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SPATIAL-DYNAMIC INTEGRATED ASSESSMENT OF WATER USE IN THE NORTHWESTERN FEDERAL DISTRICT REGIONS OF RUSSIA

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The growing problems of water resources scarcity in various countries and regions – resources essential for human livelihoods and economic activities – together with a high degree of their pollution, require the development of adequate assessment tools capable of characterizing the current situation both spatially and temporally, identifying trends, and enabling timely management decisions. In this regard, the aim of this study is to develop an integrated model for comprehensive spatialdynamic ecologicaleconomic assessment of natural resource utilization and to test it with the help of the case of water use in the regions of the Northwestern Federal District of Russia. These regions are characterized by developed and diversified industrial sector with a high ecological intensity of impact on natural water bodies. The objectives of the study included the following: the scientific literature review on water use assessment, the development of analytical ecologicaleconomic tools consistent with the stated aim, and their approbation. The scientific novelty of the research lies in the development of an integrated model for comprehensive spatialdynamic ecologicaleconomic assessment of natural resource use and its testing on the case of water resources use in the regions of the Northwestern Federal District. The research employed methods of analysis, synthesis, analytical groupings, absolute and relative values, chain substitutions, statistical data analysis, and graphical representation. The information base of the study comprised open data published on the website of the Federal State Statistics Service of the Russian Federation and the Ministry of Natural Resources and Ecology of the Russian Federation. The

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approbation results made it possible to characterize the type of ecologicaleconomic dynamics in conjunction with the type of decoupling, factor effects, and correlation relationships, as well as to identify the most priority (from the perspective of the severity of the current situation) and negative trends. The obtained results may be useful for public authorities in the development (updating) of projects and programs aimed at ensuring sustainable balanced development of the regions of the Russian NorthWest.

Water resources, environmental economics, balanced natural resource use, regional economics, sustainable development, spatial analysis, dynamic analysis, decoupling.

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Introduction

Water is a vital renewable natural resource whose quality and quantity shape both the quality of life and the development prospects of individual countries and their regions. Considerable attention is devoted to water issues in global[1] and national sustainable development agendas, including the green transition agenda of the Russian Federation[2]. At every level of governance, economic actors must be encouraged to use water resources responsibly, improve the efficiency of water use, reduce pollution of water bodies, and preserve the biodiversity of their ecosystems.

These and related issues have been widely studied. Specific water availability per territory has been examined by I.A. Shiklomanov and O.L. Markova (Shiklomanov, Markova, 1987), V.I. Danilov-Danilian and K.S. Losev (Danilov-Danilian, Losev, 2006), H. Ritchie and M. Roser (Ritchie, Roser, 2017), and others. Anthropogenic pressure on water bodies has received considerable attention in the work of I.D. Rybkina (Rybkina, 2023), V.F. Fomina (Fomina, 2023), and others. Scholars point to unsatisfactory water quality and the imbalance between per capita water availability and population density (Danilov-Danilian, Losev, 2006), highlight wasteful water use (Tretiakova, 2019; Huang et al., 2021; Li et al., 2022), and stress that the quality of aquatic ecosystems cannot be improved without reducing the discharge of polluted wastewater[3] (Tursunalieva, Toktosunova, 2022). The authors' contribution lies in developing a methodology for ecological and economic research on water use, constructing systems of analytical indicators, and providing scientific justification for the necessary management decisions.

Notably, the urgency of these problems has not diminished over time. It was high in the 1990s and remains just as acute in present-day Russia, despite newly developed

[1] Transforming our world: The 2030 Agenda for Sustainable Development. United Nations General Assembly Resolution 70/1 of September 25, 2015. Available at: https://unctad.org/system/files/official-document/ares70d1_ru.pdf (accessed: 30.03.2026).

[2] Goals and main directions of sustainable (including green) development of the Russian Federation: Decree of the Government of the Russian Federation No. 1912-r dated July 14, 2021. Available at: http://government.ru/docs/all/135692/ (accessed: 30.03.2026).

[3] Ryumina E.V. (1990). Modeling the interrelationships between the development of the national economy and environmental protection: Doctor of Sciences (Economics) dissertation abstract. Moscow. 36 p.

technologies and the capacity to deploy them on a broad scale. The shortcomings in the adoption of best available techniques (BATs) have been examined in many studies. Available findings indicate that the practical use of BATs substantially reduces the discharge of pollutants and lowers concentrations of key contaminants in water bodies, thereby promoting more sustainable water use in the regions (Adam et al., 2023). At the same time, it is important to emphasize that the piecemeal introduction of BATs in water treatment, water supply, water purification, and wastewater disposal is a necessary but insufficient condition. Only their large-scale deployment can fundamentally change the situation for the better. One obstacle to the widespread adoption of BATs is the low economic efficiency and long payback periods of the associated projects. Researchers note that the methodology for assessing efficiency in the field of water use requires updating. They also recommend developing a system of sound calculations of the cost per unit of negative impact on water bodies and of water abstraction, so as to make the introduction of such technologies economically worthwhile (Kasimova et al., 2015).

In their studies, the authors employ both absolute indicators of environmental pressure (the volume of water withdrawn from surface and underground sources and the volume of polluted wastewater discharged) and relative indicators that capture the intensity of anthropogenic impact (the ratio of environmental pressure to the economic result of economic activity) (Semyachkov, 2022; Gorbatenko, 2023; Rybkina et al., 2023). These indicators are further divided into resource-intensity measures – the water intensity of the economy as a whole or of individual economic activities – and pollution-intensity measures – the discharge of pollutants into surface water bodies per 1,000 rubles of gross output (Gorbatenko, 2023; Rybkina, 2023; Fomina, 2023; Popova, 2023).

The spatial distribution of the indicators under study is generally presented using cartographic methods, tables, or various types of diagrams. The degree of spatial heterogeneity is most often assessed using the coefficient of variation. R. Chen and colleagues use the Gini coefficient in their work (Chen et al., 2023). Changes in the indicators over time are examined by calculating rate-of-change measures (coefficients and rates of change, growth/decline in values). Many studies apply these tools in combination (Dzhamalov et al., 2022; Popova, 2023; Zhang, 2025; Nasyrov et al., 2026).

When econometric methods are used, researchers construct time-series models or panel-data models. It should be noted, however, that these are not always stationary, which limits their applicability. Owing to the wide dispersion of values, the models may not satisfy the quality requirements of various statistical tests, another important condition for their use. Such limitations encourage researchers to seek new methods and models and to build new indicator systems.

The number of publications on the rational use of resources, including water resources, shows no sign of declining. A large body of scholarly work now exists proposing various methods and tools for assessing the rationality, balance, and efficiency of natural resource use. These studies make a significant contribution to the study of existing problems. Their sheer number and diversity of focus point to the urgent need to improve assessment tools toward comprehensive, multidimensional diagnostics capable of characterizing the current situation in both spatial and temporal dimensions, identifying trends, and enabling timely management decisions. Accordingly, the aim of this study is to develop an integrated model for the comprehensive spatial-dynamic ecological and economic assessment of natural resource use and to test it on the example of water use in the regions of the Northwestern Federal District of Russia, which are characterized by a developed and differentiated industrial base with a high environmental intensity of impact on natural water bodies. The research objectives are: to review the scientific literature on water-use assessment, to construct an analytical ecological-economic toolkit that meets the stated aim, and to test it.

The calculations cover the period 2015–2024. The sample includes all 11 regions that make up the Northwestern Federal District. For each indicator analyzed, the number of observations is 110, and the total number of observations across all indicators is 630. Correlation coefficients were calculated at a significance level of 0.05; only statistically significant results are reported. The scientific novelty lies in integrating several currently sought-after methodological tools into a single research framework, substantially enhancing their combined analytical potential. The practical significance consists in providing decision-makers with essential information on a number of critical aspects in an integrated form.

Materials and methods

The information base for the study was drawn from open data published on the websites of the Federal State Statistics Service of the Russian Federation and the Ministry of Natural Resources and Environment of the Russian Federation.

The study employs methods of analysis and synthesis, analytical groupings, absolute and relative values, chain substitutions, statistical data analysis, and graphical presentation.

An integrated model for the comprehensive spatial-dynamic ecological and economic assessment of natural resource use *(Fig. 1)* was constructed on the principle of complementarity among the existing methods and analytical tools in this field. Since most authors in ecological-economic research rely on the values of economic result (ER), environmental pressure (EP), and environmental intensity (EI)[4], the first step in the analytical procedure must be to compile the corresponding database.

Presenting these data in the form of diagrams, graphs, maps, and schematic maps makes it possible to visualize their spatial distribution across Russian regions or countries of the world.

The degree of spatial differentiation of an indicator can be determined using the coefficient of variation:

$$K_v = \frac{\sigma}{\bar{x}} \cdot 100, \qquad (1)$$

where K_v is the coefficient of variation;
σ is the standard deviation of the indicator;
$\bar{x}$ is the mean value of the indicator.

A coefficient of variation of up to 10% indicates relative homogeneity of the set of

[4] EI is determined by dividing the EP indicator by the ER indicator and characterizes either resource intensity (the amount of resource per unit of economic result) or the intensity of anthropogenic pollution (the volume of pollution per unit of economic result).

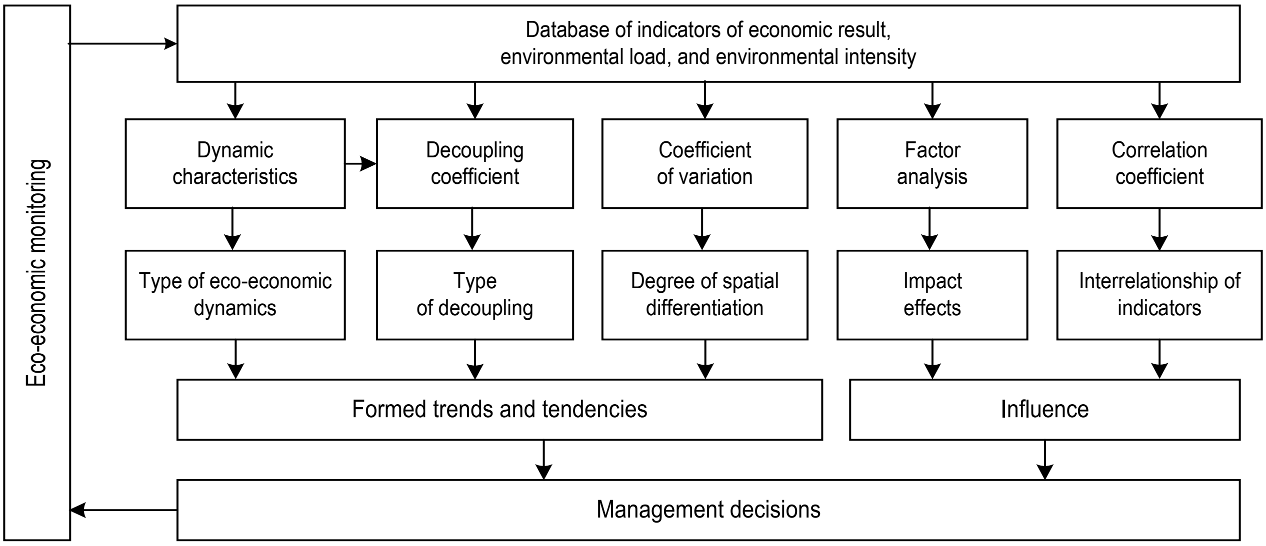


Figure 1. Integrated model for the comprehensive spatial-dynamic ecological and economic assessment of natural resource use
Source: own compilation.

objects under study; 10–33% indicates relative differentiation; and more than 33% indicates pronounced differentiation[5].

The scale of changes in indicator values over time is assessed by researchers using such dynamic characteristics as the rate of increase (decrease):

$$T_{inc(dec)} = \frac{x_i}{x_b} \cdot 100 - 100, \qquad (2)$$

where $T_{inc(dec)}$ is the rate of increase (decrease) of the indicator;

x_i is the value of the indicator in the current period;

x_b is the value of the indicator in the base period.

When $T_{inc(dec)} < 0$, the indicator declined over the period under analysis; when $T_{inc(dec)} > 0$, it increased.

The use of these dynamic characteristics makes it possible to determine the type of ecological-economic dynamics, the essence of which is discussed in detail in the literature (Victor, 2015; Shang et al., 2015; Glazyrina et al., 2015) and summarized in *Table 1*.

Table 1. Determining the type of ecological-economic dynamics

Type of dynamics	ER	EP	EI
Black growth	$T_{inc(dec)} \geq 0$	$T_{inc(dec)} \geq 0$	$T_{inc(dec)} \geq 0$
Brown growth	$T_{inc(dec)} \geq 0$	$T_{inc(dec)} \geq 0$	$T_{inc(dec)} \leq 0$
Green growth	$T_{inc(dec)} \geq 0$	$T_{inc(dec)} \leq 0$	$T_{inc(dec)} \leq 0$
Black decline	$T_{inc(dec)} \leq 0$	$T_{inc(dec)} \geq 0$	$T_{inc(dec)} \geq 0$
Green decline	$T_{inc(dec)} \leq 0$	$T_{inc(dec)} \leq 0$	$T_{inc(dec)} \geq 0$
Absolutely green decline	$T_{inc(dec)} \leq 0$	$T_{inc(dec)} \leq 0$	$T_{inc(dec)} \leq 0$
Source: compiled from (Victor, 2015; Shang et al., 2015; Glazyrina et al., 2015).			

[5] Polyakova V.V., Shabrova N.V. (2015). Fundamentals of the Theory of Statistics: A Textbook. Yekaterinburg: Ural University Press. P. 58.

Dynamic characteristics can also be used to calculate the decoupling elasticity coefficient (Kong et al., 2021; Kutyshkin, Shulgin, 2024; Tapio, 2005):

$$K_e = \frac{T_{inc(dec)}^{EP}}{T_{inc(dec)}^{ER}}, \quad (3)$$

where K_e is the decoupling elasticity coefficient;

$T_{inc(dec)}^{EP}$ is the rate of increase (decrease) of environmental pressure;

$T_{inc(dec)}^{ER}$ is the rate of increase (decrease) of economic result.

The value of the decoupling elasticity coefficient, together with the dynamic characteristics of economic result and environmental pressure, makes it possible to determine the type of decoupling *(Tab. 2)*.

The spatial heterogeneity of economic result, environmental pressure, and the intensity of economic activity, combined with the type of ecological-economic dynamics and the type of decoupling, yields a large volume of information. This information can be used to identify priority territories (regions, municipalities) based on the severity of the current situation and the nature of its dynamics – an important consideration for management decisions. It is equally important, however, to identify the factors behind this dynamics and the observed trends. To enhance the informative value of the analytical toolkit, therefore, factor and correlation analyses should be incorporated into the model.

Among the many factor models used in ecological-economic research, the IPAT model has become widespread. It holds that the scale of anthropogenic impact (*I, impact*), or environmental pressure (EP), depends on three factors: *population* (*P*), *affluence* (*A*), and *technology* (*T*): $I = P \cdot A \cdot T$ (Shkiperova et al., 2015; Tretiakova, 2019; Kong et al., 2021).

In the context of this study, the model can be written as:

$$EP = Pop \cdot Aff \cdot EI, \quad (4)$$

where EP is environmental pressure;

Pop is population;

Aff is affluence (gross product per capita);

EI is environmental intensity, characterizing the technologies in use.

The change in environmental pressure under the influence of these factors can be assessed using the method of chain substitutions. This makes it possible to quantify the contribution of each component through three effects: a population effect (change in population size), an income effect (generated within the economic system), and

Table 2. Determining the type of decoupling

Type of decoupling	ER	EP	K_e
Strong decoupling	$T_{inc(dec)} > 0$	$T_{inc(dec)} < 0$	$K_e < 0$
Weak decoupling	$T_{inc(dec)} > 0$	$T_{inc(dec)} > 0$	$K_e < 0.8$
Expansive negative decoupling	$T_{inc(dec)} > 0$	$T_{inc(dec)} > 0$	$K_e > 1.2$
Strong negative decoupling	$T_{inc(dec)} < 0$	$T_{inc(dec)} > 0$	$K_e < 0$
Weak negative decoupling	$T_{inc(dec)} < 0$	$T_{inc(dec)} < 0$	$K_e < 0.8$
Recessive decoupling	$T_{inc(dec)} < 0$	$T_{inc(dec)} < 0$	$K_e > 1.2$
Expansive coupling	$T_{inc(dec)} > 0$	$T_{inc(dec)} > 0$	$0.8 < K_e < 1.2$
Recessive coupling	$T_{inc(dec)} < 0$	$T_{inc(dec)} < 0$	$0.8 < K_e < 1.2$
Source: compiled from (Zabelina, 2019; Glazyrina, 2020; Zabelina, 2023; Kutyshkin, Shulgin, 2024; Allocca et al., 2025)			

a technological effect (change in eco-intensity as a result of technological modernization).

In the correlation analysis of ecological-economic studies, researchers most often calculate Pearson correlation coefficients (when indicators are normally distributed) and Spearman coefficients (when distributions deviate from normality). These values indicate the strength of association between the indicators under study.

The synthesis of the information obtained makes it possible to draw conclusions about the type of ecological-economic dynamics and the type of decoupling, the emerging trends of change, and the factors behind them. This, in turn, provides a reasoned basis for choosing instruments of targeted management intervention and subsequently monitoring their results. The proposed model can be used for spatial ranking of regions and for substantiating differentiated management decisions.

Results and discussion

In 2024, the volume of river runoff resources in the Northwestern Federal District amounted to 580.9 km^3/year, which is 2.0% above the long-term average (569.6 km^3/year) and 3.0% above the previous year[6]. The largest volume was recorded in the Arkhangelsk Region (353.7 km^3/year), the smallest in the Pskov Region (13.2 km^3/year).

The regions of the Northwestern Federal District are sufficiently endowed with water resources *(Fig. 2a)*. In terms of per capita water availability *(Fig. 2b)*, the Kaliningrad Region falls into the category of territories with high water availability, while the remaining regions have very high availability (Shiklomanov, Markova, 1987). The northern regions – Arkhangelsk Region, Nenets Autonomous Area, and the Komi Republic – are best supplied with water resources *(Fig. 2)*. Together with Murmansk Region, they show a slight decline in both total and per capita values.

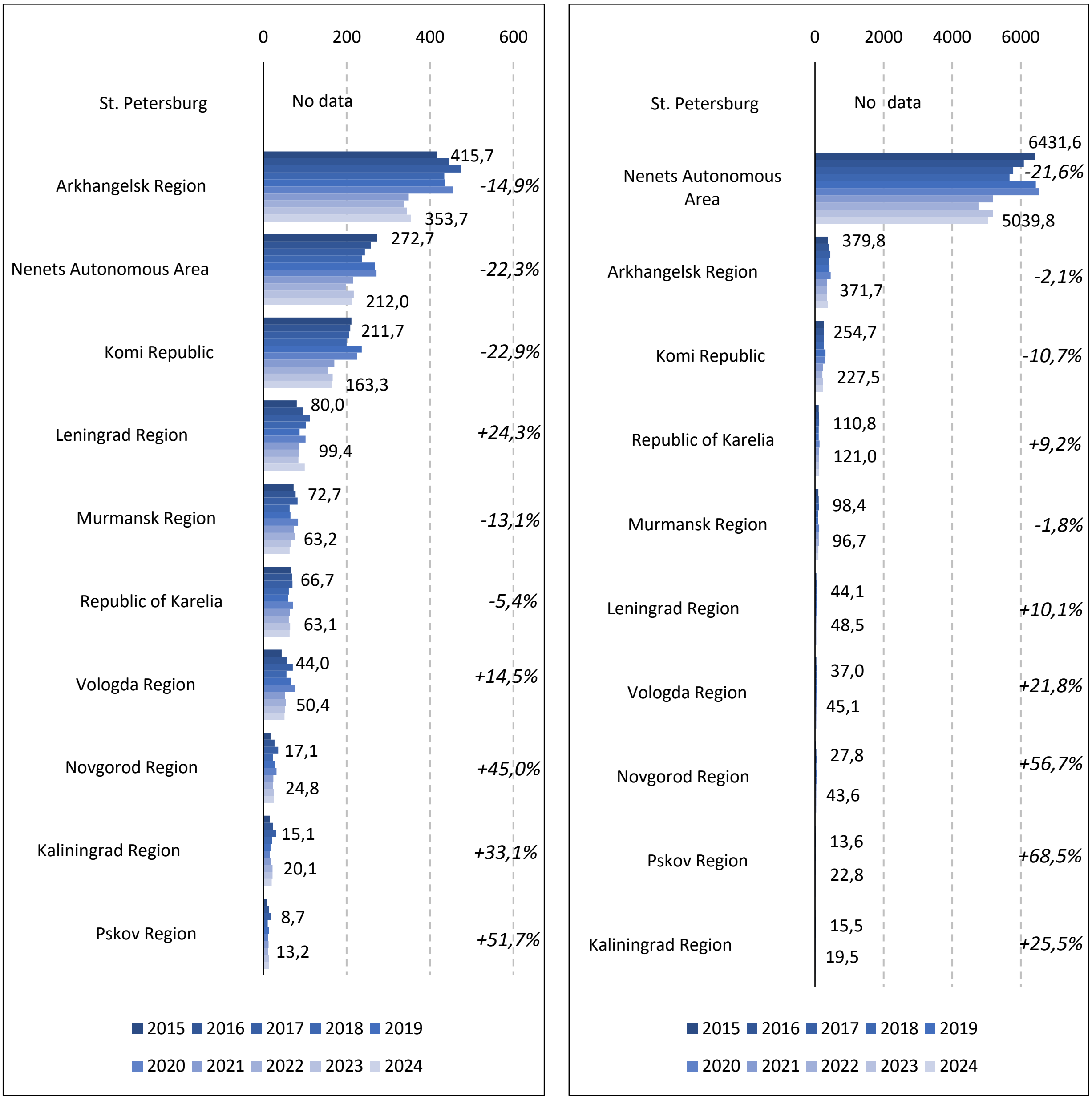
The model for assessing the type of ecological-economic dynamics is based on economic result and environmental pressure. The former was represented by gross regional product (GRP). To eliminate the distorting influence of inflation, values were converted from current to constant (2015) prices.

As shown in *Figure 3a*, most regions of the district experienced economic growth over the period analyzed. The most notable growth was in the Leningrad Region (+44.7%), St. Petersburg (+32.2%), and the Kaliningrad Region (+23.9%). A decline was observed in the Komi Republic (-7.6%) and the Nenets Autonomous Area (-2.0%), where extractive industries, which are under enormous external economic pressure, predominate.

The study found that the gross product produced is positively associated with water availability: the correlation coefficient was 0.35. When St. Petersburg, the Leningrad Region, and the Murmansk Region (which differ markedly from other regions in their indicators) are excluded from the sample, the coefficient increased to 0.66, indicating a significant role of water resources in the regional economy.

St. Petersburg, the Leningrad Region, and the Vologda Region make the largest contribution to the district's gross product. In per capita terms, however, the Nenets Autonomous Area is the leader *(Fig. 3b)* and is the only region with negative dynamics. In the Komi Republic, per capita gross product is rising due to the faster rate of population decline against the backdrop of falling total gross product.

[6] On the state and protection of the environment of the Russian Federation in 2024. State report. Moscow: Ministry of Natural Resources of Russia; All-Russian Research Institute of Ecology. 721 p.

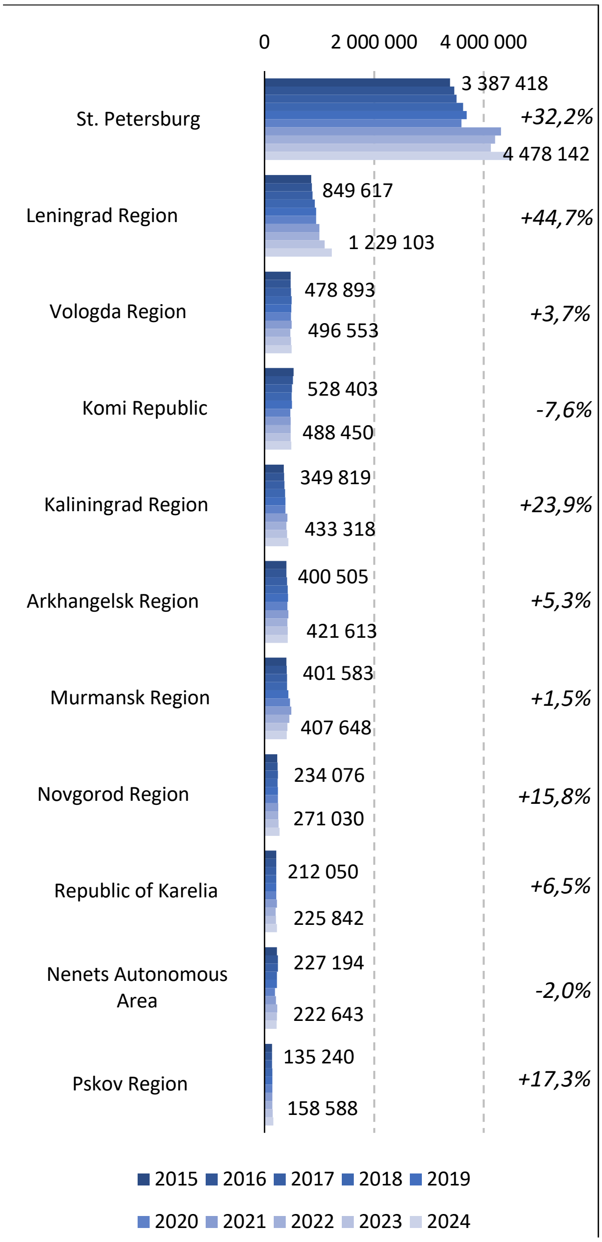


a) total, km³/year b) per capita, thousand m³

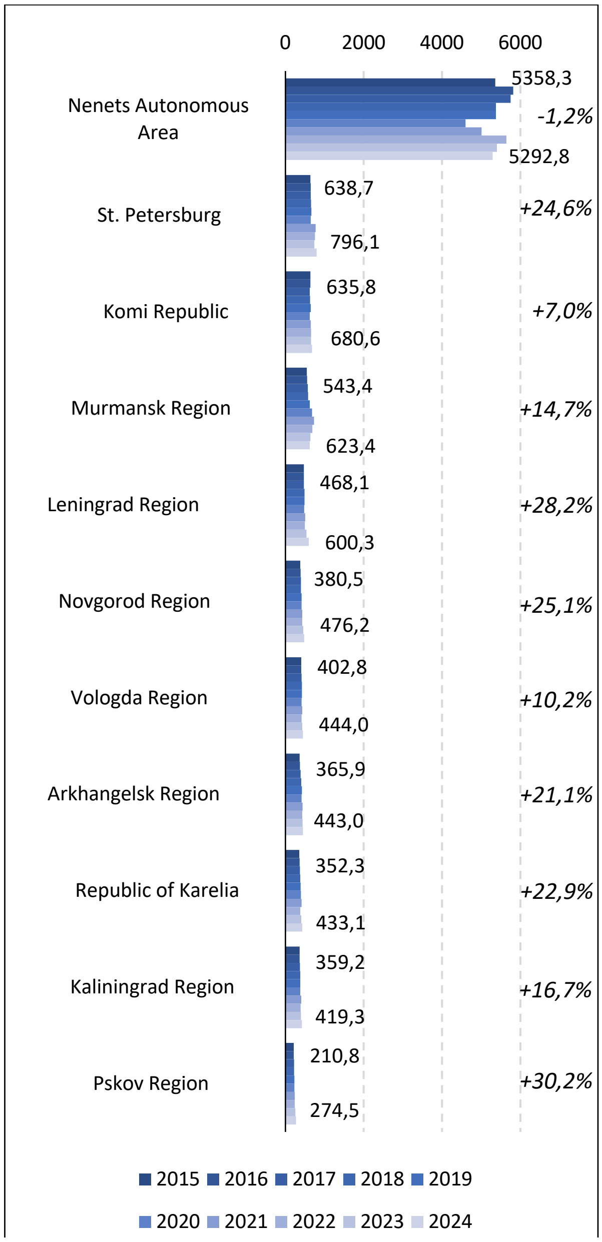
Figure 2. River runoff resources

Note: rates of decrease are shown in italics.
Source: On the State and Protection of the Environment of the Russian Federation in 2024. State Report. Moscow: Ministry of Natural Resources of Russia; All-Russian Research Institute of Ecology. 721 p.

Source: own calculation.



a) total, million rubles



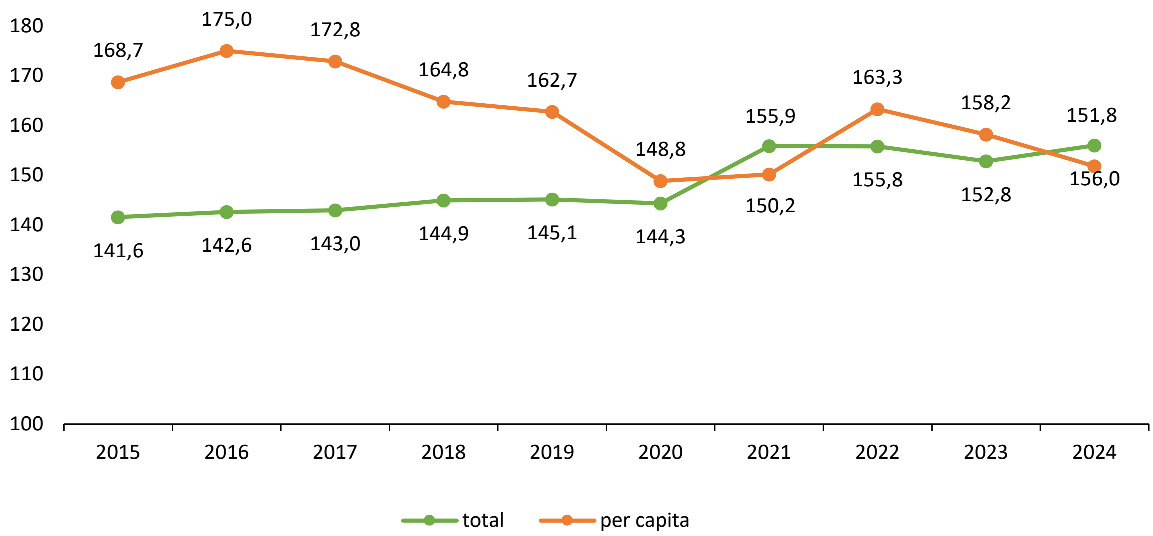
b) per capita, thousand rubles

Figure 3. Gross regional product at 2015 prices

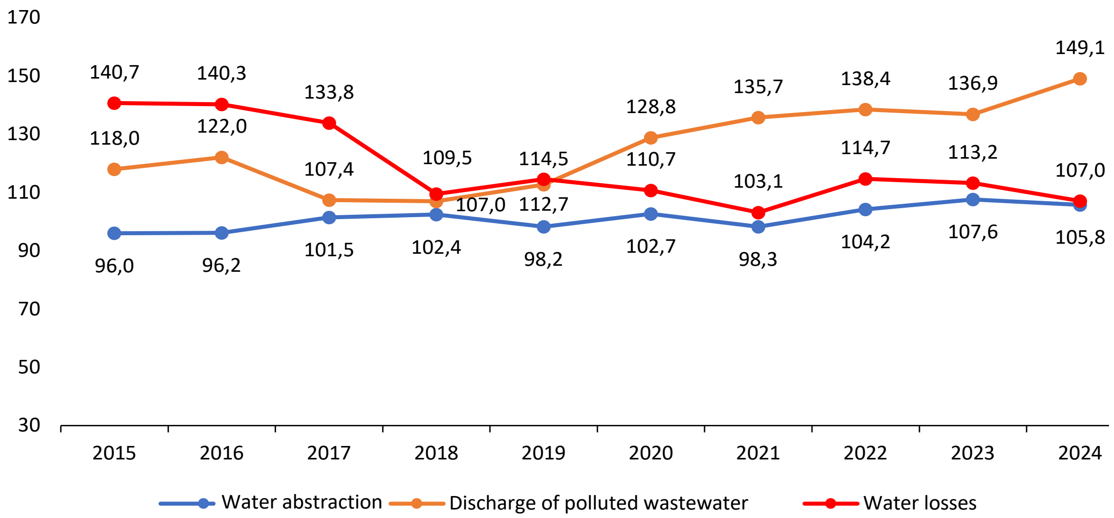
Source: own calculation based on Rosstat data. Available at: https://rosstat.gov.ru/statistics/accounts.

In terms of gross regional product, the regions of the Northwestern Federal District are highly differentiated *(Fig. 4a)*, and the level of differentiation has increased in the post-pandemic period. The difference in per capita gross product, by contrast, was greater in the pre-pandemic period.

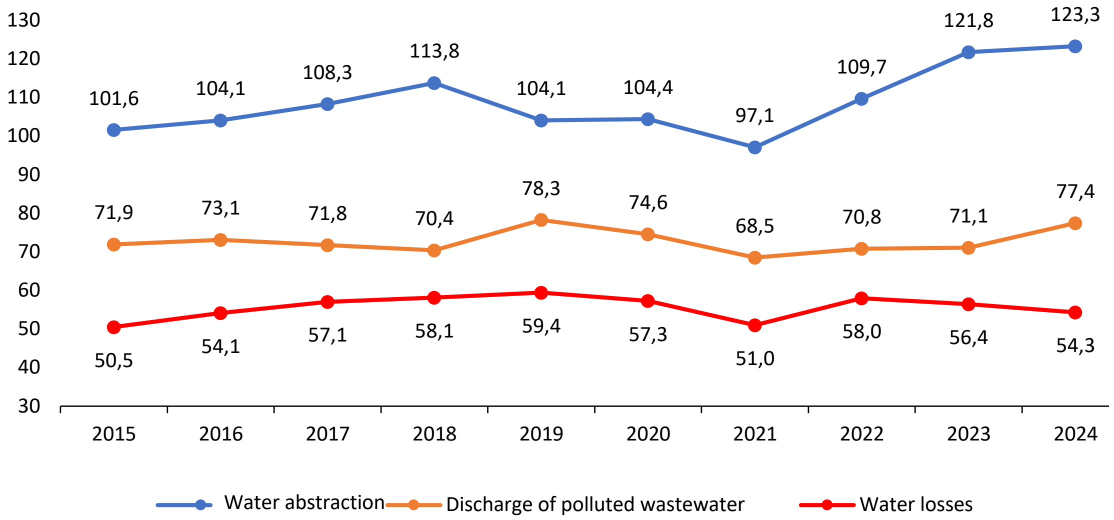
Water abstraction volumes and gross product are positively related: the correlation coefficient was 0.38 (after excluding St. Petersburg, the Murmansk Region, and the Nenets Autonomous Area from the sample). The low value may point to the presence of a decoupling effect in some regions. Water abstraction volumes are also characterized by a high degree of differentiation *(Fig. 4b)*, although it is lower than that of polluted wastewater discharge and water losses.



a) gross regional product



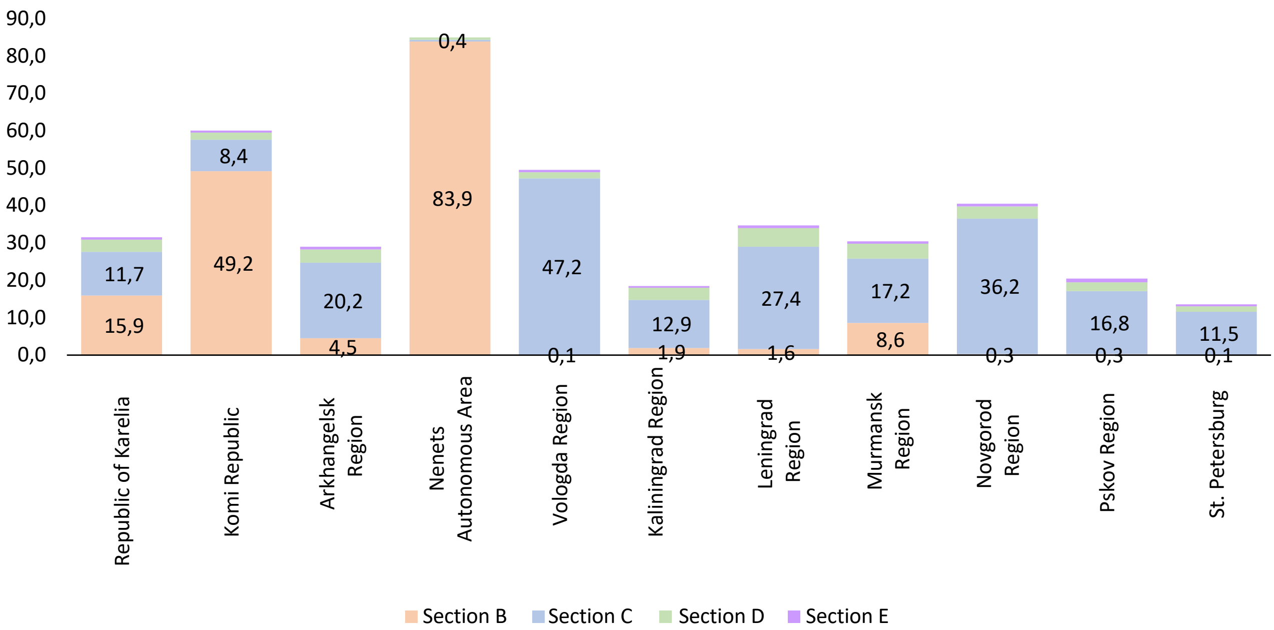
b) environmental pressure



c) environmental intensity

Figure 4. Coefficient of variation, %

Source: own calculation.



Section B – mining and quarrying; Section C – manufacturing;
Section D – electricity, gas, steam, and air conditioning supply;
Section E – water supply; sewerage, waste management, and remediation activities.

Figure 5. Share of industrial economic activities in the gross regional product structure of the Northwestern Federal District regions in 2024, %

Source: own calculation based on Rosstat data. Available at: https://rosstat.gov.ru/statistics/accounts.

Figure 5 shows substantial differences in the contribution of industrial production to gross regional product across the regions of the Northwestern Federal District.

The economic decline in the Komi Republic was accompanied by a reduction in water abstraction from natural water bodies (-3.4%), whereas the Nenets Autonomous Area, by contrast, saw an increase (+76.3%). *Figure 6a* shows that, over the period analyzed, water abstraction increased in six regions of the district and decreased in five. The leaders in this indicator are the Murmansk Region and St. Petersburg.

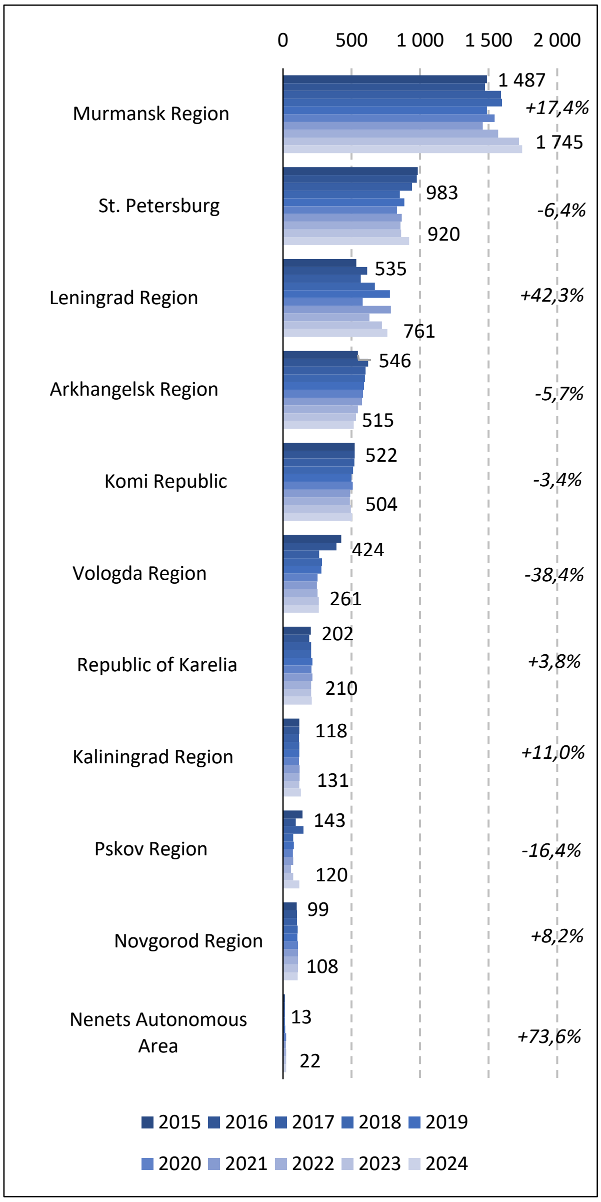
The volume of water abstraction characterizes environmental pressure on water bodies, while its ratio to the volume of gross regional product reflects the environmental intensity of impact. This intensity is highest in Murmansk and Arkhangelsk regions and lowest in the Nenets Autonomous Area and St. Petersburg *(Fig. 6b)*.

In the Northwestern Federal District, water abstraction from surface water bodies predominates. In 2024, the volume of surface water withdrawn amounted to 4,675.8 million m^3, while groundwater abstraction totaled 621.2 million m^3. The capacity of recycling water supply systems in the federal district as a whole was 14,396.6 m^3, with the largest capacities concentrated in the Vologda Region.

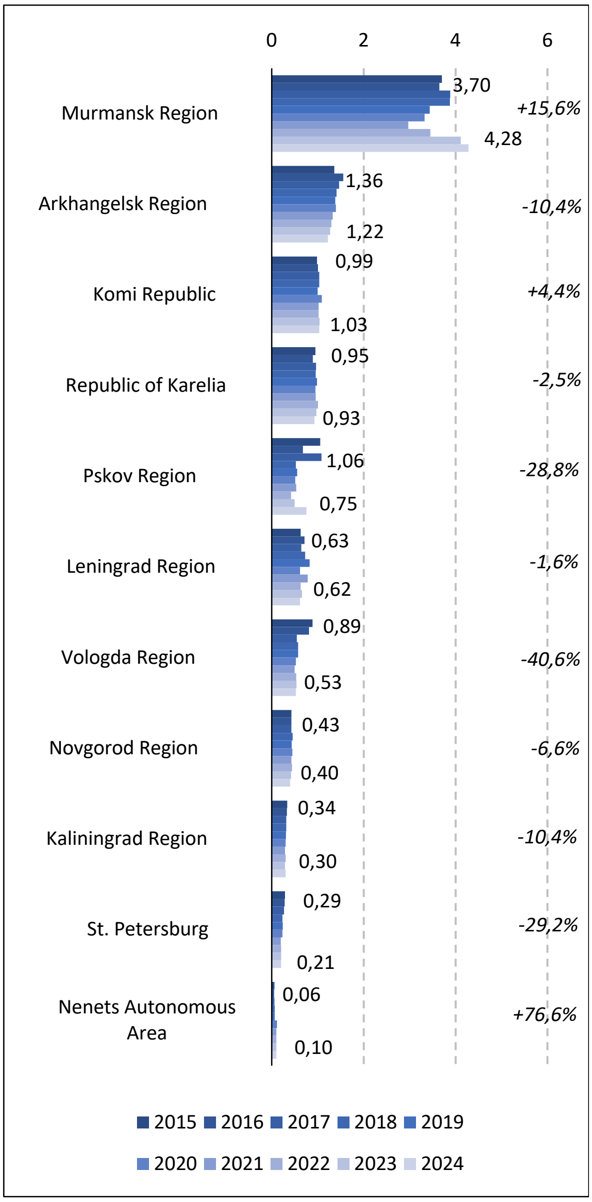
The total volume of water used was 4,849.64 million m^3, the largest share of which was directed to production needs (3,704.35 million m^3), drinking and household needs (726.15 million m^3)[7].

At the same time, it should be noted that this indicator's degree of differentiation is the highest among all the analyzed measures of

[7] On the state and protection of the environment of the Russian Federation in 2024. State report. Moscow: Ministry of Natural Resources of Russia; All-Russian Research Institute of Ecology. 721 p.



a) total, million m³



b) m³ per 1,000 thousand rubles of gross regional product

Figure 6. Water abstraction from natural water bodies

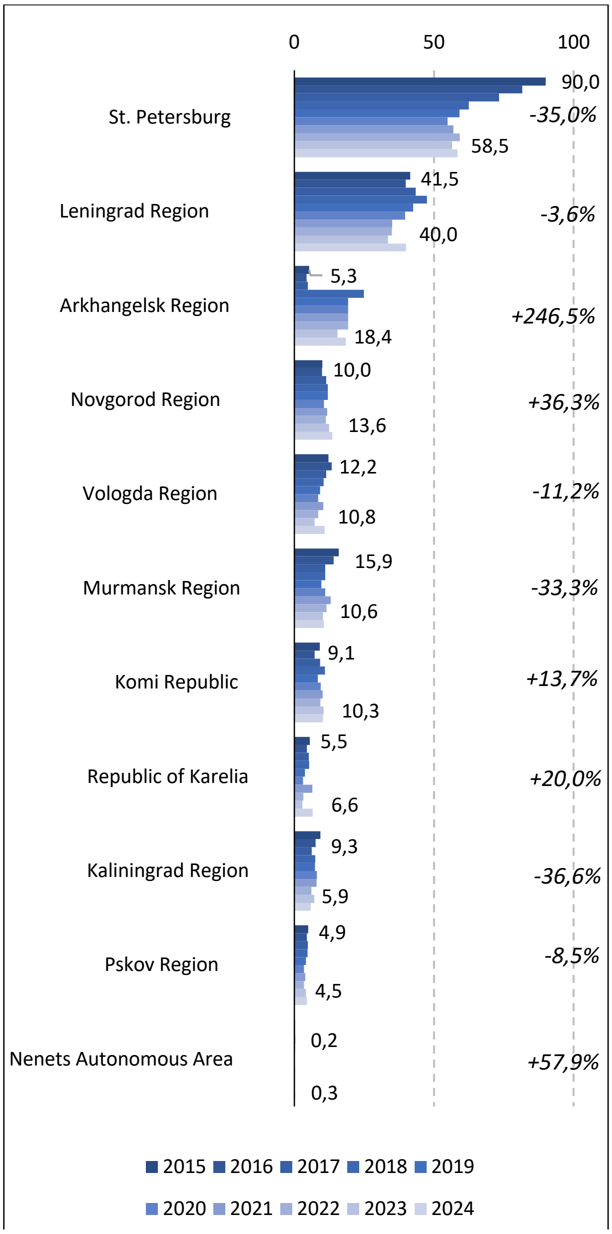
Source: On the State and Protection of the Environment of the Russian Federation in 2024. State Report. Moscow: Ministry of Natural Resources of Russia; All-Russian Research Institute of Ecology. 721 p.

Source: own calculation.

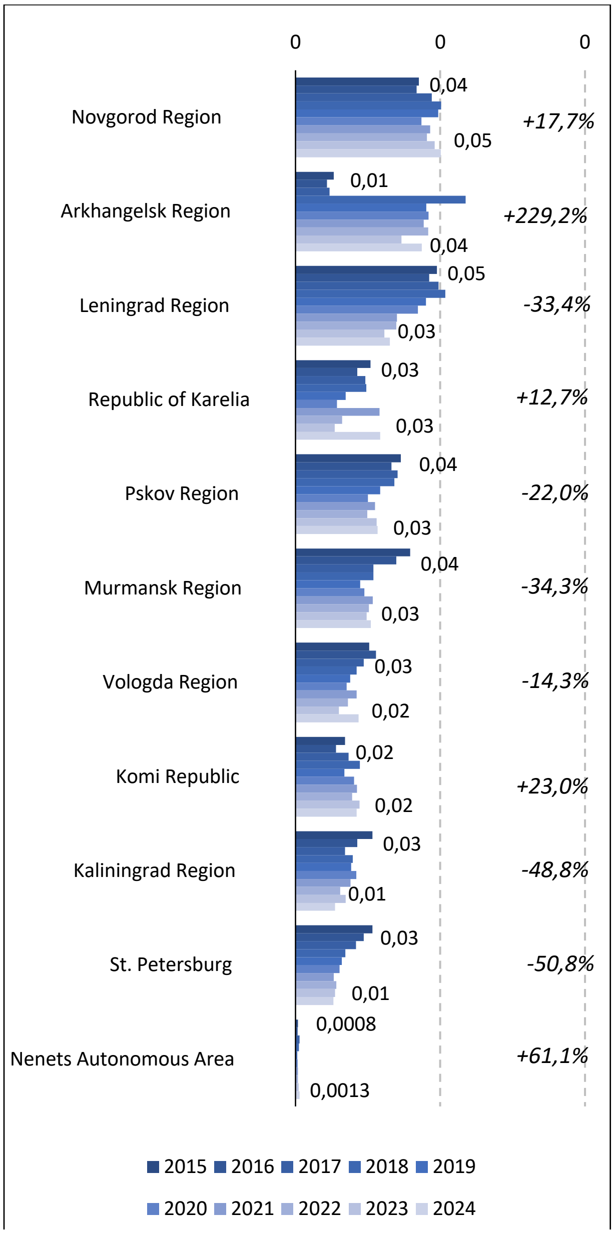
environmental intensity. In terms of dynamics, anthropogenic pressure from water abstraction increased in three regions of the district – the Nenets Autonomous Area, the Murmansk Region, and the Komi Republic – while it declined in the remaining eight regions.

Unfortunately, there is a direct relationship between water abstraction and losses during transport (correlation coefficient of 0.43). The smallest difference was in the Nenets Autonomous Area (1.3%) and the largest in the Novgorod Region (12.6%). These losses are largely attributable to the high degree of depreciation of fixed assets in the municipal sector (correlation coefficient of 0.44). Equipment wear ranges from 38.0% in the Republic of Karelia to 60.5% in the Komi Republic.

Over the period analyzed, water losses during transport were recorded in five regions of the Northwestern Federal District in both absolute *(Fig. 7a)* and relative terms *(Fig. 7b)*. The highest growth rate was observed in the Arkhangelsk Region (246.5%). St. Petersburg leads in the total volume of losses, while the Novgorod Region leads in intensity. The dispersion of absolute values of the indicator is high but has a downward tendency. The differentiation of the relative indicator is the smallest among the measures of environmental intensity, yet it remains high.



a) total, million m³



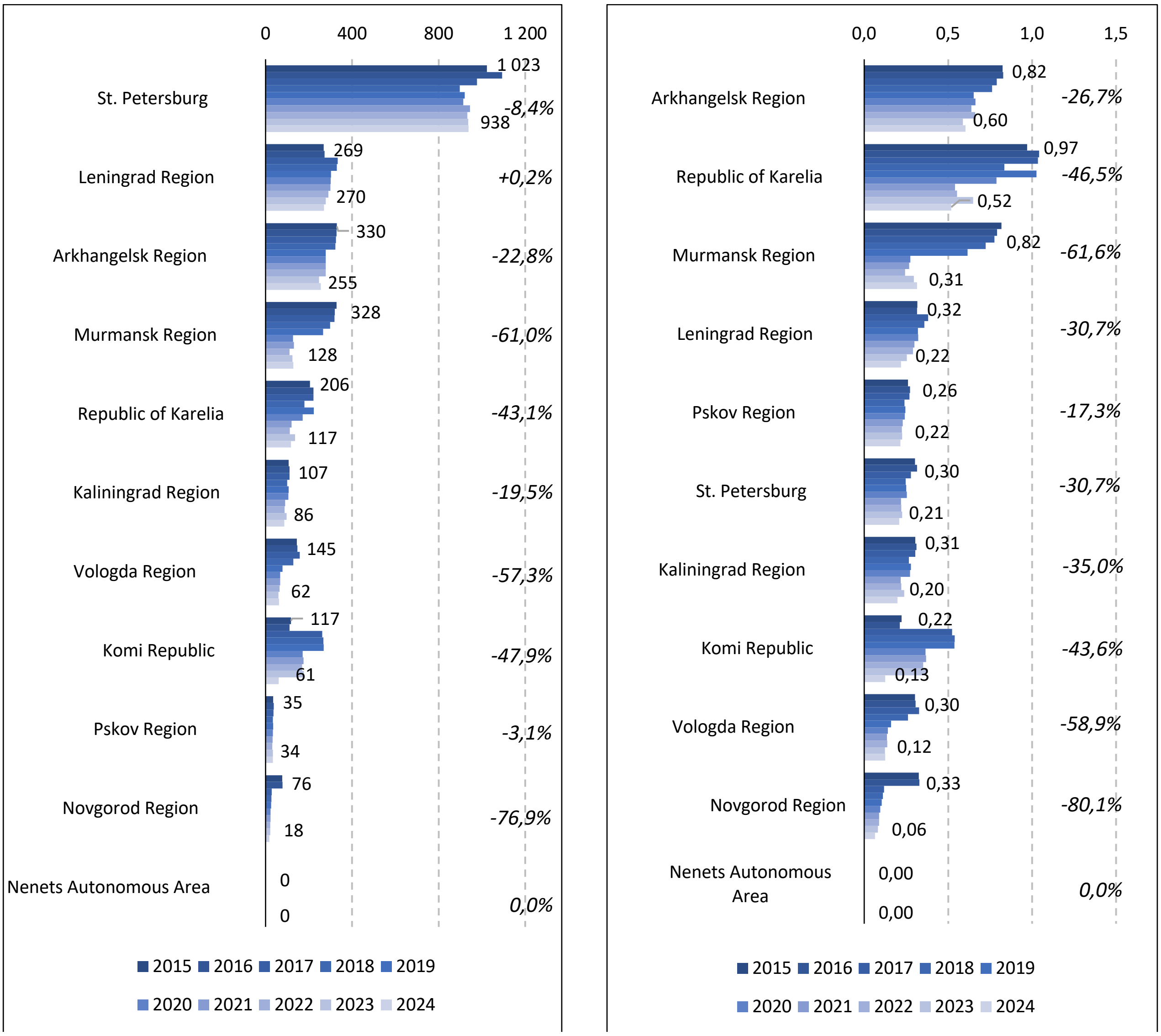
б) m³ per 1,000 rubles of gross regional product

Figure 7. Water losses during transport

Source: On the State and Protection of the Environment of the Russian Federation in 2024. State Report. Moscow: Ministry of Natural Resources of Russia; All-Russian Research Institute of Ecology. 721 p.

Source: own calculation.

Most regions of the district reduced the volume of polluted wastewater discharge *(Fig. 8a)*. It remained unchanged only in the Nenets Autonomous Area and increased slightly in the Leningrad Region (by 0.2%). However, the dispersion of values, already very high, increased over the period analyzed. St. Petersburg leads in the volume of wastewater discharge, while the Arkhangelsk Region and the Republic of Karelia lead in intensity. The degree of differentiation remained high throughout the entire study period and tended to increase. Emissions are directly related to the size of gross regional product: the correlation coefficient was 0.37 after excluding St. Petersburg, the Leningrad Region, and the Arkhangelsk Region, which differ substantially from other regions in terms of pollution volumes. The relatively low coefficient may indicate the presence of a decoupling effect in some regions of the district.



a) total, million m^3 | б) m^3 per 1,000 rubles of gross regional product

Figure 8. Discharge of polluted wastewater

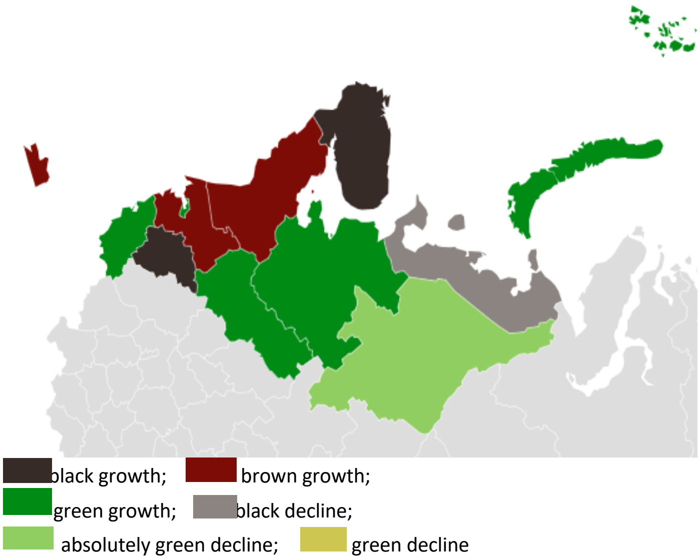
Source: On the State and Protection of the Environment of the Russian Federation in 2024. State Report. Moscow: Ministry of Natural Resources of Russia; All-Russian Research Institute of Ecology. 721 p.

Source: own calculation.

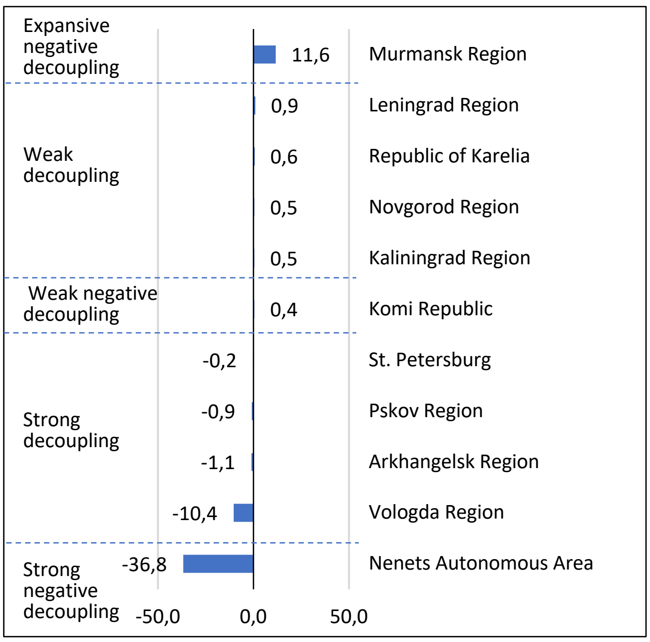
Figure 9 presents the results of determining, on the basis of the dynamic characteristics discussed above, the type of ecological-economic dynamics *(Fig. 9a)*, the type of decoupling *(Fig. 9b)*, and the factor analysis using the IPAT model *(Fig. 9c)*, which makes it possible to assess the strength of the population, income, and technological effects on water abstraction from natural water bodies.

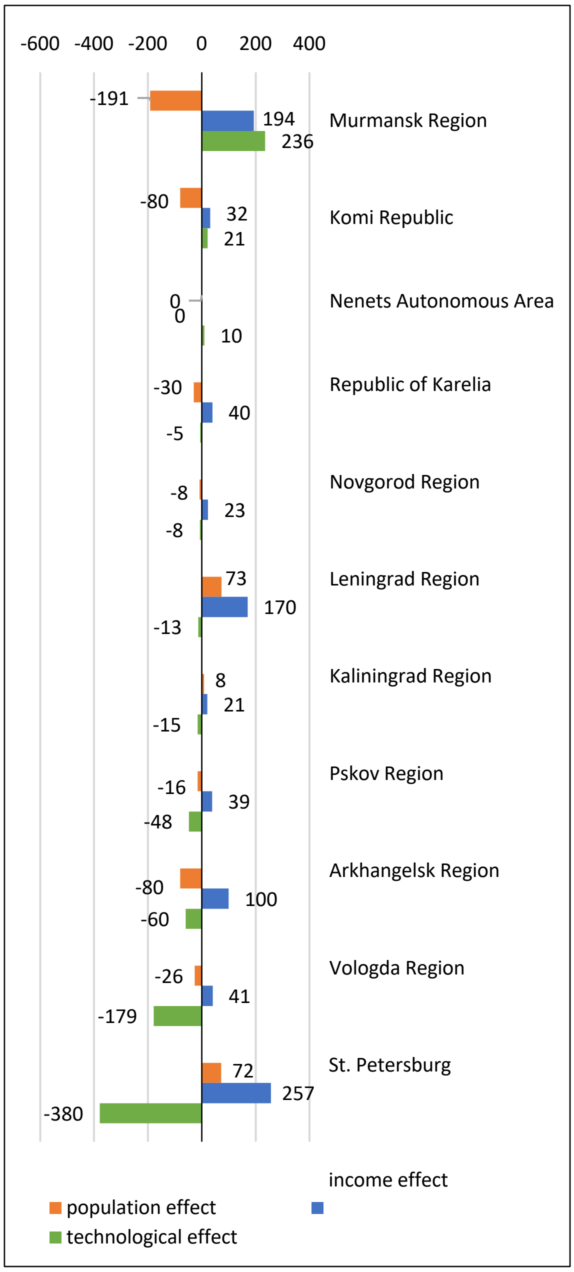
“Green” economic growth was observed in four regions of the Northwestern Federal District: St. Petersburg, the Arkhangelsk Region, the Vologda Region, and the Pskov Region. By achieving strong decoupling, driven primarily by the technological effect, the environmental intensity of economic activity decreased.

The Murmansk and Novgorod regions are characterized by “black” growth. This is caused



a) type of ecological-economic dynamics





b) type of decoupling

c) effects

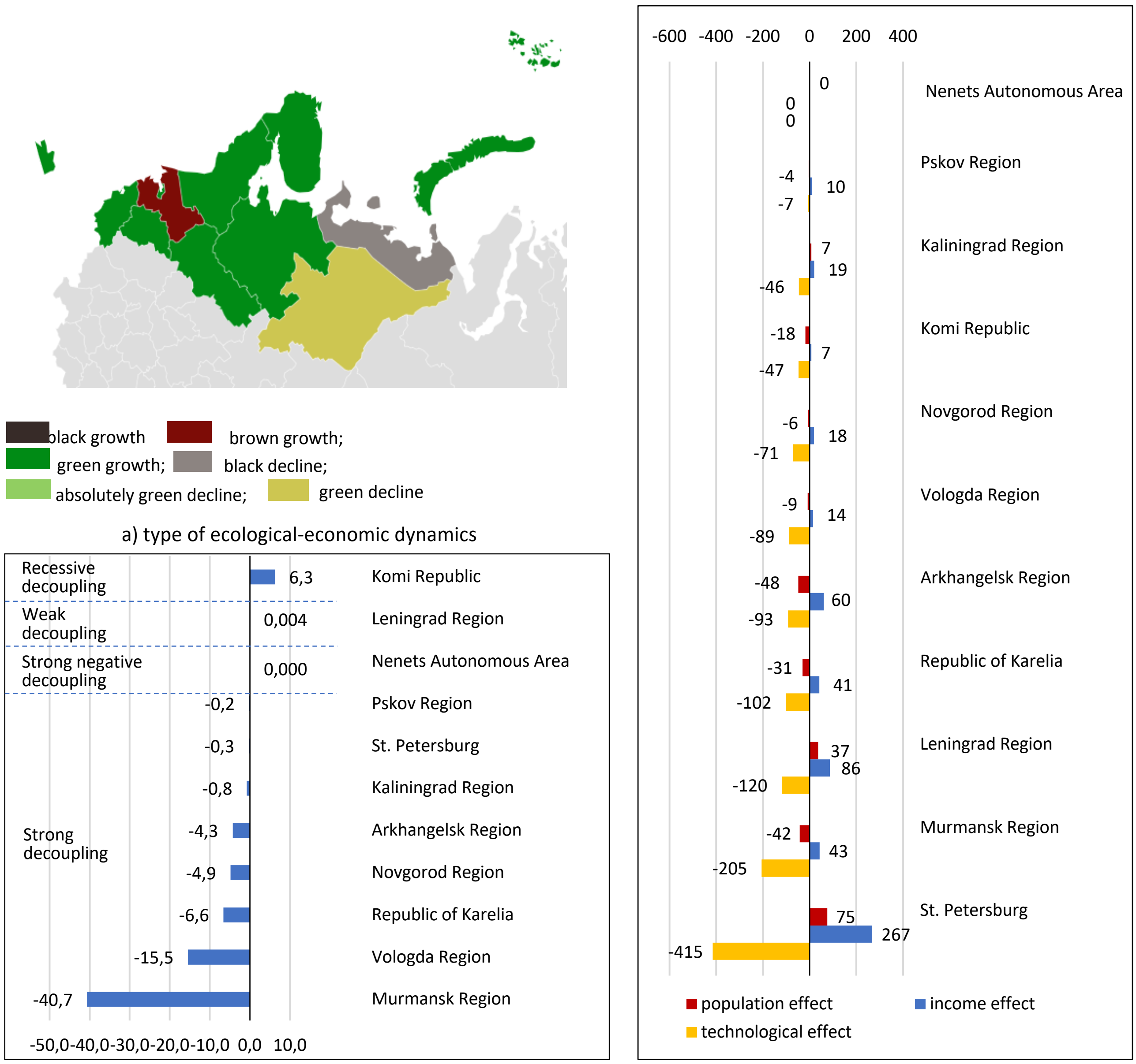
Figure 9. Results of the spatial-dynamic analysis of water abstraction from natural water bodies

Source: own calculation.

by expansive negative decoupling, in which economic growth leads to increased water abstraction (the income effect). In addition, the water-intensive technologies still in use drove up both environmental intensity and the volume of water withdrawn, a negative influence of the technological effect.

The Komi Republic experienced "green" economic decline due to weak negative decoupling, in which environmental pressure decreases more slowly than the observed economic contraction, thereby raising the environmental intensity of activity. Against the backdrop of a falling total gross product in the region (whose negative rate exceeds that of the republic's population), gross regional product per capita is nevertheless increasing.

Figure 10 presents the results of determining the type of ecological-economic dynamics *(Fig. 10a)*, the type of decoupling *(Fig. 10b)*, and the



b) type of decoupling c) effects

Figure 10. Results of the spatial-dynamic analysis of the discharge of polluted wastewater

Source: own calculation.

scale of the population, income, and technological effects *(Fig. 10c)* with respect to the discharge of polluted wastewater. The figure shows that most regions of the district are characterized by "green" growth driven by strong decoupling and the predominance of the technological effect, which reduced the environmental intensity of economic activity. The Komi Republic is distinguished by "green" decline and recessive decoupling, while the Nenets Autonomous Area exhibits "black" growth with strong negative decoupling.

Overall, the dynamics of wastewater discharge in the Northwestern Federal District are more favorable than those of water abstraction, which suggests that management efforts and their intensity could be increasingly directed toward water conservation.

The study found that wastewater disposal is directly related to current expenditures on collection and treatment, with a correlation coefficient of 0.57 *(Fig. 11)*. At the same time, it is inversely related to unit treatment costs, with a correlation coefficient of -0.37 *(Fig. 12)*. In other words, as per-cubic-meter expenditures on wastewater collection and treatment rise, a positive environmental effect is observed: environmental pressure declines through a reduction in discharge volumes.

The economic mechanism also operates with respect to water abstraction: the coefficient of variation is -0.58, meaning that as the per-unit water tax rises, abstraction volumes decline *(Fig. 13)*. A properly set water price encourages economic actors to conserve resources: higher prices induce enterprises to reduce losses, with a correlation coefficient of -0.40 *(Fig. 14)*.

These findings corroborate the view of other authors on the need to revise resource tax rates and environmental pollution charges (Zima, 2024). Recent legislative changes in this area[8] are aimed at strengthening their regulatory role; the possibility of assessing their effects will arise once the next set of statistical data is published.

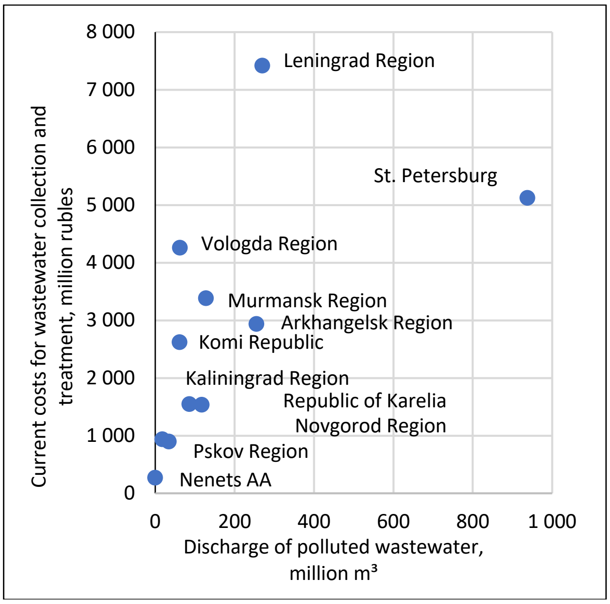


Figure 11. Discharge of polluted wastewater and current expenditures on wastewater collection and treatment in 2024

Source: own calculation.

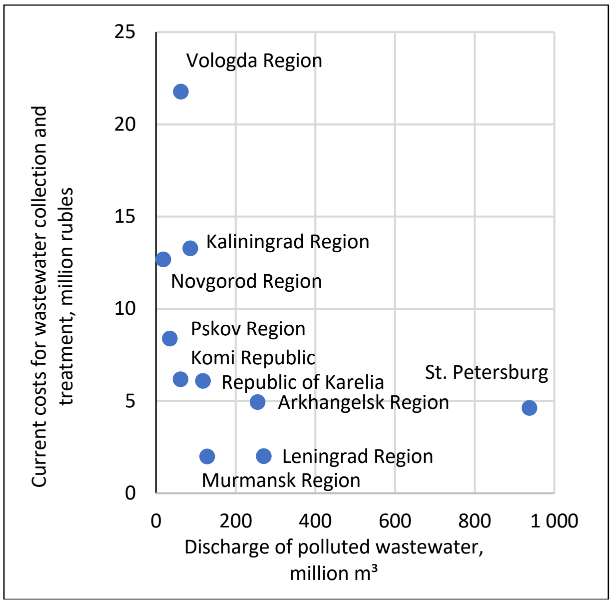


Figure 12. Discharge of polluted wastewater and unit treatment costs (excluding the Nenets Autonomous Area) in 2024

Source: own calculation.

[8] On rates of payment for negative environmental impact in 2025: Decree of the Government of the Russian Federation No. 1852-r dated July 10, 2025 (as amended on September 1, 2025). Available at: https://www.consultant.ru/cons/cgi/online.cgi?req=doc&base=LAW&n=513974&dst=101126#JfPAHOVS8Zv5jsgj2

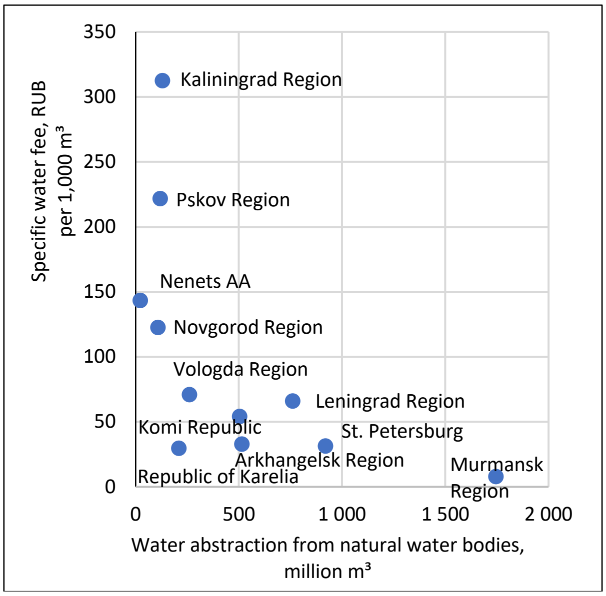


Figure 13. Unit water charges and water abstraction in 2024

Source: own calculation.

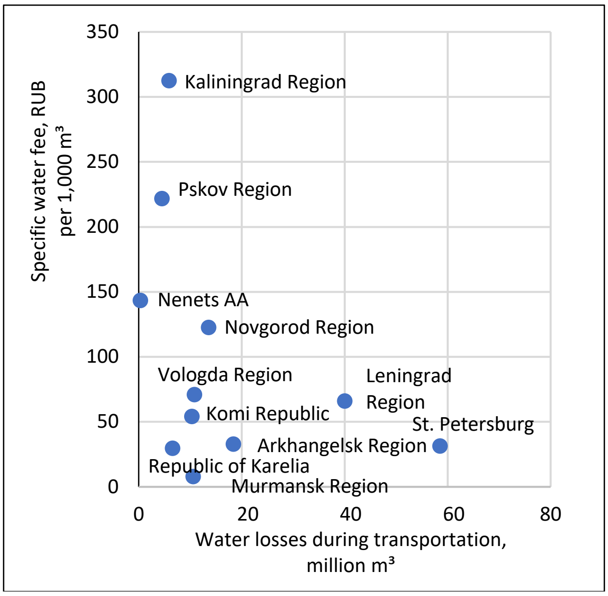


Figure 14. Unit water charges and water losses in 2024

Source: own calculation.

Conclusion

Testing the integrated model proposed in this paper for the comprehensive spatial-dynamic ecological and economic assessment of natural resource use, using water use in the Northwestern Federal District of Russia as an example, made it possible to identify the regions most problematic in terms of the water intensity of their economies and the intensity of anthropogenic environmental pollution.

In particular, the most difficult situation is observed in the Nenets Autonomous Area, which exhibits "black" economic decline characterized both by an increase in water consumption (mainly used to maintain reservoir pressure in hydrocarbon extraction) and by anthropogenic pollution of surface water bodies (with increasing volumes of wastewater discharged into groundwater bodies)[9]. The situation is aggravated by rising water losses during transportation.

Negative trends may be further exacerbated by climate change: oil infrastructure has been built on permafrost, which thaws under the thermal influence of structures, causing significant subsidence that deforms building foundations and pile bases; cracks appear in foundations and storage tanks, leading to oil leaks; and soil, ground, and groundwater become contaminated. Given these entrenched negative trends, comprehensive programs are needed to tackle the complex, multidimensional (technical, technological, economic, and other) challenges. The measures currently being implemented under the regional project "Preservation of Unique Water Bodies" – cleaning coastal strips and water protection zones of industrial and household waste, as well as monitoring the condition of the bottom and banks of water bodies within water protection zones – are clearly insufficient, since they do not address the causes that produce and reinforce

[9] Report on the state and protection of the environment of the Nenets Autonomous Area in 2024. Department of Natural Resources, Ecology, and Agro-Industrial Complex of the Nenets Autonomous Area. Naryan-Mar. 132 p. Available at: https://dprea.adm-nao.ru/ekologiya/doklady-o-sostoyanii-okruzhayushej-sredy-v-neneckom-avtonomnom-okruge/ (accessed: 21.04.2026).

the existing trends. The results of this study indicate that this region should receive priority attention from government authorities, public organizations, and the scientific community.

"Brown" growth, characterized by increasing water consumption and the discharge of polluted wastewater, is observed in the Leningrad Region, which also has a high rate of water loss during transport (though with a downward trend).

The Murmansk and Novgorod regions are distinguished by high water intensity of their economies, with water abstraction growing faster than the regional economy. This situation is largely attributable to a negative technological effect in the Murmansk Region and a weakly positive one in the Novgorod Region, both expressed in rising water intensity. In these regions, overcoming the existing trends will require, above all, measures to stimulate technological upgrading aimed at saving water in production, reducing water losses during transport, and ensuring that wastewater is treated to the required standard.

The abundant water resources of Russia's Northwestern regions cannot justify wasteful water use, and the wide differentiation of economic and environmental indicators points to the need to design programs that take regional specificities into account. Within the framework of state regulation, it is essential to combine administrative measures of standardization and control with economic incentives and restrictions, which, as the correlation analysis has shown, are also effective.

The author hopes that the approach developed here and the findings obtained will assist decision-makers in selecting a concrete set of measures for each region aimed at improving the water use situation in a targeted manner.

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Третьякова Е.А.

ПРОСТРАНСТВЕННО-ДИНАМИЧЕСКАЯ ИНТЕГРИРОВАННАЯ ОЦЕНКА ВОДОПОЛЬЗОВАНИЯ В РЕГИОНАХ СЕВЕРО-ЗАПАДНОГО ФЕДЕРАЛЬНОГО ОКРУГА РОССИИ

Нарастающие в различных странах и регионах проблемы дефицита водных ресурсов, необходимых для жизнеобеспечения людей и ведения хозяйственной деятельности, а также высокая степень их загрязнения требуют разработки адекватного оценочного инструментария, позволяющего характеризовать сложившуюся ситуацию как в пространственном, так и во временном аспектах, выявлять тренды и заблаговременно принимать соответствующие управленческие решения. В связи с этим целью исследования стало формирование интегрированной модели комплексного пространственно-динамического эколого-экономического оценивания использования природных ресурсов и ее апробация на примере водопользования в регионах Северо-Западного федерального округа России, которые отличаются развитой и дифференцированной промышленностью с высокой экологической интенсивностью воздействия на природные водные объекты. Задачи исследования ввключали: обзор научной литературы по оценке водопользования, формирование аналитического эколого-экономического инструментария, отвечающего поставленной цели, и его апробация. Научная новизна проведенного исследования заключается в формировании интегрированной модели комплексного пространственно-динамического эколого-экономического оценивания использования природных ресурсов и ее апробации на примере использования водных ресурсов в регионах Северо-Западного федерального округа. В процессе исследования были использованы методы анализа, синтеза, аналитических группировок, абсолютных и относительных величин, цепных подстановок, статистического анализа данных и графического отображения. Информационной базой исследования послужили открытые данные, размещенные на сайте Федеральной службы государственной статистики Российской Федерации и Министерства природных ресурсов и экологии Российской Федерации. Результаты апробации позволили охарактеризовать тип эколого-экономической динамики в комплексе с видом декаплинга, факторными эффектами и корреляционными взаимосвязями; выявить наиболее приоритетные (с точки зрения остроты сложившейся ситуации) и негативные тенденции. Полученные резуль-

таты могут быть полезны органам власти при разработке (актуализации) проектов и программ, нацеленных на обеспечение устойчивого сбалансированного развития регионов Северо-Запада России.

Водные ресурсы, экономика природопользования, сбалансированное природопользование, региональная экономика, устойчивое развитие, пространственный анализ, динамический анализ, декаплинг.

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