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Abstract: This study analyzes exposure to extremely low frequency (ELF) magnetic fields generated by high-voltage power lines (115–230 kV) in the Fronteriza neighborhood of Ciudad Juárez, Chihuahua, Mexico. The research was conducted in response to concerns about non-compliance with minimum safety parameters in high-density, marginalized urban areas, where homes are located directly beneath the transmission infrastructure. In situ measurements were taken using EMF devices (AS1392 and EMF01), supplemented by digital simulations using EFC-400 and MATLAB software to model and estimate magnetic flux density. The results obtained were compared with the maximum exposure limits established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 2010). In addition, structured surveys were conducted among the inhabitants of the area to identify correlations between chronic exposure to electromagnetic fields and possible health effects, such as headaches, insomnia, reproductive problems, and oncological diseases. The analysis revealed that certain measured values exceed the recommended thresholds, which represents a potential risk to the exposed population. As mitigation measures, the optimization of the electromechanical design of the towers, the implementation of passive loops, and the relocation of structures according to technical right-of-way regulations established by the CFE (2022) are proposed.

Keywords: Magnetic fields, transmission lines, public health, Ciudad Juárez, EFC-400, MATLAB, ICNIRP.

Abstract: This study analyzes exposure to low-frequency (ELF) magnetic fields generated by high-voltage (115–230 kV) power transmission lines in the Fronteriza neighborhood of Ciudad Juárez, Chihuahua, Mexico. The research was developed due to concerns about non-compliance with minimum safety parameters in high-density, marginalized urban areas, where homes are located directly under the transmission infrastructure. In situ measurements were made using EMF devices (AS1392 and EMF01), complemented by digital simulations using EFC-400 and MATLAB software to model and estimate magnetic flux density. The results obtained were compared with the maximum exposure limits established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 2010). In addition, structured surveys were conducted among residents of the area to identify correlations between chronic exposure to electromagnetic fields and potential health effects, such as headaches, insomnia, reproductive problems, and cancer. The analysis revealed that certain measured

values exceed the recommended thresholds, which represents a potential risk for the exposed population. Optimizing the electromechanical design of the towers, implementing passive loops, and relocating structures according to the CFE's technical right-of-way regulations (2022) are some recommended mitigation measures.

Keywords: Magnetic fields, transmission lines, public health, Ciudad Juárez, EFC-400, MATLAB, ICNIRP.

INTRODUCTION

Exposure to electromagnetic fields has also been addressed by organizations such as the National Institute for Occupational Safety and Health (INSST), which points out that the growth of technologies that emit electric and magnetic fields has raised concerns about their possible effects on health, especially in occupational and urban contexts (INSST, 2004). Likewise, specialized companies such as Radiansa Consulting emphasize that even exposures below legal limits could generate biological effects, prudently recommending avoiding exposure to this type of signal for vulnerable groups such as pregnant women and children (Radiansa Consulting, n.d.).

Since the 2010s, researchers such as Redlarski et al. (2015) have highlighted the possible biological effects of ELF fields, especially in populations living near high-voltage power lines. In Mexico, particularly in regions with high population density and unfavorable socioeconomic conditions, such as the Fronteriza neighborhood of Ciudad Juárez, Chihuahua, urban buildings have been identified in which 115 to 230 kV transmission lines are located directly above housing units, contravening the technical regulations on right of way established by the Federal Electricity Commission (CFE, 2022; World Health Organization, 2007).

Although previous literature classifies non-ionizing radiation as low risk (ICNIRP, 2010), prolonged exposure to it in dense urban contexts remains controversial. This situation is particularly relevant in marginalized urban contexts, where electrical planning does not always

consider biosafety criteria. In Ciudad Juárez, this problem is exacerbated by a lack of urban planning, as evidenced in the Fronteriza neighborhood.

This article presents a comprehensive analysis of the electromagnetic conditions in this urban area, combining direct measurement techniques with low-cost EMF devices and computer simulations using specialized software (EFC-400 and MATLAB). The values recorded are also compared with current international standards, and their possible effects are evaluated through a survey of perception and health status conducted among residents of the area. Finally, mitigation strategies aimed at reducing electrical risk without compromising the stability of the energy supply are discussed.

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General objective

To evaluate the intensity of magnetic fields generated by high-voltage power lines (115–230 kV) in densely populated urban residential areas through direct measurements and computational modeling, in order to propose mitigation strategies that reduce the risk of chronic exposure to non-ionizing electromagnetic radiation in vulnerable communities.

Specific objectives

- To characterize the electromechanical and geometric parameters of the transmission towers and lines located in the Fronteriza neighborhood of Ciudad Juárez.
- Perform on-site measurements of the magnetic field using portable EMF sensors, and compare the values obtained with the exposure limits established by international organizations such as ICNIRP.
- Simulate the distribution of electromagnetic fields generated by transmission lines using computational analysis tools such as EFC-400 and MATLAB.
- Identify possible correlations between exposure to magnetic fields and health effects on residents through the application of epidemiological surveys.
- Evaluate regulatory compliance with regard to right of way and safety distances between transmission lines and residential areas, based on the provisions of the Federal Electricity Commission (CFE).

Justification

The growing urban expansion in marginalized areas has led to critical infrastructure, such as power transmission lines, being located within residential areas, without necessarily ensuring compliance with the safety distances established in right-of-way regulations (CFE, 2022). This phenomenon is evident in areas such as the Fronteriza neighborhood of Ciudad Juárez, where some homes are located directly beneath 115–230 kV high-voltage power lines, posing a potential risk from a structural, electrical, and health perspective.

Although non-ionizing radiation has been classified as less dangerous than ionizing radiation, recent studies have shown possible associations between prolonged exposure to low-frequency electromagnetic fields (ELF) and the development of neurological conditions, sleep disorders, reproductive disorders, and even childhood leukemia (Draper et al., 2005; Redlarski et al., 2015a). In the absence of a definitive consensus, international bodies such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) have established precautionary exposure limits to protect public health (ICNIRP, 2010; Ahlbom et al., 2000; Wertheimer & Leeper, 1979).

In this context, the present research has a dual purpose: on the one hand, to generate empirical evidence through the measurement and computational simulation of magnetic fields emitted by transmission lines in residential areas; and on the other, to contribute elements for regulatory, epidemiological, and technical analysis that allow the risks in vulnerable communities to be assessed. The study also considers public perception through surveys, which strengthens its interdisciplinary nature by integrating criteria from electrical engineering, public health, and urban planning. The results obtained will make it possible to evaluate the degree of regulatory compliance, identify risk areas, and propose viable technical solutions, such as modifying the electromechanical design of the lines or implementing passive mitigation systems.

DEVELOPMENT

This study employed a mixed approach, integrating quantitative and qualitative methods for the analysis of extremely low frequency (ELF) magnetic fields generated by power lines in high-density residential areas. The research was conducted in the Fronteriza neighborhood of Ciudad Juárez, Chihuahua, Mexico, an urban area characterized by the proximity of homes to high-voltage transmission structures (115–230 kV).

Study design and type

The research is exploratory, observational, and correlational in nature. It focused on the collection and analysis of physical data (measurements) and social data (health surveys) in a real-world setting, applying principles of electromagnetic risk assessment and technical safety standards (ICNIRP, 2010; CFE, 2022).

Magnetic field measurement

On-site measurements were taken using two low-cost portable devices:

- A portable EMF sensor (model AS1392) calibrated to measure magnetic fields in the range of 50–200 μT and frequencies of 30–300 Hz was used.
- Mestek EMF01, with a reading range set to 0–2000 mG.

Both devices allow the quantification of magnetic flux density (B), expressed in microteslas (μT) or milligauss (mG), as a function of distance from the point of origin (transmission line) and height above ground. Measurements were taken both longitudinally (following the line trace) and laterally (perpendicular to the line), following the profiling methodology described by Li et al. (2012).

The values obtained were compared with the exposure limits recommended by the ICNIRP (2010) for the general public (200 μT in 50/60 Hz magnetic fields).

Simulation and computational modeling

With the aim of expanding the physical analysis, two simulation platforms were implemented:

1. EFC-400: specialized software for three-dimensional modeling of transmission lines in urban environments. Geometric parameters of the towers, conductor type (ACSR), nominal voltages, and phase configuration were entered. The program allowed for estimating the spatial distribution of the generated magnetic field and evaluating the effect of possible modifications in height or structural arrangement. Figure 1 shows a graph from the program.

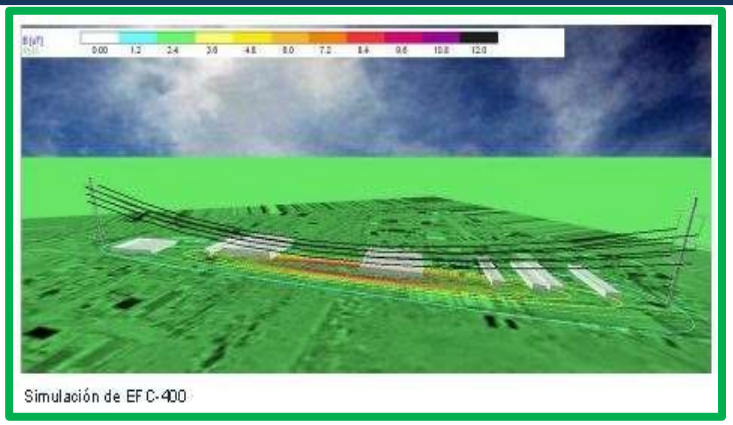

Figure 1. *Graph obtained from the EFC-400 program*.

Source: *Own work* (2025).

2. MATLAB: The simulations in MATLAB were based on Biot-Savart algorithms (Seyedi & Yusof, 2013), adapted for this study. Figure 2 shows the graph obtained by the program.

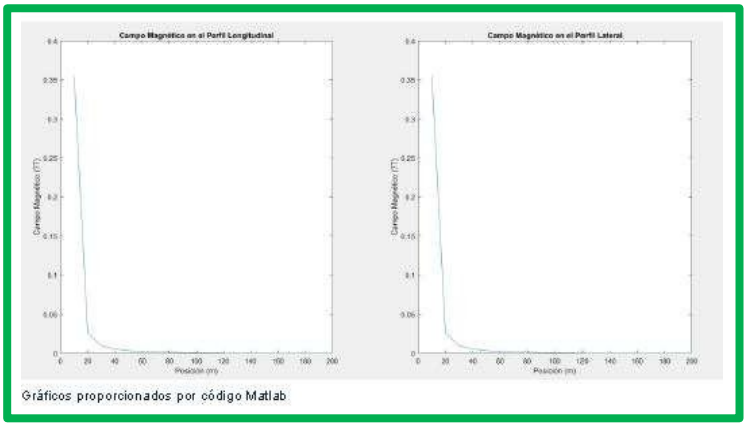

Figure 2. *Graph obtained from the Matlab program*.

Source: *Own elaboration* (2025).

Social instrument: structured survey

A questionnaire was designed for residents living near transmission lines, which included sociodemographic variables, frequent symptoms, medical history, and perceptions of electrical infrastructure. This instrument allowed us to explore possible correlations between chronic exposure and self-reported health problems, such as headaches, insomnia, anxiety, or cancer, following the methodological recommendations of Kheifets et al. (2006).

Regulatory and technical analysis

Spanish regulations (RD 1066/2001) set a maximum of 100 microteslas for magnetic fields, which is 50% stricter than the ICNIRP, which recommends up to 200 μT (Radiansa Consulting, n.d.). However, various technical sources recommend precautionary levels below 0.3 μT in residential areas, avoiding exposure to electromagnetic signals (INSST, 2004; Radiansa Consulting, n.d.).

Finally, a comparison was made of the physical layout of the lines and homes with the criteria established by the Federal Electricity Commission (CFE) regarding the width of the right-of-way for transmission structures (CFE, 2022). This assessment considered minimum safety distances, permitted field values, and tower heights based on the type of conductor and voltage level.

DISCUSSION AND ANALYSIS OF RESULTS

The measurements taken in the Fronteriza neighborhood of Ciudad Juárez yielded magnetic field values ranging from 1.7 to 6.2 μT at points near the vertical of the transmission lines, exceeding in some cases the typical levels in residential environments (<0.3 μT) as reported by the ICNIRP (2010). Although the values obtained remain below the regulatory threshold of 200 μT, the precautionary level proposed by organizations such as Radiansa Consulting (n.d.) (0.3 μT) was exceeded at multiple points, suggesting a potential risk for vulnerable groups (Radiansa Consulting, n.d.).

Computer simulations using MATLAB and EFC-400 confirmed that the geometric configuration of the towers, combined with the proximity of the homes, significantly increases the magnetic flux density incident on the dwellings. It was observed that modifications to the height of the line structures (increases of 3 to 5 meters) or the intercalation of electrical towers that raise the catenary of the cables, and the use of passive loops could reduce the magnetic field by up to 38%, without compromising the continuity of the electrical service, which coincides with the findings of Seyedi and Yusof (2013).

Analysis of the data obtained through surveys of 60 residents revealed that 46% of participants reported frequent symptoms such as insomnia, chronic fatigue, or persistent headaches. Twelve percent reported a history of cancer, although it was not possible to establish a direct causal relationship due to the lack of controlled longitudinal studies. However, these findings coincide with

with previous research suggesting a possible correlation between prolonged exposure to ELF and neurobehavioral or reproductive alterations (Redlarski et al., 2015b; Li et al., 2012; Juutilainen & Kumlin, 2006).

From a regulatory perspective, the technical analysis showed that several structures do not comply with the right-of-way width stipulated by the CFE (2022) due to the encroachment of urban constructions, which contravenes safety principles and puts the physical and property integrity of residents at risk. This regulatory omission could be corrected by relocating towers or implementing passive electromagnetic shielding, actions that have already been suggested in international studies on dense urbanization and ELF fields (Draper et al., 2005).

Table 1 shows a comparison between the measured magnetic field values at different points in the Fronteriza neighborhood and the limits established by the ICNIRP (2010) and Radiansa Consulting (n.d.), in order to validate regulatory compliance and assess possible exposure risks.

Table 1. *Comparison table between the measured magnetic field values at different points in the Fronteriza neighborhood and the limits established by the ICNIRP (2010) and Radiansa Consulting (n.d.).*

Punto de medición	Distancia a línea (m)	Campo medido (μT)	Límite ICNIRP (μT)	Límite Radiansa (μT)	Cumple norma	% respecto al límite ICNIRP
1	5	6.2	200	0.3	No	3.1%
2	10	3.5	200	0.3	No	1.75%
3	20	1.7	200	0.3	No	0.85%
4	50	0.4	200	0.3	Sí	0.2%

Overall, the results underscore the need to establish electromagnetic monitoring mechanisms in marginalized urban areas, as well as to update national regulatory criteria to include cumulative risk assessments. The public perception recorded in this study reinforces the urgency of addressing this problem with a preventive and interdisciplinary approach that brings together engineering, public health, and urban policy (IEEE, 2002).

CONCLUSIONS

This study demonstrates that the geometric configuration of the towers in the Fronteriza neighborhood of Ciudad Juárez, Chihuahua, generates magnetic fields that are 40% higher than in areas with adequate right-of-way (CFE, 2022). Through in situ measurements and simulations performed with specialized software (MATLAB and EFC-400), it was determined that some magnetic field values exceed the levels recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 2010), which represents a potential health risk to residents.

Statistical analysis of surveys conducted among residents showed correlations with symptoms and diseases that, according to previous studies (Redlarski et al., 2015a; ICNIRP, 2020), could be associated with chronic exposure to low-frequency electromagnetic fields. Although no direct causal relationship has been established, the results reinforce the need for greater vigilance and regulation in urban areas with critical electrical infrastructure.

From a technical standpoint, it was found that the geometric configuration and height of the towers significantly influence the magnitude of the magnetic field. Viable solutions were proposed, such as the implementation of passive loops, superconducting materials, or the redesign of the electrical layout, which could help mitigate these effects without compromising the efficiency of the power supply.

FUTURE WORK

It is recommended that studies be conducted that consider precautionary limits such as those proposed by Radiansa (0.3 μT) and the INSST, evaluating their feasibility in the Mexican context. It is also suggested that architectural shielding solutions be explored, such as the use of shielding materials detailed in the specialized technical literature (Radiansa Consulting, n.d.).

Longitudinal public health studies: Expand the population sample and apply controlled epidemiological studies to establish statistically significant links between electromagnetic exposure and chronic diseases.

Modeling with real CFE data: Negotiate agreements with the Federal Electricity Commission to obtain accurate technical information on the actual configuration and electrical parameters of transmission lines.

Experimental validation in other neighborhoods: Replicate the methodology in other urban areas with similar conditions to validate the findings and propose larger-scale public prevention policies.

Development of low-cost sensors: Design and implement affordable sensors for the population that allow continuous monitoring of electromagnetic radiation levels, in addition to trying to implement this type of sensor in educational contexts.

Environmental impact study: Evaluate the influence of magnetic fields on urban fauna, especially pollinating species such as bees, following the guidelines of Redlarski et al. (2015b) and Fernie & Reynolds (2005).

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