Assessment of Electromagnetic Exposure Level in an Industrial Facility

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Abstract

With the rapid advancement of technology, residential and occupational electromagnetic field (EMF) exposure has become an important issue. The electromagnetic exposure level in residents and working areas should be monitored and controlled to provide a healthy environment. This study focuses on assessing the EMF exposure levels in a factory with 250 employees. Electric and magnetic fields measurements are conducted from offices to manufacturing areas, specifically within the extremely low-frequency and radio frequency bands. Then, the results are compared with the reference levels set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the national Information and Communication Technologies Authority of Türkiye (ICTA: BTK in Türkiye). The findings indicate that EMF levels throughout the working environment are below the ICNIRP and ICTA reference levels. Consequently, the facility is classified as safe regarding electromagnetic exposure under the observed conditions.

Keywords: electric field, electromagnetic exposure, ICNIRP, magnetic field, occupational safety

1. Introduction

With evolving technology, there is a great demand and interest in electronic devices, which have become an indispensable part of human life. In occupational and residential areas, electromagnetic exposure is an unforeseen risk for people. People are surrounded by base stations, power lines, antennas, and wiring equipment in homes and occupational areas with increasing demand. Consequently, individuals are often unintentionally exposed to electromagnetic fields radiated by these sources. Electromagnetic pollution due to these demands and sources becomes an essential issue for people and can be considered a health threat in homes and workplaces. The electromagnetic exposure level should be specified and controlled to provide a healthier life for employees and residents. Therefore, measuring electromagnetic fields and evaluating them against national and international standards is crucial. Numerous studies have been conducted on human exposure to electromagnetic fields in homes, public places, and workplaces.

A three-year study was conducted to present the electromagnetic exposure of the Swiss population in daily life, and measurements were carried out in various locations, including homes, public areas, train stations, and trains [1]. Children's radio frequency (RF) electromagnetic field exposure is observed inside and outside school areas and buildings in Albacete, Spain [2]. A comparison and review study is conducted for general population electromagnetic exposure in low- and middle-income countries [3]. The electromagnetic radiation exposure levels at millimeter-wave frequencies on humans are considered and aimed to be reduced while evaluating the performance of a Distributed Base Station (DBS) network envisaged for the 6G network [4]. A survey study was carried out in different locations to evaluate occupational and residential electromagnetic exposure due to power frequencies in China [5].

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The employees can be exposed to electromagnetic fields due to the working environment, machines, and tools during working hours, and may be under high electromagnetic exposure [6]. Researchers have examined electromagnetic field levels in working areas such as dental clinics [7], factories [8-9], hospitals [10-11], universities [12-13], and power plants [14]. Also, continuous and instantaneous measurement studies are conducted and show that communication traffic directly affects the electromagnetic pollution level [15].

The potential health risks associated with electromagnetic exposures are of significant interest and have been investigated by various researchers. Research has been conducted about the possible effects of electromagnetic exposure in general and on the occupational population on sleep quality [16], male fertility [17], headaches [18], the immune system [19], and pregnancy [20]. Also, in 2013, RF electromagnetic field was classified as a 'possible human carcinogen' by the International Agency for Research on Cancer (IARC) [21].

Moreover, national and international committees have established and published regulations and standards to protect individuals from non-ionizing radiation [22-28]. The electromagnetic field levels determined by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) are used as a reference level for general public and occupational exposure by many countries.

In 2012, Act 6331, Occupational Health and Safety Law, was published and came into effect in 2013. Due to the law, employers are required to ensure that controls, measurements, examinations, and research are carried out to identify the risks linked to the working environment and to which employees may be exposed regarding occupational health and safety [29]. Electromagnetic fields in a working environment due to machines, devices, and external sources should be considered and identified as a new threat to employees' health. To create a healthier work environment, monitoring the employees' electromagnetic field exposure levels, the distance of the EM source to the employees, and the duration of the EM exposure is crucial. These factors should be systematically organized and assessed at regular intervals.

In this paper, the electromagnetic exposure level of a factory is analysed via electromagnetic field measurements, and the results are compared with ICNIRP public and occupational reference levels. Electromagnetic field measurements are conducted in offices and six factory departments, focusing on extremely low-frequency (ELF) and radio-frequency (RF) ranges. At ELF frequencies, electric and magnetic fields are measured at 52 measurement locations. Also, 52 measurements are done at RF frequencies to obtain electric field levels.

The paper is organized as follows: National and international electromagnetic safety regulations and the reference levels for occupational and public exposure are presented in Section 2. The method and measurement details are given in Section 3. In Section 4, the measurement results and their comparison with reference levels are given, and finally, Section 5 presents the conclusions and the evaluation of the paper.

2. Electromagnetic Safety Regulations

National and international committees have published regulations and guidelines to protect individuals by limiting exposure to time-varying electric and magnetic fields. ICNIRP and IEEE have published guidelines for electromagnetic exposure of employees and the general public.

ICNIRP published guidelines for various frequency ranges in 1998, 2010, and 2020 [22-24]. In 2020, ICNIRP updated the previous guidelines published in 1998 and 2010. The public and occupational exposure reference levels of ICNIRP obtained from these guidelines are given in Tables 1 and 2.

In Türkiye, ICTA has determined the electromagnetic field reference levels by considering the precautionary principle and human and environmental health. The reference levels were considered for public exposure and determined below the limits of the ICNIRP. In accordance with the precautionary principle, in cellular systems, electric field intensity values for the environment cannot exceed 70% of the limit values determined by ICNIRP [27-28]. As an additional safety measure for cellular systems, each device installed at the same emission point cannot exceed 20% of the ICNIRP limit values in Table 1 [28]. For 900 MHz, the electric field density for the environment must be lower than 28.8 V/m. If there is a single GSM base station at that point, the determined limit value is 8.25 V/m.

Table 1 ICNIRP Reference levels for general public exposure [22-24]

Frequency Range	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Magnetic Flux Density (T)
1 Hz–8 Hz	5000	$3.2x10^4/f_l^2$	$4 x10^{-2}/f_l^2$
8 Hz–25 Hz	5000	$4x10^3/f_l$	$5x10^{-3}/f_l$
25 Hz–50 Hz	5000	$1.6x10^2$	$2x10^{-4}$
50 Hz–400 Hz	$2.5x10^2/f_l$	$1.6x10^2$	$2x10^{-4}$
400 Hz–3 kHz	$2.5x10^2/f_l$	$6.4x10^4/f_l$	$8x10^{-2}/f_l$
3 kHz–100 kHz	$8.3x10^{-2}$	21	$2.7x10^{-5}$
100 kHz–30 MHz	$300/ f_M^{0.7}$	$2.2/ f_M$	$2.7x10^{-6}/f_M$
30–400 MHz	27.7	0.073	$0.092x10^{-6}$
400–2000 MHz	$1.375xf_M^{1/2}$	$0.0037xf_M^{1/2}$	$0.0046xf_M^{1/2}$
Note: f_l in kHz and f_M in MHz.			

Table 2 ICNIRP Reference levels for occupational exposure [22-24]

Frequency Range	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Magnetic Flux Density (T)
1 Hz–8 Hz	20000	$1.63x10^5/f_l^2$	$0.2/ f_l^2$
8 Hz–25 Hz	20000	$2x10^4/f_l$	$2.5x10^{-2}/f_l$
25 Hz–300 Hz	$5x10^2/f_l$	$8x10^2$	$1x10^{-3}$
300 Hz–3 kHz	$5x10^2/f_l$	$2.4x10^5/f_l$	$0.3/f_l$
3 kHz–100 kHz	$1.7x10^{-1}$	80	$1x10^{-4}$
100 kHz–30 MHz	$660/ f_M^{0.7}$	$4.9/ f_M$	$6.1x10^{-6}/f_M$
30–400 MHz	61	0.16	$0.2x10^{-6}$
400–2000 MHz	$3xf_M^{1/2}$	$0.008xf_M^{1/2}$	$0.01xf_M^{1/2}$
Note: f_l in kHz and f_M in MHz.			

3. EMF Measurement

In this paper, the EM field measurements are conducted in a factory with 250 employees. Initially, an exploration is carried out to identify the electromagnetic field sources within and around the working areas, such as machines, screens, electrical wiring, and installations. Narda SRM 3006 Selective radiation meter with 420 MHz–6 GHz isotropic E-field Probe is used for an exploration study to identify the potential electromagnetic sources such as Wi-Fi, LTE, and 5G. It shows that the exposure level around 900 MHz is very dominant compared to other EM sources. Then, the measurement frequencies are determined to be 50 Hz for the ELF band and 900 MHz for the RF band.

Measurement locations are chosen based on the exploration findings, focusing on areas where employees are predominantly active on the production line. Also, measurements are taken around some locations, such as electrical panels, power units, and at the locations of the production line machines. Generally, the employees work in fixed positions within their work areas. Measurements are taken at points outside their circle of movement. Measurements are done at 52 locations for ELF and RF frequency bands.

To minimize the operator's effect on the measurement, the field meter is mounted on a tripod during measurements. For RF measurements, results are averaged over 30 minutes in accordance with the ICNIRP guidelines published in 2020 [24]. For

ELF measurements, maximum RMS values were recorded over a 6-minute measurement period. The measurements are done between 09:00 and 16:30, the peak operational hours for employees and factory electricity consumption. All measurements are conducted by using calibrated Narda ELT-400 and HOLADAY 3060 field meters, Narda NBM 550 broadband field meter with EF0691 isotropic E-field Probe 100 kHz to 6 GHz, and Narda SRM 3006 Selective radiation meter with 27 MHz-3 GHz and 420 MHz–6 GHz isotropic E-field probes.

The ELF measurement results are compared against the reference levels outlined in the ICNIRP guidelines, and the values, along with their distribution, are presented in graphs. The same procedure is applied to the RF measurement results. Additionally, RF results are compared with the national reference levels published by ICTA.

Considering the working postures of the employees, the measurements are conducted at eye level (mid-level of the head). Therefore, measurement heights are chosen as 1.70 m for standing workers and 1.50 m for workers seated on operator chairs [8].

During measurements, the aim is to prevent operator-based errors and reduce measurement uncertainty by using the same measurement method, the same measurement setup, and conducting the measurements under the same conditions as possible. However, many other factors, such as communication traffic density, weather, or uncertainties related to the device and probe, also affect the measurements. The uncertainties of the probes and devices used in this study can be determined from the calibration certificate and listed in Table 3.

Table 3 Uncertainties of E-field measurement devices obtained from calibration documents

NBM550 EF Probe		SRM 3006 E Probe	
Frequency (MHz)	Uncertainty (dB)	Frequency (MHz)	Uncertainty (dB)
500-1000	1.5	433-1600	1.5
1800-6000	0.6	1900-3000	1

To validate the measurement results and understand and eliminate uncertainties, measurements are repeated under similar conditions. Some different results are obtained regarding the overall effect of measurement uncertainty on the measurement results (10-25%), and the highest values are considered as the measurement result.

4. Results

This study evaluates the EMF levels in a factory with 250 employees by measuring electromagnetic fields at 52 locations in 6 departments. These results are compared to the ICNIRP reference levels.

The limit values are derived from Tables 1 and 2 for a 50 Hz frequency of the ELF band. The determined electric field limit value is 5000 V/m for the general public and 10000 V/m for occupational exposure. Electric field measurement values are shown in Fig. 1. Also, the numerical distribution of electric field measurements is given in Fig. 2. The limit values for the magnetic field are calculated to be 200 µT for the general public and 1000 µT for occupational exposure. Magnetic field measurement values and numerical distribution of magnetic field values are illustrated in Figs. 3 and 4, respectively.

The ELF measurement results are between 0.54 V/m and 36 V/m. Fig. 1 demonstrates that all electric field measurement values are below the ICNIRP reference levels for public and occupational exposure. The highest recorded electric field strength, taken from the department nearest to the power lines surrounding the factory, is 36 V/m, representing 0.72% of the public limit and 0.36% of the occupational limit. According to the numerical distribution shown in Fig. 2, only two measurements exceeded 30 V/m (0.3% of the occupational limit) and nine measurements exceeded 10 V/m, while 43 measurements (82%) are below 10 V/m.

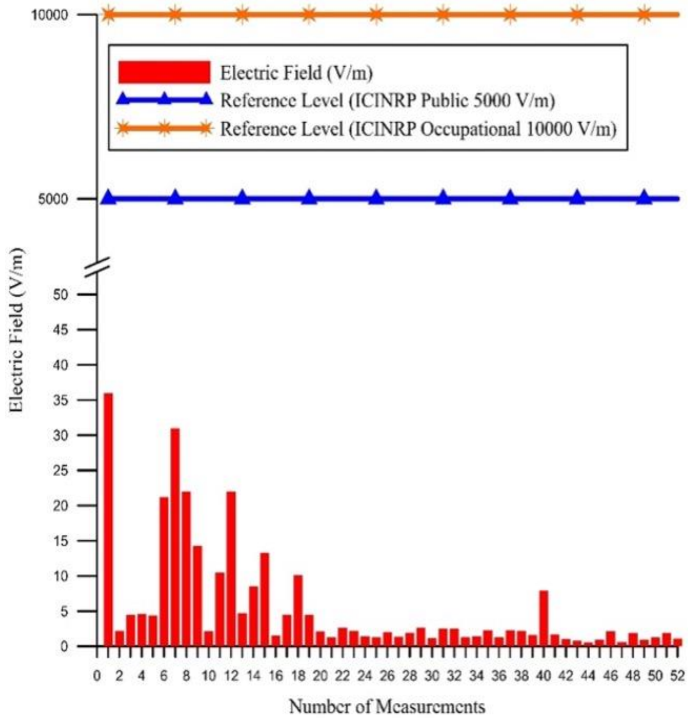

Fig. 1 ELF Electric field measurement results

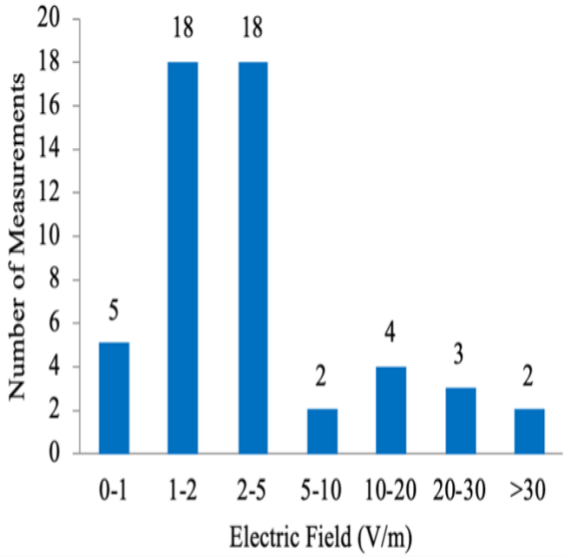

Fig. 2 Distribution of Electric Field Measurement Results

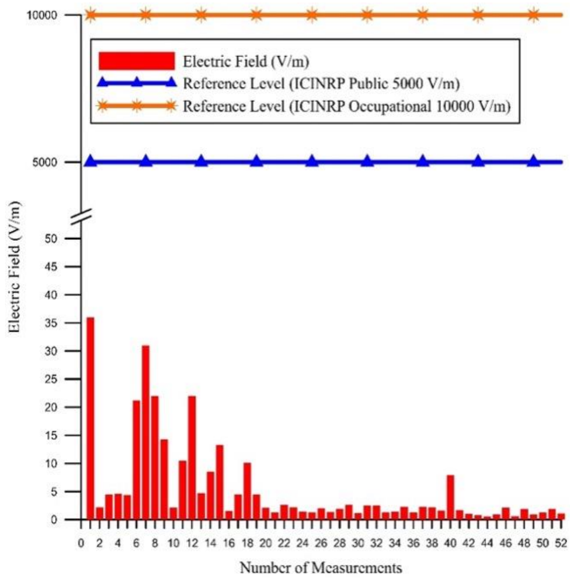

Fig. 3 Magnetic field measurement results

Also, magnetic field measurements are conducted concurrently with electric field assessments at ELF frequencies, with 52 measurements taken at the exact locations. The magnetic field measurement results are varied from 0.06 μT to 15.5 μT. The results presented in Fig. 3 clearly indicate that all magnetic field measurements are under the ICNIRP limits for the general public and occupational exposure at ELF frequencies. The highest recorded magnetic field strength was 15.5 μT, corresponding to 7.75% of the general public limit and 1.55% of the occupational limit.

The numerical distribution of all magnetic field measurement results is illustrated in Fig. 4. According to the numerical distribution shown in Fig. 4, only one measurement result (2% of measurements) was higher than 10 μT, and four measurement results (8% of measurements) were higher than 5 μT.

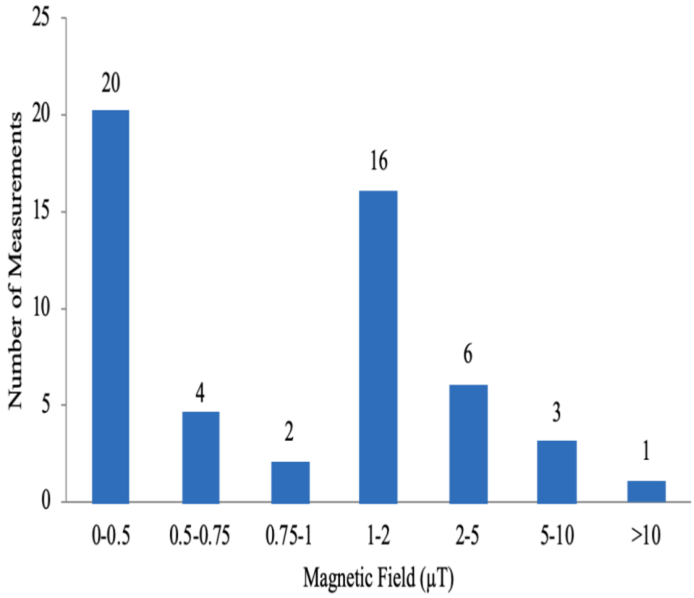

Fig. 4 Distribution of Magnetic Field Results

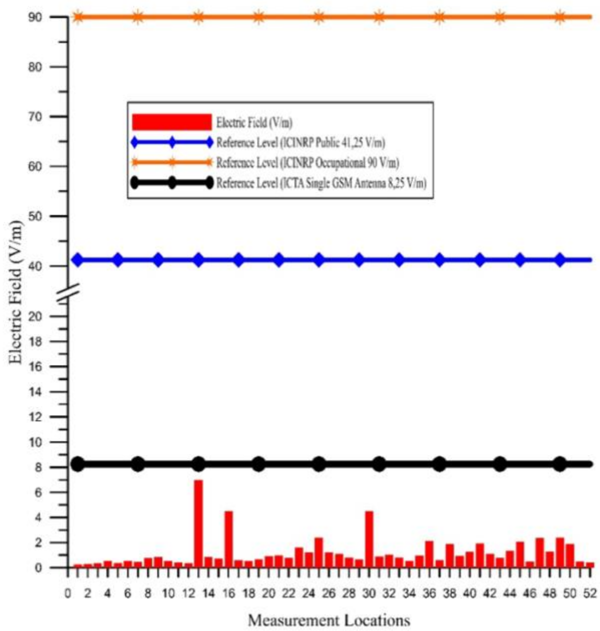

Fig. 5 Electric field measurement results (RF)

Electric field measurements at RF frequency are conducted at the exact locations as ELF measurements, and the results are shown in Fig. 5. The lowest measurement result is 0.25 V/m, and the highest is 7 V/m. For comparison, the reference exposure level for the general public at 900 MHz is established. The results are compared with the public and occupational reference levels of ICNIRP and the ICTA(BTK) reference levels. All measurements are quite below the ICNIRP reference levels. The highest measurement result is 7 V/m, which is 17% of the ICNIRP and 84% of the ICTA reference level. This value is obtained under the crinkled room fluorescent lamp. According to the ICTA reference level, this value can be considered high despite being below the limit value. ICTA's reference level is considered for a single antenna emission at the measurement point. At 900 MHz, the calculated reference level of ICTA for the environment is 28.8 V/m, and the highest measurement result is 24.3% of this level. The highest value is measured under the fluorescent lamp, and this value can be easily reduced by replacing the lighting system with newer technology. The sketch of this measurement location is given in Fig. 6.

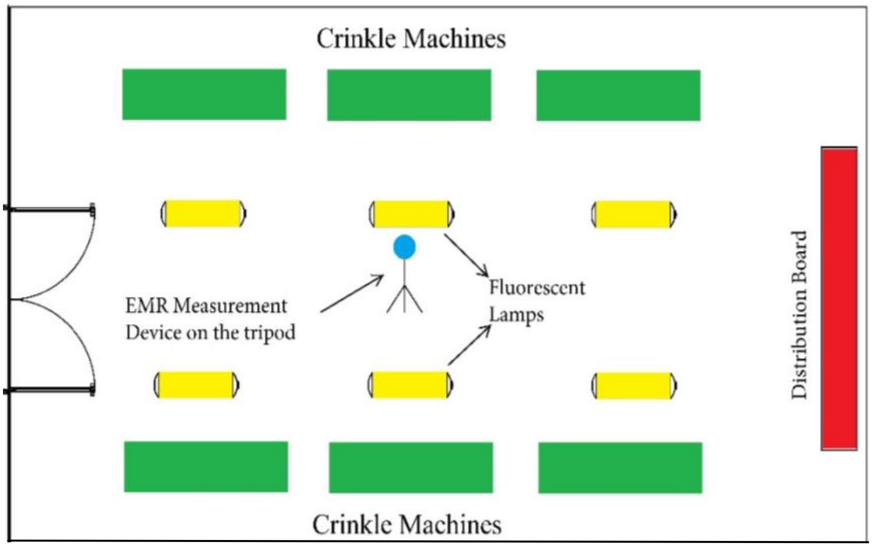

Fig. 6 Site sketch of the location with the highest 900 MHz measurement

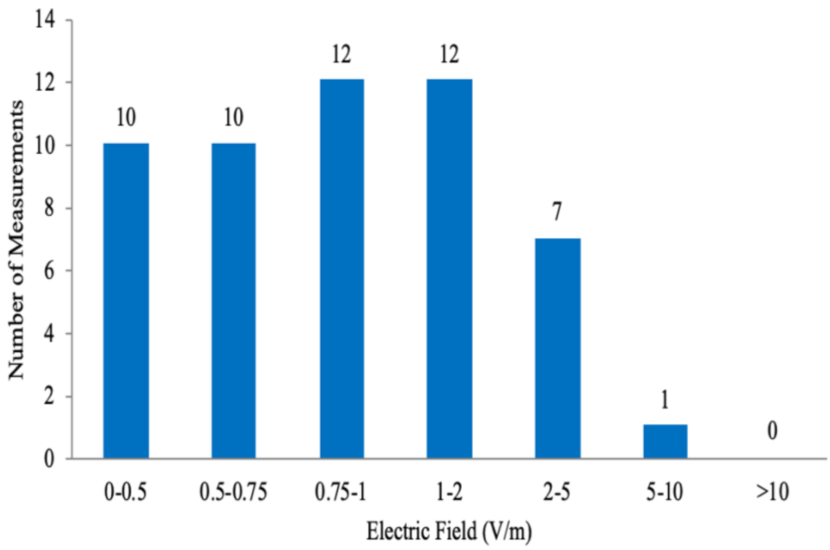

Fig. 7 Distribution of Electric Field Results (RF)

The numerical distribution of all electric field measurement results is illustrated in Fig. 7. It shows that none of the measurements exceeded the ICTA and ICNIRP limit values. Only one measurement result (2% of measurements) exceeded 5 V/m, and this value is close but below the ICTA's reference level for single-antenna emission.

Table 4 Median, IQR, p95 statistics, and confidence intervals

Measurements	Min-Max Values	Mean	Standard Deviation	Median (%95 CI)	IQR (%95 CI)	P95 (%95 CI)
ELF (H-field)	0.06 - 35	1.99	4.96	0.90(0.43 - 1.27)	1.25(1.01 - 2.29)	5.16(3.19 - 20.37)
ELF (E-Field)	0.54 - 36	5.42	7.80	2.17 (1.79 - 2.57)	3.18(1.18 - 8.97)	22.00(10.50 - 33.25)
RF (E-Field)	0.25 - 7	1.23	1.21	0.84(0.69 - 1.04)	0.75(0.49 - 1.42)	3.35(2.07 - 5.62)

In addition to the measurement study, median, IQR, p95 statistics, and confidence intervals are presented in Table 4 with standard deviation and mean values. ELF Magnetic field values range from 0.06 to 35.00, with a mean of 1.99 and a median of 0.90. The mean value is considerably higher than the median, combined with a wide P95 confidence interval, indicating a right-skewed distribution strongly influenced by high values. ELF electric field values show the highest variability among the measured results, with a mean of 5.42 and a standard deviation of 7.80. The interquartile range and the P95 confidence interval are relatively wide, suggesting a significant dispersion and the presence of high measurements. In contrast, the RF electric field values exhibit a more compact distribution. Its values range from 0.25 to 7.00, with a mean of 1.23 and a median of 0.84. IQR and P95 confidence intervals are narrower and indicate greater homogeneity and lower variability compared to the other measurement data.

5. Conclusions

This study evaluated the EMF exposure levels of the employees within an industrial facility at ELF and RF frequencies and provided a healthier working environment in accordance with the guidelines and laws. Firstly, an exploration study was carried out to determine the measurement locations, potential electromagnetic sources, and frequencies. The active positions of the employees on the production line and the locations of the potential electromagnetic sources were the primary selection criteria. As a result of this study, 50 Hz for the ELF band and 900 MHz for the RF band were selected as measurement frequencies. The key findings are summarized as follows:

(1) At ELF frequencies, the highest measured electric and magnetic field values were 36 V/m and 15.5 µT, respectively. Due to comparison with the ICNIRP reference levels, the electric field strength was only 0.36% of the occupational limit, and the magnetic field strength was 1.55%. These values are quite low according to the guidelines and are acceptable.

(2) RF measurements were compared with ICNIRP and ICTA reference levels. The highest measured electric field value was 7 V/m and was 17% of the ICNIRP, 84% of the ICTA reference level for single antenna emission, and 24.3% of the ICTA reference level for the environment. The ICTA reference level is considered for general exposure, and this value can be considered high even though it is below the limit value.

(3) The factory is currently operating on a single shift, and measurements were taken between 09:00 and 16:30. If the number of shifts is increased, it is recommended to conduct electromagnetic field measurements for the new shift system. Furthermore, measurements should be taken after renovations, such as maintenance and the installation of new machinery/equipment, to assess the new exposure level.

(4) Due to measurements, the employees' working environment in the factory can be classified as admissible within applicable limits under the observed conditions. Control measurements should be carried out periodically to maintain this standard. Also, it should be noted that the data obtained from this study is only valid for this factory and may not be directly applicable to industrial environments.

Conflicts of Interest

The authors declare no conflict of interest.

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