Methodological bases for assessing the level of environmental safety of dynamically developing urbanized territories

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Abstract. Constant transformations taking place in urban areas infrastructure lead to a change in the nature of environmental components' impact, which requires the methodological bases improvement to assess the level of environmental safety of dynamically developing urban areas. To solve this problem, authors proposed the use of environmental, economic and social criteria with the substantiation of the principles of its calculation and description of possible results for each direction. The methodological foundations presented in the article are one of the stages of constructing a methodology for assessing the level of environmental safety of dynamically developing urbanized territories, taking into account the qualitative changes in environmental factors, functional and planning transformations of the urban landscape, as well as accompanying socio-economic transformations.

1. Introduction
Based on previously performed scientific research in the field of environmental safety of urbanized areas [1–4] in this scientific study, we offer a methodological foundations to assessing the level of environmental safety of a dynamically developing urban environment based on the results of systematization of its parameters and characteristics [2].

At the same time, we have chosen the urban environment as a subject of research precisely in the process of continuously occurring changes in it. The evolutionary nature of changes in the urban environment or its dynamic development, in our opinion, manifests itself in three main directions: urban planning - including functional planning measures and zoning of the territory; ecological - reflecting changes in the state of natural and natural-anthropogenic components of the urban environment; and socio-economic - showing the transformation of the level of comfort of the study area for the residence and work of citizens.

2. Materials and Methods
An important difference between a dynamically developing urban environment and a typical urbanized area is its study in the context of constant changes. First of all, these changes occur in the urban planning direction, consistently affecting the socio-economic and environmental aspects of the development of the territory. Accordingly, the changing infrastructure of the city requires a new and improved approach to assessing the level of environmental safety.

To solve this problem, we propose to consider and use at further stages of research an ecological criterion based on the primary consequences of anthropogenic impact; an economic criterion, which consists, on the one hand, in a comprehensive characteristic of the economic effect, and, on the other
hand, in the economic damage to the surrounding urban environment; social criterion characterizing
the state of health and living conditions of the population in the study area.

When calculating integral parameters that take into account the level of pollution of more than one
component of the environment, it is logical to use the coefficients of significance of particular
parameters that characterize the influence of individual components on a comprehensive assessment.
In our approach, it is assumed that the weighting coefficients $B_\Sigma$ are determined by the values of the
economic damage $Y_j$ caused by construction and urban facilities to the corresponding components $j$ of
the surrounding urban environment:

$$B_\Sigma = \frac{\sum_n Y_{\Sigma,n}}{\sum_j Y_j}$$

Since the effect of the entire complex of various sources of environmental pollution in dynamically
developing urbanized territories is the initial consequences that determine the initial state of the
environment [5-7], the proposed methodology is based on the use of the primary objective results of
measuring the levels of pollution of various components of the surrounding urban environment. At the
same time, we used the assessment of the primary consequences of anthropogenic impact to
determine the ecological criterion.

In addition to the main environmental criterion $C_{ecol}$ assessing the state of the components of the
surrounding urban environment, we proposed to consider the economic criterion $C_{econ}$, the essence of
which lies in the complex characteristics of the economic effect $E_{ef}$ (economic benefits) from the
functioning of the infrastructure object of a city or urban economy in the investigated urbanized
territory, as well as the economic damage caused by the object of research to the surrounding urban
environment and, as a consequence, to the population of this territory.

Moreover, the value of the economic effect $E_{ef}$ depends on the functioning of a city or municipal
infrastructure facility on the volume of taxes, payments, deductions and other payments to the local
budget. When determining the economic effect $E_{ef}$ in our further studies, we used the characteristics
listed in Fig. 1.

**Figure 1.** The list of characteristics affecting the magnitude of the economic effect from the
functioning of an infrastructure object of a city or municipal economy
At the present stage of economic and economic development of urbanized territories, economic damage to the surrounding urban environment is opposed by three types of costs for infrastructure facilities of a city or urban economy, presented in Fig. 2.

| Costs for infrastructure facilities of a city or municipal economy |
|---------------------------------------------------------------|
| costs of environmental protection measures related to the prevention of emissions, discharges, waste and other types of negative impact on the urban environment, including the modernization of technological or commercial processes, ensuring the environmental safety of city infrastructure facilities, design costs for these facilities of measures to protect the urban environment and etc. C_{object} |
| environmental payments of the source of man-made impact (payments for emissions, discharges, waste removal, disposal, use of natural resources, etc.) P_{m} |
| economic effect E_{ef} (economic benefit) from the functioning of infrastructure facilities of a city or urban economy located on the considered dynamically developing urbanized area |

Figure 2. The main types of costs for infrastructure facilities of the city or urban economy

Economic criterion $C_{econ}$ the study area, in turn, can be determined by the following formula:

$$C_{econ} = \frac{D_{air} + D_{water} + D_{soil} + D_{population}}{C_{m\_object} + P_{m} + E_{ef}}$$

Along with the environmental criterion $C_{ecol}$ assessing the state of the components of the surrounding urban environment and the economic criterion $C_{econ}$ we proposed to consider also the social criterion $C_{soc}$, the essence of which is to describe the state of health of the population and living conditions in the area of a dynamically developing urbanized territory.

Among the main tasks of ensuring the environmental safety of built-up areas is the identification and correlation of the relationship between morbidity and mortality rates of the population with various factors characterizing the state of the surrounding urban environment. Research related to the establishment of these links is carried out to establish the relationship between environmental pollution of the urban environment and the occurrence of various diseases among the population of an urbanized area based on the use of statistical indicators [8-11]. To determine the social criterion for dynamically developing urbanized territories, we used the parameters of the level of comfort and improvement of the studied areas; degradation of the urban environment and deterioration of the visual and aesthetic properties of urban landscapes; parameters describing social benefits and incentives for the population; statistical parameters of publicly available information on public health.

Each case of the disease in one way or another entails direct and indirect economic losses. Direct losses consist of economic and economic damage caused to the municipal budget due to temporary or permanent disability of a part of the working population of the studied built-up area. Indirect losses are associated with insurance payments related to diseases of the working population, payments of disability pensions, payments of various types of benefits.
The losses associated with the illness of the working population, in each case, can be determined by the formula:

\[ L_{\text{dis}} = F_{\text{dis}} + S_{\text{dis}} + C_{\text{dis}} , \tag{3} \]

where: \( F_{\text{dis}} \) – loss of a city infrastructure facility or a municipal facility as a result of illness and absence of an employee (employee) to work, rubles/year; \( S_{\text{dis}} \) – social costs, rubles/year; \( C_{\text{dis}} \) – conditional losses, rubles/year.

We have combined the databases necessary to analyze the relationship between environmental factors and the state of health of the population of a dynamically developing urbanized territory into the following groups: hazardous and harmful environmental factors; data on the population living at a dangerous distance from sources of negative impact on the urban environment; data on the health status of the population of the study area, including ecologically caused diseases caused by pollution of the urban environment.

At the same time, diseases and pathological conditions that have developed among the population of the studied area of urban development under the influence of negative factors in the form of “nonspecific” and “specific” pathology on the surrounding urban environment should be classified as ecologically caused. As a rule, the indicator ecologically caused diseases include diseases of a somatic and other nature among the population of the study area, the frequency of which for a certain period of time is higher than the previous observations for 5-10 years, and the reason for their growth can presumably be attributed to the action of known local (regional) factors that negatively affect the urban environment [11-13].

Databases on the health status of the population of urbanized territories are based, as a rule, on such types of information as: reported data on morbidity and mortality of the population, as well as medical records from case histories; special registers of certain types of diseases; biomonitoring data for various types of chemicals; information on the periodic medical examinations carried out; registration of notifications of doctors about all cases of diseases; information on the number of visits to doctors or ambulance calls.

When considering a particular type of disease, the incidence was determined by us by the frequency of cases of the disease per inhabitant of the studied urbanized territory, characterized by the probability of incidence, determined by the formula:

\[ P_{i}(B_{\text{idis}}) = \frac{N_{\text{idis}}}{N_{\text{pop}}} \tag{4} \]

where: \( N_{\text{idis}} \) – the number of cases of the i-type of the disease in general per year, people.; \( N_{\text{pop}} \) – total population of the study area, people.

As a basis for assessing the factor of environmental pollution in the urban environment that affects the emergence and development of the i-th type of disease, we put the value of the absorbed individual dose of a pollutant that has entered the human body by various routes (air, through drinking water, food, etc.) time interval.

Since when analyzing the influence of the level of pollution of the urban environment on the morbidity of the population, an important problem is to take into account many factors polluting the environment, then to determine \( C_{\text{mobject}} \) we used the criteria for the pollution of those components of the urban environment that affect the considered type of morbidity.

At the same time, in order to conduct research on the influence of environmental factors on human health, a wide range of methods of statistical data analysis is used in practice. [9-10, 12-13].

When determining the social criterion, we introduced a number of restrictions associated with such problems as:

- the impossibility of accurately determining the exposure (exposure dose) for the population of the study area, since the exposure dose determined for one population group cannot always be directly transferred to another group due to differences in exposure levels, in the applied
exposure assessment methods and assessment methods for population exposed to negative factors:

- the complexity of assessing the complex impact of several polluting factors that cause a certain type of disease. Thus, suspended solids and sulfur dioxide (SO2) affect the occurrence of respiratory diseases, and the proportion of exposure to each of these pollutants is very difficult to determine;
- difficulty in presenting impact assessment results for different population groups.

Based on probability \( P(B_{dis}) \) noncommunicable diseases and/or likelihood \( P(B_{mor}) \) mortality, as well as the conditional probability of the occurrence of a factor of negative impact \( P(A_{neg}/B_{dis}) \), which affects the occurrence of the corresponding disease, we have determined the following conditions for the relationship between the probability of disease occurrence and the factor of urban environmental pollution:

\[
P(A_{neg}, B_{dis}) = P(A_{neg} \mid B_{dis}) \cdot P(B_{dis}) = P(B_{dis} \mid A_{neg}) = P(B_{dis} \mid A_{neg}) \cdot P(A_{neg}),
\]

where: \( P(B_{dis}) \) – unconditional probability of disease occurrence; \( P(A_{neg}) \) – unconditional probability of negative impact of the factor of urban environment pollution; \( P(A_{neg}/B_{dis}) \) - the conditional probability of observing the negative impact of the factor of environmental pollution in the urban environment associated with the occurrence of diseases; \( P(B_{dis}/A_{neg}) \) – the conditional probability of observing the occurrence of diseases as a result of the negative impact of the factor of environmental pollution.

We used the formula as the basis for obtaining the dependence of the social criterion proposed by us, which sums up the probabilities \( P(A_{comf}, B_{dis}) \) combining the factors of negative impact on the urban environment with the occurrence of diseases for all their considered types and can be determined by the formula:

\[
C_{soc} = \left[ 1 - \prod_{j=1}^{n} \left( 1 - P_j (A_{neg}, B_{dis}) \right) \right]
\]

where: \( j, n \) – respectively, the type and number of types of accounted for non-communicable diseases of the population in the study area of urban development.

3. Results

When calculating the environmental criterion \( C_{econ} \), the data obtained as a result of measurements on the various degrees of environmental hazard of the pollution level should be adjusted in such a way as to obtain an average estimate of the share of the degree of environmental hazard of each factor in the integral assessment of the state of the surrounding urban environment. As a result of taking the logarithm of the scale of the degree of environmental hazard for each of the components of the surrounding urban environment and reducing to a single base (for example, according to the value of the initial degree of hazard), one can obtain a single-scale scale. Such a scale will allow, on the one hand, to introduce a coefficient of the degree of environmental hazard of pollution of the surrounding urban environment for the health status of the population living or working in the territory, and, on the other hand, to transfer all pollution indicators into a single system of dimensionless indices, which will make it possible to further take them into account. complex impact and obtain a total index of urban environment pollution.

Based on the results of calculating the economic criterion \( C_{econ} \) the state of the dynamically developing urbanized territory under consideration should be attributed to one of three options:

- the first option, when the value of economic damage is greater than the value of the economic effect of economic activity, is unfavorable from the point of view of ensuring environmental safety, since the main feature of the infrastructure of the city and urban economy is their achievement of high economic indicators and the solution of problems of economic
development of infrastructure facilities of the city and urban economy priority in relation to
the tasks of ensuring environmental safety:
- the second option, when the value of economic damage is close (equal) to the value of the
economic effect of economic activity, is neutral from the point of view of ensuring
environmental safety, since in this case the solution of the problems of ensuring environmental
safety and economic development of the infrastructure of the city and urban economy of the
investigated is equivalent in its level;
- the third option, when the value of economic damage exceeds the value of the economic effect
of economic activity, is favorable from the point of view of ensuring environmental safety,
since in this case solving the problems of ensuring the environmental safety of the
infrastructure of the city and urban economy is a priority in relation to the tasks of economic
development.

With regard to our proposed method for calculating the social criterion \( C_{soc} \) assessing the state of
dynamically developing urbanized territories, its value reflects the situation with the level of health of
the population and, to a certain extent, the degree of comfort of life in the study area.

4. Discussion
As a result of the completed stage of research, we identified and systematized by groups the main
factors and parameters that largely determine the state of both individual objects of the urban
environment and urban economy, and dynamically developing urbanized areas in general. The
directions are determined, the main methodological foundations of the formation of the assessment of
the level of ecological safety of objects of the urban environment are presented and formulated. At the
same time, one of them is a comprehensive accounting of the criteria proposed by us for assessing the
state of the components of the surrounding urban environment, namely the ecological \( C_{ecol} \), economic
\( C_{econ} \) and social \( C_{soc} \). Their essence and structure provides ecological adjustment of indicators of
sustainable development and economic progress of urbanized territories, combining which into a
single balanced system is currently an urgent task and topic of scientific research [14-16].

5. Conclusions
Thus, the methodological foundations for assessing the level of ecological safety of urbanized
territories, taking into account the degree of anthropogenic impact, include an ecological criterion
based on the primary consequences of anthropogenic impact; an economic criterion, which consists,
on the one hand, in a comprehensive characteristic of the economic effect, and, on the other hand, in
the economic damage to the surrounding urban environment, as well as a social criterion
characterizing the state of health and living conditions of the population in the study area.

The methodological foundations presented in the article are one of the stages of constructing a
methodology for assessing the level of environmental safety of dynamically developing urbanized
territories, taking into account the qualitative changes in environmental factors, functional and
planning transformations of the urban landscape, as well as accompanying socio-economic
transformations.

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