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# Environmental impact of asphalt concrete plants on industrial areas via criteria-based method assessing

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**Abstract.** The study addresses the environmental risks posed by asphalt concrete plants operating in industrial zones, focusing on their impact on air, soil, and water resources. The objective was to develop and test an integrated criteria-based methodology for assessing such impacts. Three asphalt concrete plants with different production capacities and gas-cleaning efficiencies were selected as the research objects. The methodology included sequential evaluation in five areas: territorial impact, geological conditions, atmospheric emissions, soil degradation, and water pollution. Data collection involved satellite imagery, cadastral surveys, laboratory analyses of air and soil samples, and field observations. The results show that plants with higher production capacity generate significantly greater environmental loads, with $CO_2$ and $NO_x$ emissions exceeding permissible levels, and with notable soil degradation and risks to hydrogeological stability. The discussion highlights that upgrading gas-cleaning units, implementing continuous water quality monitoring, and restoring disturbed soils are essential to mitigate the negative impacts. The proposed methodology proved effective for comprehensive environmental risk assessment and can be applied to other industrial facilities with similar environmental profiles.

**Keywords:** asphalt concrete plants, environmental impact, industrial zones, air emissions, soil degradation, hydrogeological stability, impact boundaries

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# Критериальный метод оценки воздействия асфальтобетонных заводов на окружающую среду в промышленных зонах

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**Аннотация.** В процессе работы асфальтобетонных заводов в промышленных зонах возникают экологические риски, связанные с загрязнением воздуха, почвы и водных ресурсов. Авторы ставили перед собой цель разработать и проверить на практике метод комплексной критериальной оценки такого негативного воздействия. В качестве объектов исследования были выбраны три асфальтобетонных завода с различными производственными мощностями и эффективностью газоочистки. Предложенный метод предполагает последовательную оценку пяти критериев: влияния на территорию, геологических условий, выбросов в атмосферу, деградации почв и загрязнения вод. Сбор данных включал изучение спутниковых снимков, кадастровые исследования, лабораторный анализ проб воздуха и почвы и полевые наблюдения. Полученные результаты подтверждают, что предприятия с более высокими производственными мощностями оказывают значительно большее негативное воздействие на окружающую среду: превышены допустимые уровни выбросов $CO_2$ и $NO_x$, что ведет к деградации почв и риску гидрогеологической нестабильности. Для нейтрализации негативного воздействия необходимы модернизация газоочистных установок, постоянный мониторинг качества воды и рекультивация почв. Метод комплексной критериальной оценки может быть применен и для оценки других промышленных объектов с аналогичными характеристиками.

**Ключевые слова:** асфальтобетонные заводы, экологическое воздействие, промышленные зоны, промышленные выбросы, деградация почв, гидрогеологическая устойчивость, площадь воздействия

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## 1. Introduction / Введение

In the context of accelerated urbanization and expansion of infrastructure projects, environmental protection issues are of particular importance [1–3]. Asphalt concrete production plants play a key role in the development of urban and industrial zones, but their activities are associated with serious environmental risks [4, 5]. These risks are associated with negative impacts on ecosystems, which can manifest themselves in both the short and long term [6].

Despite significant developments in environmental research, significant gaps remain, particularly in the long-term impact of industrial facilities on industrial zone ecosystems [7]. Existing assessment methods tend to focus on short-term effects and do not fully take into account the complex interrelations of environmental factors [8, 9]. This is of particular concern, as long-term environmental impacts may be significantly more serious and difficult to reverse.

The main problem is the lack of a clear formulation of the main environmental factors associated with the activities of asphalt concrete plants. Uncertainty in defining the objects and subject of research hinders the creation of effective management strategies.

In Russia, a comprehensive regulatory system for environmental impact assessment of asphalt concrete plants has been established and is legally enforced. It includes risk assessment for public health and relies on a large package of regulatory documents (federal laws, sanitary norms, state standards) and certified software tools. However, existing procedures are often fragmented: they separately consider atmospheric emissions, soil pollution, or hydrological risks, without providing an integrated picture of cumulative effects. The methodology proposed in this study does not replace the regulatory framework but complements it, offering a multiparametric assessment that integrates territorial-geometric and physical impact parameters. This closes a gap in current practices, ensuring a more complete and systemic evaluation of environmental risks.

Thus, there is a need to develop and test new integration methods capable of taking into account a wide range of environmental and technological parameters. These methods should provide more detailed data that can be used as a basis for making management decisions and strategic planning. The solution to these problems will not only expand the existing scientific base, but will also significantly improve the management of environmental risks associated with the activities of asphalt concrete plants.

Production facilities located in industrial zones pose a serious problem because they generate a wide range of pollutants that affect ecosystems [10, 11]. Such facilities affect large areas, disrupting natural processes, which makes it necessary to study their impact on the environment in greater depth and develop specialized approaches to managing and reducing negative impacts.

Industrial zones located in close proximity to urban agglomerations are a source of significant environmental risks. The problem is aggravated by the fact that many existing environmental impact assessment methods do not take into account the full picture and are based on outdated data [12].

There is an urgent need to develop new, more comprehensive approaches to environmental safety assessment that would be able to integrate various environmental parameters and provide accurate data for decision making.

Existing studies on the impact of asphalt concrete production facilities on ecosystems often focus on direct effects [13, 14], such as soil and water pollution [15], habitat fragmentation and noise pollution [16–18]. However, the issue of taking into account long-term effects and an integrated approach to assessing interrelated ecological processes remains important, which requires the development of more complex models [19].

Numerous studies demonstrate that the integration of industrial ecology principles can significantly improve the effectiveness of managing environmental challenges, especially in port areas [20–23]. However, although these works have made significant contributions, they do not sufficiently take into account the complex interactions between different environmental parameters, which significantly limits their applicability in the broader context of industrial zones.

The paper pays special attention to the spatio-temporal dynamics of ecosystem changes in megacities, emphasizing the importance of using complex spatial models to accurately assess these processes [24, 25]. However, to gain a deeper understanding of ecological transitions, further research is needed to complement existing data.

A literature review has shown the significant impact of various industrial facilities on ecosystems, especially in the context of using complex models to predict environmental effects [26, 27]. In particular, the study demonstrated that traditional assessment methods do not always accurately account for the interaction of factors at the level of large industrial zones.

Research also shows that integrating ecosystem functions with business processes helps to more effectively manage environmental risks and reduce the negative impact of industrial facilities [28–30]. These studies highlight the need for joint use of environmental indicators to improve planning and monitoring of industrial zones.

In addition, emphasis is placed on the need to take into account complex ecosystem interactions, as well as the development of additional indicators and methods to improve the environmental sustainability of industrial facilities [31–33].

A number of studies have analyzed a wide range of approaches to managing industrial development [34–36] and its environmental impacts, highlighting the importance of integrating environmental and sustainability strategies into the planning and operation of industrial zones [37–41]. This confirms the need for long-term forecasting of environmental risks and highlights the importance of further research.

Several studies highlight the importance of developing new environmentally sustainable models to predict the impact of industrial facilities, including transport infrastructure, on natural resources [37, 40–45].

Further development of spatial analysis methods, as recent studies have shown, is necessary for more accurate forecasting of air and soil pollution [1, 45, 46]. The implementation of complex models such as MSPA has already confirmed their high efficiency in environmental risk management [47–48].

Thus, current research highlights the need to develop integrated approaches that can take into account spatiotemporal changes in ecosystems and predict long-term consequences of industrial impacts.

## 2. Materials and methods / Материалы и методы

Asphalt concrete plants are a significant source of anthropogenic impact on the ecosystems of industrial zones, caused by a number of specific factors characteristic of their technological processes.

The activities of asphalt concrete plants affect the surrounding areas through the pollution of soil, atmosphere and water resources. Soil pollution can occur as a result of emissions of pollutants into the atmosphere, as well as leaks and spills of raw materials used in production.

Additionally, asphalt plants can have an indirect impact on water resources. Pollution of water bodies can occur through the leaching of pollutants into groundwater, especially if runoff is not properly controlled. This poses a risk to the quality of surface and groundwater, which in turn can affect the state of ecosystems.

Thus, the impact of asphalt concrete plants on ecosystems must be assessed comprehensively, taking into account the impact on air, soil and water resources. The study uses environmental indicators such as the level of pollutant emissions, the level of soil pollution and the state of water resources in areas adjacent to the plants.

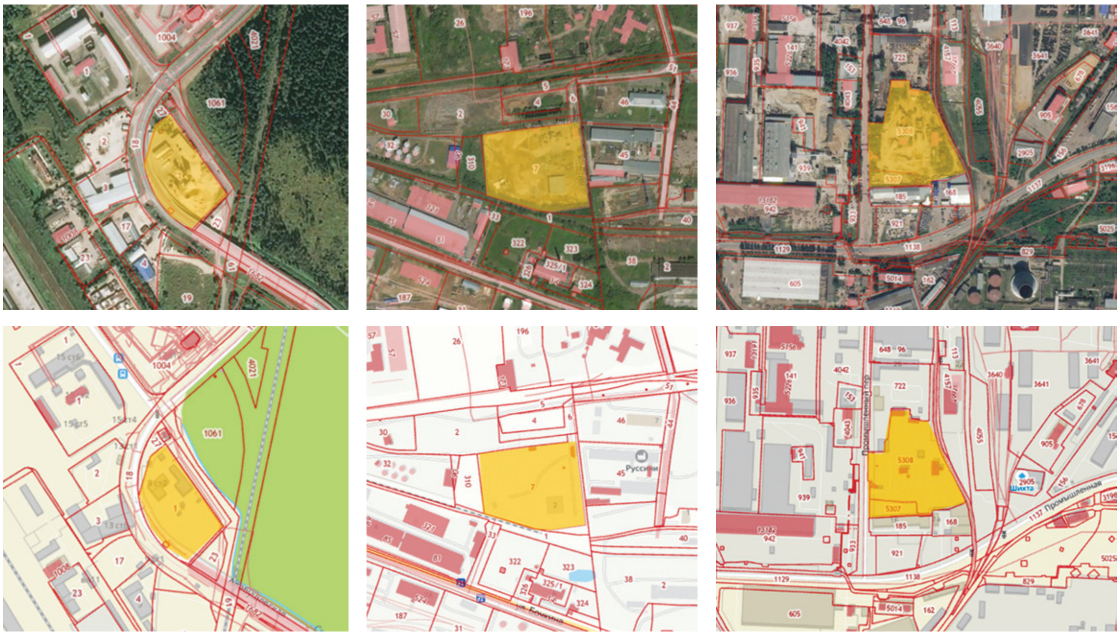
Three asphalt plants located in industrial zones were selected as objects of analysis. These enterprises were chosen due to their different production capacities and levels of gas-cleaning efficiency, which makes them representative for testing the methodology. Although the analysis was carried out on three specific plants, the developed methodology is universal and can be applied to other asphalt concrete plants or similar industrial facilities in different regions. Satellite data, cadastral survey data and laboratory analysis of air, soil and water samples were used to assess their environmental impact. The impact assessment was based on the following key indicators:

1. Atmospheric impact: measurement of pollutant emissions including $CO_2$, $NO_x$ and particulate matter.
2. Impact on soils: assessment of disturbance of natural soil layer.
3. Impact on water resources: assessment of potential level of hydrological sustainability.

To assess and visualize the location of the plants, satellite maps with the designation of the territory boundaries were used, presented in figure 1.

Based on satellite and cadastral map data, it was found that the facilities are located in different ecological zones, which allows to assess the differences in their environmental impact depending on their location.

Table 1 shows the main technical characteristics of the asphalt plants considered in this study. These data include productivity, efficiency of gas cleaning systems, height of smoke stacks, temperature of exhaust gases and power of burners.



Object 1 / Объект 1 Object 2 / Объект 2 Object 3 / Объект 3

*Fig. 1. Boundaries of asphalt concrete plant territories (fragments of satellite imagery and cadastral maps)*
*Рис. 1. Границы территорий асфальтобетонных заводов*
*(фрагменты спутниковых снимков и кадастровых карт)*

*Table 1. Technical characteristics of asphalt concrete plants*
*Таблица 1. Технические характеристики асфальтобетонных заводов*

| Technical specifications | Object 1 | Object 2 | Object 3 |
|---|---|---|---|
| Productivity, t/hour | 25 | 50 | 150 |
| Efficiency of gas cleaning devices, % | 82 | 75 | 99.93 |
| Pipe height, m | 18 | 18.5 | 18.9 |
| Exhaust gas temperature, °C | 75 | 75 | 60 |
| Burner power, MW | 3.3 | 5.5 | 9.6 |

The data obtained make it possible to identify areas of increased environmental risk near asphalt plants, and to establish that the level of impact depends on such parameters as production capacity and the efficiency of gas cleaning systems. In the future, this will allow for the development of more precise recommendations for reducing the negative impact on the environment, applicable to each specific facility.

To comprehensively assess the impact of road construction projects on industrial zone ecosystems, a research model was developed, presented in figure 2. This model structures the process of analyzing environmental impacts and defines the key parameters necessary for developing strategies to minimize negative environmental impacts.

The model includes three main components: emissions of pollutants into the atmosphere, impact on soil resources, and impact on water resources. These components are interrelated and form the structure of the analysis, which allows for a comprehensive assessment of the impact of road construction projects on ecosystems.

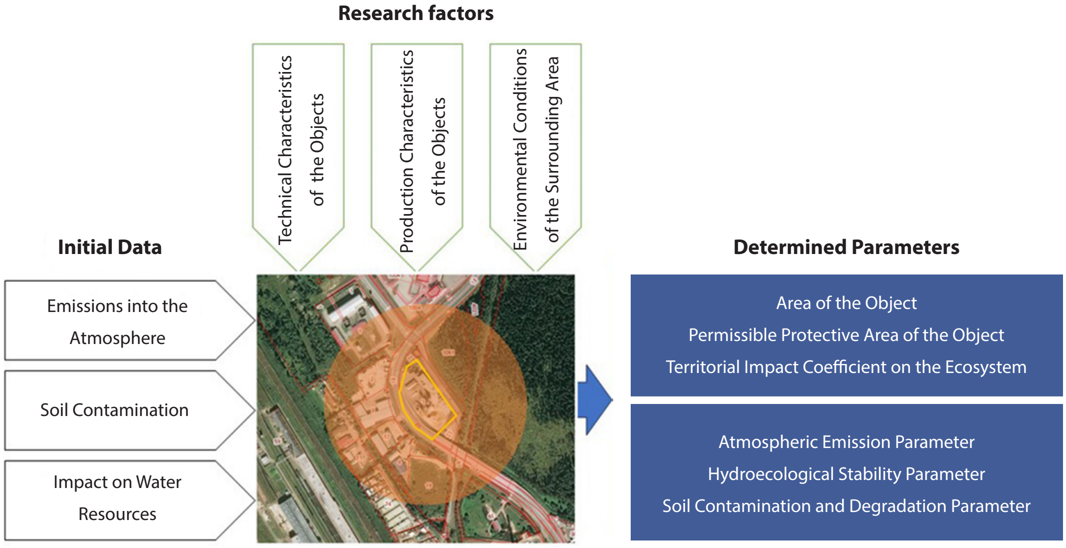



*Fig. 2. Key environmental impact factors and parameters for minimizing negative impact on industrial zone ecosystems (authors' scheme)*
*Рис. 2. Ключевые факторы воздействия на окружающую среду и параметры, минимизирующие негативное воздействие на экосистемы промышленных зон (схема авторов)*

Model study based on initial data on atmospheric emissions, soil and water conditions. The main initial data include atmospheric pollutant content ($CO_2$, $NO_x$, $SO_x$, particulate matter, hydrocarbons), soil disturbance levels and pollutant presence in water bodies.

This study identified key factors affecting the environmental conditions of industrial zones where asphalt plants operate. These factors cover a wide range of impacts, including emissions of pollutants into the atmosphere, soil pollution, and risks to water resources. A comprehensive analysis of these factors allows not only to assess the current state of the environment, but also to predict long-term environmental consequences.

1. *Impact on the atmosphere.* Atmospheric emissions are one of the most significant factors directly affecting air quality in industrial areas. During the production of asphalt, asphalt concrete plants emit significant amounts of nitrogen oxides ($NO_x$), sulfur oxides ($SO_x$), carbon dioxide ($CO_2$), particulate matter (PM) and hydrocarbons. The concentration of these pollutants in the air may exceed maximum permissible values, which leads to deterioration of public health, as well as degradation of plant communities and biota in general.
2. *Soil pollution.* Soil pollution is another critical factor, caused by both the deposition of pollutants from the atmosphere and leaks of raw materials and production waste. The accumulation of heavy metals and organic pollutants can change the physicochemical properties of soils, such as structure, acidity and organic matter content. These changes contribute to the degradation of the soil cover and can lead to a decrease in its fertility, which in the long term negatively affects the sustainability of ecosystems.
3. *Water resources.* Water resources are also at significant risk of contamination from asphalt plants. Groundwater contamination occurs through the leaching of pollutants into aquifers and surface water bodies. The lack of runoff control and filtration systems increases the risk of pollutants entering water bodies, posing a threat to ecosystems and water supplies.

Thus, a thorough analysis of the listed factors allows for a comprehensive understanding of the impact of asphalt plants on the environment. This, in turn, creates the basis for developing environmental risk management strategies. The use of complex analysis methods contributes to the accuracy of forecasting and allows for the formulation of well-founded recommendations for reducing the negative impact on industrial zone ecosystems.

In order to comprehensively assess the impact of road construction projects on industrial zone ecosystems, an original methodology based on a parametric criteria approach was developed and applied. This methodology allows for the integration of a wide range of environmental and technological parameters, which provides a more in-depth and objective analysis of the impact on the environment. The use of this approach helps to identify key risk factors, develop strategies to minimize negative impacts, and formulate well-founded recommendations to ensure sustainable development of industrial areas.

The proposed methodology includes several stages, starting with careful data collection and ending with the development of practical recommendations for environmental risk management. Each stage is included sequentially and interrelatedly, which allows for a systematic and holistic approach to assessing and managing the environmental impacts of road construction activities.

To assess the impact of asphalt concrete plants on industrial zone ecosystems, a multiparametric criteria method was developed, which includes the sequential implementation of five main stages, as shown in figure 3. This methodology provides a comprehensive analysis of environmental risks and allows for the formation of effective management strategies.

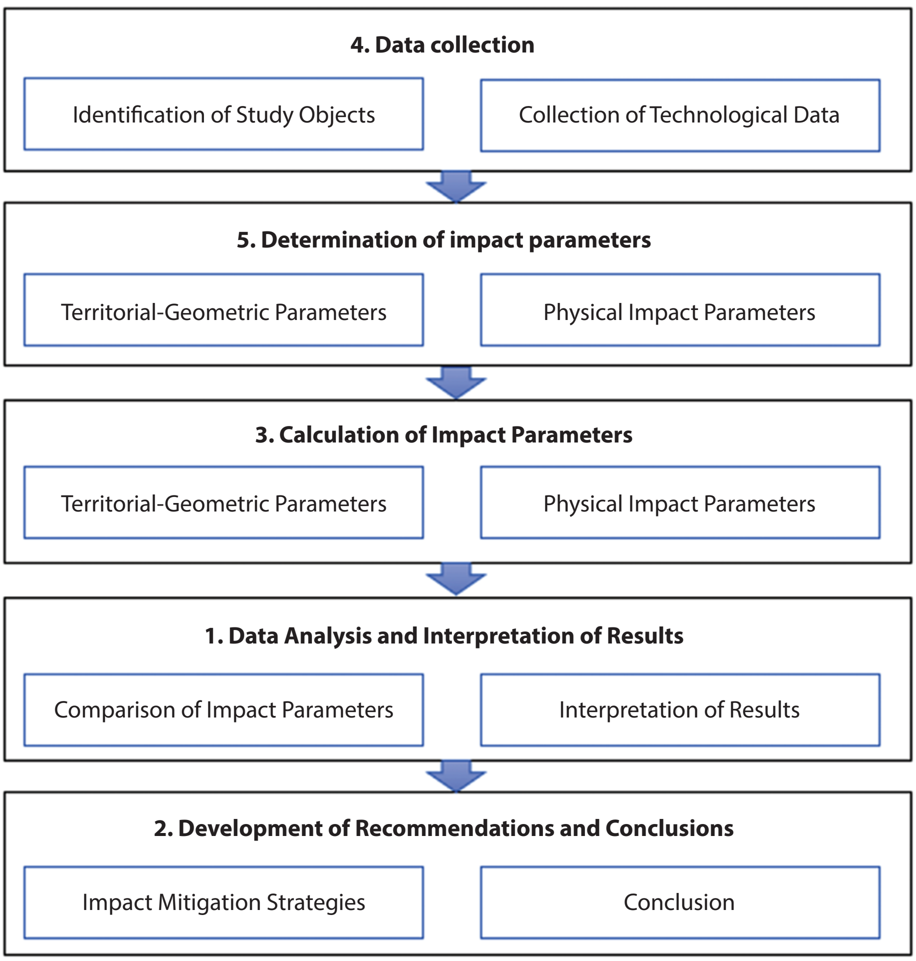



*Fig. 3. Criteria-based method assessing the environmental risks (scheme compiled by the authors)*
*Рис. 3. Критериальный метод оценки экологических рисков (схема составлена авторами)*

*Stage 1.* Data collection. The first stage involves collecting the necessary data on the technological parameters of the asphalt concrete plants, their production characteristics, and the physical and environmental conditions of the environment. This includes data on pollutant emissions, soil characteristics, and water resources. Information from the cadastral plan, environmental monitoring results, and satellite monitoring and geographic information systems (GIS) data are used.

*Stage 2.* Identification of impact factors and parameters. The second stage involves identifying key environmental factors and parameters that will be used to assess the environmental impact of the facilities. Territorial-geometric characteristics and physical impact parameters were selected as the main parameters. Each of these parameters is described in detail and classified by the degree of impact (high, medium, low), which allows for an assessment of the impact on ecosystems.

*Stage 3.* Calculation of impact parameters. The third stage involves calculating the quantitative values of each of the defined parameters using the developed formulas. For example, to calculate the atmospheric emission parameter, the total concentration of pollutant indicators is used, which is compared with the maximum permissible concentrations (MPC). Hydroecological stability and soil degradation parameters are also calculated, which allows us to determine the degree of impact on water and soil resources.

*Stage 4.* Data analysis and interpretation of results. The fourth stage involves analyzing the data obtained, including calculating and assessing the values of the impact parameters. Integration of the analysis results allows identifying the greatest environmental risks and defining critical areas requiring additional attention. Also at this stage, areas requiring special attention and possible intervention to minimize environmental damage are identified.

*Stage 5.* Development of recommendations and conclusions. The final stage is the development of recommendations for managing environmental risks and minimizing the impact of road construction projects on the environment. During the analysis, specific measures are formulated to reduce emissions, improve air and water purification methods, and optimize the use of natural resources. As a result, conditions are created for the sustainable development of industrial zones taking into account environmental safety.

When assessing the impact of asphalt concrete plants on industrial zone ecosystems, the key stage is to determine the parameters and criteria that will be used for quantitative analysis and modeling. The correct choice of these parameters and their interrelations allows not only to obtain accurate assessments of the environmental impact, but also to identify the main sources of environmental risk that require management decisions.

The proposed parametric criteria method is based on the selection of key parameters reflecting the territorial and geometric characteristics of objects, their physical impact on the environment, and the sustainability of ecosystems to anthropogenic impact. This approach takes into account the multiplicity of factors and interactions, which makes it possible to detail forecasts and develop effective strategies for managing environmental risks.

The proposed approach is based on dividing the parameters into two groups: territorial-geometric parameters and physical impact parameters. Both sets of parameters allow to assess the impact on various components of ecosystems and take into account the spatial and temporal aspects of the impact (table 2).

*Table 2. Sets of key parameters for assessing the environmental risks*
*Таблица 2. Ключевые параметры для оценки экологических рисков*

| Parameter group | Parameters |
|---|---|
| Territorial-geometric group | Object area |
| | Permissible protective area of the object |
| | Coefficient of territorial impact on the environment |
| Physical impact group | Atmospheric emission parameter |
| | Hydroecological stability parameter |
| | Soil contamination and degradation parameter |

Table 3 presents the key parameters of the parametric estimation method used in the study.

*Table 3. Criteria of the multiparametric evaluation method*
*Таблица 3. Параметры, используемые при критериальном методе оценки*

| Parameter | | Conventional designation | Unit of measurement | Environmental impact criteria | | |
|---|---|---|---|---|---|---|
| | | | | High | Medium | Low |
| **Territorial-geometric group** | | | | | | |
| 1 | Object area | $S_{ob}$ | thousand m$^2$ | ≥ 100 | 10–100 | < 10 |
| 2 | Permissible protective area of the object | $S_{pr}$ | thousand m$^2$ | ≥ 50 $S_{ob}$ | 10–50 $S_{ob}$ | < 10 $S_{ob}$ |
| 3 | Coefficient of territorial impact on the environment | $K_{ter}$ | – | ≥ 100 | 50–100 | < 10 |
| **Physical impact group** | | | | | | |
| 4 | Atmospheric emission parameter | AEP | – | ≥ 5.0 | 2.5–5.0 | < 2.5 |
| 5 | Hydroecological sustainability parameter | HSP | – | ≤ 0.6 | 0.6–0.8 | > 0.8 |
| 6 | Soil contamination and degradation parameter | SCP | – | > 0.7 | 0.3–0.7 | ≤ 0.3 |

These parameters allow to cover a wide range of environmental aspects related to the activities of road construction facilities (RCF) and provide an opportunity to more accurately assess the impact on the ecosystems of industrial zones. Such classification allows comprehensively assessing the impact of road construction facilities on various components of ecosystems and taking into account the spatial and temporal aspects of impact.

The study of the parameters and criteria determining the impact of asphalt concrete plants on ecosystems requires the use of an integrated approach that allows classifying and quantifying the environmental impacts associated with the operation and implementation of infrastructure projects. The application of the developed methodology makes it possible to comprehensively assess the anthropogenic impact on natural systems, including territorial-geometric changes, technological consequences, as well as physical and resource impacts. Each of these aspects is analyzed using specially developed quantitative indicators, which allows for objective and accurate results.

The use of these parameters and criteria helps to formulate well-founded strategic decisions aimed at minimizing environmental damage and optimizing the use of natural resources. This approach not only increases the level of environmental safety and reduces the risks of negative consequences for the environment, but also promotes the integration of sustainable development principles into the planning, design and operation of asphalt concrete plants.

1. *Object area*. The area of the object is determined by the cadastral boundaries of the territory of the object on which the assessment of the activities of the objects is carried out. The inclusion of this parameter allows taking into account the spatial aspects of the influence.
2. *Permissible protective area of the object*. The assessment of the area that should be protected within the sanitary and buffer zones allows for the consideration of high levels of anthropogenic impact and critical areas with increased risks to ecosystems.
3. *Coefficient of territorial impact on the environment.* It is a quantitative assessment that reflects the relationship between the area intended to minimize the impact on the natural environment and the area of the facility.
4. *Atmospheric emission parameter.* The parameter is a comprehensive assessment of the degree of impact of emissions on the territory of RCF for five indicator substances ($CO_2$; $NO_x$; $SO_x$; $PM_{10}$; hydrocarbons). This parameter is calculated using the formula:

$$AEP = \int_{i=5}^{5} \left( \frac{C_i}{MPC^i_{M.P.}} \right), \quad (1)$$

where $C_i$ – average concentration of the *i*-th pollutant;
$MPC_{M.P.}$ – maximum one-time maximum permissible concentration for the *i*-th pollutant in the work area.

5. *Hydroecological sustainability parameter.* Numerically reflects the level of ecosystem resistance to pollution and impact on surface soil layers. The formula used for calculation is:

$$HSP = \frac{1}{1 + 1.2\left(10K \cdot A\right)}, \quad (2)$$

where *K* is the soil filtration coefficient, which is measured in m/day and may vary depending on the type of soil;

*A* is the area of the territory under the influence of road construction facilities, measured in square kilometers.

6. *Soil contamination and degradation parameter.* The formula takes into account the ratio of the area of the disturbed layer to the total area of the site:

$$SCP = \frac{ADS}{S_{ob}} \cdot DSL, \quad (3)$$

where *SCP* – soil contamination and degradation parameter;
*ADS* – area of disturbed soil layer;
$S_{ob}$ – object area;
*DSL* – depth of soil and vegetation layer.

These indices provide a complete picture of the extent of soil and air pollution, as well as the potential for ecosystem restoration.

## 3. Results and discussion / Результаты и обсуждение

This section presents the results of the study obtained in the course of applying the parametric methodology developed for assessing the environmental impact of road construction facilities on industrial zone ecosystems. All results are presented in strict accordance with the stages set out in the methodology. This approach allowed not only to systematize the analysis process, but also to ensure a logical and consistent interpretation of the data, which is especially important for a comprehensive analysis of the impact on the environment.

*Step 1. Data Collection*

At the first stage, the necessary data on the technological parameters and characteristics of the asphalt concrete plants were collected. Table 4 presents the main characteristics of the three objects that were analyzed.

*Step 2. Determination of factors and parameters of influence*

At this stage, key factors and parameters of environmental impact were identified, including the area of the facility, the permissible protective area, the territorial impact coefficient and the parameters of physical impact, including the atmospheric emission parameter and the parameters of hydroecological stability and soil contamination.

*Step 3. Calculation of impact parameters*

At this stage, a quantitative calculation of the parameters of certain degrees of impact of road construction facilities on the environment was carried out. The calculation method and formulas used are described in detail in the previous sections. The main attention was paid to a comprehensive assessment of key parameters such as atmospheric emissions, hydroecological stability and the degree of soil degradation. The calculation results are presented in table 5.

*Table 4. Initial data for calculating impact parameters for environment*
*Таблица 4. Исходные данные для расчета параметров воздействия на окружающую среду*

| Parameter | Object 1 | Object 2 | Object 3 |
|---|---|---|---|
| Object area, thousand $m^2$ | 147 | 265 | 231 |
| Radius of protection zone, m | 500 | 500 | 500 |
| CO2 concentration, $mg/m^3$ | 15 | 10 | 8 |
| NOx concentration, $mg/m^3$ | 0.15 | 0.12 | 0.10 |
| SOx concentration, $mg/m^3$ | 0.10 | 0.08 | 0.06 |
| PM10 concentration, $mg/m^3$ | 0.05 | 0.04 | 0.03 |
| Hydrocarbon concentration, $mg/m^3$ | 0.03 | 0.02 | 0.015 |
| Soil type | Dusty sand | Clay | Sandy loam |
| Filtration coefficient, m/day | 14 | 10 | 12 |
| Area of disturbed layer, thousand $m^2$ | 13.25 | 12.50 | 11.80 |
| Depth of soil and vegetation layer, m | 0.2 | 0.2 | 0.2 |

*Table 5. Results of determining the evaluation parameters for asphalt concrete plants*
*Таблица 5. Значения параметров оценки асфальтобетонных заводов*

| Parameter | Object 1 | Object 2 | Object 3 |
|---|---|---|---|
| Object area, thousand $m^2$ | 14.7 | 26.5 | 23.1 |
| Permissible protective area of the object, thousand $m^2$ | 785 | 785 | 785 |
| Coefficient of territorial impact on the environment | 51.6 | 29.6 | 33.9 |
| Atmospheric emission parameter | 2.8 | 1.3 | 0.8 |
| Hydroecological sustainability parameter | 0.76 | 0.96 | 0.96 |
| Soil contamination and degradation parameter | 0.18 | 0.14 | 0.17 |

*Step 4. Data analysis and interpretation of results*

At the fourth stage, a comprehensive analysis of the obtained data and their interpretation was carried out in order to identify the degree of impact of the asphalt concrete plant on the environment. Using the calculation results, a comparative analysis of the calculated parameters with the limit values was carried out, which made it possible to determine the levels of environmental impact on the ecosystems of industrial zones.

The analysis included key parameters such as the territorial impact coefficient, atmospheric emission parameter, hydroecological stability and soil degradation. Each of these parameters was assessed according to the level of impact on ecosystems. Table 6 presents the final assessment for each of the parameters.

*Table 6. Analysis of parametric assessment by the level of negative impact for the objects under consideration*
*Таблица 6. Оценка параметров по уровню негативного воздействия для рассматриваемых объектов*

| Parameter | Object 1 | Object 2 | Object 3 |
|---|---|---|---|
| Object area, thousand $m^2$ | Low | Low | Low |
| Permissible protective area of the object, thousand $m^2$ | High | Medium | Medium |
| Coefficient of territorial impact on the environment | Medium | Low | Low |
| Atmospheric emission parameter | Medium | Low | Low |
| Hydroecological sustainability parameter | Medium | Low | Low |
| Soil contamination and degradation parameter | Low | Low | Low |

Based on the analysis of the environmental impact of the three asphalt plants, key differences and common trends were identified, which allow us to formulate the following conclusions:

1. Object 1 demonstrates a higher level of impact for a number of parameters, such as the permissible protective area, the territorial impact coefficient and the atmospheric emission parameter. This indicates the need for enhanced emission control and additional measures to reduce the negative impact on the environment.
2. Objects 2 and 3 show a lower level of impact, which indicates a more balanced interaction with the ecosystem. These sites are characterized by low values for most key parameters, which may indicate more efficient use of the territory and lower emissions.

Nevertheless, despite the low indicators, it is necessary to maintain a high level of environmental safety and conduct regular monitoring to prevent possible deterioration of the environmental situation.

*Step 5. Developing recommendations and conclusions*

Based on the analysis of the impact of road construction projects on industrial zone ecosystems, key environmental risks were identified and recommendations were proposed to minimize the negative impact on the environment. The main focus was on assessing the effectiveness of current environmental risk management strategies, as well as developing specific measures that can be implemented to improve the environmental situation at each facility. The study identified several critical aspects that require immediate corrective action, such as monitoring pollutant emissions, remediating soils, improving water management, and optimizing land use.

At the first stage of developing recommendations, the technological and organizational capabilities for each industrial zone were analyzed, including the specifics of their location, the capacity of asphalt plants, and the degree of impact on the environment. This made it possible to identify key risk areas and outline priority measures that can be implemented for each facility, taking into account its specifics.

One of the main areas is the modernization of treatment plants to reduce emissions into the atmosphere and minimize soil degradation. It is also important to introduce systems for continuous monitoring of the state of water resources, especially in areas with high levels of wastewater pollution. Effective use of buffer zones and recycling of industrial waste can also reduce the load on ecosystems, increasing their sustainability.

In addition, it is recommended to review approaches to the use of land in the industrial zone in order to optimize their distribution and reduce anthropogenic impact on the environment. This includes both improved zoning and the implementation of long-term plans for the reclamation of disturbed lands.

Moving on to specific recommendations for each of the objects under consideration, they are structured in accordance with the identified environmental risks and technological capabilities for their elimination. Table 7 presents key measures that can be implemented to reduce the negative impact on the environment and increase the sustainability of industrial zones.

*Table 7. Recommendations for the objects under consideration*
*Таблица 7. Рекомендации для рассматриваемых объектов*

| Recommendations | Object 1 | Object 2 | Object 3 |
|---|---|---|---|
| Equipment optimization | Modernization of gas cleaning plants | Upgrading to meet standards | Audit of technologies and implementation of alternative energy sources |
| Water resources monitoring | Implementation of water monitoring and purification systems | Continuation of monitoring programs | Expanding monitoring programs and control of effluents |
| Soil reclamation | Land reclamation and restoration of fertility | Monitoring and cleaning up contaminated soils | Minimizing soil contamination and buffer zones |
| Land use and zoning | Zoning and revision of land use | Developing long-term strategies | Developing long-term strategies taking into account environmental risks |

**4. Conclusions / Заключение**

The application of the multiparametric methodology allowed for a comprehensive assessment of the environmental impact of road construction projects and the identification of key environmental risks requiring immediate attention. This methodology has proven its effectiveness in analyzing various impact aspects, such as air emissions, soil degradation, and impact on water resources:

1. Confirmation of the significance of the developed methodology. The use of a multiparameter methodology for assessing the impact of road construction projects on ecosystems has proven to be highly effective. The use of this technique allowed for an accurate and objective integration of many factors, which made it possible to conduct a comprehensive assessment of the state of the environment and develop specific measures to minimize the negative impact.
2. Identification of critical parameters. The study confirmed that the main impact of asphalt concrete plants is manifested in such parameters as atmospheric emissions ($CO_2$, $NO_x$, $SO_x$) and soil degradation. This requires taking stricter measures to reduce emissions and improve the quality of the soil cover.
3. Recommendations for reducing the negative impact. As a result of the analysis, specific recommendations were developed to minimize environmental damage. These measures are aimed at modernizing equipment to improve emission purification, introducing water and soil resource monitoring systems, and improving the level of environmental safety.
4. Continuous monitoring and adjustment of standards. The data obtained confirm the need for regular monitoring of the environmental situation and adjustment of existing environmental standards for each facility. Constant monitoring of changes in conditions and factors of influence will allow us to adapt environmental protection measures and minimize environmental risks.

Thus, the implementation of recommendations developed on the basis of this methodology creates the basis for effective management of environmental risks at all stages of operation of road construction facilities.

Importantly, the proposed methodology represents a new approach to environmental impact assessment, as it complements the existing regulatory framework and provides an integrated multiparametric tool for identifying critical environmental risks. Its universality makes it suitable for application not only to asphalt plants but also to other industrial facilities with similar ecological profiles, and its use can improve the quality of decision-making in regional programs of ecological monitoring and sustainable industrial development.

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