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Enhancing Sustainable Urban Development: Towards Safe Electromagnetic Environment in Jordan, the Case of Amman

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ABSTRACT

Cities in the age of speed need urban plans that lead the process of their large expansion and provide the appropriate infrastructure in a way that does not pose a health risk to their residents. High-voltage electrical towers within the residential areas are one of Amman's urban problems that need further study and analysis. These high-voltage power lines expose the population to electromagnetic radiation, which has become one of the problems of the modern city and constitutes electromagnetic pollution. This study measured the levels of electromagnetic radiation in selected sites in Amman City and compared the measured values with the international standards of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The basic method adopted in this study was field measurements of the Electromagnetic fields in two residential locations in Amman City, the device used in the measurements was BR-9 EMF detection device; measurements were conducted at distances ranging from zero directly underneath the high voltage wires and ending at a far distance of 18 meters. The study concluded that all measurements were within the safe limit for constructing buildings near high-voltage lines. But for the places designated for children where they spend a long time, the standard adopted by some countries globally shows that buildings near the 132 kV lines should be 3-6 meters away, while near the 400 kV lines, it should be 15-18 meters away.

1. INTRODUCTION

Human health under overhead high-voltage electricity lines has been the subject of numerous studies over the last decades. The potential health effects of living near high-voltage power lines have been the subject of considerable debate and speculation, with many people expressing concerns about the potential risks posed by exposure to the electromagnetic fields (EMF) generated by these power lines. Overhead high voltage lines are a sub-group of a wide range of electric devices humans interact with, including cell phones, microwave ovens, hair dryers, refrigerators, Televisions, Remote controls, vacuum cleaners, and many others. A percentage of around 70% of total exposure to power frequency magnetic fields is in workplaces, especially in industrial workplaces [1]. Concerns raised about the human interaction with devices of different frequencies; in 2011, the IARC considered radiofrequency electromagnetic fields as possibly carcinogenic to humans, due to an increased risk for glioma and acoustic neuroma, associated with wireless phone use. However, scientific uncertainty and available literature do not indicate an increased risk [2]. Research reports issued by the Ministry of Health in New Zealand support the low probability of health risks due to electromagnetic field exposure [3]. Even though this article is concerned with overhead high voltage transmission lines, it is worth mentioning some issues about other sources of electromagnetic field, especially those indoors. Humans are exposed to a wide range of electrical and magnetic frequencies, either indoors or outdoors, continuous contact like home electric devices, and outdoors like transmission lines and industrial environments.

In modern times, power consumption increased, especially the low-frequency magnetic fields from power distribution lines generally called “electromagnetic pollution” widely increased. Tackling the issue of a clean environment of electromagnetic pollution has gained wide interest worldwide only in the last ten years, and many scientific explorations are still ongoing [4].

Urban design contributes greatly to proper population expansion and sprawl on the regional and urban levels, which helps enhance the quality of life and well-being and maintain a healthy environment. A missing or unorganized urban design scheme before the expansion process within Amman is a reason for many infrastructure problems facing the city, as the increasing demand for electrical energy within urban communities necessitates an increase in the number of electrical extensions.

2. THEORETICAL FRAMEWORK

The capital, Amman, is witnessing substantial urban growth and an increase in the expansion of buildings all around the city at an accelerating rate. This led to an increase in the demand for electricity and its infrastructure, including power transmission lines or transformer stations. On the other hand, buildings overlapped with existing power lines, and it became a common scene to see high-voltage lines penetrating the city's urban fabric above residential, commercial, and industrial buildings. Also, there is a rising concern within the general population regarding the effects of these transmission lines, as people tend to believe that owning a house close enough to these infrastructures might affect the occupants' health, leading to a decreased demand for these homes resulting in economic losses.

The main objectives of this study might be listed briefly; first, to conduct field measurements of the electromagnetic field; and inside buildings near overhead high voltage lines; second, to compare the measurements with international regulations standards governing the density of electromagnetic field; third, to determine the safe distance that must separate the overhead high voltage lines and the surrounding buildings to guarantee a safe electromagnetic environment for residents; fourth, to suggest recommendations for improving legislation governing construction around high-pressure lines, and safe distances to be established near high-voltage infrastructures; fifth, to determine and measure the extent of the danger posed by the presence of towers and high-voltage lines near buildings within the urban fabric of the city.

The previous objectives will help understand how good urban planning helps reduce residents' exposure to electromagnetic fields by appropriately planning multiple sources of electromagnetic pollution within urban city planning. Motivating planners and officials to develop legislations that help achieve a safe urban electromagnetic environment by controlling electromagnetic pollution sources and their distribution within the city to follow international standards.

Electromagnetic pollution from silent sources such as overhead power transmission lines has become one of the most important concerns for researchers worldwide, in terms of health and the development of a sustainable built environment.

This study is the starting point for other studies focusing on urban electromagnetic pollution, as one of the hot topics in modern urban development. To highlight the dangers of electromagnetic pollution within the urban electromagnetic environment of Amman.

3. LITERATURE REVIEW

Health effects of electromagnetic fields are gaining more attention; Experimental health studies inside and outside the body show the great importance of the biological effects of electromagnetic fields, as these studies indicate the link between exposure to electromagnetic fields and the state of some cancerous tumors. The effects of electromagnetic fields are divided into thermal and non-thermal effects. The nature of the biological symptoms that can occur because of exposure to electromagnetic fields depends on the amount of radiation absorption rate and the duration of exposure to electromagnetic radiation [5].

According to Mathloom [5], the results of the study in which he collected blood samples from people who live near high voltage lines within 100 meters or less to 600, and blood samples from people who live far from high voltage lines at not less than 5000 meters, this is related to the third objective. It was found that the electromagnetic fields emanating from the high voltage lines caused numerical changes in the blood parameters, as noticed that there was a clear increase in the number of white blood cells in the blood samples taken from people living near the high voltage lines compared to those who live far from them [5].

The International Agency for Research on Cancer (IARC) considered RF-EMFs as possibly having the potential to cause cancer in humans and warned of the danger of (ElectroMagnetic Field) EMF exposure. Neurological effects may happen because of RF-EMF exposure due to the closeness of the cranial nervous system, where the location of the cellular phone is predominantly used. These neurological abnormalities include changes in (ElectroEncelaphoGram) EEG, changes in sleep habits, and headaches [6].

Studies on the health effects of high-voltage power lines have produced mixed results, with some studies suggesting that there might be a link between exposure to high levels of EMF and an increased risk of certain health problems, including cancer, birth defects, and other diseases. However, other studies have found no such link, and the overall weight of scientific evidence suggests that exposure to high-voltage power lines does not pose a significant health risk to the general population, and this might be related to the third objective of the study.

One of the key factors that have complicated efforts to determine the potential health risks of high-voltage power lines is the difficulty in accurately measuring exposure levels. EMF levels can vary greatly depending on factors such as the distance from the power line, the orientation of the power line, and other environmental factors.

Despite the lack of clear evidence linking high-voltage power lines to adverse health effects, many people remain concerned about the potential risks posed by these structures. Some researchers have called for additional studies to be conducted to further evaluate the potential health effects of exposure to high voltage power lines and to better understand the mechanisms by which EMF might affect human health, and this is one of the reasons beyond implementing this study, this might include all objectives stated in this article.

Some epidemiological studies about the effects of exposure to 50/60 Hz electromagnetic fields reported that there is a possible correlation between exposure to Extremely Low frequencies of electromagnetic fields and the increased risk of cancer [7], and other health disturbances [8].

EMFs of 50/60 Hz do not seem directly to cause damage to the genetic material, but a few studies showed certain changes to how cells function when exposed to ELF-EMFs such as structural changes of DNA, leading to interruption in DNA sequence and other chromosomal abnormalities [9].

Alkoot and Zaeri [10] measured the ELF- magnetic field radiation levels emitted from power transmission lines in Kuwait, where they monitored the studied areas for more than 12 months, low-level densities were observed, and other areas showed high electromagnetic levels in uninhabited areas, they concluded that most inhabited regions were safe environments [10, 11], they also measured the magnetic field levels close to power transmission lines at inhabited areas in Kuwait in summer, fall, spring and winter three times a day, results showed values higher than 4 mg at house outdoor parking [11].

Similar studies implemented in the Middle East, Oman [12], Palestine [13], Egypt [14], Algeria [15], Tunisia [4, 16]. According to Tabrizi et al. [17], Ellithy measured the density of the magnetic field around and in electrical distribution substations near residential areas in Doha, Qatar; the results showed that in the majority of measurements, the density of EMF is lower than international standards set by ICNIRP. The same method was applied in Malaysia, results showed that substations close to buildings were more influential than those installed far away in the same compound [17], the fifth objective is intended to be achieved in this study.

Effects of EMF are not only restricted to humans, but they also influence animals and plants, exposure to high voltage power lines results in a decrease of 5% in milk yield, 13.8% in fat milk yield, and 16.4% in milk fat among cows; also it has been proved that EMF affects plants as well, growth characteristics like shoot length, root length, leaf area, leaf fresh weight, specific leaf weight, and total biomass content were reduced significantly [18], more about effects of EMF upon biological systems is found in previous studies [19-23]. Finally, Gajšek et al. [24] summarized some of the literature conducted in Europe, where they stated research work related to exposure assessment and monitoring in Europe; spot measurement in outdoor and indoor environments; residential exposure; measurement close to transformer stations; measurement of exposure due to transport systems; exposure to intermediate frequencies; personal exposimetry; and exposure characterization of EMF emitting devices.

3.1 Urban electromagnetic environment

Electromagnetic pollution has become one of the new urban problems facing modern cities, the lack of coordination between the planning of the city and the development of the electromagnetic environment within it leads to a gap and an increase in urban electromagnetic environmental pollution. Electromagnetic Hyper Sensitivity (EHS) or idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF) is a syndrome caused by human exposure to electromagnetic fields due to the intensive spread of electromagnetic fields in the urban environment, EHS is a new syndrome, and it can be caused by the EMF exposure below the EMF thermal effect threshold, some of the EHS symptoms may show Headaches that get progressively worse, Eye strain, dry eyes, blurred vision, facial flushing, tinnitus and other types of ringing and buzzing in the ears, nausea, dizziness, shortness of breath, pressure in the chest, irregular heartbeat, chronic fatigue and weakness, muscle aches and pains, fibromyalgia, arthritic pains, prickling sensations, numbness in fingers, burning sensations, skin rashes, itchiness, blotchiness or even whole-body skin symptoms, stress, depression, anxiety, poor concentration, other mood disorders, brain fog, memory loss, memory deficits confusion, disorientation, and disturbed sleep [25]. Sources of electromagnetic pollution that humans are exposed to are multiple, just to mention examples as electrical appliances for example, electrical wiring, electrical transformers, inverters, power boxes, radial tires in motion, high voltage power lines and transformers, elevator power rooms, air conditioning and heating systems, car electrical systems, and electric and hybrid cars [25].

4. HISTORICAL OVERVIEW

The first appearance of electrical impulse transmission over long distances was in the year 1729 by Stephen Gray, while the first high voltage transmission between Munich and Miesbach in Germany of length 60 Km in the year 1882, Figure 1 depicts the high voltage transmission development over time [26, 27].

Electromagnetic waves have the same characteristics, but they differ in wavelength and frequency. Figure 2 shows the electromagnetic spectrum and its classification. Note that when frequency increases, the wavelength decreases and vice versa. To learn about these interactions, it is important to understand the physical properties of the waves of the magnetic spectrum [27]. Electromagnetic radiation is waves consisting of two fields that spread in two perpendicular directions, the electric field and the magnetic field that carry energy called photons launched perpendicularly to both directions.

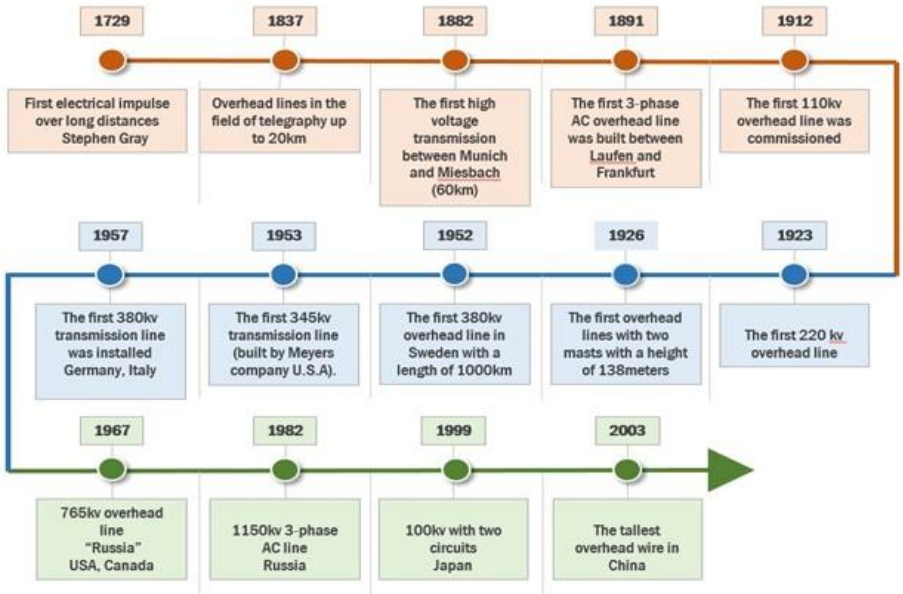


Figure 1. Chronological development of overhead high voltage transmission lines related to voltage
Source: http://www.academic-accelerator/encyclopedia, 2023

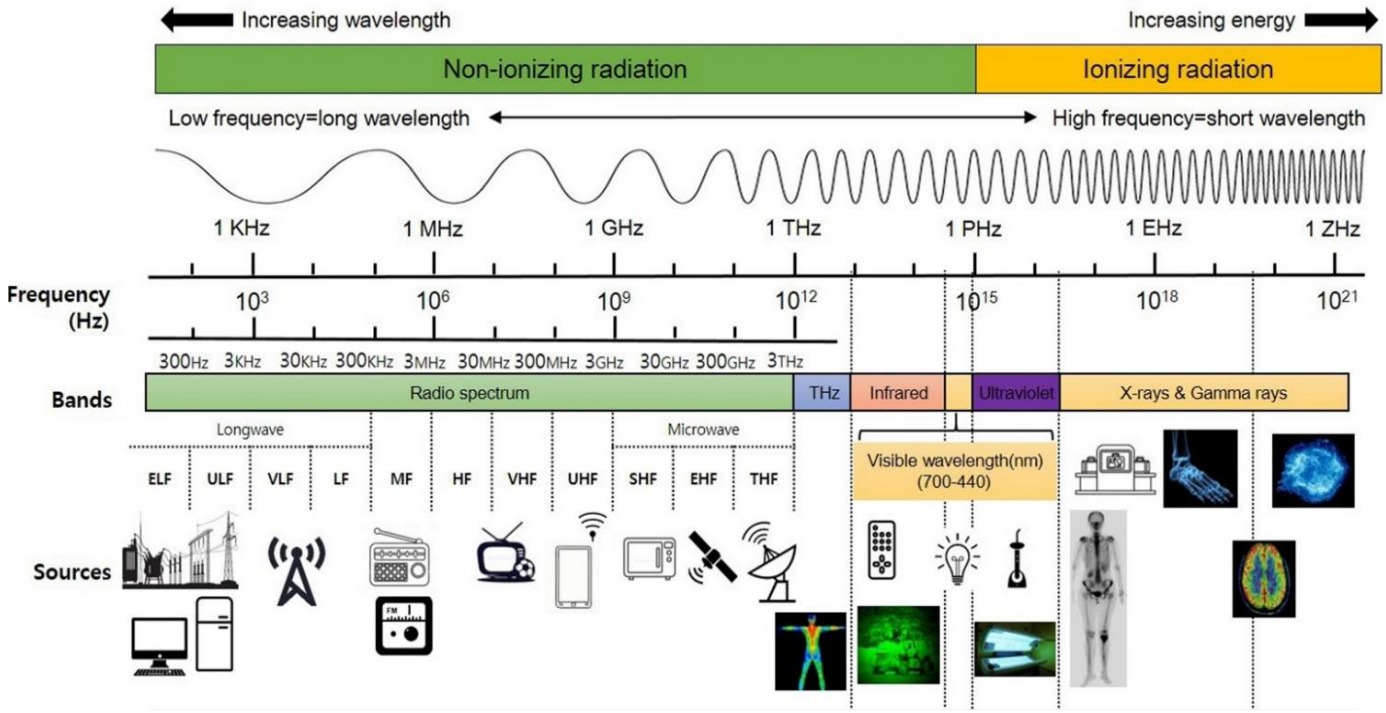


Figure 2. Electromagnetic spectrum [6]

5. THE NATURE OF HIGH VOLTAGE ELECTRICITY

Electromagnetic waves are classified according to their energy into Ionizing radiation: electromagnetic waves that have very high energy which means they "can induce the process of the ion (meaning the formation of atoms or parts of molecules charged with negative or positive charges)" [27]. They have very high frequencies (X-rays and gamma rays). Non-ionizing radiation: electromagnetic waves have weak photon energy, which is not able to break atomic bonds such as (ultraviolet, visible light, infrared, Radio waves, microwave, and extremely low-frequency waves). The energy of a photon is determined by the following relationship and depends on the frequency f:

$$E = h^* f \tag{1}$$

The value h given in the formula is the so-called Planck constant: $h = 6.63 \times 10^{-34}$ J·s. as well, mathematically, the magnetic field is calculated by the biot-savart equation, as follows:

$$\vec{B} = \mu_o \int_l i \frac{\vec{dl} \times \vec{r}_o}{4\pi r_o^3} \tag{2}$$

where, $\mu_o = 4\pi \times 10^{-7}$ Tm/A is the permeability of free space, I is the line current, dl is a differential element of the conductor in the direction of current and r_o is a distance vector from the source given by (X, Y, Z) to the field point P (X_o, Y_o, Z_o) [28]. The calculation of the magnetic flux B in the area adjacent to the line can be computed using differential equations techniques, which the above-mentioned Biot-Savart law. Which in turn could be simplified by CEI 211-4:2008 and ISO 17.220.20 technical standards [29].

Due to rapid technological development, the spread of electromagnetic radiation sources is evident, and these radiations become a major concern. Because of the possibility of health harms accompanying the exposure of the public to these waves, studies have proven the existence of a relationship, yet not understood so far. They affect sleep habits, headaches, blood pressure, and the nervous system and increase the likelihood of developing cancer and other health problems. Therefore, international organizations have released a set of rules and guidelines that govern people's exposure to such radiation, whether they are workers in the field or the public. In the early 1990s, the World Health Organization undertook research on the biological effects of radio-frequency electromagnetic waves. As a result, precise guidelines for the limitation of exposure to electromagnetic fields with frequencies up to 300 GHz were specified in 1998 [30]. These guidelines (Recommendation1999/519/EC) are prepared by an organization of independent scientists, operating in the framework of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in collaboration with the World Health Organization.

International Commission on Non-Ionizing Radiation Protection (ICNIRP) is considered the most reliable reference by countries around the world for exposure limits to electromagnetic fields. However, several other global organizations are globally accredited, such as The Society of Electrical and Electronics Engineers (IEEE), American National Standards Institute (ANSI), American Conference on Government Industries (ACGI), and The Federal Communications Commission (FCC).

According to ICNIRP [31], the reference levels for general public exposure to time-varying electric and magnetic fields are shown in Table 1 below.

Table 1. Reference levels (highlighted in yellow color) for general public exposure to time-varying electric and magnetic fields [31]

Frequency Range	E-Field Strength (V m^{-1})	H-Field Strength (A m^{-1})	B-Field (mT)	Equivalent Plane Power Density Seq (W m^{-2})
Up to 1 Hz	----	1.63×10^5	2×10^5	----
1-8 Hz	20000	$1.63\times10^5/\ f2$	$2\ 3\ 10^5/\ f2$	----
8-25 Hz	20000	$2\times10^4/\ f$	$2.5\ 3\ 10^4/\ f$	----
0.025-0.82 kHz	$500/\ f$	$20/\ f$	$25/\ f$	----
0.82-65 kHz	610	24.4	30.7	----
0.065-1 MHz	610	$1.6/\ f$	$2.0/\ f$	----
1-10 MHz	$610/\ f$	$1.6/\ f$	$2.0/\ f$	----
10-400 MHz	61	0.16	0.2	10
400-2000 MHz	$3/\ f1/2$	$0.00/\ f1/2$	$0.01\ f1/2$	$f/40$
2-300 GHz	137	0.36	0.45	50

Since the frequency of the electric current in high voltage lines is 50 hertz [27, 32, 33], the values shaded in red in the table express the limits that govern electromagnetic radiation around high voltage lines. Different countries have varying standard limit exposure values to the electro–magnetic field, and also according to ICNIRP 1998 b according to the WHO report 2007, the report stated that for Switzerland the exposure limit of magnetic fields and electric fields near homes, apartments, schools, hospitals, playground based upon the maximum rated current of the power line is determined to be 10 mG and 1 µT, 2 mG and 0.2 µT for Italy, 4 mG and 0.4 µT for Netherlands [34, 35].

Some health studies showed a relationship between magnetic fields above 0.3/0.4 µT and the risk of childhood leukemia [36]. Therefore, many countries adopt the threshold value of (0.4 µT) as the permissible limit for radiation in facilities for children occupation; Finland considers the threshold value of (0.4 µT) of magnetic flux density as a reference level for locations through which power lines pass, and where children spend time, such as homes, schools, and nurseries. Netherlands and Norway have similar standards [37].

6. MATERIALS AND METHODS

The main method conducted is the field measurement method, where some of the main questionable sites are investigated, two main overhead high voltage transmission lines were explored, 132 kV and 400 kV respectively. As shown in later sections, the major transmission lines passover the regional lands of Jordan. Investigated and measured locations were selected with high power voltage lines passing over dense residential neighborhoods in Amman City.

6.1 Current situation in Jordan

Jordan is a Mediterranean country. Its climate according to the Köppen climate classification, is a transition between Mediterranean and Semi-arid climates.

The following map shows the main routes of transmission lines through Jordan. The electricity network connects between power generation stations reaching the electricity end user. Some lines connected with neighboring countries for network integration purposes.

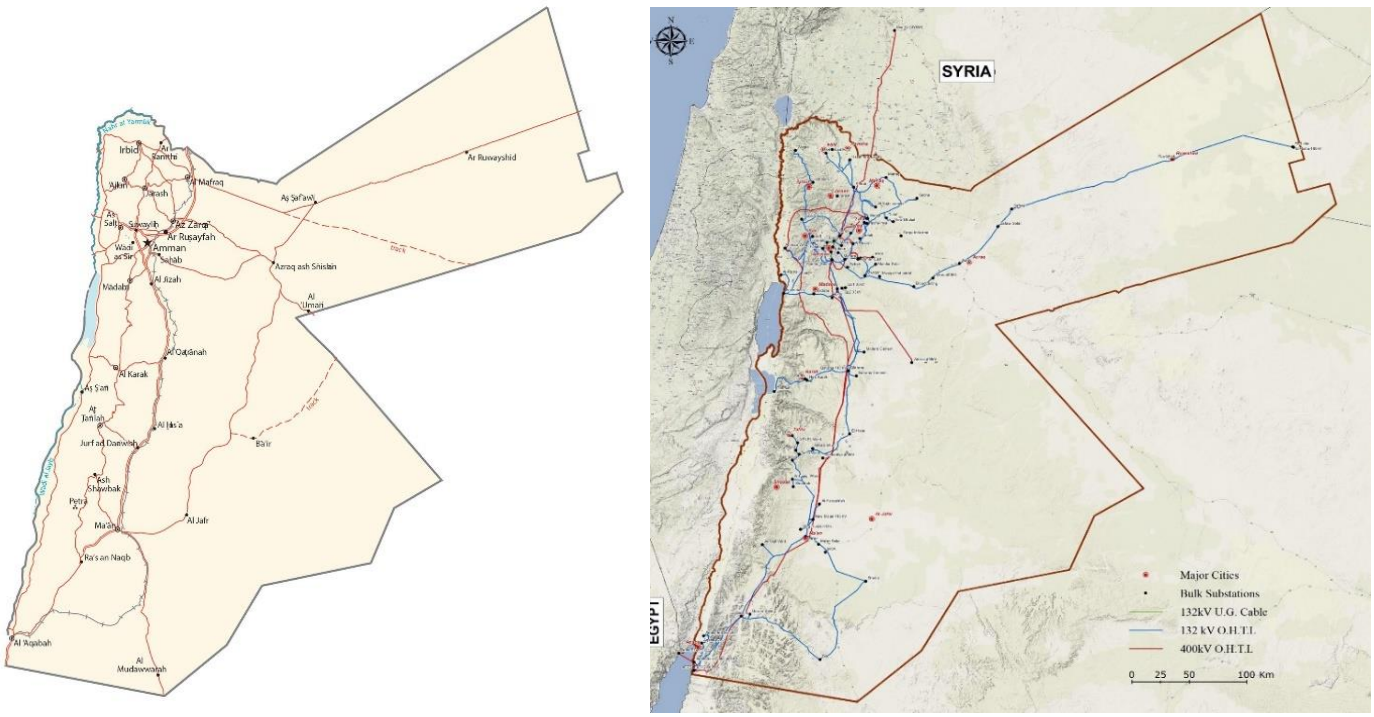


Figure 3. Map of Jordan and overhead high voltage transmission lines in Jordan, 132 kV and 400 kV [38]

The national electricity generation sector generates and distributes electricity in a well-structured and organized manner, Figure 3 shows the national electricity generation structure in Jordan, where a national hierarchical voltage grid is comprehensively distributed nationwide, and in many instances Jordan exports electricity to the neighboring countries [39]. Figure 4 displays the organizational structure of the electricity distribution throughout Jordan.

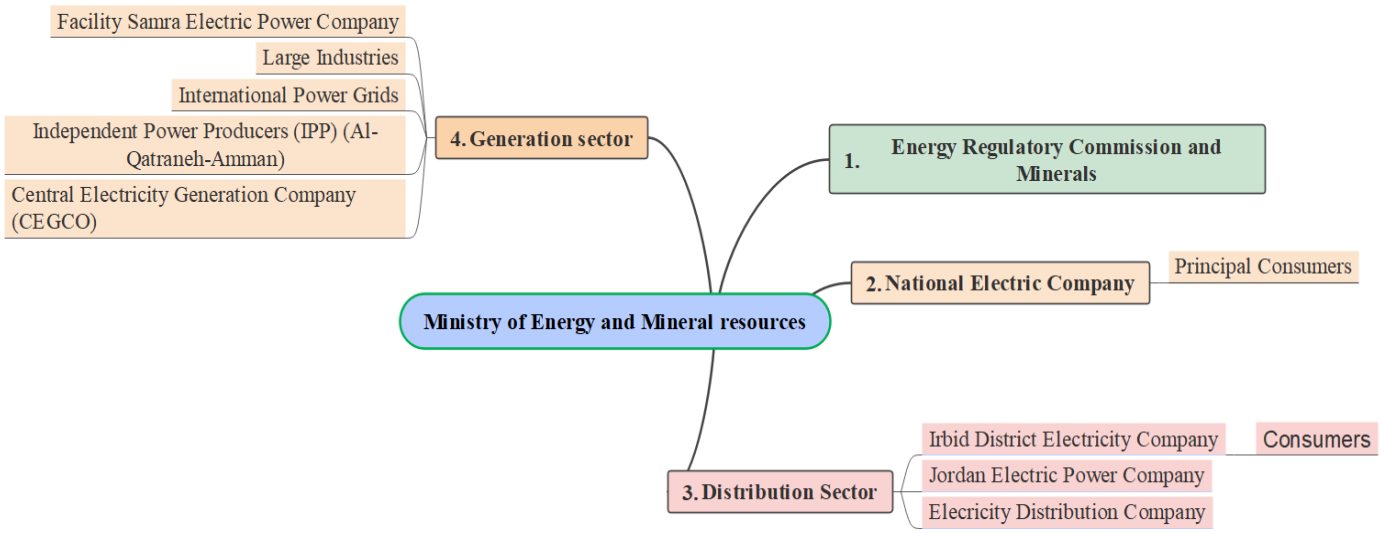


Figure 4. Network of electricity energy generation in Jordan [39]

6.2 Problem identification

The city of Amman seems to have overhead high voltage electricity transportation lines crowded over dense urban settlements, with risky heights as shown in Figure 5; researchers tracked this phenomenon to explore its spread in the city and monitor the places that represent a hot case to study. Many high-voltage current lines are of different risky values, 132 kV and 400 kV, lower voltage values also exist but it assumed to be of low risk.

Figure 5. High voltage transmission lines (double circuit lines) passing over urban settlements

6.3 Site selection criteria

The following criteria are defined for selecting the areas in which to measure the value of the electromagnetic field intensity, based on the value of high voltage line passing through the study area, it has been observed the presence of high voltage power lines, 132 kV and 400 kV, passing over both crowded and less crowded residential zones.

6.3.1 Field measurement instrument

A radiation detector called (BR-9), Figure 6, is used to measure the electric field and magnetic field associated with high-voltage lines in the mentioned sites. Specifications of the device are as follows: The threshold setting of this device is based on the EMF project of the World Health Organization (WHO) and the relevant guidelines issued by the International Commission on Non-ionizing Radiation Protection (ICNIRP) in 1998. Table 2 shows the device's technical specifications.

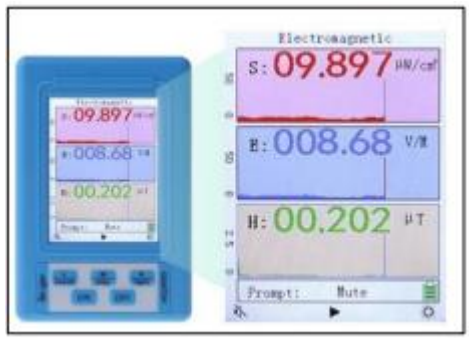


Figure 6. The device used for field measurement, (BR-9 EMF detection device)

Table 2. BR-9 technical indicators and specifications

Parameter	Specification
Test range	Power density 0-99.999 μw/cm^2 Electric field intensity 0-999.99 v/m Magnetic field intensity 0-99.999 μT
Test accuracy	Power density 0.001 μw/cm^2 Electric field intensity 0.01 v/m Magnetic field intensity 0.001 μT
Frequency range	Power density 50 MHz-5 GHz Electric field intensity 20 Hz-100 MHz Magnetic field intensity 20 Hz-1MHz

Research measurements procedure: Measurements taken of the electric field and magnetic field emitted by the high voltage lines, at a height of 1.5 from the ground, and at a height of 2.5 from the ground. The measurement points are distributed as follows: under high voltage lines, 3, 6, 9, 12, 15, and 18 meters away from the overhead centerline. The measurements also included the following cases,

Measurements inside buildings adjacent to the high-voltage line, and external measurements around the high-voltage line.

7. FIELD MEASUREMENTS

One of the major limitations of field measurements is the probability of results 'variations according to the time and conditions in which the measurement process took place, such as temperature, humidity, line length, etc. All the factors mentioned might affect the values of the electromagnetic field [27]. The measurements may differ according to the season, summer, or winter. Measurements were conducted during July 2022.

A group of sites was selected to test the values of the electric field and the magnetic field associated with high voltage lines (400 kV and 132 kV) distributed within Amman City so that the study would be as comprehensive as possible to represent most of the cases. The following map shows the selected sites for conducting field measurements of the electric field and magnetic field: sites where a high voltage line of 400 kV passes in Alyadudah and Sahab, and sites where a 132 kV line passes in Tabarbor and Wadi Alseer within Amman District (Figures 7 and 8 below).

Table 3 shows conducted field measurement locations and the related urban density constraints. Field measurements are shown in Table 4 below, the measurement device was located at predetermined distances from the center line directly under the overhead high-voltage power lines at distances: 0, 3, 6, 9, 12, 15, and 18 meters. In some cases, 21 m away is measured.

Table 3. A summary of the field measurement cases in Amman District, Tabarbour, and Sahab will be demonstrated in this article

Location	Voltage (kV)	Urban Land Use	Density
Tabarbour	132 kV	Residential area	Dense area
Wadi Al seir	132 kV	Residential area	Dense area
Alyadoudeh	400 kV	Residential area	Dense area
Sahab	400 kV	Residential area	Dense area

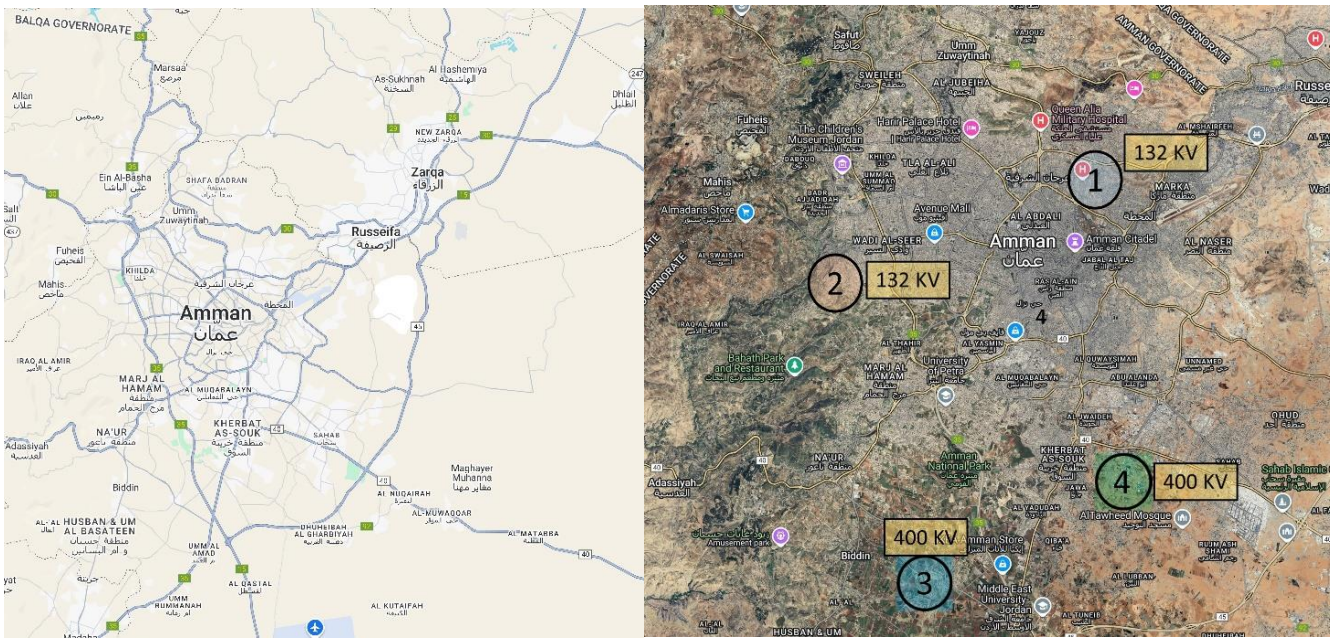


Figure 7. A map showing the selected sites, Amman City 1. Tabarbour 132 kV; 2. Wadi Alseir 132 kV; 3. Alyadoudeh 400kV; 4. Sahab 400 kV
Source: [40]

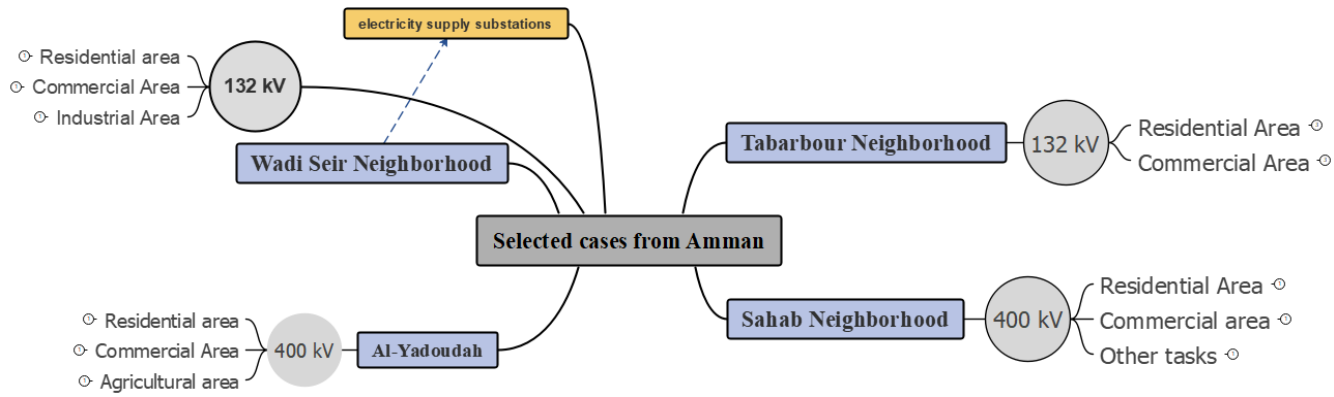


Figure 8. Schematic of main overhead high voltage transmission power lines in Amman, Tabarbour, and Sahab will be demonstrated in this article

Table 4. The electric and magnetic field measures at Tabarbor – line 132KV, measurements shown for four sections only

Field Measurements – Tabarbor Neighborhood, Voltage 132KV								
	Section 1		Section 2		Section 3		Section 4	
Distance from center line (m)	EF (v/m)	MF (µT)	EF (v/m)	MF (µT)	EF (v/m)	MF (µT)	EF (v/m)	MF (µT)
0	892.1	25	8.13	0.255	335.8	4.1	8.6	0.25
3	210	2.6	10	0.3	65.8	2.1	5	0.15
6	10	0.27	14.7	0.455	8	0.3	3.2	0.15
9	5.5	0.17	12.2	0.355	3.55	0.16	5.3	0.15
12	5.3	0.2	12	0.38	5	0.17	4.3	0.12
15	5	0.17	13.3	0.455	5.5	0.17	2.5	0.05
18	5.5	0.2	13.2	0.455	5	0.15	1.5	0.05
21	7.8	0.27	-	-	-	-	-	-

EF: Electric Field (v/m); MF: Magnetic Field (µT)

8. RESULTS

8.1 The case of Tabarbour neighborhood, Amman City

It has been noticed that the 132 kV electric wires are close to the street due to the differences in site topography shown in Figure 9. There are warning signs on the edge of the street warning the passage of vehicles higher than 3.5. The electric and magnetic values decrease rapidly when moving away from the center of the electric line as shown in Table 5. The reason for the high readings of the electric and magnetic fields may be the interference of frequencies of a telecommunication tower located on the building next to the power lines. Electricity lines pass directly above a mosque and next to a residential building. Therefore, the measurements inside the building are important to know the values of the electric and magnetic fields inside the buildings.

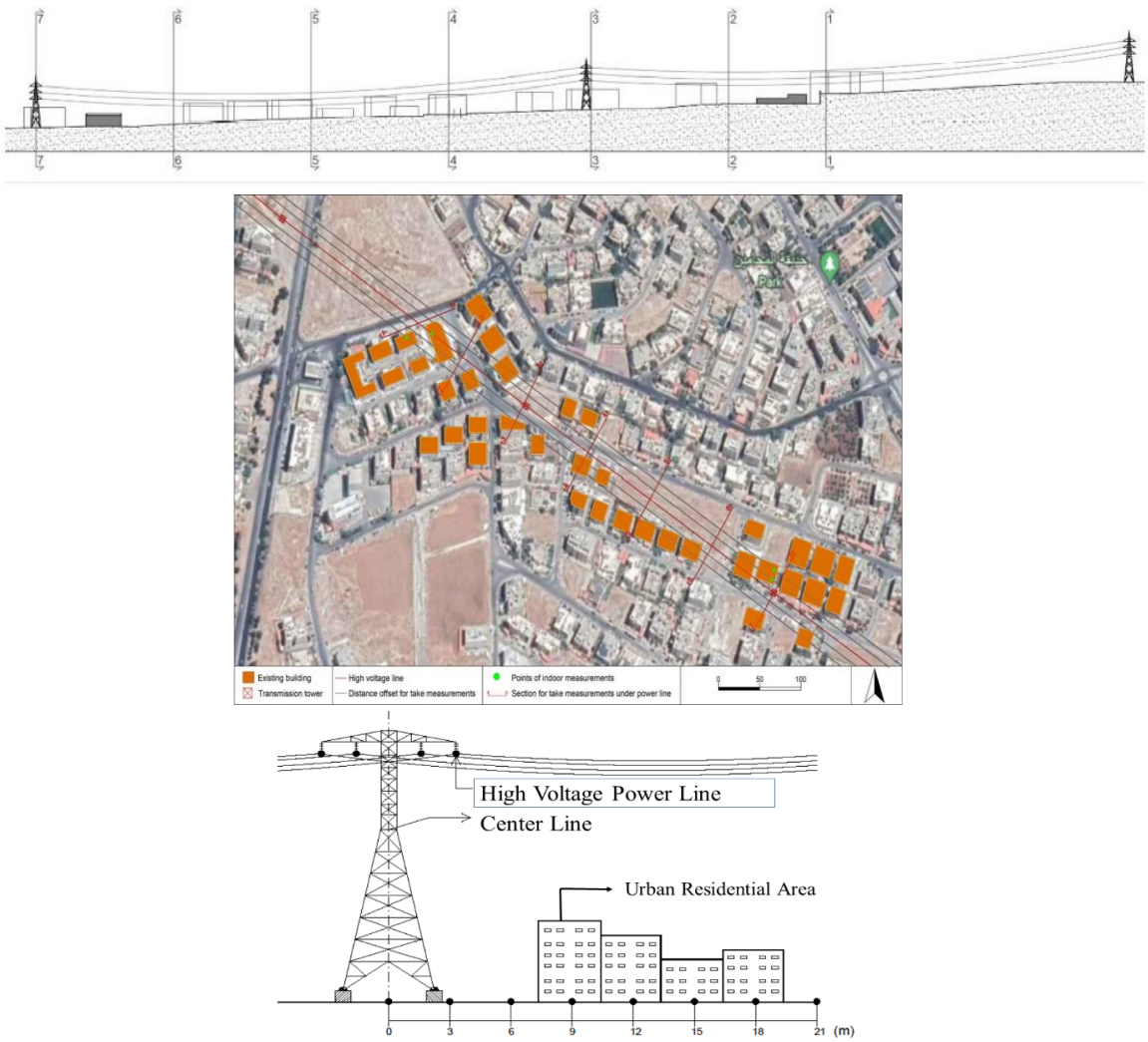
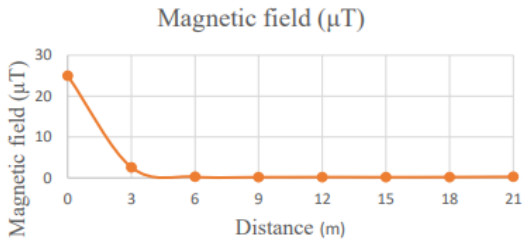
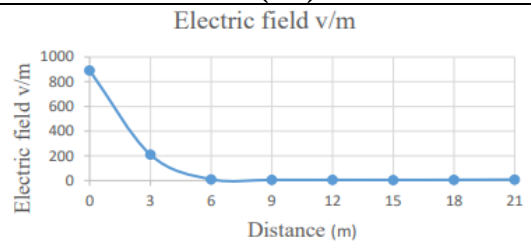
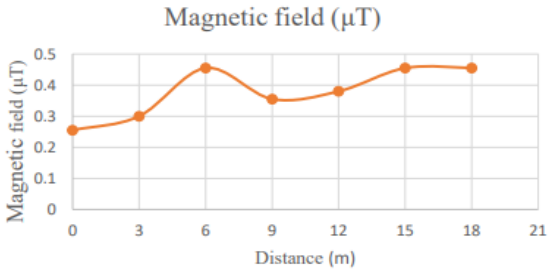
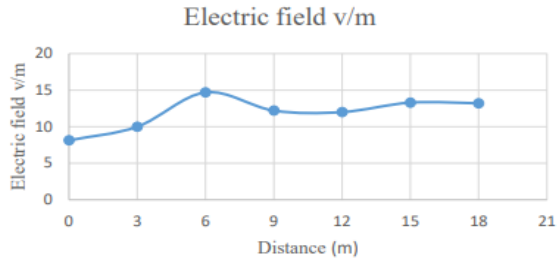
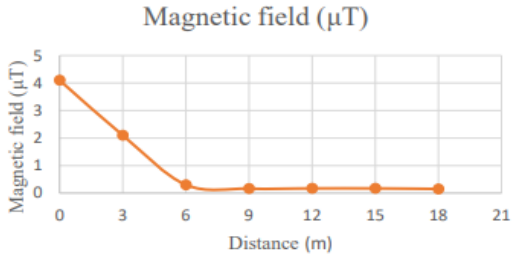
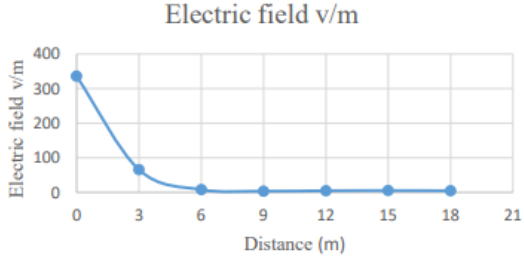
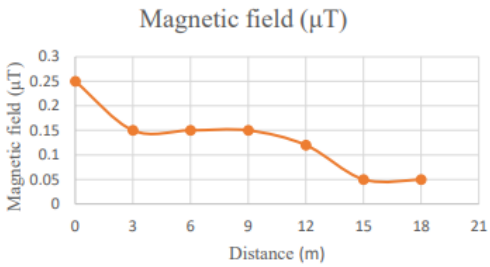
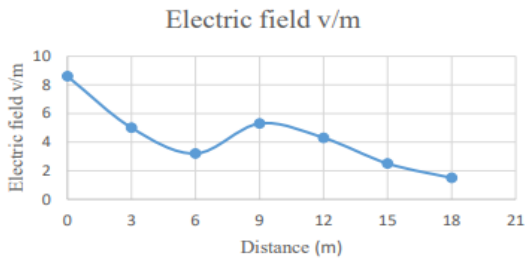


Figure 9. Location of high voltage lines in Tabarbour over a residential area a: Longitudinal section shows measurement locations through different topography (schematic); b: Top view of the overlap of high voltage line supply over residential areas (Google image); c: Section shows measurement distances (schematic)

Table 5. Field measurements under high power lines in the Tabarbour residential neighborhood, including the magnetic field and electric field at a distance range (0-18 m)

	MF (µT)	EF (v/m)
Section 1		
Section 2		
Section 3		
Section 4		

Source: Authors, 2022

Under the electricity line inside the mosque: the electric field (1.1 F/m) the magnetic field (.025 µT) The adjacent building is 20 meters from the power line: on the ground floor the electric field (.55 F/m), the magnetic field (0.0 µT). On the third, floor the electric field (10), the magnetic field (0.355 µT). The results are below the recommended levels of ICNIRP, which is 5000 v/mm for the electric field and 100mT for the magnetic field. If we take into consideration 4mT as a reference limit for the magnetic field of places where children are present for a long term of time, we note that this danger could be exceeded by moving 3 meters away from the power line.

Measurement point, section 2, topography affects the values of the electric and magnetic fields, as the measurements are taken directly above the slope. Table 4 represents the measured values; the above figures show the relationship between electric and magnetic fields as a function of distance.

8.2 The case of Sahab neighborhood, Amman City

Sahab is an industrial area, but the urban growth of Amman is fast, as the population density extends abroad quickly, Figures 10 and 11 show overlap between high voltage power lines and urban spread. The measurements were made on site in two sections, sections 1 and 2 outside and inside the neighboring buildings as shown in Figure 12. Table 6 shows the field measurements at regular distances away from the centerline under the high-voltage lines, they are 0, 3, 6, 9, 12, 15, and 18 meters respectively.

Figure 10. Scenes of the overlap between high voltage overhead lines and residential settlements

Source: Authors, 2023

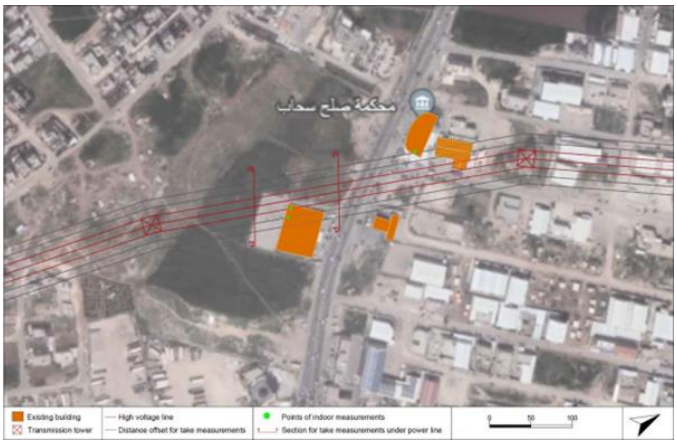


Figure 11. High Voltage layout (400 kV) over residential settlements
Source: Google Maps with modification, 2023

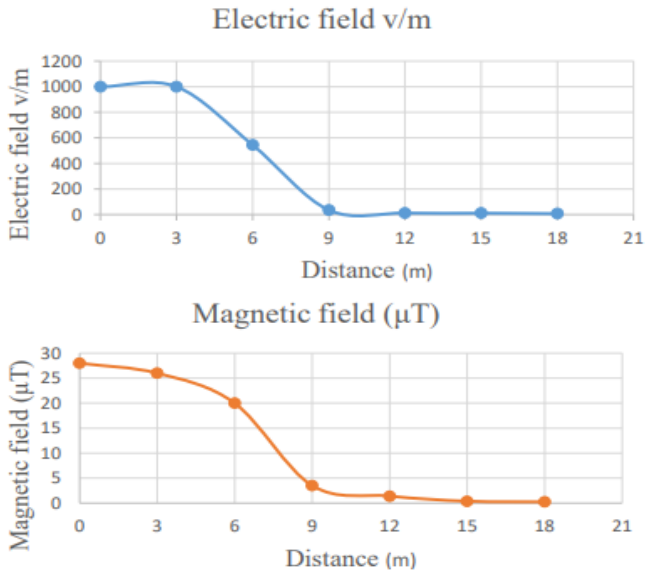


Figure 12. Measured values of electric and magnetic fields as a function of distance for Sahab District, Amman City

Table 6. Measured values of electric and magnetic fields in Sahab neighborhood, Amman City

Distance (m)	Electric Field (v/m)	Magnetic Field (µT)
0	999.9	28
3	999.9	26
6	543.9	20
9	35	3.5
12	12	1.4
15	11	0.38
18	7.3	0.25

9. CONCLUSION

Poor coordination among the competent authorities causes urban problems that expose the population to health concerns from electromagnetic radiation created by high voltage wires at very few frequencies. As a result, we advocate developing an integrated development strategy that involves the distribution of urban areas and directing the city's expansion away from infrastructure features that endanger the population's health. The vast network of high-voltage power lines within Amman's urban fabric highlights the necessity to discover safe solutions to expand high-voltage lines into the city's communities. The underground extension could be one of the most effective ways to shield inhabitants from the dangers of electromagnetic waves caused by high-voltage lines.

Amman's metropolitan development plan includes the direction of the city's growth to the southeast, toward high voltage line 400, which now extsends most of the way outside the city, and this necessitates finding urban solutions to deal with the power line as part of the city's growth strategy. The measurements made and the results obtained emphasize the importance of dealing with sources of electromagnetic radiation with caution; as long-term exposure to such radiation causes health risks, the results obtained correspond to global levels of radiation, but the residential areas in which children live and spend time require more attention of radiation levels protection, as health studies declare a relationship between electromagnetic fields and leukemia in children.

The influence of power grid changes on low-frequency field exposure remains unknown. In future electricity grids, customers may become "prosumers" (producers + consumers) due to decentralized and distributed power generation will get closer to the residential areas.

Furthermore, new uses in public settings (such as electric vehicles and chargers) will alter the exposure characteristics of the overall population. Therefore, in the real world Studies (based on both measurements, through crowdsourcing, and simulations, for example, environmental field calculations are recommended to assess the exposure impact of the technological developments occurring in electrical power production, distribution, and consumption. Further research is needed to assess the potential implications of ELF-EMF on flora and fauna, both terrestrial and marine.

With the advancement of diagnostic procedures for neurodegenerative illnesses, more clinical and epidemiological investigations are needed for validated biomarkers; which could study any relationship between ELF-EMF exposure and their disorders, including any underlying mechanisms that are involved. These findings help policymakers to develop urban and regional regulations regarding the high voltage power line paths through urban and regional locations and their proximity to urban settlements; especially in Amman City case. Further research is still necessary to overcome any pending research questions in this regard.

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