

Measuring and Evaluation of Power Density Emitted by Communication Towers with Location and Time for Selected Areas in Karbala, Iraq

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ABSTRACT

This study aims to measure and evaluate the energy density of electromagnetic radiation emitted by cell phone towers in three locations in Karbala, Iraq. The first location is the area between the Holy Shrine of Imam Hussain and Abbas that represents religion area, while the second area is Al-Hussein District Street which represents a commercial location. The third place is Al-Ghadeer District (a residential area). Field measurements were performed by using an HF 59B Analyzer. This device is distinguished by its accuracy in measuring the energy density levels of electromagnetic radiation in the bands used in modern communication systems. The results showed that the highest radiation power density was recorded at 6:00 PM between the two Holy Shrine, with the average radiation intensity in some evening periods exceeding $2,000 \mu\text{W}/\text{m}^2$. This is attributed to increased human activity during the evening hours and increased use of mobile phones during that time. In the Al-Ghadeer District, peak radiation was observed at 1:00 PM.



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1. INTRODUCTION

With the rapid growth of the telecommunications sector, the proliferation of telecom towers has increased significantly. Since mobile phones have become an integral part of people's daily lives due to the development of telecommunications, the widespread use of these phones has led to a massive increase in the number of mobile phone towers installed in communities. This expansion has led to increased exposure to microwave electromagnetic waves, especially those used in the 900 and 1800 MHz frequencies, which has contributed to the rise in electromagnetic pollution. Such towers comprise antennas and electronic equipment that transmit cell phone signals using radio frequency waves (Jafaar & Nema, 2019) (Yahya, 2019) (Zamanian & Hardiman, 2005). These towers are supplied with antennas and other apparatuses essential for getting and transmitting signals (Gupta, 2015).

There is increased stress, fatigue, irritability, poor sleep quality, headaches, and a host of other difficulties due to increased used of mobile phones (Miller et al., 2019) (Ying et al., 2013). The brain absorbs radio frequency (RF) or electromagnetic field (EMF) emitted by such phones through the skull (Wiart et al., 2008).

This absorbed electromagnetic radiation causes health problems. These problems have sparked the interest of researchers and scientists to study the effect of radiation levels on the human body (Foster et al., 1997).

The Federal Communications Commission (FCC) has set standards and controls to ensure that radio frequency levels, including Global System for Mobile Communications (GSM) frequencies, remain within safe limits that do not cause harmful effects. Mobile phone systems are divided into three main generations: the first generation operates in the frequency range of 450-900 MHz, the second generation (GSM) relies on digital technology in the range of 900, 1800, and 1900 MHz, while the third generation operates in the 2000 MHz range (Cansiz et al., 2016).

Although humans and animals are constantly exposed to electromagnetic radiation, analyzing its internal effects is a significant challenge due to its absorption within tissues. These effects vary depending on the radiation source, as they depend on the frequency, modulation methods, specific absorption rate (SAR) specifications, and duration of exposure. Variations in SAR values lead to tissue heating, causing different changes depending on the level of absorption. Exposure

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to low levels of electromagnetic radiation may also lead to electromagnetic hypersensitivity in humans (Traini et al., 2023) . Reported symptoms from electromagnetic radiation exposure include headaches, body aches, lethargy, tinnitus, nausea, burning sensations, irregular heartbeat, and anxiety (Kızıloğlu et al., n.d.).

Workers interact with wireless communication devices, exposing them to varying degrees of electromagnetic radiation depending on the device specifications and frequency of operation. The effect of radiation varies according to the absorption rate of each individual, so the distribution of electric and magnetic fields is analyzed to determine potential risks. Despite theoretical and experimental research, studies on radiation exposure from communication devices remain limited. According to the 2020 International Commission on Non-Ionizing Radiation Protection (ICNIRP) report (Kavet & Tell, 2023), guidelines have been developed to limit exposure, but no explicit minimum value has been established, as this depends on biological and environmental factors. Exposed groups are classified into professionals and the general public, and this research focuses on the effects on the general public.

Read (Read, 1980) explained that when a wave is emitted from its source, it emits a certain energy. As it propagates, this energy is distributed spherically and equally in all directions around the source. The further away we are from the source, the less energy the wave has. This means that as the distance from the source increases, the energy density decreases, and there is an inverse proportion between the energy density and the square of the distance. Despite the differences in the frequencies of electromagnetic waves, the waves retain the same basic shape and characteristics (Juutilainen et al., 2009) . Electromagnetic waves are used in communication processes between two points separated by a large distance, without the need for transmission media or wire lines to transmit data between the transmitter and receiver. These systems are known as wireless communication systems, which rely primarily on antennas to convert electrical signals into electromagnetic waves capable of traveling long distances. These systems have witnessed significant development due to technological advances in antenna design, given their pivotal role in improving the efficiency and success of wireless performance (Rappaport et al., 2013) (Murch & Letaief, 2002).

In study in Sri Lanka, where residential areas have witnessed an increase in the installation of mobile base stations, concerns have been raised about radio frequency radiation and its health impacts. The results showed that current exposure levels are below the permissible limits, although they are relatively high in the cities of Ratnapura and Gampaha. The highest exposure was in

Ratnapura due to the 2 GHz range, but it was still at one-tenth of the permissible limit (Karunaratna et al., 2018).

In France, in 2020, Re Grain, Caudeville (Re Grain et al., 2020) presented a mapping design to assess population exposure to radio frequency sources. Maps were developed that integrate geodatabases of individual exposure to electromagnetic frequencies (RF-EMF) within the frequency range (100 kHz - 300 GHz). A statistical tool was also designed to assess population exposure, integrating geodatabases and alternative models to describe temporal and spatial exposure to outdoor, indoor, and mobile phone sources. They concluded that built-up areas experience higher absorption rates than unbuilt areas. When the results were compared with the recommendations of the ICNIRP, the measured values were found to be significantly lower than the permissible values.

In 2020, a study was conducted in Mosul, Iraq, where the power density levels of mobile phone towers for the downlink of GSM 900 and GSM 1800 bands were measured for both Asiacell and Korek, operating in Mosul. The measurements were compared with local and international standards. An SRM-3006 device was used to measure the power density of electromagnetic radiation emitted by the towers. The results showed that the highest total density measured was 0.17914139 W/m², which was within local limits as well as within the FCC and ICNIRP limits, but exceeded the permissible limits in Russia (Al-Tamer & Al-Ahmady, 2020) .

Another study investigated the effect of electromagnetic energy density emitted by mobile phone towers in Al-Kifl District, Babil Governorate, Iraq. An EMF Strength Meter was used to measure radiation within frequencies (900–1800 MHz) at 30 points covering the study area. The results showed that the highest readings were recorded in the center of Al-Kifl District, an area characterized by its high population density and the presence of a large number of towers. Despite the high readings in some areas, they remained within the limits permitted by CMC, ICNIRP, and FCC (Huwait, 2024).

This study is a necessary study in the city of Karbala, Iraq as it fills a research gap in this field. Studies on similar topics, such as electromagnetic radiation in Karbala, are lacking. This thesis provides a comprehensive understanding of the effects of electromagnetic radiation on the residents of the holy city of Karbala. Furthermore, this thesis will provide important information to government agencies and companies involved in developing and improving the communications infrastructure, contributing to improved public health and reducing potential negative impacts on the population.

2. DEVICE USED IN THE RESEARCH: HF 59B ANALYSER

The HF 59B Analyser is a device designed to measure the energy density of high-frequency (HF) electromagnetic radiation. It is a handheld device with high accuracy operating from 700 MHz to 3.3 GHz, particularly in the critical lower and upper frequency ranges. It is equipped with a compensated antenna for frequencies from 700 MHz to 2.7 or 3.3 GHz to improve measurement accuracy. It is manufactured in Germany by Gigahertz Solutions. This device is used to measure the electromagnetic energy density emitted by cell phone towers. It is equipped with a non-folding antenna, which enables it to receive frequencies. Figure 1 shows a picture of this device. The units used to measure radiation intensity per unit area ($\mu\text{W}/\text{m}^2$) were used.



Figure 1. HF 59B Analyzer

3. DETERMINE PEAK TIME

The power density emitted by mobile phone towers varies from hour to hour throughout the day, and also from day to day throughout the week. On weekends, for example, radiation intensity levels are different from other days of the week, depending on the number of mobile phone users. To determine the peak time during a single day, three points were selected to represent three locations in the city of Karbala (one point representing a religious area, one point representing a commercial area, and one point representing a residential area). The first point was selected to represent a religious area located in the center of Karbala, in the area between the two holy shrines (the shrines of Imam Hussein and Al-Abbas. This area is considered the primary destination for visitors to the city of Karbala, and is characterized by thousands of people visiting the holy shrines daily. On important religious occasions, such as the Arbaeen and Sha'ban pilgrimages, the number of visitors reaches millions in a matter of days. On Thursdays and Fridays of each week, the number of visitors reaches hundreds of thousands. Based on the above, a study point was selected in the area between the two holy shrines. The study was conducted on Thursdays, where the population density is in the

hundreds of thousands. The second point was selected in the Al-Hussein District Street, which represents a major commercial area and a second destination for visitors to Karbala, home to malls, restaurants, and shopping areas. The third point was selected in the Al-Ghadeer District, a large and densely populated District. The coordinates of the points were determined using GPS technology, as shown in Figures 2, 3, and 4. Multiple readings were taken at these points throughout the day, at a rate of three readings per hour, starting at 7:00 a.m. and ending at 12:00 midnight.

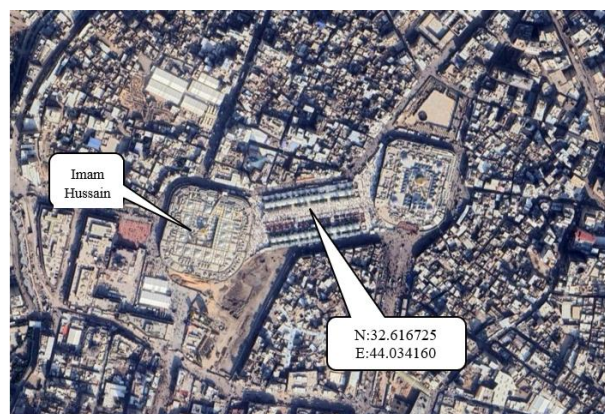


Figure 2. An aerial photo showing the study area between the two shrines in Karbala



Figure 3. An aerial photo showing the study area in Al-Hussein District Street



Figure 4. An aerial photo showing the study area in Al-Ghadeer District.

3.1. Determining Peak Times in the Area Between the Two Holy Shrines

The area shown in Figure 2 was selected, and its GPS coordinates are shown in Table 1. This table shows the readings of electromagnetic energy intensity levels in the study area (the area between the two Holy Shrines in the centre of Karbala) during time periods starting from 7:00 AM to 12:00 AM. Thursday was chosen for the study, as visits to the holy shrines are at their peak on this day of the week, meaning very high population density. Note that the table above shows electromagnetic energy intensity measurements ($\mu\text{W}/\text{m}^2$) in four different directions (I_1, I_2, I_3, I_4).

We note from the table that there is a very sharp increase in energy levels starting at 7:00 a.m. and continuing until 7:00 p.m., the peak time. Energy intensity levels remain high thereafter until midnight. The results of electromagnetic energy intensity measurements in this area show a clear pattern linked to the activity of visitors and the intensive use of mobile phones. It is noted that values were low in the early morning hours (although high compared to the rest of Karbala), with the lowest reading recorded at 7:00 a.m., averaging 170 microwatts/ m^2 . Then, as the day progressed, we observed that values began to gradually rise until they reached an average peak at 12:00 p.m. (266 microwatts/ m^2) (around the time of the noon prayers). We then observed a temporary decrease in the afternoon due to the high air temperature (approximately 43°C). After 3:00 PM, we notice a sharp increase in the average electromagnetic energy intensity, coinciding with the increasing number of visitors to the area, reaching its highest levels at 7:00 PM (close to the time of the Maghrib prayer), at an average of 2,040 microwatts/ m^2 . This is due to the increased number of users, as thousands of people gather in one area. This in turn prompts base stations to pump higher power to provide wider coverage and better connection quality. A slight decrease was observed after that, reaching 1,777 microwatts/ m^2 at 8:00

PM (Figure 5). This indicates the presence of strong sources of electromagnetic radiation in that area, such as towers. At least three mobile phone towers were observed in the area between the Two Holy Shrines, and these towers were at low altitudes.

TABLE 1. Energy density readings in the area between the two Holy Shrines in the center of Karbala city.

GPS					N:32.616725 E:44.034160	
Time	I_1 , $\mu\text{W}/\text{m}^2$	I_2 , $\mu\text{W}/\text{m}^2$	I_3 , $\mu\text{W}/\text{m}^2$	I_4 , $\mu\text{W}/\text{m}^2$	$I_{av.}$, $\mu\text{W}/\text{m}^2$	
7:00 am	165	174	186	154	170	
8:00 am	184	169	181	164	175	
9:00 am	220	194	191	225	226	
10:00 am	265	205	190	215	233	
11:00 am	265	271	199	201	246	
12:00 am	236	246	256	215	266	
1:00 pm	215	236	199	232	221	
2:00 pm	201	245	236	198	220	
3:00 pm	321	354	421	298	349	
4:00 pm	521	621	456	512	592	
5:00 pm	1201	1001	998	856	1014	
6:00 pm	1610	1645	1821	2645	1930	
7:00 pm	1921	1954	1832	2452	2040	
8:00 pm	2545	1452	1356	1221	1777	
9:00 pm	2565	1642	1564	1452	1806	
10:00 pm	1712	516	1532	2071	1714	
11:00 pm	1545	1215	2812	1121	1673	
12:00 pm	1152	1456	2724	1624	1739	

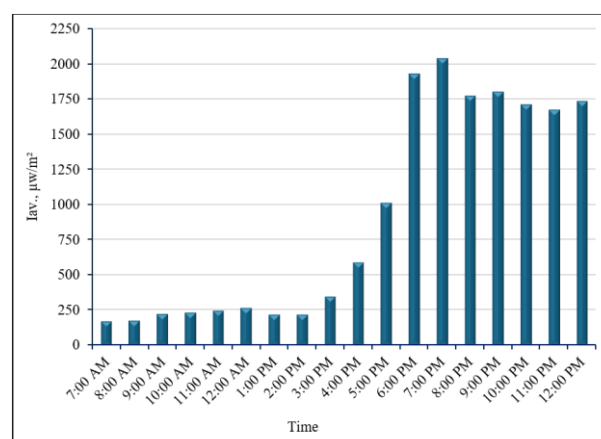


Figure 5. A diagram of the relationship between time and energy density in the area between the two holy shrines / Karbala

3.2. Determining Peak Times in the Al-Hussein District Street

We note that the values in Table 2 and Figure 6 start in the morning at relatively low levels (less than $30 \mu\text{W}/\text{m}^2$), with a morning average of approximately $20\text{-}30 \mu\text{W}/\text{m}^2$. The values then gradually increase during the day, with rates increasing significantly and reaching 34.7

$\mu\text{W}/\text{m}^2$ at 3:00 p.m., reflecting increased activity during the daytime. The highest average electromagnetic radiation values are then seen in the evening and night, with rates ranging from $38.8 \mu\text{W}/\text{m}^2$ to $57.1 \mu\text{W}/\text{m}^2$, with a peak at 11:00 p.m. This indicates the presence of strong radiation sources or increased electromagnetic activity during these hours. We also note a clear variation in values between different points, indicating an uneven distribution of radiation sources or local effects such as buildings. It can be concluded that radiation is low in the early morning, begins to rise as the day progresses, and peaks in the evening hours (6:00–8:00 p.m.). Average values (I_{AV}) range from approximately $19.8 \mu\text{W}/\text{m}^2$ in the morning to $56.8 \mu\text{W}/\text{m}^2$ at midnight.

TABLE 2. Energy density readings in the Al-Hussein district

GPS					N:32.596955 E:44.017655
Time	I_1 , $\mu\text{w}/\text{m}^2$	I_2 , $\mu\text{w}/\text{m}^2$	I_3 , $\mu\text{w}/\text{m}^2$	I_4 , $\mu\text{w}/\text{m}^2$	$I_{av.}$, $\mu\text{w}/\text{m}^2$
7:00 am	22.3	29.2	13.4	14.3	19.8
8:00 am	15.6	24.3	28.1	15.2	20.8
9:00 am	27.3	25.3	14.4	17.5	21.1
10:00 am	19.2	27.5	25.1	18.4	22.6
11:00 am	36.2	22.4	14.6	45.3	29.6
12:00 am	45.2	25.1	18.3	25.4	28.5
1:00 pm	25.6	36.4	45.2	35.1	35.6
2:00 pm	51.2	36.2	18.4	28.6	33.6
3:00 pm	18.5	27.6	35.4	57.2	34.7
4:00 pm	45.6	28.7	35.6	45.3	38.8
5:00 pm	72.3	35.4	25.4	36.2	42.3
6:00 pm	35.2	85.3	37.6	52.6	52.7
7:00 pm	96.1	35.4	62.6	29.3	55.9
8:00 pm	76.9	56.3	42.4	45.2	55.2
9:00 pm	45.2	44.3	78.2	51.4	54.8
10:00 pm	70.2	52.4	37.2	55.3	53.8
11:00 pm	76.3	51.4	45.6	54.9	57.1
12:00 pm	76.4	49.5	52.6	48.5	56.8

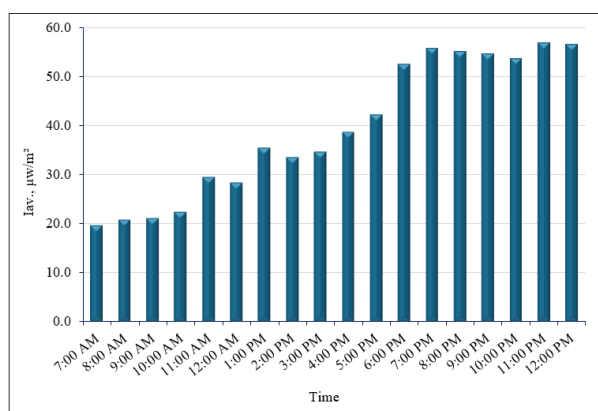


Figure 6. Time-energy density relationship diagram in the Al-Hussein commercial district

3.3. Determining Peak Times in the Al-Ghadeer District

Measurements were taken every hour from 7 a.m. to 12 midnight (Table 3 and Figure 7). Four electromagnetic radiation intensity values were recorded (I_1, I_2, I_3, I_4), with an average of (I_{avg}). We note from the average electromagnetic radiation intensity that the lowest value is approximately $36.5 \mu\text{W}/\text{m}^2$ (7 a.m.), while the highest value is $69.9 \mu\text{W}/\text{m}^2$ (1 p.m.). After that, a relative decrease is observed during the afternoon (2 p.m.). It is also noted that most values range between 55 and $70 \mu\text{W}/\text{m}^2$ during most of the day and evening hours. In the evening, it is noted that the values maintain an average level of $60\text{--}68 \mu\text{W}/\text{m}^2$. At 8:00 p.m., we notice a clear increase, reaching a value of ($96.4 \mu\text{w}/\text{m}^2$) is the highest I_4 value in the table, with the average continuing to rise ($68.1 \mu\text{w}/\text{m}^2$).

TABLE 3. Energy density readings in the Al-Ghadeer district

GPS					N:32.608023 E:43.994475
Time	I_1 , $\mu\text{w}/\text{m}^2$	I_2 , $\mu\text{w}/\text{m}^2$	I_3 , $\mu\text{w}/\text{m}^2$	I_4 , $\mu\text{w}/\text{m}^2$	$I_{av.}$, $\mu\text{w}/\text{m}^2$
7:00 am	36.2	45.6	29.6	34.6	36.5
8:00 am	45.3	39.2	45.6	48.1	44.6
9:00 am	56.3	62.3	48.4	45.2	53.1
10:00 am	81.6	77.3	49.4	45.3	63.4
11:00 am	91.1	82.4	45.6	38.3	64.4
12:00 am	82.3	40.3	72.3	51.2	61.5
1:00 pm	90.3	76.3	56.4	56.5	69.9
2:00 pm	91.4	68.3	34.5	25.6	55.0
3:00 pm	82.3	45.6	45.6	56.4	57.5
4:00 pm	49.3	56.3	80.2	58.3	61.0
5:00 pm	60.3	84.6	54.6	48.6	62.0
6:00 pm	61	76.5	50.1	79.3	66.7
7:00 pm	77.1	53.2	79.4	54.2	66.0
8:00 pm	68.4	40.3	67.2	96.4	68.1
9:00 pm	91.2	68.3	60.5	45.9	66.5
10:00 pm	86.5	47.3	97.2	32.1	65.8
11:00 pm	50.6	87.2	45.3	88.4	67.9
12:00 pm	76.4	81.7	49.5	56.2	66.0

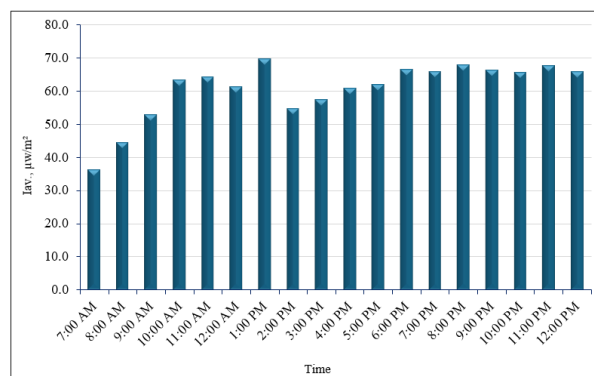


Figure 7. The relationship between time and energy density in the Al-Ghadeer district

3.4. Comparison of peak times

Figure 8 show a comparison between the peak measurement areas for the average intensity of electromagnetic energy density ($I_{avg.}$, $\mu\text{W}/\text{m}^2$) in three different areas of Karbala city, representing diverse urban and functional patterns: religious (the area between the two Holy Shrines), residential (Al-Ghadeer District), and commercial (Al-Hussein District Street). This comparison helps clarify the extent to which the type of human activity and the intensity of technological uses in each area affect energy density levels.

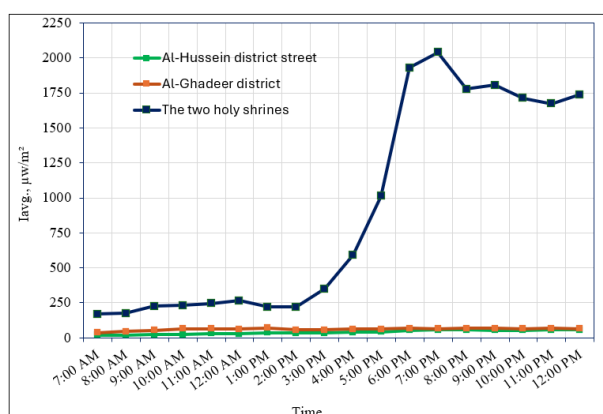


Figure 8. Comparison between peak measurement areas over a full day

4. CONCLUSIONS

Based of the result of this study, the following can be concluded:

- The measurement results showed a clear variation in electromagnetic radiation intensity levels between the studied areas. The area between the Two Holy Mosques recorded the highest electromagnetic energy intensity values, with averages reaching more than $2,000 \mu\text{W}/\text{m}^2$ in some time periods. This is attributed to the high density of telecommunications towers and increased human activity in this area, in addition to the presence of multiple radiation sources within a narrow geographical area.
- To demonstrate the effect of time on radiation energy density, three points were selected within different areas of Karbala city center, including the area between the two holy shrines, Al-Ghadeer District, and Al-Hussein District Street. At each point, coordinates were established, and measurements were conducted throughout the day, starting from 7:00 a.m. until 12:00 a.m. The location between the two holy shrines, considered an important religious area, recorded high levels of more than $2,000 \mu\text{W}/\text{m}^2$ at 6:00 p.m., reflecting peak usage in this densely populated area during the evening hours. On the other hand, areas such as Al-Hussein District Sreet

and Al-Ghadeer District recorded relatively low radiation levels, ranging between 20 and $70 \mu\text{W}/\text{m}^2$, reflecting the scarcity of radiation sources and the low number of towers in these areas, which have relatively lower population densities compared to the city center.

- When readings were taken at different times of the day, a relationship was observed between the timing of the measurement and the recorded radiation energy intensity levels, with radiation intensity gradually increasing as the day progresses, reaching its peak in the evening hours (particularly after 5 pm and until 9 pm). This is attributed to the increased heavy use of mobile phone networks during these times of the day as a result of intense population activity.
- Although some relatively high readings were recorded in some locations, all measurements remain within the permissible limits recommended by the WHO and the ICNIRP, indicating that there are no immediate risks to public health at these levels.
- The results of field measurements in different areas of Karbala showed a clear variation in the radiation levels recorded from one area to another, depending on the nature of each area in terms of population density, commercial activity, and the number of communication towers available. These results underscore the importance of continuing to monitor radiation levels regularly, especially in densely populated areas, and of working to distribute telecommunications towers in a thoughtful manner that balances service quality with maintaining public safety.

Acknowledgments

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