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Research article

Measuring and assessing the effects of extremely low-frequency electromagnetic fields (ELF-EMF) on blood parameters and liver enzymes of personnel working in high voltage power stations in a petrochemical industry

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ABSTRACT

Introduction: Exposure to electric and magnetic fields (EMF) is a phenomenon that has always been present. In the last two decades, there have been numerous worries about the possible effects of extremely low-frequency (ELF) fields on human health. Consequently, this study aims to measure and evaluate the effect of ELF fields on blood parameters and liver enzymes of personnel working in high-voltage power stations in the petrochemical industry.
Methods: This cross-sectional, descriptive-analytical study was done in a petrochemical industry in southern Iran in 2021. Two groups of 50 people were selected to attain the research goals and classify jobs with the risk of exposure to extremely low-frequency electromagnetic fields (ELF-EMF) and the time spent on work. One group was exposed to ELF-EMF, and the other was regarded as the control group. Electromagnetic fields were measured using the HI-3604 device and the standard method of IEEE 1994-644. The workers' demographic data, blood parameters, and liver enzymes were also obtained from the workers' medical records. The course of changes in each of the blood parameters and liver enzymes and demographic variables in the control and case groups were then examined. In the last stage, the effect of the electric field and magnetic field on the blood parameters and liver enzymes of the two control and subject groups was conducted using the multiple regression model.
Results: The measured points in all stations are 200, and the minimum and maximum values of the magnetic field was 0.8 and 2019 mG, respectively. The minimum and maximum values of the electric field intensity was 0.003 and 215 V/m, respectively. The average results of the demographic variables and blood and liver indices in the control and case groups from 2018 to 2020 revealed that the average variables were not significantly different in the case and control groups (p-value>0.05). Moreover, workers' exposure to ELF-EMF was below the permissible limit.

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Conclusion: Based on the results of the present study, **ELF-EMF** does not have any significant effects on demographic factors, blood parameters, and liver enzymes.

1. Introduction

Exposure to ELF-EMF is a phenomenon that has always existed. However, during the 20th century, it is progressively increasing due to environmental exposure to manufactured electromagnetic fields [1]. In the last two decades, there have been numerous worries about the conceivable effects of ELF-EMF on human health [2]. According to the frequency range, electromagnetic fields are divided into very low frequency (VLF) and extremely low frequency (ELF) ranges. Generally, the ELF region of the electromagnetic spectrum is defined as frequencies from 3 to 3000 Hz [3]. These fields are generated by electrical devices, high-voltage power distribution networks, residential and business sources, and power lines.

The effects of electromagnetic fields with low frequency are different from those of these fields at high frequency because, at low frequency, the current voltage is high, a situation in which living organisms are exposed to such fields easily and without protection [4]. So, researchers have recently drawn attention to magnetic fields, especially ELF waves in 50–60 Hz frequencies [5]. In recent years, electromagnetic fields with different frequencies and high intensities have been considered a significant factor in the environment. Due to the fear of the occurrence of unidentified diseases, changes in blood composition, effects on nervous systems, genetic changes, and the occurrence of diseases such as cancerous growth of cells, people's concern and the research motivation of the scientific centers of the world have increased [6]. According to the international agency for research on cancer (IARC) assessment of carcinogenic risks for humans, possible human carcinogenic ELFs have been evaluated [7]. Several studies have been conducted on living organisms and humans to investigate the effects of exposure to ELF-EMF. In most animal studies, many cells showed increased oxidative stress caused by ELF-EMF [8]. Nevertheless, from the past decades until now, studies on human exposure to electromagnetic fields have had opposing results [9,10].

Cakir et al. (2009), investigating blood changes in rats exposed to ELF fields of 50 Hz, showed that ELF-EMF exposure might cause minor but significant changes in statistics in some blood parameters mice in the physiological range [11]. Also, Hosseinabadi et al. research in 2019 on the effect of chronic occupational exposure to ELF on inflammatory cytokines and blood parameters designated a significant increase in these parameters in the occupationally exposed group with magnetic fields compared to other groups [12]. On the other hand, based on the investigations conducted by Karimi et al., in 2021, there is no comprehensive mechanism to explain the biological effect of ELF-EMF, which is associated with childhood cancer, Alzheimer's disease, and abortion. However, no consistent evidence shows adult cardiovascular disease and cancer mortality due to ELF-EMF exposure [13]. In the same year, Seomun et al. during a meta-analysis of 30 studies and more than 36,000 children with childhood leukemia, observed a statistically significant relationship between exposure to ELF-EMF and childhood leukemia. In addition, the possibility of exposure to ELF-EMF and childhood leukemia was high [14]. Despite many studies, the question of the positive or negative effect of electromagnetic fields on living organisms remains an unanswered question; hence, the present study was designed with the following objectives:

1 determining and measuring electric fields around the high-voltage power station;
2 determining and measuring magnetic fields around the high-voltage power station;
3 drawing distribution maps of electric fields in power stations with Surfer software;
4 drawing distribution maps of magnetic fields in power stations with Surfer software;
5 determining and measuring blood parameters and liver enzymes;
6 determining the regression relationship between the values of ELF-EMF with the values of blood and liver parameters.

2. Materials and methods

2.1. Industry selection

The petrochemical industry refers to industries in which crude oil or natural gas hydrocarbons are converted into chemical products. In Iran, for the first time in 1964, the National Company of Petrochemical Industries, affiliated with the National Iranian Oil Company, was formed and started its activities in this industry field. The petrochemical industry in Iran is about half a century old [15]. Using abundant and diverse equipment and instruments in petrochemical industries creates conditions where people in these industries are exposed to numerous electromagnetic fields. Consequently, investigating these fields is essential in the petrochemical industry.

2.2. Study design

This cross-sectional, descriptive-analytical study was done in the petrochemical industry in southern Iran in 2021. Two groups of 50 people were selected to attain the research objectives (i.e., classifying jobs with the risk of exposure to ELF-EMF and the time spent on work). The case group included workers who were exposed to electromagnetic fields chronically (at least three consecutive years) and during their working days (except for rest hours). The control group included workers from administrative and service sectors who

Fig. 1. High voltage power station of the power plant.

were not exposed to electromagnetic fields (field intensity) electromagnetic field of the work environment (less than 0.5 mT). It should be noted that all the employees were men. Since people's health level is important, the potential participants' health status was assessed in light of medical standards. People with underlying blood and liver diseases were excluded from the study. Only healthy people were included in demographic information, including age, work experience and body mass index (BMI), blood parameters, and liver enzymes (including red blood cells (RBC), white blood cells (WBC), hemoglobin (Hgb), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), platelets (PLT) and liver enzymes (Serum Glutamate Pyruvate Transaminase (SGPT), Serum Glutamic Oxaloacetic Transaminase (SGOT), were extracted from the occupational examination records of the workers (which is done annually). EMFs were also measured.

Lastly, the course of changes in each blood parameter and demographic variables in the control and case groups were examined from 2018 to 2020.

2.3. Measurement of electromagnetic fields

The EMFs were measured through the HI-3604 device by Honoy Company (US) and the standard IEEE 1994-644 method to realize the research goals. It should be mentioned that regarding the anticipated standard, the device was placed at a height of 1 m above the ground. In terms of time, all measurements were made between 9 and 15 h and in similar weather conditions (completely sunny) [16]. Due to the nature of static electricity, EMFs in these frequencies act separately from each other and are measured separately [17]. To enhance the measurement accuracy, despite the calibration certificate, the device was re-calibrated by the country's atomic energy organization with a calibration factor of 1; the measurements were performed according to the people's workstations, 3 to 5 times in each station, and finally, their mean was determined as an index. Fig. 1 shows the high-voltage stage power station of the power plant.

After gathering all the data required for the research, in the first stage, it was determined that the measured points in all stations were 200 points. In addition, the maximum and minimum values were designated in these measurements, and after measuring the EMFs, these values were compared with the threshold limit values (TLV) [18]. The measurement results were reported in units of volts per meter for electric fields and mill gauss for magnetic fields in the SI system [19].

2.4. Drawing distribution maps of ELF-EMF

ELF-EMF distribution maps for posts with the highest values of infinite EMFs (generator room and substation) were designed by Surfer v.13 software and compared with the permissible occupational exposure limits.

2.5. Statistical analysis

Generally, the collected data were analyzed using $SPSS_{17}$ software, and multiple regression was carried out for data analysis. We used the multiple regression model to investigate the effect of the distance from the electric and magnetic field, and the control group and the case were analyzed on each blood parameter and liver enzyme (precisely) so that each blood parameter and the liver enzyme was separately included as a response variable in the regression model and the results were interpreted.

Table 1
Results of measuring the intensity of electric fields [11] and magnetic fields[22] in all stations.

Type of waves	Number of measurements	Min.	Max.
Magnetic field intensity (mG)	200	0.8	2019
Electric field intensity (V/m)	200	0.003	215

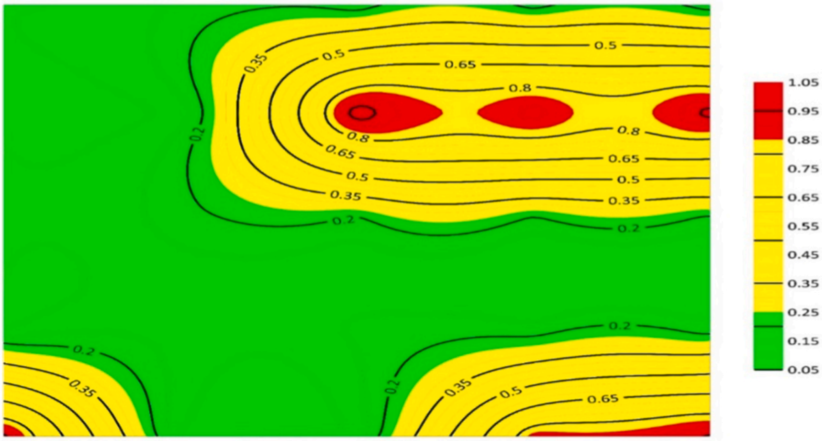

Fig. 2. Electric field distribution map around the post of the generator room.

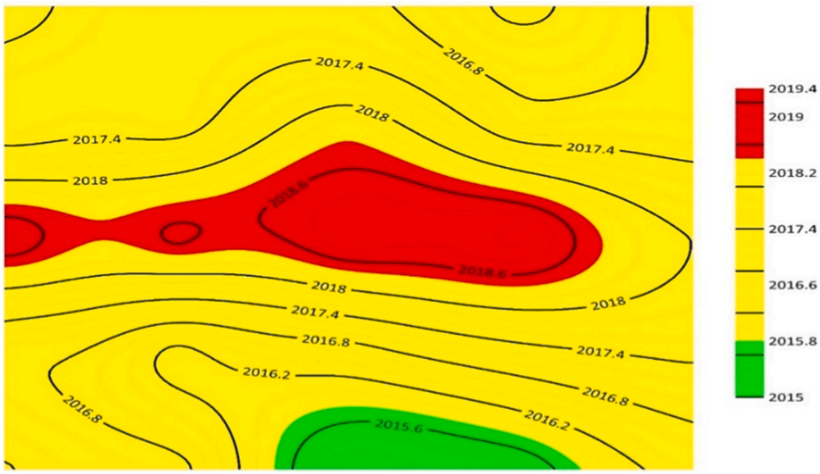

Fig. 3. Magnetic field distribution map around the post of the generator room.

2.6. *Ethical code*

Before carrying out the project, all its steps were approved by the ethics committee of Kerman University of Medical Sciences and Health Services (project code of ethics IR.KMU.REC.1399.589). Written informed consent was obtained in the study, and the workers were assured that their personal information would be kept confidential.

3. Results

3.1. *Measurement results of EMFs*

Workstations of the case and control group members were determined. Table 1 shows the results of electric and magnetic field measurements for all the mentioned stations:

Based on Table 1, the number of measured points in all stations is 200, and the minimum and maximum values of the magnetic field were 0.8 and 2019 mG, respectively. In line with the intensity of the electric field, the minimum and maximum values were 0.003 and 215 V/m, respectively.

3.2. Distribution map of electromagnetic fields

3.2.1. 1- Drawing the electric field distribution map around the post of the generator room

Fig. 2 shows how the electric field spreads around the post of the generator room. Accordingly, all measurements were within the permissible occupational exposure range.

3.3. 2- drawing the distribution map of the magnetic field around the post of the generator room

Fig. 3 shows how the magnetic field spreads around the post of the generator room. Accordingly, all the measurements were within the permissible range of occupational exposure.

3.4. Average demographic variables and blood parameters

Table 2 shows the examining course of changes in each of the blood parameters and demographic variables in the control and case groups from 2018 to 2020. The mean and standard deviation of the demographic information of the study subjects include the age, which was 35.54 ± 4.44 years in the case group and 35.08 ± 4.21 years in the control group, and the BMI of the subjects was 24.95 ± 1.75 kg/m2 in the case group and 24.21 ± 1.89 in the control group.

Table 3 shows the investigating effect of the electric and magnetic field and the difference between the case and control groups on the response variables (blood parameters and liver enzymes). As observed, the regression coefficients of the response variables (WBC, RBC, HGB, HCT, MCV, MCH, MCHC, PLT, SGOT, and SGPT) were shown in three consecutive years. It should be mentioned that the multiple regression model was done specifically for each of the blood and liver parameters.

As shown in Table 3, the relationship between the values of RB and the values of magnetic fields was statistically significant (p-value = 0.042).

Also, the relationship between MCHC and magnetic field values was statistically significant (p-value = 0.039).

4. Discussion

Current studies have shown the harmful effects of ELF-EMF on human health, especially in some cancers, depression, and cardiovascular diseases, and the effect on the central nervous system and abortion. Likewise, limited studies have been conducted on the effect of fields on blood biochemical parameters and liver function [20,21].

As can be seen in Table 1, the number of measured points in all posts is 200 points. The maximum and minimum values in these measurements show that the maximum values of the magnetic and electric field are related to the station of the generator room of the power plant in region 2. The minimum values of these fields are related to the central control room of UIT region 3.

The magnetic field of the studied stations is lower than the permissible limit set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 5000 mG and the American Conference of Governmental Industrial Hygienists (ACGIH) 10000 mG. On the other hand, regarding the permissible occupational limits for the magnetic field in Iran, no special division has been defined for different frequencies. The amount of occupational contact with the magnetic field for the whole body was declared to be 600 Gauss. For the electric field, all measurements are less than the occupational limit of 25 kV/m set by ACGIH and 8.3 kV ICNIRP [22].

The results of a study conducted by Ranjbarian et al. (2020) in high voltage substations kv230 in Golestan province revealed that all measurements of EMFs are within the range of occupational exposure limits [23]. Moreover, a study by Mohammadian et al. (2017), which aimed to measure the electromagnetic field in the displays in the electrical substations of an oil products distribution company in Mazandaran province, revealed that the intensity of all the measured EMFs was lower than the limits of the national and international standards. The authors concluded that probably the workers were facing the safe limits of the electromagnetic field [24], which is consistent with our study. Also, in the study conducted by Sepehr et al., entitled "Measurement of EMFs in the control rooms of 3 power plants in Iran and compared them with the permissible limit values", the intensity of the magnetic field measured in this power plant was less than the permissible limits as in this study [25].

Table 2 shows that during the years 2018–2020, there was no significant difference in the average variables (WBC, RBC, HGB, HCT, MCV, MCH, MCHC, PLT, SGOT, SGPT, BMI, age, and work experience) in the case group and the control group (p-value >0.05).

Table 3 shows the regression coefficients of the response variables (WBC, RBC, HGB, HCT, MCV, MCH, MCHC, PLT, SGOT, and SGPT) in three consecutive years. It should be noted that the multiple regression model is done exclusively for each of the blood and liver parameters.

WBC regression coefficients for the years 2018–2020 are interpreted as follows:

In 2018:

Control and case group variable: In the control group, the average WBC is 108 units more than that of the case group. The effect of

[1] In this study, the intensity of the electric field in all cases is in terms of v/m.

[2] In this study, the magnetic field in all cases is in mG.

Table 2
Average demographic variables and blood parameters in the years 2018–2020.

Year	2018			2019			2020		
Variable	Case	Control	p-value	Case	Control	p-value	Case	Control	p-value
WBC	6412 ± 923.3	6520 ± 815.66	0.53	6400 ± 962.56	6490 ± 805.90	0.61	6436 ± 967.16	6484 ± 799.83	0.78
RBC	0.37 ± 5.13	5.22 ± 0.31	0.16	5.16 ± 0.55	5.23 ± 0.32	0.43	5.16 ± 0.42	5.21 ± 0.34	0.54
HGB	15.39 ± 0.85	15.52 ± 0.81	0.43	15.36 ± 1.05	15.52 ± 0.83	0.41	15.47 ± 0.76	15.42 ± 0.84	0.77
HCT	45.58 ± 3.69	45.05 ± 3.66	0.46	45.39 ± 3.73	44.84 ± 3.75	0.46	45.4 ± 3.79	44.95 ± 3.72	0.55
MCV	84.92 ± 4.06	85.62 ± 3.34	0.34	85.06 ± 4.38	85.41 ± 3.21	0.64	85.20 ± 4.36	85.65 ± 3.41	0.57
MCH	28.54 ± 1.78	28.81 ± 1.49	0.42	28.36 ± 2.15	28.57 ± 1.58	0.59	28.54 ± 1.86	28.76 ± 1.47	0.51
MCHC	37.76 ± 0.89	35.08 ± 1.29	0.16	34.50 ± 1.24	35 ± 1.31	0.06	34.65 ± 1.09	35.09 ± 1.19	0.06
PLT	249440 ± 47082.28	272880 ± 74794.86	0.66	249460 ± 47316.22	272620 ± 74561.82	0.07	249820 ± 48184.04	272840 ± 747787.96	0.07
SGOT	29.3 ± 7.65	27.5 ± 7.26	0.23	29.14 ± 7.25	27.22 ± 7.07	0.18	29.78 ± 7.79	27.22 ± 7.23	0.09
SGPT	30.34 ± 7.53	28.94 ± 7.21	0.34	30.56 ± 7.48	28.84 ± 6.82	0.23	30.96 ± 7.66	28.8 ± 7.12	0.15
Age	35.15 ± 4.44	34.70 ± 4.20	0.59	36.16 ± 4.44	35.7 ± 4.20	0.59	37.2 ± 4.42	36.7 ± 4.20	0.56
BMI	25.04 ± 0.27	24.52 ± 0.27	0.18	24.95 ± 0.25	24.66 ± 0.28	0.42	24.92 ± 0.26	24.91 ± 0.27	0.99
Work experience	10.68 ± 4.20	10.76 ± 4.30	0.92	11.64 ± 4.18	11.76 ± 4.30	0.88	12.66 ± 4.17	12.66 ± 4.31	1

WBC: White blood cell; RBC: Red blood cell; HGB: Hemoglobin; HCT: Hematocrit; MCV: Mean Corpuscular Volume; MCH: Mean Corpuscular Hemoglobin; MCHC: Mean Corpuscular Hemoglobin Concentration; PLT: Platelets; SGOT: Serum Glutamic Oxaloacetic Transaminase; SGPT: Serum Glutamate Pyruvate Transaminase; BMI: Body Mass Index.

Table 3
Regression coefficients of blood and liver parameters of multiple regression model in the years 2018–2020.

		2018			2019			2020		
Response variable	Variable	Regression coefficient	SE	p-value	Regression coefficient	SE	p-value	Regression coefficient	SE	p-value
WBC	group	108	173.11	0.534	90	174.72	0.608	48	175.44	0.785
	Mag	0.27	0.15	0.078	0.34	0.15	0.057	0.32	0.15	0.051
	Elc	−15.88	366.06	0.962	−13.54	399.20	0.968	55.03	340.59	0.872
RBC	group	0.09	0.06	0.155	0.07	0.09	0.420	0.04	0.07	0.542
	Mag	0.000058	0.00	0.331	0.016	0.00016	0.042	0.000068	0.00	0.311
	Elc	−0.21	0.13	0.105	−0.16	0.17	0.333	−0.14	0.14	0.323
Hgb	group	0.13	0.16	0.423	0.15	0.19	0.414	−0.05	0.17	0.771
	Mag	−0.00	−0.000091	0.526	−0.000013	0.00	0.934	0.000059	0.00	0.688
	Elc	−0.59	0.32	0.065	−0.63	0.36	0.086	−0.60	0.32	0.068
HCT	group	−0.54	0.73	0.461	−0.55	0.74	0.458	−0.45	0.74	0.549
	Mag	0.00087	0.00	0.175	−0.0010	0.00	0.120	−0.00083	0.00	0.207
	Elc	1.39	1.41	0.327	1.31	1.43	0.363	1.18	1.45	0.415
MCV	group	0.70	0.74	0.342	0.35	0.76	0.643	0.44	0.78	0.574
	Mag	0.0010	0.00	0.108	0.0010	0.00	0.132	0.00090	0.00	0.189
	Elc	0.07	1.43	0.956	0.05	1.48	0.969	0.16	1.52	0.916
MCH	group	0.26	0.33	0.423	0.20	0.38	0.594	0.22	0.33	0.517
	Mag	−0.00006	0.00	0.836	0.00013	0.00	0.678	−0.00001	0.00	0.971
	Elc	−0.41	0.64	0.521	−0.06	0.73	0.930	−0.28	0.65	0.668
MCHC	group	0.32	0.22	0.156	0.49	0.25	0.053	0.44	0.22	0.056
	Mag	0.00024	0.00	0.203	0.00046	0.00	0.039	0.00028	0.00	0.156
	Elc	0.45	0.43	0.298	0.44	0.48	0.363	0.23	0.44	0.604
PLT	group	23440	12064	0.055	23160	12061	0.058	23020	12155	0.061
	Mag	−6.20	10.56	0.559	−6.54	10.56	0.537	−6.74	10.64	0.528
	Elc	6.14	10.56	0.512	6.20	10.31	0.546	7.2	10.80	0.543
SGOT	group	−1.8	1.50	0.234	−1.92	1.44	0.186	−2.56	1.51	0.094
	Mag	−0.0010	0.00	0.446	−0.0010	0.00	0.387	−0.0012	0.00	0.057
	Elc	−0.71	2.91	0.807	−0.33	2.79	0.904	−0.27	2.93	0.926
SGPT	group	−1.4	1.47	0.345	−1.72	1.43	0.233	−2.16	1.48	0.149
	Mag	−0.0012	0.00	0.345	−0.0015	0.00	0.228	−0.0013	0.00	0.286
	Elc	−3.11	2.86	0.280	−1.92	2.78	0.491	−2.04	2.88	0.478

Group: (Control And Case Group); Mag: (Magnetic Field); Elc: (Electric Field); WBC: White blood cell; RBC: Red blood cell; HGB: Hemoglobin; HCT: Hematocrit; MCV: Mean Corpuscular Volume; MCH: Mean Corpuscular Hemoglobin; MCHC: Mean Corpuscular Hemoglobin Concentration; PLT: Platelets; SGOT: Serum Glutamic Oxaloacetic Transaminase; SGPT: Serum Glutamate Pyruvate Transaminase; BMI: Body Mass Index.

the group this year is not significant (p-value >0.05).

Magnetic field variable: For each increase in the distance from the magnetic field, the average WBC increases by 0.27 units. The effect of this variable is not significant (p-value >0.05). Electric field variable: For each unit increase in the distance from the electric field, the average WBC decreases by 15.88 units, the effect of which is not significant (p-value >0.05).

In 2019:

Control and case group variable: In the control group, the average WBC is 90 units more than that of the case group. The group variable's effect this year is not significant (p-value >0.05).

Magnetic field variable: For each unit increase in the distance from the magnetic field, the average WBC increases by 0.34 units. The effect of this variable is significant (p-value <0.05).

Electric field variable: for each unit increase in the distance from the electric field, the average WBC decreases by 13.54 units. The effect of this variable is not significant (p-value >0.05).

1 N 2020:

Control and case group variable: In the control group, the average WBC is 48 units more than that of the case group. The effect of the group variable is not significant (p-value >0.05) this year.

Magnetic field variable: For each unit increase in the distance from the magnetic field, the average WBC increases by 0.32 units. The effect of this variable is not significant (p-value >0.05).

Electric field variable: For each unit increase in the distance from the electric field, the average WBC decreases by 55.03 units. The effect of this variable is not significant (p-value >0.05).

In the study by Fani et al. (2006) on aluminum electrolysis workers, although the average blood parameters of the exposed group in two consecutive years in the category of white blood cells, red blood cells, hemoglobin, hematocrit, and MCV were higher than those of the control group clinically, both the case and control groups were in the normal range. In this sense, they were consistent with our study [26]. Xin Liu et al. (2013) conducted a study entitled "Effects of extremely low-frequency electromagnetic field on the health of workers in the automotive industry." The analysis of hematological parameters, contrary to our research, showed that in the exposed group, HCT, MCH, lymphocyte, and MCV were significantly higher than those in the control group ($p < 0.05$) [27]. Dasdag et al. (2002) conducted a study entitled "effects of extremely low-frequency electromagnetic fields on hematologic and immunologic parameters in welders." In this study, the blood parameters in both the exposed and non-exposed groups were in the normal range, which

Table 4
List of abbreviations and acronyms.

Abbreviation	Explanation
ELF-EMF	Extremely Low-Frequency Electromagnetic Fields
EMF	Electric and Magnetic field
VLF	Very Low Frequency
ELF	Extremely Low Frequency
TLV	Threshold Limit Values
Mag	Magnetic Field
Elc	Electric Field
BMI	Body Mass Index
RBC	Red Blood Cells
WBC	White Blood Cells
Hgb	Hemoglobin
HCT	Hematocrit
MCV	Mean Corpuscular Volume
MCH	Mean Corpuscular Hemoglobin
MCHC	Mean Corpuscular Hemoglobin Concentration
PLT	Platelets
SGPT	Serum Glutamate Pyruvate Transaminase
SGOT	Serum Glutamic Oxaloacetic Transaminase

is consistent with the results of our research. However, considering some blood parameters between the exposed and non-exposed groups, such as the mean of neutrophils, hemoglobin, hematocrit, MCH, MCV, and platelets, there was a statistically significant difference, which is not consistent with our findings [28]. Also, our findings contradict the research results reported by Dr. Roknian et al. (2009). They stated that electric fields have an inflammatory effect on the number of white blood cells, which causes a slight increase in this parameter in the mentioned period. The magnetic field causes a kind of leukocytosis phenomenon and mild macrocytic anemia [29].

Ghorbani et al. (2010) study measured the electromagnetic field in high-voltage substations with an infinite frequency. They found that the minimum and maximum value of the electric field was 1.35 and 3110 v/m, respectively, and the minimum and maximum value of the magnetic field was Tμ 1, respectively. It was 504.13 and 2.504, and all the values of electromagnetic fields were less than the standard set by ACGIH, which is consistent with the results of the present study [15]. Also, Sharififard et al. (2010) aimed to measure the magnetic field in 230 KV power stations. They demonstrated that in none of the stations the field value was higher than the standard limit of the International Commission on Protection against Non-Ionizing Radiation, which is consistent with the results of the present study [30].

This study has three major strengths:

1 The selected industry (i.e., the petrochemical) was suitable for this study due to its high-voltage power sources.
2 The study succeeded in drawing a map of electromagnetic fields using Surfer software around high-voltage power sources.
3 The study examined the relationship between the values of blood and liver parameters with the values of electromagnetic fields.

The limitations of this study include the followings:

1 Preparing, finding, and gaining access to the device for measuring electromagnetic fields was difficult.
2 It was difficult to convince the industry authorities to coordinate with the industry to carry out the study.

5. Conclusion

Based on the results of our study, exposure to ELF-EMF does not have any statistically significant effects on demographic, hematological, and liver factors. Likewise, in this study, like most of the research on exposure to ELF-EMF, hematological and liver factors are in the normal range. Thus, probably exposure to ELF-EMF has no clinically significant effects. In general, the workers' exposure to ELF-EMF was less than the permissible limit.

List of Abbreviations and Acronyms.

Table 4 shows a list of abbreviations.

Author contribution statement

Sajad Zare: Conceived and designed the experiments. Soode Moslemi: Performed the experiments; Wrote the paper. Mohammad Reza Ghotbi ravandi: Contributed reagents, materials, analysis tools or data. Hamidreza Tohidi Nik: Analyzed and interpreted the data.

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Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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