RUDN Journal of Ecology and Life Safety
Вестник РУДН. Серия: Экология и безопасность жизнедеятельности
ISSN 2313-2310 (Print); ISSN 2408-8919 (Online)
2024 Vol. 32 No. 4 337–346
http://journals.rudn.ru/ecology

DOI: 10.22363/2313-2310-2024-32-4-337-346
EDN: MWYWHM
UDC 504.054

Research article / Научная статья

Assessment of the impact of motor transport on the ecological state of urbanized areas using the pollution index

Svetlana A. Novikova[1,2] ✉, **Sergey M. Ugay**[2]

[1] *Irkutsk State Transport University, Irkutsk, Russian Federation*
[2] *Siberian Federal Scientific Center for Agrobiotechnology of the Russian Academy of Sciences, Krasnoobsk, Russian Federation*
✉eco-science@mail.ru

Abstract. A new method for calculating the pollution index of urbanized areas from motor vehicles is proposed based on three parameters (air pollution, noise level, soil pollution) and the weights of each parameter in it are determined. A primary component-by-component assessment of all the indicators under consideration and subsequent calculation of the pollution index for the cities of the Irkutsk agglomeration are carried out. A scientifically based approach to the development of priority areas of environmental protection measures is proposed.

Keywords: automobile transport, urban areas, hierarchy process analysis, pollution index

Authors' contribution. *Novikova S.A.* – conceptualization of the study, development of methodological foundations for calculating the index of pollution of urbanized areas by motor vehicles, visualization and interpretation of the obtained results; *Ugai S.M.* – conceptualization of the study, critical analysis of the text.

Article history: received 23.02.2024; revised 21.05.2024; accepted 12.06.2024.

Conflicts of interest. The authors declare no conflicts of interest.

For citation: Novikova SA, Ugay SM. Assessment of the impact of motor transport on the ecological state of urbanized areas using the pollution index. *RUDN Journal of Ecology and Life Safety.* 2024;32(4):337–346. http://doi.org/10.22363/2313-2310-2024-32-4-337-346

Оценка влияния автомобильного транспорта на экологическое состояние урбанизированных территорий через индекс загрязнения

С.А. Новикова[1,2]✉, С.М. Угай[2]

[1]*Иркутский государственный университет путей сообщения, Иркутск, Российская Федерация*

[2]*Сибирский федеральный научный центр агробиотехнологий РАН, Краснообск, Российская Федерация*

✉eco-science@mail.ru

Аннотация. Предложен новый способ расчета индекса загрязнения урбанизированных территорий от автотранспортных средств на основе трех параметров (загрязнение атмосферного воздуха, уровень шума, загрязнение почвы) и определены веса каждого параметра в нем. Проведена первичная покомпонентная оценка всех рассматриваемых показателей и последующий расчет индекса загрязнения для городов Иркутской агломерации. Разработан научно обоснованный подход к разработке приоритетных направлений природоохранных мероприятий.

Ключевые слова: автомобильный транспорт, метод анализа иерархий, индекс загрязнения урбанизированных территорий

Вклад авторов. *Новикова С.А.* – концептуализация исследования, разработка методологических основ по расчету индекса загрязнения урбанизированных территорий автотранспортом, визуализация и интерпретация полученных результатов; *Угай С.М.* – концептуализация исследования, критический анализ текста.

История статьи: поступила в редакцию 23.02.2024; доработана после рецензирования 21.05.2024; принята к публикации 12.06.2024.

Заявление о конфликте интересов. Авторы заявляют об отсутствии конфликта интересов.

Для цитирования: *Новикова С.А., Угай С.М.* Оценка влияния автомобильного транспорта на экологическое состояние урбанизированных территорий через индекс загрязнения // Вестник Российского университета дружбы народов. Серия: Экология и безопасность жизнедеятельности. 2024. Т. 32. № 4. С. 337–346. http://doi.org/10.22363/2313-2310-2024-32-4-337-346

Introduction

Motor vehicle has a significant impact on the environment and, as a consequence, on the health of the population of urbanised areas [1]. Thus, high levels of noise and air pollution are created in residential areas, degradation of soils and vegetation of roadside strips occurs. In this regard, it is important to objectively assess the ecological state of the urban environment in terms of pollution from road transport.

Currently, there are indicators for assessing the state of individual environmental components, such as the air pollution index, total soil pollution index, noise pollution index, but there is no index that would combine these three indicators, although its existence would allow solving the following tasks: to assess the pollution of the territory by motor transport in an integrated manner and to develop priority directions of environmental protection measures based on the assessment of the most vulnerable components of the environment. The difficulty in developing such indices is the lack of the necessary data set to check the objectivity of priorities of some parameters over others.

Earlier attempts were made to calculate an integral ecological indicator of the state of urban environment. Thus, in [2] the pollution index was defined as the sum of ratios of the obtained results to the established maximum permissible concentrations (MPC) or background values of the studied environmental parameters: atmospheric air, soil and vegetation. It should be noted that in this approach quality standards are set only for a limited list of pollutants, and background values are not legislated.

Scientists [3] have proposed an index of technosphere compatibility that takes into account socio-economic indicators and allows the use of artificial neural networks for risk forecasting. The authors [4] developed a methodology for assessing the level of environmental safety of natural water from different water supply sources and ranked them based on the integral index of anthropogenic pollution.

All the scientific works described above do not solve the problems set earlier. The authors of this study consider the use of the analytical hierarchy process (AHP) (T.L. Saaty method) [5], which, despite the subjectivity of the approach, allows successfully to solve such problems. Thus, the use of AHP helped the author [6] to identify the location of zones of possible groundwater occurrence, which served as a prerequisite for the development of a set of measures for the rational use of water resources. Scientists [7] performed an analysis of the biopositivity of different types of road surfaces and made a choice in favour of asphalt concrete. In [8], using the T.L. Saaty method, priority scenarios for the development of emergency situations at the facilities of the fuel and energy complex were identified.

The authors [9] determined the indicators and evaluated the environmental component of locomotives using different energy sources, and identified the prospects for solving environmental problems in the process of designing and creating innovative locomotives. In the study [10], the most and least effective ways of waste utilisation were established according to the complex criteria of AHP, taking into account both economic and environmental components. Thus, the chosen method, has shown its validity in studies close to the subject of this article. The purpose of this study is to develop and validate the approach to assessing environmental pollution of urbanised territories by road transport.

Research methods

The development of an index of pollution of urbanised areas by motor vehicles included two main stages:

1) to determine priorities between indicators using the analytical hierarchy process;

2) to search for a mathematical solution allowing to objectively rank the combinations of adopted classes of atmospheric air pollution by emissions, noise level and soil pollution by increasing danger.

Analytical hierarchy process consists of decomposing the problem into simpler constituent parts and further processing the sequence of judgements by pairwise comparisons. This method allows to justify decision making in the presence of several criteria. It involves comparing each parameter with others and assigning a relative importance value. The decomposition principle involves structuring the problem in the form of a hierarchy. In order to prioritise the criteria and obtain scores for alternative solutions, the AHP constructs matrices of pairwise comparisons. For each matrix, a vector of local priorities is determined [5]. Analytical hierarchy process is based on the basic principles.

1. *Partitioning:* breaking down the problem into smaller, manageable components, which are then organised into a hierarchical structure, allowing the key elements of the problem and their relationships to be identified.

2. *Pairwise comparisons:* assessing the relative importance of each parameter by comparing them in pairs in a hierarchy at the same level.

3. *Hierarchical synthesis:* synthesising pairwise comparisons to obtain an overall ranking of parameter priorities at each level of the hierarchy.

4. *Consistency analysis:* assessing the mutual consistency of pairwise comparisons to ensure logical judgements using a consistency coefficient.

5. *Sensitivity analysis:* assessing the susceptibility of the results to changes in pairwise comparisons to identify the most critical parameters and reveal the stability of the solution.

Results and discussion

Based on the previously conducted long-term studies of the state of the environment [11–13] affected by motor vehicles, three main parameters were identified using the analytical hierarchy process: air pollution by emissions, noise level and soil pollution. To determine the weight of each parameter in the pollution of urbanised areas by motor vehicles, a pairwise comparison and priority matrix (Table 1) was drawn up on the basis of a scale of relative importance, in which each element reflects the ratio of the importance of one criterion with respect to the other. In this case, the element in the first row and second column is equal to two, which means that atmospheric pollution is considered twice as important as noise level and three times as important as soil pollution.

Table 1. **Pairwise comparison and priority matrix**

Parameter	Air pollution (AP)	Noise level (NL)	Soil pollution (SP)
Air pollution (AP)	1	2	3
Noise level (NL)	1/2	1	2
Soil pollution (SP)	1/3	1/2	1
Sum	1.83	3.5	6.0

Source: compiled by S.A. Novikova.

Emissions from road transport are emitted directly into the atmospheric air, directly affecting this component of the environment and, as a consequence, the health of people living in the pollution zone. Noise pollution ranks second in the rating of environmental problems (after air pollution) affecting the health of the population of urbanised areas[1]. Soil is an accumulator of harmful substances, including those coming from atmospheric air. The assessment of the danger of contaminated soil in settlements is determined by its role as a source of secondary pollution of the air basin[2].

Next, the priority matrix was calculated (see Table 1), where each matrix element is equal to the sum of row elements divided by the sum of column elements. Thus, the normalised matrix was obtained, which was used to calculate the weights of parameters (Table 2).

Table 2. **Normalized matrix**

Parameter	(a_1) Air pollution (AP)	(a_2) Noise level (NL)	(a_3) Soil pollution (SP)
(A_1) Air pollution (AP)	0.55	0.57	0.50
(A_2) Noise level (NL)	0.27	0.29	0.33
(A_3) Soil pollution (SP)	0.18	0.14	0.17

Source: compiled by S.A. Novikova.

The weights (w) of the parameters were calculated using the following formulas:

$$w_1 = \sqrt[3]{A_1a_1 \times A_1a_2 \times A_1a_3} \; ; \tag{1}$$

$$w_2 = \sqrt[3]{A_2a_1 \times A_2a_2 \times A_2a_3}; \tag{2}$$

$$w_2 = \sqrt[3]{A_3a_1 \times A_3a_2 \times A_3a_3}. \tag{3}$$

[1] Assessment of potential health benefits of noise abatement measures in the EU. *Phenomena project.* Available from: https://op.europa.eu/en/publication-detail/-/publication/f4cd7465-a95d-11eb-9585-01aa75ed71a1 (accessed: 25.10.2024).
[2] MU 2.1.7.730-99. Hygienic assessment of soil quality in populated areas.

1. Atmospheric Pollution (AP):

$$w_1 = w\text{AP} = \sqrt[3]{0.55 \times 0.57 \times 0.5} = 0.538 \sim 0.5.$$

2. Noise Level (NL):

$$w_2 = w\text{NL} = \sqrt[3]{0.27 \times 0.29 \times 0.33} = 0.296 \sim 0.3.$$

3. Soil contamination (SC):

$$w_3 = w\text{SC} = \sqrt[3]{0.18 \times 0.14 \times 0.17} = 0.163 \sim 0.2.$$

The weights of parameters are normalised so that their sum is equal to 1. Thus, the weights of parameters (w) correspond to: AP – 0.5, NL – 0.3, SC – 0.2. In fact, the criteria weights are equal to the arithmetic mean of the elements of each row of the normalised matrix. The arithmetic mean gives an idea of the importance of each criterion as a whole. According to the obtained criteria weights, atmospheric pollution has the highest contribution to the total pollution of urbanised areas (50%), followed by noise (30%) and soil pollution (20%).

Further in the work the degree of data consistency was determined. Consistency means that in the presence of the main (basic) array of raw data, all other data can be logically derived from them, i.e. the relations of the elements of the whole matrix should not be contradictory. The degree of consistency was determined by the formula:

$$\lambda_{\max} = 0.5 \times 1.83 + 0.2 \times 3.5 + 0.2 \times 6 = 3.16. \quad (4)$$

A consistency index (CI) was used to test the consistency of the judgement matrices:

$$\text{CI} = \lambda_{\max} - n/(n-1) \quad (5)$$

where $\lambda_{\max}$ is the maximum eigenvalue of the matrix, n is the number of parameters; (n – 1) is the number of all possible pairwise comparisons of a given element in a fixed row for an nth order square matrix.

Consequently, the CI has the meaning of the deviation from absolute consistency attributable to one pairwise comparison. A criterion called the consistency ratio (CR) is introduced:

$$\text{CR} = \text{CI}/\text{RCI}, \quad (6)$$

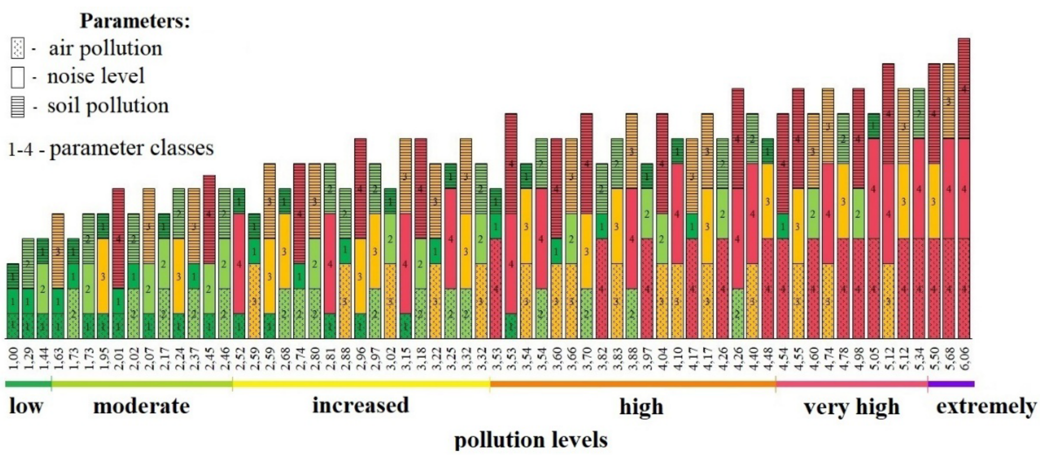
where RCI is the random consistency index. The RCI values in the AHP are pre-calculated. An acceptable CR value of no more than 20% is acceptable. Specifically, CI = (3.165 – 3) / (3 – 1) = 0.083, CR = 0.083/0.58 = 0.14 = 14%, hence the data is agreed.

As a basis for classification of the proposed complex pollution index the authors used gradations given in normative documents[3] for three indicators: air pollution, noise level, soil pollution, each of which can be characterised by four classes, which corresponds to 64 variants of combinations of these classes. We assume that the same order classes of different indicators are equivalent to each other. Consequently, we can calculate the index of pollution of urbanised territories by motor vehicles (IPUT_{MV}), which is equal to the sum of products of parameter weights (w) by the corresponding parameter values:

$$\text{IPUT}_{\text{MV}} = 0.5 \times (\text{AP})^{1,m} + 0.3 \times (\text{NL})^{1,m} + 0.2 \times (\text{SP})^{1,m} \quad , \qquad (7)$$

where 0.5, 0.3, 0.2 – mathematical weights of chemical pollution of atmosphere, noise level and chemical pollution of soil, respectively; AP, NL и SP – indexes of indicator classes in order; m = 0, if AP, NL, SP = 1; m = 3, if AP, NL, SP > 1.

Exponentiation to the degree of 1.3 allows to correct ranking of classes of the proposed pollution index taking into account combinations of parameter classes (atmospheric emissions, noise level, soil pollution) and their mathematical weights. Ranking the index values, we obtain a classification for assessing pollution of urbanised territories by motor vehicles (Figure).



Visualization of the classification of the complex index of pollution of urbanized areas by motor vehicles
Source: compiled by S.A. Novikova.

As a test of the proposed index based on the results of earlier studies [11–13], the authors carried out calculations for the cities of the Irkutsk

[3] See: Resolution of the Chief Sanitary Doctor of the Russian Federation No. 2 of 28.01.2021 'On Approval of Sanitary Rules and Norms SanPiN 1.2.3685-21 "Hygienic Norms and Requirements to Ensure Safety and (or) Harmlessness to Human Habitat Factors"; RD 52.04.667-2005. Guidance document. Documents on the state of atmospheric pollution in cities for informing state bodies, public and population. General requirements for development, construction, presentation and content.

agglomeration, which showed that the territory under consideration is characterised by a high level of pollution (Table 3). It should be noted that with the same qualitative indicators, the quantitative values of the index differ. Thus, in the cities of Irkutsk and Angarsk the values of $IPUT_{MV}$ are 3.54, which corresponds to the upper boundary of the proposed gradation (see Figure), while in Usolye-Sibirsk and Shelekhov $IPUT_{MV}$ are equal to 4.48, i.e. practically on the border with an extremely high level of pollution, which indicates the need for increased attention to the problem of urban pollution. Based on the ranking of parameters, the priority measures should be aimed at reducing emissions into the atmospheric air (AP = 4).

Table 3. **Index of pollution of urbanized areas by motor vehicles in the cities of the Irkutsk agglomeration**

Cities of the Irkutsk agglomeration	Air pollution	Noise level	Soil pollution	Index of urbanized areas pollution by motor vehicles	Pollution level
Irkutsk	3	3	1	3.54	High
Angarsk	3	3	1	3.54	High
Usolye-Sibirskoye	4	3	1	4.48	High
Shelekhov	4	3	1	4.48	High

Source: compiled by S.A. Novikova, S.M. Ugay.

Thus, the paper proposes a method of determining the index of pollution of urbanised areas by motor vehicles, which makes it possible to identify the level of technogenic load on the state of the environment, and the analytical hierarchy process provides a systematic approach in assessing complex environmental problems.

Conclusion

The interest in using the results of summary calculations for managing the quality of environmental components in cities of the Russian Federation is constantly growing. Moreover, one of the strategic objectives of the country's development is to radically reduce the level of atmospheric air pollution in large industrial centres[4].

The method described in this paper allows us to assess in a first approximation the overall pollution of urbanised areas based on three indicators:

1) air pollution;
2) noise level;
3) soil pollution.

[4] Decree of the President of the Russian Federation dated 07.05.2024 No. 309 'On the national development goals of the Russian Federation for the period up to 2030 and for the perspective up to 2036'.

In the presence of approbation, technically this approach allows to obtain the necessary information on the level of pollution of urbanised territories, is convenient and easy to use. The complex index can be considered universal, as it is based on generally accepted classifications of the indicators included in it and can potentially be applied in any locality subject to regulatory and legal acts[5].

References

[1] Novikova SA. The Impact of air pollution on the health of the population of the Baikal region. *National Priorities of Russia.* 2018;(3):65–71. (In Russ.)

[2] Sedykh VA, Kurolap SA, Mazurov GI, Kozlov AT, Zakusilov VP. Integral geoecological assessment of technogenic pollution of the urban environment of a large center of the metallurgical industry (on the example of Lipetsk). *Bulletin of the Dagestan State Pedagogical University. Natural and exact sciences*. 2023;17(2):84–93. (In Russ.). http://doi.org/10.31161/1995-0675-2023-17-2-84-93

[3] Ugai SM, Golokhvast KS, Mikhailova OG. *Environmental assessment of noise pollution in Primorsky Krai according to its residents*. Monograph. Vladivostok: Far Eastern Federal University; 2023:110 (In Russ.)

[4] Ignatiev YuA, Aleksandrova ML, Kulbitsky GN, Babaina EV. Integral index of technogenic pollution as a measure of environmental safety of products consumed by humans. *Medicine of extreme situations*. 2011;1:22–28. (In Russ.)

[5] Saati TL. Decision Making. The Analytic Hierarchy Process. Translated from English by Thomas L. Saaty. *The Analytic Hierarchy Process*. 1993:320. (In Russ.)

[6] Myslyva TN. Use of the analytic hierarchy process and assessment of multiple influence factors in predicting potential groundwater occurrence zones. *Melioration*. 2021;(3):50–66. (In Russ.)

[7] Shestakov NI, Titarenko BP. Comparison of the biopositivity of road pavement surfaces using the analytic hierarchy process. *Bulletin of the Volgograd State University of Architecture and Civil Engineering. Series: Construction and Architecture*. 2021;(3):25–34. (In Russ.)

[8] Kovalsky FS, Mosolov AS, Akinin NI. Analysis of the application of the shifted ideal and analytic hierarchy processes in categorizing a fuel and energy complex facility. *Occupational Safety in Industry*. 2021;(3):15–20. (In Russ.)

[9] Koroleva LA, Malygin IG. Using the method of hierarchy analysis for environmental assessment of locomotive traction on hydrogen fuel cells. *Transport: science, technology, management. Scientific information collection*. 2023;(7):18–26. (In Russ.)

[10] Kolibaba OB, Kozlova MV, Gariaev AB. Development of criteria for assessing the effectiveness of municipal solid waste management methods. *Bulletin of the Ivanovo State Power Engineering University*. 2024;(3):20–28. (In Russ.)

[5] See: Resolution of the Chief Sanitary Doctor of the Russian Federation No. 2 of 28.01.2021 'On Approval of Sanitary Rules and Norms SanPiN 1.2.3685-21 "Hygienic Norms and Requirements to Ensure Safety and (or) Harmlessness to Human Habitat Factors"; RD 52.04.667-2005. Guidance document. Documents on the state of atmospheric pollution in cities for informing state bodies, public and population. General requirements for development, construction, presentation and content.

[11] Novikova SA. Pollution of the atmosphere of large cities of the Irkutsk region by motor vehicle emissions. *Bulletin of Irkutsk State University. Series Earth Sciences*. 2015;11:64–82. (In Russ.)

[12] Novikova SA. Assessment of noise pollution in the city of Irkutsk by road transport. *Bulletin of the Russian Academy of Sciences. Geographical Series*. 2019;(5):111–120. (In Russ.). http://doi.org/10.31857/S2587-556620195111-120

[13] Novikova SA. Assessment of the impact of motor vehicle emissions on the geoecological state of soils and vegetation of the cities of the Irkutsk agglomeration. *Bulletin of Peoples' Friendship University of Russia. Series: Ecology and Life Safety*. 2023;31(4):533–543. (In Russ.). http://doi.org/10.22363/2313-2310-2023-31-4-000-0

Bio notes:

Svetlana A. Novikova, Senior Lecturer, Department of Technosphere Safety, Irkutsk State Transport University, 15 Chernyshevsky St, Irkutsk, 664074, Russian Federation; postgraduate student of the Siberian Federal Scientific Center of Agrobiotechnology of the Russian Academy of Sciences, 2b Centralnaya St, Novosibirsk Region, Krasnoobsk urban settlement, 630501, Russian Federation. ORCID: 0000-0003-2534-3379; SPIN-code: 8593-1545. E-mail: eco-science@mail.ru

Sergey M. Ugay, Doctor of Technical Sciences, Associate Professor, Head of the Special Experimental Design and Technology Bureau, Siberian Federal Scientific Center of Agrobiotechnology of the Russian Academy of Sciences, 2b Centralnaya St, Novosibirsk Region, Krasnoobsk urban settlement, 630501, Russian Federation. ORCID: 0000-0003-1615-5544; SPIN-code: 6524-6765. E-mail: usm64@mail.ru