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Public Exposure from Radiofrequency Electromagnetic Smog in the West Bank – Palestine

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Thesis Approval

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1. Head of the committee: Prof. Adnan Lahham Signature

2. Internal examiner: Dr. Hussein ALMasri Signature

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Dedication

I dedicate this work as a token of my deep respect for my***father, mother, and brothers.***And with my great love and gratitude to my wife ***Nida*** for her unlimited support.To my sons and daughter as a blessing from God.All my family members and all my friends who supported me.

Thank you all

Declaration

I certify that this thesis - or any part of it - which I submitted for the Master degree in Medical Imaging Technology – Radiologic Science track – is a result of my own work and research, under supervision of my supervisor, except where otherwise acknowledged, and this thesis – or any part of it – has not been submitted for a higher degree to any University or institution.

Signed

Mahmoud N. AlKhatib

Date: 8/6/2020

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Abstract

Since the increase of sources and technologies that usingRadiofrequency (RF) Electromagnetic radiation worldwide and locally, and increase in public fear about the adverse health effect of RF, especially after it has been classified as possibly carcinogenic to humans (Group 2B) by the International Agency for Research on Cancer (IARC) as a part of World Health Organization (WHO), this study was performed to show the RF levels in the West Bank, and compare them with the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Experimental measurements conducted in 149 locations over the area of the West Bank, using exposure meter EME Spy 140, measured the Electric field strength (Vm^{-1}). These measurement results show that the highest exposure level at any point was 7.428 Vm^{-1}, at Ramallah city center which is a highly-populated area. The main contributor was the FM frequency with 50% of total exposure, the next main contributors were the mobile phone base stations downlinks with 34%. The exposure in dense urban areas was significantly the highest compared to other types of areas. The total exposure quotient (TEQ) is calculated for each location, the maximum TEQ was 0.13. All of these results ensure that the level of RF in the West Bank is below the ICNIRP level.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AM: Amplitude Modulation

ARPANSA: Australian Radiation Protection and Nuclear Safety Agency

CENELEC: European Committee for Electrotechnical Standardization

CITC: Communication and Information Technology commission

DECT: Digital Enhanced Cordless Telephone

Electric field strength (E): the force E on a stationary unit positive charge at a point in an electric field, measured in volt per meter Vm^{-1}

EMF: Electromagnetic Field

ELF: Extremely Low Frequency

EQ: Exposure Quotient

FM: frequency modulation

GSM: Global System for Mobile communications

IARC: International Agency for Research on Cancer

ICNIRP: International Commission on Non-Ionizing Radiation Protection

IEEE: Institute of Electrical and Electronics Engineers

IRPA: International Radiation Protection Association

ITU: International Telecommunications Union

LTE: Long Term Evolution

MPE: Maximum Permissible Exposure or known as the reference level

MPP: maximum peak point

Power density (S): the rate of flow of electromagnetic energy per unit of surface area, expressed in watt per meter square Wm^{-2}

RF: Radio Frequency

SAR: Specific Absorbed Rate

SCENIHR: Scientific Committee on Emerging and Newly Identified Health Risks

TETRA: Terrestrial Tuned Radio - emergency services

TEQ: Total Exposure Quotient

TBL: times below the limit

TV: Television

UMTS: Universal Mobile Telecommunications Systems

WHO: World Health Organization

WiFi: Wireless Fidelity

WiMAX: Worldwide Interoperability for Microwave Access

WLAN: Wireless Local Area Network

I. Introduction

1.1. Background

Electromagnetic Radiation consists of electromagnetic waves which are synchronized oscillations of electric and magnetic fields. In a vacuum, electromagnetic waves travel at the speed of light,carrying energy, without requiring a material medium between the emission source and the receiver,indeed it can propagate in a vacuum, the oscillations of the two fields are perpendicular to each other and perpendicular to the direction of energy as shown in figure 1.Electromagnetic waves of different frequencies are called by different names since they have different sources and effects on the matter as shown in the electromagnetic spectrum shown in figure 2. The radiofrequency (RF) electromagnetic field (EMF) is an electric, magnetic and electromagnetic field with frequencies from 100 kHz to 300 GHz(International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998). Electric, magnetic and electromagnetic fields are intrinsic to the environment and naturally occur within it (Magiera & Solecka, 2019).

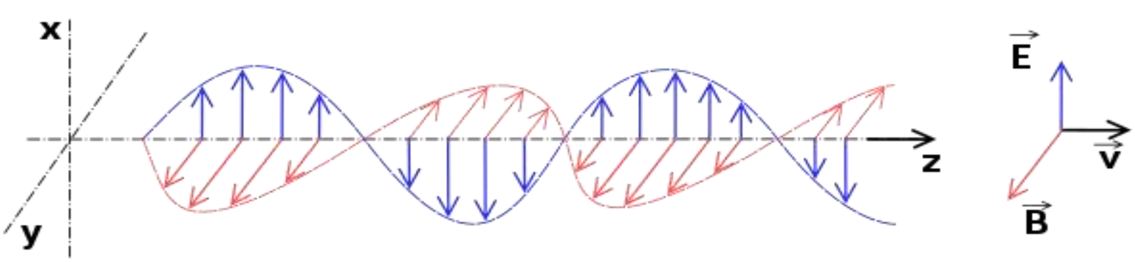

Figure 1. Electromagnetic wave propagation.(Magiera & Solecka, 2019)

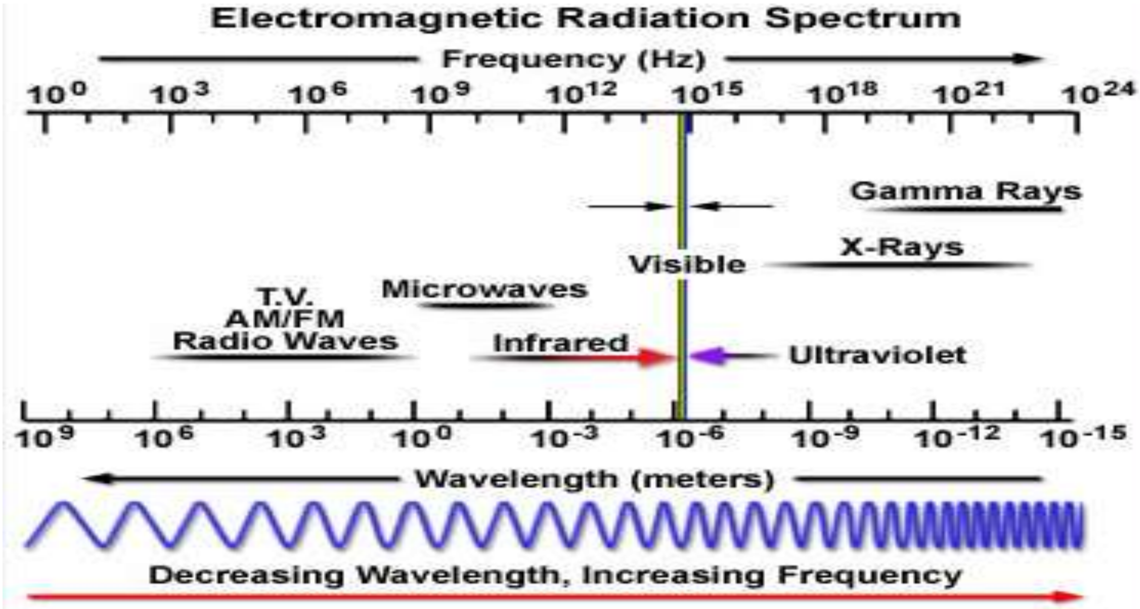

Figure 2. Electromagnetic radiation (Zhao et al., 2019).

Radiofrequency (RF) used mainly in a wireless telecommunication system and other aspects of life exposing the general population to these radiofrequency electromagnetic fields (RF-EMF) and may lead to adverse health effects, mainly due to rising the body temperature because of the thermal effect of these radiations(Wood, A. W., & Karipidis, 2017). In recent years, people are progressively exposed to RF-EMF and also the frequencies used are changing continuously with a range of applications. Humans are exposed to electromagnetic emissions from both indoor and outdoor sources, which are mainly Manmade.

The World Health Organization (WHO) in their research agenda in 2010 has recommended the quantification of personal and public RF-EMF exposure and identification of the determinants of exposure in the environment for the general population as a major issue with priority to assess the typical range of exposures from emerging wireless technologies(Gkonis, Samaras, & Boursianis, 2017; Sagar, Struchen, Finta, Eeftens, & Röösli, 2016; World Health Organization (WHO), 2010).

International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 1998 expressed guidelines on exposure for RF-EMF in the frequency between 100 kHz and 300 GHz. ICNIRP level is based on acute health effects such as the increase of tissue temperatures as a result from absorption of energy during exposure to RF-EMF ranged from 100 kHz to 300 GHz(International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998). The outcomes of studies on possible long-term effects such as cancer were not considered to be sufficient for setting limits on a solid scientific basis (Buckus et al., 2017).

Many studies in Palestine proposed to evaluate the general public exposure to RF-EMF, spot measurements out-door and in-door environments,and personal exposure studies have been conducted.Previous studies conducted by the Center for Radiation Science & Technology at Al-Quds University in 2008 and 2010 have shown that (FM) source is the main contributor to the general public exposure within the West Bank in each outdoor and indoor environments. Since that point, a lot of sources have been deployed over the geographical region(Lahham & Ayyad, 2019). Thus, the levels of electromagnetic are modified dramatically. It's here necessary to state, that the complexness of the electromagnetic fields as well as its spatial distribution is a function of time.

Lahham et al 2012reported in their study about out-door exposure to RF, where only GSM900 was in operation in Palestine and the contribution of corresponding base stations downlinks to the total public exposure was about 32% as the second main contributor after FM with 66%(Lahham & Hammash, 2012).Lahham et al, 2015 was about an in-door exposure to RF(Lahham, Sharabati, & Almasri, 2015). Lahham et al 2019 were about personal exposure to RF(Lahham & Ayyad, 2019). All of these studies except Lahham et al 2019 have been done when there was just one mobile phone operator in the West Bank. Since another mobile company was operated and another generation of communication has been adopted in theWest Bank, it is important to perform new studies to evaluate exposure to RF-EMF for the general public. The necessity of these types of studies also increased due to the variation of frequency used or adding a new one on use, increasing the number of RF sources such as mobile phone station towers, and the accelerated increase of mobile phone users, too.

The area of the West Bank is extended over 5655 km^2 with a population of about 2.88 million (Palestinian Central Bureau of Statistics (PCBS), 2018). Recently, there are 30 TV broadcasting stations(Palestinian News and Info Agency (WAFA), 2020a), 28 FM radio stations(Palestinian News and Info Agency (WAFA), 2020b), 2 Palestinian mobile phone operators, and 5 Israeli mobile phone operators transmitted RF over the area of the West Bank. No AM radio stations are operated by the Palestinian Authority.

International Agency for Research on Cancer (IARC), which is a part of the world health organization (WHO) has classified radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B)(International Agency for Research on Cancer (IARC), 2011). For risk communication, assessment, and management, it is essential to estimate the radiofrequency electromagnetic field (RF-EMF) exposure of the population (Sagar et al., 2018).

This study aims at evaluating the public exposure from RF-EMF sources, with frequencies ranging from 88MHz to 6 GHz, located over the West Bank-Palestine.

1.2. Problem Statement

In the last decade, public interest in Palestine on the potential health problems arising from exposure to electromagnetic smog has raised primarily after the spread of mobile phone base station towers over the country and therefore the increase of mobile phone users. Recently, individuals are also concerned about the health result of the mobile phone itself, mainly after theclassification of the RF-EMF as possibly carcinogenic (Group 2B) by the International Agency for Research on Cancer (IARC). Individuals are also concerned regarding the result of extremely low-frequency fields from power line supply and electrical appliances within the home. This interest has highlighted the importance of getting accessible and simple to understand information on the amount of electromagnetic smog in their environment. This information should be based on scientific background. Environmental Radiofrequency electromagnetic field (RF-EMF) exposure has become not only a scientific topic but also a social issue, therefore it's necessary also to inform the individuals about the source – exposure relation and potential health effects resulting from being exposed to this form of non-ionizing radiation.

1.3. Significanceof the Study

Nowadays in Palestine, there are two mobile telephony networks operators, GSM900 operated by Jawwal and GSM1800 operated by Ooredoo. The antennas of 5 Israeli mobile telephony base stations (UMTS2100) operators are also directed towards the Palestinian areas and contribute to the general public exposure of the Palestinians.

The importance of this research is to verify the compliance of exposure to radiofrequency electromagnetic radiation in the West Bank with the International Commission on Non-Ionizing Radiation Protection guidelines EMF safety standards. The public interest for having accessible and easy to understand information on the levels of electromagnetic radiation is an important demand.

1.4 Study Objectives

This study is proposed to evaluate the population exposure from electromagnetic fields emitted by different major sources which form the Electromagnetic smog in highly populated areas in the major cities of the West Bank-Palestine.

The main goal of this work is to provide qualitative and quantitative scientific data on electromagnetic fields forming the major components of the environmental RF-EMF in the West Bank- Palestine and to evaluate the population exposure resulting from these fields.

Specific objectives:

1. Performing experimental measurements of RF-EMF emissions to evaluate the dispersion of RF-EMF in the environment generated by 14 RF sources namely: FM radio (88 – 108 MHz), TV3 (174 – 223 MHz) TETRA (380 – 390 MHz), TV 4 & 5 (470 – 830 MHz) GSM900 uplink (880 – 915 MHz), GSM 900downlink (925 – 960 MHz), GSM1800 uplink (1710 – 1785 MHz), GSM 1800 downlink (1805 – 1880 MHz), DECT (1880 – 1900 MHz), UMTS 2100 uplink (1920 – 1980 MHz), UMTS 2100 downlink (2110 – 2170 MHz), WiFi 2G (2400 – 2500 MHz), WiMAX (3400 – 3800 MHz), andWiFi 5G (5150 – 5850 MHz) in selected areas of the West Bank.

2. Study the spatial distribution of the RF-EMF in the environment and construct the radio-frequency electromagnetic field (RF-EMF) maps for evaluating existing exposure levels over large areas of cities.

3. Compare the obtained results of RF-EMF emission levels with international safety standards (public exposure limits).

4. Provide scientific data for developing legislations, laws, and recommendations on EMF at national levels, to protect the health and safety of people, and to protect the environment, from the possible harmful effects of RF-EMF.

5. To clarify the relative contribution of different sources of RF-EMF to the total exposure of the general public.

II. Radiofrequency Electromagnetic Fields (RF-EMF)

2.1. Sources of RF-EMF

The only best-known natural source of microwave electromagnetic wave is that the negligibly weak cosmic radiation from space, though important sources of natural radiation have existed at lower radio frequencies because of atmospherical phenomena like the northern lights and thunderstorms (Marshall & Heil, 2017).

Unlike ionizing radiation, radiofrequency electromagnetic field (RF-EMF) can neither break chemical bonds nor cause ionization in living cells. The existing safety guidance of RF-EMF exposure recommended by the International Commission of Non-Ionizing Radiation Protection (ICNIRP) depended on the conclusion that high-frequency exposure below the thermal threshold is improbable to be associated with adverse health effects (International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998).

Electromagnetic smog is relatively a replacement term used to describe the non-ionizing radiation generated from artificial electrical devices and transmitters of wireless applications. This type of radiation includes low frequency electrical and magnetic fields called extremely low frequencies (ELF), Amplitude Modulation **(**AM), frequency modulation **(**FM), TV broadcasting, Long Term Evolution (LTE)800, Global System for Mobile communications (GSM) GSM900, GSM1800, Universal Mobile Telecommunications Systems **(**UMTS)2100, Wireless Fidelity **(**Wi-Fi), Mobile telephone handsets, Digital enhanced cordless telephone (DECT), microwaves and alternative sources within the frequency vary from 50Hz to 300 GHz. Every year, the amount and nature of radio and microwaves contained in this Electromagnetic smog will increase (Marshall & Heil, 2017).

People are progressively exposed to electromagnetic radiation in their environment generated from multiple sources. The use of electromagnetic waves in telecommunication and different aspects of life has augmented greatly in recent years, and also the frequencies used are changing continuously with a range of applications. Humans are exposed to electromagnetic emissions from each indoor and outdoor sources, that are mainly Manmade (Lahham et al., 2015).

Radio and television terrestrial transmitters offer an Omni-directional coverage space to serve the entire population around the site. Typically a restricted zone around transmission antennae is provided to limit the exposure of the general public to comparatively high levels of electromagnetic fields (Lahham & Hammash, 2012)**.**

Recently, we are witnessing a serious growth of radio communication systems in our everyday life. The foremost popular system is a mobile telephone, which is constantly evolving to attain better coverage, higher output, and quality of service which will meet the requirements of additional and additional demanding users. All this interprets into more effective usage of the electromagnetic spectrum and as a consequence – higher levels of electromagnetic field (EMF) intensity in the human surrounding(Bienkowski & Zubrzak, 2015).

WIRELESS technologies like laptops, smartphones, and tablets are used for academic and other purposes, and for daily use in all public places. Additionally, wireless local area networks (WLAN) using Wireless Fidelity (WiFi) technology are introduced. This rabid enlargement of networks and wireless devices leads to a growing concern for the public relating to the attainable adverse health effects because of radio-frequency (RF) electromagnetic fields (EMF) (Verloock et al., 2014).

The main area of public issues regarding attainable health effects due to exposure to electromagnetic smogis mobile telephone base station towers. These base stations transmit power levels from many Watts to a hundred Watts or more. Their antennae emit radiofrequency beams that are typically very narrow within the vertical direction, however quite broad within the horizontal direction. As a result of the narrow vertical spread of the beam, the RF power intensity at the ground directly below antenna is low. the field intensity will increase slightly as one moves far away from the base station then decreases at larger distances from the antenna (Lahham & Hammash, 2012).

The market for mobile phones worldwide remains growing rapidly. In some parts of the world, they're the foremost reliable or solely phones available. Mobile phone handsets form a possible source of exposure to people. Even though they operate at low output powers (0.2 to 0.6 Watt), their proximity to the body of the user allows for a large quantity of radiation to be absorbed by the body tissue. Smartphones are used additionally for communication through social media and also the internet. analysis of the exposure from mobile phones is extremely sophisticated based on the measurement of the specific absorbed rate (SAR) (near field measurements), but it's attainable to estimate the exposure in far-field conditions whereas positioning the mobile phone on the pelvis area during communication with wireless networks.

2.2. Biological Effects of RF-EMF

The continuously increased public exposure to RF-EMF has made its effects on human health a point of concern for the general public and scientists. To respond to these concerns, an extensive research effort has been developed over the past decade to clarify various specific questions about the possible health effects of RF-EMF.

The aim of much research into the biological results of exposure to RF-EMF is to the understanding of how such exposure may compromise the normal biological functioning of humans. Since many experimental procedures cannot be performed on human subjects, studies of animal subjects must usually be substituted (Eleanor R. Adair, 2002).

The potential health effects of RF have been studied intensively for many years, and many high-quality expert multidisciplinary evidence-based reviews are available (McPherson, Mark Elwood, 2019),such as the potential health risk of exposure to RF-EMF from mobile phone base stations. As a result, many studies addressed the possible association between RF-EMF exposure and the development of various and health problems. If such health effects exist, they are likely to be small; accordingly, accurate and efficient RF-EMF exposure assessment for large populations is essential for epidemiological studies (Martens et al., 2016). Only some researches have investigated the outcomes of long-term exposure of animals to controlled RF fields. Almost without exception, different published long-term studies have failed to prove any deleterious nonthermal effects, including cancer, on the exposed animal subjects (Eleanor R. Adair, 2002).

Nevertheless, a disagreement might exist about “nonthermal” biological effects of RF, however, there is no doubt that the dominant mechanism by which RF produces biological effects is through the deposition of energy, therefore resulting temperature increase within the biological system (Wood, A. W., & Karipidis, 2017).

As electromagnetic energy is absorbed by tissue, it is converted into heat. In the absence of heat transfer, this will result in a rate of increase in temperature ***T***with time ***t***

$$\frac{dT}{dt} = \frac{1}{Cp} SAR \qquad (1)$$

Where*Cp* is the specific heat of the material and

SAR is the specific absorption rate.

The SAR is related to the root mean square of electric field strength ***E*** by equation (2)

$$SAR = \frac{\sigma E^2}{\rho} \quad (2)$$

Where

$\boldsymbol{\sigma}$ is the electrical conductivity of the tissue (S m^{-1})

$\boldsymbol{\rho}$ is mass density (Kg m^{-3}).

In the nonexistence of heat transfer, a SAR of 1 WKg^{-1} will appear as a rate of temperature increasing about 0.018 °C/min in typical soft tissue. The rate of heating is dependent on the root-mean-squared field strength and doesn't directly relate to the frequency of the field. RF energy interacts with biological material to cause an increase in temperature. It has been noted that the chief concern of RF exposure is that local temperatures may rise sufficiently to cause irreversible damage to proteins. To a certain extent, the body's thermoregulatory system is ready to deal with added heat input from RF exposure by stimulating mechanisms such as sweating or panting (Wood, A. W., & Karipidis, 2017).

From more than 30 expert group opinions that were devoted to health effects of radiofrequency fields that were published, the vast majority did not consider that there is a demonstrated health risk from RF exposure from mobile phones and base stations and different wireless communication devices. The only exception comes from the Bioinitiative report (Luc, 2012).The following are the most relevant.

ICNIRP reports indicate that it is not possible to deny the occurrence of nonthermal effects following RF-exposure, but they consider evidence in favor of such adverse effects very weak. ICNIRP, therefore, decided that there are no indications of non-thermal adverse health effects.

The conclusions and summary of the Scientific Committee on Emerging and Newly Identified Health Risks in 2009 and updated in 2015 (Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), 2015) report that RF-EMF is unlikely to be carcinogenic, although further researches on long-term cancer effects are needed due to the large latency period for most brain tumors.

The Bionitiative report2012, was written by several individual scientists and public health and public policy workers who believe that existing public exposure standards for as well extreme low-frequency fields (power lines) as radiofrequency radiation (mobile phones) are inadequate(BioInitiative Working Group, 2012). Notably, not all authors were scientists and not all can be considered independent (Luc, 2012).

The conclusion is that radiofrequency fields should be classified in Group 2B (possibly carcinogenic)(International Agency for Research on Cancer (IARC), 2011). This illustrates that classification in the IARC group 2B should not be interpreted by the public as proof of carcinogenicity at the same level as group 2A and 1. This is of course not correct but very often done.

Australian Radiation Protection and Nuclear Safety Agency in their fact sheet update (ARPANSA Radiofrequency Expert Panel, 2012), and U.S. Food & Drug Administration ((FDA), 2020) in the USA, both state that there is no solid evidence in the existing scientific literature that the use of mobile telephones poses a long-term public health hazard and no clear evidence that such exposure accelerates the growth of already-existing cancer, although the possibility of a small risk cannot be ruled out.

All records, except the Bionitiative report, presume that there is until these days, no clear evidence of adverse health effects from RF-exposure, especially from applications for wireless communication purposes. They usually remain prudent concerning long-term bio-effects, not because of strong indications that such effects might occur, but only because there are so far not enough data available to form a sound conclusion.

Because of remaining uncertainties, especially concerning long-term exposures, some caution is still expressed, even though the weight of scientific evidence has not linked to any adverse health effect. This is the reason why IARC recently classified RF-electromagnetic fields as 2B(possibly carcinogenic) (Luc, 2012).

International organizations, such as the Institute of Electrical and Electronics Engineers (IEEE) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) have considered a broad range of evidence, all of the available peer-reviewed scientific literature and used the weight of scientific evidence strategy to set-up the guidelines or limits for RF exposures in occupationally exposed individuals and the general public to protect against proved adverse effects (Vijayalaxmi & Scarfi, 2014).

It is typical to set a safety margin between the levels at which the biological effect becomes a concern and the level which is set as the exposure limit. This is to allow for uncertainties in the estimation of SAR and biological variation.However, for most RF exposure, the SAR value above 4 W Kg^{-1} has been determined to which tissue temperature could rise by more than 1 °C in 30 minutes and therefore hazardous to health. A margin for 10 is used to set the occupational limit on SAR, then a further margin of 5 for general public exposure.Thus, for exposure to the whole of the body, a SAR value of 4/10 = 0.4 W Kg^{-1} is the limit for occupational exposure and 4/ (5 × 10) = 0.08 W Kg^{-1} for the general public (Wood, A. W., & Karipidis, 2017).

Tissue heating is the most important effect of RF-EMF exposure of biological organisms that have been unequivocally demonstrated. Most of the published physiological researches have concerned thermoregulatory mechanisms that quantify the ability of an organism to manage its body temperature (Eleanor R. Adair, 2002).

2.3. The Safety Levels of RF-EMF

The guidelines of the International Commission on non-ionizing Radiation Protection (ICNIRP) based on acute health effects, such as increasing tissue temperatures as a result of the absorption of energy during exposure to RF-EMF. If the experimental values of measurements of electric field strength and/or power density are equally or less than safety limits recommendation by ICNIRP, then it is probable that there is no health risk. By definition, the risk is that the probability, or likelihood, that an individual is going to be harmed by a specific hazard from the RF-EMF (World Health Organization (WHO), 2010).

There are several national and international regulations, standards, and recommendations to organize RF-EMF exposure. The limits are generally very similar and are ordinarily based on recommendations from the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), Federal Communication Commission (FCC), the International Radiation Protection Association (IRPA), European Committee for Electrotechnical Standardization (CENELEC), Institute of Electrical and Electronics Engineers (IEEE), and the Australian Radiation Protection and Nuclear Safety Agency(ARPANSA)(Abdelati, 2005).

On the Present day, international standards are recommended by ICNIRP, IEEE, CENELEC, and other international and national commissions. Such organizations set guidelines that restrict the amount of electromagnetic energy dissipated in the human body. These limits are presented for both the general public and personnel working on-site, i.e. occupational limits. Since the environment for workers can somewhat be controlled, occupational exposure limit is generally higher than non-occupational (public) exposure limit in all international protection standards (Nahas & Simsim, 2011). These three mentioned organizations followed by the majority of national commissions, taking into account just the thermal, acute, and pathological effects of RF-EMF, the basis for their standards some years ago, some sounds say these RF-EMF standards do little to protect the general population (Grigoriev, 2010).

Some international organizations, such as International Commission on Non-Ionizing Radiation Protection(ICNIRP),Institute of Electrical and Electronics Engineers (IEEE),and Federal Communications Commission (FCC),have developed guidelines to protect humans against the adverse health effects of non-ionizing EMFs. For this reason, exposure limits or reference levels have been recommended by these organizations. The common used electrical quantities for reference levels are Electric field strength (E), magnetic field strength (H), and power density (S). Many developed countries, have adopted ICNIRP guidelines.(Table .1) (Cansiz, Abbasov, Kurt, & Celik, 2018). All these three sets of limits are in the process of revision and updating (Foster, Ziskin, & Balzano, 2017).

Table 1. Reference levels of ICNIRP for general public exposure to a time-varying electric field.

Frequency range	Electric Field strength E ($V\ m^{-1}$)	Power density S ($W\ m^{-2}$)
10 – 400 MHz	28	2
400 – 2000 MHz	$1.375 f^{1/2}$	$f / 200$
2 – 300 GHz	61	10

Where f is the defined frequency

In the U.S.A, the limits of the Federal Communications Commission ((FCC), 1996, 2016, 2019) is applied, but most of the European countries set the exposure limits of their national standards of the RF-EMF exposure based on the guidelines authorized by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) from 100 kHz to 300 GHz (International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998). Other countries have preferred to force further restrictive limits by following a precautionary approach in terms of electric or magnetic field magnitude. In any case, in order to protect the general population against adverse health effects from RF-EMF exposure, the regulation frame plans to reduce the RF-EMF exposure level of the general public and to comply with the limit restrictions (Fernández-García & Gil, 2017).

Unlike ionizing radiation, RF-EMF can neither break chemical bonds nor cause ionization in living cells. The existing safety guidance of RF-EMF exposure recommended by the International Commission of Non-Ionizing Radiation Protection (ICNIRP) depended on the conclusion that high-frequency exposure below the thermal threshold is unlikely to be associated with adverse health effects (International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998). Nonetheless, various potential health effects of RF-EMF, including electromagnetic hypersensitivity, behavioral problems, degenerative diseases, fertility, and reproductive issues, and biological effects such as modifications to gene and protein expression, immune function, melatonin, cancers, and blood-brain barrier changes have been reported (BioInitiative Working Group, 2012). However, to date, researchers have not been able to establish a causal relationship between RF-EMF exposure below recommendation limits and potential health effects (Choi et al., 2018).

More restricted to ICNIRP, the BioInitiative Reports 2012, built their evaluation on the non-thermal effects of RF radiation. The BioInitiative 2012 Report assessed ~1,800 new peer-reviewed studies published between 2006 and 2012, these studies documented that the new and lower scientific threshold for health harm to be 30 - 60 μW m^{-2} (0.106 - 0.15 V m^{-1}), which is 0.0003 - 0.0006% below of ICNIRP's guidelines. Also considering long-term exposure and sensitivity among children, the precautionary target level was proposed to be 10% of this value, namely 3 - 6 μW m^{-2}(0.03 - 0.05 Vm^{-1}) (Carlberg, Hedendahl, Koppel, & Hardell, 2019; Hardell, Carlberg, Koppel, & Hedendahl, 2017; Misek et al., 2018)

The growth and ubiquitous use of wireless technology in society have increased public concerns about potential adverse health effects from RF-EMF exposure. This has forced some countries (e.g., Switzerland and Belgium) to lower the recommended regulatory exposure limits, whereas other countries (e.g., the Netherlands) retained exposure limits as proposed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The ICNIRP regulatory levels are frequency-dependent; 41 V m^{-1} for 900 MHz, 58 V m^{-1} for 1800 MHz, and 61 V m^{-1} for 2100 MHz (Urbinello, Joseph, et al., 2014).

The RF-EMF exposure levels consider acceptable vary greatly between countries. As noted in the BioInitiative Report 2012, exposure levels range from 4 μW cm^{-2} (3.88 V m^{-1}) in Switzerland, 6 μW cm^{-2} (4.75 V m^{-1}) in China, and 10 μW cm^{-2} (6.14 V m^{-1}) in Russia and Italy to 580 μW cm^{-2} (46.76 V m^{-1}) in the United States and 5800 μW cm^{-2} (147.87 V m^{-1}) in the United Kingdom (Grigoriev, 2010).

In daily life, individuals very rarely receive acute exposures, all populations within the world have been chronically exposed on every day to low levels of RF-EMF which will cause biological effects, and standards need to be set consequently to require this into consideration (Grigoriev, 2010).

Guidelines for exposure limits have been set by national and international groups, composed predominantly of scientific experts, and their reports include detailed discussions of the scientific evidence. Standards cited in regulations are legal documents, so they are more formal (Luc, 2012; McPherson, Mark Elwood, 2019). For this study, the ICNIRP level will be the reference level as it is the most followed guideline internationally. Other levels mentioned here are just for knowledge.

In Palestine, the researches related to RF-EMF started at Al-Quds University since 2003 by the Radiation Research Unit (RRU) then, in 2007 by the Center of Radiation Science and Technology (CRST), bothhave been completed and reported their findings on the environmental levels of RF-EMF over the West Bank and Gaza Strip. Other institutions perform control measurements to ensure the safety of RF-EMF sources are the Environmental Quality Authority (EQA) and the Ministry of telecommunication and Information Technology.

The Environmental Quality Authority (EQA) is the governmental supervising body responsible for setting standards, policies and legislations, and enforcement concerning the protection of the public against both ionizing and non-ionizing radiation. EQA published its regulations for RF-EMF as follows:

- The power density level in the places accessible for the general public should not exceed 1/250 from ICNIRP level.

- The areas designed for passing-through have permits power density up to 1/25 from the ICNIRP level.
- For places designed for purposes other than passing, and people stay for a short time but not on a daily basis, the permitted exposure level should be between the two levels mentioned above.

III. Literature Review

After reviewing the scientific literature, till the 1950s, Electromagnetic smog frequencies remained out of the microwave region, however by the 1960s TV channels began microwave transmissions. Mobile phone technologies emerged throughout the 1980s; wireless local area network throughout the 1990s. Each extensively uses microwave frequency bands (Marshall & Heil, 2017).

In the public environment today, it is a fact that people are exposed to both natural and man-made electromagnetic radiation. These radiofrequency (RF) emissions are generated by devices operating within the RF range of the electromagnetic spectrum and are the results of the demand for the associated technologies. Deatanyah et al, 2018, reported in their study around selected mobile base stations that the potential exposure values ranged from 0.0717 to 0.895 mWm^{-2} (mean 0.296 mWm^{-2} = 0.33 Vm^{-1})

Health concerns can be classified into two main categories: short-term and long-term adverse health effects. The short-term effects involve brain electrical activity, sleep disorders, heart rate, and blood pressure. On the other hand, the long-term effects are associated with epidemiologic effects including cancer and brain tumors. Among whole risks, the key attention has been with the cancer risk for populations living in the proximity of mobile base stations, however, effects on the environment are generally increased.(Magiera & Solecka, 2019).

Wireless technology is based on widespread networks of base stations that connect users through radiofrequency (RF) signals. The accelerated growth in the number of mobile phone subscribers has resulted in an increased number of base stations all over the world. In general, base stations are more numerous in populated areas than in non-populated ones. Nahas & Simsim, 2011, found in their study about the Electromagnetic Fields Radiated from Mobile Base Stations in the Western Region of Saudi Arabia, that RF-EMF levels at all surveyed sites are far below the national and international guidelines for public exposure to RF-EMF and the maximum measurement was in a highly-populated area.

The development of civilization has caused a huge number of sources of electromagnetic fields. In recent years, this field of telecommunications has developed very dynamically, which caused a fast increase in the range of mobile phone users. As a result, the problem of exposure to radiation from mobile phones and base stations has become the topic of research and analysis, because it currently affects the bulk of the population. The chance considerations not only individuals using mobile phones but additionally individuals within the area of base station radiation. The problem is exacerbated in densely inhabited areas, mainly in big cities wherever the number of mobile users and base stations is the highest. Magiera & Solecka, 2019, found in their review of the results of many studies, there was no clear answer on the possible carcinogenic effects of RF-EMF onhealth. Detection of cancer shortly after exposure is the most difficult task in analyzing the results. In the case of the negative effects of electromagnetic fields on brain activity, sleep, heart rate, cognitive function, and blood pressure, no consistent evidence has been obtained either.

In recent years, with the accelerated technological development of electromagnetic (EM) technology in the wireless telecommunication industry, mobile phones have become increasingly popular. The number of mobile phone subscriptions per 100 people in 2016 was 101.5 global. Choi et al., 2018, in their study to assess the personal radiofrequency electromagnetic field (RF-EMF),reported that the mean of the total power density was174.9 μWm^{-2} (0.257 Vm-1) for all participants, and the main contributor was the downlink from mobile base stations. This spread of mobile phones increasing human non-ionizing exposure. This fact has initiated many scientific studies on the possible health effects of FR-EMF on human organisms. Human head and associated body parts that engage during mobile communication are exposed to radiofrequency RF-EMF. Misek et al., 2018, found in their measurement of low-level radiofrequency electromagnetic fields in thehuman environment, that the highest total E-field intensitywas measured in the residential area (approximately 1.85 Vm^{-1}). All measured values were below the legal limits of the national and ICNIRP safety guidelines.

The population is likely to be increasingly exposed to EMF of these additional wireless connections, along with well-known sources as high-voltage power lines, radars, radio and television broadcast facilities, and some other EMF sources as well as the appearance of new EMF sources, along with their proximity to users, constantly arouses the public concerns on potentially dangerous exposure to EMF radiation. In recent years, such concerns have initiated several EMF surveys and measurements campaign on an international scale, testing the compliance of various EMF sources with national and international standards. Djuricet al., 2015, found in their study about continuous monitoring system of daily EMF exposure in an open area environment, that the results of monitoring suggest that potential exposure is far below the allowable limit, regarding reference levels prescribed by the national and international legislation for the general population.

The installations of mobile base station antennas give rise to widespread anxieties among the population regarding possible harmful effects on human health due to the exposure to the RF-EMF emitted by these base station antennas. Accordingly, it is necessary to determine the exposure levels of main cities and city centers due to RF radiation transmitted by the mobile base station antennas concerning all RF-EMF sources. Karunarathna, et al., 2019, found in their study about RF radiation distribution & corresponding exposure levels due to mobile base stations in Sri Lanka that the total exposure quotient (TEQ) was 0.279 of the national and FCC limits.

The keen attention of the public to RF-EMF exposures is related to the dense deployment of base stations, which are positioned on buildings in residential and urban environments. Therefore, RF-EMF generated by base stations has been questioned a lot and is recognized by the general people as a possible hazard. Iyare, et al., 2019, reported in their study that the highest averaged E value was 1.71 Vm^{-1}, all measurements indoor and outdoor were compliant with ICNIRP limits.

Advancement in wireless communication technology has been Rapid within the last twenty years and as a result, the exposure pattern to radiofrequency (RF) electromagnetic field (EMF) has modified in the everyday environment considerably. This pattern can further still change within the future. The spatial and temporal distribution of radiofrequency electromagnetic field (RF-EMF) levels in the environment are highly heterogeneous. It is thus noted is not entirely clear how to monitor spatial variability and temporal trends of RF-EMF exposure levels in the environment of daily life. Sagar et al., 2016, found in their study that the maximum mean of RF-EMF was 0.53 Vm^{-1} in the industrial zone compared with other zones, and 0.69 Vm^{-1} in trams compared to other public transportations. Ramirez-Vazquez, et al., 2019, compare the RF exposure before and after an event, conclude that the installation of mobile base stations and dense population using mobile phones increase the RF exposure for the same area, all measurements were below the ICNIRP limits.

Over the past thirty years, new technologies of communication such as mobile phones and their base stations, wireless local area network (WLAN), Wireless Fidelity (WiFi) access points, among others, have been developed and still evolving rapidly. These mobile technologies express the main contributor to exposure to radiofrequency electromagnetic fields (RF-EMF) in the general population (Deventer, et al., 2011).

As the RF-EMF sources become more varied every day, researchers resume evaluating the safety of human exposure to RF-EMF, encouraging caution, and emphasizing the necessity for additional study. Many European types of research have attempted to characterize the quantity and variability of exposure to RF-EMF in the general population and observed that the exposures to be consistently are greatly below the recommended limits. Notwithstanding, the public and scientific societies remain concerned about exposure to RF-EMF. Therefore, it is essential to continue evaluating this exposure with the latest technologies through measurement studies to properly understand this exposure now and in the future. Birks et al., 2018, reported in their study about personal exposure that the median total exposure was 75.5 μWm^{-2} (0.169 Vm^{-1}) and downlink was the main contributor to total personal exposure.

Sánchez-Montero et al., 2017, mentioned that exposure from different sources such as Wi-Fi systems, radio, or TV is considerably less than mobile phones. For example, wireless systems typically emit ten times less peak power than mobile phones (0.1–0.2W). Furthermore, the significant increase in the use of these systems implies a potentially greater exposure level. In conclusion, it is not generally advised to neglect a priori the contributions from other RF sources than mobile phone base stations, and also it is essential to have a more reliable knowledge of the real exposure values taking into account all the existing RF-EMF sources. A long term exposure evaluation from 2006 to 2015 shows a variation in exposure between 2006, 2010, and 2015, the mean measured electric fields were 0.277 Vm^{-1}, 0.406 Vm^{-1},and 0.395 Vm^{-1} respectively. Also, it was concluded that the probability of finding a value of 14 Vm^{-1} (half of ICNIRP limit) is less than 0.01% and the probability of finding a value of 28 Vm^{-1} (the threshold limit) is negligible.

Due to the development of wireless technologies, the population exposed to a complicated mix of electric and magnetic fields on a broadband frequency spectrum, especially from manmade sources. The public worry about the potential health effects of radiofrequency electromagnetic fields (RF-EMF) due to the current environmental electromagnetic radiation is a major issue in our society. Anyway, it is mandatory to decrease the electric and magnetic field intensity as much as possible to minimize possible health hazards. Fernández-García & Gil, 2017,in their study, evaluate the level of exposure to broadband RF-EMF in a mid-sized Europeancity following the ICNIRP guidelines.The maximum mean electromagnetic field is measured was 3.39 Vm^{-1}in the city center,It represents12.11% from minimum ICNIRP guidelines. Most of the measurements were lower than 0.5 Vm^{-1}. The maximum measured E field was 4.28 Vm^{-1}. Since the minimum reference level for general public exposure to the time-varying electric field is 28 Vm^{-1} for the public, all measurementsalong the city are much lower than the safety level of RF-EMF regulations.

Grigoriev, 2010,in his article, concludes that everyone has to know that mobile phones are not toys and should be used carefully.Limiting the maximum permissible limit of RF-EMF and the establishment of alternative legislation are issues of worldwide interest, taking into account the contradictory information about mobile phones, mobile phone base stations, and their probable dangerous effects on human health.

Buckus et al., 2017,in their scientific field measurements of public exposure to RF-EMR, specifically from mobile base station antennas in the residential area environment.The RF-EMF power density values at distances of 50, 100, 200, 300, 400, and 500 m from the base station are very low within intervals of 0.002 to 0.05 Wcm^{-2}(0.009 to 0.43Vm^{-1}). The resultscompared with ICNIRP guidelines.

During the last 10 years, the number of radiofrequency electromagnetic fields (RF-EMF) transmitters such as mobile phone base stations and wireless local area networks (WLAN) has increased (International Telecommunication Union (ITU), 2019). There is considerable uncertainty about the consequences of these developments for the RF-EMF exposure of the public (30 MHz–300 GHz) (Foster et al., 2017; Urbinello et al., 2014).RF-EMF is essentially used for communication, hence it occurs everywhere such as residential areas (Thielens et al., 2018),educational environments (Bhatt et al., 2017; van Wel et al., 2017), and transportation environments(Gryz & Karpowicz, 2015; Hardell et al., 2017), in urban, suburban, and rural areas (Sagar et al., 2016). Jalilian, Eeftens, Ziaei, & Röösli, 2019, found in their systemic review for public exposure to RF-EMF in Europe that the Mean outdoor exposure values ranged from 0.07 to 1.27 Vm^{-1}, the downlink signals from mobile phone base stations were the main contributor of RF-EMF, and it increases with increasing urbanity.

Kurnaz, Engiz, & Bozkurt, 2018, concluded in their study that as the technology is still advancing, it is required to update existing studies and to proceed to new ones. Some of these studies are as follows: some EMF measurements have been made on university campusesand schools. EMF values specifically caused by base stations have been measured. Although, there are many studies about Wi-Fi EMF measurements. Additionally, there have also been other studies on long-term EMF measurements and evaluations. Kurnaz et al., 2018, reported in their measurements in school gardens that the highest mean Evalue was 2.34 Vm^{-1}, mostly from downlink, and this value is below the limit valuesdetermined by ICNIRP.

Urbinello, Huss, et al., 2014; Urbinello, Joseph, et al., 2014found in their studies that the maximum mean E valueswere 0.44 Vm^{-1}, 0.69Vm^{-1}in Amsterdam respectively,and the most contributor in both was the downlink from GSM 900 band to all RF exposure.

Communication technology has been rapidly changed over the last decade with the introduction of smartphones and new communication technologies such as Long-Term Evolution (4G). Recent data of European countries indicates that mobile-cellular telephone subscription rates were 91.7 per 100 inhabitants in 2005 and 118.2 per 100 inhabitants in 2017 (International Telecommunications Union (ITU), 2019).

Based on IARC classification, further epidemiological researches on correlations between the health issues and RF-EMR exposure are one of the priorities for additional research. A more reliable understanding of the various factors determining the exposure pattern of subjects involved in such studies is a key factor required for more investigations that are systematic. Further studies in order to improve the monitoring of RF-EMR exposure and identify its pattern in the context of possible adverse health effects due to chronic exposure are included, among other things, by recommendations from the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), 2015). Those studies need to provide tools for identifying the dominant sources of RF-EMR affecting a particular workplace or environment of the general public (Gryz & Karpowicz, 2015).

Many research works have been formed in order to characterize the impact of RF-EMF for the general public in real situations, considering the RF communication specific frequency bands. Those works involve communication standards such as FM radio, TV-broadcast, GSM, LTE, DECT, UMTS, and Wi-Fi, typically up to 3 GHz (Urbinello, Huss, et al., 2014; Urbinello, Joseph, et al., 2014). Some others are extended up to 6 GHz, including WiMAX and WiFi 5G (Bhatt et al., 2017). Furthermore, some researchers have been focused on specific population sections such as children or adolescents (Bhatt et al., 2017; Birks et al., 2018) and occupational sectors (Litchfield, van Tongeren, & Sorahan, 2017). Those works, usually consider on-body calibrated exposure meters and they take into account the different uplink and downlink narrow frequency bands and determine the total electric field exposure by means of the sum of all the peak field values received (Fernández-García & Gil, 2017).

Karunarathna et al., 2019, found notable concerns are raising on possible health effects due to exposure to RF-EMF, mainly after the accelerated installation of the mobile telecommunication systems. individuals who live within 100 m – 300 m from the base of mobile phone base station (when the antenna is visible) are generally more worried about possible health effects associated with living nearby to it. Nahas & Simsim, 2011, in their study, compare the locations of the maximum peak points (MPP) with respect to the base station locations, they noted that the maximum horizontal distance was 285 m while the minimum distance was 70.81 m. It is obvious that all MPPs fall within the distance range estimated by the communication and information technology commission (CITC) which is 50 to 300 m,while ARPANSA estimated that the MPP will occur in the range from 75m to 200m as shown in figure 3 (Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 2017).

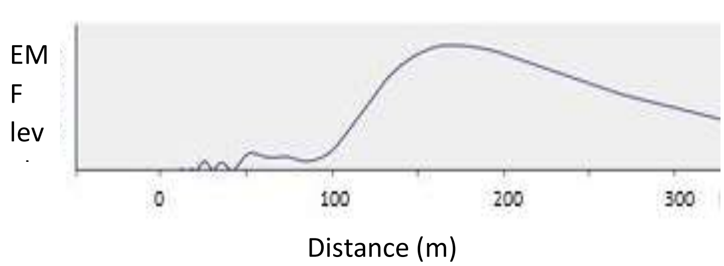

Figure 3. RF-EMF strength propagation with distance from the source.

(ARPANSA, 2017)

Litchfield et al., 2017 in their study about occupational exposure mentioned that one of the most dominant emitters of RF could be found in the telecommunications and broadcasting industries. Hence, the exposure of the workers they employ is of particular interest. The nature of occupational exposure in these working situations is dependent upon the RF and power of the antennas they encounter, the physical properties of the environment where they are housed, and the regularity with which they are visited. As a result, and dependent upon their roles and responsibilities, workers can experience exposures of varying duration and intensity, which are not part of the interest of this study.

IV. Methodology

It is difficult to characterize the Typical exposure of the general public to radiofrequency electromagnetic field (RF-EMF) within the everyday environments, because of many communication technologies, the complicated nature of RF-EMF exposure quantification and high spatial and temporal variability of RF-EMF within everyday environments(Sagar et al., 2018).

Scientific field measurements of public exposure to RF-EMF specifically to radiofrequency radiation from mobile base station antennas and RF electromagneticfield (EMF) intensity parameters in the environment are discussed in this chapter.

The accurate experimental determination of the electric field strength of antennas in complex environments is a difficult task. This is mainly due to the presence of three fundamental physical properties of electromagnetic waves: reflection, absorption, and interference. For instance, under uncontrolled conditions, different measurements can lead to quite different results due to changing conditions. Moreover, because of the complicated environment, the settings of the measurement equipment may affect theaccuracy of the measured values. Extraordinary attention should be paid to the exposure measurement methodology (Buckus et al., 2017).

The spatial and temporal distribution of radiofrequency electromagnetic field (RF-EMF) levels in the environment are highly heterogeneous. It is thus not entirely clear how to monitor RF-EMF exposure levels in the environment in a representative and efficient manner (Sagar et al., 2016).

Different spatial and temporal measurement techniques can be used. Most of the current RF-EMF literature has used four main methods to estimate RF-EMF exposure including (1) spot measurement, made with portable devices that can be set up temporarily at various places. (2) fixed-site monitoring, where data is collected using measurement devices at fixed locations, usually in the framework of routine monitoring. (3) personal measurement with volunteers carrying a device during their daily activities, and (4) mobile micro-environmental measurement with trained researcher walking, bicycling, or driving through various microenvironments carrying a personal measurement device(Jalilian et al., 2019; Röösli & Danielle Vienneau, 2014).

Spot measurement is the best of static measurement techniques to observe the RF-EMF exposure level of the area of interest(Jalilian et al., 2019). By usinga mobile measurement technique, many measurement samples were taken in a short time in a large area. All of these measurement techniques allow us to analyze the RF-EMF exposure in detail.

Environmental measurements have many advantages. First, all sources can be measured, such as wireless local area network (WLAN) hotspots and uplink from different people's mobile phones, which is not possible for simulation programs to study as data on these sources, these data are not available for large scale modeling. Second, collect the data by a qualified technician enables one to adhere stringently to a measurement protocol and to control the quality of data. This may not be true in the case in volunteer studies, where the volunteer may manipulate measurements by placing the measurement device near to sources or provide imprecise activity information while the data collection measurements (Bolte & Eikelboom, 2012; Sagar et al., 2018).

Measurements nearby mobile base stations are becoming more essential because of the number of arising technologies. It is very essential that scientific measurements are benchmarked against established regulations that seek to prevent unnecessary exposure. In doing so, appropriate methodologies are required (Deatanyah et al., 2018).EMF level in mobile base station surrounding depends on its user activity. The more terminals meaning higher throughputs, the higher is the transmitted power. Some trends can be observed in RF-EMF intensity during a time of day related to a certain day of the week or particular hours(Bienkowski & Zubrzak, 2015).

The International Telecommunications Union (ITU) has published many recommendations concerning measurements, protocols, and technical standards associated with EMF emissions and protection. Recommendation

ITU-TK.113 (International Telecommunication Union (ITU), 2015)presents guidance on a way to make the radio-frequency electromagnetic field (RF-EMF) maps for evaluating existing exposure levels over large areas of cities or territories and for proper public acknowledgment of the results, simply and understandably(Sánchez-Montero et al., 2017).

Displaying the measurement event on a map has many advantages. The RF-EMF exposure levels can be reviewed visually on the satellite map street by street. When using this method, the exposure levels around sensitive sites such as school, kindergarten, and hospital can be detected. Then, if it is necessary, the exposure level can be compared with the official limit.

4.1. Study Area

The area of the West Bank extends over 5655 km^2 with a population of about 2.88 million (Palestinian Central Bureau of Statistics (PCBS), 2018). It has a nine major governorate the most of the populations live within, the major cities are Ramallah, Nablus, and Hebron. Jerusalem which is the capital of Palestine not all included since it occupied by Israel, just the east Jerusalem included in this study.This study has faced several limitations. The Israeli colonial hegemony over the West Bank, where the colonial forces ban such studies in many regions of the West Bank including East Jerusalem.

Recently, there are 30 TV broadcasting stations (Palestinian News and Info Agency (WAFA), 2020a), 28 FM radio stations(Palestinian News and Info Agency (WAFA), 2020b), 2 Palestinian mobile phone operators, and 5 Israeli mobile phone operators transmitted RF over the area of the West Bank. No AM radio stations are operated by the Palestinian Authority.

4.2. Instruments

An EME SPY 140 exposure meter (SATIMO, EMF Measurement & Simulation Tools, Brest, France), with the ability to measure 14 different frequency bands was used in this study. This exposure meter is one of the most widely used exposure metersin such studies (e.g. (Beekhuizen et al., 2014; Ramirez-Vazquez et al., 2019; Urbinello, Huss, et al., 2014; Urbinello, Joseph, et al., 2014; van Wel et al., 2017) EME SPY 140 is a light (400 gm) and portable exposure meter that continuously measures the exposure level to the electromagnetic field in the range from 88 MHz to 6GHz with Tri-axial E field probe. The lower detection limit of the EME Spy 140 is 0.005 Vm^{-1} (0.066 μWm^{-2}), the sensitivity of EME-Spy 140 is 0.005 Vm^{-1}.

The frequency bands of the EME Spy 140 cover the frequencies of most public RF-EMF emitting devices currently used in Palestine. The EME Spy measures different telecommunications protocols including FM (frequency modulation) radio broadcasting, TV (television) broadcasting, TETRA emergency services (police, rescue, etc.), GSM (global system for mobile communications) second-generation mobile communications, UMTS (universal mobile telecommunications systems) third-generation mobile communications 3G, DECT (Digital enhanced cordless telephone) cordless telephone systems standard,WiFi wireless local area network protocol, WiMAX (worldwide interoperability for microwave access) wireless communication standard for high-speed data and Internet. Table 2 describes the all frequency band and range of each frequency.

Table 2. Predefined measurements frequency bands and frequency ranges of EME Spy 140 exposure meter

Frequency band	Source	Frequency Range (MHz)
FM	Radio	88 – 108
TV3	Digital audio	174 – 223
TETRA	Terrestrial tuned radio	380 – 390
TV 4 & 5	Television	470 – 830
GSM 900 UL	GSM mobile devices	880 – 915
GSM 900 DL	GSM base stations	925 – 960
GSM 1800 UL	GSM mobile devices	1710 – 1785
GSM 1800 DL	GSM base stations	1805 – 1880
DECT	Cordless telephone	1880 – 1900
UMTS 2100 UL	3G mobile devices	1920 – 1980
UMTS 2100 DL	3G base stations	2110 – 2170
WiFi 2G	Wireless networks	2400 – 2500
WiMAX	Wireless networks	3400 – 3800
WiFi 5G	Wireless networks	5150 – 5850

Where:

UL uplink from mobile handset to the mobile base station

DL downlink from the mobile base station to mobile handset

4.3. Experimental Measurements of RF-EMF Electric Field Strength

First, it has been found that performing such kind of surveys requires good interpersonal and communication skills to deal with the curiousness of people and circumvent any problem, which might occur due to lack of familiarity among the general public. An important issue to consider is that the measurements team should always have an official letter which states the purpose of their job and lists the names of the team members. Also, it is worth noting that such measurements require a high degree of accuracy and integrity as the results are directly related to the safety of human beings.

A total of 149 measurement locations were selectedover the area of the West Bank, Palestine as shown in figure 4. These locations are distributed over the dense urban (city centers and commercial centers), urban (highly populated residential areas), suburban (residential areas), and some rural areas, in all cities in the West Bank, as demonstrated in figure 5. It should be noted that the selected public places may not representative of the whole country, but it is an effort to do so. The measurements were performed in the period from 20/3/2019 to 13/11/2019, concerning all 14 frequencies.

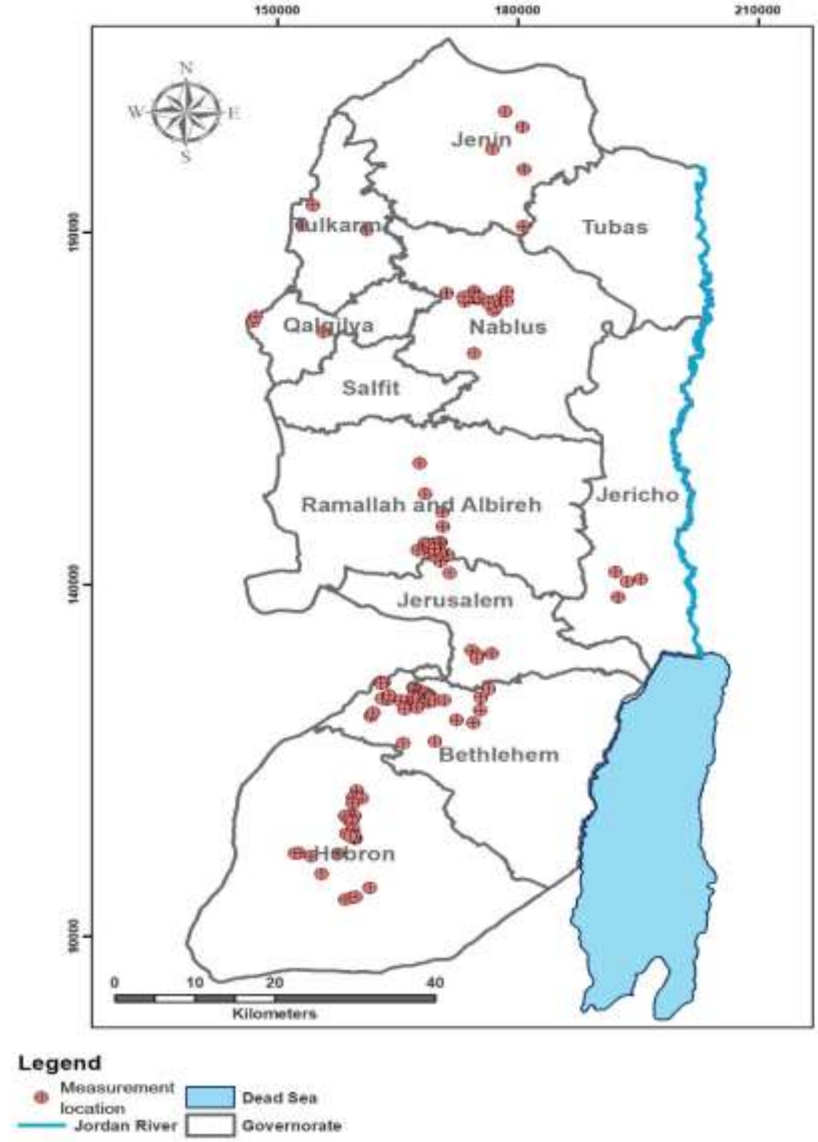

Figure 4. All measurement locations in the West Bank.

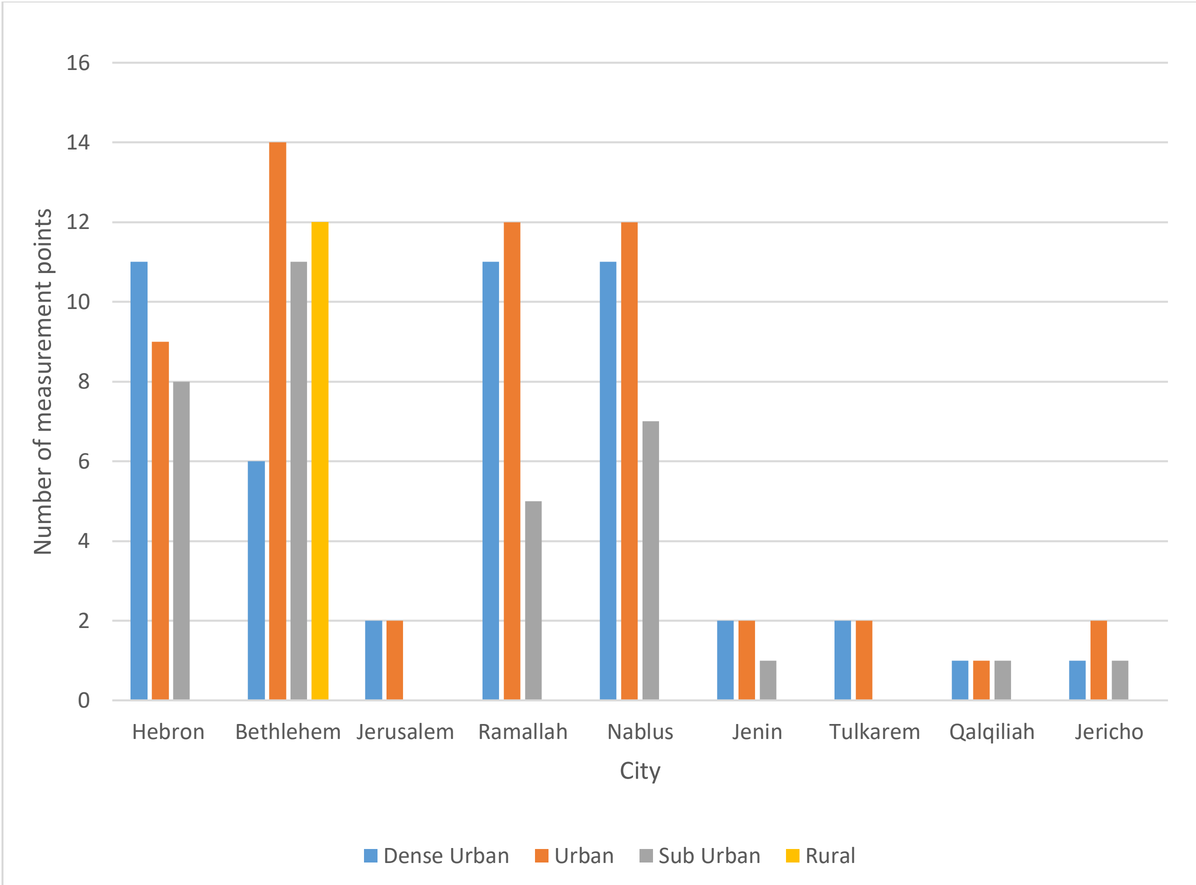

Figure 5. Area types ofmeasured locations over the cities of the West Bank.

For proper RF-EMF exposure assessment, the measurements cannot be performed in the early morning or late evening, because the results would not be relevant (underestimation error). It can also change mostly according to distance and weather conditions (Bienkowski & Zubrzak, 2015). All measurements were performed in workdays, in real-life conditions, with suitable weather conditions between 8:00 and 18:00, which are work hours to prevent underestimation error.

Following the ICNIRP guidelines that stipulate that the RF-EMF measurements have to be averaged through 6 min intervals. The sampling time used in this study was every two seconds, which is the fastest for the given exposure meter. A total of 180 data samples(6 minutes / 2 samples per second) per frequency band were collected for each measurement point.

These measurements are referred to as environmental RF exposure levels, were carried out at outdoor locations that were accessible to the general public, at ground level on the pavement, in a relatively open area. The measurement system includes the exposure meter (EME Spy 140) with a nonmetallic tripod and compatible laptop. At the time of the measurement, all the instruments have been well-calibrated. The exposure meter was held on a nonmetallic tripod about 1.7 m above the ground at a sufficient distance from any object to ensure minimum shielding. Personal mobile phones were switched off while taking the measurements and a mobile phone with a timestamp app was used in flight mode to record the start and end times of each measurement, which was 6 minutes, and record the global positioning system (GPS) coordinate at each measured point.

Measurements of the electric field performed only at a sufficiently large distance from the source, in the so-called far-field region, it is sufficient to evaluate the RF-EMF(Buckus et al., 2017; Cansiz et al., 2018). All measurement samples conducted in the far-field region of the mobile base station antennas or any other seen sources of RF-EMF. In the far-field region, E values can be converted into H or S values by equation (3). In this study, E value (Vm^{-1}) measured as RF-EMF exposure levelin all investigated sites.

$$S=E^2/377=377H^2 \quad (3)$$

(Abdelati, 2005; (ICNIRP), 2009)

Where:
S is the power density
E is the electric field strength
H is the magnetic field

4.4.Evaluation of Exposures

In a complicated frequency environment, all of the individual signals will contribute to public exposure because their effects are additive. Therefore, the total exposure can be expressed in terms of exposure quotient, based on the measured power density S or electric field strengthE for each detected signal, and the ICNIRP recommendation level corresponding to the frequency of the signal. Indeed The electric field strength, E, and power density, S, of an electromagnetic field are two quantities whose limiting values are specified by international and national standards for public safety.

If the maximum electric field E (Vm^{-1}) at a particular location due to all RF sources in the environment can be obtained by measurement, then the power density S (Wm^{-2}) of the electromagnetic field at that location can be estimated from the equation (4)(Karunarathna et al., 2019).

$$S(W/m^2) = \frac{E^2}{\eta} \qquad (4)$$

Where η is the intrinsic impedance of free space = 377 Ω.

To ensure compliance with the reference level which is also called the Maximum Permissible Exposure (MPE) for the environment, a dimensionless quantity recognized as the exposure quotient (EQ) is calculated. This quantity is represented in terms of the calculated power density S from measured results of the field strength and the MPE in power density. Thus

$$EQ = \frac{S_i}{S_{ref,i}} \quad \text{Or the same as} \quad EQ = \frac{S}{MPE} \quad (5)$$

For a certain location, all the signals from different RF frequencies were considered. The sum of the ratios of the measured power density to the corresponding MPE of the power density identified as total exposure quotient (TEQ), TEQ should not exceed one to ensure safety. That is

$$TEQ = \sum_{i=1}^{n} \frac{S_i}{S_{ref,i}} \quad (6)$$

Where,

S_i is the Power Density at the *i* frequency, frequency is given in MHz

$S_{ref,i}$- Reference level of the Power Density at the *i* frequency

n- Total number of transmitting signals (RF frequencies)

Another way to calculate TEQ by using electric field strength E instead of power density S, the ratio of measured exposure value at each frequency, and the reference level for that frequency. The TEQ is the sum of all EQ for all ratios of RF considered. Thus (7)

$$TEQ = \sum_{i=1}^{n} \left(\frac{E_i}{E_{l,i}} \right)^2 \qquad (7)$$

Where,

n is the total number of RF frequencies

Ei is the electric field strength at frequency *i*

El,i is the electric field reference level for frequency *i*

For both equations 6 and 7, TEQ has to ≤ 1. This condition has to been met to ensure environment safety. Also, it is a usual practice to estimate how many times the exposure level is below the safe limit. The times below limit (TBL) can be derived easily from equation (8).

$$TBL = \frac{1}{TEQ} \quad (8)$$

Note: Where conversion is required: 1 watt per square meter (Wm^{-2}) = 100 microwatts per square centimeter (μWcm^{-2}) = 1000 milliwatts per square meter (mWm^{-2}).

4.5. Statistical Methods

Microsoft (MS) Excel sheet was prepared for every point measured, the average over 6 minutes has been calculated and presented as one measurement in SPSS, MS Excel also used to calculate the EQ for each frequency and TEQ for each measurement point.

The statistical parameters of exposure to the E-field were analyzed for each frequency range and total value,SPSS v.23 has been used to calculate means, median, minimum and maximum value as electric field strength in Vm^{-1} for all measured frequency bands.

It has to be noted that with the presented measurement procedure, the instantaneous exposure is determined and not the exposure at maximal traffic. Thus, the values that will be reported are representative for 6-min averaged field strengths and can be compared to the ICNIRP reference levels.

V. Results and Discussion

This chapter describes the results of measured locations in the West Bank area where measurements were made and present the RF-EMF levels. The electric field strengths (E) of 14 predefined RF sources were detected within the frequency range from 88MHz to 6GHz. The data were analyzed in a way to discuss the RF levels from many points of interest that are the exposure from different RF sources, the dominant contributor of RF to theWest Bank, the effect of urbanity on RF exposure, and variation of RF exposure between cities in the West Bank.

5.1. Results of Exposure to RF from Different Frequency Bands

Measurements of electric field strength (Vm^{-1}) from all 149 measurement locations, mean, median, minimum, and maximum exposure, and the corresponding ICNIRP limit for each band, and the exposure quotient (EQ) for each frequency are demonstrated in table 3.

Table 3. Results of electric field strength E (Vm^{-1}) measurementsfrom all 149 measured locations and the corresponding ICNIRP limit andthe exposure quotient (EQ) for each source.

RF source	Mean	Median	Minimum	Maximum	ICNIRP Limit	EQ (of the mean)
FM	**0.929**	**0.298**	0.05	**5.989**	28	**0.033**
TV3	0.022	0.020	0.01	0.084	28	0.0008
TETRA	0.011	0.010	0.01	0.058	28	0.0004
TV4&5	0.026	0.010	0.01	0.674	35	0.0007
GSM900UL	0.032	0.010	0.005	0.631	41.2	0.0007
GSM900DL	**0.435**	**0.332**	0.005	**2.154**	42.2	**0.010**
GSM1800UL	0.032	0.009	0.005	1.330	57.5	0.0006
GSM1800DL	0.119	0.064	0.005	1.254	59	0.002
DECT	0.164	0.084	0.005	1.172	59.8	0.003
UMTS2100UL	0.017	0.006	0.005	0.657	60.7	0.0003
UMTS2100DL	**0.599**	**0.415**	0.005	**3.426**	61	**0.010**
WiFi2G	0.037	0.026	0.005	0.241	61	0.0006
WiMAX	0.029	0.020	0.005	0.444	61	0.0005
WiFi5G	0.215	0.121	0.01	1.284	61	0.004

From the table above, it is clear that the maximum means were for FM, UMTS 2100 DL and GSM 900 DL, 0.93, 0.60, and 0.44 Vm^{-1}, the measurement of the maximum valuesalso were 6.00, 3.43 and 2.15 Vm^{-1} respectively. Even the maximum values are far below the ICNIRP limits.

For FM band frequency 88 - 108 MHz, the maximum measured value of exposuresaveraged over 6 minutes was 6 Vm^{-1}, it is considerably below the ICNIRP level for FM which is 28 Vm^{-1}. The EQ ofthe mean value of 0.93 $Vm^{-1}$is 0.033. The high exposure value from the FM source is due to the presence of many FM-radio stations in the West Bank.

For TV3 band frequency 174 - 223 MHz, the maximum measured value of exposures was 0.08 Vm^{-1}, it is considerably below the ICNIRP level for TV3, which is 28 Vm^{-1}. The EQ ofa mean value of 0.02 Vm^{-1} is 0.0008. The low exposure value from TV 3 sources is due to the low number of TV-channels antennas use this frequency.

For TETRA band frequency 380 - 390 MHz, the maximum measured value of exposures was 0.058 Vm^{-1}, it is considerably below the ICNIRP level for TETRA,which is 28 Vm^{-1}. The EQ of a mean value of 0.01 Vm^{-1} is 0.0004. The exposure value is low because this frequency is used by emergency services, which are limited in sources.

For TV 4&5 band frequency 470 – 830 MHz, the maximum measured value of exposures was 0.67 Vm^{-1}, it is considerably below the ICNIRP level for TV 4&5, which is 35 Vm^{-1}. The EQ of a mean value of 0.03 Vm^{-1} is 0.0007.The low exposure value from TV 4 & 5 sources is due to the low number of TV-channels antennas use this frequency.

For GSM 900 UL band frequency 880 - 915 MHz, the maximum measured value of exposures was 0.63 Vm^{-1}, it is considerably below the ICNIRP level for GSM 900 UL,which is 41.2 Vm^{-1}. The EQ of a mean value of 0.03 Vm^{-1} is 0.0007.

For GSM 900 DL band frequency 925 - 960 MHz, the maximum measured value of exposures was 2.15 Vm^{-1}, it is considerably below the ICNIRP level for GSM 900 DL,which is 42.2 Vm^{-1}. The EQ of a mean value of 0.43 Vm^{-1} is 0.01. The GSM 900 is operated by JAWWAL Company, which is the first, and the most spread in the West Bank, the high number of GSM 900 base stations distributed over the West Bank is the reason of high exposure level from GSM 900 DL.

For GSM 1800 UL band frequency 1710 - 1785 MHz, the maximum measured value of exposures was 1.33 Vm^{-1}, it is considerably below the ICNIRP level for GSM 1800 UL,which is 57.5 Vm^{-1}. The EQ of a mean value of 0.03 Vm^{-1} is 0.0006.

For GSM 1800 DL band frequency 1805 - 1880 MHz, the maximum measured value of exposures was 1.25 Vm^{-1}, it is considerably below the ICNIRP level for GSM 1800 DL,which is 59 Vm^{-1}. The EQ of a mean value of 0.12 Vm^{-1} is 0.002. This frequency operated by Ooredoo, which is the second Palestinian mobile company in the West Bank, this exposure, may be increased in the future as the mobile base stations of this operator are increasing.

For DECT band frequency 1880 - 1900 MHz, the maximum measured value of exposureswas 1.17 Vm^{-1}, it is considerably below the ICNIRP level for DECT, which is 59.8 Vm^{-1}. The mean was 0.16 Vm^{-1}. The EQ of a mean value of 0.16 Vm^{-1} is 0.003.

For UMTS 2100 UL band frequency 1920 - 1980 MHz, the maximum measured value of exposures was 0.66 Vm^{-1}, it is considerably below the ICNIRP level for UMTS 2100 UL, which is 61 Vm^{-1}. The EQ of a mean value of 0.017 Vm^{-1} is 0.0003.

For UMTS 2100 DL band frequency 2110 - 2170 MHz, the maximum measured value of exposures was 3.43 Vm^{-1}, it is considerably below the ICNIRP level for UMTS 2100 DL, which is 61 Vm^{-1}. The EQ of a mean value of 0.60 Vm^{-1} is 0.01. The reason for the high exposure level from UMTS 2100 that the Israeli operators use it and many Israeli mobile base stations were built on the West Bank and directed to Palestinian areas.

For WIFI2G-band frequency 1400 – 2500 MHz, the maximum measured value of exposures was 0.24 Vm^{-1}, it is considerably below the ICNIRP level for WIFI 2G-band which is 61 Vm^{-1}. The EQ of a mean value of 0.04 Vm^{-1} is 0.004.

For WiMAX band frequency 3400 – 3800 MHz, the maximum measured value of exposures was 0.44 Vm^{-1}, it is considerably below the ICNIRP level for WiMAX,which is 61 Vm^{-1}. The EQ of a mean value of 0.03 Vm^{-1} is 0.007.

For WiFi5G-band frequency 5150 – 5850 MHz, the maximum measured value of exposures was 1.28 Vm^{-1}, it is considerably below the ICNIRP level for WiFi 5G-band,which is 61 Vm^{-1}. The EQ of a mean value of 0.22 Vm^{-1} is 0.021.

For all 14 frequency bands, the maximum measured value of exposuresaveraged over 6 minutes was 7.43 Vm^{-1}, this measurement is located in Ramallah city center.The total exposure quotient was 0.13 for this location, which represented as 7.7 times below limit. Thetotal exposure quotient(TEQ)mean for all measurement locations was 0.009. TEQ below 1 is below ICIRP's limits.

The mean value for all locations in the West Bank was 1.39 Vm^{-1} while it was 1.18 Vm^{-1} (0.37 μWcm^{-2}) according to Lahham & Hammash, 2012.This increase in exposure is due to the increase of RF-EMF sources especially the mobile base stations and the development of new technologies in the last decade. This increase in a few years is compatible with the result of Sánchez-Montero et al., 2017 study which shows a variation in exposure between 2006, 2010, and 2015,by a long term exposure evaluation from 2006 to 2015.

The distribution of all measurements value except TV3 are fit to the lognormal distribution, only TV3 band is fit to the normal distribution. The distribution of all frequencies shown in figures 6 – 20.

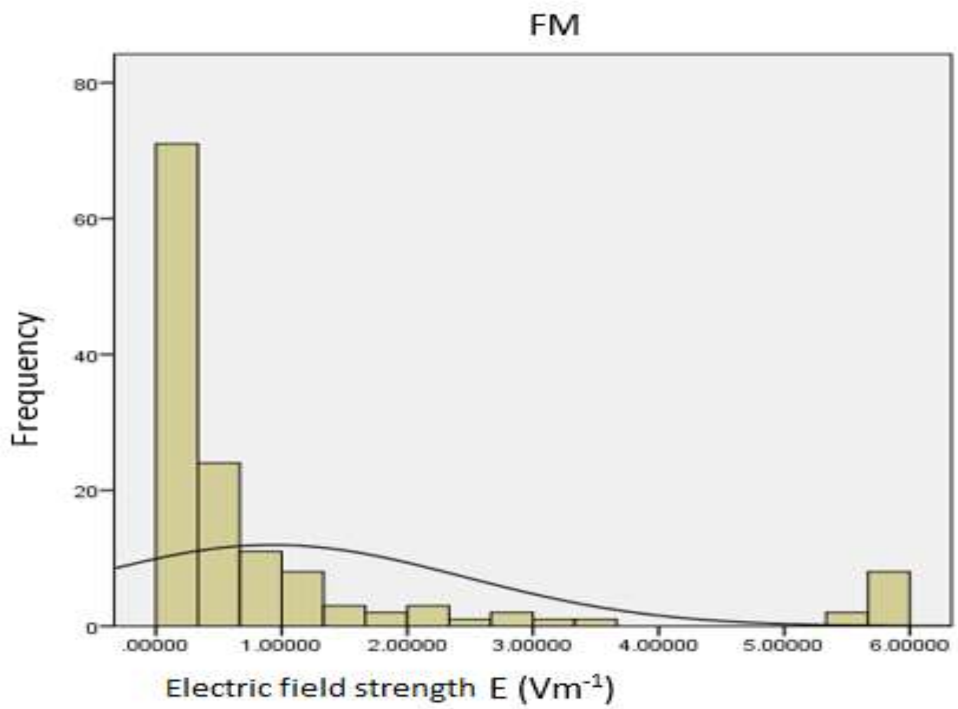

Figure 6. Distribution of exposure values resulted from FM sources.

The distribution of FM exposure is fitted to the log-normal distribution since there are many sources and FM-towers spread over the West Bank, hence, most of the measured values were far from the sources, while the maximum results were near to the sources.

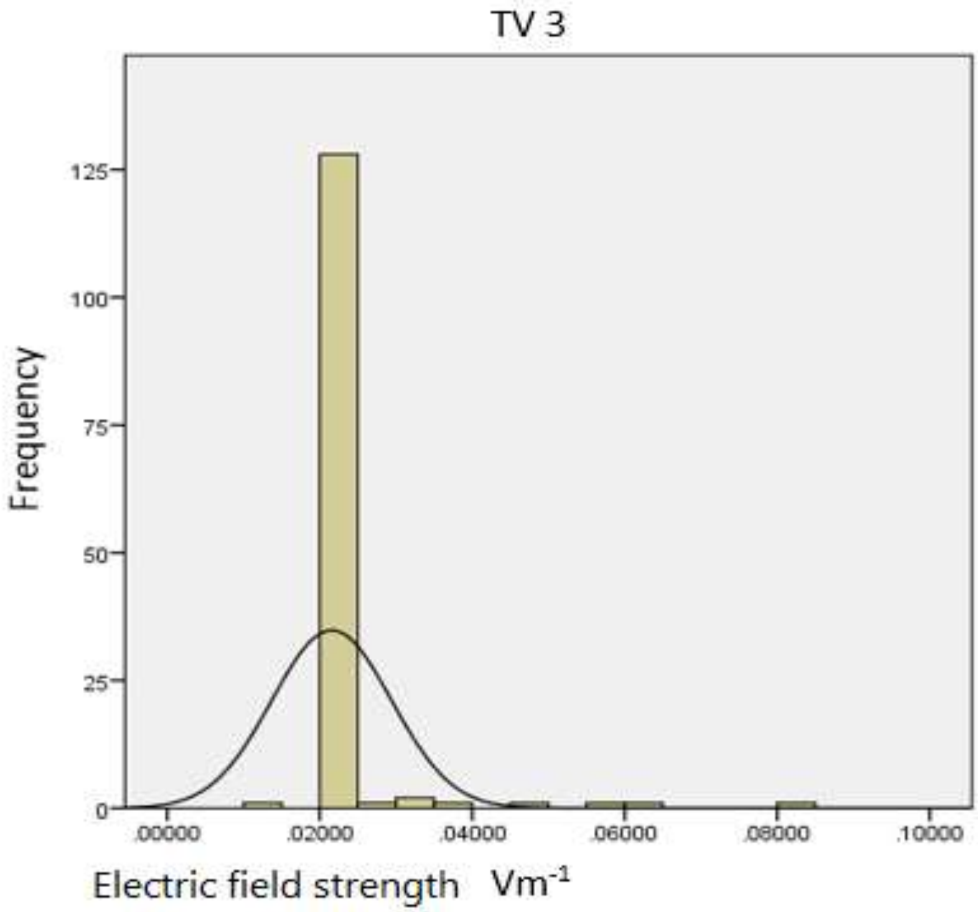

Figure 7. Distribution of exposure values resulted from TV 3 sources.

The distribution of TV 3 exposures is fitted to the normal distribution since there is only one antenna covers a wide area, hence, most of the measured values were close, and nearly with the same distances from the sources.

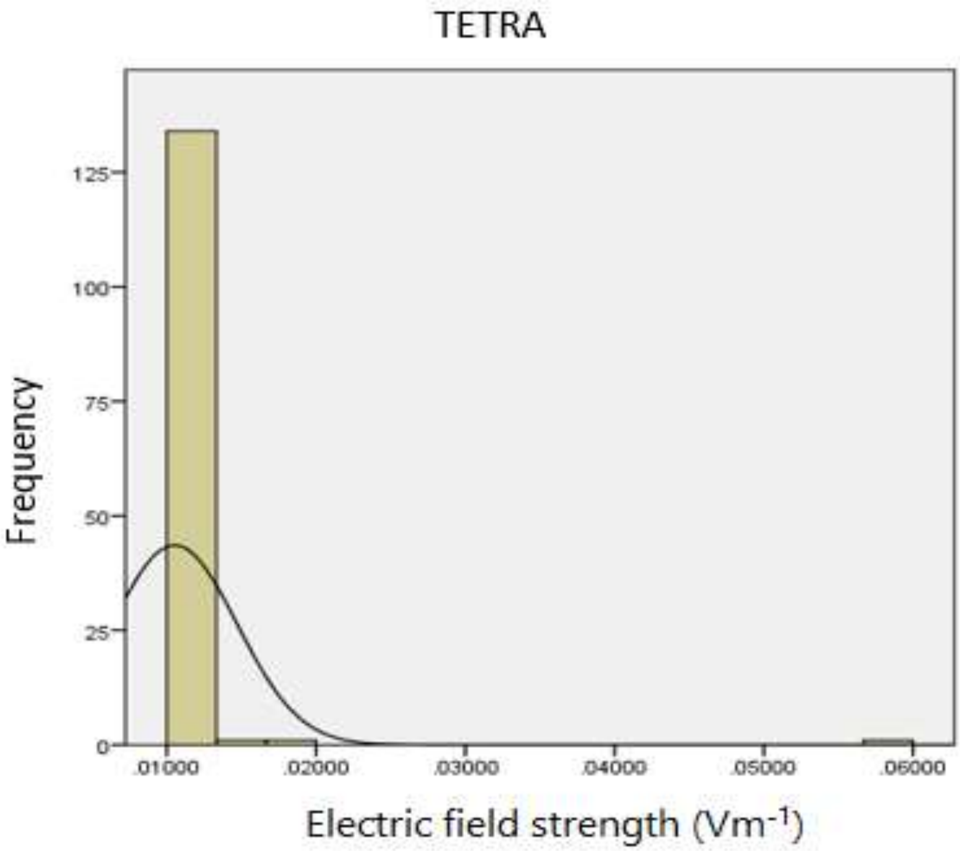

Figure 8. Distribution of exposure values resulted from TETRA sources.

The distribution of TETRA exposures is fitted to the log-normal distribution since this frequency used by emergency services, and there are few sources of it.

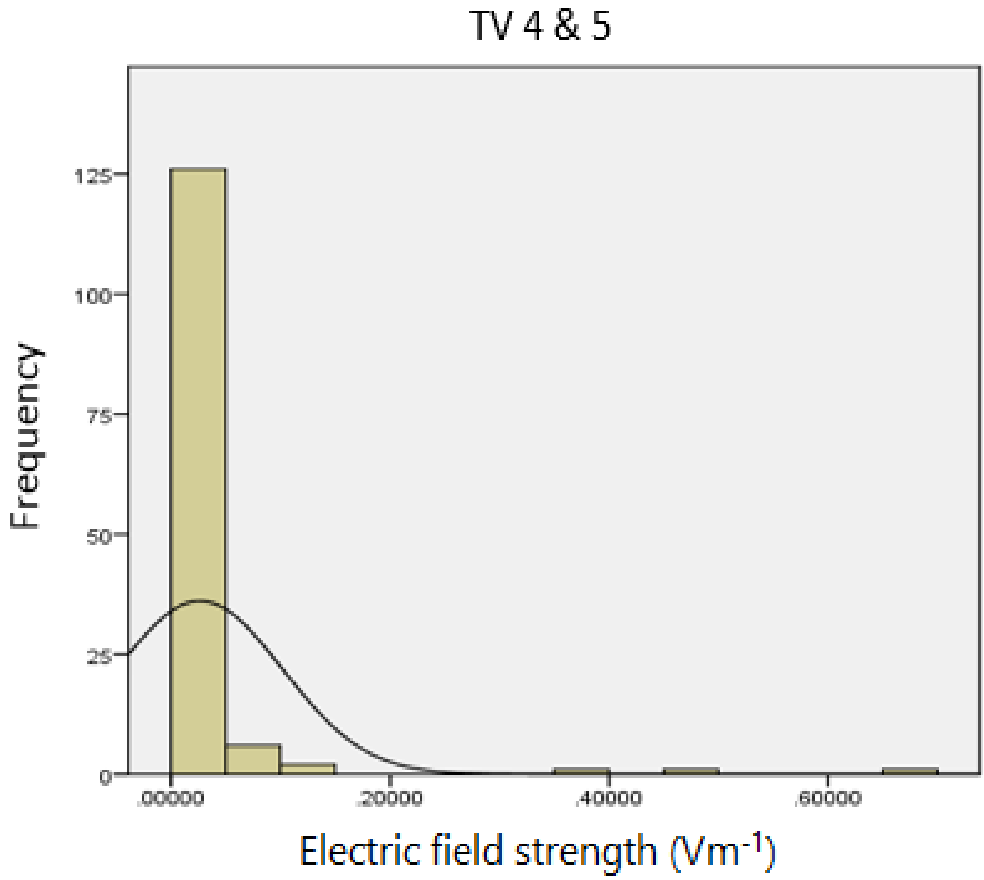

Figure 9. Distribution of exposure values resulted from TV 4 & 5 sources.

The distribution of TV 4 & 5 exposures is fitted to the log-normal distribution since there are few sources, hence, most of the measured values were far from the sources, while the maximum results were near to the sources.

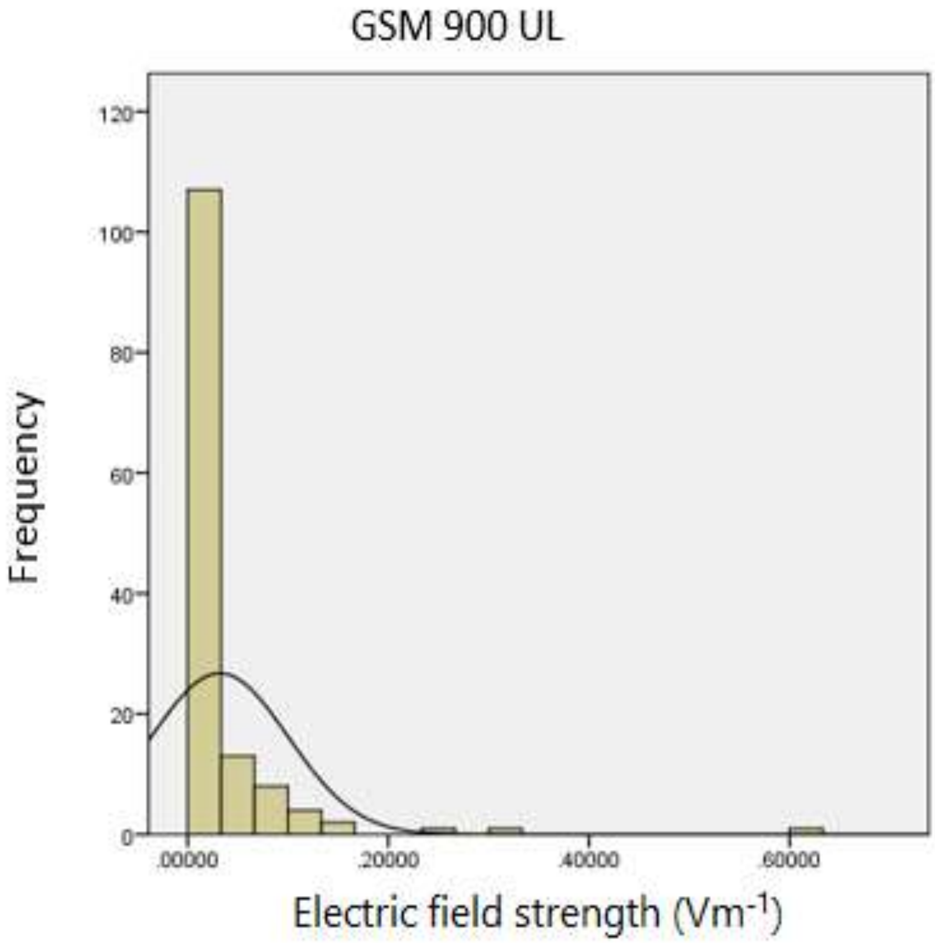

Figure 10. Distribution of exposure values resulted from GSM 900 UL source.

The distribution of GSM 900 UL exposures is fitted to the log-normal distribution since the sources are the mobile phones which are not transmitted unless it used, hence, most of the measured values were there are no mobiles in use, while the maximum results were when there are one or more mobiles in use.

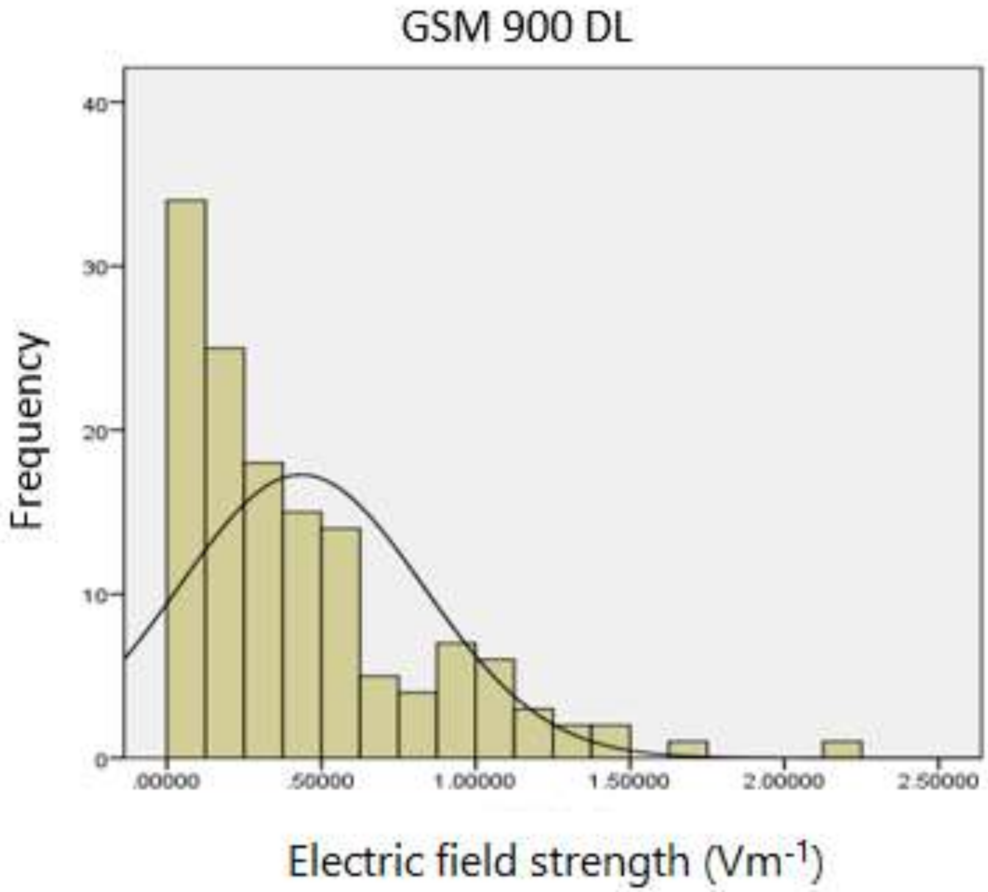

Figure 11. Distribution of exposure values resulted from GSM 900 DL sources.

The distribution of GSM 900 DL exposure is fitted to the log-normal distribution since there are many sources and GSM 900 DL base stations spread over the West Bank, hence, most of the measured values were far from the sources, while the maximum results were near to the sources from 70 to 300 m as described previously.

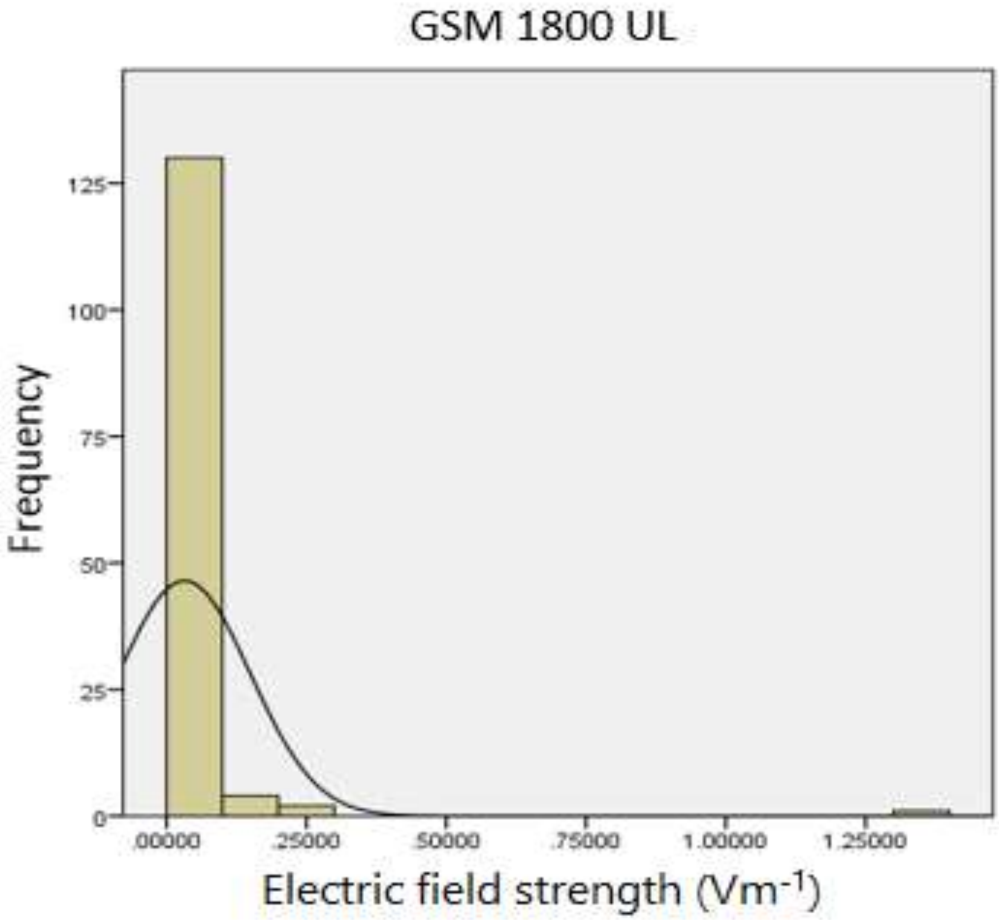

Figure 12. Distribution of exposure values resulted from GSM 1800 UL sources.

The distribution of GSM 1800 UL exposures is fitted to the log-normal distribution since the sources are the mobile phones which are not transmitted unless it used, hence, most of the measured values were there are no mobiles in use, while the maximum results were when there are one or more mobiles in use.

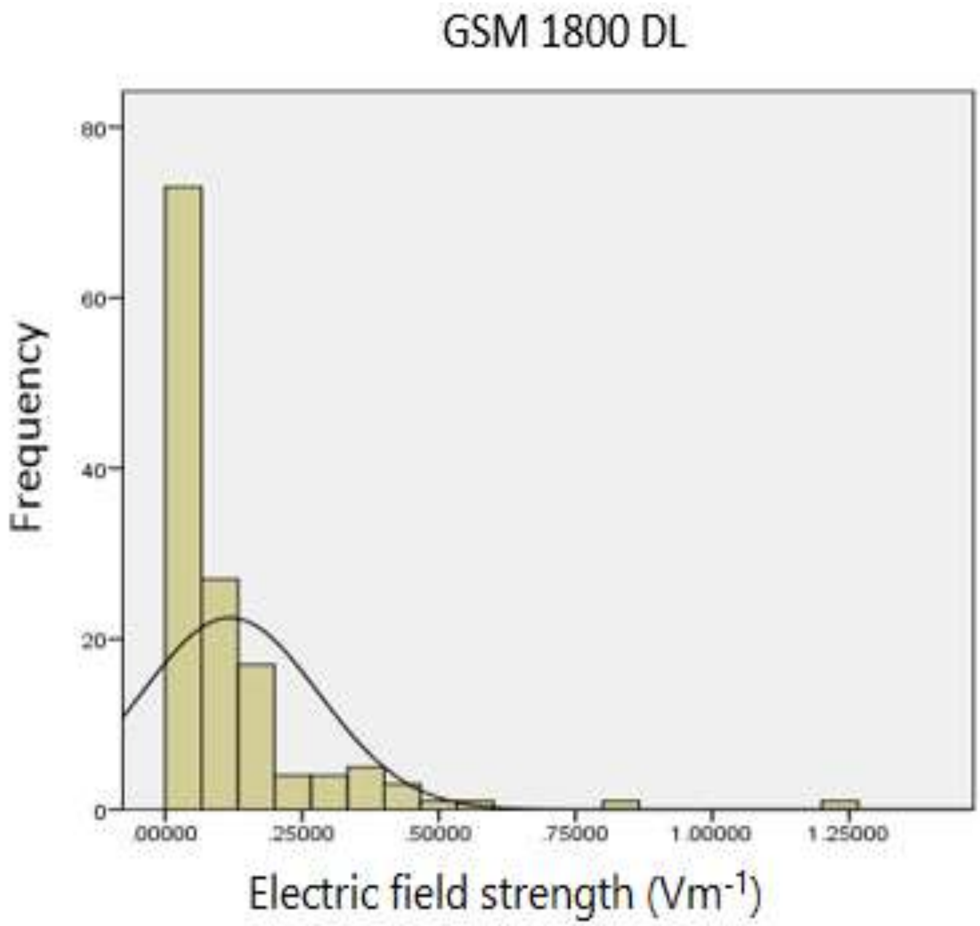

Figure 13. Distribution of exposure values resulted from GSM 1800 DL sources.

The distribution of GSM 1800 DL exposure is fitted to the log-normal distribution since there are many sources and GSM 1800 DL base stations spread over the West Bank, hence, most of the measured values were far from the sources, while the maximum results were near to the sources.

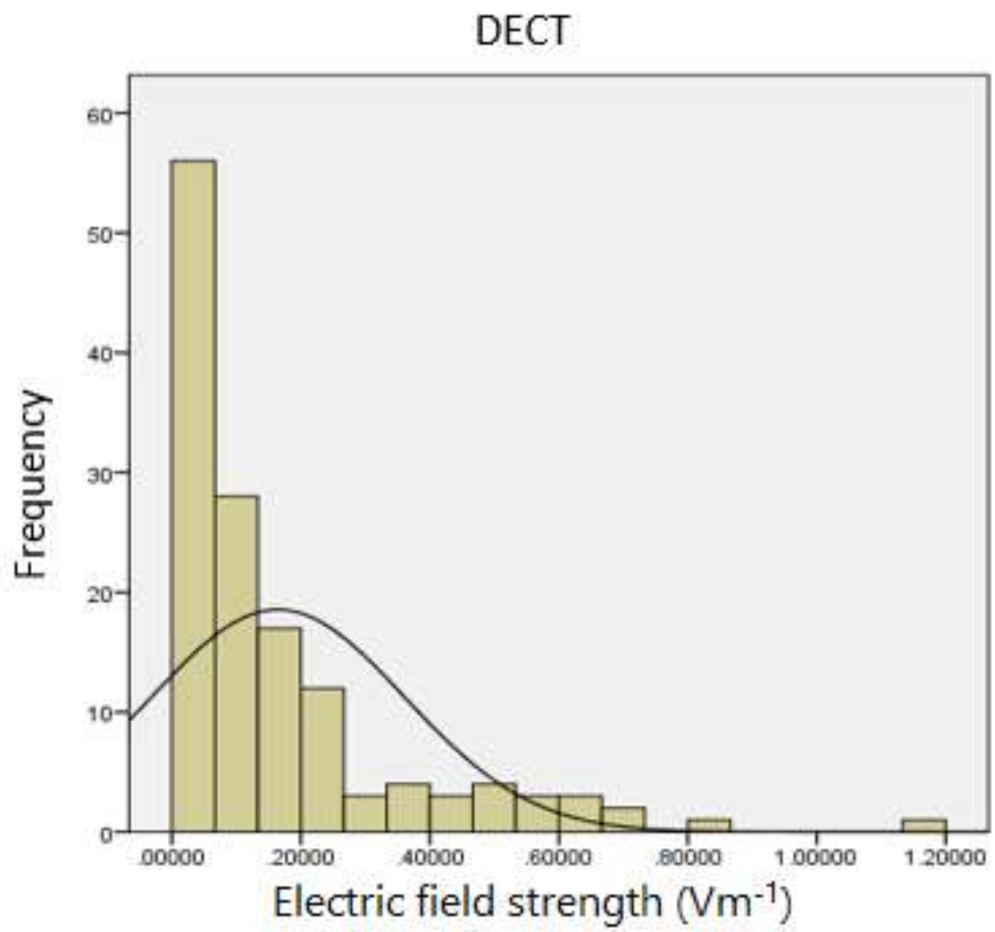

Figure 14. Distribution of exposure values resulted from DECT sources.

The distribution of DECT exposures is fitted to the log-normal distribution since there are few sources outdoor and used mainly indoor, hence, most of the measured values were far from the sources, while the maximum results were near to the sources in offices, homes, and markets or other indoor environments.

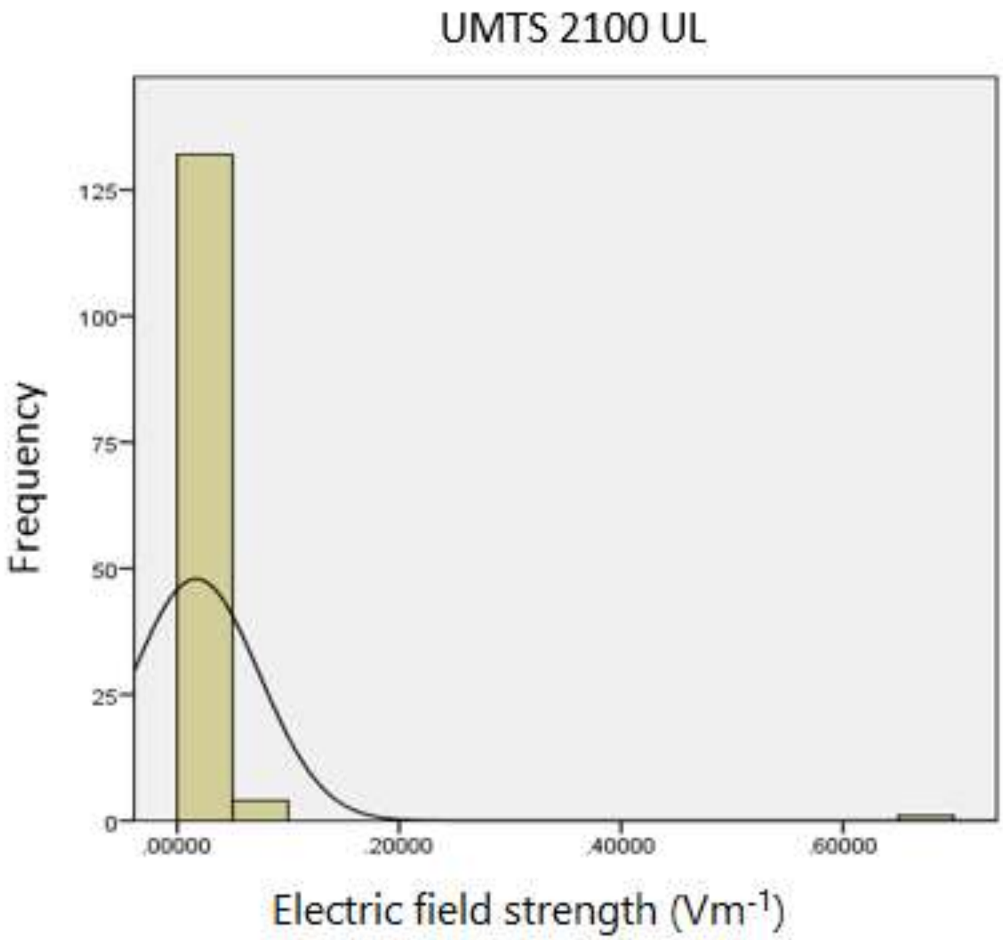

Figure 15. Distribution of exposure values resulted from UMTS 2100 UL source

The distribution of UMTS 2100 UL exposures is fitted to the log-normal distribution since the sources are the mobile phones which are not transmitted unless it used, hence, most of the measured values were there are no mobiles in use, while the maximum results were when there are one or more mobiles in use.

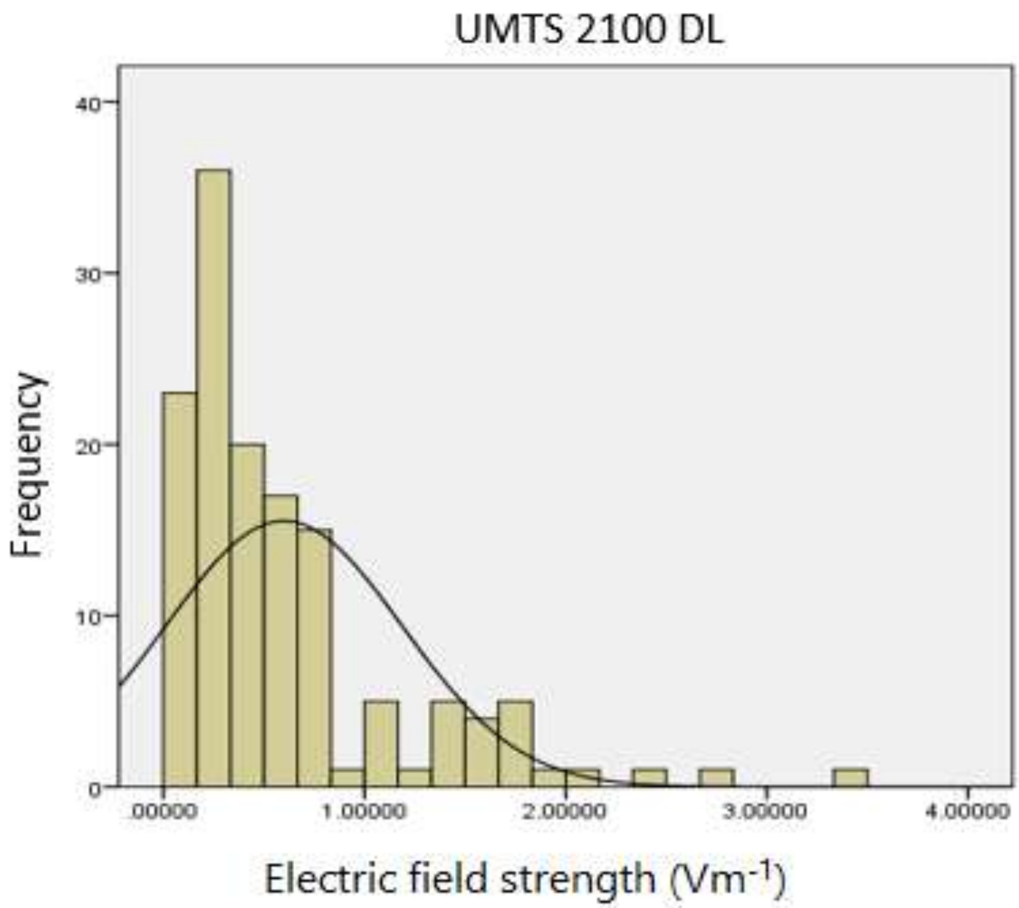

Figure 16. Distribution of exposure values resulted from UMTS 2100 DL sources.

The distribution of UMTS 2100 DL exposure is fitted to the log-normal distribution since there are many sources and UMTS 2100 DL base stations spread over the West Bank, hence, most of the measured values were far from the sources, while the maximum results were near to the sources.

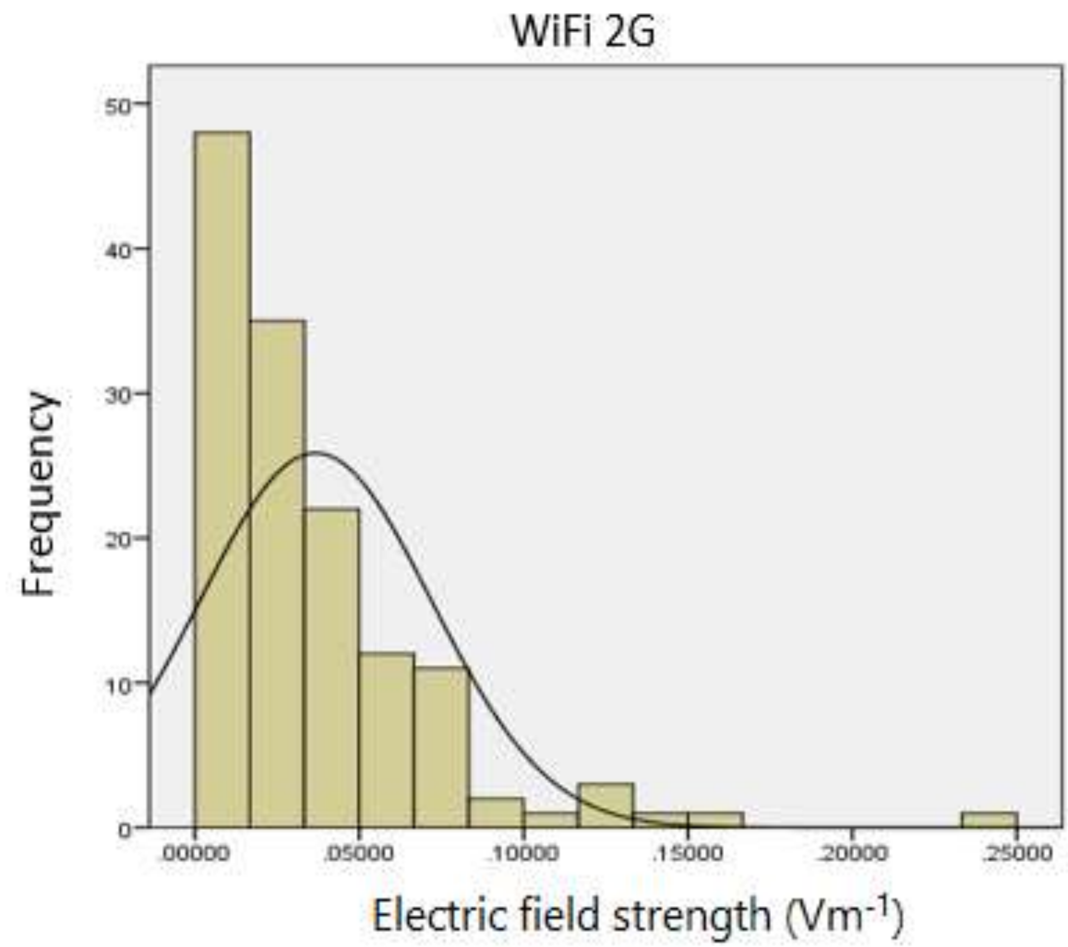

Figure 17. Distribution of exposure values resulted from WiFi 2G sources.

The distribution of WiFi 2G exposures is fitted to the log-normal distribution since there are few sources outdoor and used mainly indoor, hence, most of the measured values were far from the sources, while the maximum results were near to the sources in offices, homes, and markets or other indoor environments.

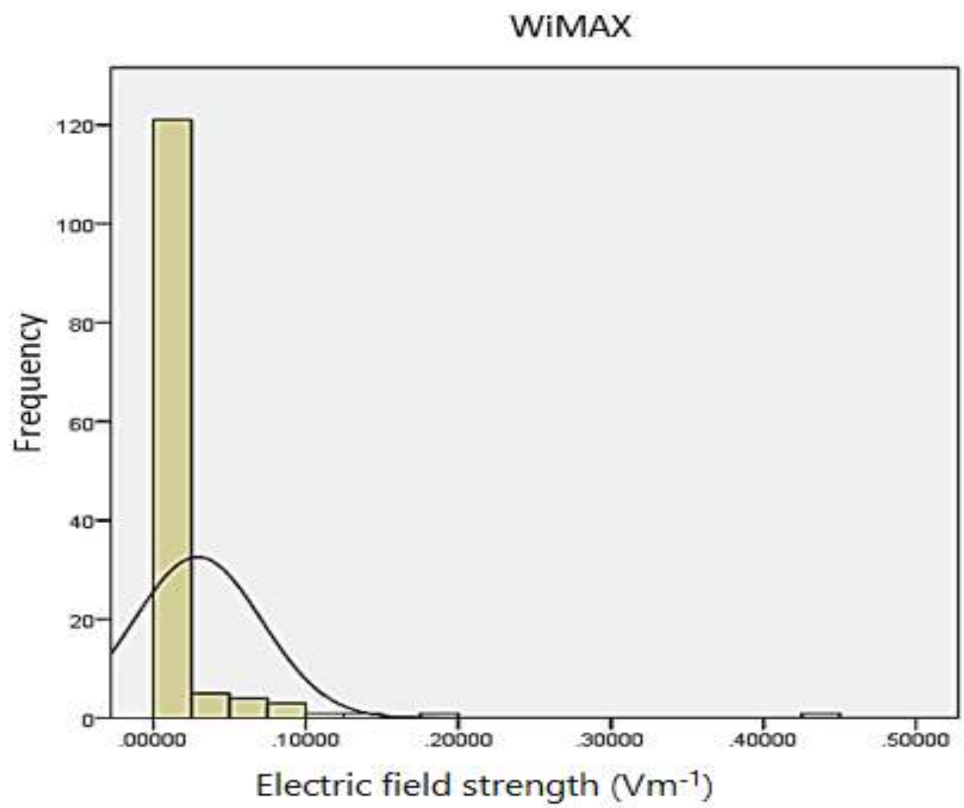

Figure 18. Distribution of exposure values resulted from WiMAX sources.

The distribution of WiMAX exposures is fitted to the log-normal distribution since there are few sources outdoor and used mainly indoor, hence, most of the measured values were far from the sources, while the maximum results were near to the sources in offices, homes, and markets or other indoor environments.

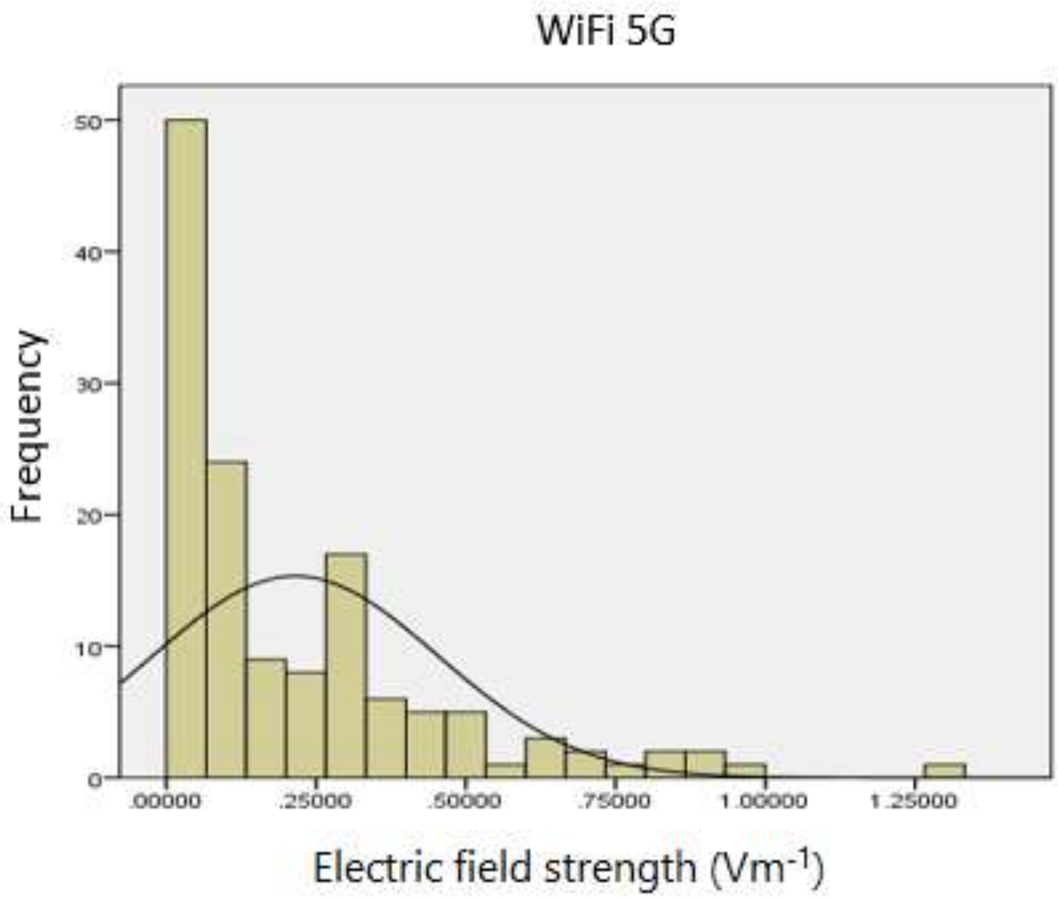

Figure 19. Distribution of exposure values resulted from WiFi 5G sources.

The distribution of WiFi 5G exposures is fitted to the log-normal distribution since there are few sources outdoor and used mainly indoor, hence, most of the measured values were far from the sources, while the maximum results were near to the sources in offices, homes, and markets or other indoor environments.

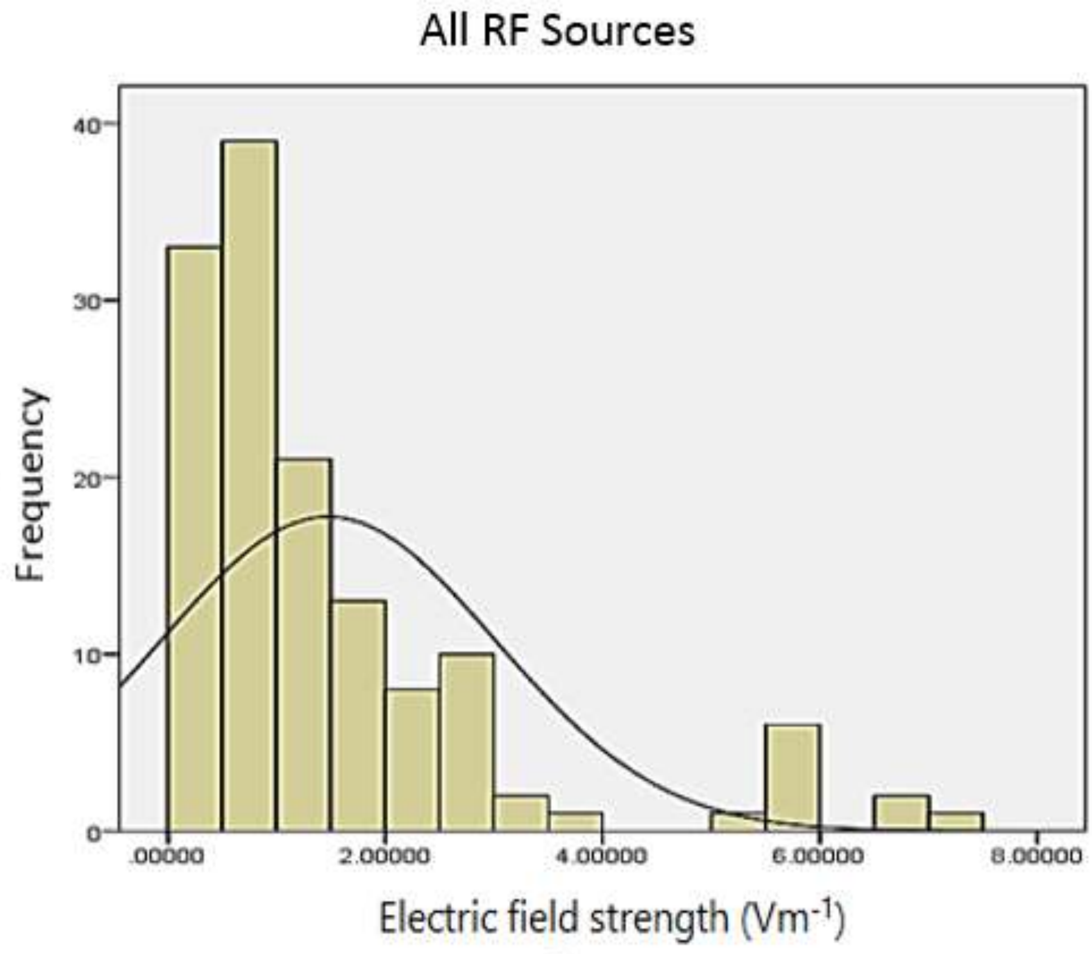

Figure 20. Distribution of exposure values resulted from all RF sources.

Typically, the exposures from FM, mobile base stations, and other sources of RF-EMF usually fit the log-normal distribution(Joseph, Verloock, Goeminne, Vermeeren, & Martens, 2012; Lahham, Sharabati, & Masri, 2017), the only source fit to the normal distribution in this study was the TV 3 source.

RF-EMF measurements in the West Bank indicated that the mean electric field strength E was 1.39 Vm^{-1}. The vast majority (56%) of measured E values were below 1 Vm^{-1}, 35% between 1 and 3 $Vm^{-1,}$ and less than 9% are above 3 Vm^{-1} as shown in table 4.None of the measured exposures were above the ICNIRP level.

Table 4. Frequency distribution table for all conducted measured exposure values in this study

E (Vm^{-1})	**Frequency (number of measurements)**	**Percent %**
0 – 0.99	**83**	**55.7**
1 – 2.99	**53**	**35.6**
3 – 4.99	**3**	**2.0**
5 – 6.99	**9**	**6.0**
> 7	**1**	**0.7**
Total	**149**	**100.0**

These resultsare in line with the results of Gajšek et al., 2015, which reported that more than 60% of measured electric field strengths were below 1 Vm^{-1} and the mean value between 0.08 and 1.8 Vm^{-1} in Europe. Röösli et al., 2017 reported that the mean E value was 0.63 Vm^{-1} ranging from 0.11 to 1.59 $Vm^{-1,}$ and this result somewhat in line with this study results.

5.2. Contribution of Different Sources to the Total Exposure in the Environment ofthe West Bank

To find the main RF contributor for the general public in the West Bank, the exposure quotient of each RF source is calculated and represented as percent ratio to TEQ as shown in figure 21.

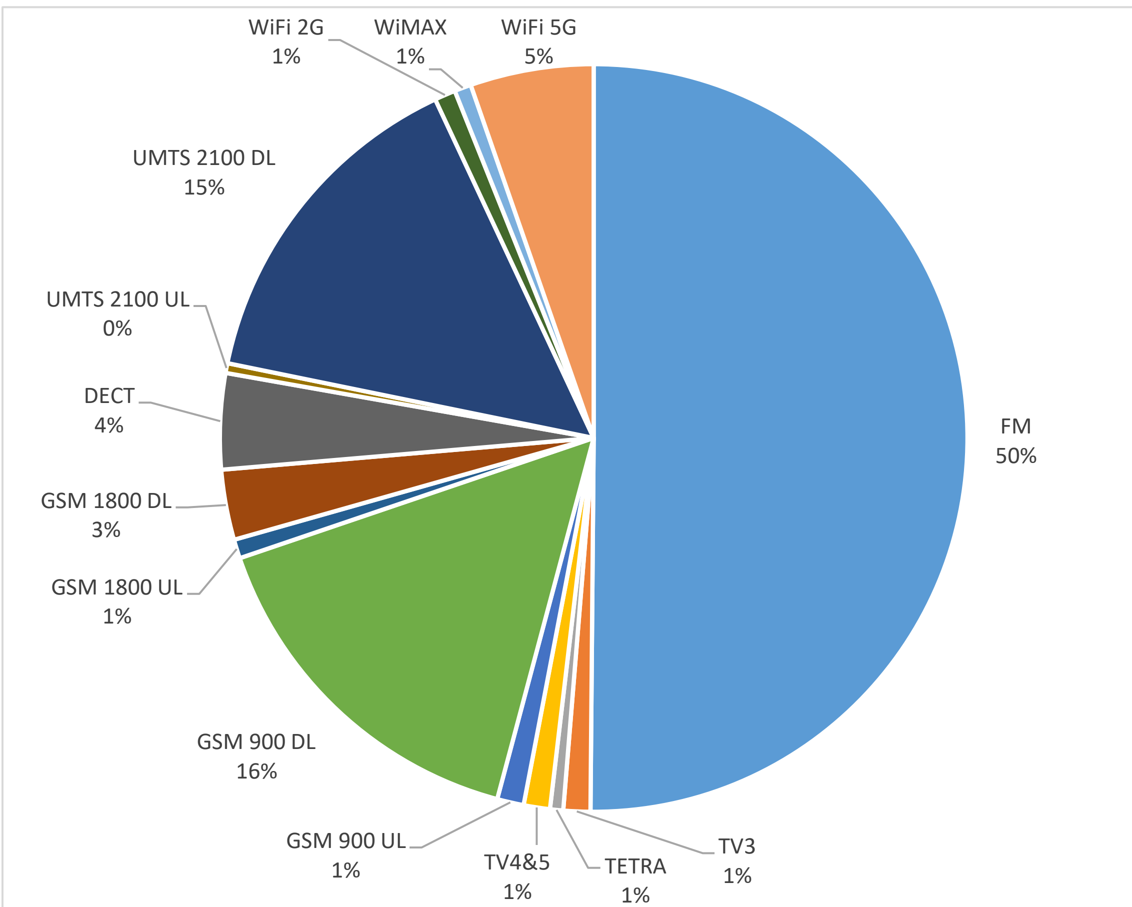

Figure 21. Relative contribution to the total exposure from various RF sources in the West Bank

It is clear from the figure20 that the main contributor to RF-EMF in the West Bank is FM frequency with 50% of TEQ, which is compatible with the previous study done in 2009 by the center of radiation at Al-Quds University (Lahham & Hammash, 2012). The next most contributors are the GSM 900 downlink16%,15%for UMTS2100 downlink, 5% for WIFI 5G, 4% for DECT, 3% for GSM 1800 downlink and nearly 1% for each other frequencies.

Nevertheless, if all downlinks from all mobile phone base stations are added to each other, the downlink from all base stations will be 34%. Thus, it will be the second main contributor of RF-EMF for the general public.This result is partially compatible with many studies worldwide. For example,Cansiz et al., 2018 reported that the main contributor in their study was UMTS 2100 band.Bhatt et al., 2017, and Pasquino, 2017 reported that the main contributor was GSM 900 downlink.Sagar et al., 2016, Röösli et al., 2017, and Birks et al., 2018 reported that the downlink was the most common source of RF-EMF for the general public environment.Hardell et al., 2017 found that the highest mean values were obtained for GSM 900 and UMTS downlink.

Another study advised to be performed after a few years as there is a high probability of an increase in mobile stations and their exposure due to the high development as well as excessive usage of telecommunications.

5.3. Variation of RF Exposures due to Urbanity of Areas

Many studies show that the increasing of urbanity lead to a rise of RF level (e.g. Birks et al., 2018; Thielens et al., 2018), the results below discussed if there are significant differences in the measurements due to the urbanity of areas in the West Bank, table 5 shows the distribution of the measurementsfrom the urbanity point of view.

Table 5. Distribution of all RF results of exposure over different area types in the West Bank.

Area Type	Number Of Locations	Mean Exposure (Vm^{-1})	Maximum Exposure (Vm^{-1})
Dense Urban	46	2.080	7.428
Urban	57	1.178	5.827
Sub Urban	34	1.156	5.982
Rural	12	0.466	1.241
All Areas	149	1.394	7.428

The highest exposure 7.43 Vm^{-1} was taken in a dense urban environment, which is compatible with studies worldwide. The significant increase of exposure in dense urban areas is shown in table 6, and that is compatible with many studies worldwide proved that the general public exposed to more RF in the dense urban areas(Birks et al., 2018; Thielens et al., 2018). In another hand, even the maximum measurement is still far below the ICNIRP limit.

There is an interesting high-value measurement of 5.98 Vm^{-1}that was taken in a suburban environment; it is at the top of the southern mountain of Nablus city. There were many towers for FM radio and a mobile base station on that site. These towers may be transmit with high power output to serve a wide area and a high number of population. Hence, it seems to be a good site for long-term studies.

The differences between every two areas are calculated using SPSS One-Way ANOVA at the level of 0.05, table 6 shows the differences between areas as a result of the ANOVA test.

Table 6. Differences of RF exposures in different area types

Area 1	Area 2	Sig. Diff.
Dense Urban	Urban	*** 0.010**
	Sub Urban	*** 0.025**
	Rural	*** 0.004**
Urban	Sub Urban	1.000
	Rural	0.401
Sub Urban	Rural	0.480

- Differences calculated by SPSS – One-Way ANOVA
- The mean difference is significant at the 0.05 level.

There was a significant difference ($P \leq 0.05$) between the areas of urbanity by using a One-Way ANOVA test (SPSS v23). A significant difference between the dense urban area in comparison with urban areas (P=0.010). Also a significant difference between dense urban and suburban areas (P = 0.025). The most significant difference was between dense urban and rural areas (P = 0.004).

Dense urban – cities centers - show considerably higher strengths and as predicted rural areas with low capacity of the population show lower RF strengths, due to the increasing of RF-EMF sources in dense urban areas such as mobile phone base stations to serve the population. This result is compatible with the result of other studies such as Karunarathna et al., 2019.There is no significant difference between urban, suburban, and rural areas at the level of ($P \leq 0.05$) as shown in table 6.

5.4.RF Exposure Variation Between Cities

In a complicated frequency environment, all of the individual signals will contribute to public exposure because their effects are cumulative. Therefore, the total exposure can be expressed in terms of exposure quotient EQ, based on the measured electric field strength E for each detected signal, and the ICNIRP recommendation level corresponding to the frequency of the signal.Since the widespread of RF sources, the results below discussed the measurement results for each city to make a meaningful result for the population in each city. Table 7 shown a statistical overview of RF exposure of the major cities in the West Bank, and the maximum Total exposure quotient (TEQ) for each city is calculated as described in equation 7 and its times below limit (TBL) as described in equation 8. Any TEQ below one is safe, **all TEQ in this study are below 1**. Figure 22 comparesthe cities' mean and maximum exposures.

Table 7. Electric field strength (Vm^{-1}) exposure of major cities in the West Bank in all locations and correlated maximum TEQ and TBL.

City	Number of locations	Mean exposure	Minimum exposure	Maximum exposure	Max TEQ	TBLof Max TEQ
Hebron	28	**1.299**	0.002	**5.943**	**0.05**	20
Bethlehem	43	0.858	0.001	5.817	0.05	20
Jerusalem	4	0.800	0.411	1.780	0.007	143
Ramallah	28	**2.453**	0.230	**7.428**	**0.13**	**7**
Nablus	30	**1.654**	0.255	**6.516**	**0.10**	**10**
Jenin	5	0.869	0.228	1.792	0.007	143
Tulkarem	4	1.318	0.146	2.702	0.02	50
Qalqiliah	3	1.006	0.585	1.337	0.003	333
Jericho	4	1.259	0.430	2.288	0.007	143

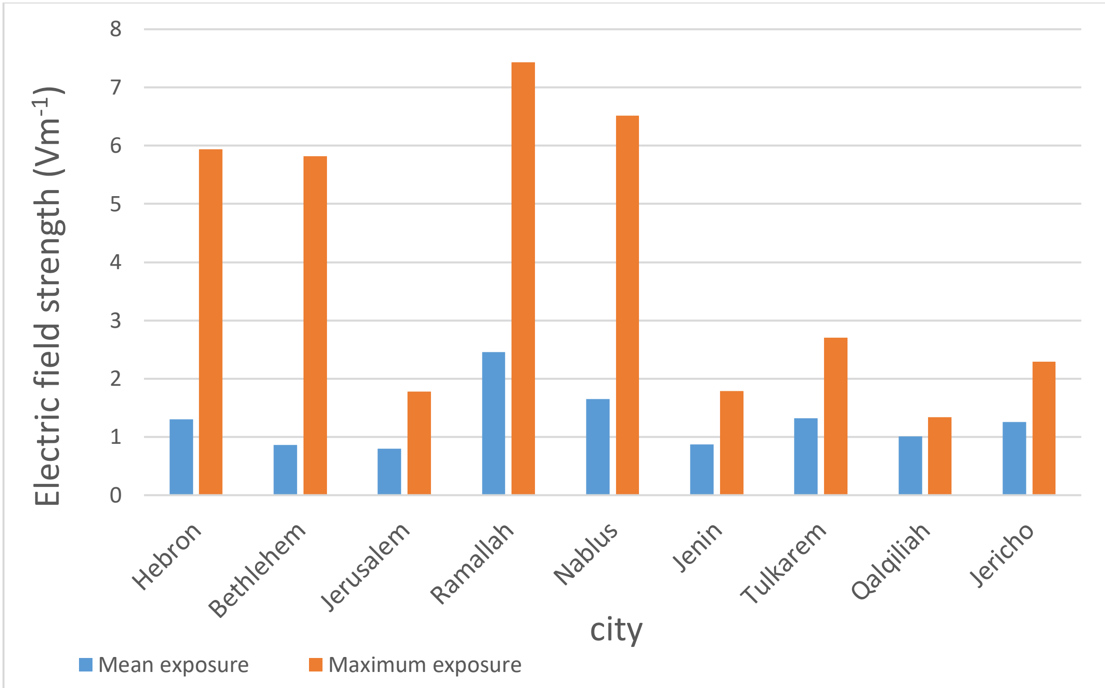

Figure 22. Mean and maximum electric field strength exposures for all cities in the West Bank

From table 7 and figure 22, it is clear that the highest exposures measured in the West Bank were in Ramallah, Nablus, Hebron with 7.43 Vm^{-1}, 6.52 Vm^{-1}, 5.94 Vm^{-1} respectively. These cities are the biggest and the most populated in the West Bank. All of these maximum exposures were conducted in the city centers. All of these valuesare much more than the highest value measured by Abualkbash, 2006(Lahham, Alkbash, & ALMasri, 2017)for the West Bank which was 2.5 Vm^{-1} (1.66 μWcm^{-2}) and by Lahham & Hammash, 2012 which was 3.8 Vm^{-1} (3.86 μWcm^{-2}). The increase of exposure values in the West Bank is a result of the increasing of RF-EMF sources such as mobile base stations and RF technologies developed in the last decades.The mean E exposure valuesin $Vm^{-1}$for each source band contributes to a certain city exposure is listed in table 8.

Table 8. Electric field strength mean exposure (Vm^{-1}) of all sources to all cities in the West Bank

Sourceband	City								
	Hebron	Bethlehem	Jerusalem	Ramallah	Nablus	Jenin	Tulkarem	Qalqiliah	Jericho
FM	**0.794**	**0.513**	**0.640**	**1.789**	**1.025**	**0.292**	**0.807**	0.078	0.215
TV 3	0.020	0.020	0.020	0.021	0.021	0.034	0.036	0.022	0.025
TETRA	0.010	0.010	0.010	0.012	0.010	0.010	0.010	0.010	0.010
TV 4&5	0.011	0.049	0.010	0.020	0.012	0.010	0.052	0.011	0.136
GSM 900 UL	0.035	0.030	0.012	0.022	0.043	0.007	0.030	0.011	0.084
GSM 900 DL	**0.295**	**0.300**	**0.159**	**0.600**	**0.536**	**0.455**	**0.408**	**0.652**	**0.683**
GSM 1800 UL	0.018	0.060	0.019	0.017	0.043	0.008	0.010	0.016	0.015
GSM 1800 DL	0.134	0.067	0.039	0.156	0.145	0.081	0.070	0.171	0.089

Source band	City								
	Hebron	Bethlehem	Jerusalem	Ramallah	Nablus	Jenin	Tulkarem	Qalqiliah	Jericho
DECT	0.137	0.105	0.014	0.264	0.157	0.082	0.295	**0.246**	0.240
UMTS 2100 UL	0.013	0.028	0.006	0.018	0.011	0.013	0.012	0.029	0.009
UMTS 2100 DL	**0.517**	**0.291**	**0.272**	**0.935**	**0.707**	**0.460**	**0.745**	**0.474**	**0.837**
WiFi 2G	0.039	0.026	0.049	0.036	0.045	0.046	0.033	0.037	0.027
WiMAX	0.021	0.025	0.021	0.051	0.025	0.020	0.020	0.025	0.029
WiFi 5G	0.183	0.131	0.127	0.342	0.225	0.170	0.290	0.139	**0.278**

Where

UL is uplink. DL is downlink

It is clear from table 8 that in most cities the FM, UMTS 2100 DL, and GSM 900 DL bands are the highest exposure source.

5.4.1 Variation of Total Exposure Quotient TEQ with Location

For all measurements in different cities, no exposure found above the ICNIRP level, the maximum TEQ for each city illustrated in figure 23explains the differences between cities, major cities show considerably higher exposure quotient.

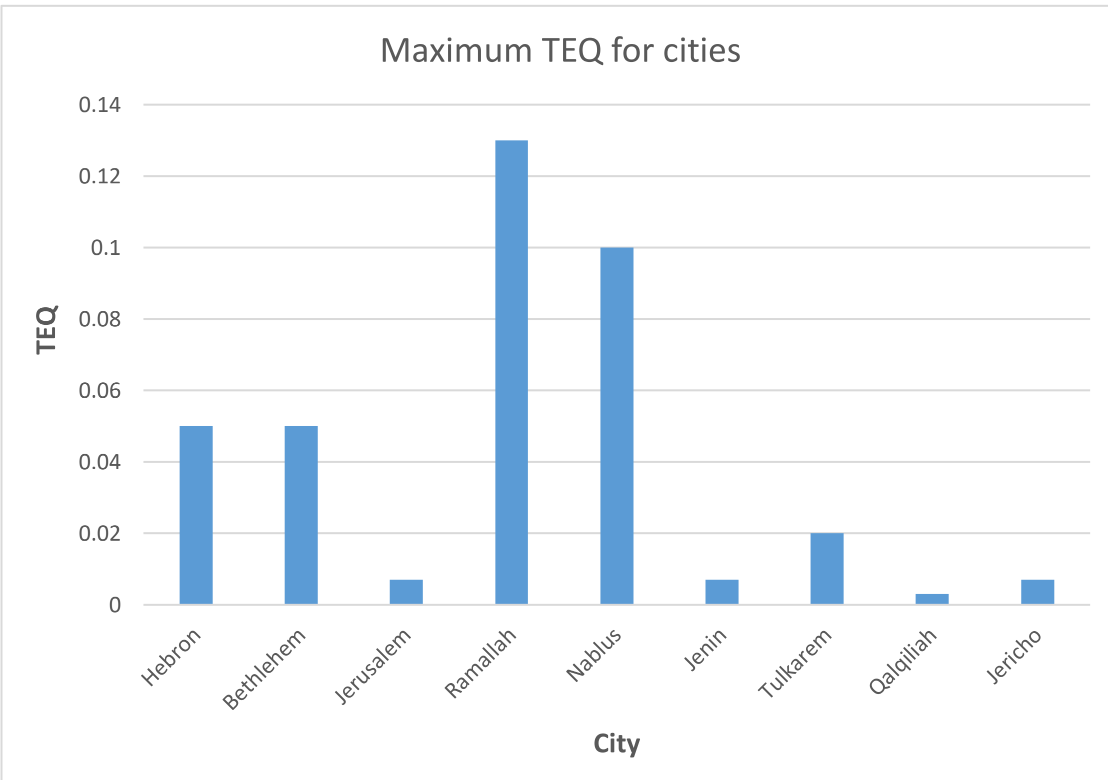

Figure 23. Maximum total exposure quotient for all cities of West Bank

The maximum TEQ was found in Ramallah city which is 0.13 and that represents just about 7 times below ICNIRP guidelines. Figure 24 shows the TEQ map of the West bank.

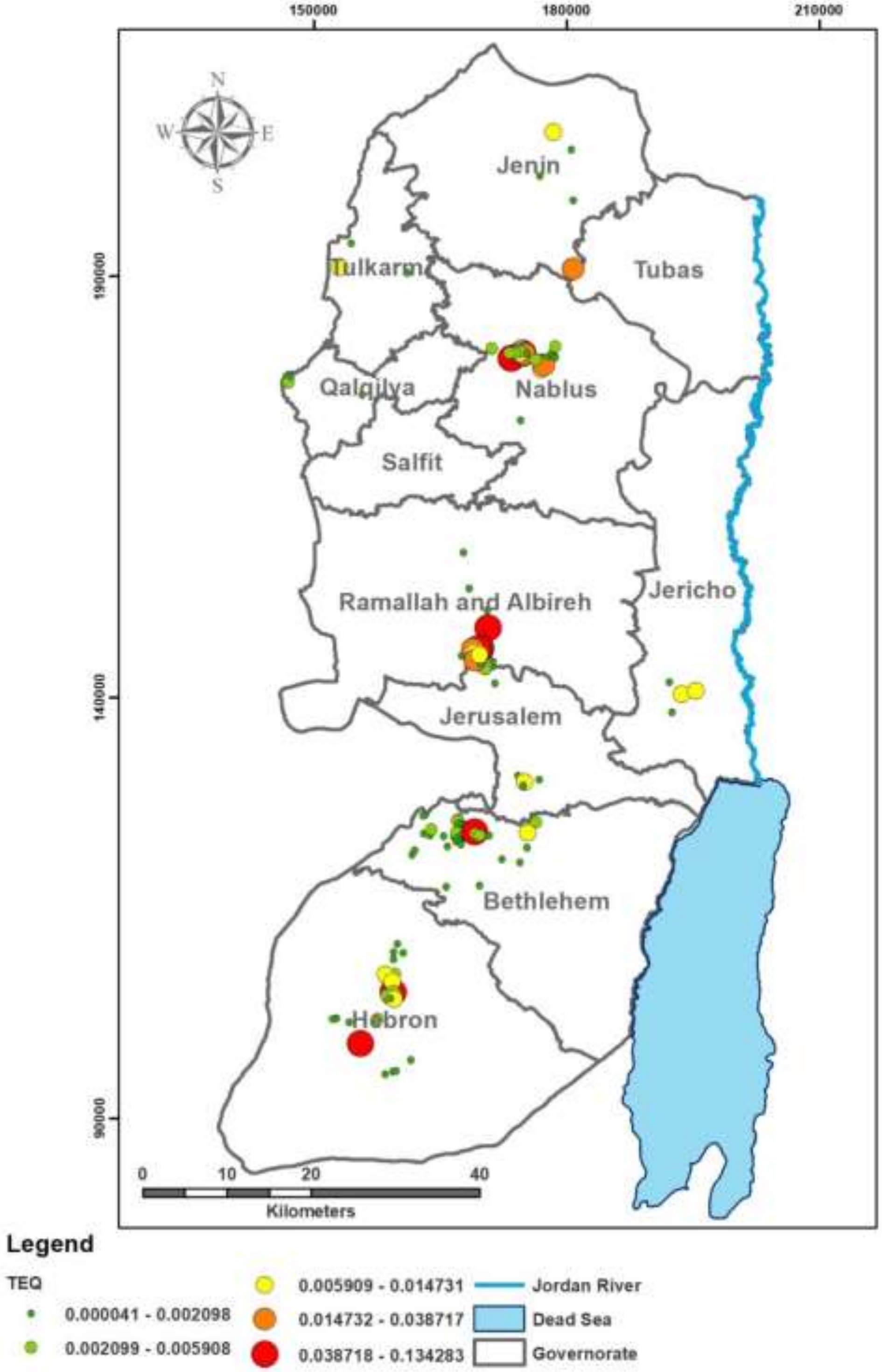

Figure 24. Map of the West Bank showing the TEQ in measurement locations

It is clear from figure 24 that the highest TEQ (red points) located in the city centers of the biggest cities especially Ramallah, Nablus, and Hebron and dense urban areas. This result is predicted as the city center environments always have more sources of RF-EMF to serve the public and gain more coverage of the mobile base stations in crowded areas.

5.4.2HebronArea

Total measurement points taken forthe Hebron area were 28 points, 11 in dense urban, 9 in urban, and 8 in suburban areas. The exposures from each frequency band in Hebron are shown in table 9.

Table 9. Exposure levelfrom RF-sources contribute to the Hebron area (Vm^{-1})

Band	Mean	Minimum	Maximum
FM	**0.794**	0.050	**5.924**
TV3	0.020	0.020	0.020
TETRA	0.010	0.010	0.012
TV4&5	0.011	.01000	0.049
GSM900UL	0.035	0.005	0.631
GSM900DL	**0.295**	0.033	0.801
GSM1800UL	0.018	0.005	0.198
GSM1800DL	0.134	0.005	0.835
DECT	0.137	0.011	0.702
UMTS2100UL	0.013	0.005	0.045
UMTS2100DL	**0.517**	0.067	1.607
WiFi2G	0.039	0.005	0.126
WiMAX	0.021	0.020	0.034
WiFi5G	0.183	0.020	0.847

The maximum exposure from any source in Hebron was 5.924 Vm^{-1}, this exposure related to the FM band in Hebron city center.The maximum exposure means were FM, UMTS2100 downlink, and GSM 900 downlink, 0.79 Vm^{-1}, 0.52 $Vm^{-1,}$ and 0.29 Vm^{-1} respectively.

5.4.3Bethlehem Area

Total measurements point taken for Bethlehem area was 31 points, 6 in dense urban, 14 in urban, and 11 in suburban areas. The exposures from each frequency band in Bethlehem are shown in table 10.

Table 10. Exposure level from RF-sources contribute to the Bethlehem area (Vm^{-1})

Band	Mean	Minimum	Maximum
FM	**0.513**	0.050	5.784
TV3	0.020	0.010	.02000
TETRA	0.010	0.010	.01720
TV 4&5	0.049	0.010	.67470
GSM900UL	0.030	0.005	.33100
GSM900DL	**0.300**	0.005	1.118
GSM1800UL	0.060	0.005	1.330
GSM1800DL	0.067	0.005	0.388
DECT	0.105	0.005	0.549
UMTS2100UL	0.028	0.005	0.657
UMTS2100DL	**0.291**	0.005	1.172
WiFi2G	0.026	0.005	0.241
WiMAX	0.025	0.005	0.185
WiFi5G	0.131	0.010	0.834

The maximum measurement in Bethlehem was 5.78 Vm^{-1}, this measurement related to the FM band in Bethlehem city center. The maximum measurements means were FM GSM 900downlink and UMTS 2100 downlink, 0.51 Vm^{-1}, 0.3 Vm^{-1}, and 0.29 Vm^{-1} respectively.

5.4.4Jerusalem Area

The total measurement points taken forthe Jerusalem area were 4 points, 2 in dense urban, and 2 in urban areas. The exposures from each frequency band in Bethlehem are shown in table 11.

Table 11. Exposure level from RF-sources contribute to the Jerusalem area (Vm^{-1})

Band	Mean	Minimum	Maximum
FM	**0.640**	0.065	**1.663**
TV 3	0.020	0.020	0.020
TETRA	0.010	0.010	0.010
TV 4&5	0.010	0.010	0.010
GSM900UL	0.012	0.005	0.026
GSM900DL	**0.159**	0.040	0.332
GSM1800UL	0.019	0.013	0.030
GSM1800DL	0.039	0.022	0.059
DECT	0.014	0.005	0.038
UMTS2100UL	0.006	0.005	0.006
UMTS2100DL	**0.272**	0.080	0.415
WiFi2G	0.049	0.017	0.075
WiMAX	0.021	0.020	0.022
WiFi5G	0.127	0.035	0.267

The maximum measurement in Jerusalem was 1.66 Vm^{-1}, this measurement related to the FM band in Jerusalem city center. The maximum measurements means were FM, UMTS2100 downlink and GSM 900 downlink, 0.64 Vm^{-1}, 0.27 Vm^{-1}, and 0.16 Vm^{-1} respectively.

5.4.5Ramallah Area

Total measurements point taken for Ramallah area were 28 points, 11 in dense urban, 12 in urban, and 5 in suburban areas. The exposures from each frequency band in Bethlehem are shown in table 12.

Table 12. Exposure level from RF-sources contribute to the Ramallah area (Vm^{-1})

Band	Mean	Minimum	Maximum
FM	**1.789**	0.056	**5.989**
TV 3	0.021	0.020	0.055
TETRA	0.012	0.010	0.058
TV 4&5	0.020	0.010	0.111
GSM900UL	0.022	0.005	0.099
GSM900DL	**0.600**	0.013	2.154
GSM1800UL	0.017	0.005	0.090
GSM1800DL	0.156	0.006	1.254
DECT	0.264	0.006	0.811
UMTS2100UL	0.018	0.005	0.074
UMTS2100DL	**0.935**	0.085	3.426
WiFi2G	0.036	0.005	0.114
WiMAX	0.051	0.020	0.444
WiFi5G	0.342	0.028	1.284

The maximum measurement in Ramallah was 6 Vm^{-1}, this measurement related to the FM band in Ramallah city center. The maximum measurements means were FM, UMTS2100 downlink and GSM 900 downlink, 1.79 Vm^{-1}, 0.93 Vm^{-1}, and 0.59 Vm^{-1} respectively.

5.4.6Nablus Area

Total measurement points are taken forthe Nablus area were30 points, 11 in dense urban, 12 in urban and 7 in suburban areas.The exposures from each frequency band in Nablus are shown in table 13.

Table 13. Exposure level from RF-sources contribute to the Nablus area (Vm^{-1})

Band	Mean	Minimum	Maximum
FM	**1.025**	0.050	**5.806**
TV 3	0.021	0.020	0.031
TETRA	0.010	0.010	0.013
TV 4&5	0.012	0.010	0.044
GSM900UL	0.043	0.005	0.252
GSM900DL	**0.536**	0.005	1.698
GSM1800UL	0.043	0.005	0.232
GSM1800DL	0.145	0.019	0.575
DECT	0.157	0.015	1.172
UMTS2100UL	0.011	0.005	0.094
UMTS2100DL	**0.707**	0.073	2.715
WiFi2G	0.045	0.006	0.164
WiMAX	0.025	.020	0.125
WiFi 5G	0.225	0.162	0.024

The maximum measurement in Nablus was 5.8 Vm^{-1}, this measurement related to the FM band in Nablus city center. The maximum measurements means were FM, UMTS2100 downlink and GSM 900 downlink, 1.02 Vm^{-1}, 0.71 Vm^{-1}, and 0.54 Vm^{-1} respectively.

5.4.7Jenin Area

Total measurement points taken forthe Jenin area were 5 points, 2 in dense urban, 2 in urban, and 1 in suburban areas. The exposures from each frequency band in Jenin are shown in table 14.

Table 14.Exposure level from RF-sources contribute to the Jenin area (Vm^{-1})

Band	Mean	Minimum	Maximum
FM	**0.292**	0.050	0.785
TV 3	0.034	0.020	0.064
TETRA	0.010	0.010	0.010
TV 4&5	0.010	0.010	0.011
GSM900UL	0.007	0.005	0.011
GSM900DL	**0.455**	0.099	0.991
GSM1800UL	0.008	0.005	0.015
GSM1800DL	0.081	0.016	0.139
DECT	0.082	0.018	0.134
UMTS2100UL	0.013	0.006	0.020
UMTS2100DL	**0.460**	0.105	**1.089**
WiFi2G	0.046	0.015	0.127
WiMAX	0.020	0.020	0.020
WiFi5G	0.170	0.031	0.531

The maximum measurement in Jenin was 1.08 Vm^{-1}, this measurement related to UMTS 2100 downlink band in Jenin city center. The maximum measurements means were UMTS2100 downlink, GSM 900 downlink and FM, 0.46 Vm^{-1}, 0.45 Vm^{-1}, and 0.29 Vm^{-1} respectively.

5.4.8TulkaremArea

Total measurement points are taken forthe Tulkarem area were 4 points, 2 in dense urban and 2 in urban areas. The exposures from each frequency band in Tulkarem are shown in table 15.

Table 15. Exposure level from RF-sources contribute to the Tulkarem area (Vm^{-1})

Band	Mean	Minimum	Maximum
FM	**0.807**	0.050	**1.900**
TV 3	0.036	0.020	0.084
TETRA	0.010	0.010	0.010
TV 4&5	0.052	0.010	0.134
GSM900UL	0.030	0.009	0.064
GSM900DL	**0.408**	0.018	0.884
GSM1800UL	0.010	0.006	0.019
GSM1800DL	0.070	0.006	0.186
DECT	0.295	0.034	0.658
UMTS2100UL	0.012	0.005	0.025
UMTS2100DL	**0.745**	0.014	1.475
WiFi2G	0.033	0.012	0.064
WiMAX	0.020	0.020	0.021
WiFi5G	0.290	0.020	0.621

The maximum measurement in Tulkarem was 1.9 Vm^{-1}, this measurement related to the FM band in Tulkarem city center. The maximum measurements means were FM, UMTS2100 downlink and GSM 900 downlink, 0.81 Vm^{-1}, 0.75 Vm^{-1}, and 0.41 Vm^{-1} respectively.

5.4.9Qalqiliah Area

Total measurement points are taken for Qalqiliah area were 3 points, 1 in dense urban, 1 in urban and 1 in suburban areas. The exposures from each frequency band in Qalqiliah are shown in table 16.

Table 16. Exposure level from RF-sources contribute to the Qalqiliah area (Vm^{-1})

Band	Mean	Minimum	Maximum
FM	0.078	0.050	0.120
TV 3	0.022	0.020	0.027
TETRA	0.010	0.010	0.010
TV 4&5	0.011	0.010	0.013
GSM900UL	0.011	0.005	0.018
GSM900DL	**0.652**	0.117	**1.218**
GSM1800UL	0.016	0.005	0.034
GSM1800DL	0.171	0.032	0.442
DECT	**0.246**	0.042	0.580
UMTS2100UL	0.029	0.006	0.075
UMTS2100DL	**0.474**	0.446	0.501
WiFi2G	0.037	0.007	0.068
WiMAX	0.025	0.020	0.036
WiFi5G	0.139	0.023	0.203

The maximum measurement in Qalqiliah was 1.22 Vm^{-1}, this measurement related to GSM 900 DL band in Qalqiliah city center. The maximum measurements means were GSM 900 downlink, UMTS2100 downlink and DECT, 0.6.5 Vm^{-1}, 0.47 Vm^{-1}, and 0.25 Vm^{-1} respectively.

5.4.10Jericho Area

Total measurement points are taken for Jericho area were 4 points, 1 in dense urban, 2 in urban, and 1 in suburban areas. The exposures from each frequency band in Jericho are shown in table 17.

Table 17. Exposure level from RF-sources contribute to the Jericho area (Vm^{-1})

Source	Mean	Minimum	Maximum
FM	0.215	0.084	0.351
TV 3	0.025	0.020	0.038
TETRA	0.010	0.010	0.010
TV 4&5	0.136	0.010	0.452
GSM900UL	0.084	0.029	0.124
GSM900DL	**0.683**	0.266	1.058
GSM1800UL	0.015	0.005	0.031
GSM1800DL	0.089	0.044	0.133
DECT	0.240	0.076	0.441
UMTS2100UL	0.009	0.005	0.013
UMTS2100DL	**0.837**	0.201	**1.786**
WiFi2G	0.027	0.005	0.082
WiMAX	0.029	0.020	0.054
WiFi5G	**0.278**	0.025	0.616

The maximum measurement in Jericho was 1.79 Vm^{-1}, this measurement related to UMTS 2100 DL band in Jericho city center. The maximum measurements means were UMTS2100 downlink, GSM 900 downlink, and WiFi 5G, 0.84 Vm^{-1}, 0.68 Vm^{-1}, and 0.28 Vm^{-1} respectively.

VI. Conclusion

The statistics of RF-EMF exposures were computed for 14 frequency bands between 88 MHz and 6 GHz. Of the 14 bands, the highest three sources of environmental RF-EMF exposures were: FM, UMTS 2100 downlink, and GSM 900 downlink. The mean environmental exposures were: 0.929 Vm^{-1}, 0.600 Vm^{-1}, 0.435 Vm^{-1} respectively. These results are higher than the results of the West Bank in previous studies (Abualkbash, 2006; Lahham, Alkbash, et al., 2017; Lahham & Hammash, 2012). This is also proof that RF exposure increasing within the years.

It was statistically proved that the main contributor band to the total environmental exposure levels from RF-EMF, from 14 frequency bands range from 88 MHz to 6 GHz in the West Bank was the FM radio broadcasting 50%. Moreover, the total exposure from all mobile base stations downlinks 34%, which considered to be the second-largest source of environmental exposure. This finding is partially in line with previous studies that identified mobile phone base stations as a major source of RF-EMF exposure.It should be mentioned that the mobile phone base station exposures from GSM 900 DL contributed the highest share of total downlink exposures.

The RF exposure in the dense urban areas was higher than in other areas; the highest RF mean exposures were in Ramallah, Nablus, and Hebron 2.452 Vm^{-1}, 1.654 $Vm^{-1,}$ and 1.299 Vm^{-1} respectively,which are the major three cities in the West Bank. The maximum exposure measured at any location in the West Bank was 7.428 Vm^{-1}, it was in Ramallah city center and it is 7 TBL.

More than 90% of measurements were below the level of 3 Vm^{-1} which represents 0.1 from the lowest ICNIRB level (28 Vm^{-1}).

It was concluded that all measured RF-EMF exposure levels even the highest exposure level in the West Bank were lower than the reference levels recommended by ICNIRP for general public health.

VII. Recommendations

Another study is advised tobe performed with including more measurement locationsin wider areas of the West Bank- Palestine to make a better acknowledgment about RF-EMF exposure to the public.

Another study is also advised to be performed after a few years as there a high probability of an increase in mobile stations and their exposure due to the high development as well as excessive usage of telecommunications.

The decision-maker can use the results of this study to make simple understanding brochures to the public to inform them about the level of RF-EMF in the West Bank, and about the national and international levels, and the adverse health effects.

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ملخص الدراسة

منذ ازدياد المصادر والتكنولوجيا التي تستخدم الاشعاعات الكهرومغناطيسية(EMR) العاملة بترددات الراديو(RF) عالميا و محليا, زاد القلق لدى المواطنين من اثارها الضارة بالصحة, خصوصا بعد ان تم تصنيفها كمسبب محتمل للامراض السرطانية من الجمعية العالمية للبحث بامراض السرطان (IARC) و هي جزء من منظمة الصحة العالمية (WHO). تم عمل هذه الدراسة لقياس مستوى موجات الراديو (RF) في الضفة الغربية و مقارنتها مع المستويات المسموح بها عالميا من المنظمة العالمية للحماية من الاشعاعات غير المؤينة (ICNIRP).

تم عمل 149 قياس فعلي في مواقع منتشرة في مناطق الضفة الغربية, باستخدام جهاز قياس التعرض للاشعة غير المؤينة , لقياس قوة المجال الكهربائي. نتائج هذه القياسات اوضحت ان اعلى مستوى للتعرض في الضفة الغربية كان بقيمة 7.428 في وسط مدينة رام الله و هي منطقة مكتظة جدا. المصدر الاكثر مساهمة في نسبة التعرض الكلي على مستوى الضفة الغربية كان من مصادر FM بنسبة 50%, و المصدر التالي هو الموجات من ابراج بث الاتصالات الخليوية بنسبة 34%. كانت كميات التعرض لترددات الراديو في المناطق كثيفة السكان اعلى بشكل واضح مقارنة مع باقي المناطق. تم حساب نسبة التعرض الكلي لجميع نقاط القياس, حيث كانت اعلى نسبة تعرض كلي مقارنة بالمستويات الامنة للمنظمة العالمية للحماية من الاشعاعات غير المؤينة 0.13 و ذلك يعني ان كل القياسات في الضفة الغربية كانت اقل بكثير من المستوى المسموح به.