Deanship of Graduate Studies
Al-Quds University

Exposure of the Palestinian Population from Environmental Electromagnetic Fields

Ala'a Aldin M. Hammash

M.Sc. Thesis

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Thesis Approval

Exposure of the Palestinian Population from Environmental Electromagnetic Fields

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Declaration

I certify that this thesis, which is submitted for the Master degree in environmental studies, is the result of my own research, 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……………

Ala' Aldin Mohammad Hammash

Date: / / 2009

Dedication

To my father, mother, brothers and sisters

To my wife and my son, Rami

To my friends

Acknowledgements

I am very pleased to express my deep gratitude to my supervisor Dr. Adnan Lahham for his supervision, guidance and insightful suggestions. Also, I would like to thank the Palestinian Ministry of Telecommunications as well as the Palestine Cellular Communications Ltd. *(Jawwal)*. for the useful statistics they provided the research with. Many thanks are due to Mohammad Abu Ajamieh, Maher Brouk, Khalid Hijeh, Arafat Tmaizi, Fadi Jafar and Mohammad Sbeih for their assistance. A special kind of debt is due to my dear uncle, Dr. Khader Jum'a for his constant encouragement and help.

My sincere thanks go to my father, mother, wife, brothers and sisters, for their unlimited support.

Abstract

This study presents the results of exposure levels to radio frequency radiation emitted from various electromagnetic sources in the Palestinian environment. These sources include FM and TV broadcasting stations as well as mobile phone base stations. A database of sources officially registered at the Palestinian Ministry of Telecommunications and IT, has been established. All relevant technical data has been provided by this ministry and in case of mobile phone base stations by the Palestine Cellular Communications Ltd (Jawwal). This database includes information about 550 mobile phone base stations, 37 TV and 56 FM broadcasting stations. Locations and types of these sources are illustrated on a West Bank map using GIS techniques. Power density and electric field strength are measured in about 35 locations distributed over the West bank area. These locations include centers of the main cities, highly populated areas as well as rural areas. Also a 24 hours activity level is investigated for a mobile phone base station to determine the maximum activity level for this kind of radio frequency radiation sources. All measurements were conducted at a height of 1.7 m above ground level using two spectrum analyzers (BK 2650 and Narda SRM 3000), with different antennas capable of collecting radio frequency signals in the frequency bandwidth from 75 MHz to 3 GHz. Contributions from all relevant radio frequency sources to the total exposure are evaluated in the city centers and found to be 66% from FM radio, 2% for TV broadcasting and 32% from mobile phone base stations. This indicated that the main source of exposure in our environment is FM radio broadcasting and not mobile phone base station (which is the main source of public concern). The average value of power density resulted from FM radio broadcasting in all locations is 0.148 $\mu W/cm^2$, from TV broadcasting is 0.007 $\mu W/cm^2$ and from mobile phone base station is 0.089 $\mu W/cm^2$. The maximum power density measured at any location was 2.66$\mu W/cm^2$, and is resulted from FM radio broadcasting at the city center of Ramallah. This maximum measured power density is about 1.3% of the maximum permissible level (200 $\mu W/cm^2$) recommended by the International Commission on Non-Ionizing Radiation Protection for the general public.

الملخص

تعرض هذه الدراسة نتائج قياس مستويات التعرض الاشعاعي لأشعة التردد الراديوي المنبعثة من المصادر المختلفة في البيئة الفلسطينية بما في ذلك البث الأذاعي (FM) والبث التلفزيوني ومحطات البث الخلوي. حيث تم انشاء قاعدة بيانات لمصادر الاشعاع الكهرومغناطيسي المنتشرة في أنحاء الضفة الغربية والمسجلة رسمياً لدى وزارة الاتصالات وتكنولوجيا المعلومات الفلسطينية. وقد تم تزويدنا بجميع المعلومات التقنية من قبل الوزارة المذكورة وفي حالة محطات البث الخلوي حصلنا على المعلومات التقنية من قبل شركة الاتصالات الخلوية الفلسطينية (جوال). وتحوي قاعدة البيانات التي تم انشاؤها في هذه الدراسة على معلومات تقنية مفصلة عن حوالي 550 محطة بث خلوي و37 محطة بث تلفزيوني و56 محطة بث اذاعي. وقد تم عرض المواقع المختلفة لمصادر الاشعة هذه بأنواعها في خارطة للضفة الغربية باستخدام تقنية GIS. لقد تم قياس كثافة القدرة وشدة المجال الكهربائي في خمسة وثلاثين موقعاً موزعاً في انحاء الضفة الغربية ويشمل مراكز المدن الرئيسية والمناطق ذات الكثافة السكانية العالية إضافة الى مناطق ريفية. كذلك تم فحص نشاط محطة بث خلوي على مدار 24 ساعة لمعرفة فترات البث الأعظمي من هذا النوع من مصادر أشعة التردد الراديوي. جميع القياسات تمت باستخدام جهازي تحليل الطيف الكهرومغناطيسي من نوع (BK 2650 and Narda SRM 3000) بحيث استخدمت هوائيات لتغطي مجال الترددات من 75 ميجا هرتيز إلى 3 جيجا هيرتز. وتمت جميع القياسات على ارتفاع 1.7 م فوق سطح الارض وقد تم التقاط الاشارات الواردة من جميع الاتجاهات. وبعد تحليل نتائج القياسات تم حساب وتحديد مساهمات المصادر المختلفة لأشعة التردد الراديوي في الجرعة الكلية التي يتعرض لها المواطن الفلسطيني. وقد تبين ان هنالك ثلاثة مصادر رئيسية للتعرض هي البث الأذاعي والبث التلفزيوني والبث الخلوي. ويساهم كل منها بما نسبته 66% و 2% و32% على التوالي وذلك في مراكز المدن

الرئيسية. فعلى عكس تخوفات الجمهور التي تعطي الأولوية لمحطات البث الخلوي يشكِل البث الإذاعي المساهم الرئيسي (الأعلى) في الجرعة الكلية التي يتعرض لها المواطن. فمتوسط التعرض من البث الإذاعي في جميع اماكن القياس هو 0.148 ميكرو واط/سم^2 ومن البث التلفزيوني هو 0.007ميكرو واط/سم^2 ومن محطات البث الخلوي هو 0.089 ميكرو واط/سم^2.وكان أعلى مستوى لكثافة القدرة تم قياسها على الإِطلاق من جميع المصادر هو 2.66 ميكرو واط/سم^2 وكان ذلك في وسط مدينة رام الله وناتج عن محطات البث الإذاعي (FM). وتشكل هذه القيمة ما نسبته 0.6% من الحد الأعلى المسموح به للجمهور حسب توصيات اللجنة الدولية للوقاية من الإشعاعات الغير مؤينة.

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Definitions and Abbreviations

Antenna Gain: The increase in power transmitted by a directional antenna when compared to a reference antenna, which is usually an ideal isotropic antenna. Gain is a ratio of the power required at the input of a loss-free reference antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength or the same power density at the same distance. Gain may be expressed in decibels (dB) or as a pure number.

Antenna: A device for radiating radiofrequency energy.

Averaging Time: The appropriate time period over which exposure is averaged for purposes of determining compliance with the exposure limits.

Contact Current: Current flowing between an energized, isolated, conductive (metal) object and ground through an electrical circuit representing the equivalent impedance of the human body.

Decibel (dB): Ten times the logarithm to the base ten of the ratio of two power levels …. $dB=10 \log_{10} P_1/P_2$).

EIRP (Effective Isotropically Radiated Power): This term applies to directional antennas. The power that would have to be transmitted by an isotropic antenna to produce the same power density at any given point along the directional antenna's axis. EIRP is the gain of a transmitting antenna multiplied by the net power delivered to the antenna from the connected transmitter.

Electric Field Strength: The force (E) on a stationary unit positive charge at a point in an electric field, measured in volt per meter (V/m).

Electric Field: The region surrounding an electric charge, in which the magnitude and direction of the force on a hypothetical test charge, is defined at any point.

Electromagnetic Radiation: The propagation of time-varying electric and magnetic fields through space at the velocity of light. For the purposes of this document, the frequency range of interest lies between 0 Hz and 300 GHz.

ELF (Extremely Low Frequency): Frequency below 300 Hz.

EMF: Electric, magnetic and electromagnetic fields.

Employer: Any person, firm, organization, or other legal entity having the overall responsibility for any work carried out in connection with the utilization of a source of electromagnetic radiation, such as a RF device.

ERP (Effective Radiated Power): The product of the power supplied to an antenna and its gain relative to a half wave dipole in a given direction.

Exposure: Exposure occurs when a person is subjected to electric, magnetic or electromagnetic fields, or contact or induced currents other than those originating from physiological processes in the body and other natural phenomena.

Far-Field Region: The space beyond an imaginary boundary, extending to infinity, around an antenna marking the beginning where the angular field distribution is essentially independent of the distance from the antenna. In this region the field has a predominantly plane wave character.

Field Strength: The magnitude of the electric or magnetic field, normally a root-mean-square (rms) value.

Frequency: The number of sinusoidal cycles made by electromagnetic waves in one second, expressed in terms of Hertz (Hz). 1 kHz = 1000 Hz, 1 MHz = 1000 kHz, 1 GHz = 1000 MHz

General Public Exposure: All exposure to EMF experienced by members of the general public excluding occupational exposure and exposure during medical procedures.

General Public: All persons other than those designated as RF workers.

ICNIRP: International Commission on Non-Ionizing Radiation Protection.

Induced Current: Current induced in a human body exposed to electromagnetic fields.

Isotropic Antenna: An antenna capable of radiating or receiving equally well in all directions, and equally responsive to all polarizations of electric and/or magnetic fields. In the case of transmitting coherent electromagnetic waves, an isotropic antenna does not exist physically, but represents a convenient reference antenna for expressing directional properties of an actual transmitting antenna.

Isotropic: Having the same properties in all directions.

JMPBSs: Jawwal Mobile Phone Base Stations.

Leakage Radiation: Any unintended or accidental radiation emitted by a RF device outside its external surface.

Magnetic Field Strength: An axial vector quantity (H) which specifies a magnetic field at any point in space, and is expressed in ampere per meter (A/m).

Magnetic Field: A region of space surrounding a moving charge (e.g. in a conductor) being defined at any point by the force that would be experienced by another hypothetical moving charge.

Magnetic Flux Density: A vector field quantity (B) that results in a force that acts on a moving charge or charges, and is expressed in tesla (T). The magnetic field strength and the magnetic flux density are related by a constant of proportionality called the *magnetic permeability* of value $4\pi \times 10^{-7}$, such that $\mathbf{B} = 4\pi \times 10^{-7}\, \mathbf{H}$. A magnetic field strength of 1 A/m is equivalent to a magnetic flux density of 1.257 µT. In describing a magnetic field for protection purposes, only one of the quantities B or H needs to be specified.

Microwave: For the purposes of this document, this applies to the portion of the electromagnetic spectrum which has a frequency range between 300 MHz and 300 GHz.

Multiple-Transmitter Environment: A situation where more than one transmitter contributes a significant exposure to RF radiation at the location being examined, even from RF transmitters not on the same site.

Near-Field Region: A region in the field of an antenna, located near the antenna, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point. The near-field region is further subdivided into the *reactive* near-field region, which is closest to the antenna and contains most or nearly all of the stored energy associated with the field of the antenna, and the *radiating* near-field region. If the antenna has a maximum overall dimension that is not large compared with the wavelength, the radiating near-field region may not exist. For most antennas, the outer boundary of the reactive near-field region is commonly taken to exist at a distance of one-half wavelength from the antenna surface.

Non-thermal Effect: Any effect of electromagnetic energy absorption not associated with or dependent upon the production of heat or a measurable rise in temperature.

Occupational Exposure: The exposure of workers to time varying electric, magnetic and electromagnetic fields as a direct and necessary requirement of their work.

Power Density: The rate of flow of electromagnetic energy per unit surface area, usually expressed in W/m^2 or mW/cm^2 or $\mu W/cm^2$.

Radiating Near-Field: That region of the field, which extends between the reactive near-field region and the far-field region, wherein radiation fields predominate and the angular field distribution is dependent upon distance from the antenna.

Radiofrequency (RF): For the purposes of this document, this applies to the portion of the electromagnetic spectrum, which has a frequency range between 300 Hz and 300 GHz.

Reactive Near-Field: That region of the field immediately surrounding the antenna wherein the reactive field predominates.

RF Device: For the purposes of this document, this includes any fixed machine, equipment or installation, which generates RF energy.

RF Facility: One or more radiofrequency transmitters owned, controlled or maintained by the same operator. In the case where a RF site has multiple RF transmitters, each operator is considered to have a separate facility at that same site.

RF Site: A fixed structure or area where RF facilities are placed.

RF Survey: The process of carrying out measurements using suitable equipment to perform any evaluation of the RF field strengths, induced and contact currents, in any accessible area on and around a RF site.

RF Transmitter: The RF device, which is used to generate and transmit radiofrequency electromagnetic radiation.

RF Worker: An employee who is exposed to RF radiation as a direct and necessary requirement of his/her work.

Scattering: The process that causes waves incident on discontinuities or boundaries of media to be changed in direction, frequency, phase or polarization.

Specific Absorption (SA): The radiofrequency energy absorbed per unit mass of body tissue, expressed in joule per kilogram (J/kg). Specific absorption is the time integral of specific absorption rate.

Specific Absorption Rate (SAR): The rate of radiofrequency energy absorbed per unit mass of body tissue, expressed in units of watts per kilogram (W/kg).

Transmitter Duty Cycle: For the purposes of this document, this is a measure of the temporal transmission characteristic of an intermittently transmitting RF transmitter, e.g. paging or mobile phone base stations) obtained by dividing the average transmission duration by the average period for transmissions. A duty factor of 1.0 corresponds to continuous operation.

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I. ELECTROMAGNETIC FIELD IN THE ENVIRONMENT OF MAN

1.1. Introduction

Electromagnetic fields (EMF) are present everywhere in our environment. Man is constantly exposed to electromagnetic radiation (EMR) which consists of waves of electric and magnetic energy moving together through space.

Radio-frequency radiation (RFR) is one of several types of electromagnetic radiation which is in the part of the spectrum of electromagnetic waves. The term ‘RF’ covering all frequencies used for communications, radar, satellites, etc.

EMR originates from natural sources as well as from man made sources. Examples of natural electromagnetic field (EMF) sources are the discharges in the earth’s atmosphere or in the sun and deep space. On the other hand the AM and FM Radio broadcasting towers, TV broadcasting towers and mobile phone base stations and other such sources as shown in Figure

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1.1 are examples of man-made EMF sources. Man-made sources of electromagnetic fields are found at the relatively long wavelength and low frequency end of the electromagnetic.

Man is mainly exposed to the EMFs radiated by transmitting antennas of AM and FM radio broadcasting in the range of 88 MHz – 108 MHz, TV Broadcasting in the VHF and UHF range and mobile phone base stations, (Karunarathana and Dayawana, 2005).

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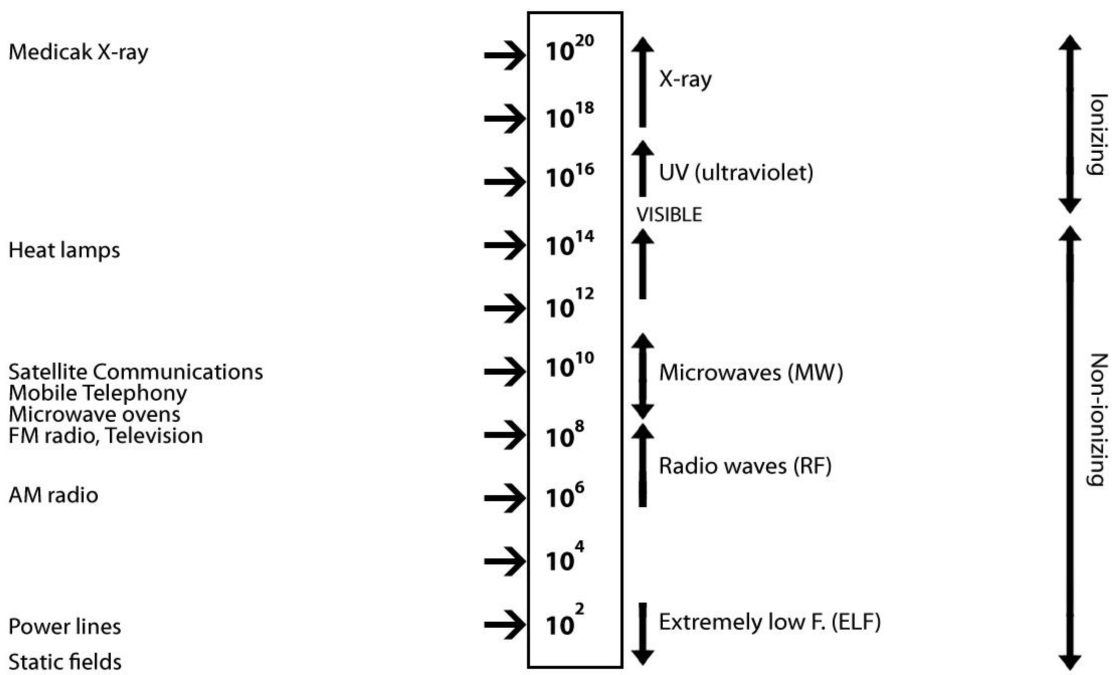

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Figure 1.1: The Electromagnetic Spectrum

This study is concerned with the evaluation of the population exposure from electromagnetic radiation emitted by different electromagnetic radiation sources. Common sources of electromagnetic fields (EMF) include: AM and FM radio, television broadcast, mobile telephones, microwave ovens, radars, microwave communications and other electro medical devices.

Radio and TV terrestrial transmitters provide an Omni-directional coverage area in order to serve the whole population around the site. Usually a restricted zone around transmitting antennae is provided to limit the exposure of the general public to relatively high levels of electromagnetic filed. Measurements can be performed around such sites in order to verify that exposure levels comply with safety standards.

Mobile telephony base stations transmit power levels from a few Watts to 100 Watts or more. Their antennas emit radiofrequency beams that are typically very narrow in the vertical direction, but quite broad in the horizontal direction. Because of the narrow vertical spread of the beam, the RF power intensity at the ground directly below antenna is low. The field intensity increases slightly as one moves away from the base station and then decreases at greater distances from the antenna.

In many countries, over the half population already use mobile phones and the market is still growing rapidly. In some parts of the world, they are the most reliable or only phones available. In this year there are about 2 billion mobile phone subscribers worldwide. This increased used of mobile phones has led to an increased deployment of base stations and antennae. As a reaction to this development, public debates and in several situations concerns about the possibility of adverse health effects due to exposure to EMF have also increased.

In Palestine there are about one million of mobile telephone subscribers. The Palestine Cellular Communications Ltd (Jawwal) covers about 50% of the Palestinian cellular market. This company operates about 650 base stations distributed over the West Bank and Gaza Strip. Other base stations in the country are operated by Israeli operators and are located in areas that are not accessible for the Palestinians. These base stations also contribute to the total exposure of the Palestinian population from RF fields. Other EMF sources in Palestine include mainly FM radio transmitters and UHF, VHF TV stations.

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Public interest in Palestine in the possible health issues arising from exposure to electromagnetic fields has increased after the spread of mobile phone base station towers over the country. This interest has highlighted the importance of having accessible and easy to understand information on the levels of EMF radiation in their environment. This information should be based on scientific background. It is important also to inform the people about the source – exposure relation and possible health effects resulting from being exposed to this type of non-ionizing radiation.

Studies published in Palestine on this issue are either locally oriented or only based on theoretical estimations of the exposure levels. Also only one source of exposure to RF radiation is considered.

1.2. AM, FM Radio and TV Broadcasting Towers

AM and FM radio, TV, Walkie-talkies and cell phones, all these systems need transmitters from which radio waves are transmitted to the receiving equipment.

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Broadcast towers are used for transmitting a range of services including AM and FM radio and TV will either act as an antenna itself or support one or more antennas on its structure, including microwave dishes. There are two types of broadcast towers.

The first type is used at medium frequency (MF) (approximately 530 kHz to 1600 kHz) amplitude modulated (AM) radio stations. This tower is usually a relatively slim, tall structure of triangular cross-section, as shown in Figure 1.2, (ARPANSA, 2003).

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Figure 1.2: AM radio broadcasting tower

AM broadcasting signals propagate from the transmitter by three mechanisms: ground wave, space wave and sky wave as shown in Figure 1.3.

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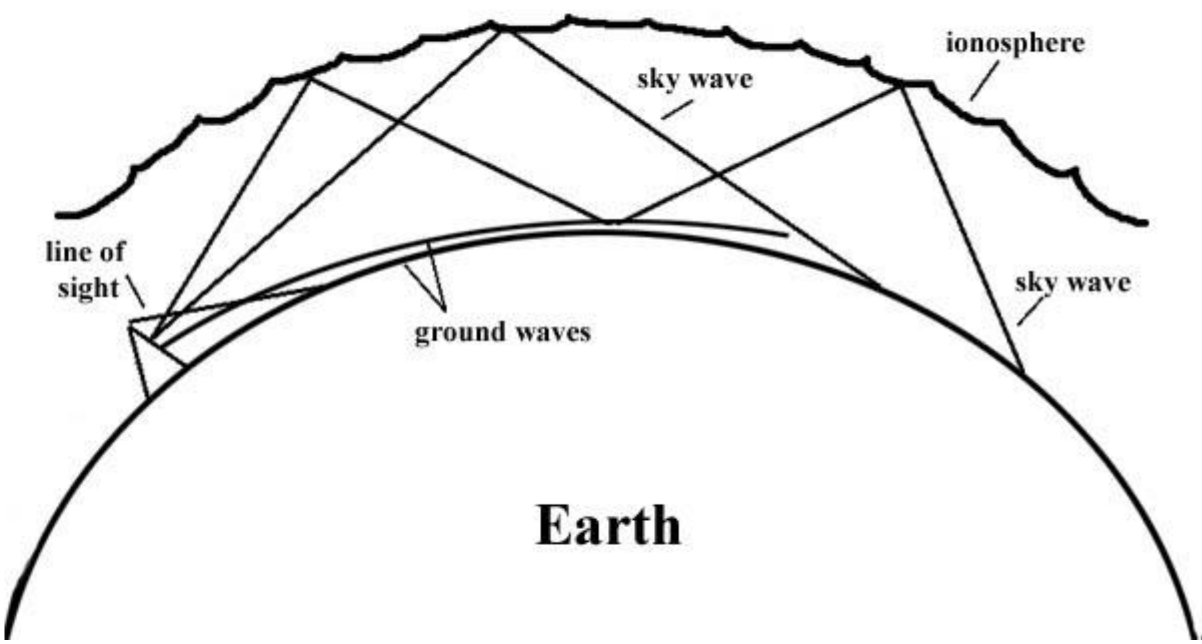

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Figure 1.3: Mechanisms of AM broadcasting signals propagate from the transmitter

The second type is used for FM radio and very-high frequency and ultra-high frequency (VHF/UHF) television transmissions. These towers may be either self-supporting structures with four main vertical members, or a triangular guyed slim structure similar to MF radio towers. At smaller stations, the tower may be a robust concrete pole. The service area of the TV and FM station depend on the propagation of space waves from the transmitter to the receiver as shown in Figure 1.4. FM radio and TV towers are located on the highest point in an area so the transmitted signal has a direct path to receiving antennas. The transmitted antenna pattern is designed so that the radiating beam is projected away from the tower almost horizontally so that as much area as possible is covered. The higher level fields therefore occur at a height which is not accessible to the general public, (ARPANSA, 2003).

The transmitter coverage depends on the antenna height and the Effective Radiated Power (ERP). The FM radio and TV antennas are usually mounted on high towers and transmit relatively high powers. TV transmitter antennas radiate electromagnetic waves up to 2 MW which is extremely high (Çolak and Koçsalay , 2007).

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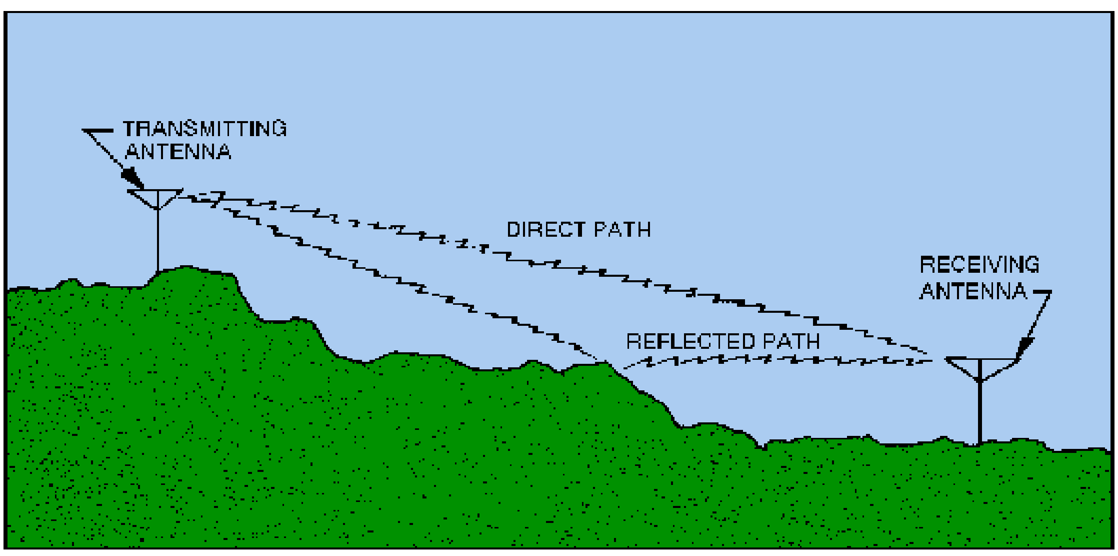

Figure 1.4: Mechanisms of FM radio and TV broadcasting signals propagate from the transmitting antenna to the receiving antenna

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AM and FM radio broadcasting provide the major source of human exposure to RF radiation shown in Figure 1.5, (ARPANSA, 2000). Exposure to RF radiation is not uniform and can vary from place to place.

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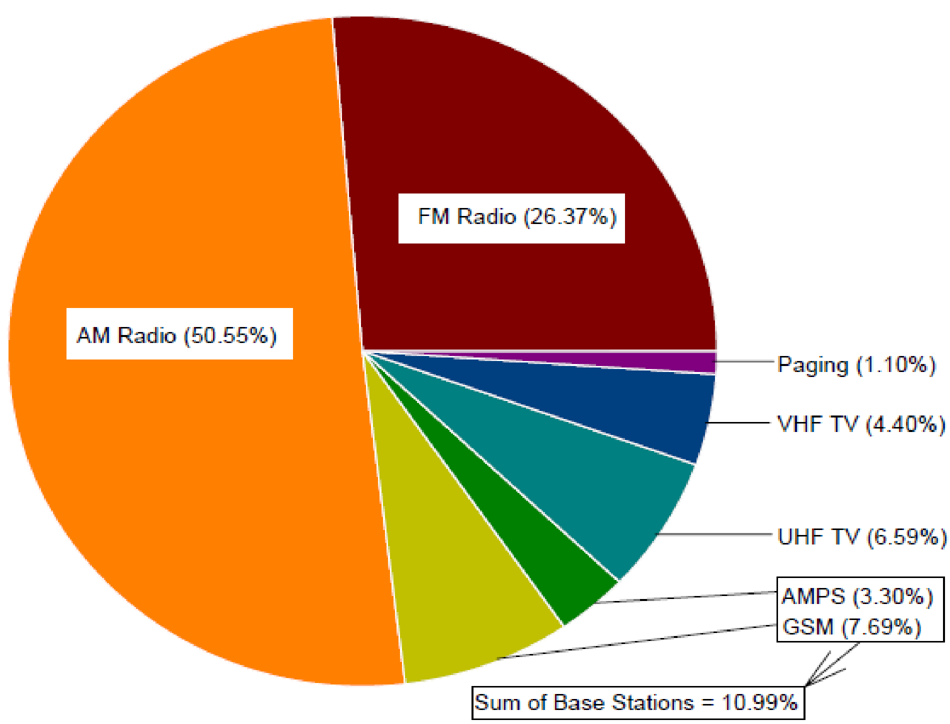

Figure 1.5**:** Ratio of mean environmental radio frequency power flux density levels

1.3. Radio Frequency Radiation From Mobile Phone Base Stations

Mobile phones and there base stations transmit and receive signals using electromagnetic waves. Radiofrequency signals are transmitted from the mobile phone to the nearest mobile base station and received signals are sent from the mobile base station to the mobile phone at a slightly different frequency.

In GSM 900 system there are two frequency bands, 890-915 MHz for the uplink (mobile phone to mobile base station) and 935-960 MHz for the downlink (mobile base station to mobile phone). The downlink of a particular channel is 45 MHz higher than the uplink (duplex operation). The GSM 1800 system uses the frequency bands of 1710-1785 for the uplink and 1805-1880 MHz for the downlink.

Base stations are deployed for two reasons – coverage and capacity. Without coverage, subscribers will not have any service. If there is not enough capacity, then at overcrowded time, users may make several calls before being able to make a call or their incoming calls may not be delivered.

The area around a mobile base station for which the mobile base station provides coverage is known as a cell. In each cell there is a mobile base station used a number of channels to provide coverage and user capacity see Figure 1.6.

Cells vary in size depending on number of mobile phone subscribers and the topography of the surrounding area which are classified as Macrocells, Microcells or Picocells.

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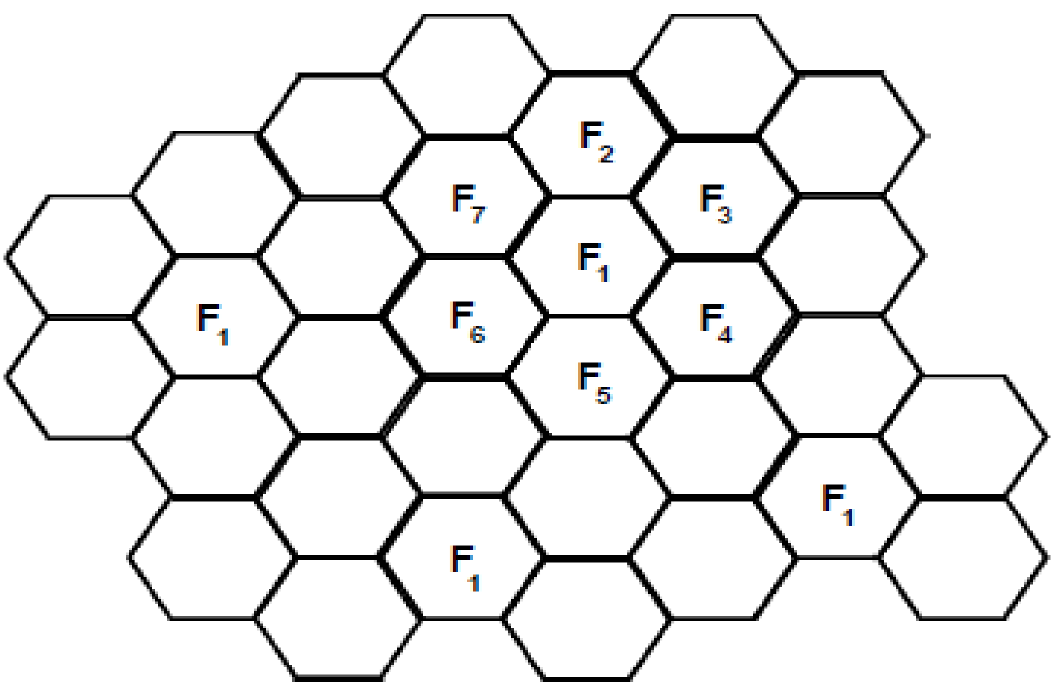

Figure 1.6: Schematic representation of a network's cellular structure. Neighboring cells have different frequencies (F1 through F7)

Macrocells: provide the main coverage in a mobile network with a radius of several hundred metres to ten kilometres. The antennas for macrocells are mounted on ground-based masts, rooftops and other existing structures. They are positioned at a height that is not obstructed by surrounding buildings and terrain. Macrocell base stations have a typical power output of tens of watts, (Cooper et al., 2004).

Microcells: provide infill radio coverage and additional capacity where there are high numbers of users within macrocells. The antennas for microcells are mounted at street level, typically on the external walls of existing structures, lamp posts and other street furniture. The antennas are smaller than macrocell antennas and can often be hidden as building features. Typically, microcells provide radio coverage across smaller distances and are placed 300–1000 m apart. They have lower outputs than macrocells, usually a few watts, (Cooper et al., 2004).

Reducing the cell size reduces the distance between base station and the mobile phone. As telephones are constructed such that they always transmit using the lowest possible power, a smaller cell size will result in the transmitted power and field strength around the phone being lower than within larger cells, (The Hague, 2000).

Picocells: provides more limited to small area coverage than a microcell. They are normally found inside buildings where coverage is poor or where there are a high number of users, such as airport terminals, train stations or shopping centers.

In the present, there is one national mobile technology operator in Palestine: Jawwal (GSM 900 MHz), a new cellular telecommunications company will provide its first services to the public at the begging of this year.

Two types of antenna installed at the local mobile base stations. These are mobile phone sector antennas and microwave dish antennas.

Mobile phone sector antennas produce radiofrequency wave beams that are transmitted into the cell around the mobile base station. These beams are narrow in the plane of elevation and

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are titled slightly downwards so the top edge of the main beam is approximately horizontal and the lower edge is directed 5 to 10° below horizontal. The main beam from the sector antenna would be expected to reach ground level typically between 50 and 300 meters from the mast, see Figure 1.7.

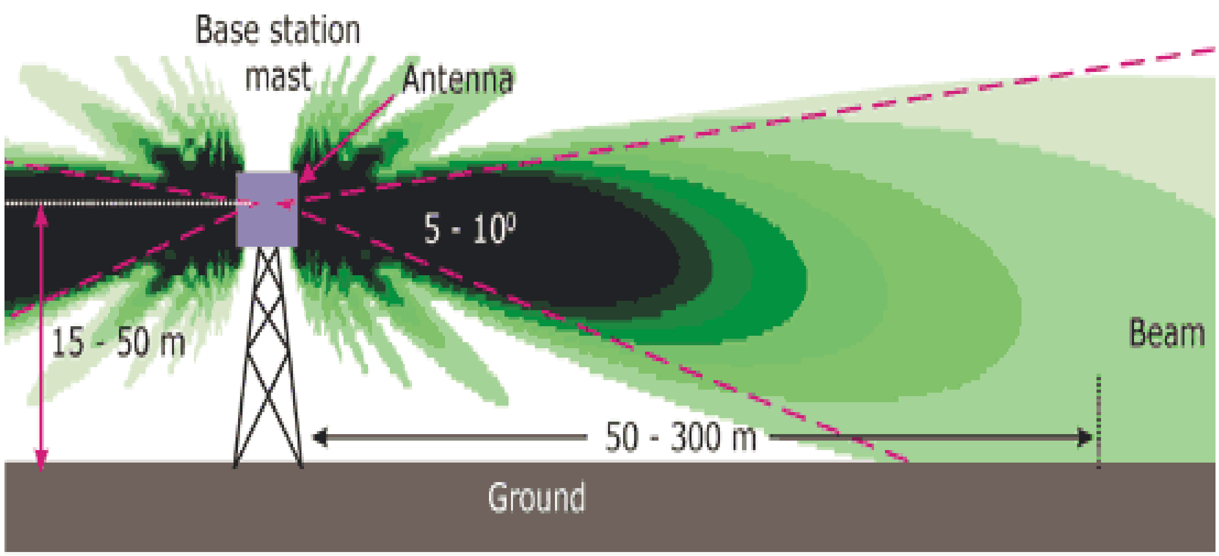

Figure 1.7: Shape of the beam produced by typical mobile phone base station sector antenna

Dish antennas transmit and receive a highly focused radio wave in one direction and are used for point to point communication links. These antennas produce narrow beams that are 1 to 2° wide and allow data to be transmitted between mobile base stations. They are also used for long distance data transmission by these and other operators. The microwave dish antennas are not directed towards the ground, they have a direct line of sight to the receiving antenna at the distant site as shown in Figure 1.8. The exposure levels at the ground level from the radio frequency waves resulting from microwave dish antennas will be negligible in comparison to those from sector antennas, (Fuller et al., 2002).

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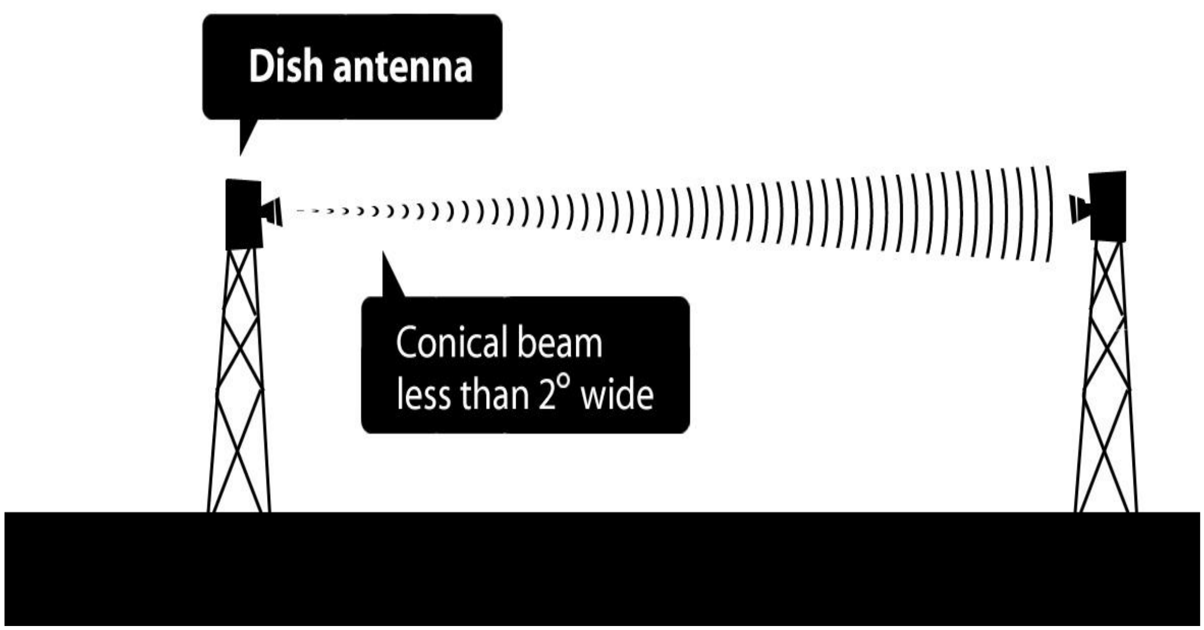

Figure 1.8: Microwave dish antennas used for point to point microwave Link

1.4. Other Sources of Electromagnetic Fields in the Environment

1.4.1. Microwave Ovens

Microwaves are a part of the electromagnetic spectrum and are extremely high frequency radio waves. Microwaves travel in straight lines and may be reflected, transmitted or absorbed by matter in their path. Metallic materials totally reflect microwaves.

The microwave radiations penetrate food and cause water molecules within the food to vibrate at a frequency of the microwaves (2450 MHz). The vibration causes considerable molecular friction which produces heat and results in a rapid rise in temperature. The rate of heating depends on moisture content, shape, volume and mass of food present. This can produce uneven heating with some foods where the outside may be only warm while the inside may be close to boiling. The oven walls and cooking tools are not directly heated by microwaves because they do not absorb microwave energy. However, they frequently get very warm from direct contact with the hot food.

Old or faulty door seals are the most common causes of microwave radiation leakage. Mechanical neglect, a build up of dirt, or simple wear and tear of continued use can cause door seals to be less effective.

1.4.2. Radar

Radars are very complex electromagnetic systems. Radar systems are composed of many different subsystems, which themselves are composed of many different components. There is a great diversity in the design of radar systems based on purpose, but the fundamental operation and main set of subsystems is the same.

There are many varieties of radar equipment in use around the world. Most involve movement of the antenna system, i.e. rotation or movement in azimuth, movement in elevation, etc. Leaving aside HF radar, radar systems are generally characterized by using microwave beams which are usually relatively narrow in azimuth but the characteristic in the elevation plane depends on the nature and function of the radar. The applications include:

1. Defense

2. Air traffic control
3. Meteorology and the study of weather changes
4. Mapping the earth
5. Specialized applications ranging from radars for measuring the state of the sea and sea wave motion, to hand held police radar speed meters for checking motor vehicle speeds.

A more well-known type of surveillance radar is the approach control system for airfield control. This is a radar with a mean power of 550 W and a peak power of 650kW. The frequency coverage is 2.7 to 2.9 GHz. It uses a high efficiency two beam antenna system and transmitters in dual diversity. More usually these systems are tower or roof mounted but this example gives a clearer picture! Surveillance radars of this type rotate continuously. The rectangular antenna on top of the parabolic antenna is an SSR (secondary surveillance radar) for aircraft identification and height data in normal air traffic control.

Aircraft, both civil and military, carry powerful radar equipment. Problems may arise if such equipment are left running on the ground or if ground tests are not conducted under suitably controlled conditions. Similar problems can arise with aircraft communications, navigational and military jamming equipments where control is needed for ground testing and servicing, (Kitchen, 2001).

1.5. Aims and Objectives

The main goal of this thesis (work) is to evaluate the radiation exposure of the Palestinian population from various sources of electromagnetic fields in the Palestinian environment.

Specific objectives:

The present study has the following sub objectives:-

- Performing experimental measurements of radio frequency emissions from mobile phone base stations, FM radio and TV broadcast and evaluate the contribution of these various EMF sources to the total public exposure.

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- Constructing contour maps of radiofrequency levels for regions of interest in Palestinian areas

- Compare the obtained results of radiofrequency emission levels with international safety standards (public exposure limits)

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II. METHODS OF DETERMINING EXPOSURE FROM ELECTROMAGNETIC FIELDS

The physics of electromagnetic emission from an antenna produces different circumstances for measurements depending on the distance r from the source. For practical purposes, this is commonly described as the existence of three zones as shown in Figure 2.1.

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At a sufficient distance from the source, beyond the reactive near field, the electric and magnetic fields oscillate in time phase and in directions that are both mutually orthogonal and orthogonal to the direction of propagation.

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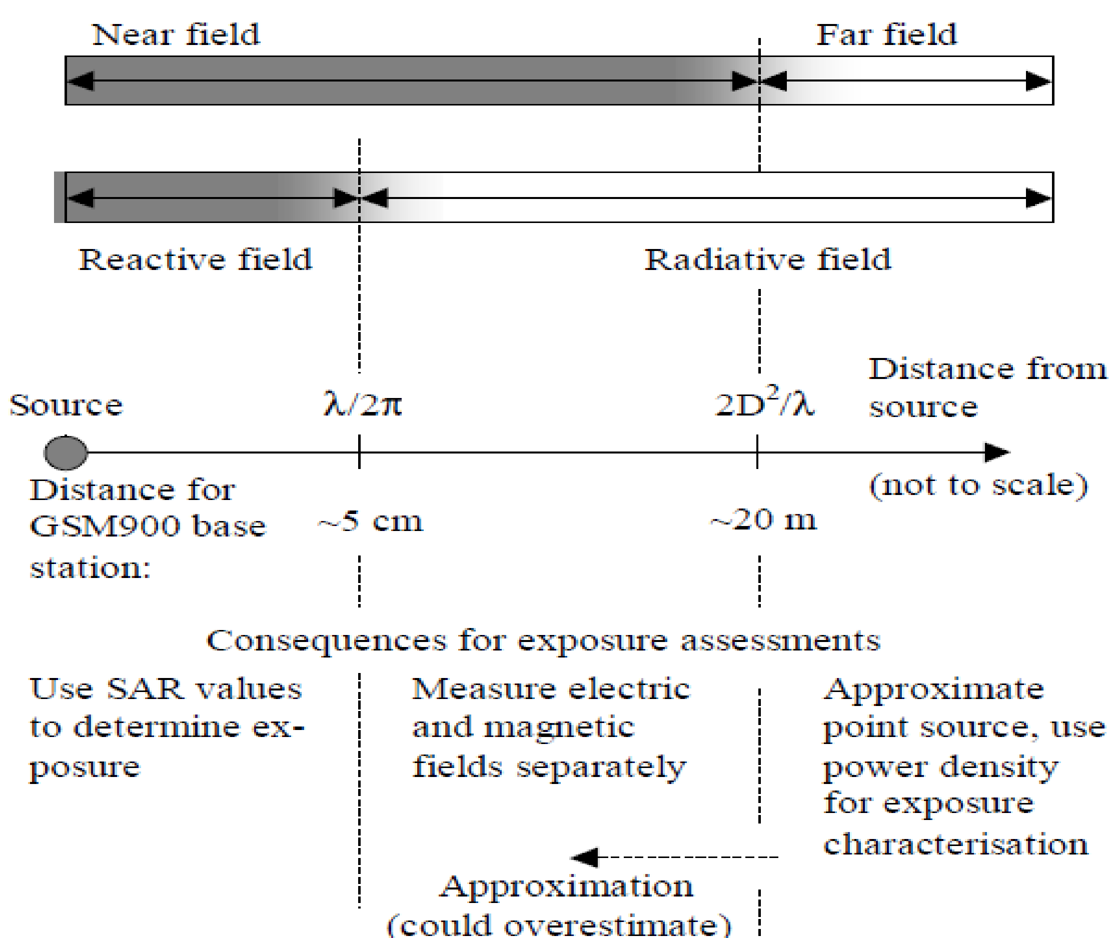

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Figure 2.1: Illustration of three zones: Reactive near field, Radiative near field and Radiative far field. D = largest dimension of source. λ= wavelength (33 cm for 900 MHz). SAR = Specific Absorption Rate

At a sufficiently large distance from the source, in the so-called far-field region, the electric and magnetic field components are closely related, and it is sufficient to evaluate only one of them. This region can be expected at a distance larger than about $\mathbf{2D^2/\lambda}$, where D is the largest dimension of the antenna, and λ is the wavelength.

The electric field intensity, *E*, and power density, *S*, of an electromagnetic field are two quantities whose limiting values are specified by international standards for public safety. If the maximum electric field at a particular location due to all RF sources in the environment can be obtained by measurement, then the power density, of the electromagnetic field at that location can be estimated from equation (1), (Karunarathana and Dayawana, 2005).

$$\mathbf{S = E^2/\eta} \qquad \mathbf{(W\ m^{-2})} \qquad (1)$$

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

In order to assess the human exposure and to compare it to the safety limits, there are two possibilities:

I. Theoretical prediction of power density, computational capabilities in order to simulate the propagation of radiofrequency waves in the space of interest and compute the electric field *E*-field value or the power density *S*-value.

II. Measuring the actual values by using the appropriate system and methodology.

2.1. Theoretical Prediction of Power Density

Many methods have been proposed for the theoretical prediction of the power density of radio waves transmitted by antennas connected with mobile phone base stations as well as all other significant sources such as TV and FM radio. Such methods vary from the simplest form of calculations that assume free space conditions to the sophisticated computer modeling techniques which take into account the three dimensional representations of the environment,(Cichon, 1999).

The propagation models are based on the assumption that exposure occurs in the far region of the RF antenna. As already described above, a location is said to be in the far region of an antenna providing the distance *r* between the location and the antenna satisfies the expression $r \geq 2D^2/\lambda$, (Cooper et al., 2004).

2.1.1. A One-Ray Path Propagation Model

A one-ray path propagation model is the most simply approach to simulate radio wave propagation. It uses only basic free-space propagation attenuation as shown in Figure 2.2. It is due to geometric spherical expansion of waves. (Siwiak, 1995).

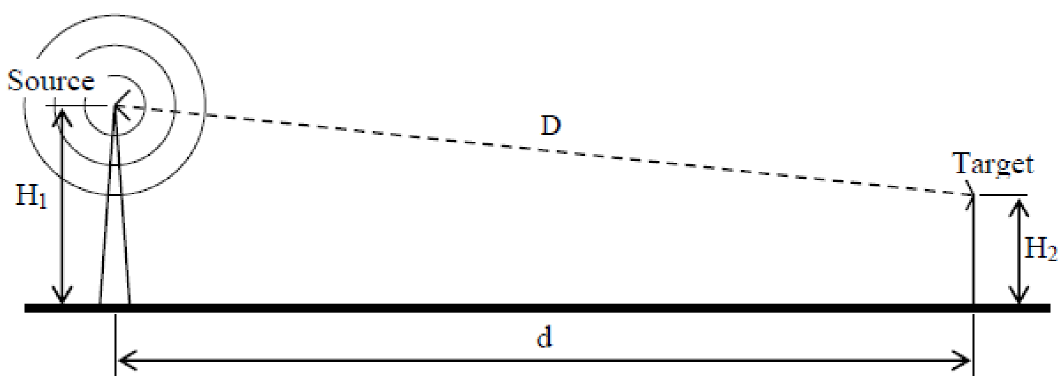

Figure 2.2: One-ray propagation model

The power density *S* of radio waves is decreased with increasing distance following inverse-square law.

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$$\mathbf{S} = \frac{\mathbf{P\,G}}{\mathbf{4\pi\,R}^2} \qquad (2)$$

where:

S = power density (W/m^2)

P = transmitted power (W)

G = linear power gain of the antenna in the direction of interest relative to an isotropic radiator

R = distance to the centre of radiation of the antenna (m)

or:

$$S = \frac{EIRP}{4\pi R^2} \tag{3}$$

where:

EIRP = equivalent isotropic radiated power

These equations are generally accurate in the far-field of an antenna but will over-predict power density when close to the antenna (or in the “near field”). In this case they may still be used for making a "worst case" or conservative prediction, (ACA, 2000).

2.1.2. A Two-Ray Path Propagation Model

The one-ray model omits all reflections on boundaries. In many physical situations the free space path is only one of a number of propagation paths that may exist. The geometry of two –ray propagation model is depicted in Figure 2.3.

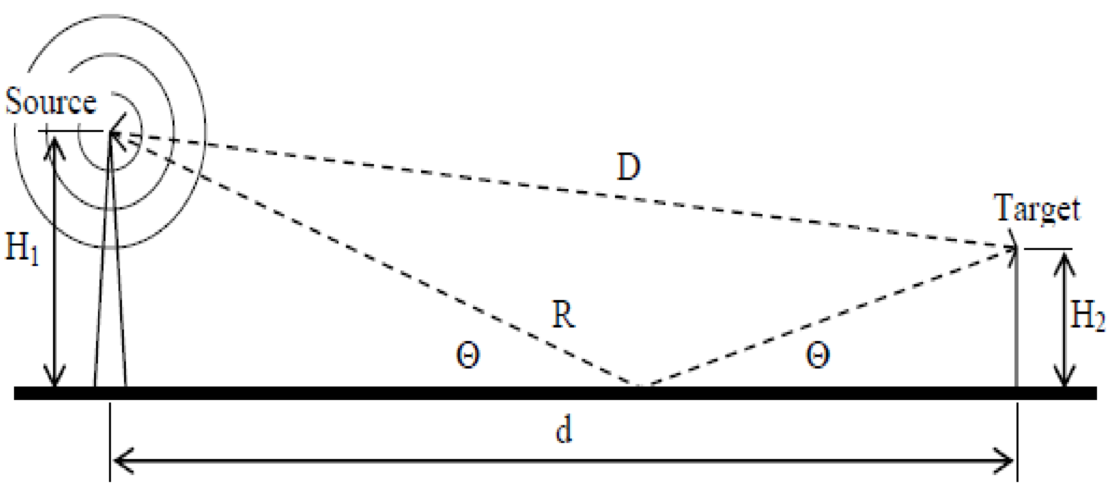

Figure 2.3: Two-ray propagation model

The most important paths are the direct path and the second path that arises from a single reflection from the ground. Reflections may increase or decrease the power density from that calculated by equation (2) if the path length traveled by a reflected wave is comparable with the direct path to the radiated source. This situation could be occurring where a radio frequency wave was reflected from the ground, as shown in Figure 2.3. If the wave Reflections would be expected to increase the electric field strength by a factor of up to two, therefore the total power density would be increased by a factor of up to four (Abualkbash, 2006).

2.2. Experimental Determination of Power Density

Two types of Measurements are used for measuring the exposure to radiofrequency electromagnetic fields:
Broadband and frequency selective measurements.

The main difference between both measurements is that in the first type the total contribution over a large frequency range is obtained without distinction of the contribution of different sources operating at different frequencies, mean while in the second type actually obtains using frequency selective devices because they allow distinguishing between the specific contributions in the different frequency ranges.

Probes and hand-held measuring instruments are used with Broadband measurements, while for frequency selective measurements spectrum analyzers attached to antennas are used. Due to their sensitivity, the broadband devices are often used for compliance assessment. With a typical sensitivity of around 0.2 V/m such measurements can be performed with enough accuracy. Spectrum analyzers can identify signals being at least 8 to 10 orders of magnitude lower as the limits specified in the standards, guidelines or other documents. Spectrum analyzers are well suitable for frequency selective measurements, (Neubauer et al., 2005).

2.2.1. Broadband Measurements

For broadband measurements a probe, usually isotropic, and a field meter are used. Probes can be distinguished whether they are only able to measure the fields in one direction or they are isotropic and measure the field components in the three orthogonal directions in space and calculate the magnitude of the resultant field strength, and as a consequence the assessment procedures can be obtained.

Obtaining a result is not complex, precise and fast. Nevertheless, nominal qualifications are needed to avoid false results. Due to the isotropic characteristic of the field probe, the unknown direction of the maximum field component and the divergence are typically not relevant. In such cases, the reading corresponds to the squared sum of the field components.

The broadband field probe is not designed to distinguish between radio frequency electromagnetic fields sources of different frequencies such as radio and TV broadcast stations, , or a mobile base station. Hence, the field probe does not provide information as to whether the meter reading corresponds to e.g. base station's emissions or to some other signal within the probe's measurement range. In fact, the reading will correspond to the sum of several signals and can be sensitive even to out-of-band signals (Neubauer et al., 2005).

2.2.2. Frequency Selective Measurements

Frequency selective measurements require the following components:

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1. Frequency analyzer or a receiver.
2. Receiver antenna (according to the type of measurements).
3. RF-cable to connect the antenna to the spectrum analyzer.

The antenna receives the energy of the signals at the location of investigation, these signals are feed to the spectrum analyzer through the RF-cable, and the analyzer will display the voltage corresponding to the field strengths in the frequency range chosen (using a filter).

For measures in the surroundings of mobile communications base stations the range must at least cover the frequencies from 900 MHz to 2.3 GHz. The most suitable antennas for this purpose are dipole antennas with low directivity, like biconical antennas. Because the purpose of the measurement is often to obtain the maximum strength of the radio frequency electromagnetic fields, the spectrum analyzer might be set to achieve such a purpose so that every maximum value measured will substitute the value that was formerly saved.

Within this study, broadband and frequency selective measurement data were considered. The frequency ranges covered by the various measurements generally encompassed FM radio, TV broadcast and mobile base stations.

2.2.3. Advantages and Disadvantages of Theoretical and Experimental Methods of Power Density Determination

Both methods have their strength and weaknesses. A measurement can be used determine the effective field strength at a given position with a given moment of time. Measurements are expensive, however, and therefore it is often used for determining the field strength of individual points only. They can hardly resolve the details of the small-scale features which are characteristic of the fields of radio frequency electromagnetic field sources.

Theoretical prediction modeling could in principal be carried out on an arbitrarily fine grid and with arbitrary precision, as the physical laws covering the propagation of electromagnetic waves are well known. In practice, the theoretical model requires an extremely detailed description of the sources and the paths of propagation by reflections, scattering, diffraction and absorption due to the ground, buildings, and vegetation.

Theoretical models for extended regions typically use simplifications in their description of the sources, the propagation paths and the obstacles. The results of the theoretical models can be used for testing against measurements, by this means combining the strengths of both methods.

Measurements can be used to test the strength of the computational models, to asses the magnitude of their errors and to improve the model parameters. On the other hand, a computational model can put a measurement point in relation to its environment and show how representative it is, (Bürgi, et al., 2005).

2.3. Safety Guideline and Exposure Assessment

Countries set their own national standards for exposure to electromagnetic fields. However, the majority of these national standards draw on the guidelines set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The ICNIRP after reviewing the scientific literature, formulated in 1998 guidelines on exposure limits for electromagnetic fields in the frequency range from 0 Hz up to 300 GHz. These guidelines are based on acute health effects such as elevation of tissue temperatures resulting from absorption of energy during exposure to electromagnetic fields between 100 kHz and 300 GHz (ICNIRP, 1998).

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This non-governmental organization, formally recognized by WHO, evaluates scientific results from all over the world.

In Palestine, there is still no specific law for the protection of health from electromagnetic fields issued. Palestine Environmental Quality Authority (EQA) issued instructions for the protection of non ionizing radiation which is based on ICNIRP's recommendation. EQA also controls the compatibility and the levels of emissions from the mobile base stations.

If the experimental values of electric field, E, and power density, S, are less than the safety limits recommended by the accepted international organizations, then it is assumed that there is no health risk. In order to ensure compliance with the Maximum Permissible Exposure (MPE) for the environment, a dimensionless quantity known as the *exposure quotient* is calculated (Cooper et al., 2004). This quantity is expressed in terms of the calculated power density S from measured results of the field strength and the Maximum Permissible Exposure (MPE) in power density. Thus,

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$$\textbf{MPE } \textbf{\textit{exposure quotient}} = \frac{S}{\text{MPE}} \qquad (4)$$

For all the EMF sources such as FM radio, TV and Mobile Base stations, the sum of the ratios of the measured power density to the corresponding MPE of the power density should not exceed unity to ensure safety. That is

$$\sum_{i=1}^{n} \frac{Si}{MPEi} \leq 1 \qquad (5)$$

If this condition is not met, then safety of environment is not guaranteed. It is also the usual practice to estimate how many times the present electromagnetic radiation level (EMR) is below the safe limit. 'Times Below Limits' abbreviated as TBL is easily obtained from equation (6):

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$$\textbf{\textit{TBL for Power Density}} = \frac{\mathbf{1}}{\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}} \frac{\boldsymbol{S\,i}}{\boldsymbol{MPEi}}} \qquad (6)$$

where,

S_i - Power Density at the i_{th} frequency, frequency given in MHz

MPE_i - Reference level of the Power Density at the i_{th} frequency

n - Total number of transmitting signals

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III. METHODOLOGY

3.1. Methods

This study presents field survey measurements data and provides information on the levels of the environmental RF electromagnetic field radiations. These RF radiations are basically emitted from mobile base stations as well as all other significant RF levels such as the FM and

TV broadcasting towers. These RF levels are determined by assessing the electric field and power density in the frequency range from 75 MHz to 3 GHz.

All measurements were conducted by using two RF spectrum analyzers, the BK Precision 2650 spectrum analyzer and the Narda SRM-3000 selective radiation meter. Measurement procedures were as follows:

3.1.1. Measurements of Environmental Radio frequency Electromagnetic Field Levels

Measurements of Environmental RF EMF levels resulting from the mobile telephone base stations as well as all other significant sources such as TV and FM radio were performed according to the following protocol:

- All these measurements were performed in the West Bank and are referred to as the environmental RF EMF levels.
- The measurements were taken at a height of approximately 1.7 m above ground level.

- Measurement antennas were directed in various orientations and locations in order to obtain local maximum signal strength for the Particular frequency band being measured.
- The time taken to record each the measurement is approximately one hour divided over six minute period scanning.
- Measurements were performed for all known sources of electromagnetic fields including FM, TV and MPBS in the frequency range from 75 MHz to 3 GHz.

3.1.2. Measurements of RF EMF Levels Resulting from Mobile Base Stations

Measurements of RF radiation resulting from mobile base stations were performed in different areas and locations. These locations were selected to fulfill the following criteria:

- Population density
- The existence of nearby RF emitters
- Coverage of the whole West Bank area

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The measurements were conducted under real-life conditions and only downlink frequencies of the GSM cellular base stations were considered. For each narrow band region of interest GSM 900 MHz data collection was conducted for 6 × 1 min. scanning time. The power density levels are expressed in $\mu W/cm^2$ and the electric field levels are given in V/m.

3.1.3. Measurements of Mobile Base Station Activity

The intent of these measurements is to determine the RF EMF level resulting from all mobile telephone services. 24 hours measurements for GSM base station were performed at a fixed location close to the base station by the analyzer continuously scanning the signal data across the mobile telephone frequency band comes from single sector. The number of scans is dependent on the number of signals present in the band. The recorded data were used to determine the sequential activity for the GSM system over 24 hour period. GSM system has a minimum eight time slots and a maximum of thirty two time slots for any given sector, the activity level of the data samples was determined by counting the number of active time slots using over one hour period.

3.2. Instrumentation

Measurements of radiofrequency levels are made by using the following equipments:-

3.2.1. The BK 2650 Handheld Spectrum Analyzer.

This equipment functions as a sophisticated radio receiver, which allows each received radio signal to be analyzed, allowing the accurate measurement of magnitude and frequency. It is a compact and lightweight.
Here are the antennas which were used with the BK 2650:

- AN301 BK Precision AN 301 Dipole Antenna (0.8 to 1GHz)
- AN302 BK Precision AN 302 Dipole Antenna (1.25 to 1.65GHz)
- AN303 BK Precision AN 303 Dipole Antenna (1.7 to 2.2GHz)
- AN304 BK Precision AN 304 Dipole Antenna (2.25 to 2.65GHz)
- AN305 BK Precision AN 305 Dipole Antenna (390 to 410MHz)

AK2650 PC Interface Software:

The AK 2650 software and serial interface cable allows the 2650 to display screen resolutions on a PC that are four times greater then the 250 points displayed on the horizontal axis of the 2650's LCD display. The BK 2650 samples its input at 1000 points per sweep and it can output these points through its RS 232 port to a PC (the maximum transfer rate is 38,400bps). The AK 2650 allows spectrum analyzer setup via a PC.

3.2.2. Narda's Selective Radiation Meter SRM-3000.

The SRM-3000 is an instrument designed to measure electromagnetic fields in the frequency range from 100 kHz to 3 GHz. The SRM-3000 is a system designed to measure the individual contributions of multiple emitters and to generate a tabular or spectrum view of the total exposure over the 100 kHz to 3 GHz frequency range**.**

The SRM has several operating modes which are designed to give immediate on-site results that require no further processing or evaluation. These modes are described bellow:

- "Safety Evaluation" mode, in this mode a list of frequency ranges within which the field strength can be measured. The results in each frequency range of the so-called Service Table defined in this way are displayed in units of field strength or as a percentage of a selected safety standard. The displayed value 100% indicates that the limit value defined in the standard has been reached.

- "Spectrum Analysis" mode, all the field components in the selected environment can be detected to give an overview of the spectrum or for determining maximum values. Here too, the extended functions of the instrument allow evaluation of the measured values directly on site.

- "Time Analysis" mode, the SRM makes selective, continuous measurements at a fixed, user-defined frequency. This allows detection of even short duration spikes, e.g. from pulsed radar equipment. The operating mode is ideal for timer-controlled measurements.

The antenna used connected to the SRM-3000:

Isotropic Antenna: a three axis antenna is included as standard with SRM-3000. This antenna covers the frequency range from 75 MHz to 3 GHz. It covers the frequency range of main interest from FM radio to 3rd generation mobile radio systems. It automatically determines the three spatial components of the field being measured. It is mainly designed for outdoor application and for performing measurements in areas that are difficult in terms of accessibility. It covers the frequency range of main interest from FM radio to 3rd generation mobile radio systems. The SRM evaluates the field strengths it measures in accordance with the applicable regulations, and delivers results as a field strength level or as a percent of the legal limit.

3.2.3. RF-Map Program Overview

The RF-Map program is a software tool The RF-Map software tool calculates the EME levels from multiple transmitter sites in a matter of seconds. The levels can be represented graphically to show the variation in EME emissions around a base station and the margin by which these emissions comply with the safety standard. for the assessment of cumulative environmental electromagnetic emission (EME) levels around single or multiple radio communications transmitter sites. This includes cellular mobile telephone base stations. The program gives users a significant competitive edge through time saving in calculating the EME levels. The program is ideal for network operators, EME assessment contractors, and authorities managing environmental emission levels. It allows a pre-cautionary approach to be used in RF site development and operation. The RF-Map survey area consists of a grid comprising more than 22,000 calculation points for each antenna system selected in the fine resolution mode. RF-Map itself has no limit to the number of transmitter sites and antenna systems that can be modeled, provided the antenna data is available. The advanced map-imaging feature allows real-time assessments to be overlaid on drawings or street maps.

3.3. Collection of Data about the Sources of EMF in Palestinian Areas

Prior of surveying measurements, a collection of data has been performed to compile a detailed database of all EMF sources in the West Bank area. This involves a collection of all relevant information on the EMF sources which includes location, site characteristics and transmitter technical parameters. All these information are provided by the Ministry of Telecommunications and in case of mobile stations by the Palestine Cellular Communications Ltd Ltd. (*JAWWAL*). This database includes information about 550 mobile base stations, 37

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TV broadcasting stations and 56 FM radio stations. This data includes source address /coordinates, transmitter output power, frequencies, and antennas gain and pattern.

Figure 3.1. shows a map of the West Bank area and provides information about all these sources which were constructed. This map is mainly identifying the locations of base station towers, FM radio transmitters and TV signals transmitting towers. Areas of interest were selected for detailed EMF levels measurements and analysis of exposure.

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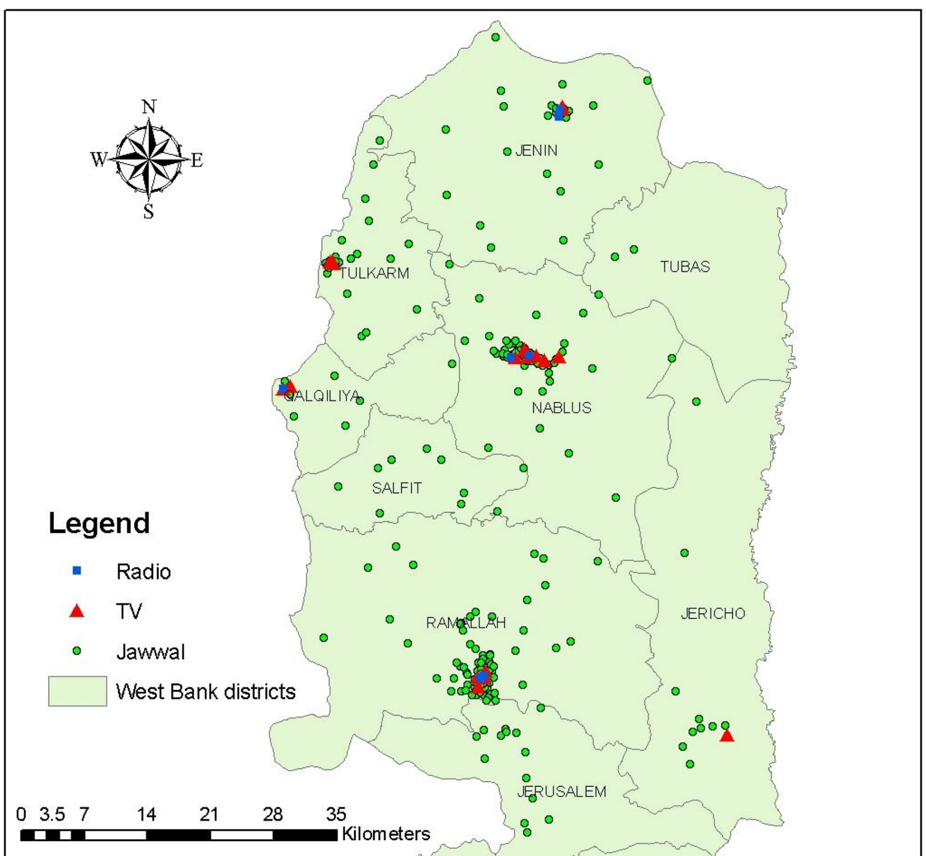

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Figure 3.1: Locations of radio frequency electromagnetic field sources in the West Bank

IV. RESULTS AND DISCUSSION

4.1. Measurements of Environmental Radio Frequency Electromagnetic Field Levels

This chapter describes the surveyed locations in the West Bank area where measurements were made and presents the environmental radio frequency EMF levels. The power densities of all radio signals were detected within the frequency range from 75 MHz to 3GHz.The measured data were also analyzed in order to determine which of the local EMF sources were the dominant contributors to people's total exposure.

4.1.1. RF Radiation in Bethlehem Area

Bethlehem area has 4 TV stations, 3 FM radio stations and approximately 23 mobile phone base stations. The measurements were performed at 18 separate locations in Bethlehem area according to the population density. Most of measurements took place in urban and extra-urban locations which were taken at a height of approximately 1.7 m above ground level as well as the measurement antennas were directed in various orientations and locations in order to obtain the maximum strength of the measured signal.

Figure 4.1 shows a typical high frequency spectrum analysis overview in the frequency range 0.075-3GHz detected at Bethlehem Hotel in Bethlehem city. The spectrum includes four main RF sources (FM, TV, GSM 900 MHz and GSM 1800 MHz).

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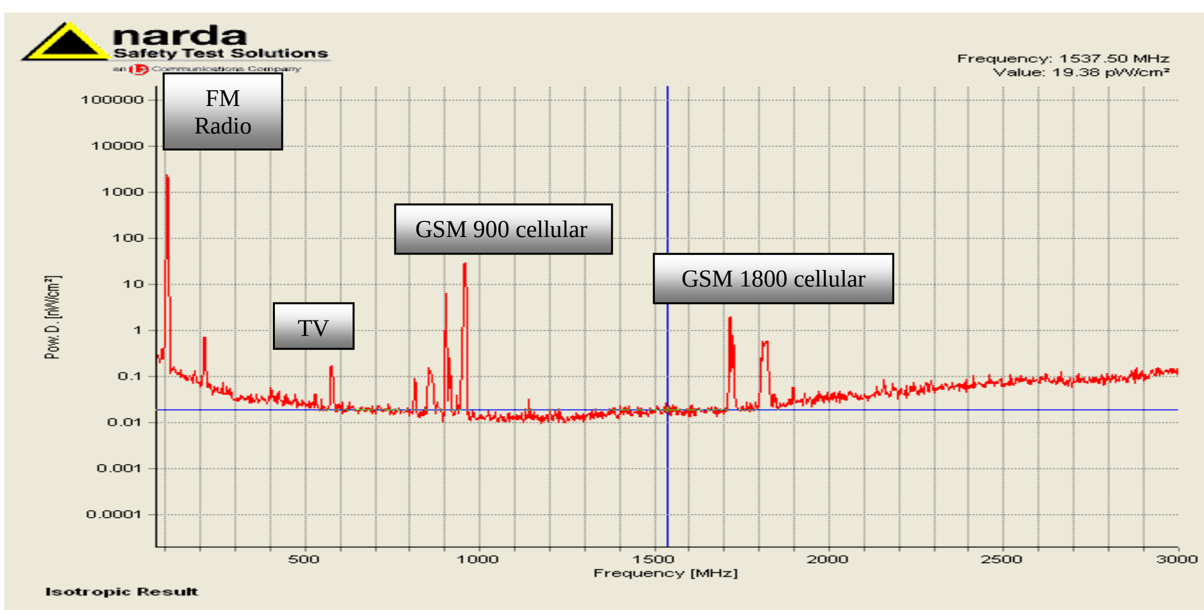

Figure 4.1: Radio frequency spectrum, in the range from 75 MHz to 3GHz detected at Bethlehem Hotel in Bethlehem city

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Table 4.1 lists the Results of radiofrequency radiation from FM radio, TV Broadcasting and MPBS emissions. Six locations were taken at Al- Khader town, two locations at Al- Doha city, three locations at Beit Jala city, one location at Beit Sahour city and eight locations in Bethlehem city.

Figures 4.2.a,b,c present the Radio Frequency Electromagnetic Field power density levels for FM, TV as well as MPBS respectively at 18 locations in Bethlehem area.

The maximum RF EMF power density levels were found at Location 12 in Table 4.1 Bethlehem Hotel for FM radio (0.66 $\mu W/cm^2$) is close to Radio Mawwal station. This value is about 303 times below the limit recommended by ICNIRP for the general public (200 $\mu W/cm^2$).

Most of the TV Broadcasting Towers in Bethlehem area are at the top of Beit Jala city. Locations 7, 8,9,10 and 11 in Table 4.1 were chosen to be measured in the vicinity of TV Broadcasting Towers. The maximum RF EMF power density levels were measured in location 9 in Table 4.1 Beit Jala – Love Bird (0.0106 $\mu W/cm^2$) and it is the nearest accessible point to the TV Broadcasting towers at the top of Beit Jala city. This value (i.e. 0.0106 $\mu W/cm^2$) is

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about 42,452 times below the limit of ICNIRP recommended for the general public (450 μW/cm²).

For mobile phone base stations, the maximum RF EMF power density levels were measured in Al-Khader center, a location near the two Jawwal mobile phone base stations, which is represented in location 3 in Table 4.1 (0.2939 μW/cm²). This value is about 1531 times below the limit of ICNIRP recommended for the general public (450 μW/cm²).

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No.	City	Location	FM (µW/cm²)	TV (µW/cm²)	Mobile (µW/cm²)	Total (µW/cm²)
1	AL-KHADER	Al-Nashash	0.0002	0.0007	0.0038	0.0047
2		Al-Khader Stadium	0.0002	0.0021	0.0165	0.0189
3		Al-Khader Centre	0.0004	0.0019	0.2939	0.2962
4		Al-Khader 60'' st.	0.0004	0.0013	0.0151	0.0168
5		Al-Khader's Gate	0.0003	0.0007	0.0470	0.0479
6		Al-Khader, near Arab Bank	0.0003	0.0007	0.0010	0.0019
7	AL -	Al-Jerashi Co.	0.0018	0.0033	0.0126	0.0178

8		Industrial area	0.0008	0.0038	0.0002	0.0048
9	BEIT JALA	Love Bird Restaurant	0.0211	0.0106	0.0132	0.0449
10		Diegole pool	0.0024	0.0018	0.0025	0.0067
11		Maya Supermarket	0.0023	0.0015	0.0046	0.0084
12	BETHLEHEM	Bethlehem Hotel	0.6593	0.0013	0.0272	0.6878
13		Nativity Church	0.0010	0.0008	0.0400	0.0417
14		Cinema Square	0.0296	0.0008	0.0032	0.0335
15		Al-Madbasah	0.1642	0.0007	0.0268	0.1917
16		Al-phoenix Org.	0.0011	0.0014	0.0020	0.0045
17		Al - Jabal St’	0.0020	0.0013	0.0028	0.0061

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18	BEIT SAHOUR	Al-Sha'b Market	0.0004	0.0008	0.0008	0.0020
19		**Average**	**0.05**	**0.002**	**0.03**	**0.08**

Table 4.1: FM, TV and mobile phone base stations power density levels measured at eighteen locations in Bethlehem area

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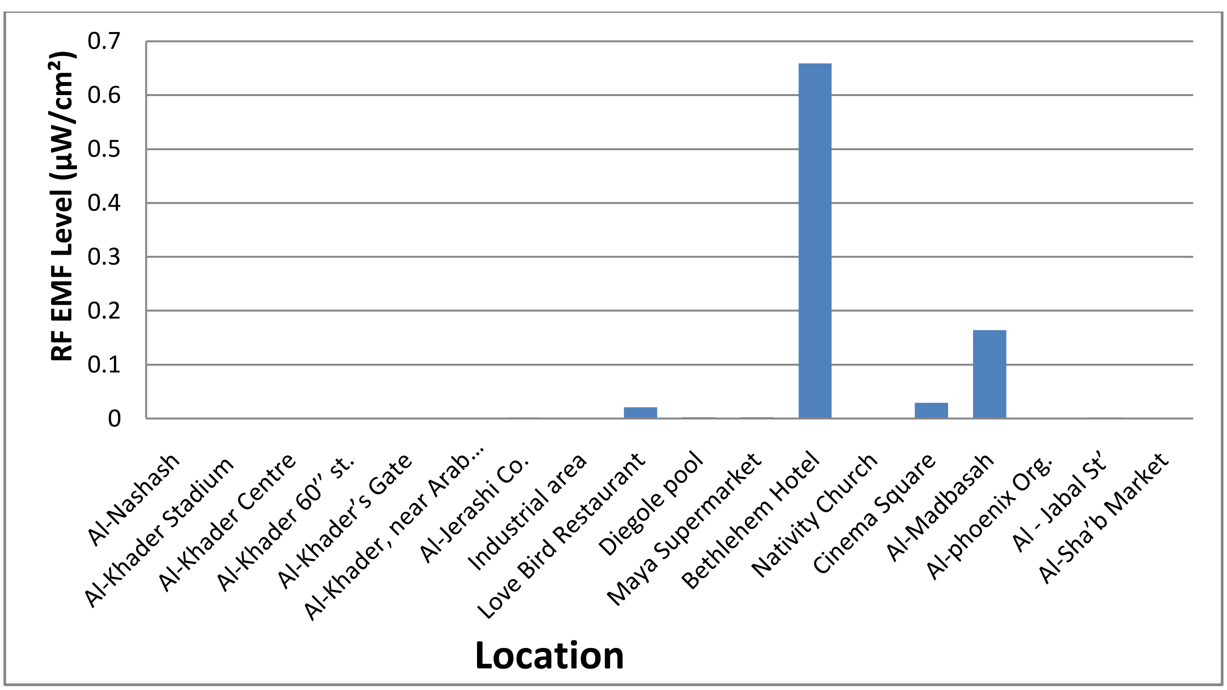

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Figure 4.2.a: Radio frequency power density levels for FM radio stations measured at eighteen locations in Bethlehem area

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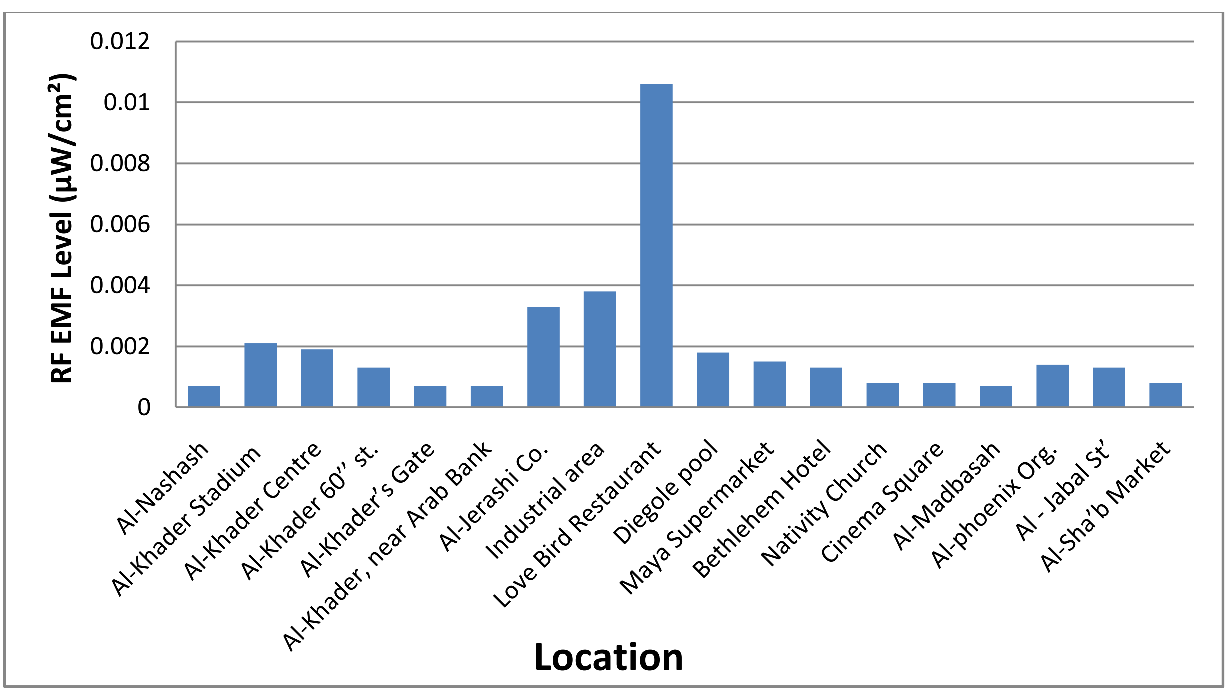

Figure 4.2.b: Radio frequency power density levels for TV broadcasting towers measured at eighteen locations in Bethlehem area

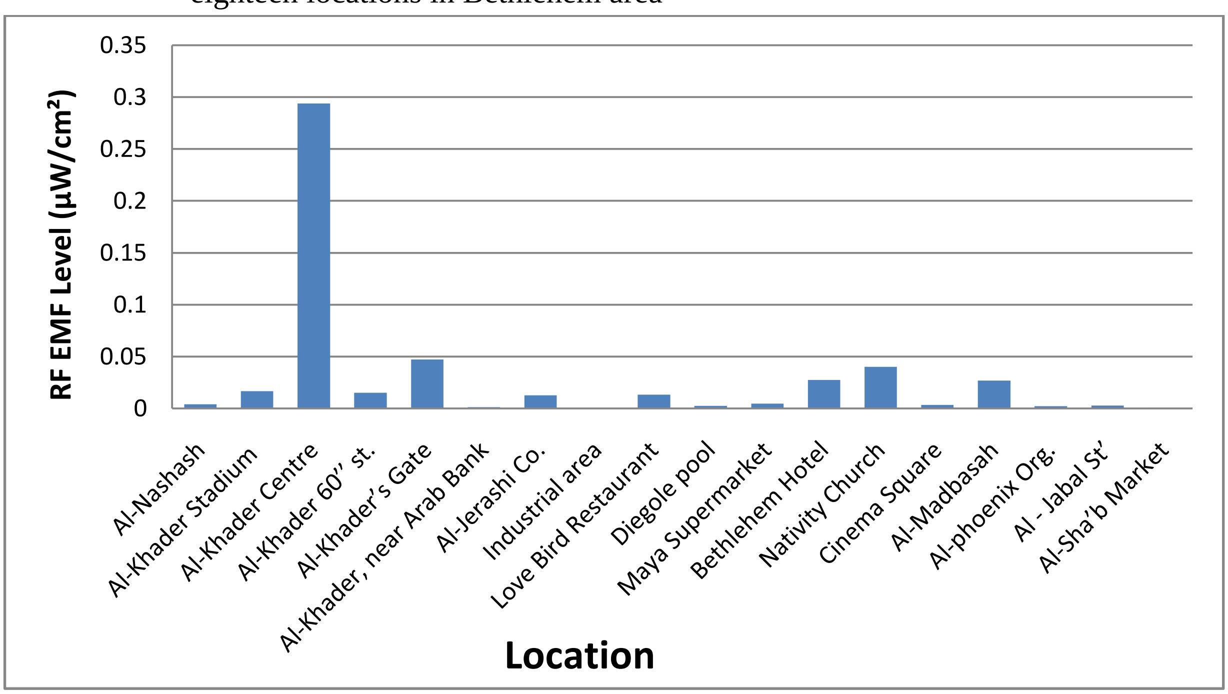

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Figure 4.2.c: Radio frequency power density levels for mobile phone base stations measured at eighteen locations in Bethlehem area

Figure 4.3 illustrates the relative contributions of various RF sources in the total EMF exposure received by the population at 18 locations in Bethlehem area. FM radio signals contribute by the largest amount of electromagnetic radiation in the total exposure

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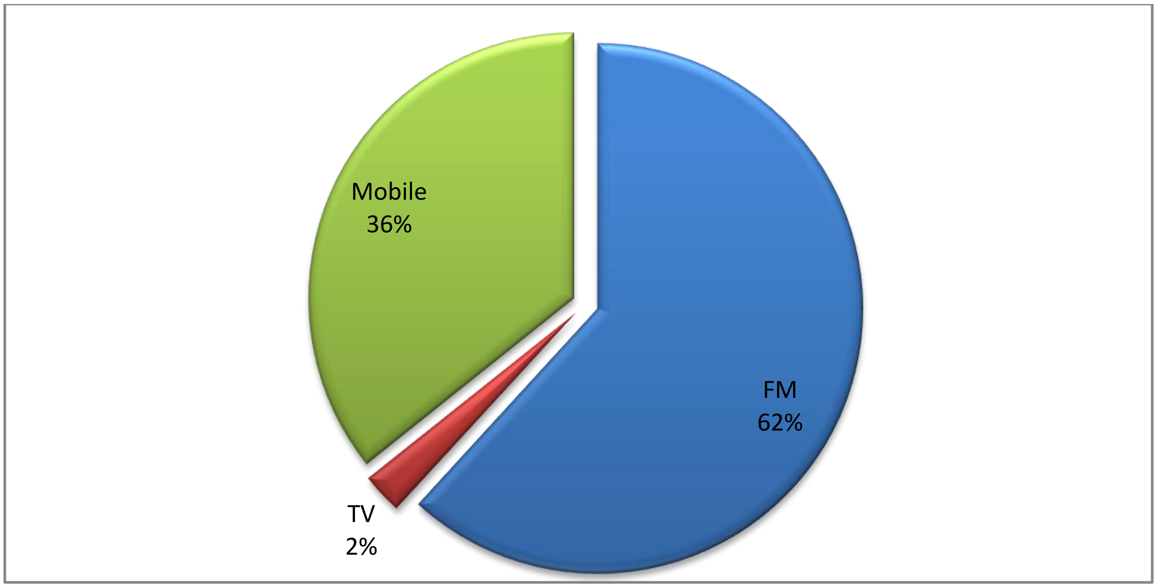

Figure 4.3: Relative contributions to the total exposure from various radio frequency radiation sources evaluated at eighteen locations in Bethlehem area

4.1.2. RF Radiation in Hebron Area

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The measurements were performed at six separate locations in Hebron area according to the population density. Most of the measurements were taken in urban and extra-urban locations at a height of approximately 1.7 m above ground level. The measurement antennas were directed in various orientations and locations in order to obtain the maximum strength of the measured signal. These locations are:

Location 1	Halhul City – Jawwal Exhibition
Location 2	Halhul Municipality
Location 3	Halhul – Hebron St'
Location 4	Hebron City – Ras Al-Joura
Location 5	Hebron City – Dowwar Al-Seha
Location 6	Hebron Municipality

Measurements at Location 1 were made in Halhul city close to Jawwal Exhibition. This position has a clear line of sight with FM Radio Towers. At Location 2, the measurements were taken in the vicinity of Halhul Municipality. There was a clear line of sight with Jawwal MPBS and FM Radio Towers from this position. Location 3 was at Halhul – Hebron St., this place has a good line of sight with FM Radio Towers. Measurements at Location 4 were taken at Ras Al – Joura in the entrance of Hebron city. There was a clear line of sight with Jawwal MPBS and FM Radio Towers from this position. At location 5, Hebron city – Dowwar Al – Seha, there was no direct line of sight with any of the local transmitters from this position. Location 6 was in the vicinity of Hebron Municipality and the measurements were taken nearby Jawwal MPBS.

Table 4.2 lists the results of radiofrequency radiation from FM radio, TV Broadcasting and MPBS emissions. The measurements were performed at three locations in Halhul city and Hebron city.

The maximum value of the RF EMF power density levels measured in Halhul city was at location 3 from FM Radio (0.344 $\mu W/cm^2$) , this value is about 581 times below the limit of ICNIRP recommended for the general public (200 $\mu W/cm^2$). The maximum value of the RF EMF power density levels measured in Hebron city was at location 6 from MPBS (0.516

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μW/cm²). This value is about 872 times below the limit of ICNIRP recommended for the general public (450 μW/cm²).

Figures 4.4.a,b,c present the radio frequency electromagnetic field power density levels for FM, TV and MPBS respectively at 6 locations in Hebron area.

No.	City	Location	FM (μW/cm²)	TV (μW/cm²)	Mobile (μW/cm²)	Total (μW/cm²)
1	Halhul city	Jawwal Exhibition.	0.172	0.005	0.024	0.201
2		Halhul Municipality	0.152	0.009	0.117	0.278

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3		Halhul - Hebron St'	0.344	0.008	0.011	0.363
4	Hebron city	Ras Al-Joura	0.169	0.004	0.115	0.288
5		Dowar Al-Seha	0.013	0.0007	0.030	0.044
6		Hebron Municipality	0.022	0.0007	0.516	0.5387
7		**Average**	**0.15**	**0.005**	**0.14**	**0.29**

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Table 4.2: FM, TV and mobile phone base stations power density levels in Hebron area

Figure 4.5 illustrates the relative contributions of various RF sources in the total EMF exposure received by the population at six locations in Hebron area. FM radio signals contribute by the largest amount of electromagnetic radiation in the total exposure.

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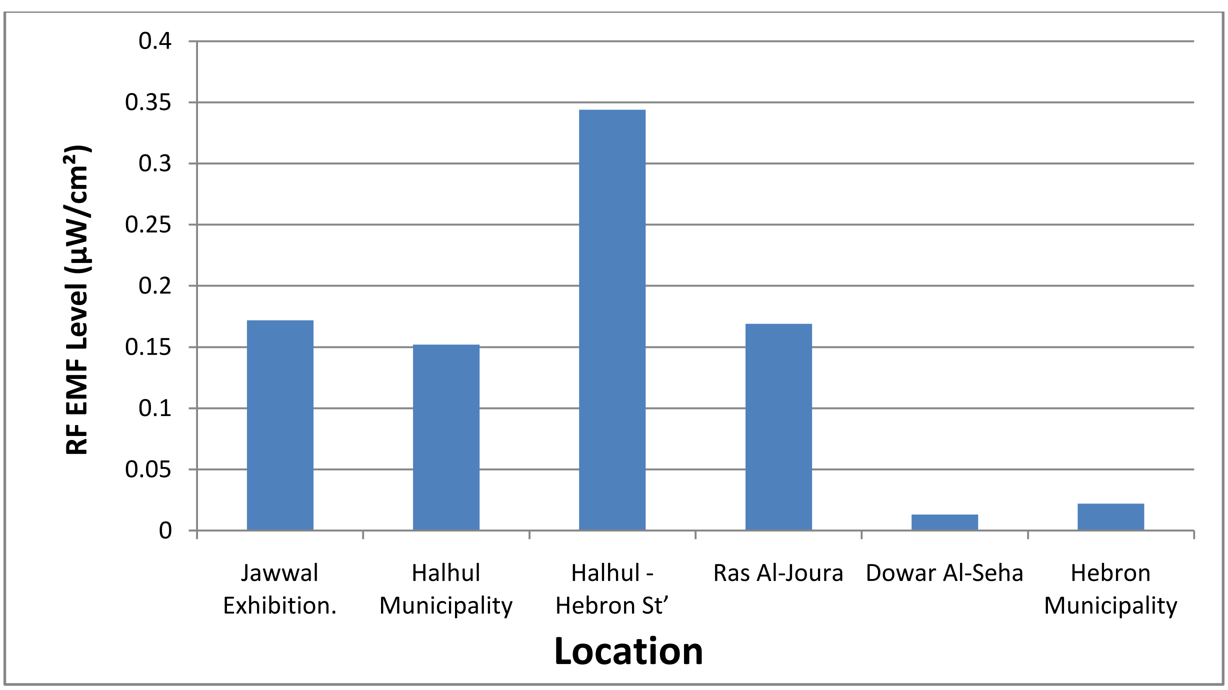

Figure 4.4.a: Radio frequency power density levels for FM radio stations at six locations in Hebron area

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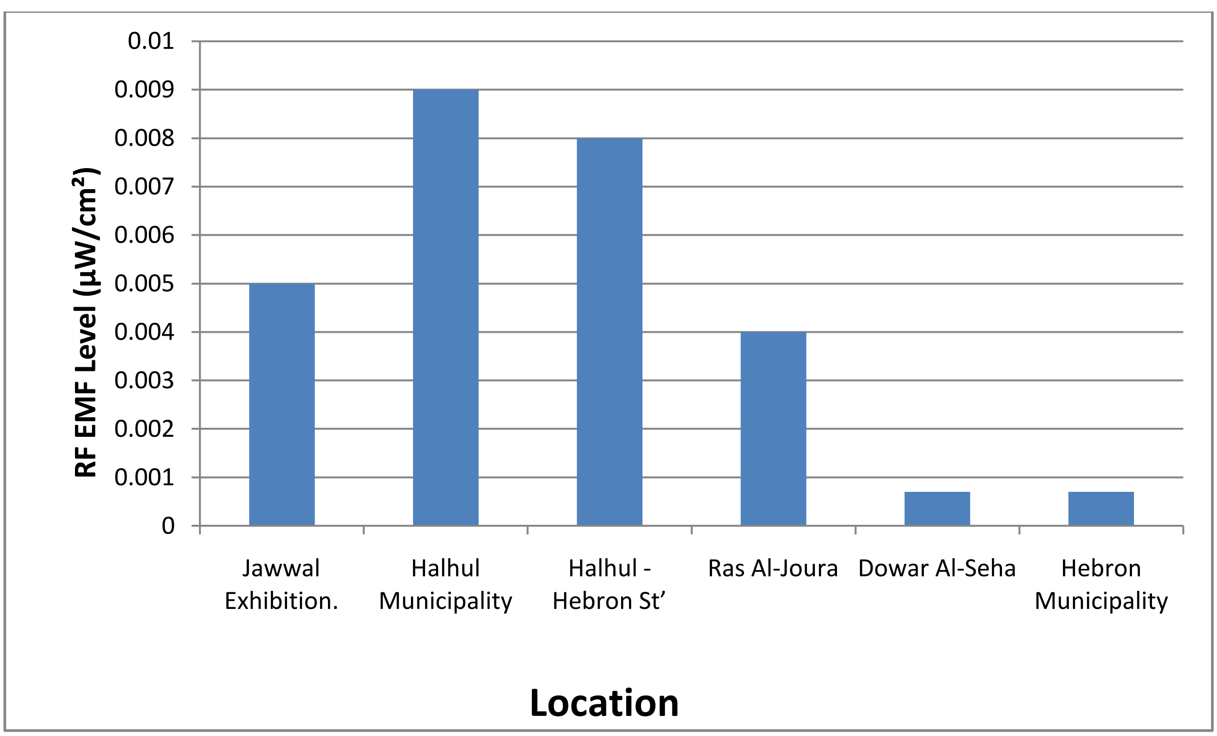

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Figure 4.4.b: Radio frequency fields power density levels for TV broadcasting towers at six locations in Hebron area

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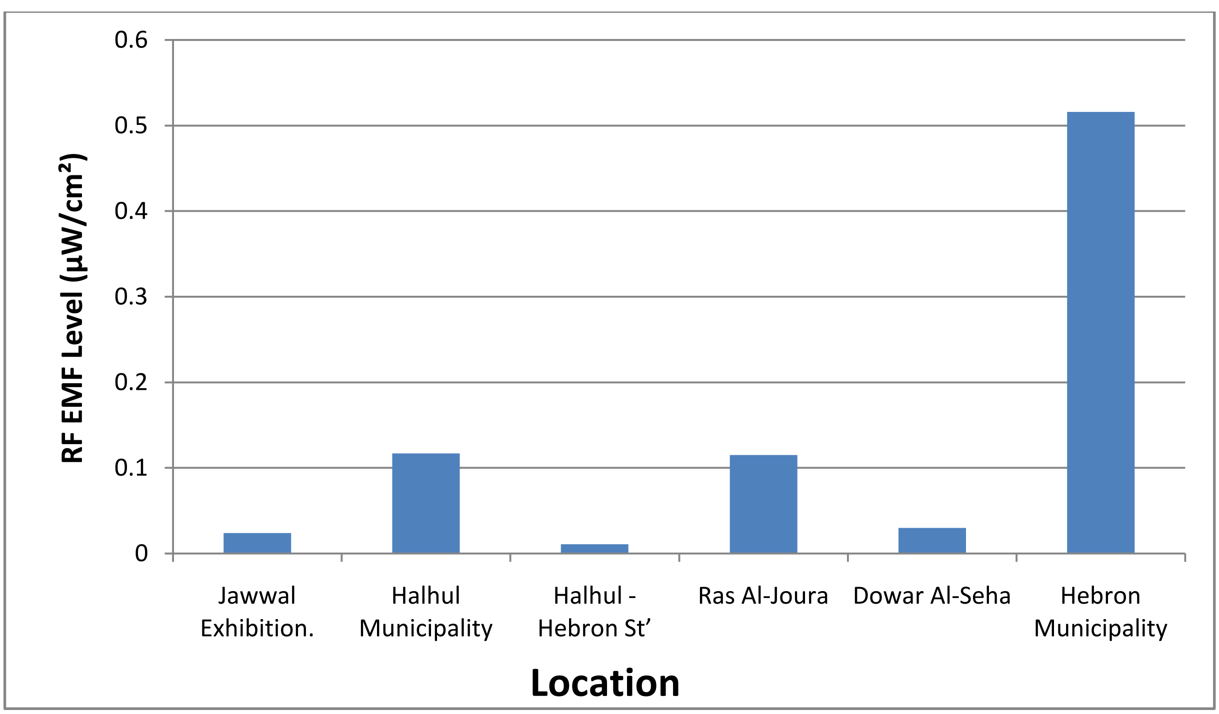

Figure 4.4.c: Radio frequency fields power density levels for mobile phone base stations at six locations in Hebron area

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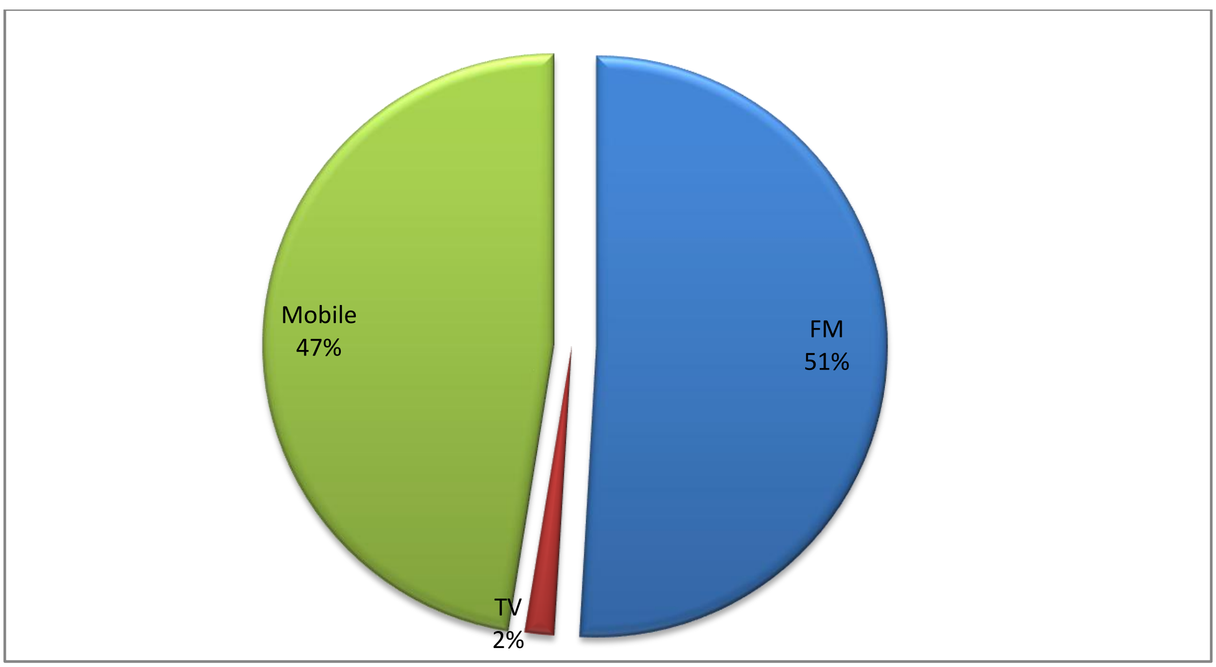

Figure 4.5: Relative contributions to the total exposure from various radio frequency radiation sources evaluated at six locations in Hebron area

4.1.3. RF Radiation in Nablus Area

The measurements were performed at four locations in Nablus area selected on the basis of population density. Most of measurements took place in urban and extra-urban locations which were taken at a height of approximately 1.7 m above ground level as well as the measurement antennas were directed in various orientations and locations in order to obtain the maximum strength of the measured signal.

Figure 4.6 shows a typical high frequency spectrum analysis overview in the frequency range 75 MHz to 1GHz detected at Rafedia location in Nablus city. The spectrum includes three main RF sources (FM, TV, GSM 900 MHz).

Table 4.3 lists the results of radiofrequency radiation from FM radio, TV Broadcasting and MPBS emissions. The maximum value of the RF EMF power density levels measured in Nablus Area was at location 3 from FM Radio (0.176 $\mu W/cm^2$) , this value is about 1136 times below the limit of ICNIRP recommended for the general public (200 $\mu W/cm^2$).

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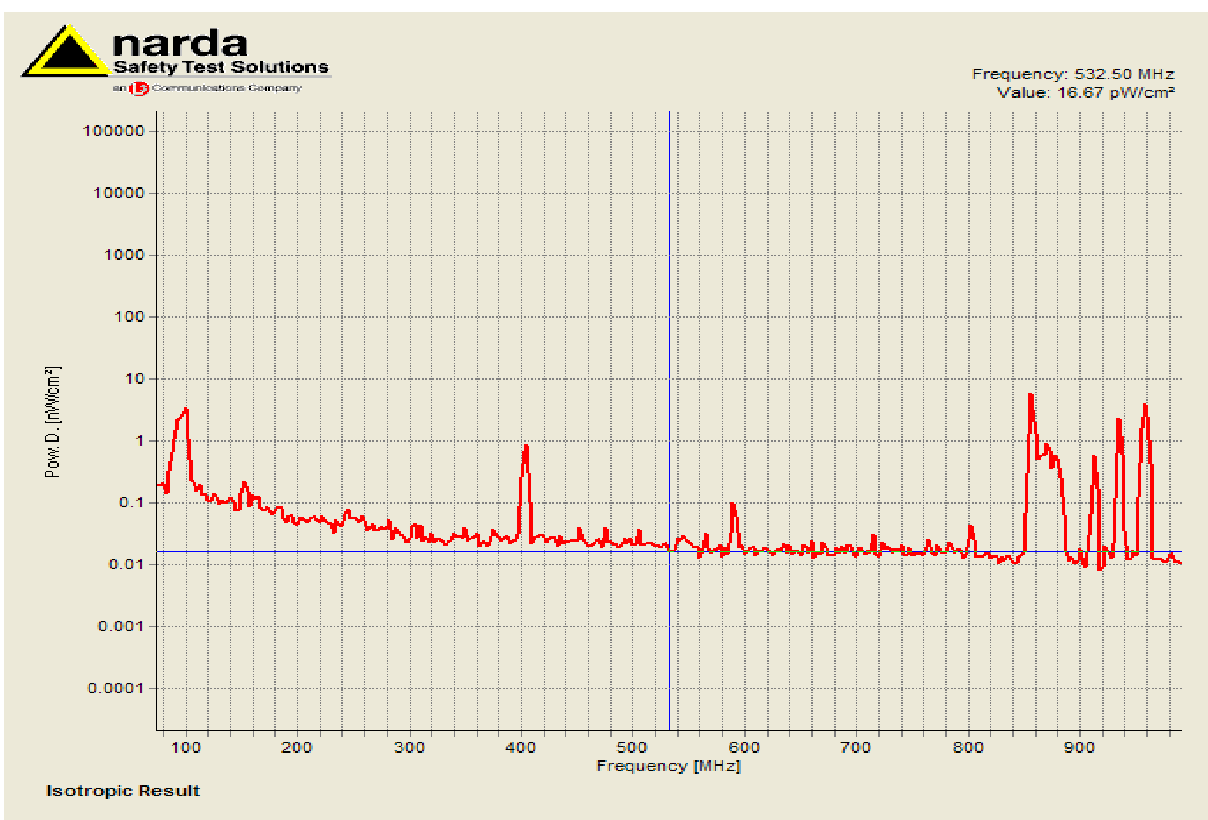

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Figure 4.6: Radio frequency spectrum in the range from 75 MHz to 1 GHz measured at

No.	Location	FM ($\mu W/cm^2$)	TV ($\mu W/cm^2$)	Mobile ($\mu W/cm^2$)	Total ($\mu W/cm^2$)
1	Dowar Nablus	0.045	0.033	0.043	0.121
2	Grnata St’	0.078	0.006	0.019	0.103
3	Falestin St’	0.176	0.101	0.161	0.438
4	Rafedia	0.004	0.002	0.008	0.014
5	**Average**	**0.08**	**0.04**	**0.06**	**0.17**

Rafedia location in Nablus city

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Table 4.3: FM, TV and mobile phone base stations power density levels measured in Nablus area

Figures 4.7.a,b,c present the radio frequency electromagnetic field power density levels for FM, TV and MPBS respectively at 4 locations in Nablus area.

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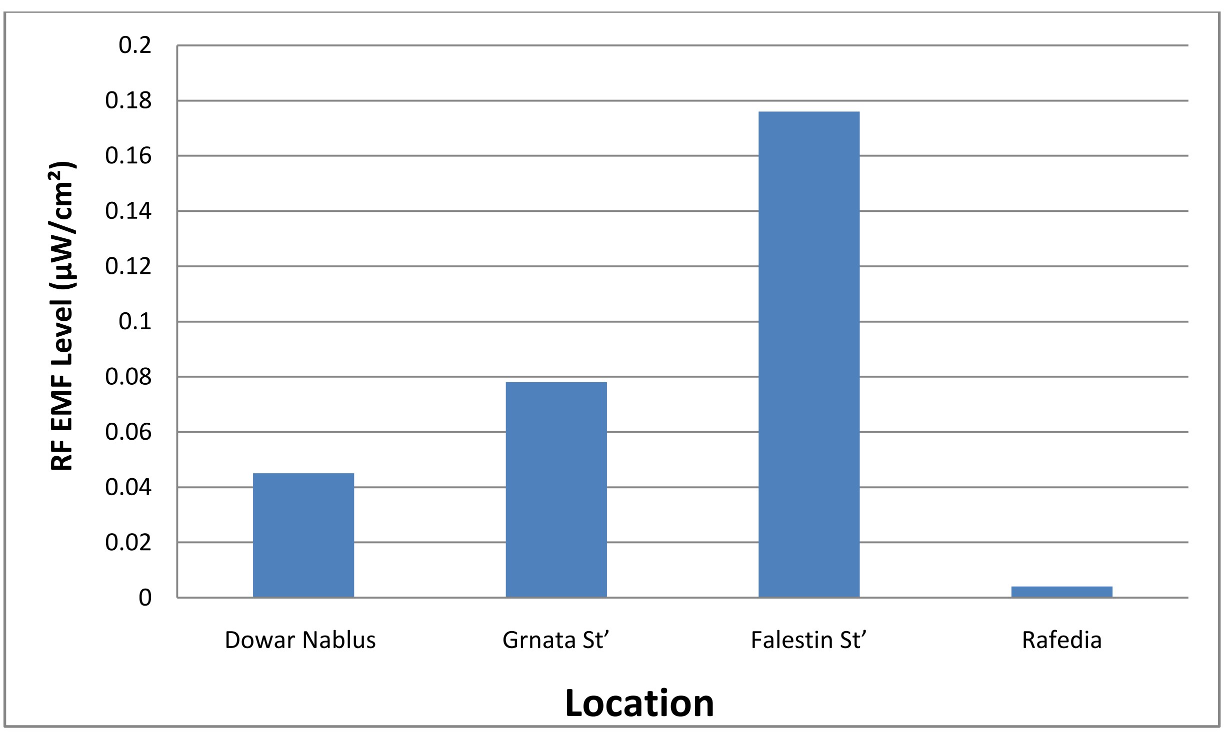

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Figure 4.7.a: Radio frequency power density levels for FM radio stations at four locations in Nablus area

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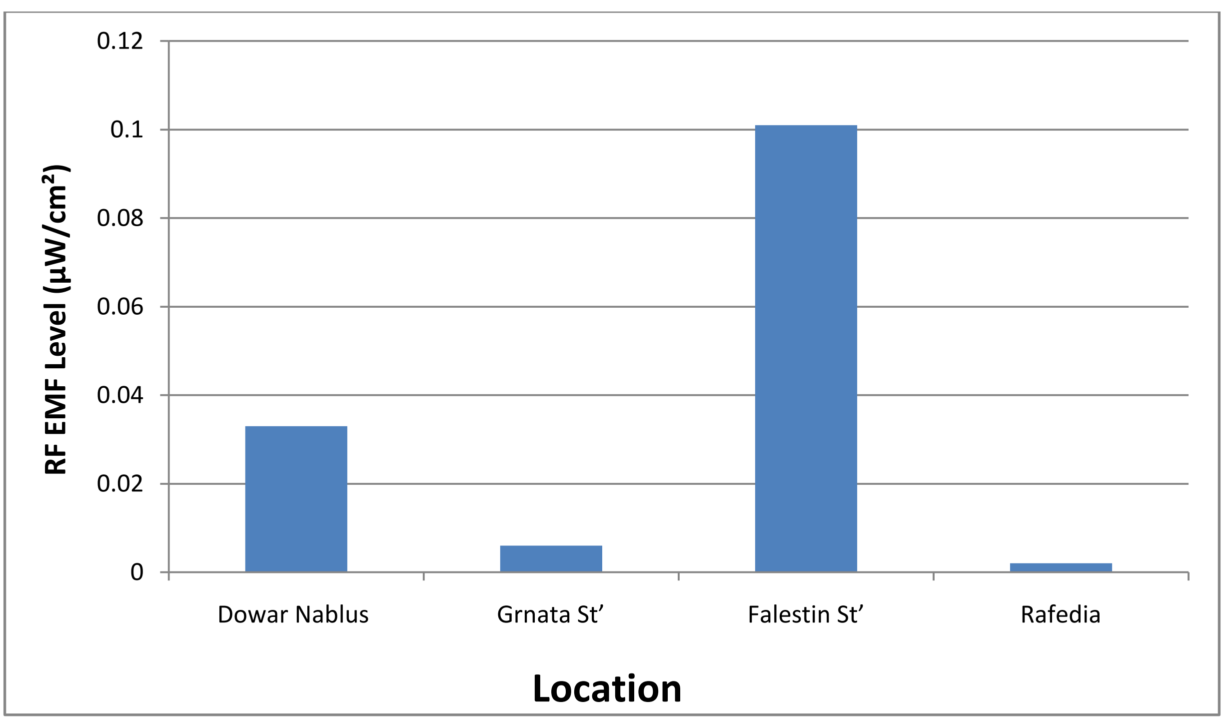

Exposure of the Palestinian Population from

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Figure 4.7.b: Radio frequency power density levels for TV broadcasting towers at four locations in Nablus area

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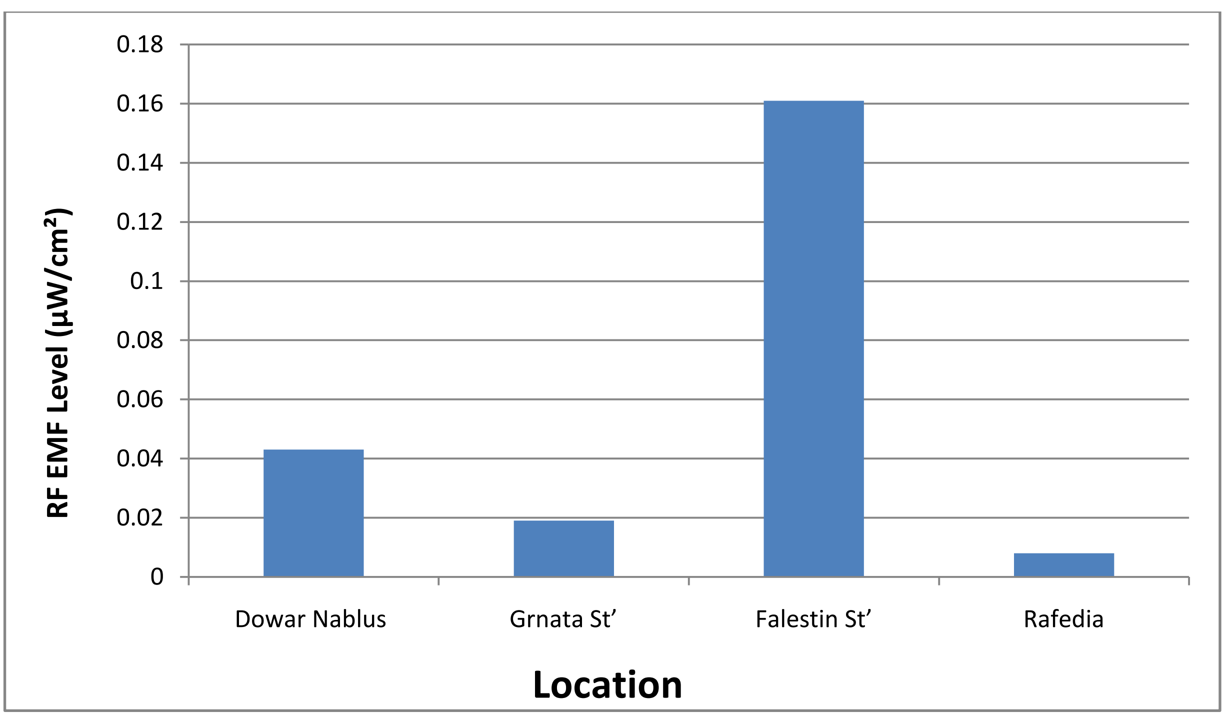

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Figure 4.7.c: Radio frequency power density levels for mobile phone base stations at four locations in Nablus area

Figure 4.8 illustrates the relative contributions of various RF sources in the total EMF exposure received by the population at Four Locations in Nablus area. FM radio signals contribute by the largest amount of electromagnetic radiation in the total exposure.

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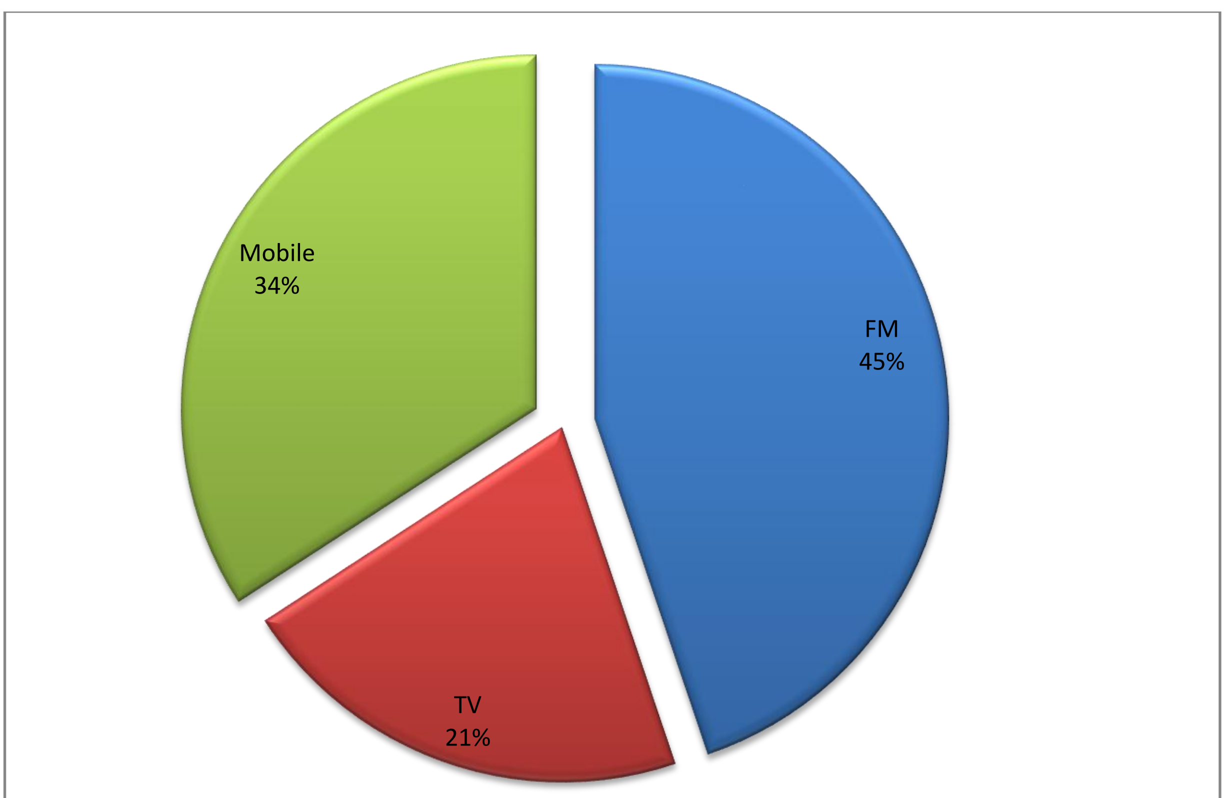

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Figure 4.8: Relative contributions to the total exposure from various radio frequency radiation sources evaluated at four locations in Nablus area

4.1.4. RF Radiation in Ramallah Area

The measurements were performed at two locations in Ramallah area. Measurements at Location 1 were performed at Dowwar Al – Manarah. This place is distinguished for its highly population density and the number of RF transmission towers. Location 2 is at Al- Balou' residential area which has a line of sight with FM radio towers and Jawwal mobile base stations. Most of measurements were taken at a height of approximately 1.7 m above ground level. In addition, the measurement antennas were directed in various orientations and locations in order to obtain the maximum strength of the measured signal.

Table 4.4 lists the results of the maximum value of radiofrequency radiation power density levels from FM radio, TV Broadcasting and MPBS emissions.

The maximum value of the RF EMF power density levels measured in Ramallah Area was from FM Radio (2.662 $\mu W/cm^2$). This value is about 75 times below the limit of ICNIRP

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recommended for the general public (200 µW/cm²). Figure 4.9 shows FM spectrum detected at location 1, the spectrum includes about 26 radio stations, the maximum peak level was at 103.4 MHz (Radio Ajyal) and 92.3 MHz (radio Angham).

The maximum value of the RF EMF power density levels from MPBS was at location1 (1.167 µW/cm²), This value is about 386 times below the limit of ICNIRP recommended for the general public (450 µW/cm²). The maximum value of the RF EMF power density levels from TV broadcasting was at location 1 (0.035 µW/cm²), this value is about 12857 times below the limit of ICNIRP recommended for the general public (450 µW/cm²).

The Radio Frequency Electromagnetic Field power density levels for FM, TV and MPBS in Ramallah area are presented in Figure 4.10.

Figure 4.11 illustrates the relative contributions of various RF sources in the total EMF exposure received by the population in Ramallah area. FM radio signals contribute by the largest amount of electromagnetic radiation in the total exposure.

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No.	Location	FM ($\mu W/cm^2$)	TV ($\mu W/cm^2$)	Mobile ($\mu W/cm^2$)	Total ($\mu W/cm^2$)
1	Dowar Al –Manarah	2.662	0.035	1.167	3.864
2	Al- Balou’	0.374	0.001	0.082	0.457
3	**Average**	**1.52**	**0.02**	**0.63**	**2.16**

Table 4.4: FM, TV and mobile phone base stations power density levels in Ramallah area

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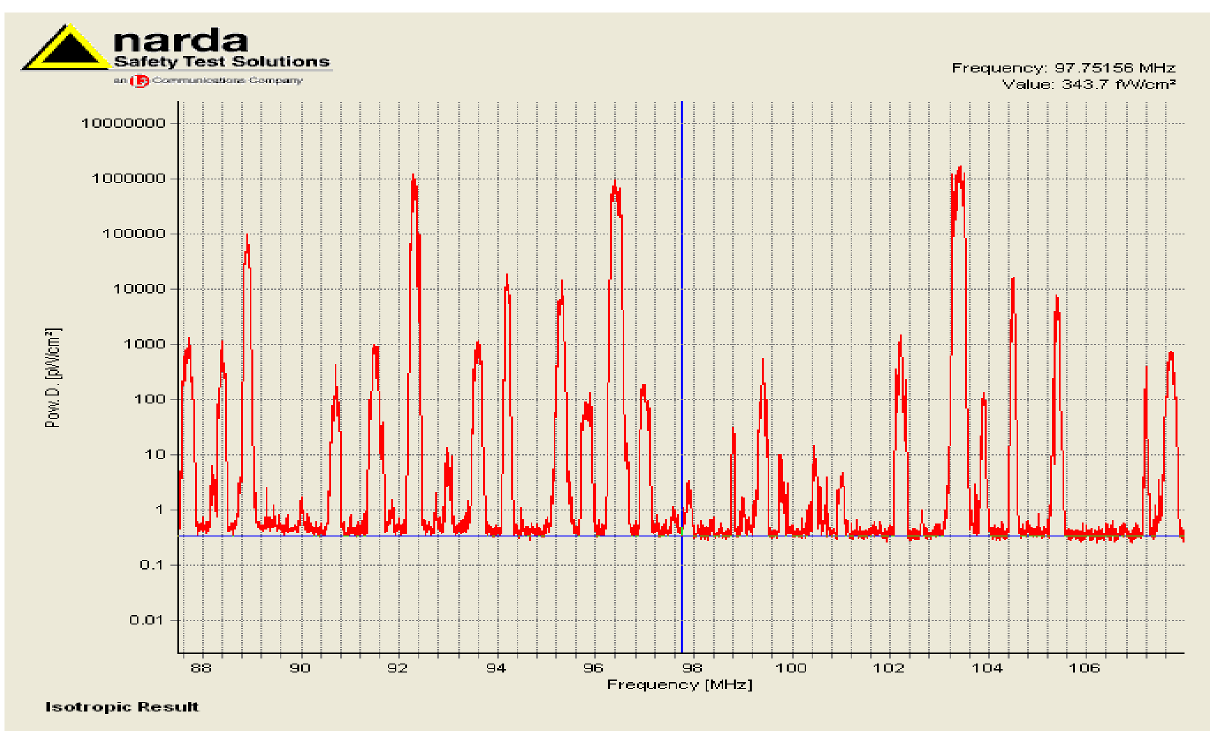

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Figure 4.9: FM spectrum in the frequency range 88 - 106 MHz measured in the city center of Ramallah

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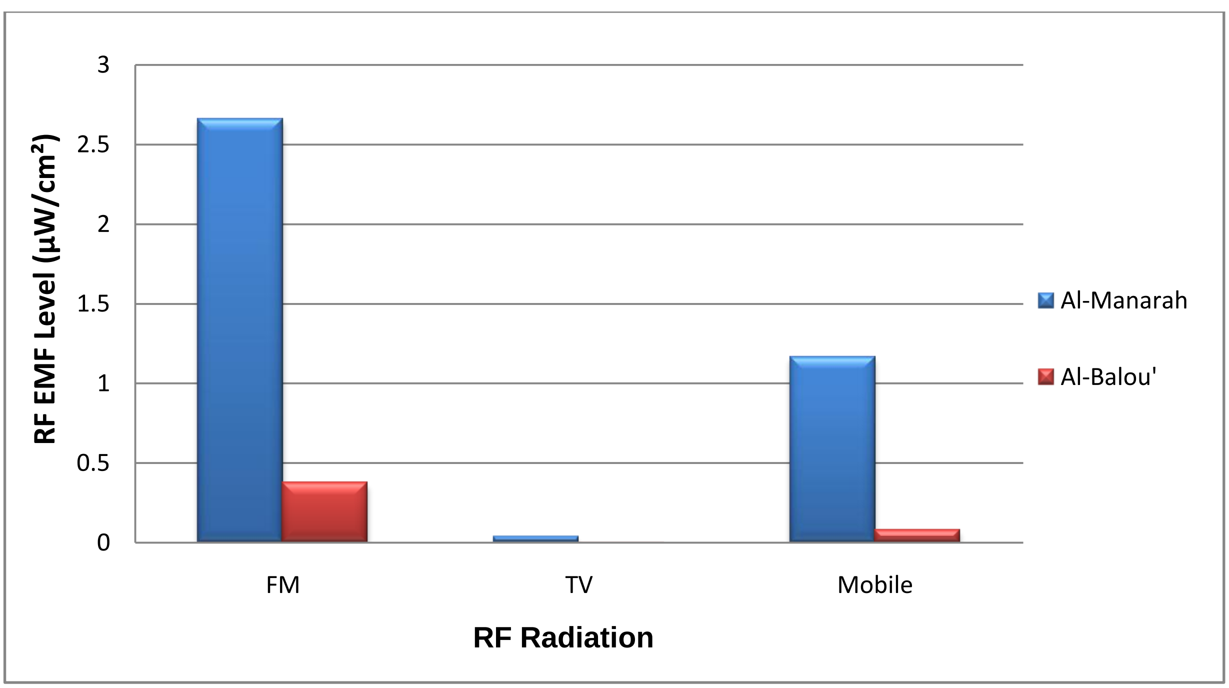

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Figure 4.10: Radio frequency power density levels for FM, TV and mobile phone base stations in Ramallah area

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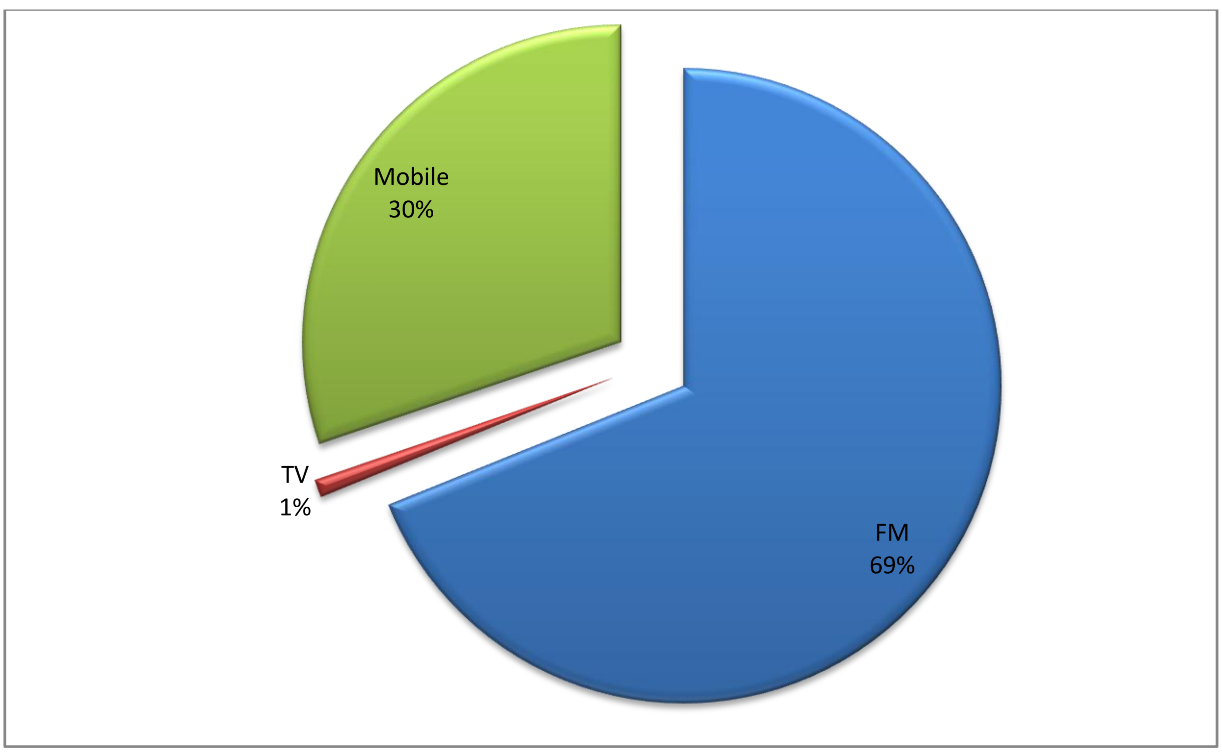

Figure 4.11: Relative contributions to the total exposure from various radio frequency radiation sources evaluated in Ramallah area

4.1.5. RF Radiation in Jenin Area

The measurements were performed at two locations in Jenin area. Measurements at location 1 were made in the Jenin market place which is overcrowded and has a line of sight with Jawwal MPBS. Location 2 is in Tora Al-Gharbia village, which is an open spacious residential area without any station.

Most of measurements were taken at a height of approximately 1.7 m above ground level as well as the measurement antennas were directed in various orientations and locations in order to obtain the maximum strength of the measured signal.

The Results of the observed radiofrequency radiation power density levels from FM radio, TV Broadcasting and MPBS emissions are presented in Table 4.5.

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The maximum value of the RF EMF power density levels from MPBS was found at location1 (0.08 µW/cm²) which is about 5625 times below the limit of ICNIRP recommended for the general pubic (450 µW/cm²). The maximum value of the RF EMF power density levels from FM Radio was at location 1 (0.07 µW/cm²). This value is about 2857 times below the limit of ICNIRP recommended for the general public (200 µW/cm²). The maximum value of the RF EMF power density levels from TV broadcasting was at location 2 (0.001 µW/cm²), this value is about 450,000 times below the limit of ICNIRP recommended for the general public (450 µW/cm²).

Figure 4.12 illustrates the relative contributions of various RF sources in the total EMF exposure received by the population in Jenin area. MPBS radio signals contribute by the largest amount of electromagnetic radiation in the total exposure.

No.	Location	FM	TV	Mobile	Total

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		(μW/cm²)	(μW/cm²)	(μW/cm²)	(μW/cm²)
1	Jenin Market	0.070	0.001	0.08	0.151
2	Tora Al- gharbia	0.002	0.001	0.002	0.005
3	**Average**	**0.04**	**0.001**	**0.04**	**0.08**

Table 4.5: FM, TV and mobile phone base stations power density levels in Jenin area

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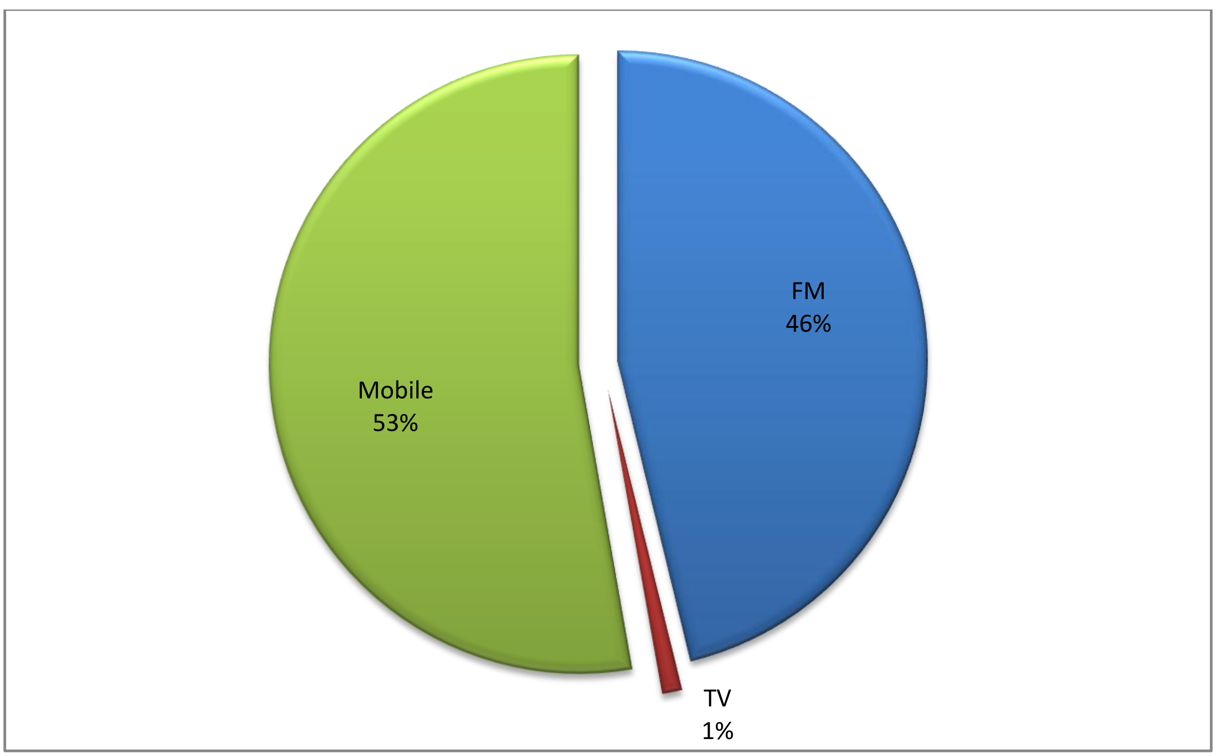

Figure 4.12: Relative contributions to the total exposure from various radio frequency radiation sources in Jenin area

4.1.6. RF Radiation in Tulkarem Area

The measurements were performed at the center of Tulkarem city. There was a clear line of sight with Jawwal MPBS from this position.

All the measurements were taken at a height of approximately 1.7 m above ground level as well as the measurement antennas were directed in various orientations and locations in order to obtain the maximum strength of the measured signal.

The maximum value of the RF EMF power density levels from MPBS was (0.038 µW/cm²). This value is about 11,842 times below the limit of ICNIRP recommended for the general public (450 µW/cm²). The maximum value of the RF EMF power density levels from FM Radio was (0.017 µW/cm²) which is about 11,764 times below the limit of ICNIRP recommended for the general public (200 µW/cm²).The maximum value of the RF EMF

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power density levels from TV broadcasting was (0.0007 μW/cm²) which is about 642,857 times below the limit of ICNIRP recommended for the general public (450 μW/cm²).

Figure 4.13 illustrates the relative contributions of various RF sources in the total EMF exposure received by the population in Tulkarem area. MPBS radio signals contribute by the largest amount of electromagnetic radiation in the total exposure.

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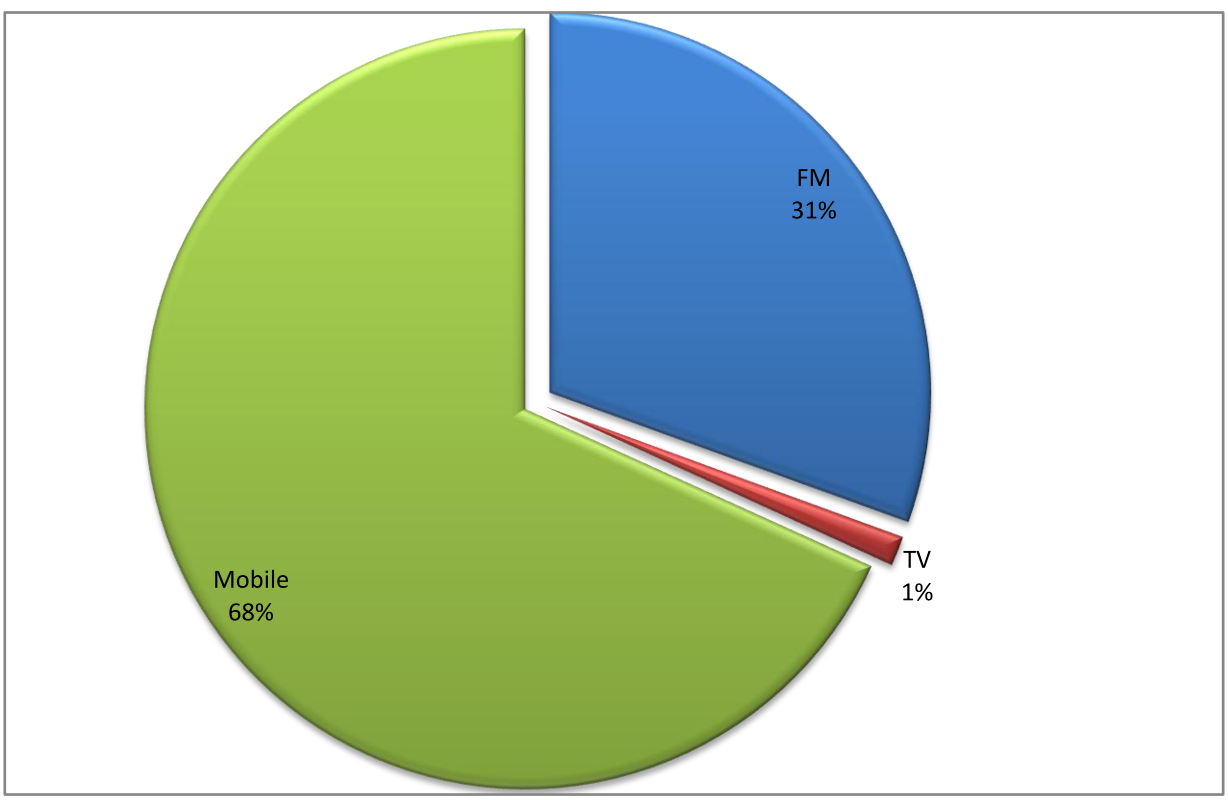

Figure 4.13: Relative contributions to the total exposure from various radio frequency radiation sources evaluated in Tulkarem area

4.1.7. RF Radiation in Jericho Area

The measurements were performed at Al- Estraha location which is overcrowded and has a direct line of sight with Israel’s mobile base station and Jawwal mobile base station.

All measurements were conducted at a height of approximately 1.7 m above ground level. Moreover, the measurement antennas were directed in various orientations and locations in order to obtain the maximum strength of the measured signal.

The Results of the electric field and power density levels of the observed radiofrequency radiation from FM radio, TV Broadcasting and MPBS emissions are presented in Table 4.6.

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The maximum value of the RF EMF power density levels from FM Radio was (0.002 µW/cm²) which is about 100,000 times below the limit of ICNIRP recommended for the general public (200 µW/cm²). The maximum value of the RF EMF power density levels from TV broadcasting was (0.002 µW/cm²) which is about 264,706 times below the limit of ICNIRP recommended for the general public (450 µW/cm²). The maximum value of the RF EMF power density levels from Jawwal MPBS was (0.083 µW/cm²). This value is about 5435 times below the limit of ICNIRP recommended for the general public (450 µW/cm²). The maximum value of the RF EMF power density levels from Israel's MPBS was (0.099 µW/cm²) at 900Mhz which is about 4532 times below the limit of ICNIRP recommended for the general public (450 µW/cm²).

RF source	**Electric Field (V/m²)**	**Power Density (µW/cm²)**
FM Radio	0.08	0.002

TV broadcasting	0.08	0.002
Jawwal MPBS	0.56	0.083
Israel's MPBS	0.61	0.099

Table 4.6: Electric field values and power density levels from FM, TV and mobile phone base stations in Jericho area

Figure 4.14 illustrates the relative contributions of various RF sources in the total EMF exposure received by the population in Jericho area. Israel's MPBS radio signals contribute by the largest amount of electromagnetic radiation in the total exposure.

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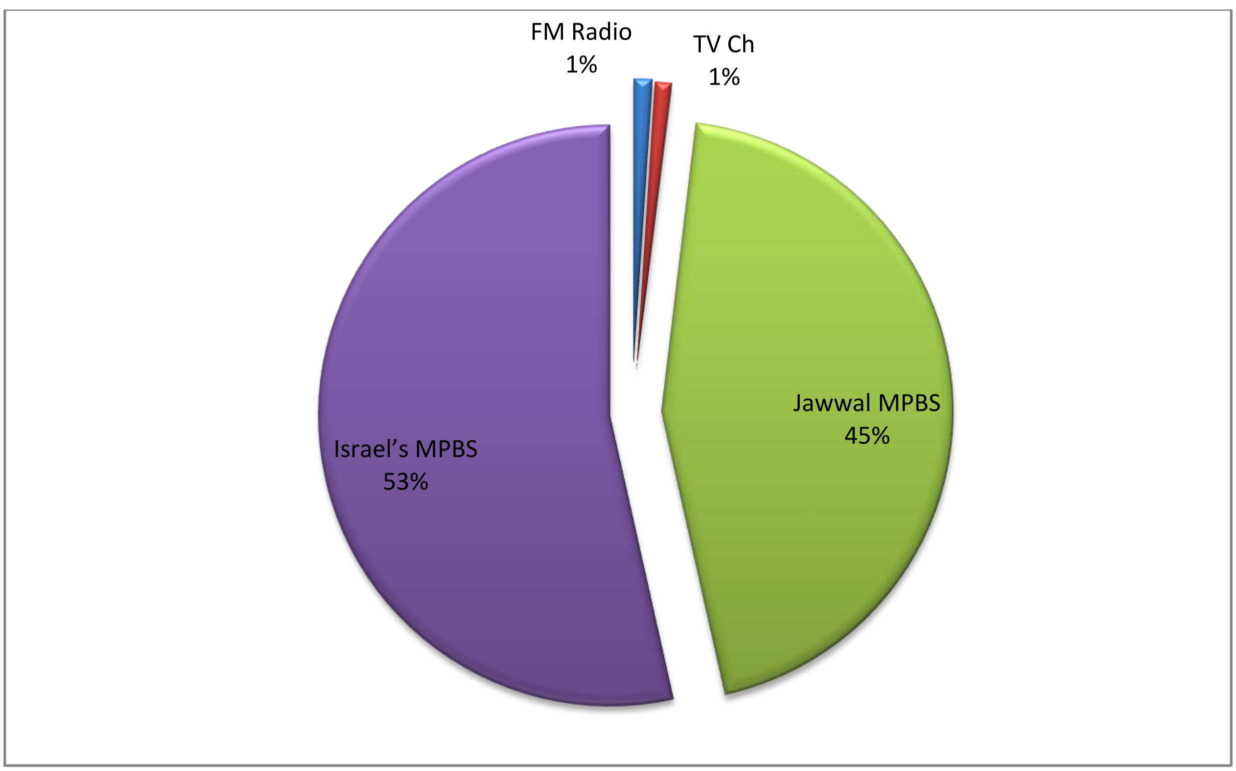

Figure 4.14: Relative contributions to the total exposure from various radio frequency radiation Sources evaluated in Jericho area

4.1.8. RF Radiation in the Area East of Jerusalem

The measurements were performed at Al- Quds University campus located in Abu Dies village, east of Jerusalem Area. There is a Jawwal mobile phone base station at the top of the building of Science College.

All measurements were taken at a height of approximately 1.7 m above ground level as well as the measurement antennas were directed in various orientations and locations in order to obtain the maximum strength of the measured signal.

The maximum value of RF EMF power density levels was from mobile phone base stations $0.014 \mu W/cm^2$, and this value is about 32,143 times below the limit of ICNIRP recommended

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for the general public (450 μW/cm²). Figure 4.15 shows a typical high frequency spectrum analysis overview in the frequency range 800 MHz to 2 GHz detected at Al- Quds University campus in Abu Dies village, east of Jerusalem Area. The spectrum includes two sources (GSM 900 MHz and GSM 1800 MHz).

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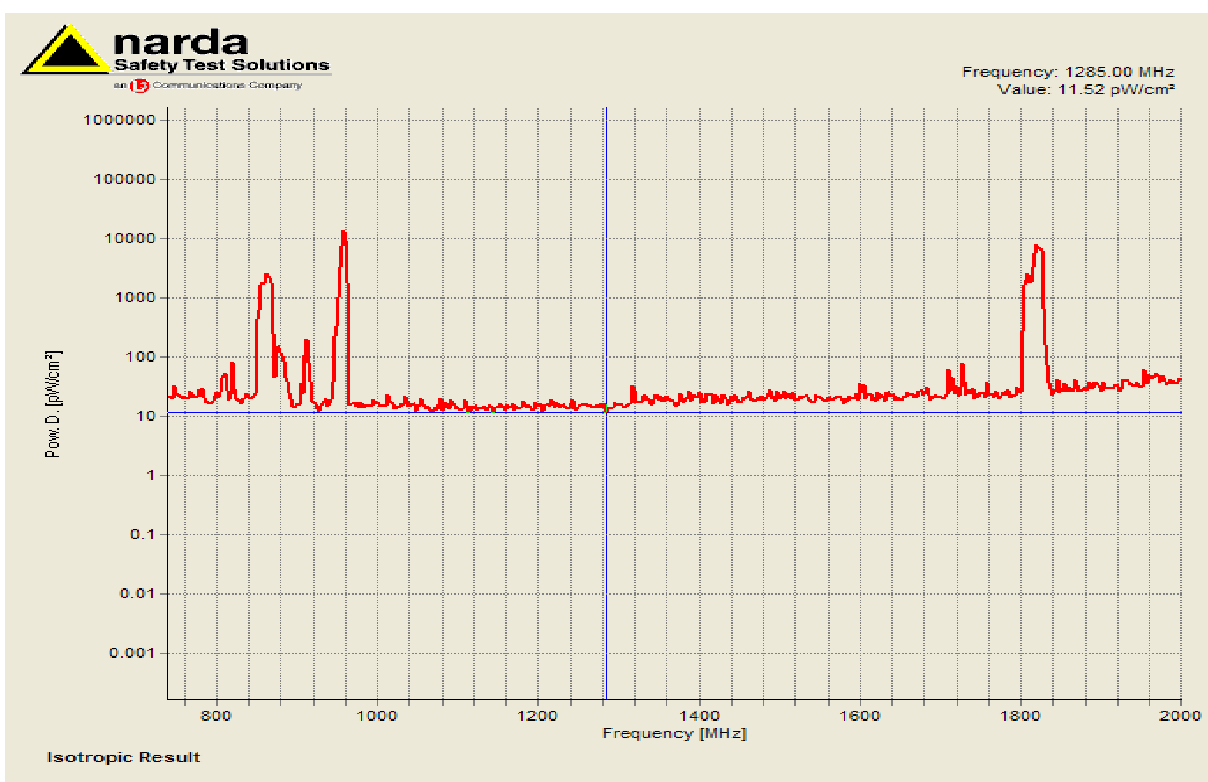

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Figure 4.15: Radio frequency spectrum in the frequency range 800 MHz to 2 GHz measured at Al- Quds University campus located in Abu - Dies town, east of Jerusalem

The maximum value of RF EMF levels for FM Radio was 0.0008$\mu W/cm^2$ and this value is about 250,000 times far below the limit of ICNIRP recommended for the general public (200 $\mu W/cm^2$).

The maximum value of RF EMF levels for TV broadcasting towers was 0.0009$\mu W/cm^2$ and this value is about 500,000 times below the ICNIRP's limit for the general public (450 $\mu W/cm^2$).

Figure 4.16 represents the results of RF EMF power density levels from FM, TV as well as MPBS at Al- Quds University campus located in Abu- Dies town, east of Jerusalem.

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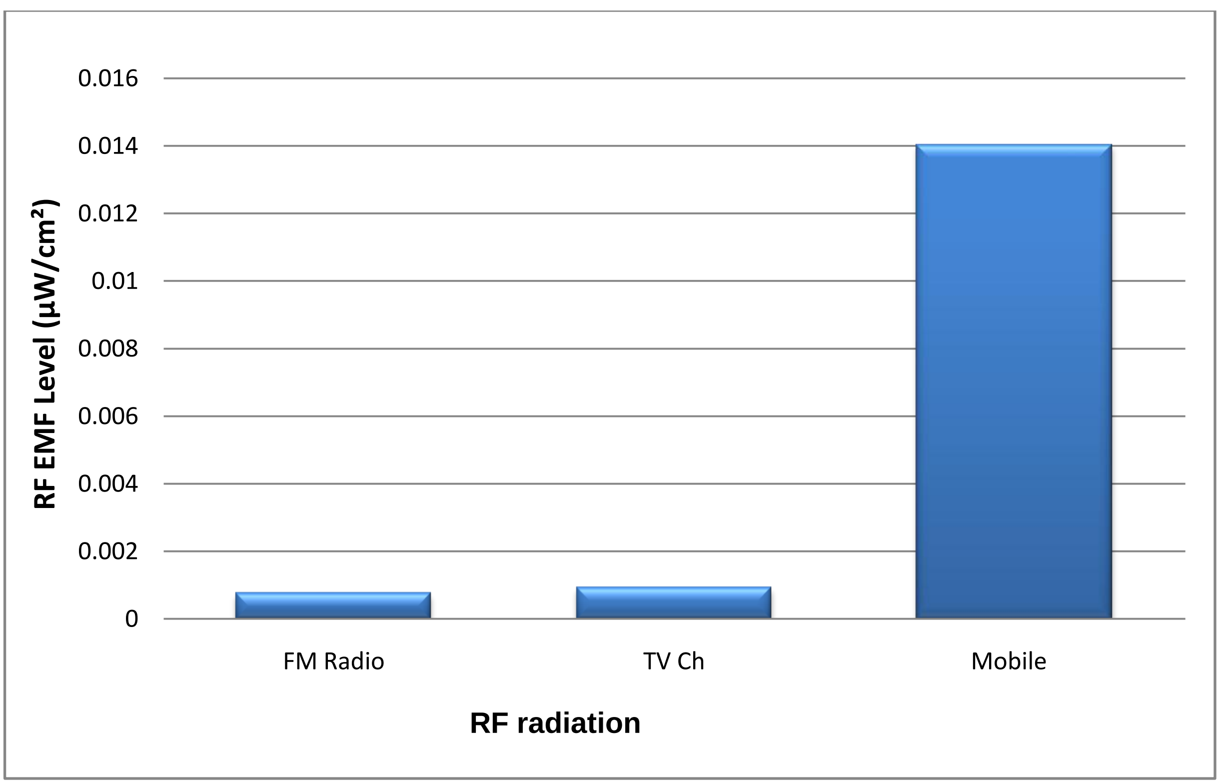

Figure 4.16: Radio frequency power density levels for FM, TV and mobile phone base stations at Al- Quds University campus located in Abu Dies town, east of Jerusalem

Figure 4.17 illustrates the relative contributions of various RF sources in the total EMF exposure received by the population at Al- Quds University campus located in Abu Dies village, east of Jerusalem. MPBS radio signals contribute by the largest amount of electromagnetic radiation in the total exposure.

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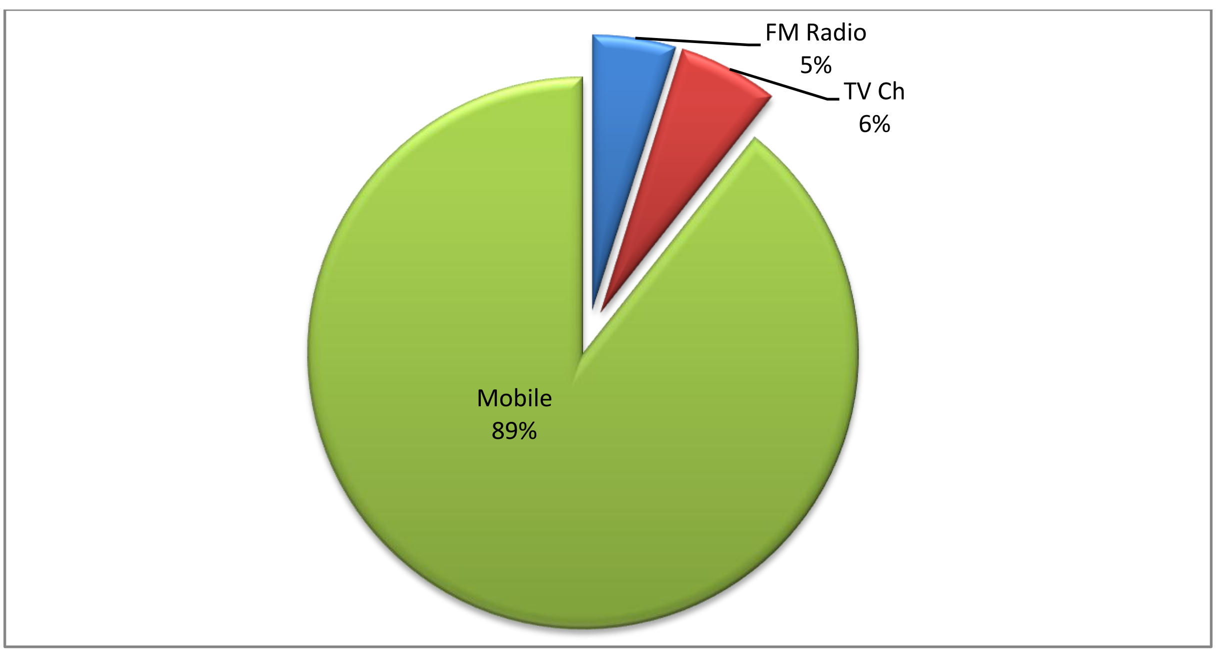

Figure 4.17: Relative contributions to the total exposure from various radio frequency radiation Sources evaluated at Al- Quds University campus located in Abu Dies town, east of Jerusalem

4.2.Total Exposure at Main Cities Centers

In all major cities over the West bank, one location in the city center is investigated for total exposure from all relevant RF sources. Measurements were conducted with the antenna positioned 1.7 m above ground level.

The Results of radiofrequency radiation from FM radio, TV Broadcasting and MPBS emissions are presented in Table 4.7. The highest total exposure was 3.86 $\mu W/cm^2$ at Ramallah city center (location 5). Referring to eq. 6, this value is about 60 times below the limit of ICNIRP recommended for the general public.

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The results of RF EMF power density levels at the seven locations of the West Bank are shown in Figure 4.18. Figure 4.19 illustrates the same results in Figure 4.18 except for Ramallah location.

Figure 4.20 illustrates the relative contributions of various RF sources in the total EMF exposure received by the population in the City Centers of Major Cities in the West Bank. FM radio signals contribute by the largest amount of electromagnetic radiation in the total exposure.

No.	City	FM ($\mu W/cm^2$)	TV ($\mu W/cm^2$)	Mobile ($\mu W/cm^2$)	Total ($\mu W/cm^2$)

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1	Bethlehem	0.029	0.001	0.003	0.034
2	Halhul	0.152	0.009	0.117	0.278
3	Hebron	0.013	0.001	0.030	0.044
4	Nablus	0.045	0.033	0.043	0.121
4	Jenin	0.068	0.001	0.078	0.147

5	Ramallah	2.662	0.035	1.167	3.864
6	Tolkarim	0.017	0.001	0.038	0.056
7	**Average**	**0.43**	**0.01**	**0.21**	**0.65**

Table 4.7: FM, TV and mobile phone base stations power density levels at seven city centers of the major cities of the West Bank

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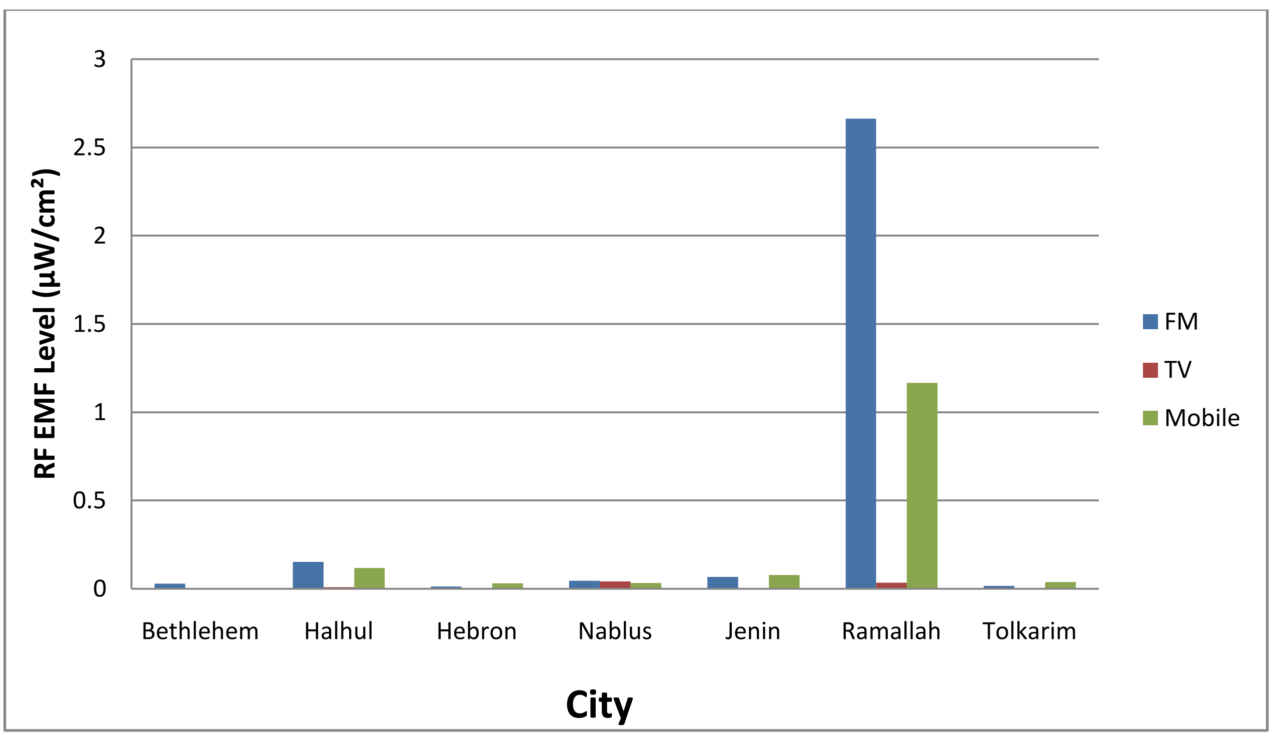

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Figure 4.18: Radio frequency power density levels for FM, TV and mobile phone base stations in city centers of the West Bank major cities

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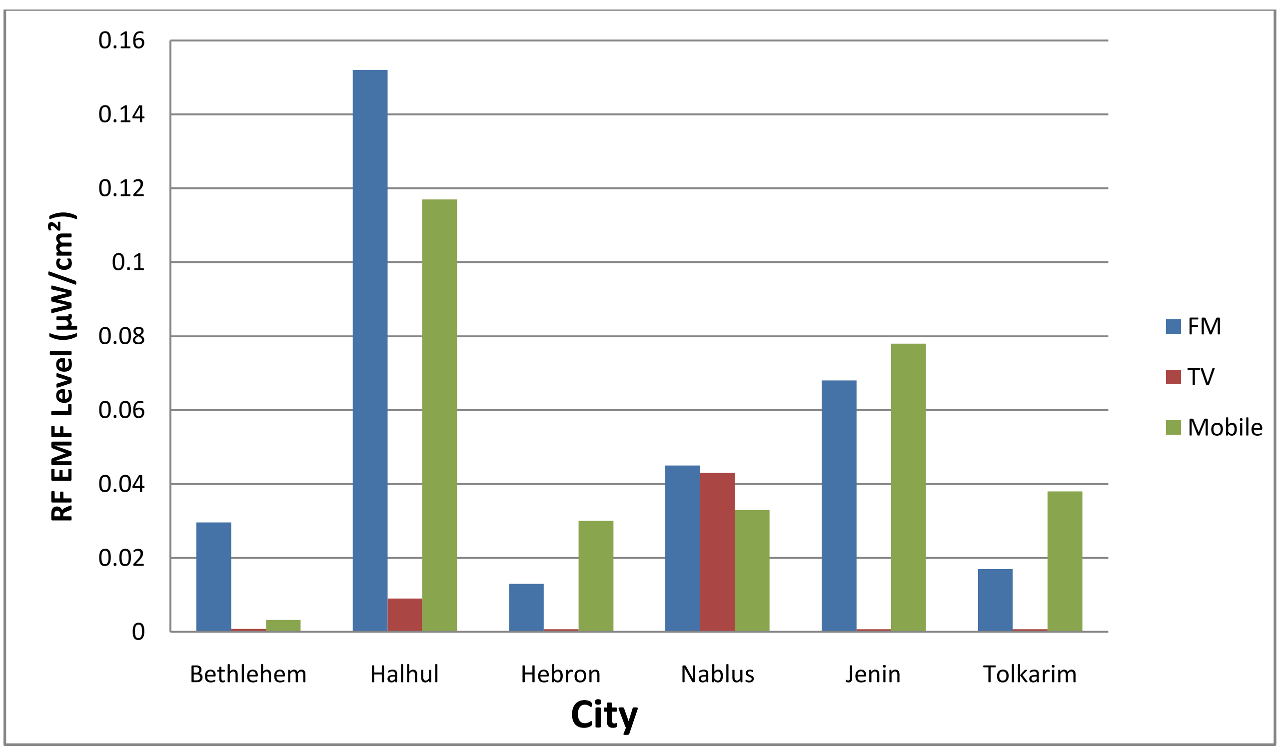

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Figure 4.19: Radio frequency power density levels for FM, TV and mobile phone base stations in city centers of the West Bank major cities except Ramallah

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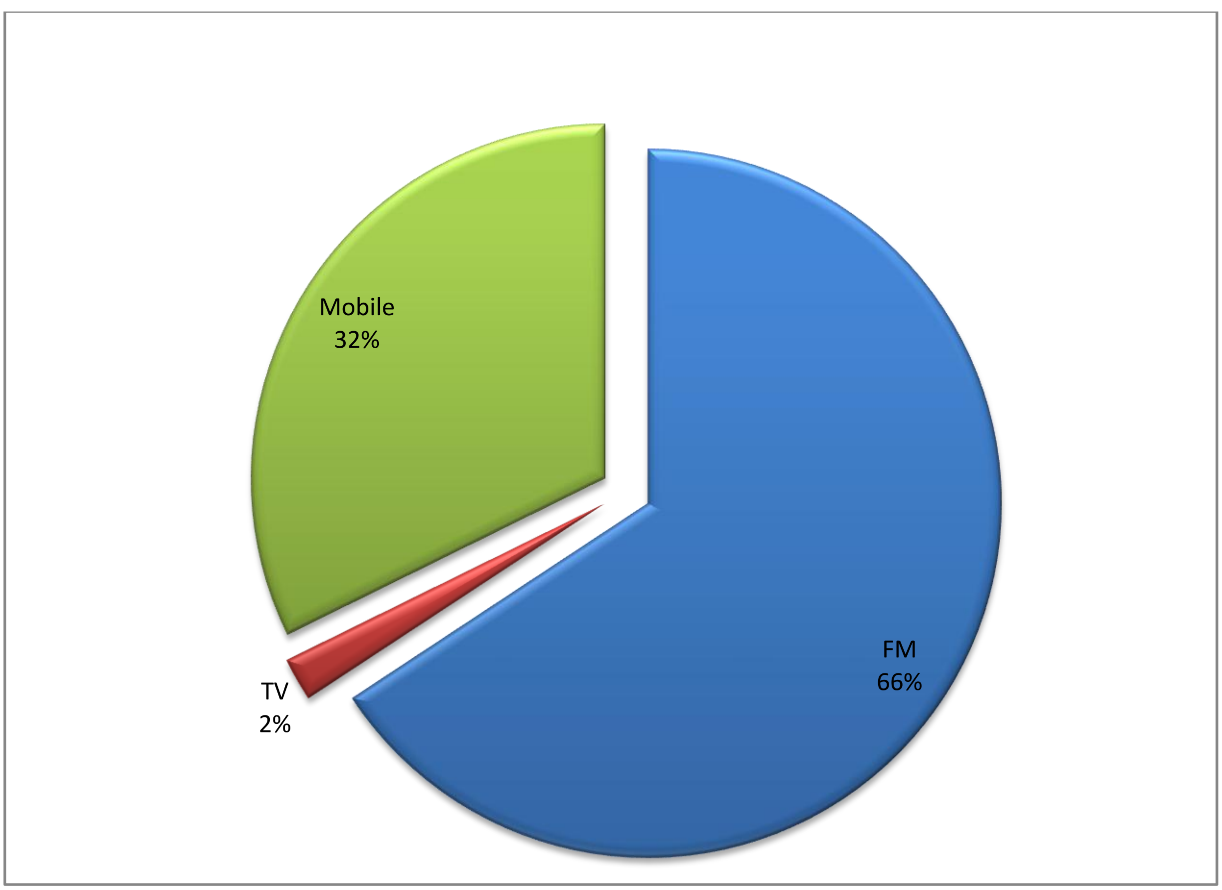

Figure 4.20: Relative contributions to the total exposure from various radio frequency radiation Sources evaluated in the city centers of major cities in the West Bank

4.3. Measurements of Mobile Base Station Activity

24 hour measurements were performed at a fixed location on top of an old residential building very close to Jawwal mobile phone base station. The site is installed on the Bethlehem Municipality building. The measurements were made using the Narda SRM 3000 by continuously scanning the signal data across the mobile telephone frequency band comes from single sector. The number of scans is dependent on the number of signals present in the band. The recorded data were used to determine the sequential activity for the GSM system over 24 hour period. The activity level of the data samples was determined by counting the number of active time slots using over one hour period.

Figure 4.21 shows 24 hours activity levels in terms of percentage and the mobile phone traffic during 24 hours at Bethlehem Municipality site. The highest activity period was between 11:00 and 22:00. The maximum activity level was at 14:00 hour.

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The maximum value of RF EMF power density levels from this particular site was 0.04µW/cm², and this value is about 11250 times far below the limit of ICNIRP recommended for the general public (450 µW/cm²).

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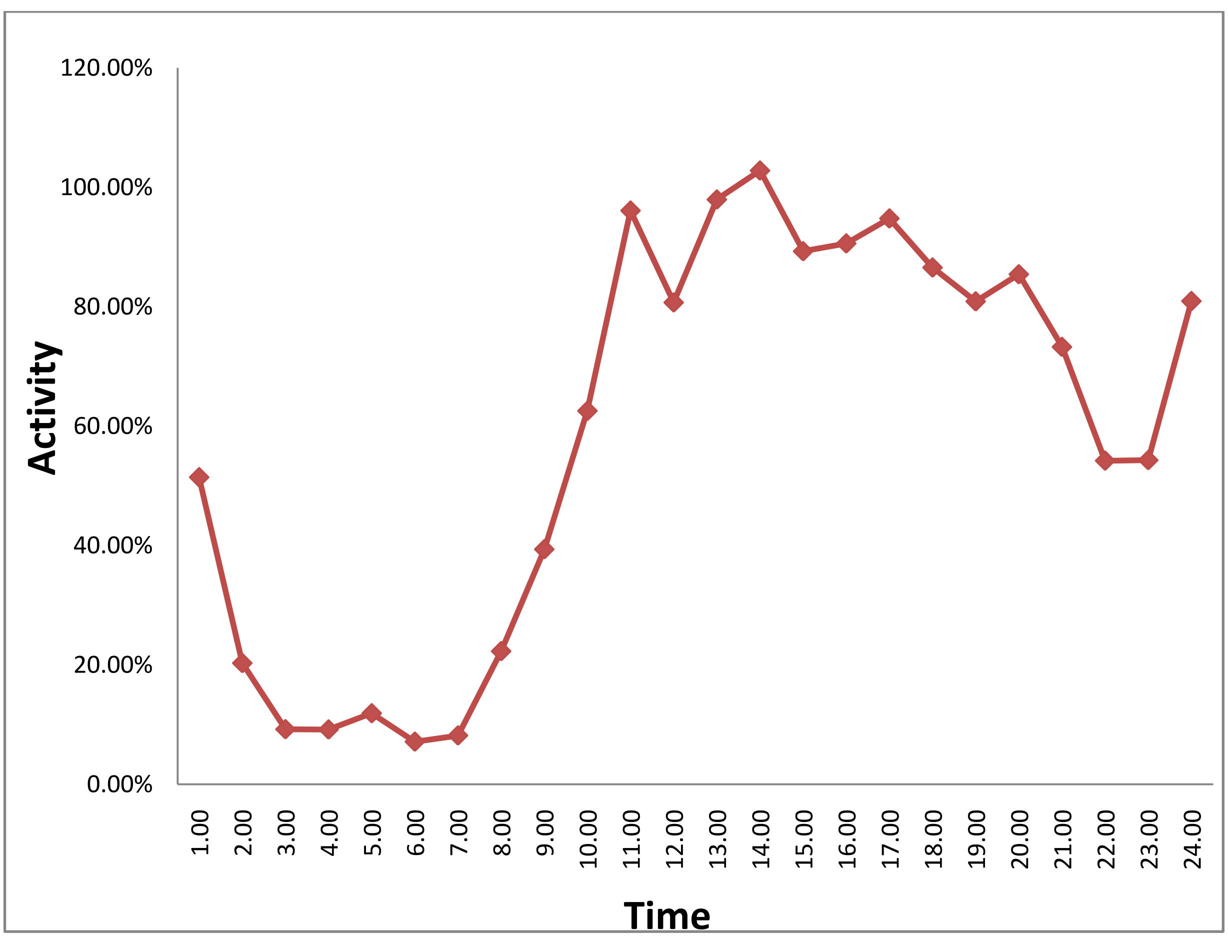

Figure 4.21: 24 hours activity of the Jawwal mobile phone base station located in Bethlehem area on the top of the Bethlehem Municipality

4.4. Comparison between Measured and Simulated Radiation Fields

It is of interest to compare measurements of power density with theoretical results for an indication of how reliably exposures may be predicted. The prediction allowed the levels of highest exposure to be identified and provided the measurement locations for the audit. As the predictions and the measurements provided data for the exposure levels at the same location a comparison between the measured and predicted was made possible.

A comparison between measured and simulation radiation fields were performed for a Jawwal MPBS. Using site specific information along with the horizontal and vertical antenna gain characteristics, computer models of the predicted RF EMF levels of the mobile base stations were produced using the RF Map software.

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The measurements were conducted along the radial from the mobile base station where the predicted maximum was found from modeling.

The site selected fall in Halhul city at the city center, Prophet Younis Str. This is a GSM 900 site with a base station and antenna installed on the accessible rooftop of a private residential building. The site had three antenna sectors fixed on the same mast mounted separately. The mast is 9 m above the accessible rooftop area.

Calculations were performed at a survey high of 1.5 m. Figure 4.20 shows the location of the Jawwal MPBS and the power density levels in the area around the site. As shown in Figure 4.22 the maximum RF EMF power density levels were at the south and the North West from the site is 0.37µW/cm², and this value is about 1216 times below the ICNIRP's limit recommended for the general public (450 µW/cm²).

The measurements were conducted along the radial from the mobile phone base station where predicted maximum RF EMF power density levels were found from the modeling. The maximum measured RF EMF power density levels at the mentioned area was 0.27µW/cm².

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The calculated value of power density is in good agreement with experimental data.

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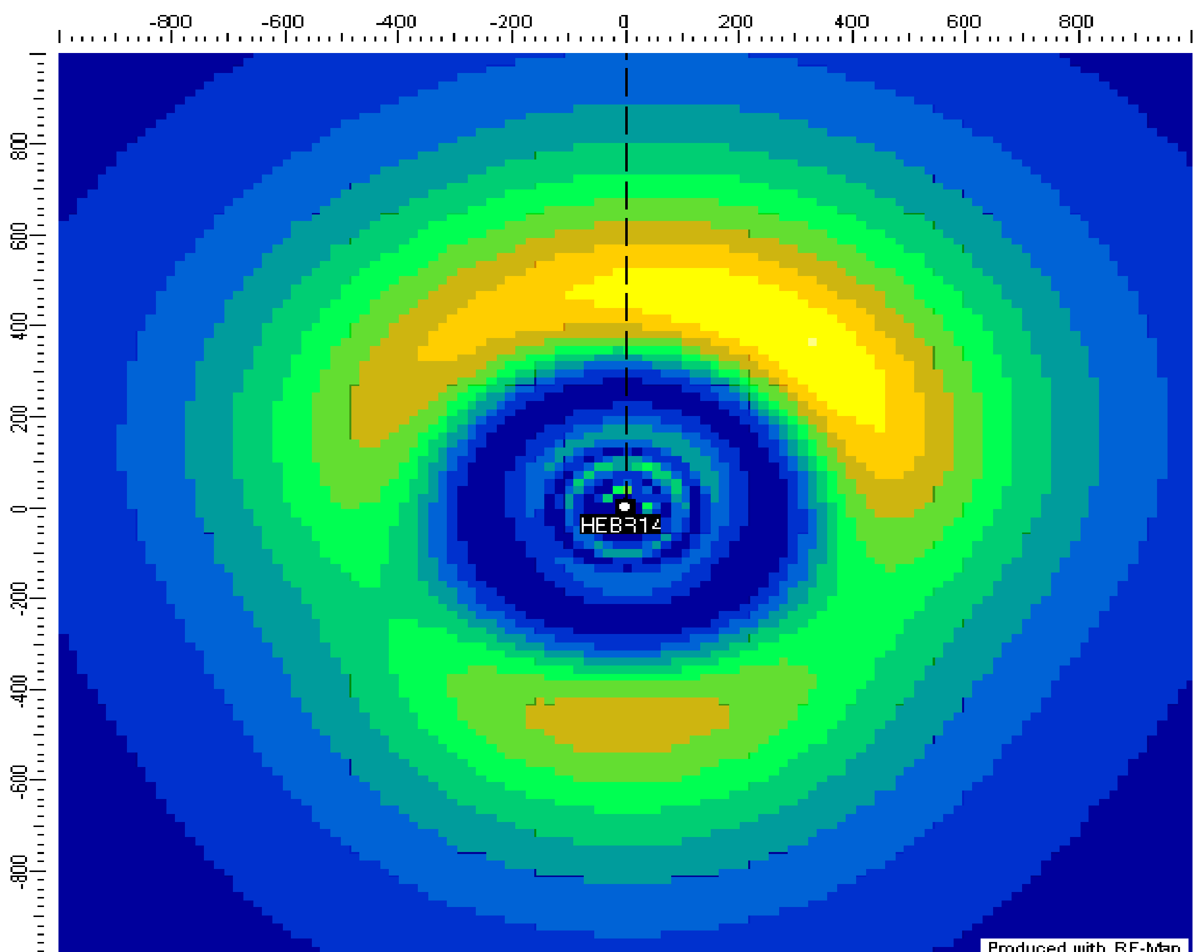

1unit= 1 meter

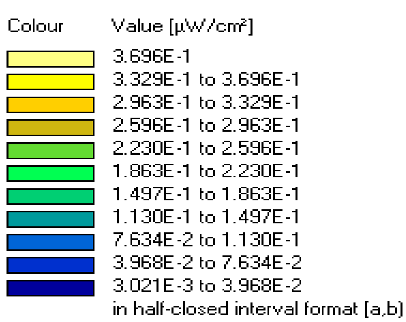

Figure 4.22: Estimated levels of electromagnatic radiation emitted from the mobile phone base station at Halhul city

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4.5. Conclusion

The total exposure from RF EMF in the frequency range from 75MHz to 3GHz were studied and were found to vary from one city to another in the West bank area depending on the distribution and type of RF sources in the area.

The average contributions from mobile base stations, FM and TV broadcasting stations in the city centers were, 32%, 66% and 2% respectively. All the measured exposures were far below the limits recommended by ICNIRP.

The maximum power density measured at any location from specific RF source category is 2.66μW/ cm^2, and was found in the city center of Ramallah. This value represents the cumulative power density resulted from FM radio stations (frequency interval 88 MHz – 108 MHz). The total power density at that location was about 3.9μW/ cm^2 and constitutes only 0.86% of the 450 μW/cm^2 ICNIRP's limit recommended for the general public.

It was found that FM radio broadcasting contributes by the largest amount to the total exposure recieved by the population from RF radiation fields (sources). In general, this outcome was expected, since in many studies, FM broadcasting is considered the second main

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source of exposure to RF radiation in urban areas.the main source is AM radio broadcasting, which is not present in palestine as a direct source of RF radiation located in the palestinian areas. AM signals present in palestinian areas are from sources existing outside the country.

This work has proved that FM is the main source of exposure to RF radiation in the Palestine environment, while the main public concern is oriented towards the mobile phone base station.

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