

Assessment of the level of impact and degree of environmental safety of industrial facilities in the urban environment

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Abstract. The problem of a comprehensive assessment of the level of impact and the degree of ensuring the ecological security of built-up areas has not been fully resolved. For its solution, we suggest a methodical approach based on the use of three coefficients for assessing the quality of the state of the environment and the effectiveness of measures to ensure environmental safety in urban areas, in particular, the coefficients of environmental hazards, economic losses and social discomfort. Its use will allow the maximum objective selection of a complex of ecologically efficient and economical architectural and planning, organizational, technological and special engineering and environmental measures in the design of new and operation of existing industrial facilities. The results received at the completed stage of the research can be used as a basis for further development aimed at creating a methodological basis for the assessment, selection, calculation, design and implementation of a complex of ecologically efficient and economical architectural, planning, organizational, technological and special engineering and environmental measures to ensure environmental safety built-up areas in general.

1. Introduction

Every year the problem of ensuring the ecological security of built-up areas affects more and more areas of human activity. The continuation of intensive anthropogenic activities without highly effective measures to ensure environmental safety becomes very damaging to the environment and contradicts the basics of the theory of sustainable development [1–2]. The removal of the most production facilities beyond the central part of urban settlements does not completely solve the problem of reducing the negative impact of these facilities on the environment. In addition, the tendency of increasing the number and size of agglomerations, along with an increase in the rate of de-urbanization, leads to a rapprochement of the residential areas under construction with new industrial areas [3].

The consequences of various impacts on the sustainability of the urban ecosystem can be divided into explicit, directly affecting the safety of the population, and hidden, which can include the results of social and economic changes reflected in the statistics or even in the value of real estate. The explicit consequences include the depletion of the fertile layer of urban vegetation, the



disturbance of the temperature and aeration modes in the soil, and as a consequence, the complex conditions for the growth and development of vegetation, the scarcity of fauna, and the pollution of the air basin and the aquatic environment as a result of anthropogenic activity. In our opinion, the growth of certain types of diseases in various groups of the population, depending on the nature of the prevailing pollution, and also the decrease in the attractiveness of certain capital construction projects located in an unfavorable zone should be considered as hidden.

In this regard, one of the important directions for overcoming the ecological crisis and solving the problem of ensuring the ecological safety of built-up areas is the development of criteria assessing the impact of industrial facilities on the urban environment, with subsequent development on their basis of a methodology for selecting, designing and implementing a set of highly efficient and economical architectural, planning, technological and special engineering-ecological measures aimed at overcoming the negative effects of industrialization and increasing environmental safety.

2. Materials and Methods

Functional zoning of almost every settlement can be characterized as follows:

- residential areas, which includes both the existing building of the central (historical) part, and the zone of individual, as a rule, single-family private housing construction and the territory of new micro districts with multi-storied buildings;
- industrial zones, which include operating enterprises, warehouses, bases, etc.;
- zones of engineering and transport infrastructures;
- public and business zones used for placement of objects of trade, education, business, health, etc.;
- recreational zones or a natural complex, dividing into virgin and fallow lands, gardens, parks, boulevards and public gardens, and also forest parks [4].

In our scientific work, the main attention should be paid to the objects of industry in the urban environment. As it is known, their functioning is aimed at solving such important economic tasks of municipal entities as creating new engineering and transport infrastructure facilities, increasing the taxable base and revenues of the consolidated budget of the subject of the federation, increasing the rate of industrial growth, and creating new jobs, in turn, entails an increase in the standard of living of the population and an improvement in the investment climate. Thus, the geography of location of industrial objects plays a big role in building the territorial-economic system of a particular region from the point of view of economic geography.

In its turn, on the territory of each industrial site it is possible to perform a separate division of the territory into the following areas:

- industrial and technological, within which the main production and technological buildings and facilities, warehouses, engineering infrastructure facilities, power engineering, garages, cargo areas, railway access roads, berths and other transportation facilities, as well as supporting and maintenance facilities are located;
- social, which can include all buildings and facilities used to provide the required sanitary and hygienic conditions at the enterprise;
- recreational area within which employee recreation areas are located and green plantations of various types and structures (trees, bushes, annual and perennial decorative plants, etc.) grow and perform ecological, environmental and sanitary-hygienic and aesthetic functions.

The impact of a complex of sources of environmental pollution in the areas of production facilities in the urban environment leads to economic damage from air pollution D_{air} , water sources pollution D_{water} , land (soil) pollution D_{soil} and pollution by physical fields D_{phf} .

Herewith, three types of economic costs of production facilities as objects of environment are contrasted with the economic damage to the environment:

- expenditures on environmental measures aimed at preventing the impact of emissions, waste, discharges, etc. on the environment (modernization of production processes, compliance with environmental safety of manufactured products, the costs of designing environmental protection

measures for environment, investments aimed at increasing the ecologization of production, etc.) $V_{extreme}$;

- ecological payments of the object of anthropogenic impact (payment for discharges, emissions, removal and utilization of waste, use of natural resources, etc.) C_{osi} ;

- economic benefit (economic effect) for the urban settlement from the operation of environmental management facilities located on the investigated territory of the industrial zone (payments, taxes, contributions and other payments to the local budget, investment commitments aimed at the development of the social sphere, rents, etc.) E_{ef} .

The costs of industrial facilities aimed at preventing the impact of emissions, discharges, waste and the impact of physical fields on the environment and the health of the population of the adjacent territory of the industrial zone, including the sanitary protection zone $V_{extreme}$, consist of the measures costs to protect the air basin, water bodies, soil cover and vegetation, as well as measures to reduce the level of pollution by physical fields.

Assessment of the state of industrial facilities in the urban environment requires a complex accounting of the three main parameters groups: ecological, economic and social, determining the overall quality of the territory examined as a whole. Taking into account that the values of economic, environmental and social characteristics vary depending on the functional area of the examined urban area, in determining the integrated assessment, it is also necessary to take into account the inequalities of the indicators included in it. The approach suggested by us allows, taking into account various territorial characteristics with different dimensions, to obtain the resulting dimensionless coefficients of ecological danger, economic losses and social discomfort, respectively [5].

The factor of ecological danger of industrial objects in the urban environment directly characterizes the state of the environment in the area of their location. Experts use the parameters characterizing the level of pollution and the effectiveness of air protection, the degree of use and effectiveness of protection water bodies, the degree of use and effectiveness of protection the soil cover, as well as parameters characterizing the level of impact as the main parameters describing the quality of the environment physical fields (noise, vibration, electromagnetic and ionizing radiation).

As the main characteristics of the state of the environment, we took the amount of emissions into the air basin, discharges into water bodies, as well as wastes generated as a result of the functioning of the examined object and the actual values of pollution levels in the area where the object is located.

Based on these characteristics, we obtained dependencies for determining the relative levels of pollution of the main components of the environment:

$$V_j = \sum_{i=1}^n \frac{Q_{ap}}{Q_{ev}} \quad (1)$$

where Q_{ap} – the actual pollution level, mg / m³ (mg/kg, dBA, V/m, microR/hour); Q_{ev} – value of permissible level of pollution, mg/m³ (mg/kg, dBA, V/m, mR/h).

A regulatory framework for assessing the statistical characteristics of the state of the environment is a hierarchically ordered system of general documents that regulate environmental factors both at the international and at the national level. In particular, in the Russian Federation they include: international legal acts, provisions of the Constitution of the Russian Federation, federal laws of the Russian Federation, decrees and orders of the Government of the Russian Federation, decrees of the President of the Russian Federation, legal acts of ministries and departments, as well as laws and regulations of regions of the federation and local government bodies.

When using the characteristics of the state of the environment, it is possible to determine the distribution of concentrations of harmful substances, as well as the levels of pollution by physical fields in the examined area. In our opinion, this is not enough to calculate the socio-ecological and economic assessment of the condition of the territories of industrial zones of large cities and the adjacent elements of urban infrastructure.

To combine the pollution coefficients of the components of the environment V_j into a criterion of total pollution V_{total} , we used the following formula:

$$V_{total} = (V_{air} + 1)^{D_v^{air}} \cdot (V_{water} + 1)^{D_v^{water}} \cdot (V_{soil} + 1)^{D_v^{soil}} \cdot (V_{phf} + 1)^{D_v^{phf}} - 1 \quad (2)$$

where D_v^j – the weighting factor of the corresponding component of the environment.

To calculate integral coefficients that take into account several components of the environment, it is necessary to apply the significance coefficients of the partial criteria $B_{\beta j}$ that characterize the dynamics and influence of individual components of the overall assessment. In our approach, we offer to calculate the weighting factors in accordance with the values of economic damage caused by man-made objects of the corresponding environmental component j :

$$D_j = \frac{D_j}{\sum_j D_j} \quad (3)$$

Formula (2), in our opinion, is characterized by such advantages as

- ease of use in practical calculations;
- taking into account the weight factors of the main components of the environment;
- sufficiently high accuracy, since the opposite values of the factors that it includes are taken into account, which does not happen when using the linear method calculation of the average arithmetic sum and the ball method.

The use of the weighting factor D_v^j highlights the fact that some components of the environment are more significant than others, because at the present time they are mostly negatively affected, and therefore they need to be taken into account to a greater extent.

The method we developed is based on the measurements data of the state of various areas. The pollution coefficients of the main components of the environment have been determined in comparison with the normative (maximum permissible and background) values, which are in turn determined on the basis of hygienic and epidemiological conclusions.

The impact of a complex of sources of environmental pollution on the territories of industrial facilities in the urban environment leads to the emergence of primary effects that determine the state of the environment at a particular time. Our methodological approach to the determination of the coefficient of environmental hazard contains an assessment of the primary consequences of anthropogenic impact, which is based on accurate data from measurements of the states of different areas.

Thus, the coefficient of ecological danger of the state of the environment of industrial facilities in the urban environment C_{ecol} is calculated on the basis of the characteristics of the state of the components of the environment and the consequences of human activities, leading to negative changes in this state.

The essence of the economic losses factor in assessing the production facilities of the urban environment and the adjacent areas is in the characterization of economic benefits (economic effect), as well as economic damage to the environment and the health of the population of the adjacent territory, obtained as a result of the functioning of the man-made object.

The amount of economic benefit from the operation of each facility is affected by the volume of taxes, deductions, payments and other payments to the local budget, which determine the benefits of the object for the economy of the city and the region as a whole.

To determine the economic effect obtained from the functioning of a man-made object in this methodology, the following are used:

- profit of the environment object, directly affecting the amount of payments, taxes and deductions that come to the local budget from a specific enterprise;

- financial effect that determines the rent, the amount of taxes and other revenues to the local budget;
- the cost of production, which determines the profit of the environment object.

The values mentioned above are interchangeable – one can be used to calculate the other two. To determine the economic effect of E_{ef} , which is included in the formula for calculating the economic losses factor, we offered to use one of these quantities, depending on the conditions. In addition, we took into account rent for land and premises. On the one hand, the final profit of the enterprise depends on it, and, on the other hand, it supplies the local budget.

Also, economic benefits from the operation of the facility include investment commitments aimed at developing the social sphere, the infrastructure of the region, payments related to the transfer of land from one category to another.

Significant financial resources from payments for negative impact on the environment can be accumulated in the local budget by municipal and regional authorities and subsequently used for environmental protection.

The general principles of assessing economic damage imply that the damages of industrial facilities include real damage to the environment and the health of the population of the adjacent territory. Calculation of the amount of damage in monetary terms from various types of violations of environmental legislation was carried out by us on the basis of the principles of compensation for damages set out in the Civil Code of the Russian Federation and the Federal Law "On Environmental Protection".

Estimation of damages from pollution is understood as the calculation in monetary terms of economic and non-economic losses caused by deterioration of buildings and structures [5], corrosion of metals, disruptions in technological processes, an increase in the incidence rate and a decrease in the working capacity of the population adjacent to the industrial zone, and other phenomena caused by chemical, physical and biological pollution of the environment. Finance in this case is not only an economic characteristic, but also the magnitude of social and economic damage. Financial (economic) assessment is possible only in the final values, but social damage can be endless with irretrievable losses of the basic life values of a person [6].

Calculation of annual values of economic damage from air pollution can be carried out according to the formula [6]:

$$Da = \gamma t \cdot \sigma(\lambda) \cdot f(\lambda) \cdot (\sum A_i(\lambda) \cdot m_{it}), \quad (4)$$

Results where γ_t – monetary unit of emission, rub./cond.t; $\sigma(\lambda)$ – coefficient, by means of which regional features of the territory affected by harmful influence are taken into account; $f(\lambda)$ – correction including the dispersion of impurities in the atmosphere; $A_i(\lambda)$ – the coefficient of reduction of the impurity of the i species to the mono-pollutant, cond. t/t; m_{it} – volume of release of the i type of contaminant admixture, t/year.

Economic assessment of damage to water bodies is carried out according to the formula [6].

$$De = \rho t \cdot \beta(\lambda) \cdot (\sum D_i(\lambda) \cdot V_{it}), \quad (5)$$

where ρ_t – monetary valuation of the discharge unit, rub./cond.t; $\beta(\lambda)$ – coefficient allowing to take into account the features of the reservoir, which is subject to harmful influence; $D_i(\lambda)$ – the coefficient of reduction of the impurity of the i species to the mono pollutant; V_{it} – volume of discharge of the i type of impurity pollutant, t/year.

The economic assessment of the amount of damage from the degradation of the environment afterwards by contamination with harmful substances and littering of the soil cover on the territory of the industrial zone is determined by the formula [6].

$$Dn = N_c \cdot S \cdot C_e \cdot C_{env}, \quad (6)$$

where N_c – rate of land value, thousand rubles/ha; S – the area of the soil cover degraded, contaminated with harmful substances or littered in the reporting period, ha; C_e – coefficient

of ecological status and ecological significance of the territory; $C_{env.}$ – coefficient for the territories under protection.

To calculate the economic evaluation of the damage caused by a high level of sound pressure to the health of the population, one can use formula [6].

$$Ds.pressure = B \cdot g \cdot c \cdot S / (\rho \cdot N \cdot 1002), \quad (7)$$

where B – average output per worker per year, rubles/person; g – percent of city-forming group, %; c – a coefficient that takes into account the decline in labor productivity, %; S – area of discomfort to the maximum permissible level (60 dBA), ha; ρ – density of production fund, m²/ha; N – norm of total space per employee (15 m²/person).

Economic evaluation of the damage from the vibration effects on the environment can be determined by means of the following formula [6].

$$Dvibr. = \gamma \cdot \sum z_i \cdot v_i \cdot r_i \cdot [\sum (B_j - B_H)], \quad (8)$$

where B_j (B_{nij}) – the actual (standard) vibration level of the j frequency level; n – number of buildings in the examined territory; z_i – coefficient of significance of the i building (it can be determined by the result of an expert evaluation or repairing costs); v_i – coefficient reflecting the rate of destruction of the i building (depending on the age of the building, the state of the structures, as well as used in the construction and reconstruction of materials); r_i – distance to the building; γ – the cost estimation for the reference influence option.

Since the results of calculating the economic losses factor, the status of the industrial zone in question should be attributed to one of the following:

- economic damage is greater than economic benefits from economic activity. This option is mostly unfavorable, because this territory "works" for economic indicators. It is necessary to recommend measures to improve the existing situation;
- economic damage and economic benefits from the operation of environmental management facilities are equal. The issues of environment protection and the dynamics of the economic development of the territory are of equal interest;
- amount of economic damage is less than the value of economic benefits from economic activity. This option is most favorable.

That is why the coefficient of economic losses of industrial sites in the urban environment of Racon was determined on the basis of parameters of economic damage to the environment, the costs of environmental protection measures, and non-environmental investments of environmental management objects into the local budget.

The essence of the social discomfort coefficient is the characterization of the health status of the working and living population, living conditions in the area of the industrial facilities of the urban environment and the surrounding urban infrastructure, including the sanitary protection zone.

The manuals on health statistics contain information on establishing the relationship between levels of diseases and mortality of the population and various characteristics of the state of the environment. The development of effective recreational activities is impossible without knowledge of this relationship. The most common reason for conducting such studies is the need to establish the causes of diseases associated with environmental pollution, while specialists apply methods to study the patterns of the spread of non-infectious etiology among the population adjacent to the industrial zone, including the sanitary protection zone, based on the use of statistical indicators.

The characteristics used to determine the social discomfort of urban industrial areas and adjacent urban infrastructure elements include the comfort and well-being of the examined areas, the emergence of public goods, the degradation of the environment and the loss of aesthetic properties of landscapes [7], as well as data on the social benefits of the adjacent to the industrial zone of the territory population, including the sanitary protection zone [8], employed in hazardous areas of production and the results of statistical analysis of existing information on the health of the

population of the territory adjacent to the industrial zone, including the sanitary protection zone, based on the analysis of occupational injuries and occupational diseases.

Every case of disability to work entails losses – direct and indirect. Their performance depends on the production performance of the enterprise. Direct losses result from losses of the enterprise and economic damage. These losses are related to the economic activities of the enterprise and affect production performance. Indirect losses are payments made by the trade union organization and social insurance in case of disability.

Occupational diseases and incidents of injuries can have different consequences for the restoration of work capacity and the ability to perform labor functions. In diseases or injuries that cause a decline in labor productivity, a transfer to a work required an easier, lesser qualification that is not associated with a harmful production factor is required. For diseases or injuries that lead to a decrease in productivity and disability, a disability pension is required. Disability with a fatal outcome leads to the payment of benefits to the family of the victim.

Loss of ability to work for each of the above cases can be determined:

$$L=O+S+C, \quad (9)$$

where O – loss of organization; S – social costs; C – conditional losses.

On the other hand, the economic loss of working capacity can be divided into the following groups: losses caused by injuries L_{ir} ; losses caused by microtrauma L_{mtr} ; losses caused by occupational diseases L_o , and costs of compensation due to the presence of harmful production factors L_C :

$$L=LTR+LMTR+LO+LC. \quad (10)$$

The total amount of the conditional production losses in case of injury C_{tr} is compiled from the loss of production in connection with the absence of the injured worker at work C_{tr}^1 , and the cost of nonproduced products on idle equipment as a result of injury C_{tr}^2 .

$$C_{tr} = C_{tr}^1 + C_{tr}^2. \quad (11)$$

The economic losses of the organization O_{tr} in this case are the following: from the cost of the spoiled materials; cost of damaged equipment, tools and destroyed structures O_{tr}^2 ; cost of repair works O_{tr}^3 ; payments on sick leave O_{tr}^4 ; surcharges to earnings in case of a decrease in professional capacity for work O_{tr}^5 ; payment of pensions for a disability or fatal outcome O_{tr}^6 ; costs for re-qualification of the victim and training of new workers O_{tr}^7 .

Thus,

$$O_{tr} = \sum O_{tri}. \quad (12)$$

The social costs S_{tr} , which are covered from public consumption funds, are formed from the cost of outpatient treatment S_{tr}^1 , clinical treatment S_{tr}^2 , payments of pensions by the means of social insurance to disabled people with injuries S_{tr}^3 , expenses for sanatorium treatment S_{tr}^4 :

$$S_{tr} = \sum S_{tri}. \quad (13)$$

Microtrauma, which does not lead to loss of capacity for work in day/person, also causes damage to the economy, being associated with the costs of first aid, the transfer of the victim to easier work, lower labor productivity, cost of repair or adjustment of equipment.

Economic consequences associated with occupational diseases P_d , are made up of the same three components – the losses of the organization of O_d , conditional losses of C_d and social costs of S_d .

The conditional loss of production can be determined with sufficient accuracy by the average cost of production P produced per working hour and the loss of working time T in connection with the illness of the victim:

$$C_d = PT. \quad (14)$$

Other economic losses are defined similarly to the case of injuries, except for losses associated with damage to equipment and its repair.

The economic costs of P_d , connected with the presence of harmful production factors, additionally contain expenditures for special food, individual means of protection, the maintenance of sanatoria and dispensaries, the need to establish a shorter working day, additional vacations, additional intra-shift breaks, reduced length of service before retirement etc.

The information databases needed to analyze the relationship between environmental characteristics and the health of the population of the adjacent territory, including the sanitary protection zone, are divided into three types:

- database on hazardous and harmful environmental factors;
- database on the exposition of the population living near industrial zones;
- database on the health status of the population adjacent to the industrial zone, including the sanitary protection zone, including diseases caused by environmental pollution (environmentally caused diseases).

Ecologically caused diseases include diseases and pathological conditions that have developed among workers in a particular territory under the influence of harmful factors of the production environment in the form of a "nonspecific" and "specific" pathology.

Indicative ecologically caused diseases include somatic and other diseases which are common among the population adjacent to the industrial zone, including the sanitary protection zone, whose frequency over a certain period of time exceeds the recorded values over the previous 5 to 10 years of observations. The reason for their growth can be the action of known both local and regional unfavorable environmental factors.

Information databases on the health of the population may contain the following types of information:

- results of periodic medical examinations;
- available and regularly updated reporting data on disease and mortality levels of the population, as well as medical records from the case histories;
- registers of special data (congenital malformations, oncological diseases, occupational diseases, etc.);
- results of bio monitoring (determination of lead in blood and other exposures);
- account of doctors' notices about all cases of diseases;
- general data on the number of visits to doctors and ambulance calls.

In the study of a particular case of a disease, the incidence rate is defined as the incidence of cases per person (probability of disease):

$$P(G_{dis}) = \frac{N_{I dis}}{N_{pop}}, \quad (15)$$

where $N_{i dis}$ – incidence number of i disease per year in total, person; N_{pop} – total number of employees of the enterprise in the examined area, person.

In addition, a difficult task is to determine the quantitative characteristics of the probability of the factor and the reasons that the disease can be caused. First of all, it is necessary to take into account the factors that describe the degree of environmental pollution. The probability of a negative factor is the probability of a negative effect for a person and is defined as the probability of occurrence of this effect under specific conditions. Most of the methods previously offered by specialists use for calculating this probability the ratio of the level of contamination to the permissible value, which in our work is determined by the criterion of general pollution P_{total} .

The main principle on which calculation of the pollution factor assessment acting on the i type of the disease is based is the use in calculation of the value of the individually absorbed dose of a harmful substance that has got into the human body by airborne droplets, through drinking water or food, etc. for a certain time period.

Thus, when analyzing the effect of the level of environmental pollution on the incidence of the population of the examined territory, an important problem is the factor-based accounting of the pollution effect on the examined coefficient.

3. Results

The received data on high, medium, moderate and low pollution should be corrected taking into account the level of danger of each degree of pollution. For this, it is necessary to introduce calculation coefficients to obtain an average estimate of the contribution of the hazardous influence of each factor to the overall assessment of the environmental conditions of the examined territories.

The result of the logarithm of the hazard scale for each of the environmental components and bringing them all to the same basis (the initial hazard indicator) is to obtain a single-scale scale. This allows, taking into account the level of danger of each degree of pollution, to introduce the calculated hygienic hazard coefficient of the health status of the population of the territory adjoining the industrial zone, including the sanitary protection zone, and to bring all the indicators, expressed in different units of measure, to a single system of dimensionless indexes, that gives the possibility of their further summation and the obtaining of a total index of environmental pollution in the territories of industrial zones of large cities and adjacent elements of urban infrastructure [9-10].

Gradation levels of pollution of individual components of the environment, which are used to calculate the hazard coefficients, are scientifically valid from the point of view of the health impact of the population adjacent to the industrial zone, as defined by specialists on the basis of hygienic or epidemiological studies. Our approach to assessing the dangers of pollution levels proceeds from the mentioned above. Therefore, according to the degree of danger, these levels are quite comparable. Conducting instrumental measurements with subsequent calculations makes it possible to obtain maps of environmental assessment of the state of the environment in the area of industrial zones where the distribution of the values of total air pollution, water bodies, soil cover, and pollution with physical fields can be visually represented.

4. Discussion

The use of the offered criteria that assess the quality of the state of the environment and the effectiveness of measures to ensure environmental safety will make it possible to select the complex of ecologically effective and economical architectural and planning, organizational, technological and special engineering and environmental measures in urban planning as possible when designing new and operating existing industrial facilities. At the same time, the city itself or the urban agglomeration, as an environment, can significantly reduce the impact of pollutants formed during production processes.

5. Conclusions

Thus, the completed stage of research and the results obtained can be used as a basis for further development aimed at creating a methodological basis for the assessment, selection, calculation, design and implementation of a complex of ecologically efficient and economical architectural, planning, organizational, technological and special engineering and environmental measures for ensuring the ecological security of built-up areas in general.

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