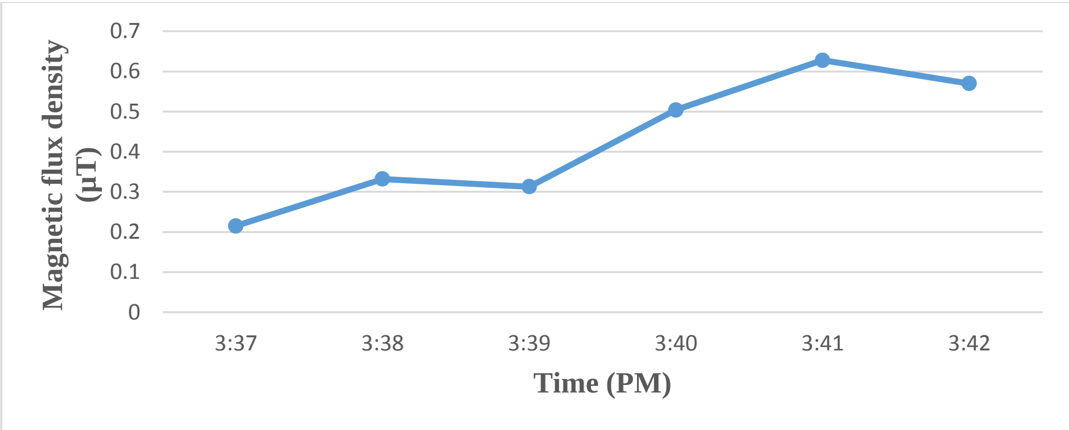

Fig (4. 15): Variations of background ELF magnetic flux densities over 6-minutes period, and one meter above ground level at residence R5.

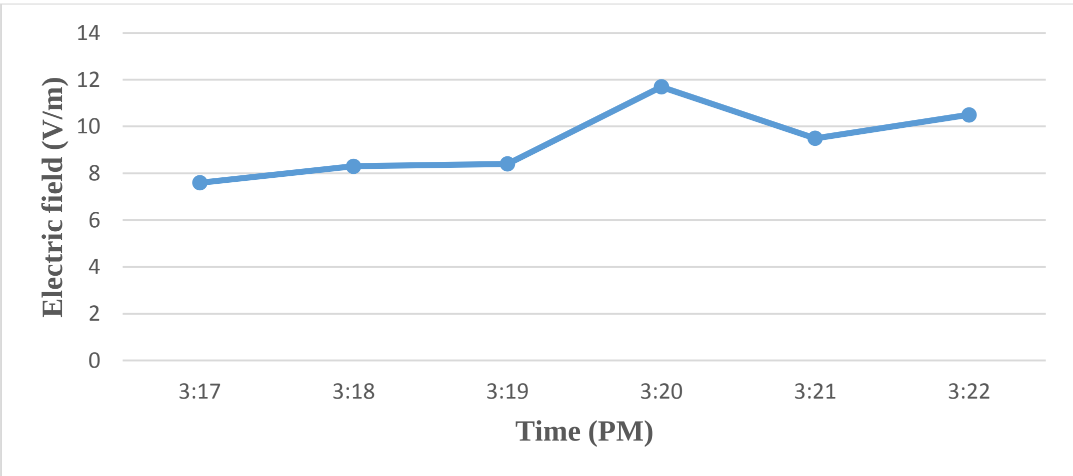

Fig (4. 16): Variations of background ELF electric fields over 6-minutes period, and **one meter above ground level at residence R4.**

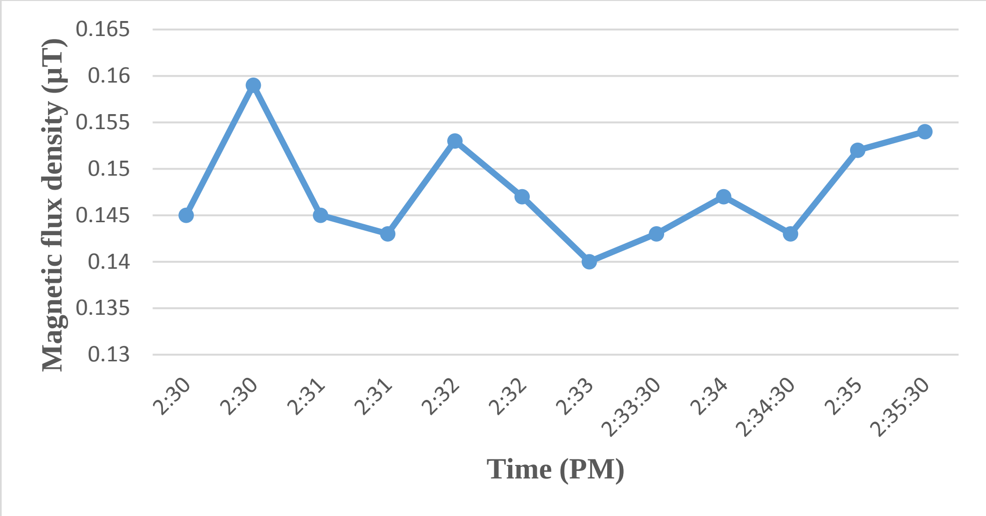

Fig (4. 17): Variations of background ELF magnetic flux densities over 6-minutes period, and one meter above ground level at residence R27.

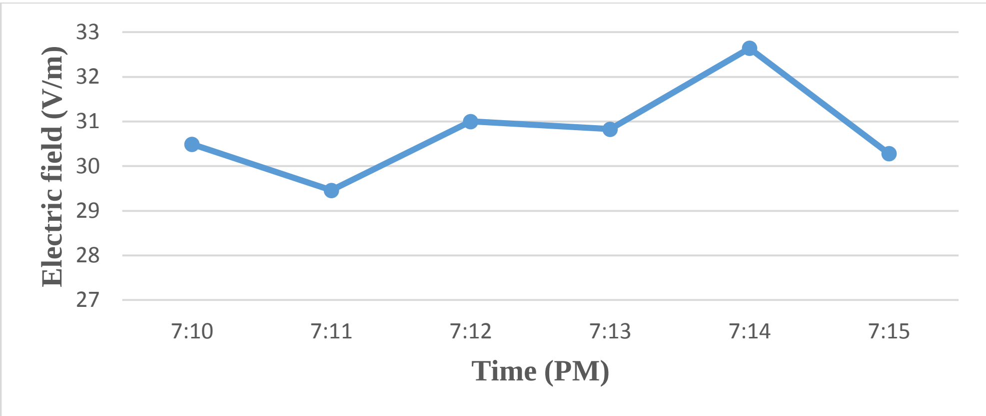

Fig (4. 18): Variations of background ELF electric fields over 6-minutes period, and one meter above ground level at residence R31.

4.3 Comparison between zero and normal-power fields.

This section introduces the variations between ELF field's intensities under zero and normal-power uses.

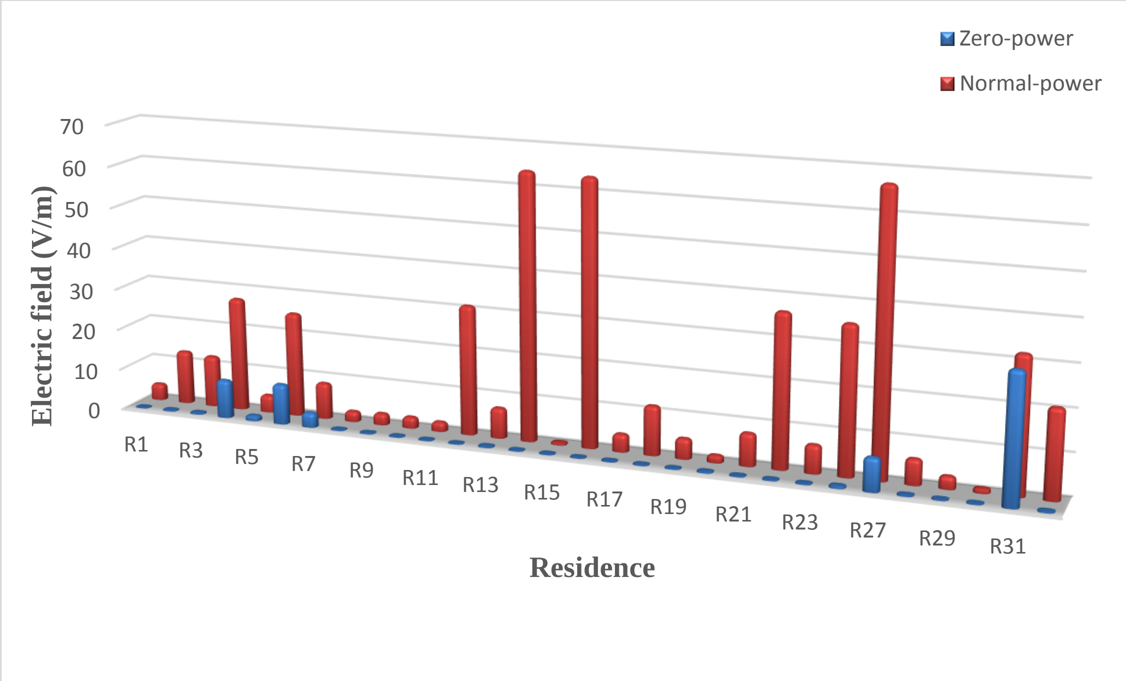

Fig (4. 19): Comparison of average ELF electric fields under zero and normal-power uses.

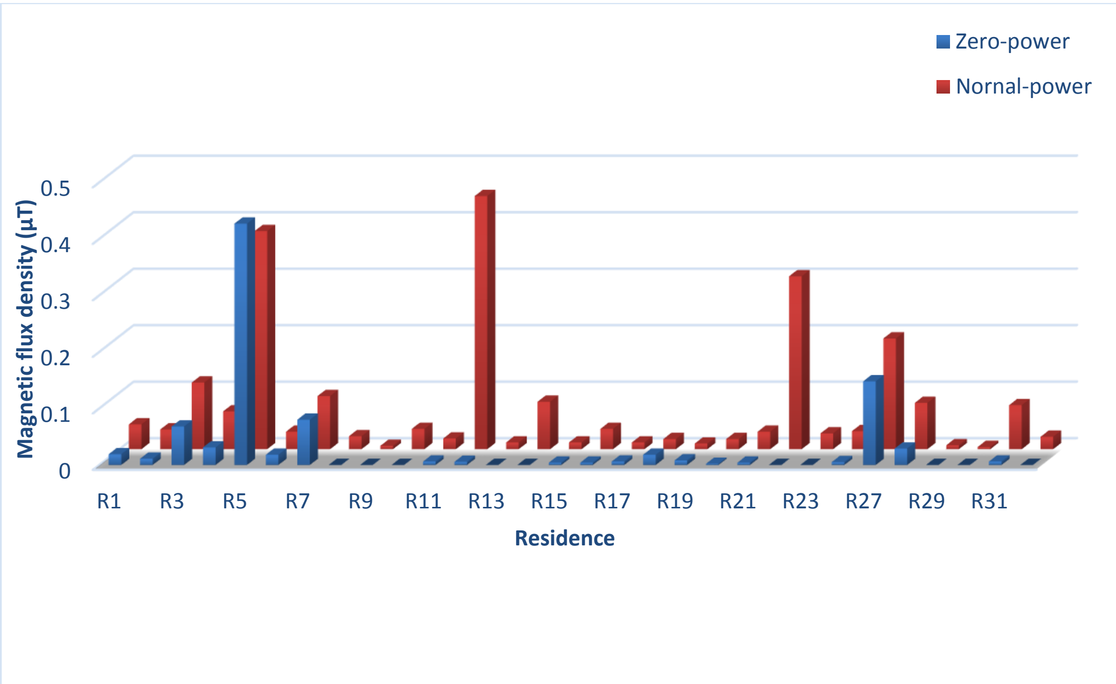

Fig (4. 20): Comparison of average ELF magnetic flux densities under zero and normal-power uses.

4.4 Extremely low frequency fields from certain appliances.

During the study, a number of commonly used household appliances was under investigations of field's intensities. See table 4.4.

Table (4. 4): Average ELF electric and magnetic fields from certain appliances.

E-field (V/m)			B-field (μT)	
Appliance*	Range	Average	Range	Average
Food processor	56 – 73	64.17	3.17 – 5.46	3.66
Laptop charger	59.1 – 73.7	65.46	7.6 – 8.4	7.86
TV (LCD)	53.3 – 71.9	60.78	0.058 – 0.066	0.062
Microwave oven	52 – 76	65.3	9.9 – 15.1	13.67
Electric heater	43 – 48.3	45.93	5.6 – 9.85	7.63
AC	49.2 – 68	53.9	0.129 – 0.866	0.441
Phone charger	48.8 – 71.7	62.83	0.027 – 0.037	0.032
Hair dryer	57 – 77	67.35	0.812 – 1.99	1.32
Vacuum cleaner	57.2 – 74.5	66.28	4.8 – 8.06	6.48
Meter board	62.2 – 67.2	64	4.84 – 5.6	5.16
Refrigerator	2.19 – 3.8	2.88	0.196 – 0.246	0.228
Toaster	59 – 78.25	66.77	1.725 – 3.414	2.82

*** 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-minutes.**

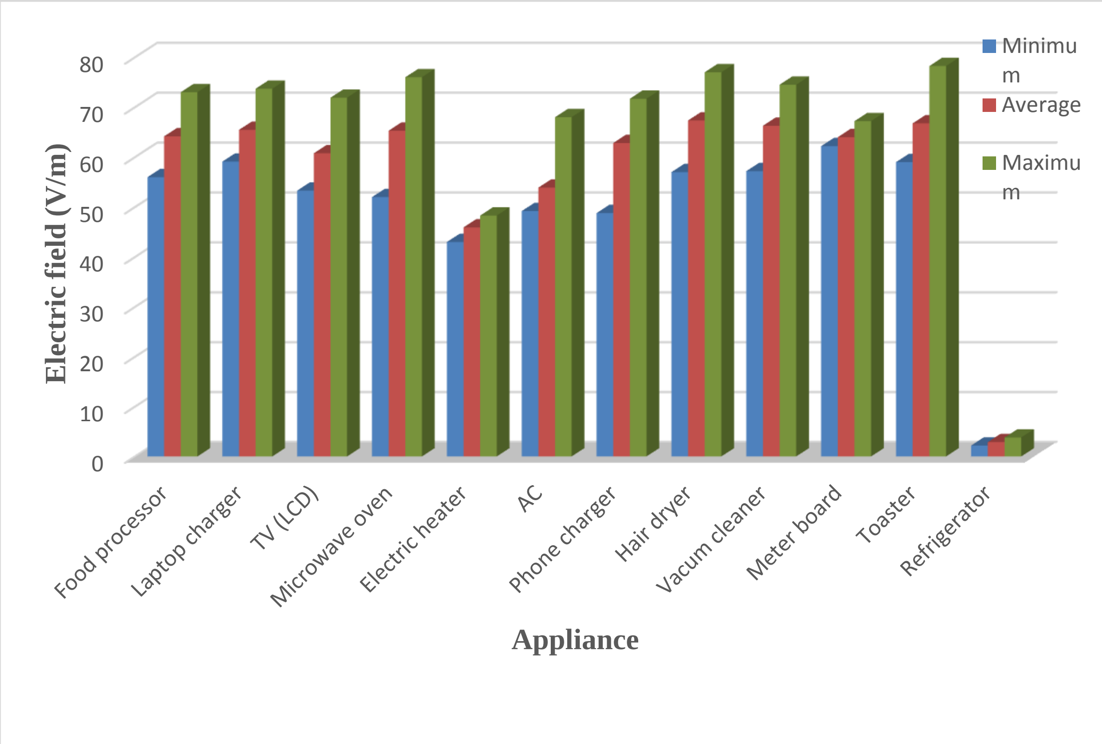

Fig (4. 21): Minimum, maximum, and average ELF electric fields from certain appliances.

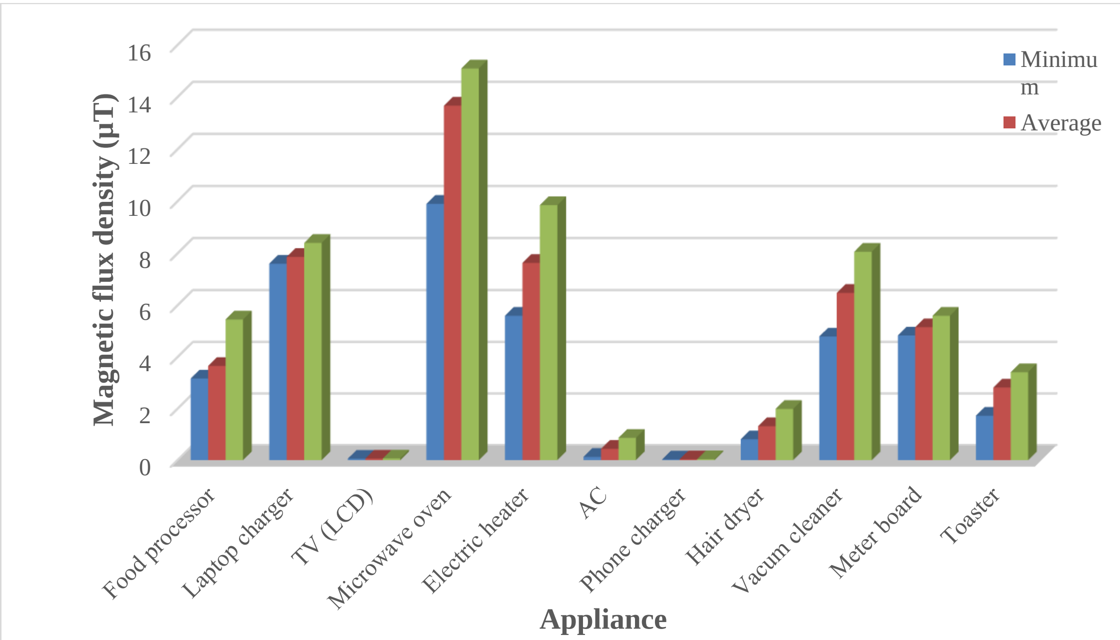

Fig (4. 22): Minimum, maximum, and average ELF magnetic flux densities from certain appliances.

4.5 Data analysis.

The analysis of data showed a log-normal distribution for both indoor ELF electric and magnetic fields. On the other hand, only outdoor ELF electric fields were log-normally distributed.

4.5.1 Distribution of outdoor extremely low frequency fields.

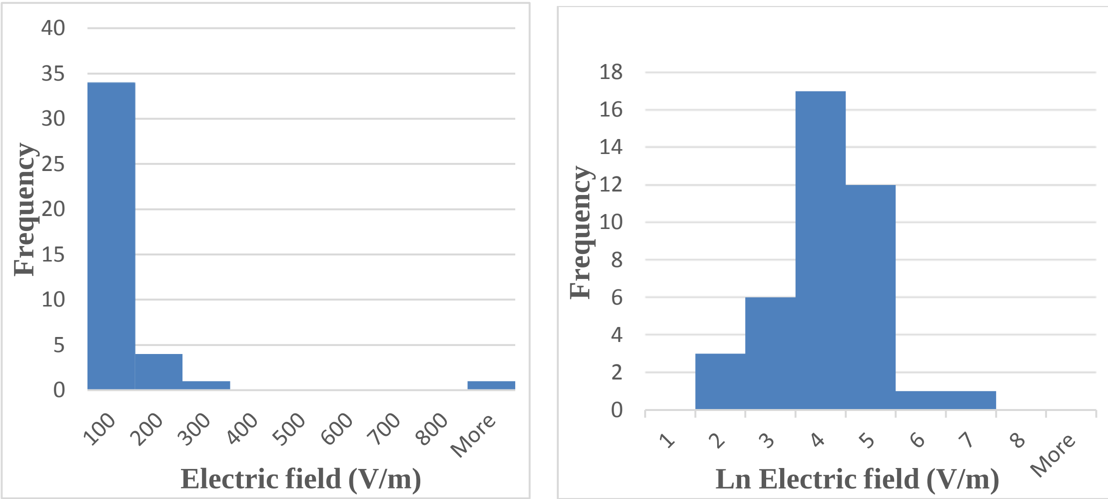

Fig (4. 23): A histogram of ELF electric fields (left) and ln of ELF electric fields (right) based on maximum recorded intensities at the 40 power lines.

Table (4. 5): Probability density functions of maximum ELF electric fields recorded at the 40 power lines.

Electric field (V/m)	PDF*
45.1	0.0083437
2.9	0.0069188
60.6	0.0055969
35.2	0.010953
43.5	0.0087124
71.03	0.0043661
27.1	0.0137151
44.6	0.0084569
47.1	0.0079088
8.63	0.0173064
56.7	0.0061672
110.8	0.0019217
17.8	0.0172202
39	0.0098554
136.9	0.0012189
28.9	0.0130544
58.4	0.0059101
57.9	0.0059843
873.3	0.0000038
25.9	0.0141676
25.8	0.0142057
17.9	0.0171867
24.7	0.0146274
110.7	0.0019252
31.5	0.012145
27.2	0.0136778
10.9	0.0182281
28.5	0.0131991
65.4	0.0049826
222.1	0.0003676
107	0.0020633
23.7	0.0150144
5.4	0.0133707
24	0.0148981
34.3	0.0112316
66.8	0.0048195
12.2	0.0183528
54.6	0.0065042
19.7	0.0165483
5.8	0.0140927

***Based on the values of parameters $\mu = 3.58\ V/m$ and $\sigma = 1.03\ V/m$.**

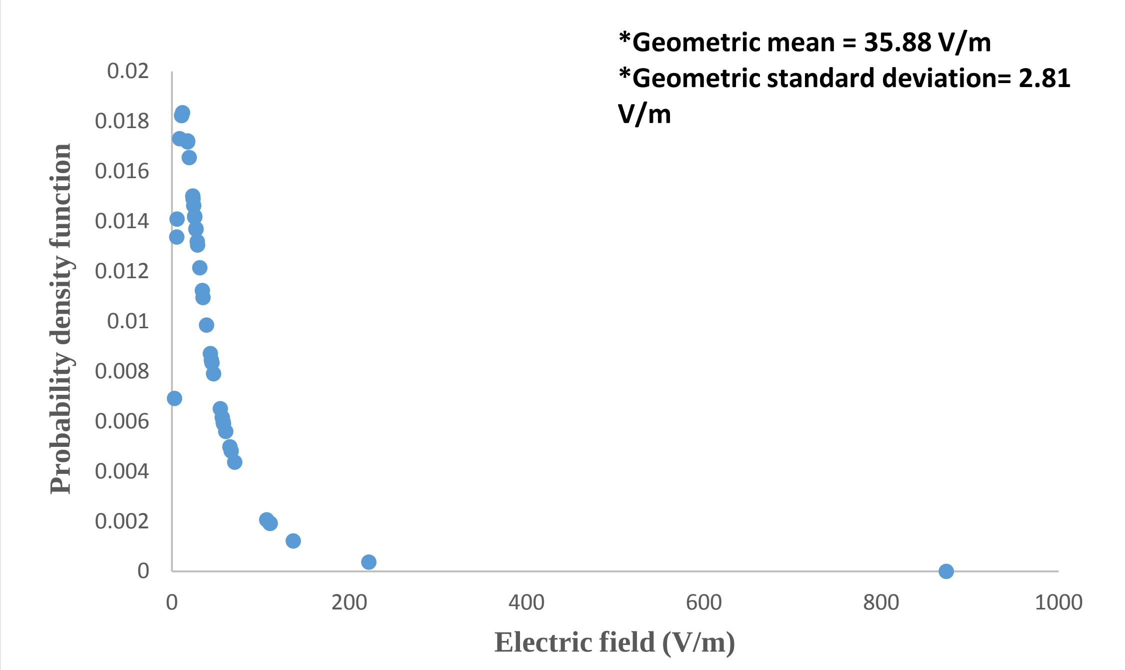

Fig (4. 24): The log-normal distribution of maximum recorded ELF electric fields from the 40 power lines.

4.5.2 Distribution of indoor extremely low frequency fields.

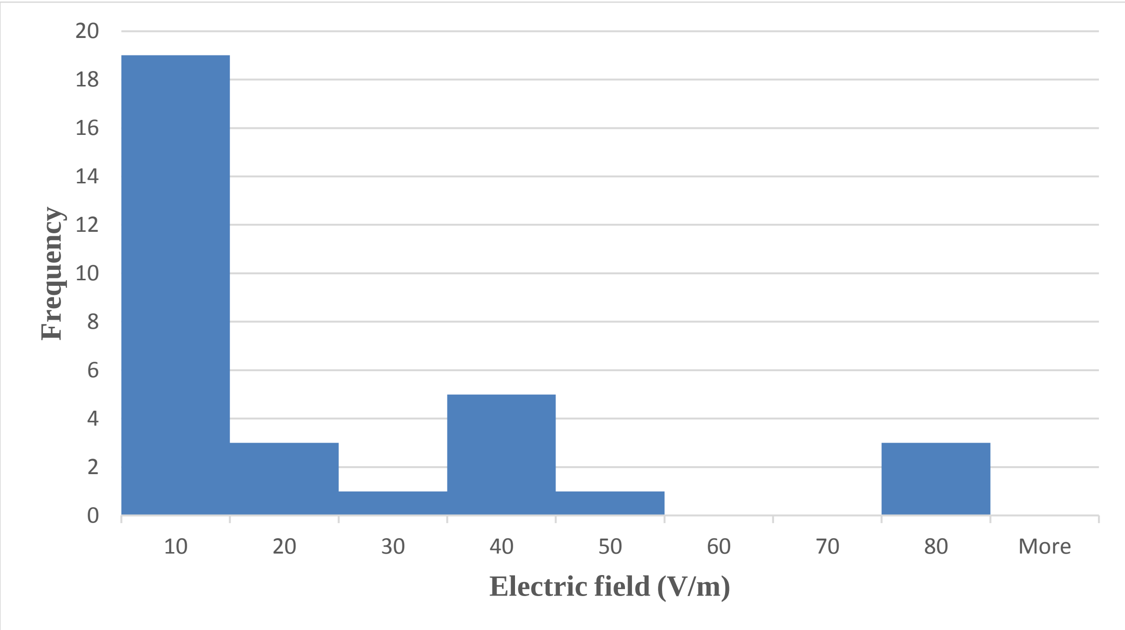

Fig (4. 25): A histogram of ELF electric fields based on maximum recorded intensities at the 32 residences.

Table (4. 6): Probability density functions of maximum ELF electric fields recorded at the 32 residences.

Electric field (V/m)	PDF*
8.1	0.039028
16.6	0.017466
13.03	0.02377
33.8	0.005689
4.9	0.056336
30.45	0.006845
9.1	0.035031
2.72	0.07051
3.14	0.068132
2.85	0.069829
3.01	0.068918
41.5	0.003876
7.7	0.040796
77.3	0.001027
0.719	0.051745
76.5	0.001052
5.7	0.051311
17.8	0.015871
5.74	0.051071
2.1	0.07255
8.26	0.038349
38.7	0.00443
7.56	0.04144
39.84	0.004192
4.42	0.059541
3.19	0.06782
78.7	0.000985
6.4	0.047296
3.89	0.063166
1.21	0.066835
38.05	0.004574
22.91	0.010937

***Based on the values of parameters $\mu = 2.26\ V/m$ and $\sigma = 1.25\ V/m$.**

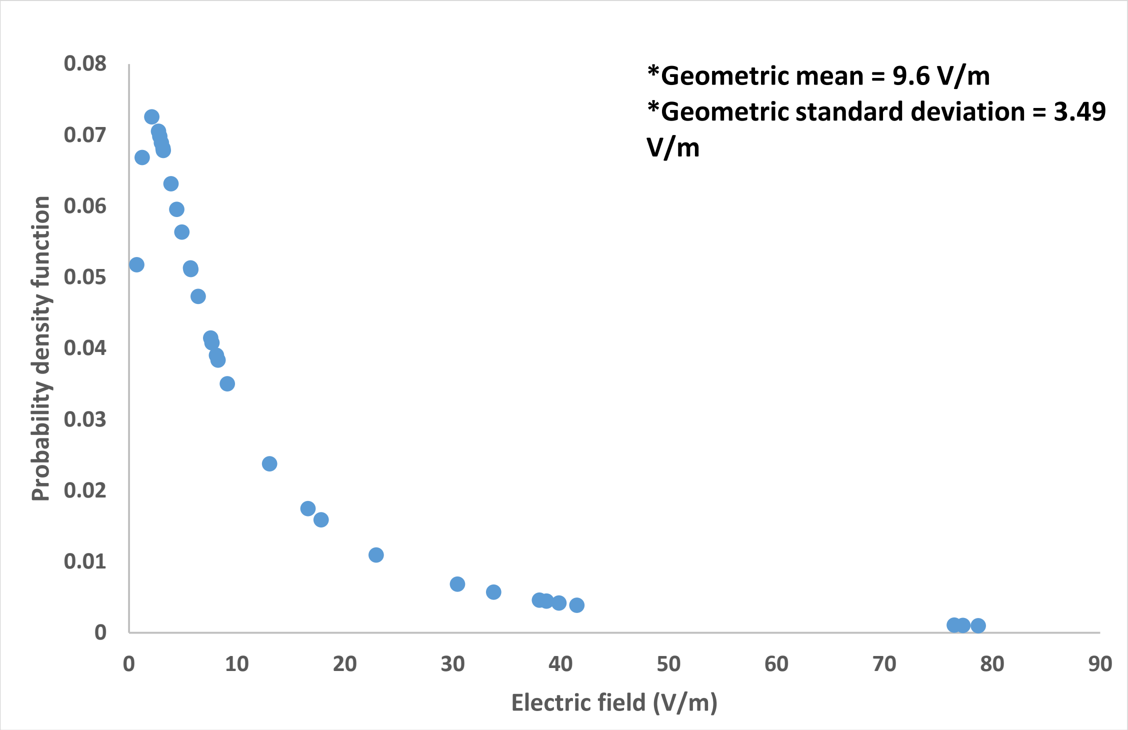

Fig (4. 26): The log-normal distribution of maximum ELF electric fields from the 32 residences.

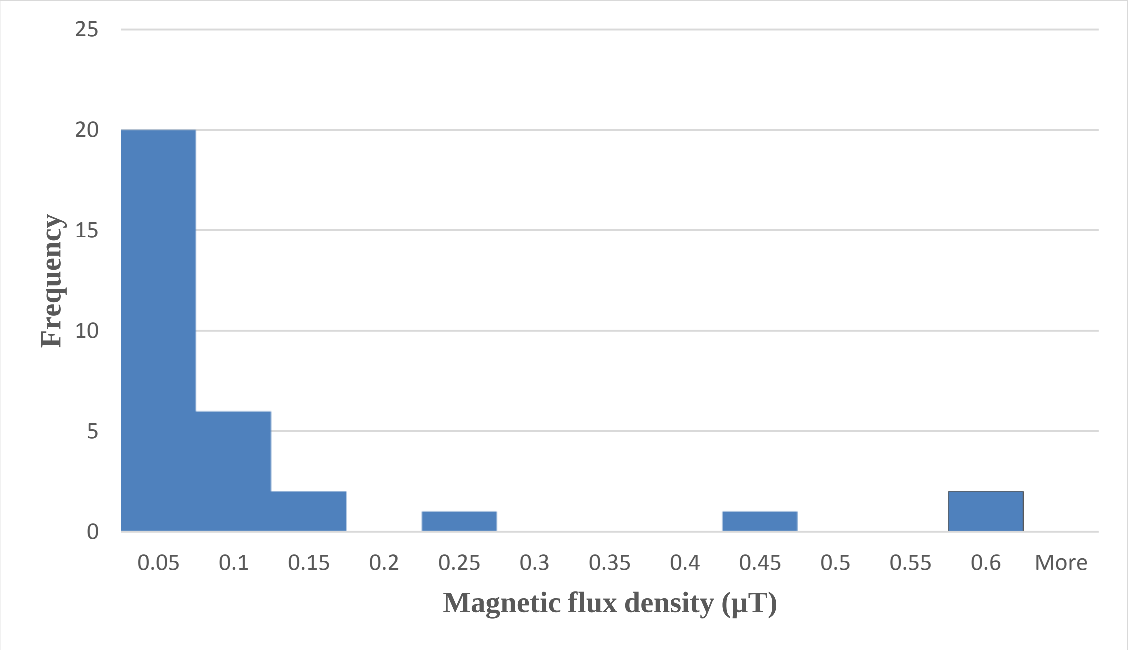

Fig (4. 27): A histogram of ELF magnetic flux densities based on maximum recorded fields at the 32 residences.

Table (4. 7): Probability density functions of maximum ELF magnetic flux densities recorded at the 32 residences.

B-Field (μT)	PDF*
0.053	6.4325
0.042	8.2088
0.127	1.7922
0.087	3.3427
0.0635	5.1755
0.037	9.2169
0.132	1.6717
0.04	8.5953
0.009	14.8497
0.047	7.3328
0.022	13.0698
0.588	0.048
0.016	14.6487
0.0105	15.1595
0.016	14.6487
0.042	8.2088
0.014	15.0232
0.022	13.0698
0.015	14.8532
0.062	5.334
0.039	8.7968
0.425	0.1196
0.031	10.6186
0.04	8.5953
0.021	13.3524
0.555	0.0567
0.21	0.663
0.091	3.1215
0.01	15.0898
0.007	13.8211
0.092	3.0693
0.029	11.1327

*** Based on the values of parameters $\boldsymbol{\mu = -3.12}$ μT and $\boldsymbol{\sigma = 1.16}$ μT**

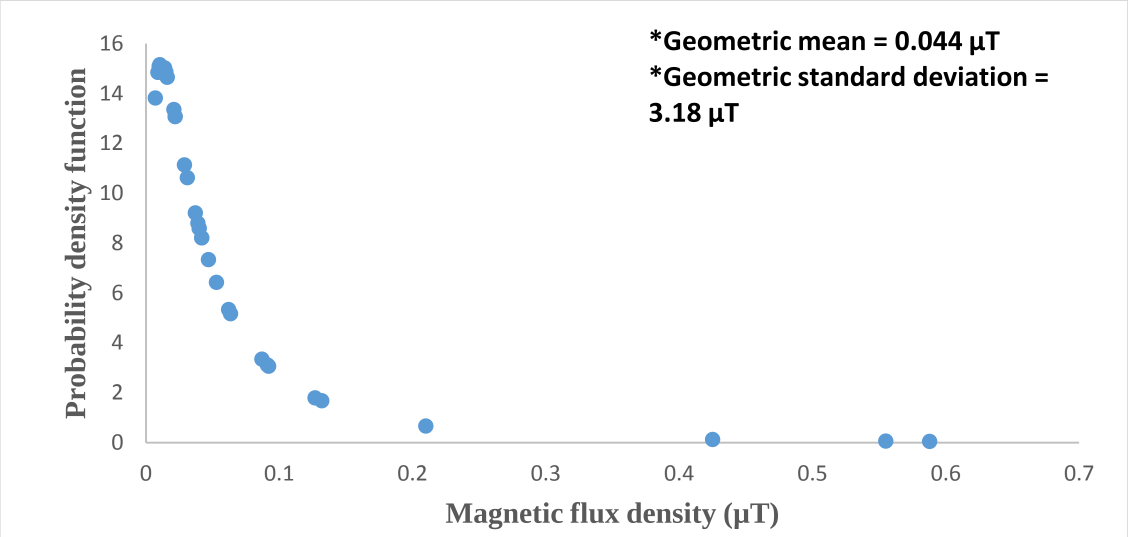

Fig (4. 28): The log-normal distribution of maximum ELF magnetic flux densities from the 32 residences.

4.5.3 Correlation between indoor fields and distance from appliances.

The correlation 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 – 0.8 and p-value 0.000 . On the other hand, a moderate negative correlation was found between mean magnetic fields and distnce with coefficient of correlation – 0.41 and p-value 0.020 (see the next two figures).

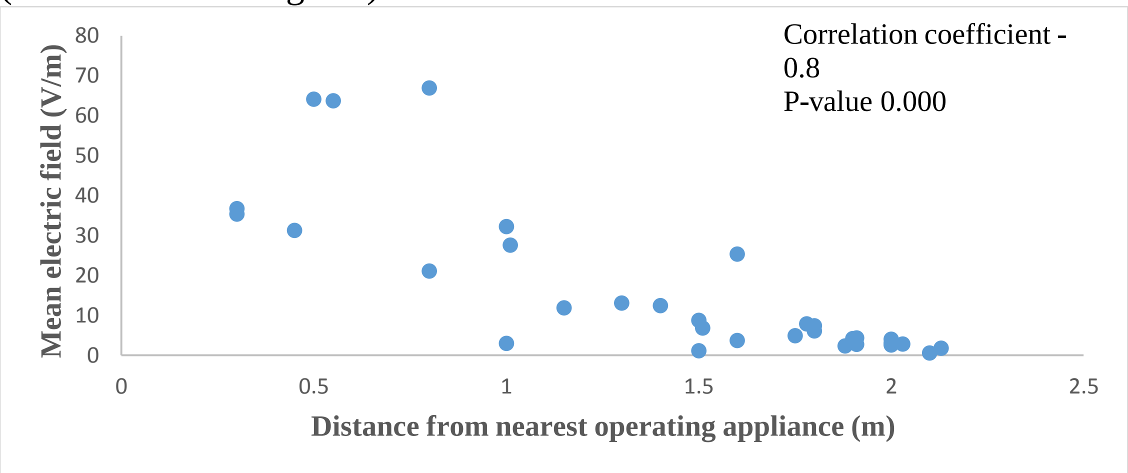

Fig (4. 29): A scatter plot showing the strong negative correlation between mean electric fields measured among the 32 residences and distance from nearest operating appliance.

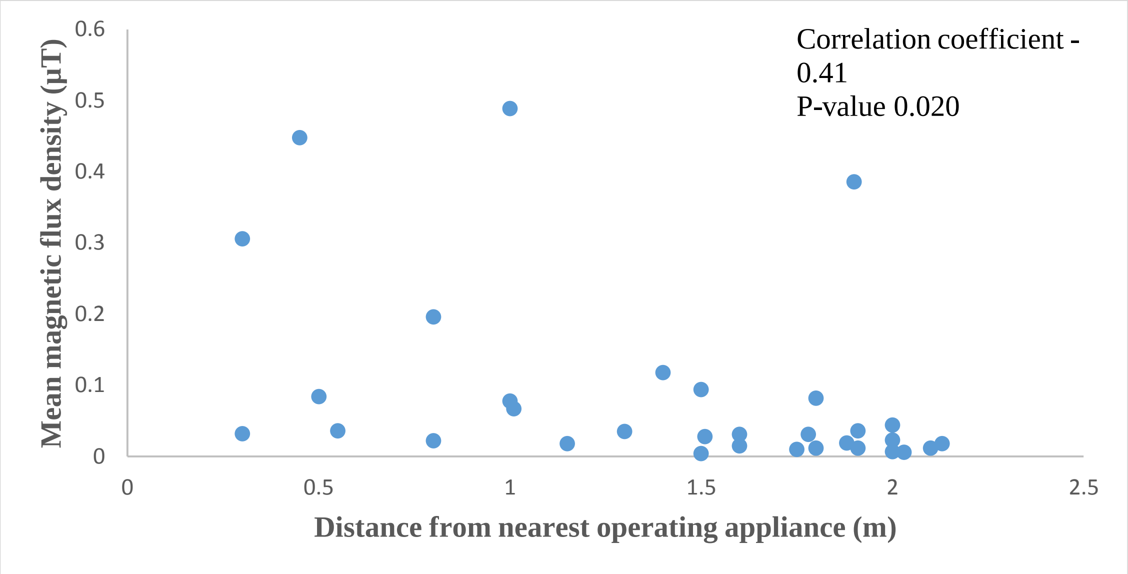

Fig (4. 30): A scatter plot showing the moderate negative correlation between mean magnetic fields measured among the 32 residences and distance from nearest operating appliance.

However, these correlations between indoor ELF fields and distance from operating appliances, make a very good sense with the physical facts that state diminishing of ELF fields with increasing distances from point sources (Kaune W. T., 1993).

Chapter Five

Discussion and Conclusions

The strength of ELF fields amongst the different targets of the study, varied in a reasonable manner. This chapter introduces a discussion for obtained field's intensities and factors might had affected them.

5.1 Outdoor extremely low frequency fields.

5.1.1 Outdoor extremely low frequency magnetic fields.

No significant divergence was noticed in the ELF magnetic field intensities measured at power lines. The highest and lowest means (3.5 µT and 0.894 µT) were found at power lines P1 and P13 respectively. Electric current and electricity load at the instance of measurement might be two possible justifications for the gap between these two readings. However, the rest of power lines experienced approaching means of magnetic fields within the range (2.211 – 3.463) µT.

5.1.2 Outdoor extremely low frequency electric fields.

For ELF electric fields, on contrast, an obvious variation of field's intensities was noticed amongst different power lines. The lowest means (3.89, 4.4, 9.37, 9.4, 14.91, 16.71, and 22.47) V/m belonging to power lines P40, P33, P27, P37, P22, P39, and P32 respectively. However, these low fields make a good sense with the fact of lines category as distributors, where low-voltage electricity is carried.

The highest means (769.4, 202.76, 130.45, and104.1) V/m were found at power lines P19, P30, P15, and P24 respectively. Likewise, these high fields are compatible with the lines category as HV power lines.

5.2 Indoor extremely low frequency fields.

The variations of ELF fields among residences of the study is attributed to different reasons:

- Proximity to working appliances.
- Proximity to outdoor power lines.
- Existence of indoor power-substation (HV transformer).
- Type and location of house (flat, detached, or in a camp).

5.2.1 Indoor extremely low frequency magnetic fields.

The highest (> 0.1µT) ELF magnetic fields under normal-power use were found at the residences R26, R12, R5, R22, R27, and R3. With average field intensities 0.489, 0.448, 0.389, 0.306, 0.196, and 0.118 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 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. However, the highest two measured (not averaged) magnetic fields were 0.635 and 0.555 μT at R5 and R26 respectively. In accordance, the average background fields within these residences were relatively high. Speaking of background magnetic fields, about 33% and 7% of residences experienced average magnetic fields at zero-power conditions of 0 μT and > 0.1 μT respectively.

Table (5. 1): 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 %

5.2.2 Indoor extremely low frequency 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, 63.75, 36.7, 35.37, 32.24, 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 (< 1m) 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 a power line.

The highest two measured (not averaged) electric fields were 78.7 and 77.3 V/m at R27 and R14. However, the means of background electric fields were relatively very low (< 1V/m in 80 % of residences) except at R31 with average background of 30.78 V/m.

Table (5. 2): 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 %

For fields from appliances, the highest average electric field was from hair dryer (67.35 V/m). On contrast, the highest average magnetic field was from microwave oven (13.67 µT).

5.3 Public exposure to extremely low frequency fields in Ramallah city (assessment findings).

Numerous previous studies were focused on the effect of ELF fields, and mainly magnetic fields, on health and whether they were possible human carcinogenic. 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 public exposure to ELF fields in Ramallah city.

During the study, no single result surpassed the ICNIRP limits (100µT and 5000V/m for general public exposures to ELF fields). 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 (about 13 %) experienced fields in the rage 0.3 – 0.4

μT, which is an interval stated by IARC for long-term exposures that might be linked to non-thermal possible health impacts as childhood leukemia.

Exposure assessment is more complicated than we think; 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 day 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. The next two figures give an overview of exposures based on average fields.

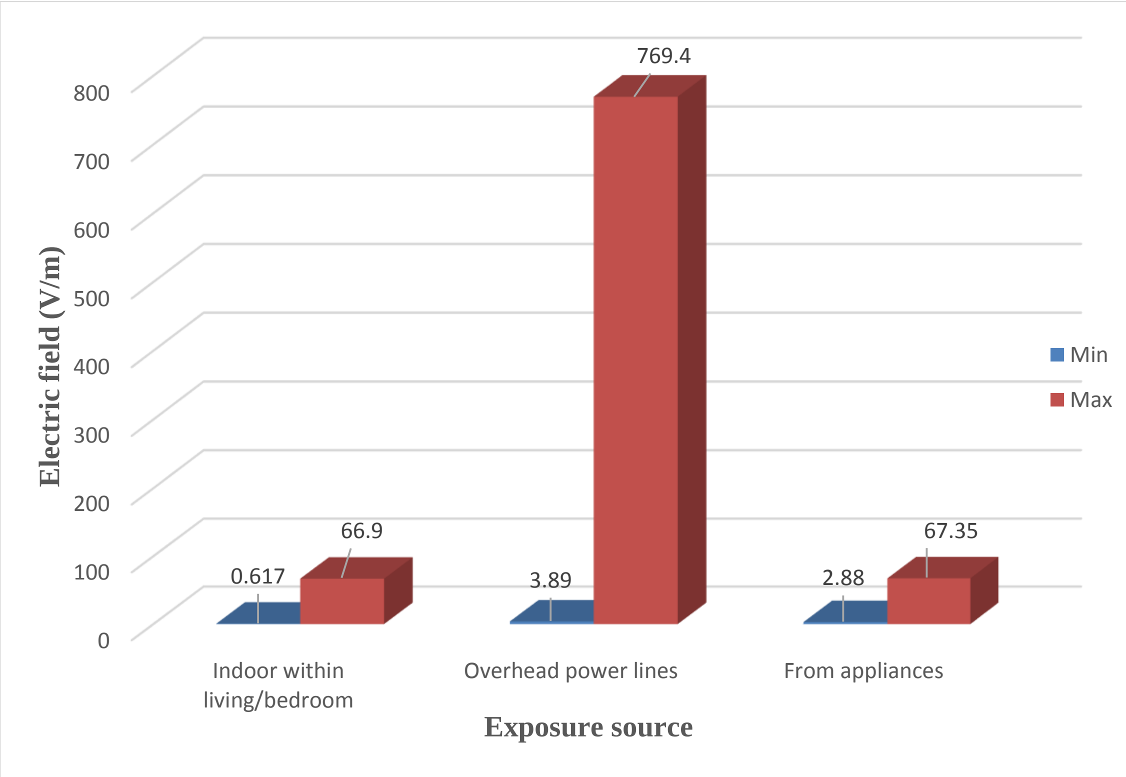

Fig (5. 1): Comparison of minimum and maximum exposures to ELF electric fields based on different sources.

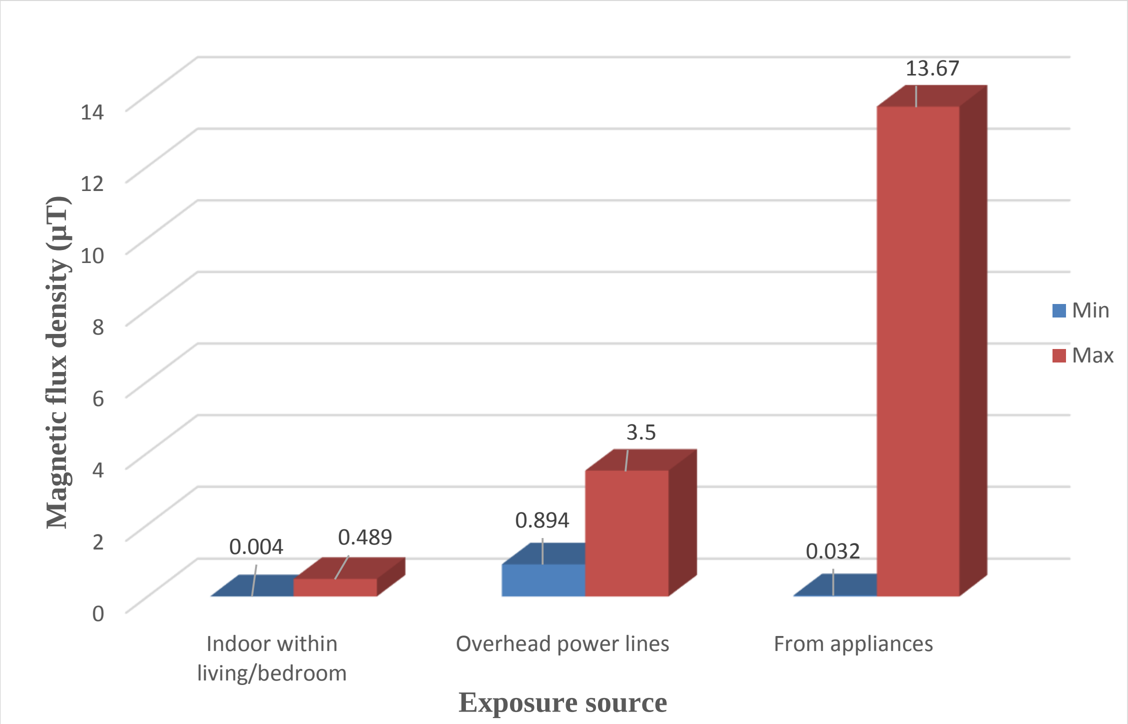

Fig (5. 2): Comparison of minimum and maximum exposures to ELF magnetic flux densities based on different sources.

Chapter six

Recommendations

As an outcome of the study, it is worthy to give recommendations regarding the public exposure to ELF fields in Ramallah city:

- Avoid plugging electrical appliances when they are not in use, since the E-fields are generated when they are just plugged in.
- Avoid charging mobile phones and laptops when in use, these chargers are usually, provided with internal transformers that produce relatively high fields.
- Keep a safe distance (>1 m) from working microwave ovens, food processors, and toasters (NRL, 2008).
- When applying electrical distributions within a house, keep the meter board away from locations where people usually spend a significant amount of time.
- Keep wall electric sockets away from the bed sides.
- Before buying a house, check the internal electrical wirings to avoid any faults.
- When constructing overhead power lines, keep a safe distance from buildings.
- Use underground power lines provided with appropriate magnetic shielding materials on a broad range, for their lesser generated fields (Riadh W.Y., 2002).
- Keep HV transformers away from populated areas and avoid locating indoor power substations inside residential buildings.

- Plant trees in vicinity to overhead power lines, since E-fields are easily shielded by them.
- Give attention to the brand of appliances, because sometimes, one brand of an appliance generates higher fields than another.

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جامعة النجاح الوطنية

كلية الدراسات العليا

تعرض الجمهور للمجالات المغناطيسية والكهربائية ذوات الترددات شديدة الانخفاض في مدينة رام الله–فلسطين

اعداد

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اشراف

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قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في الفيزياء بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس – فلسطين .

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الملخص

تمركزت هذه الدراسة حول تعرض الجمهور للمجالات الكهربائية والمغناطيسية ذوات الترددات شديدة الانخفاض والصادرة عن تردد الطاقة 50 هيرتز في مناطق داخلية وخارجية من مدينة رام الله–فلسطين. تم استخدام القياسات الموضعية لتسجيل كثافة المجالات خلال فترة زمنية مدتها ستة دقائق. نفذت القياسات الخارجية على ارتفاع متر فوق سطح الارض مباشرة تحت خطوط الكهرباءالعلوية (40 عمود كهربائي بتصنيفات مختلفة تم اختيارها بشكل عشوائي ولكن موزعة بشكل عادل في مختلف أرجاء المدينة). تباينت شدة المجالات الكهربائية الخارجية بالاعتماد على نوع خطوط الكهرباء (خط كهرباء علوي, خط محول كهرباء, خط موزع كهرباء) حيث كان المعدل الأدنى لشدة المجالات الكهربائية 3.89 فولت لكل متر تحت خط موزع كهربائي بينما كان المعدل الأعلى 769.4 فولت لكل متر تحت خط كهرباء علوي شديد الفولتية. على أية حال, كانت شدة المجالات الكهربائية من خطوط الكهرباء موزعة بشكل لوغارتمي طبيعي بقيمة وسط هندسي وانحراف معياري هندسي 35.88 فولت لكل متر و2.81 فولت لكل متر على التوالي. على العكس لم تكن شدة المجالات المغناطيسية المقاسة تحت خطوط الكهرباء موزعة بشكل لوغاريتمي طبيعي حيث كان المعدل الأدنى والأعلى 0.894 ميكرو تسلا و3.5 ميكرو تسلا على التوالي. بالنسبة للقياسات الداخلية فقد شملت مجموعة من 32 بيتا اختيرت بشكل شبه عشوائي وموزعة في مناطق مختلفة داخل المدينة. هذه القياسات الداخلية تم اجراؤها على ارتفاع متر فوق سطح الأرض داخل غرفة النوم أو المعيشة لكل بيت. بحيث قيست المجالات الكهربائية والمغناطيسية عند وضعين

للطاقة: الوضع الصفري والوضع الطبيعي. كانت شدة المجالات الكهربائية تحت ظروف الطاقة الطبيعية داخل البيوت الى حد ما قليلة حيث أن حوالي 59% من البيوت شهدت معدل مجالات كهربائية أقل من 10 فولت لكل متر وكان معدل القيمة العظمى 66.9 فولت لكل متر داخل البيت رقم(27). على أية حال فان شدة المجالات الكهربائية داخل البيوت اتبعت توزيعا لوغاريتميا طبيعيا بقيمة متوسط هندسي وانحراف معياري هندسي 9.6 فولت لكل مترو 3.49 فولت لكل متر على التوالي. قيمة المجالات الكهربائية تحت الوضع الصفري للطاقة كانت قليلة جدا بحيث شهدت حوالي 80% من البيوت شدة مجالات كربائية أقل من 1 فولت لكل متر عند وضع الطاقة الصفري. تحت ظروف الطاقة الطبيعية كان متوسط القيمة العظمى لشدة المجالات المغناطيسية 0.448 ميكرو تسلا داخل البيت رقم (26) الموجود داخل مبنى مزود بمحطة محول ضغط عالي داخلي. وقد شهدت حوالي 81% من البيوت متوسط مجالات مغناطيسية أقل من 0.1 ميكرو تسلا وكان توزيع هذه المجالات المغناطيسية(بين 32 بيتا) توزيعا لوغاريتميا طبيعيا بقيمة متوسط هندسي وانحراف معياري هندسي 0.044 ميكرو تسلا و 3.14 ميكرو تسلا على التوالي. بالاضافة فقد شهدت حوالي 7% من البيوت معدل مجال مغناطيسي أكبر من 0.1 ميكرو تسلا تحت الظرف الصفري للطاقة. كانت القيمة العظمى لشدة المجالات الكهربائية الصادرة عن الأجهزة في البيوت هي 67.35 فولت لكل متر من مجفف الشعر, بينما بلغت القيمة القصوى لشدة المجالات المغناطيسية الصادرة عن الأجهزة في البيوت 13.67 ميكرو تسلا من فرن الميكرويف. وقد وجد ارتباط سلبي قوي بين شدة المجالات الكهربائية والمسافة من أقرب جهاز كهربائي في وضع التشغيل حيث كانت قيمة معامل الارتباط وقيمة(بي) الاحتمالية 0.8 – و0.000 على التوالي. من ناحية أخرى فقد وجد ارتباط سلبي متوسطي بين شدة المجالات المغناطيسية والمسافة من أقرب جهاز كهربائي في وضع التشغيل حيث كانت قيمة معامل الارتباط وقيمة(بي) الاحتمالية 0.41 – و0.020 على التوالي. خلال الدراسة لم تكن هناك أية قيمة تتعدى المستويات المرجعية الخاصة باللجنة الدولية للحماية من الاشعاع غير المؤين.