

Original Research

IDENTIFICATION AND ANALYSIS OF NON-IONIZING ELECTROMAGNETIC RADIATION IN THE ENVIRONMENT: CASE STUDY OF LESKOVAC CITY, REPUBLIC OF SERBIA

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Abstract

The man is daily exposed to radiation and heat while moving through space and carrying out his activities, and these physical hazards adversely affect both people and the environment. The subject of this paper is the identification and analysis of non-ionizing electromagnetic radiation transmitted through the area of Leskovac city. In the paper, 12 measurements of non-ionizing electromagnetic radiation were carried out during the day (from 6:00 a.m. to 6:00 p.m.) and in the evening (from 6:00 p.m. to 10:00 p.m.) at 12 selected monitoring places on the territory of the Leskovac city from June 2024 until April 2025. Monitoring places 1, 3, 7, 9, and 11 can be considered sources of non-ionizing electromagnetic radiation of special interest. The impact of non-ionizing electromagnetic radiation on the population of Leskovac city, as well as workers who work outdoors during the day and evening, has not been identified.

Keywords: monitoring, electromagnetic radiation, people's health.

INTRODUCTION

Physical agents in the environment, such as heat, illuminance, noise, and electromagnetic radiation, have adverse effects on biological systems, people, animals etc. The effects of radiation are invisible to the naked eye, while the impact of increased noise can be felt with the sense of hearing and poor illuminance with the sense of sight [1].

”Invisible pollution” of a physical nature that occurs in the environment is non-ionizing radiation (NIR). These are electromagnetic radiations that do not have sufficient quantum energy to cause ionization of atoms, molecules, or tissues: ultraviolet radiation (UV), visible light, infrared radiation (IC), radiofrequency radiation (RF), extremely low-frequency electromagnetic fields (ELF), and static and stationary electromagnetic fields. The harmful effects of electromagnetic fields or waves on the environment can be monitored by measuring the strength of the electric (E) and magnetic fields (H), as well as radiation power density-

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irradiance (S) [2–4]. There is some evidence that non-ionizing radiation adversely affects human and animal health. Biological systems exposed to weak electromagnetic fields, even below safety guidelines, show changes in functionality [5]. The International Agency for Research on Cancer (IARC) and the World Health Organization (WHO) have classified ELF magnetic fields produced by electrical devices in group 2B (possibly carcinogenic to humans). These organizations also pointed out that RF radiation can increase the risk of malignant brain tumors in humans [6].

Leskovac city is suitable for living and basic economic activities thanks to its mild temperate-continental climate, favorable altitude (210–240 m), and good location between the highlands and lowlands. In recent years, the city of Leskovac has been developing economically and infrastructurally, which in turn has led to an increase in traffic intensity, communal noise, greater availability of household electrical and wireless devices and appliances, radio and television antennas, mobile phone base stations, and the expansion of electrical and distribution transmission lines. Therefore, the aim of this paper is to identify and analyze the non-ionizing radiation in the urban environment of the city of Leskovac, determine the monitoring places that threaten its quality and the safety of people.

MATERIALS AND METHODS

Description and methodology of measurements and monitoring place

Measurements of electromagnetic radiation in the environment on the territory of Leskovac city were carried out with portable measuring instrument at 12 selected monitoring places (Table 1) bimonthly from June 2024 to April 2025 (16–17 June 2024, 18–19 October 2024, 22–23 February 2025, and 20–21 April 2025). The selected monitoring locations are situated near high-frequency repeaters, mobile phone base stations, and radio and television antennas on the buildings. There are gas stations and construction sites of many facilities near some monitoring places.

Table 1 Monitoring places of non-ionizing electromagnetic radiation in the city of Leskovac

Number of monitoring place	Location of the monitoring place	GPS coordinates	
		N	E
1.	The intersection of Bulevar oslobođenja and 28 Marta streets	42°59'47.7"	21°57'20.3"
2.	The intersection of Bulevar oslobođenja and Južnomoravskih Brigada streets	42°59'46.7"	21°56'34.8"
3.	Moše Pijade Street - a park in the city center	42°59'43.2"	21°56'52.7"
4.	Sava Kovačević Street - Elementary School "Vuk Karadžić"	43°00'08.0"	21°56'45.9"
5.	Tekstilna Street - Factory "Falke"	43°00'23.7"	21°56'29.2"
6.	Niška and Nikola Pašića Bulevar Street - roundabout near the "Metla Komerc" store	43°00'12.7"	21°56'10.3"
7.	Dubočica Street - Trade and Hospitality School	42°59'54.8"	21°55'38.4"
8.	Stanoja Glavaša Street near the "Aman" store	42°59'27.9"	21°55'43.9"
9.	Roundabout near the Leskovac City Hospital	42°59'39.3"	21°56'18.7"
10.	Vlajkova Street - Chemical Technology School "Božidar Đorđević Kukar"	42°59'04.3"	21°56'58.4"
11.	The intersection of Njegoševa and Jadranska streets	42°59'50.3"	21°57'42.0"
12.	Kralja Petra Prvog Street - near the "Mol" pump	42°59'30.4"	21°57'38.2"

Physical hazards were detected at each monitoring place during the day (from 6:00 a.m. to 6:00 p.m.) and in the evening (from 6:00 p.m. to 10:00 p.m.). At each of the 12 monitoring places during the observed month in the specified period, two reference 15-minute measurements were performed in the day and evening periods. The paper analyses the following physical agents: electric (E , V/m), magnetic field strength (H , A/m) and irradiance (S , W/m²).

Portable device was used for measurements is 480836 RF/EMF Strength Meter (Extech, Taiwan) for monitoring high-frequency radiation in the range of 50 MHz to 3.5 GHz characteristic of mobile phone base stations, locating RF access points, detecting RF wireless networks (Wi-Fi) through electric and magnetic field strength and irradiance.

The results obtained in the paper were statistically processed and compared with the prescribed values according to the laws, regulations and standards of the Republic of Serbia and in the world and available safety guidelines.

RESULTS AND DISCUSSION

The regulation in field of non-ionizing electromagnetic radiation in the Republic of Serbia is regulated by: the Law on non-ionizing radiation protection [7], the Rulebook on the limits of exposure to non-ionizing radiation [8], the Rulebook on the sources of non-ionizing radiation of special interest, types, sources, manner, and period of their examination [9], the Rulebook on preventive measures for safe and healthy work when exposed to electromagnetic field [10] and the SRPS EN 50413:2020/A1:2025 standard [11].

The Rulebook on the limits of exposure to non-ionizing radiation prescribes reference limit levels for persons' exposure to electric, magnetic, and electromagnetic fields (Table 2). The adopted basic limits and reference limit levels in the Rulebook are stricter than those recommended by the ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines [12]. Reference limit levels are used to assess population exposure and determine the probability of exceeding basic limits. ICNIRP prescribes basic limits and reference limit levels for two exposure scenarios (occupational and general public) depending on the time of exposure to the electromagnetic field of frequencies from 100 kHz to 300 GHz.

Table 2 Reference limit levels of exposure of the population to the electromagnetic field for the investigated range of radiation frequencies

Frequencies	Electric field strength, E (V/m)	Magnetic field strength, H (A/m)	Power density (equivalent plane wave), S_{eq} (W/m ²)
0-400 MHz	11.200	0.0292	0.326
400-2000 MHz	$0.55 f^{1/2}$	$0.00148 f^{1/2}$	$f/1250$
2-10 GHz	24.400	0.064	1.600

f - radiation frequencies

The Rulebook on the sources of non-ionizing radiation of special interest, types, sources, manner, and period of their examination [9] defines sources of non-ionizing radiation of special interest. These are sources of electromagnetic radiation that can be harmful to human

health and are defined as stationary and mobile sources whose electromagnetic field in the zone of increased sensitivity reaches at least 10% of the reference limit value prescribed for that frequency. The owners of these sources are obliged to perform periodic measurements.

According to frequency, non-ionizing electromagnetic fields are classified into very low (ELF, up to 300 Hz), intermediate (IF, from 300 Hz to 10 MHz), and radio frequency fields (RF, 10 MHz to 300 GHz). In addition to the mentioned classification, the European Commission divides non-ionizing radiation into one more group static fields, *e.g.*, electric fields of capacitors of certain systems in industry and fields of natural and artificial magnets [3,13]. The sources of the ELF field are devices that transmit electrical energy at a frequency of primarily 50 or 60 Hz, high-voltage transmission lines, distribution networks, and household electrical appliances. Telecommunication systems such as mobile phone base stations, radio and television transmitters, mobile phones and wireless devices, microwave medical devices used in diagnosis and therapy, and microwave link systems produce RF fields [3,14,15].

In countries with modern economies, there is increased concern about the harmful effects of RF radiation from mobile phones and radiation due to the increase in mobile phone base stations and Wi-Fi stations, especially with the introduction of 5G wireless systems operating at higher frequencies [5].

Table 3 shows the average electric (E_{av}) and magnetic field (H_{av}) strength and radiation density (S_{av}) at the observed monitoring places during the day and night periods.

The highest measured average value of the electric field strength is at monitoring place 11 (the intersection of Njegoševa and Jadranska streets), 2.004 V/m (Table 3), which is lower than the reference limit levels in the detection frequency range (50 MHz-3.5 GHz), 11.200–24.400 V/m (Table 2). The exposure factor is determined by calculating the ratio of the average measured electric field value to the reference limit level. If we consider the lower reference limit, the exposure factor is 0.179, which cannot exceed 1 or 100%. All measured values of electric field strength are within the established reference exposure limit level. At the monitoring place 1 (The intersection of Bulevar oslobođenja and Južnomoravskih Brigada streets), 3 (Moše Pijade Street - a park in the city center), 7 (Dubočica Street - Trade and Hospitality School), 9 (Roundabout near the Leskovac City Hospital), in certain months of measurement in the daytime and evening period, the exposure factor for the strength of the electric field is greater than 0.1 and 10%, respectively. This indicates the possibility that the sources of non-ionizing radiation that cause the increased intensity of the electric field at these measuring points are considered sources of special interest. There are two high-frequency repeaters near the intersection of Njegoševa and Jadranska Street, which probably contribute to the increase of non-ionizing radiation at the examined monitoring places. Monitoring place 1 is near measuring point 11, so high-frequency electromagnetic waves from two larger repeaters spread at this place as well. In addition, there is a possibility of the influence of antennas and station devices for telephones and cable television on the tops of surrounding buildings. The roundabout near the city hospital Leskovac (monitoring place 9) has a higher mean electric field strength, which is most likely a consequence of the existence of a large high-frequency radiation repeater on Hisar hill. Monitoring places 3 and 7 are surrounded by residential blocks where there are smaller transmitters of mobile phones, TV stations, and

cable television that contribute to higher values of physical quantities that characterize electromagnetic radiation.

Table 3 Average values of electric and magnetic field and irradiance at the monitoring places for the day and evening

Monitoring place	Day						Evening					
	Jun.	Aug.	Oct.	Dec.	Feb.	Apr.	Jun.	Aug.	Oct.	Dec.	Feb.	Apr.
E_{av} (V/m)												
1.	1.313	1.280	1.525	0.488	0.609	0.661	1.740	1.189	1.196	1.300	0.576	0.638
2.	0.359	0.510	0.459	0.245	0.330	0.386	0.080	0.327	0.755	0.315	0.327	0.240
3.	0.861	0.945	1.625	0.744	0.550	0.461	0.634	0.715	1.167	0.744	0.675	0.312
4.	0.353	0.197	0.182	0.051	0.110	0.057	0.056	0.329	0.501	0.019	0.051	0.026
5.	0.639	0.233	0.485	0.303	0.154	0.301	0.226	0.509	0.565	0.438	0.313	0.312
6.	0.145	0.016	0.010	0.006	0.005	0.007	0.028	0.017	0.060	0.003	0.011	0.011
7.	0.702	0.430	1.147	0.661	0.664	0.275	0.320	0.465	1.378	0.620	0.187	0.205
8.	0.236	0.396	0.350	0.105	0.264	0.257	0.469	0.433	0.358	0.310	0.371	0.043
9.	0.569	0.838	0.193	0.765	0.535	0.428	1.493	1.667	0.654	0.897	0.596	0.356
10.	0.504	0.049	0.017	0.041	0.036	0.023	0.519	0.189	0.023	0.012	0.025	0.019
11.	1.794	1.715	2.004	1.000	0.896	0.858	1.383	1.668	1.826	1.560	0.843	0.617
12.	0.191	0.299	0.124	0.154	0.203	0.303	0.385	0.299	0.261	0.108	0.357	0.228
H_{av} (mA/m)												
1.	4.001	3.396	4.255	1.217	1.617	1.753	4.618	3.156	3.173	3.448	1.196	1.692
2.	0.889	1.137	1.196	0.650	0.817	1.025	0.212	0.745	1.352	0.835	0.931	0.637
3.	2.138	2.707	4.312	1.974	1.461	1.223	1.627	1.895	3.096	1.974	1.792	0.827
4.	0.938	0.502	0.477	0.135	0.223	0.151	0.150	0.874	1.327	0.052	0.460	0.070
5.	1.612	0.778	1.286	0.625	0.408	0.798	0.610	1.465	1.641	1.163	0.831	0.529
6.	0.391	0.044	0.039	0.015	0.016	0.022	0.079	0.046	0.170	0.008	0.031	0.031
7.	1.894	0.918	2.960	1.753	1.402	0.729	0.890	1.233	3.645	1.617	0.498	0.544
8.	0.633	1.050	0.928	0.144	0.702	0.681	1.137	1.147	0.949	0.846	1.021	0.114
9.	1.511	2.224	0.532	2.030	1.636	1.163	3.962	4.655	2.187	2.380	1.582	0.946
10.	1.204	0.132	0.047	0.129	0.104	0.079	1.376	0.545	0.062	0.033	0.066	0.051
11.	4.761	4.684	5.368	2.653	2.380	2.276	3.671	3.575	4.844	4.138	2.249	1.655
12.	0.543	0.645	0.330	0.408	0.539	0.642	0.623	0.912	0.693	0.287	0.946	0.606
S_{av} (mW/m²)												
1.	3.716	4.349	7.110	0.603	0.986	1.056	8.036	3.014	3.720	4.482	0.742	1.080
2.	0.342	0.689	0.560	0.186	0.251	0.396	0.016	0.284	1.513	0.263	0.349	0.153
3.	1.971	2.268	6.938	1.469	0.558	0.564	1.068	1.165	3.613	1.032	1.211	0.258
4.	0.363	0.097	0.085	0.006	0.018	0.008	0.008	0.288	0.664	0.001	0.006	0.002
5.	1.121	0.105	0.624	0.025	0.062	0.240	0.130	0.616	0.812	0.510	0.260	0.135
6.	0.083	0.001	0.001	0.000	0.001	0.000	0.002	0.001	0.001	0.006	0.000	0.000
7.	1.539	0.409	3.303	2.316	0.742	0.200	0.305	0.574	5.037	1.019	0.093	0.111
8.	0.135	0.322	0.325	0.008	0.185	0.131	0.530	0.497	0.168	0.254	0.424	0.004
9.	0.886	1.974	0.117	1.554	1.009	0.510	5.367	8.170	2.100	2.137	0.943	0.337
10.	0.721	0.006	0.001	0.001	0.004	0.002	0.714	0.112	0.001	0.001	0.000	0.001
11.	0.642	8.412	10.860	2.118	2.137	1.954	3.787	6.386	8.849	3.414	1.886	1.056
12.	0.125	0.157	0.042	0.063	0.109	0.155	0.263	0.322	0.181	0.036	0.337	0.155

Also, in monitoring place 11, the maximum average magnetic field strength was identified, 0.005368 A/m. These values also do not exceed the prescribed reference limit levels ($H = 0.0292\text{--}0.064$ A/m). Monitoring at locations 1, 3, 7, 9, and 11 shows that during certain months and both daytime and evening periods, the average magnetic field strength exceeds 10% of the reference limit value when compared to a lower reference limit. In this context, the exposure factor ranges from 0.101 to 0.184. Based on the measured average values of magnetic field strength, the sources contributing to these levels at places 1, 3, 7, 9, and 11 may be classified as sources of non-ionizing radiation of special interest. It is recommended

that the magnetic field strength be measured periodically. In general, in the months of June, August and October, higher mean values of the magnetic field were detected compared to the other months of measurement and for the daytime and evening measurement periods.

From the physical parameters measured in this paper, the Rulebook on the limits of exposure to non-ionizing radiation [8] prescribes a basic limit of population exposure to radiation only for power density in the frequency range of 10-300 GHz (10 W/m^2). The average measured values of physical parameters for the electromagnetic field at the monitoring places in the territory of the city of Leskovac are below the defined limit reference levels in the Republic of Serbia. Residents of the city of Leskovac at the investigated monitoring places are exposed to electromagnetic radiation of 50 MHz-3.5 GHz, without risk to health (insignificant biological tissue response).

RF radiation from high-power telecommunication systems can cause serious damage to the human body if a person is near the RF source and in the direction of the direct beam of radiation. The impact of electromagnetic radiation on a living organism depends on the intensity and frequency of the radiation and the distance of the person from the radiation source. High-frequency radiation with irradiance over 10 mW/cm^2 can cause tissue heating in humans, the so-called thermal effect [2]. According to experimental tests by many authors, in people exposed to RF radiation, the concentration of reactive oxygen species (ROS) increases or decreases, as does the degree of cancer cell growth. This may indicate that a person exposed to RF radiation suffers from oxidative stress and that there is a probability of some form of cancer [5].

From Table 3, it is evident that the mean power density values are significantly lower than the basic limits specified in the rulebook. The mean irradiance values do not exceed the reference limit values; in fact, they are even below 10% of the reference limit, $S_{\text{eq}} = 0.326\text{--}1.600 \text{ W/m}^2$, (indicating an exposure factor of less than 0.1) at all monitoring places during both daytime and evening periods across all months of measurement. The highest mean power density was recorded at monitoring place 11, with a value of 0.010860 W/m^2 . Monitoring places 1, 3, 7, 9, and 11 are notable for their elevated mean power density values. Additionally, the measurements taken in June, August, and October show higher power density levels in most places during both daytime and evening periods compared to the other months measured.

CONCLUSION

Today, urbanization and infrastructural development of cities, intensive traffic development, production of technical devices, creation of ozone holes, and the greenhouse effect have increased the number of potential pollutants and physical hazards in the environment.

On the territory of the city of Leskovac, measurements were carried out from June 2024 to April 2025.

Non-ionizing radiation do not endanger the inhabitants of Leskovac. The values of radiation parameters, electric and magnetic field strength, and irradiance are far below the prescribed basic and reference levels.

For the electric and magnetic field strength parameters at monitoring places 1, 3, 7, 9, and 11, the exposure factor ranges from 0.1 to 0.2. During specific months of measurement at these locations, the average values of electric and magnetic field strength were recorded at levels exceeding 10% of the reference limit. The sources contributing to the higher intensity of the electromagnetic field at these monitoring places include high-frequency repeaters, mobile phone base stations, mobile phone transmitters, TV stations, and cable television. These are considered sources of non-ionizing radiation that warrant special attention. It is essential to periodically monitor electromagnetic radiation from these sources by measuring its intensity.

Measured non-ionizing radiation do not affect the mental and physical health of the population of the city of Leskovac.

REFERENCES

- [1] Vulević, B., Čedomir, B. *Ecologica* 2012, 67, 497–500.
- [2] Arandjelović, M., Jovanović, J. *Medicina rada*. Niš: Medicinski fakultet; 2009.
- [3] Krstić, I., Krstić, D., Kusalo, A. *Inž. Zaštite*. 2011, 1 (1), 45–58.
- [4] Vulević B, Belić Č In: *Proceedings of the Environment to Europe – EnE13*; 2013; Belgrade, Serbia.
- [5] Barnes, F., Freeman, E.R. *Front. Public Health*. 2022, 10, 994758.
- [6] International Agency for Research on Cancer. *IARC Monogr*. 2013, 102.
- [7] Official Gazette of the Republic of Serbia, No. 36/2009. Law on Non-ionizing Radiation Protection.
- [8] Official Gazette of the Republic of Serbia, No. 16/2025. Rulebook on the limits of exposure to non-ionizing radiation.
- [9] Official Gazette of the Republic of Serbia, No. 104/2009. Rulebook on the sources of non-ionizing radiation of special interest, types, sources, manner, and period of their examination.
- [10] Official Gazette of the Republic of Serbia, No. 111/2015 and 130/2021. Rulebook on preventive measures for safe and healthy work when exposed to electromagnetic fields.
- [11] SRPS EN 50413:2020/A1:2025. Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz - 300 GHz), 2025.
- [12] International Commission on Non-Ionizing Radiation Protection. *Health Phys*. 2020, 118 (5), 483–524.
- [13] European Commission. Possible effects of electromagnetic fields (EMF) on human health. 2007.
- [14] Lewczuk, B., Redlarski, G., Žak A., *et al.* *Biomed Res. Int*. 2014, 169459.
- [15] Čubonović S, Ranković A, Mijailović V In: *Proceedings of the 36th CIGRE Serbia Conference*; 2023; Zlatibor, Serbia. p. 1529–1541.