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Application of Risk-Oriented Approach for Improvement of the Environmental Security of the Urban Area

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ABSTRACT

Improved comfort of urban environment is inseparably related with consumption and transfer of various types of energy for illumination and heating of buildings, provision of radio and TV broadcasts, mobile communications and transport. Energy transfer is accompanied by generation of electric fields, which propagate in ambient environment and affect human and biota. In this regard, the safety of urban environment becomes more and more urgent issue, especially along highways. This work describes a risk-oriented approach to analysis and estimation of risks of electromagnetic safety of urban territories with consideration for combined action of electromagnetic fields of various frequency range on humans. The authors have analyzed electromagnetic pollution from three most common sources of exposure, and the territories of urban environment have been selected with the highest level of electromagnetic hazard for population. Application of risk-oriented approach to estimation of electromagnetic hazard demonstrates the necessity of improvement of valid normalization system with accounting for simultaneous impact of electromagnetic fields from several sources on human and environment, which would provide development of more efficient measures of city population protection against this negative factor.

1. INTRODUCTION

Nowadays the criteria, which determine the quality of urban living, are comprised not only of standards of living including indices of health care, education, demography, economic conditions, but also of indices of living conditions [1, 2]. The latter include mainly the indices of environmental safety. The main task of the security system is to prevent the possibility of the emergence and implementation of environmental hazards, the causes of which are possible changes in the state of the air basin, soils, natural waters of various locations, atmospheric precipitation, the main components and elements of the transport network, buildings, structures, engineering networks for various purposes, elements landscaping, enterprises with environmentally hazardous industries and technologies, and others under the influence of several man-made and other factors [3]. To improve the level of environmental safety in the city, it is necessary to develop special methods and systems for tracking pollution flows and resource consumption and measuring the resulting impacts of structures and engineering networks for various purposes. We believe that these developments will make possible a new structure of institutional response to environmental problems [4]. Therefore, analysis and estimation of environmental safety of urban living are very important.

Analysis and estimation of environmental safety of urban territories as well as of risks of occurrence of abnormal situations [5] are usually based on estimation of level of ambient air pollution, pollution of surface and underground waters, pollution of soils [6], estimation of levels of noise and radiation hazard in residential areas [7]. Such approach is reflected in:

- legal regulations for engineering and environmental surveys for construction aimed at estimation of possible negative impact [8].
- scientific investigations into negative impact of urban environment factors on human health [9].

Analysis of experimental results of urban environment safety demonstrates that major portion of the investigations is devoted to determination of influence of negative chemical factors (toxic matters) on plants and human health [10-13]. This could be attributed only to the fact that high concentrations of toxic matters in air can influence on major portion of inhabitants [14], initiate acute intoxications, and require for significant resources of health care system to eliminate the consequences [15]. Influence of lower concentrations of toxic matters could be related with cumulative effect and cause chronic diseases of inhabitants in the territories affected by air pollution and using certain water supply system [16]. Due to immensity of consequences of negative impact of chemical factors, solution to this problem is highly important.

The influence of negative physical factors (radiation, noise, electromagnetic emissions, vibration, thermal and optical impacts, etc.) on human health is nearly always characterized by cumulative pattern and not by acute form [17, 18]. Exceptions are abnormal (emergency) situations, when the levels of physical factors of negative impact exceed significantly preset norms. Therefore, the range of scientific works devoted to detection of impacts of negative ambient factors on human and environment is not very wide. Very few works are devoted to analysis of integrated influence of electromagnetic fields of various frequency on human, and to overall electromagnetic safety of urban environment. At the same time, negative technogenic factors can cause diseases of high health risk, including allergic diseases, blood diseases, oncology, circulatory diseases, diseases of digestive system, and others [17].

The studies of negative impact of physical factors become more important with development of industrialization since harmful impact on human health is exerted mainly by technogenic physical factors of high intensity.

Nowadays, negative impact of physical technogenic factors is estimated together with analysis of electromagnetic pollution of urban environment [19-21]. The main sources of technogenic electromagnetic fields (EMF) are mainly high-voltage overhead power lines, TV broadcast and radar stations, mobile base stations, industrial engineering equipment, transport [22-26].

The authors believe that the electromagnetic safety of territories is an urgent issue, its importance will grow due to increase in the number of various sources of electromagnetic fields, hence, it would be reasonable to carry out risk analysis of urban environment with consideration for these variations and combined impact of electromagnetic fields of various frequency band on humans.

To minimize the negative impact on human health, it is necessary to conduct a risk analysis of various factors inherent in the digital urban environment. In the context of our study, we consider it necessary to highlight the man-made physical factors of the negative impact that must be considered when developing a methodology for risk analysis of the urban environment.

1.1 Literature review

Electromagnetic fields of overhead power lines. According to official data by Federal Grid Company of Unified Energy System, as a consequence of implementation of the program of energetics reformation in Russia, the length of overhead power lines is constantly increasing together with the number of substations and amount of consumed electricity [27].

There exists regulation system limiting the impact of electromagnetic fields of overhead power lines on humans, which provides electromagnetic safety by means of sanitary protective areas [28]. At the same time the performed experimental and instrumentation studies of electromagnetic fields of overhead power lines and estimation of negative impact of electromagnetic fields of overhead power lines on human health have demonstrated that existence of 500 kV overhead power lines in residential districts increases the risk of cardiovascular diseases and nervous disorders.

Analysis of the results demonstrates that there exists correlation between the incidence rate and voltage class of overhead power lines, as well as distance of residential district from overhead power line of various voltage.

Electromagnetic fields of electronic cellular aids. There is a distinct trend to increase in electromagnetic radiation in urban areas from electronic cellular aids. According to official data of Federal Service for Supervision in the Sphere of Communications [29], due to increased demand for ICT services and data transmission in mobile networks, the amount of radio-electronic aids managed by the four major mobile network operators in Russia (Beeline, MTS, Megafon, Tele2) only in 2018 increased by 50% in comparison with the previous year equaling to more than 240 thousands of base stations.

One of the indicators of quality cellular communication services is the coverage of main roads, which indicates the deliberate installation of transmitting radio facilities along highways and, accordingly, higher electromagnetic field indicators. There is also regulation in the frequency ranges of 30 kHz-300 MHz and 300 MHz-300 GHz [30], which provides for the establishment of sanitary protection zones violated in practice.

Electromagnetic fields in the road environment. Currently, much attention is paid to ensuring the electromagnetic compatibility of vehicles. The most relevant, due to the high degree of integration of systems with microprocessor control, are the problems of noise immunity because failures that occur when exposed to electromagnetic interference can lead to various kinds of consequences [31]. To minimize risks in operation, solutions are laid down at the development stage of both the products themselves and vehicles in general [32]. The final step in confirming the correctness of the approaches to electromagnetic properties is tests. The manufacturer is obliged to comply with both international standards and its own internal regulatory documents containing specific test requirements [32]. However, the general approach for conducting immunity tests considers the interaction of one vehicle and one source of electromagnetic interference. The motor vehicle is also treated as a static object, even though driving cycles are simulated on the chassis dynamometer [33].

In the following, we describe our study, its results, and possible recommendations that, in our opinion, will improve the use of risk analysis in urban areas. To achieve this goal, in the Methods section, we describe mixed methods we used to collect electromagnetic field indicators, which included experimental and instrumental methods, numerical methods, and analysis of literature data. In general, two stages of work were carried out. The first stage made it possible to collect data as a result of field studies (urbanized areas, bench studies). The second stage refers to the desk type of research. In the Results section, we consider the data that we divided into the blocks "Electromagnetic fields of vehicles" and "Electromagnetic fields of overhead power lines, transmitting radio engineering objects, and radar installations installed along highways". The study made it possible to obtain the result that the influence of electromagnetic fields of cars and objects with a small effective radiated power has an impact on the environment and human health. However, in Russia, the supervisory authorities pay insufficient attention to this. This manifests itself in a low level of control as an increase in the electric field strength, which is not considered when designing roads and is not regulated when determining the number of installed objects with a small effective radiated power. We believe that the results obtained distinguish our study from other studies conducted in this area.

In the Discussion, the obtained data are interpreted from the point of view of the need to introduce a comprehensive indicator of the impact of the electromagnetic field and improve the special regulatory documentation. After that, in the Conclusion, we outlined the conclusions that will be useful for the legal and executive levels to improve the safety of the environment and increase the level of protection of people from the negative effects of electromagnetic fields. At the very end of the article, we outline the prospects for further research.

2. METHODS

In this study, we proceeded from the situation that in order to improve the environment and increase the level of human safety, it is necessary to identify how a large number of stationary transmitting radio engineering objects with a small effective radiated power, power lines, and a dense flow from moving vehicles at the maximum permissible speed within the city affect to increase the electric field strength.

The indices of electromagnetic fields for risk analysis of urban territories were studied with the use of experimental and instrumentation methods, numerical methods, data from published sources.

For research in 2020 in Noginsk, Moscow region (Russia), territories with approximately the same population were selected:

- residential district No. 1, crossed by 500 kV overhead power lines;
- residential district No. 2, crossed by 330 kV overhead power line;
- residential district No. 3, crossed by 110 kV overhead power line;
- residential districts Nos. 4, 5, 6 at the distance of more than 300 m from overhead power line.

The sites were selected based on the proximity to highways and other transport routes, along which power lines pass in the immediate vicinity or power lines cross highways. An example of a territory selected for study in the Noginsk district (microdistrict No. 1) is shown in Figure 1.

Figure 1. Highway near Noginsk (Moscow Region, Russia)

Based on universities, bench studies of hybrid cars were carried out to determine the effect of car speed on an increase in electric field strength.

In the scope of this problem, the electromagnetic fields were analyzed with regard to the most common sources in urban environment:

1. Overhead power lines, mobile base stations, and radar installations. Based on data from secondary studies, statistics, and reports of specialists at the UNIVERSITET research laboratory, we investigated at what frequencies the devices installed along highways operate.

2. Engines and vehicles. We collected indicators of electromagnetic fields along the road in the territory selected for the study (at a traffic intensity of 60 cars per minute) and indicators of electromagnetic fields during the operation of hybrid cars, carried out in bench conditions. The measurements were carried out in the frequency ranges of 5-2 kHz and 2-400 kHz. In addition, in bench conditions, we collected indicators of EMF sources in a wide frequency range of 0-1,000 Hz caused by the operation of traction motors.

In accordance with this regulation, certain stationary transmitting radio aids in the territories selected for research do not require for permissions by Rospotrebnadzor and obtaining sanitary epidemiological statements for location and commissioning. Mainly this is applied to aids with moderate effective radiated power, though, under conditions of simultaneous operation of several radiation sources, for which the same permissible exposure levels are established, the following conditions should be satisfied:

$$\left(\sum_{i=1}^{n} E_i^2\right)^{\frac{1}{2}} \leq E_{pel} \quad (1)$$

$$\left(\sum_{i=1}^{n} EFD_i\right) \leq EFD_{pel} \quad (2)$$

where, E is the electric field intensity created by the i-th electromagnetic field source, V/m; EFD is the electric flux density created by the i-th electromagnetic field source, W/m^2; E_{PEL} is the permissible exposure level of electric field intensity of normalized band, V/m; EFD_{pel} is the permissible exposure level of energy flux density of normalized band, W/m^2; n is the number of electromagnetic field sources.

3. RESULTS

Electromagnetic fields of automotive transport. Certain electromagnetic pollution along highways is generated by automotive transport. The results are summarized in Table 1.

Such studies of hybrid cars under test-bench conditions show that with the increase of vehicle speed from 20 to 80 km/h, the electric field intensity in the frequency band of 2 kHz – 400 kHz increases from 0.05 to 0.2 V/m, and in the band of 5 Hz-2 kHz – from 5 to 25 V/m.

Electric transport (trolleybuses, trams, metro trains, and others) is also a powerful source of electromagnetic field in the wide frequency band of 0-1,000 Hz. Herewith, the main radiation source is mainly traction electric motors, including overhead current collectors for trolleybuses and trams. Table 2 summarizes the data on magnetic induction for certain types of electric transport [34].

Table 1. Indices of electromagnetic fields along highway

Specifications		Near road edge	1 m from road edge	2 m from road edge	3 m from road edge
Electric field intensity	5 Hz - 2 kHz	6 V/m	1 V/m	1 V/m	2 V/m
	2 kHz - 400 kHz	0.8 V/m	0.67 V/m	0.3 V/m	0.12 V/m
Magnetic flux density	5 Hz - 2 kHz	0.2 µT	0.15 µT	0.01 µT	0.12 µT
	2 kHz - 400 kHz	1 nT	1 nT	1 nT	1 nT

Electromagnetic fields of overhead power lines, transmitting radio engineering facilities, and radar facilities installed along highways. Radar facilities generally radiate narrow directional radio beam. Periodic antenna movements in space lead to spatial discontinuity of radiation. They operate at the frequencies from 500 MHz to 15 GHz, however, certain facilities can operate at the frequencies up to 100 GHz and higher. Due to peculiar radiation pattern, they can create local areas with high density of energy flux (100 W/m^2 and higher) [34].

Table 2. Magnetic induction from electric transport

Type of electric transport and consumed current	Average magnetic induction, μT	Maximum magnetic induction, μT
Suburban electric trains	20	75
DC electric transport (Battery driven cars, etc.)	29	110

4. DISCUSSION

As a result of our research, we determined that all considered sources of electromagnetic fields are regulated by appropriate specifications aimed at limitation of electromagnetic field inactive impact on environment and humans, except for automotive transport. At present, there are nearly no regulations which restrict negative impact of automobile electromagnetic fields on residential areas together with requirements to designing and erection of highways with consideration for these indices [35]. The authors have revealed the only document: Recommendations for consideration of environmental protection requirements upon designing of highways and bridge crossing, where the electromagnetic impact of vehicles on environment and special protection measures are described. At the same time, modern experimental results of negative impact of automotive transport in terms of these indices demonstrate that in 18-32% of urban territories, the electromagnetic fields are generated as consequence of or with accounting for traffic. Since in modern technogenic environment the number of vehicles is continuously growing and traffic structure is modified towards increasing number of electric and hybrid cars, it is possible to assume that electromagnetic pollution along highways will also increase, hence, further studies of vehicle electromagnetic field are required together with development of electromagnetic monitoring with accounting for contribution of automotive transport to generation of electromagnetic pollution of territories.

Analysis of electromagnetic pollution from the considered sources of electromagnetic impact (overhead power lines, transmitting radio aids, and automotive transport) allows to highlight the territories with combined impact from several sources, hence, increased risk of negative impact of electromagnetic fields on humans. Analysis of published data has demonstrated that one of the indices of high-quality cellular phone services is coverage of highways, which evidences intentional installation of radio aids along highways, hence, higher indices of electromagnetic fields.

In order to estimate the level of negative impact of electromagnetic fields in urban territories, it is required to carry out their zoning and to apply integrated index of electromagnetic field impact as the index of electromagnetic hazard for urban environment according to the proposed intensity metering approach [36, 37].

In addition, it is required to supplement and to expand regulations for the impact (similar to [34]), when the following conditions should be met upon simultaneous impact of several sources of electromagnetic fields regulated by different PELs:

$$\sum_{j=1}^{m} \left(\frac{E_{tot\ j}}{E_{pel\ j}}\right)^2 + \sum_{k=1}^{q} \left(\frac{EFD_{tot\ k}}{EFD_{pel\ k}}\right) \leq 1 \qquad (3)$$

where, E is the cumulative intensity of electric field generated by electromagnetic field sources of the j-th normalized band, W/m; E_{pel} is the permissible exposure level of electric field of the j-th normalized band; EFD is the cumulative energy flux density generated by electromagnetic field sources of the k-th normalized band, W/m^2; m is the number of bands, for which E is normalized; q is the number of bands, for which EFD is normalized.

5. CONCLUSION

In the context of the development of urbanization in urban space, in our opinion, in order to increase the sustainable functioning of the socio-economic, production, and transport infrastructure with minimization of risks to human health, the practical implementation of the concept of Smart City is a necessary condition. As a result of our research, based on the application of the risk-based approach, we were able to identify the factors, the influence of which must be minimized to increase the level of environmental safety in urbanized areas. On the one hand, this allows expanding the methodology of the risk-based approach for assessing the level of impact on the environment and the threat to human life and health. On the other hand, the legislative and executive authorities, especially the heads of territories, Rospotrebnadzor, the construction industries, and other decision-makers should pay attention to the identification of the most dangerous sources of EMF. In our study, these sources were: power lines, base stations for cellular communications, vehicles, radiolocating and radar installations. In our opinion, to increase the level of ecological safety in urban environments, it is advisable to further study the effect of EMF of industrial frequency on the health of the population, in particular. The results of the study should become the basis for revising the regulatory legal acts on the establishment of sanitary protection zones for power lines. In order to estimate the level of negative influence, it would reasonable to carry out zoning of these territories and to use integrated electromagnetic field impact intensity index as the index of electromagnetic hazard for urban environment. City leaders need to initiate a program aimed to improve the valid system of electromagnetic field normalization with accounting for simultaneous impact of electromagnetic fields from several sources of various frequency bands on human and environment. It is expedient to further study the impact of power frequency EMF on the health of the population. The results of the study should become the basis for the revision of regulatory legal acts on the establishment of sanitary protection zones for power lines.

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