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EVALUATION AND EXPRESS-CONTROL OF RISK TO HUMAN HEALTH ON THE URBAN RECREATIONAL AREAS

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ОЦЕНКА И ЭКСПРЕСС-КОНТРОЛЬ РИСКА ДЛЯ ЗДОРОВЬЯ ЛЮДЕЙ НА РЕКРЕАЦИОННЫХ ТЕРРИТОРИЯХ ГОРОДА

Summary. The scientific paper describes the results of a study aimed at assessing the impact of motor transport pollution on the ecological state of recreational areas of cities. The paper assesses the non-carcinogenic risk to the health of people resting in the investigated urban recreational areas. The comparison of the obtained results with the data on the developed by the author complex indicator of technogenic load CITL was done. It was concluded that predicting the dangerous levels of recreational areas located nearby roads requires precision monitoring data on the content and volumes of emissions of the main environmental pollutants, knowledge of their chemical and physico-chemical properties, potential toxicological effects on human health, etc. The results of the corresponding calculations are presented. The objects of study (recreational areas), which are the most attractive for urban residents (containing a water body or a park zone), and at the same time are susceptible to significant effects of emissions from motor vehicles and can be potentially dangerous for the population, have been identified.

Аннотация. Описаны результаты оценивания влияния автотранспортного загрязнения на экологическое состояние рекреационных территорий городов. В работе оценен неканцерогенный риск для здоровья людей, отдыхающих на исследуемых городских территориях рекреационного назначения, проведено сравнение с разработанным авторским комплексным показателем техногенной нагрузки. Сделан вывод о том, что для прогнозирования уровней опасности прилегающих к дорогам рекреационных территорий требуются прецизионные мониторинговые данные по содержанию и объемам выбросов основных загрязнителей окружающей среды, знание их химических и физико-химических свойств,

потенциального токсикологического воздействия на здоровье людей. Приведены результаты соответствующих расчетов. Определены объекты исследования (рекреационные зоны), которые являются наиболее привлекательными для городских жителей (содержат водный объект или парковую зону) и при этом поддаются значительному воздействию выбросов двигателей автотранспортных средств и могут быть потенциально опасными для населения.
Keywords: environmental safety, risk, saline contamination, exhausted gases pollutants, recreational territories, traffic flow, vehicle emissions, technogenic load.

Ключевые слова: экологическая безопасность, риск, солевое загрязнение, выбросы автотранспортных средств, рекреационные территории, автотранспортный поток, выбросы от автотранспорта, техногенная нагрузка.

Problem statement. Environmental pollution significantly affects the processes that occur in ecosystems. Anthropogenic load on the natural ecosystems, including from the motor transport complex (MTC), in particular from vehicles, degrades the quality of soils, surface and groundwater, residential areas, etc., and, therefore, poses a significant threat to public health, especially in recreational urban areas designed for relaxation and recovery of citizens.

Literature review and methods of research. Information on the state of the environment and the health of the population living in a certain area is necessary for solution of the environmental protection problems at both the national and local levels. And the quantitative assessment of the potential health risk for the population of citizens, who during their lives rest in urban recreational territories, many of which are located near roads and motor transport infrastructure objects is especially important today.

It was determined that the development of the city of Kyiv has an environmentally unfavorable structure of the road network, especially in the central areas of the city, including the recreational territories (parks, squares, water bodies etc.). Additional ecological problems are created by the almost undeveloped car parking system in the capital of Ukraine, which, in turn, contributes to the formation of traffic jams, reducing the speed of vehicles. A serious threat is posed by the growth of road areas, reduction of greenery, and the use of anti-icing agents in winter, in particular, sand-salt mixtures. All these factors cause the deterioration of the ecological state of the territories located near highways, degradation of groundwater and surface water bodies, has a negative impact on wildlife, human health, etc.

Gichev Yu. P. [1] has developed a classification of ecologically significant human diseases and identified three main groups of pathological processes that depend on the state of the environment. These include:

– indicator ecological pathology (oncological diseases, perinatal mortality, congenital pathology, genetic defects, occupational diseases, allergic reactions, etc.);

– ecologically dependent pathology, indicators of which are mortality of infants and young children, general infant mortality, chronic bronchitis and children pneumonia, secondary immunodeficiencies, exacerbation of major respiratory and cardiovascular diseases because of the meteorological conditions worsening in cities;

– ecologically determined pathology, for the characterization of which statistical data on pathologies of pregnancy, chronic bronchitis diseases and adult pneumonia, children anemia, major diseases of the cardiovascular system, etc. can be used.

The method described in [2−5] was used to determine the technogenic load from the emissions of vehicle engines on the urban recreational areas. Data on the harmful effects of the vehicle exhausts ingredients on human health have been analyzed in [6]; methods of sampling and application of methods of express-analysis are discussed in [7, 8]. Methods of express-analysis of environmental components (in particular, methods of conductometry, potentiometry, optical methods and methods of analytical determinations, as well as densimetry, viscosimetry and stalagmometry) in combination with mathematical modeling methods are especially important for the study of geoecological state of urban recreational areas. This is due to the fact that the express determination of abrupt changes in the characteristics of a particular object of study (water body, soil cover, precipitation, etc.) allows to identify sources of pollution and make the right (and, if necessary, even urgent) management decisions [6, 9].

For example, the study of changes in the specific conductivity of aquatic environments over time makes it possible to conclude about the presence in the water body (from the soil, precipitation, etc.) of electrolyte substances, their accumulation or, conversely, neutralization, deposition, etc. The pH value is also an important characteristic of the quality of the environment, as the hydrogen index of natural water or soil solution is usually a constant value. This is due to the presence of a buffer system consisting of an aqueous solution of carbon dioxide and bicarbonates. Therefore, any noticeable changes in the pH of the medium are a signal of water pollution, for example, by domestic and/or industrial effluents, the impact of MTC, etc.

In this case, the simultaneous entry into the water body or soil environment of both electrolytes and surfactants through the formation of a double electric layer on the surfaces of colloidal particles significantly worsens the geoecological state of the natural object. Therefore, optical methods were used for express-analysis, in particular, refractometry, which allows, firstly, to identify the contaminant, and, secondly, to quickly control the quality of the investigated environment and on this basis to make decisions about sources of toxicants possible appearance and their neutralization, potential impact on the human health, etc. [10, 11].

Thus, the generalization of the existing in national and international practice approaches and methods of assessing the geoecological conditions of urban areas (including recreational territories), measures to improve their ecological safety proves the need and relevance of improving the system of environmental monitoring of urban areas located nearby roads, using methods of express-analysis and comprehensive assessment of technogenic load.

Determination of the previously unsolved aspects of the problem. The implementation of the concept of sustainable development on urban areas involves the use of reliable mechanisms for managing the environment, human health and natural balance on the basis of precise monitoring data. In this regard, we have chosen for investigation recreational urban areas (on the example of the city of Kyiv), near which the roads are located. Particular attention was paid to recreational areas, where there are also natural and artificial water bodies, park areas, etc. near the roads.

Harmful substances can get into the natural environment in different ways and in different aggregation states – from atmospheric air, with precipitation and groundwater, because of anti-icing agents usage, etc. Among the main air pollutants there are oxides of Nitrogen, Carbon and Sulfur, polycyclic hydrocarbons (in particular, benzo[a]pyrene), formaldehyde, and other aldehydes. Compounds of heavy and other metals (Pb, Cd, Ni, Mo, Zn, Cu, Hg, Sn, Fe, etc.), as well as dust of various origins can be present in the fine state too.

Soils and the aquatic environment are also polluted with nitric and sulfuric acids, sulfates, nitrates and other toxicants. As a result, there is a significant change in acidity – hydrogen indicator pH, salt composition, etc. Due to the possible chemical and biochemical transformations, the toxicity of primary pollutants in the environment can increase significantly, creating additional threats to human health.

The aim of the study is to investigate the level of ecological safety of urban recreational areas located near motor transport roads, as well as to improve the system of their ecological monitoring and control through a comprehensive assessment of technogenic load depending on the type of human activity and recreation.

Results and discussion. In the system of ecological monitoring of the city a very difficult task is the control of the whole spectrum of environmental toxicants. Therefore, electrical conductivity (conductometry method), pH acidity (potentiometry method) and optical properties of natural solutions (in particular, using refractometry) were chosen as indicators in order to assess the ecological safety of the studied areas and to investigate the dynamics of changes in the quality of environmental components. Such physico-chemical analysis methods as density (densimetry), viscosity (viscosimetry) and surface tension (by stalagmometry) determination were also used. Organoleptic characteristics of samples were also studied for water bodies.

These characteristics were chosen because, firstly, they fairly accurately characterize the complex impact of many factors on the quality of environmental components, and, secondly, they can be easily measured, including with the help of portable devices.

It is known that the dispersion of pollutants in the air is influenced by temperature and humidity, wind regime, orography of the area (including the data on the nature and density of urban development, if available). Therefore, to study the dispersion of motor transport emissions ingredients and to assess environmental risks, the climatic conditions of the city of Kyiv were analyzed, the orography of the studied areas, as well as the features of urban development were studied. This allows to predict the level of technogenic load on the surface air from the emissions of motor transport engines (taking into account meteorological conditions and orography of the particular territory) using methods of mathematical modeling and computational experiment and on this basis to comprehensively assess the level of environmental hazards for recreational areas and risk to human health using express analysis methods.

As a quantitative criterion of salt contamination in the soil solution the indicator $K_{s.c.}$ (%) was used, which was defined as the ratio of the concentration of chlorine ions in the soil extract of the sample taken at a certain observation point $C(Cl^-)$, to the value of the background concentration of ions Cl^- $C_f(Cl^-)$ at the control point:

$$K_{s.c.} = C(Cl^-)\ 100\ \%\ /\ C_f(Cl^-). \qquad (1)$$

As a consequence of the acid-salt contamination of the soils of the studied areas in the spring, after the snow melting, a significant change in the acidity of soil solutions was recorded in the range from (5.9… 8.0) units (at a control value of 5.7) to (7.5…9.0) units (at a control value of 6.1). So, in almost all studied areas alkalization of the soil was observed after the snow cover melting leading to the pollution of the territory by the remnants of anti-icing reagents.

Qualitative and/or quantitative analyzes of the content of mobile forms of chemical elements in the soil solution and water samples, which are the most bioavailable and therefore the most dangerous for humans, other living organisms and the natural environment, were used to assess the degree of pollution of recreational areas [12]. For determination of the degree of ecological load on the recreational areas of the city of Kyiv, the content of such chemical elements as Pb, Cd, Hg and Zn (first hazard class), as well as Cu and Cr (second hazard class) was assessed.

Insoluble (immobile) forms of chemical elements are also not completely safe for living organisms and the environment, because in the form of fine dust and due to adsorption on the soot particles they can enter the respiratory system of humans, higher animals, etc., and be transported over long distances, form local hazardous areas of secondary pollution and then under the new environmental conditions they can turn into water-soluble, bioavailable forms.

In order to establish the level of air pollution in urban recreational areas, field observations on the characteristics of traffic flows moving on the roads located near the studied areas were conducted. Then, by the mathematical modeling method using the differential equation of turbulent diffusion [13, 14] in the MathCad software environment, a computational experiment was performed in order to predict the pollution levels of the air and adjacent to the roads areas in different weather conditions.

The results of the research have shown that due to the refusal to use leaded gasoline for MTC power supply in Ukraine, as well as due to significant renewal of the Kyiv car park, the share of water-soluble forms of heavy metals (HM) in the soil generally has not exceeded the permissible norms. This means that mobile, biologically active forms of HM, although involved in technogenic flows and food chains, do not pose a significant threat to biota. However, the same cannot be said, for example, about soil solutions and surface waters, especially intended for swimming. Although the studied water bodies on average have shown safe concentrations of water-soluble compounds of HM, they can be potentially dangerous for aquatic organisms and plants, for example, due to a bioaccumulation and sorption in bottom sediments.

According to the empirical data on the acid and salt contamination of surface water samples and soil extracts [7], the indicator of acid-salt contamination ($K_{a\text{-}s.c.}$) was calculated. It was determined for each observation area separately at different periods of the year as an unweighted sum of the change of the acid-base equilibrium of the studied area (in terms of pH_i / pH_f) and the relative indicator of salt contamination of the soil ($C_{sal.i} / C_{sal.f}$), which was determined similarly to the rate of $K_{s.c.}$ (formula (1)). The linear dependences of $K_{a\text{-}s.c.}$ from salt contamination of the soil of the studied recreational areas (R^2 is approaching 0.99) were obtained:

– in the autumn-winter period of the year:

$$K_{a\text{-}s.c.} = 1.0391\, C_{sal.i} / C_{sal.f} + 0.9616; \qquad (2)$$

– in the spring period of the year:

$$K_{a\text{-}s.c.} = 1.0136\, C_{sal.i} / C_{sal.f} + 1.1399. \qquad (3)$$

For the acid contamination, similar dependences also have a linear character, except for those areas where there is an increase in acidity both in the autumn-winter period of the year and in the spring period, after the snow melts. This, in our opinion, is caused by special conditions of location and specific types of anthropogenic activity near the studied territories. Thus, we conclude that there is a close interdependence of acid and salt contamination, especially in the spring.

The qualitative chemical analysis revealed the presence of HM ions in some soil and water samples, such as Zn, Cd, Pb (first hazard class) and Cu (second hazard class). The content of these ions increases significantly in the spring, which is due not only to emissions from vehicle engines, but also because of the rotary transshipment of snow on roadside soils, which takes place in Kyiv. Hg^{2+} ions were not detected in the studied samples. In addition, no radiation contamination was found in any of the studied territories.

Environmental risk assessment usually includes such basic steps as: hazard identification; establishing the dependence "dose/concentration – response"; assessment of the impact (exposure) of chemical compounds on humans and risk characterization; comparison of the calculated risks with acceptable levels; ranking of risks according to the degree of significance; setting priorities, as well as those risks that need to be reduced to an environmentally friendly level or even prevent their occurrence [15]. In this case, depending on the purpose of risk assessment, the number of stages may vary; sometimes it is sufficient to conduct, for example, only a screening evaluation.

In the study, the non-carcinogenic health risk from the appearance of harmful substances (ingredients of MTC emissions) into the human body during rest was assessed using inhalation exposure [16–18]. To determine the risk to the health of the population resting in the studied areas, the monitoring data from the Borys Sreznevsky Central Geophysical Observatory on the ingredients of air pollution of the capital were analyzed. Within the studied recreational areas, averaged concentrations of pollutants were calculated – for Carbon monoxide, Nitrogen oxides in terms of NO_2, particulate matter PM up to 10 μm in size. The computational experiment was used to predict the levels of exceeding the maximum permissible concentrations of pollutants in the investigated areas, as well as to establish environmentally friendly distances from the road at which the harmful effects of MTC pollution are almost absent.

Quantitative assessment of non-carcinogenic effects was carried out according to the method described in [19–21] by calculating the hazard factor *HQ* for a particular pollutant during its inhalation:

$$\mathrm{HQ} = \mathrm{C(X)} / \mathrm{RfC(X)}\,, \qquad (4a)$$

$$\mathrm{HQ} = \mathrm{AD} / \mathrm{RfD}, \qquad (4b)$$

where *C(X)* is the average concentration of the substance, mg/m^3; *RfC(X)* – its reference concentration, mg/m^3; *AD* – average dose, mg/kg; *RfD* – reference pollutant dose, mg/kg.

In the process of the risk assessing, it was considered that if the *HQ* does not exceed the value of 1, the probability of appearance of harmful effects for humans from exposure to the toxicant over a period of time is negligible. Otherwise, the probability of negative effects on human health increases in proportion to the value of *HQ* (Table 1). To assess the risks due to chronic exposure to harmful substances, we used the average annual concentrations of toxicants, as well as their upper 95 % confidence limits. When determining the risks of acute effects (up to 24 hours) we have used the maximum concentrations of pollutants [19–21].

Table 1.

Criteria for non-carcinogenic risk of toxicants [15]

Risk characteristics	Risk factor *HQ*
The risk of negative effects is considered to be negligibly small	< 1
A limit value that does not require urgent action, but cannot be considered as enough acceptable one	1
The probability of developing negative effects increases in proportion to the increase in *HQ* value	> 1

The peculiarity of this methodology of health risk assessment is that the emphasis is on the long-term exposure to relatively low concentrations of the pollutant, such as chronic exposure to the particular substance every day or in our case – during the rest-time. Exceeding the reference dose does not always lead to harmful effects on human health, but it is necessary to emphasize that the higher is the exposure to the pollutant and the more times it exceeds the reference dose, the greater is the likelihood of harmful effects for the humans and population in general.

The magnitude of the danger to human health is assessed using the dose-response relationship and the study of the full range of harmful effects [19–21]. Therefore, the result of exposure assessment based on reference doses and concentrations of pollutants are hazard factors for individual ingredients of the mixture, which is harmful to the human body, HQ_i (formulas (4a) and (4b)) and hazard indices *HI*, which are determined in the case of combined exposure to pollutants:

$$HI = \sum_i HQ_i \quad (5)$$

Analysis of the literature shows that most often (but not always) the combined effect of toxicants is manifested by the effect of summation, i.e. there is an additive harmful effects of pollutants on the human body [19]. Therefore, taking into account the summation effects, although can provide slightly higher values of danger to human health, but, according to the international experts, has certain advantages over assessing the impact of each pollutant individually.

The resulting stage of health risk assessment is to inform the public in general, public organizations, and local governments about the risk. In particular, in our study, when calculating the risk of non-carcinogenic effects in the population, it was found that for the two studied recreational areas of Kyiv city, the ecological risk was unacceptable for the population (under the previously mentioned conditions of exposure to pollutants). This allowed to focus attention of the management on eliminating the drawbacks and providing environmentally friendly conditions for recreation of the urban population in these areas.

In a further study, the results of risk assessment were compared with the values of the developed complex indicator of technogenic load (CITL), which takes into account the type of human activity and recreation and was proposed by us to establish the level of environmental hazard of urban recreational areas. CITL was calculated on the basis of pre-established indicators of geochemical pollution of individual components of the environment – air, soil, natural and artificial water bodies, etc. by the following formula:

$$CITL = \sum_{i=1}^{n} k_i \cdot x_i, \quad (6)$$

where n is the total number of indicators included in the CITL; k_i – weighting coefficient for each of the studied indicators; x_i – the value of each of the contamination indicators that form the CITL.

Indicators of geochemical pollution of soils and water bodies were determined using express-analysis methods (conductometry, potentiometry, optical research methods, stalagmometry, densimetry and viscosimetry), as well as using the method of analytical determinations. Levels of geochemical pollution of atmospheric air and, as a consequence, areas located nearby roads were established by field observations of traffic flows and by modeling the dispersion fields of pollutants – the main ingredients of vehicle engine emissions. Using a computational experiment and the created fields of dispersion of toxicants in the surface air layer of the studied recreational areas (modeled under different meteorological conditions), the multiplicity of exceeding the maximum permissible concentrations was established and on this basis the conclusions about the level of their environmental hazards in the inhalation of the pollutants were made [22]. The results for risk and CITL calculation are presented in Table 2.

Table 2.

The results of the assessment of the non-carcinogenic risk to the health of humans resting in the studied urban areas and data on CITL

Objects of research	Object characteristics	CITL*	Acceptability of the non-carcinogenic risk to human health
Recreational area near the lake (1)	The status of the lake – it is a landscape reserve of local significance	5	Extremely acceptable
Recreational area near the lake (2)	Located in the residential area; the lake was formed as a result of alluvium for the construction of a residential area	4	Extremely acceptable
Recreational area near the lakes (3)	Located in the residential area; located next to a loaded highway of international importance	6	Unacceptable for the population
Recreational area near the lake (4)	Located next to a loaded highway	5	Extremely acceptable
Recreational area near the lakes (5).	The area is polluted with household waste	4	Extremely acceptable
Recreational area near the lake (6).	It is located in a residential area, a park is planned to be built near the lake	4	Extremely acceptable
Recreational area near the lakes (7).	Located in a residential area, it is planned to build a fitness park near the lake	6	Extremely acceptable
The system of ponds (8).	Located in the residential area, the area is contaminated with household waste	6	Extremely acceptable
Pond (9).	Located in the suburbs, it is a place of rest for residents of the capital, the area is contaminated with household waste	5	Extremely acceptable
Recreational area near the lake in the park (10).	It is located in a residential area, a loaded highway passes nearby	6	Unacceptable for the population
Recreational areas on the banks of the Dnieper river (11).	The area is polluted with household waste	4	Extremely acceptable
Recreational areas on the Dnieper river seafront (12).	The area is clean enough, next to it a residential area is located.	4	Extremely acceptable
Park in the city center (13)	The area is located next to a loaded highway of international importance, near the residential area is located	5	Extremely acceptable
Park in the city center (14)	The area is located next to a loaded highway of international importance, near the residential area is located	5	Extremely acceptable
Recreational area in the park (15)	The area is located next to a loaded highway of international importance, near the residential area is located	5	Extremely acceptable
Mini-park (16).	The area is located next to a loaded highway of international importance and intersections in two levels, near it the residential area is located	4	Extremely acceptable

Note. *without taking into account the pollution of water bodies and their use for swimming.

Conclusions. Thus, the analysis of the scientific literature, as well as our own experimental studies have led to the conclusion that in order to predict the level of environmental danger for the recreational areas located nearby roads, we need the accurate monitoring data on the content and emissions of major pollutants, knowledge of their chemical and physical properties, potential toxicological effects on human health, as well as data on the life time of toxicants in the environment, their possible transformations under the influence of various factors, the average time of development of these processes, etc.

It was found that important information can be taken from the study of motor transport emissions from traffic flows along the studied areas. As for recreational areas outside the city, located near the loaded traffic "arteries", these observations in Ukraine are now almost unorganized. Therefore, all this requires additional research in the field of studying the impact of traffic flows on urban and suburban recreational areas, as well as in the field of risk assessment for the health of people who rest in these areas.

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