Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales.
47(182):141-150, enero-marzo de 2023. doi: https://doi.org/10.18257/raccefyn.1864

Original article

Study of non-ionizing radiation emissions in two zones of Xochimilco, México City

Estudio de las emisiones de radiación no ionizante en dos zonas de Xochimilco, Ciudad de México

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Abstract

The objective of this study was to estimate electromagnetic pollution by radio frequency (RF) and magnetic field (CM) over one year by measuring the intensity near schools, hospitals, business premises, and homes in a commercial and a residential zone of Xochimilco, México City. The RF and the CM were measured using an EXTECH® EMF450 meter. We compared the values of non-ionizing radiation (NIR) found in the environment with the levels reported to affect the biological systems of both humans and animals. We also compared these values with the limits established both nationally and internationally. The highest average CM and RF values in the central zone were 6.38 µT and 1316 µW/m^2, respectively, while in the housing area, they were 5.08 µT and 66 µW/m^2. The values we registered were below the permissible limits both nationally and internationally. However, they were above the reported threshold that could trigger adverse health effects according to some authors. These values are within the limits established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Further studies are required as there is still nothing conclusive regarding this type of radiation and its effects.

Key words: Biological effects; Electromagnetic pollution; Magnetic field; Radiofrequency.

Resumen

El objetivo de este estudio fue estimar la contaminación electromagnética de radiofrecuencia (RF) y campo magnético (CM) durante un año registrando su intensidad cerca de escuelas, hospitales, locales comerciales y viviendas en una zona comercial y en otra residencial de Xochimilco, Ciudad de México. La RF y el CM se midieron utilizando un medidor EXTECH® EMF450. Los valores obtenidos de radiación no ionizante (RNI) en el medio ambiente se compararon con aquellos que, según algunos autores, afectan los sistemas biológicos tanto en humanos como en animales. Asimismo, se compararon los valores con los límites establecidos a nivel nacional e internacional. Los valores promedio más altos de CM y de RF en la zona comercial fueron de 6.38 µT y de 1316 µW/m^2, respectivamente, en tanto que en el área residencial fueron de 5.08 µT y 66 µW/m^2. Los valores registrados estuvieron por debajo de los límites permisibles a nivel nacional e internacional, sin embargo, se encontraron por encima del umbral que, según reportes de algunos autores, podría desencadenar efectos adversos en la salud, aunque estaban dentro de los límites establecidos por la *International Commission on Non-Ionizing Radiation Protection* (ICNIRP). Es necesario investigar más al respecto, ya que aún no hay nada concluyente sobre este tipo de radiación y sus efectos.

Palabras clave: Efectos biológicos; Contaminación electromagnética; Campo magnético; Radiofrecuencia.

Citation: Álvarez-Ortiz FA, Azorín-Nieto J, Soto-Sumuano JL, Esquivel-Herrera A. Study of non-ionizing radiation emissions in two zones of Xochimilco, México City. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales. 47(182):141-150, enero-marzo de 2023. doi: https://doi.org/10.18257/raccefyn.1864

Editor: Gabriel Tellez

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Received: February 13, 2023
Accepted: March 10, 2023
Published on line: March 17, 2023

Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales.
47(182):141-150, enero-marzo de 2023. doi: https://doi.org/10.18257/raccefyn.1864

Introduction

Every day we are more exposed to non-ionizing electromagnetic radiation (NIR) of anthropogenic origin (**Djuric *et al*.,** 2011; **Dode *et al*.,** 2011; **Vian *et al*.,** 2016; **Buckus *et al*.,** 2017). Electromagnetic pollution (electropollution or electrosmog) is defined as the types of irradiated signals that can damage living organisms or affect natural processes in an ecosystem (**Balmori,** 2009; **Cobzaru,** 2015). The rapid development of electronic and telecommunications technologies has led to significant changes in the general population's exposure to electromagnetic fields (EMF), particularly the massive use of wireless electronic devices in modern society inevitably implies exposure to electromagnetic waves (**Kim *et al*.,** 2019) from cell phones, communication towers, wireless devices, wireless internet (Wi-Fi) and power lines (**Mortazavi,** 2015). This situation is alarming as constant exposure to NIR in the form of radiofrequency (RF) and extremely low frequency (ELF) radiation has been associated with adverse health effects including immune system disorders, arrhythmias, vascular problems, depressive disorders, memory problems, behavioral disorders, learning problems, hearing problems, free radical production, and DNA breakdown (**Bayat *et al*.,** 2017; **Chauhan *et al*.,** 2017; **Da Silva *et al*.,** 2015; **Kelfkens**, 2017; **Khurana *et al*.**, 2010; **Paulraj & Behari,** 2006). Likewise, the relationship between chronic RF exposure and subfertility (**Forgács *et al*.,** 2006), brain tumors (**Persson *et al*.,** 1997; **Salford *et al*.,** 2003), and other types of non-cerebral cancers (**Richter *et al*.,** 2000; **Velizarov *et al*.,** 1999) has been reported.

Mexico City (CDMX) is one of the fastest-growing megacities in the world, especially in the southern zone, specifically in Xochimilco (**Aguilar *et al.,*** 2022; **Wigle,** 2010). Urban growth leads to the development of electrical and telecommunications infrastructure derived from the increasing demand for energy and communication services every year. This infrastructure is distributed ubiquitously across urban areas and is the main emitting source and most relevant contributor to artificial NIR (**Jalilian *et al*., 2019; Khurana *et al*.,** 2010). In this context, the objective of our study was to evaluate contamination by NIR in two locations of Xochimilco, CDMX.

Materials and methods

Study area

The study area (**Figure 1**) is located to the south of México City, in northeast Xochimilco, and comprises a portion of the metropolitan area of the city. Measurements were taken in two zones: The first one corresponded to a fraction of the urban center of Xochimilco and the second was a residential area of the Ampliación Tepepan neighborhood, specifically Avenida de las Torres (towers), so named because the avenue is crossed longitudinally by high voltage lines with a telecommunications base station at each end of the avenue.

Measurements

Nineteen critical points were selected considering their infrastructure or the activities taking place in their vicinity. We included schools, hospitals, commercial premises, and houses. Measurements were taken twice a month on Tuesdays and Thursdays over one year from April 2016 to April 2017 and from 9:30 to 11:30 am and 19:00 to 21:00 pm to compare their variation. The measurements were taken following the methods of the International Agency for Research on Cancer (**IARC,** 2002; 2011), i.e., at the locations where individuals spend most of their time both at home and at work, such as bedrooms, living rooms, desks, etc. All measurements were taken within 400 m of one or more cellphone base stations.

An Extech® EMF450 meter was used to measure the electric and magnetic fields and the RF within a magnetic field-measurement range of 0.01 to 200 microteslas (μT) and 1 to 2000 volts per meter (V/m) for both MFs and EFs on the frequency range of 50/60 Hz. The frequency range for RF was 50 MHz to 3.5 GHz with a measurement range between 0.02 microwatt per square meter ($\mu W/m^2$) and 554.6 milliwatt per square meter (mW/m^2). For

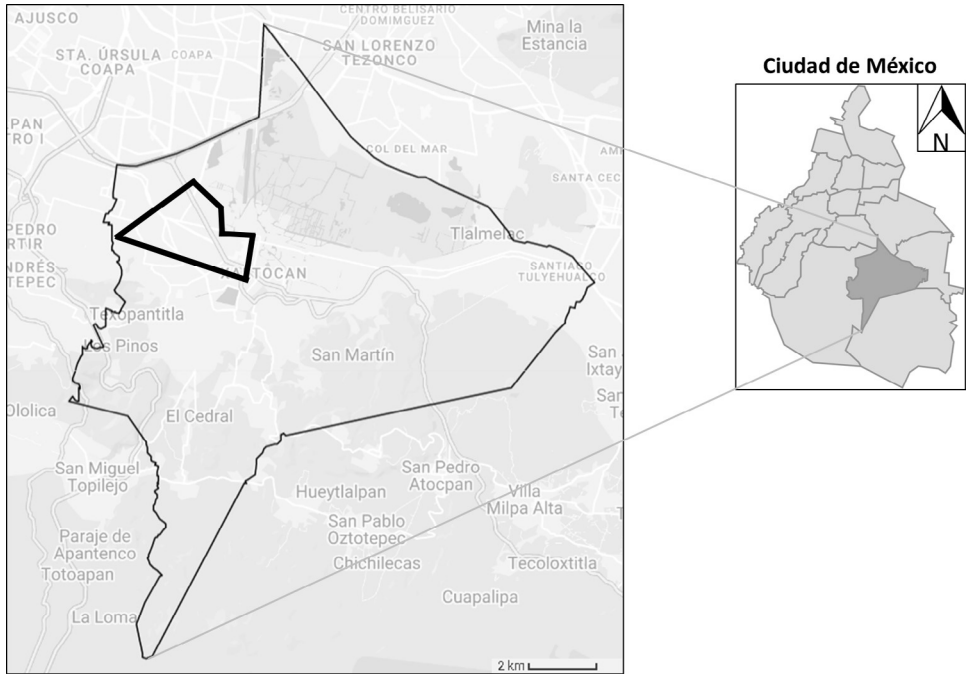

Figure 1. Polygon of the study area located in the northwest part of Xochimilco municipality (México City) characterized by its fast population and telecommunications infrastructure growth

the analyses we used the Shapiro-Wilk normality test, the Kruskal-Wallis non-parametric ANOVA, and the Dunn test using R version 3.4.3 (**R Development Core Team,** 2014) of the Dunn's test package (**Dinno,** 2017).

Results

The magnetic field measurements in the central zone of Xochimilco and the corresponding sampling sites are shown in **table 1**. The magnetic field maximum average value recorded during the morning was 6.38 μT in market 1 (first section) while during the evening it was 5.9 μT in market w (second section). No electric field emissions were detected in the central area of Xochimilco. Regarding radio frequencies, the minimum average values (13.46 and 19.93 $\mu W/m^2$) were recorded in two business premises while the maximum ones were registered in an elementary school (1016.03 $\mu W/m^2$) and in the Children's Hospital (1316.03 $\mu W/m^2$), with the highest value.

The sampling sites and magnetic field measurements in Ampliación Tepepan are shown in **table 2**. During the morning the minimum magnetic field average value was 0.14 μT (culture house) while the maximum was 5.08 μT (public playground); the highest average and maximum values (5.13 and 5.54 μT) were recorded in the evening in the public playground. Regarding the electric field, only in the exercise equipment and the public playground (sites 1 and 6, respectively) we recorded mode values of 2000 V/m, which corresponded to the maximum limit of the meter used. In the case of radio frequencies, the average value (18.15 $\mu W/m^2$) was estimated in a domestic room while the maximum value (111.35 $\mu W/m^2$) was recorded in a business premise.

The statistical analysis showed that there was no significant difference between morning and evening emissions within the same location or in either of the two locations. In general, there were no significant differences in the measurements between the downtown area of Xochimilco and Ampliación Tepepan ($p>0.05$ in every test). It is worth mentioning that during the measurement, pulses of up to 10 W/m^2 were recorded outside the sampling points since the meter was left turned on while moving from one sampling point to another.

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Table 1. Average and maximum values of magnetic field obtained in the morning and the evening and radio frequency values registered in the central area of Xochimilco (See the text for site correspondence)

Central area	Magnetic field (μT)				Radio frequency (μW/m²)	
Site	**Day avg.**	**Day max.**	**Night avg.**	**Night max.**	**Avg.**	**Max.**
Market 1	2.90	6.38	2.10	4.99	21.11	34.50
Market 2	1.66	3.88	2.03	5.90	52.53	155.33
Health Center	0.11	0.22	ND	0.84	20.65	26.70
Business premise	0.68	0.86	0.31	1.10	19.93	28.00
Business premise	0.80	4.80	0.23	0.37	23.30	41.06
Business premise	1.20	2.92	1.80	5.10	129.32	254.93
Business premise	1.52	0.15	1.52	2.71	13.46	18.56
Secondary school	0.07	0.18	1.35	1.72	185.02	428
Primary school	0.05	0.10	0.26	0.62	1035.16	1962.00
Kindergarden	0.02	0.03	0.02	0.05	200.23	427.56
Children Hospital	0.04	0.13	ND	ND	1316.03	2050.00

ND: not detected; Avg: average value; max: maximum value

Table 2. Average and maximum values of magnetic field during the morning and the evening and radio frequency values in the Ampliación Tepepan residential area (See the text for site correspondence)

Residential area	Magnetic field (μT)				Radio frequency (μW/m²)	
Site	**Day avg.**	**Day max.**	**Night avg.**	**Night max.**	**Avg.**	**Max.**
Public exercise equipment	3.60	4.36	4.33	5.02	31.38	42.70
Primary school	1.33	1.86	1.36	2.01	43.90	66.95
Culture House	0.14	0.19	0.18	0.35	18.38	19.90
Yoga center	0.48	1.10	0.17	0.33	22.33	25.97
House	1.65	2.37	1.36	1.91	18.15	49.90
Public playground	4.00	5.08	5.13	5.54	66.06	82.27
Business premise	2.64	3.40	2.46	2.91	63.22	111.35
Health center	1.16	1.36	1.06	1.21	21.65	24.95

Avg: average value; max: maximum value

Discussion

We had no access to the premises of the elementary school, the kindergarten, the secondary school, or domestic spaces, so the readings obtained corresponded only to the outside areas of these places.

The general MF average values recorded in the present study were 0.95 μT in the central zone and 1.94 μT in the residential zone, which are equivalent to the values obtained in similar studies in other cities around the world, for example, Tehran, Iran (**Zazouli *et al.*,** 2013). The overall average RF values were lower than those from the studies conducted in Minas Gerais, Brazil: 19800 μW/m² (**Dode *et al.*,** 2011) and Greece: 7900 μW/m² (**Gotsis *et al.*,** 2008), but close to those obtained in Łódź, Poland: 1700 μW/m² (**Bortkiewicz *et al.*,** 2012), Selbitz, Germany: 1200 μW/m² (**Eger & Jahn,** 2009), and Rimbach, Germany: 76.9 μW/m² (**Buchner & Eger,** 2011). **Marinescu & Poparlan** (2016) recorded a wide

interval of RF power density values, from 65 to 18650 μW/m^2, within the range of 100-500 m of the mobile phone base stations in Craiova city, Romania. It should be noted that the RF EMF power density was affected both by the distance to the source and having a clear line of sight (**Marinescu & Poparlan,** 2016). On the other hand, a systematic review of studies in Europe done by **Jalilian *et al.*** (2019) reported a mean RF-EMF exposure between 4.24 to 1532.09 μW/m^2 inside houses, schools, and offices and mean exposure values between 12.99 a 4278.24 μW/m^2 outdoors, which represents a notably higher range of exposure outdoors.

Regarding the magnetic field, most of the values obtained in the morning and evening in the residential area were above 0.3 μT, which is relevant because children's residential exposure to intensities above this level has been linked to the development of different types of acute leukemia (AL) (**Ferris *et al*.,** 2010; **Kelfkens,** 2017), particularly the lymphoblastic and myeloid types (**Tlacuilo-Parra *et al*.,** 2017). In four of the five business premises where readings were taken, we registered values above 1 μT reported as enough to trigger sleep disorders (**Dyche *et al*.,** 2012).

On the other hand, **Buchner & Eger** (2011) have reported that RF intensities close to 100 μW/m^2 are sufficient to trigger alterations in the secretion of stress-associated neurotransmitters, such as phenylethylamine, adrenaline, norepinephrine, and dopamine. In more extreme cases, a correlation between reception at intensities above 1000 μW/m^2 and mortality due to neoplasia has been reported (**Dode *et al*.,** 2011).

Our results suggest that Xochimilco residents are at potential risk of developing some of the conditions related to chronic exposure to NIR, particularly behavioral problems associated with the proximity (less than 500 meters) to cellphone base stations within the signal beam that may be related to the appearance of emotional, behavioral, and interpersonal relationship problems, and even to the increase in the number of children diagnosed with attention deficit hyperactivity disorders (ADHD) (**Thomas *et al.,*** 2010). Although some studies discard a relation between RF-EMF low power flux densities and sleep disorders (**Mohler *et al*.**, 2010), others affirm that this relation exists within 16 mW/m^2 (**Lebedeva *et al*.**, 2000; **Hinrikus *et al*.**, 2021), but the electro hypersensitivity of exposed subjects may also be an important factor (**Hinrikus *et al*.,** 2021), as well as the so-called idiopathic environmental intolerance attributed to electromagnetic fields (**Rubin *et al*.**, 2010), although this is still subject to debate (**Dömötör, Ruzsa, *et al*.,** 2022; **Dömötör, Szabolcs, *et al*.**, 2022; **Röösli *et al*.**, 2021)this conclusion was drawn from environmental and experimental studies that are not without methodological limitations. In the current study, as part of a complex biopsychosocial approach, an ecological momentary assessment (EMA).

Despite the substantial evidence on the biological effects of NIR on living organisms (**Balmori**, 2006, 2009, 2010; **Bandara**, 2016; **Hardell**, 2017; **Bandara & Carpenter**, 2018; **Kostoff *et al.,*** 2020), the issue is still discussed. In this respect, it should be noted that many studies are conducted under experimental conditions and that the result of NIR exposures under real-life conditions is rarely reflected (**Buchner & Eger**, 2011; **Kostoff *et al*.**, 2020). While some countries have taken precautionary measures to protect the public from NIR (**Dhami**, 2012), the international limits established by the ICNIRP (**Table 3**) remain well above the threshold associated with adverse effects (**Table 4**). Currently, in México there is no regulation on the limits of exposure to NIR for the general public, although the General Law of Ecological Balance and Environmental Protection (LGEEPA) mentions that the prevention and control of electromagnetic radiation emissions fall under federal, state, and municipal regulatory authority (**General Law of Ecological Balance and Environmental Protection,** 2012). Only the NOM-013-STPS-1993 is available, which applies solely to the planning, organization, and operation of workplaces where non-ionizing electromagnetic radiation is generated (**Farell**, 1993).

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Table 3. National (NOM-013) and international (ICNIRP) NIR exposure limits

Occupational						
ICNIRP		**NOM-013**		**ICNIRP**		**NOM-013**
EF	MF	EF	MF	RF/MW		
25 Hz-300 Hz		-	-	400 – 2000 MHz; 2 – 300 GHz		-
(V/m)	(μT)	(V/m)	(μT)	(W/m²)		
5000	1000	200	0.6	40	50	100
General public						
50 – 400 Hz		-	-	400 – 2000 MHz; 2 – 300 GHz		-
2500	200	-	-	10	10	-

EF: electric field; MF: magnetic field; RF/MW: radio frequency/microwaves

Table 4. Frequency (GHz) and intensity (W and μW/m² for RF; μT for MF) value threshold of NIR RF and MF and its associated negative effects reported in the literature. Note that these effects are reported for long-term chronic exposure and the mechanism of action is yet to be clarified.

Reference	Frequency (GHz)	Intensity (W/m²)	Effects
Paulraj & Behari, 2006	2.45	1 – 3	DNA breakage
Chauhan *et al.*, 2017	2.45	2	Free radicals production (e. g. LPOs)
Bayat *et al.*, 2017	0.9	0.9	Extend durations of some infections
Lebedeva *et al.*, 2000; **Hinrikus *et al.***, 2021	0.3 - 5	0.016 – 0.6	Sleep disorders
Forgacs *et al.*, 2006	1.8	0.2	Subfertility
Persson *et al.*, 1997; **Salford *et al.***, 2003	0.9 - 1.8	0.01 – 0.2	Brain tumors
Velizarov *et al.*, 1999; **Richter *et al.***, 2000	0.5 - 3	0.05 – 1	Cancers other tan brain cancer
Khurana *et al.*, 2010	0.3 - 5	0.001	Arrhythmias, vascular problems
		(μW/m²)	
Thomas *et al.*, 2010	0.9 – 2.4	100	Behavioral disorders
Buchner & Eger, 2011	1.8	100	Hormonal disorders
Thomas *et al.*, 2010; **Hardell *et al.***, 2016	0.9 – 1.8	1 - 6	Behavioral disorders
	(Hz)	**(μT)**	
Kelfkens & Pruppers, 2017	50 - 60	0.3	Childhood acute leukemia

Conclusions

According to the literature, the NIR highest average values obtained in the field: 2.9 μT MF in market 1; 1035 and 1316μW/m² RF in the primary school and the Children's Hospital, respectively, and 4 μT MF in the public playground are high enough to trigger symptoms such as anomia, focusing difficulty, memory, learning, and behavior problems, as well as sleep and immune system disorders. They are also related to severe conditions such as acute childhood leukemia. It is important to emphasize that the adverse effects reported occur under long-term chronic exposure conditions and their mechanism of action is yet to be clarified. The fact that the values obtained in the present study are below the limits allowed by the ICNIRP explains why in México only the local legal norm is applied regardless of the regulations and standards valid internationally.

There are especially vulnerable groups (children and adolescents) within the population that are susceptible to specific problems (behavioral problems and acute childhood leukemia), and it is precisely in the study locations where these population groups gather that we found the highest exposure values (playground, elementary school, Children's Hospital). In this sense, actions should be taken to minimize people's exposure to NIR until its effect on health is clearly demonstrated.

Further research is required regarding the effects of NIR on health, as well as continuous emission monitoring to avoid health problems such as neoplasms or acute childhood leukemia. Finally, it is recommended to apply the precautionary principle to this public health problem considering that there are other pollution problems of different origins that may interact synergistically with NIR to generate adverse health effects.

Acknowledgments

To the *Universidad Autónoma Metropolitana* for its support through its scholarship program and especially to the people of Xochimilco, México City.

Conflicts of interest

The authors declare no conflicts of interest.

Author contributions

FAAO conceived the research, performed the measurements in the field, and analyzed the data; JAN, JLSS, and AEH contributed with the bibliography, assisted in writing the manuscript, and directed and advised during the research.

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