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Assessment of the Environmental Sustainability of Regional Development Based on the Driving Forces – State – Response Model

Kutyshkin A.V. [a] and Shulgin O.V. [b]
Federal State Budgetary Educational Institution of Higher Education Nizhnevartovsk State University, Nizhnevartovsk, Russia
avk_200761@mail.ru , shul.oleg.val@mail.ru

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Abstract : The aim of the study is to assess the environmental sustainability of the ecosystem of the Khanty-Mansi Autonomous Okrug - Yugra (KhMAO-Yugra) for the period from 2013 to 2023 based on the Driving Forces - State - Response (PSR) model. The Environmental Sustainability Index (ESI) of the ecosystem under consideration was determined using the Driving Forces - State - Response model, the system of indicators of which was modified taking into account the natural and climatic features of the region. The ESI values were calculated using the TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) method, while the weighting coefficients of the PSR model indicators, in turn, were calculated using the weighting method of their information entropy (WIE). The weighting coefficients of the model components were defined as composite indices from the VC of the corresponding indicators. The state of sustainability of the ecosystem of the region was determined according to the classification of states of sustainability of the functioning of large systems described by a fixed set of indicators. Calculated values of the IEI index show that from 2013 to 2023, the Khanty-Mansi Autonomous Okrug-Yugra ecosystem was in a "State with Signs of Instability." From 2013 to 2017, ecological resilience declined rapidly, but since 2018, it has shown steady growth, reaching a "State Near Stable." Using the PSR model and the TOPSIS method with the MVIEP allows us to identify historical trends in changes in the region's ecosystem resilience, which is important for analyzing the effectiveness of organizational and technical solutions developed by the regional administration and key actors in its economic system.

[a] https://orcid.org/0000-0003-3226-0360
[b] https://orcid.org/0000-0002-1989-3975

1 INTRODUCTION

The sustainable functioning and development of economic, environmental, and social systems at various spatial levels is a response to the depletion of natural resources, growing social tensions, economic differentiation between countries and regions, rising poverty levels, and a number of other pressing contemporary challenges. The concept of "sustainable development," formulated in the 1987 UN report "Our Future," has undergone significant methodological and institutional evolution, reflected in the development of universal goals and a primary set of indicators for national sustainable development by the UN Commission on Sustainable Development. Since 2015, when the list of UN Sustainable Development Goals (SDGs), corresponding targets, and indicators was updated, each country has intensified the development of its own set of SDGs, taking into account national priorities and specific circumstances. Russia has also developed a list of SDGs and national indicators for their achievement, including at the regional level. Integrated measures of sustainable development, both national and regional, as well as their main subsystems, have not yet been developed. In this regard, a highly relevant scientific and practical task is not only the formation of a regional set of SDGs but also the adaptation of existing methodological support for assessing the sustainable development of regions and their key subsystems. When applied to assessing the sustainability of a regional ecological subsystem, this task is complicated by the diversity of indicators characterizing its condition and the impact of the region's economy and society on it.

the World Commission on Environment and Development (WCED) Report, environmental sustainability of regional socio-economic systems (RSES) is defined as achieving the environmental goals of their sustainable development, which are aimed at ensuring environmental quality at a level sufficient to meet the needs of current and future generations. It is generally accepted that the environmental sustainability of RSE development is characterized by the preservation and development of the natural capital of the country and region.

When assessing the sustainability of a region's ecosystem, both locally and as part of an overall assessment of its development sustainability, the state of this system is described by a fixed set of indices or indicators. These indicators are selected by the researcher based on the principles of completeness, comparability, and accessibility, taking into account the specifics of the region's economy and its natural and climatic characteristics. There are no limits on the number of indicators as such.

To quantitatively assess the ecosystem sustainability index (ESI, environmental sustainability index) of a region, Russian researchers currently typically use geometric averaging (Tret'yakova, Mirolyubova, Myslyakova, SHamova, 2018; Valeeva, Patrakova, 2019) and, less commonly, arithmetic averaging (Selimenkov , Kuznecov , 2014) of the values of selected indicators or ratings of the state of the regional ecosystem. Qualitative analysis of changes in the values of these indicators is also often used. Based on its results, an assessment of regional environmental sustainability is formed, see, for example, (Preobrazhenskij, Fyodorov, 2023; Erlygina , SHtebner , 2022; Imamverdieva , Bubnova , 2021). Correlation and regression analysis are used less frequently (Aleshnikova, Burceva, 2023; Zemcov , Barinova , Kidyaeva , Lan'shina , 2020).

According to the authors, the disadvantages of the above methods and models include:

- there is no consideration of the relationship between the influence of indicators on each other and the influence of the external environment of the ecosystem - the economic and social subsystems of the RSES.

- “weighting coefficients of indicators or relative values based on them, as well as ratings”, which are used in the dependencies of geometric and arithmetic means are equal to “1”, which is generally not entirely correct.

The Pressure - State - Response (PSR) model (Sausheva, Majkova, Kirdyashkina, 2020; Zakharova, ZHerebyat'eva, 2024) is also actively used to assess the environmental sustainability of the regional ecosystem. It is also used by the Organisation for Economic Co-operation and Development (OECD) to study and analyze the structure of various environmental problems. Using this model, assessments of a number of environmental aspects of the use of water resources by the RSES (Li, Su, Wei, 2019), agricultural lands (Surendra , Kalu , 2023), as well as the general state of the regional ecosystem and its sustainability (Zhang , Wang , Xiong , 2023) were obtained at different spatial levels. The significance of the model indicators in determining the index of ecological sustainability (IES) of the regional ecosystem was taken into account using the method of weighting the information entropy of the indicators (MIIE) (Li, Su, Wei, 2019; Surendra , Kalu , 2023; Zhang , Wang , Xiong , 2023). The value of the IES itself is most often assessed using the TOPSIS method (The Technique for Order of Preference by Similarity to Ideal Solution) (Zhang , Wang , Xiong , 2023; Lobkova , 2019; Yuqing , Yongchao , Jingliang , Ruirui , 2020). The PSR model , showing "what happened, why it happened and what we will do about it," allows us to describe the cause-and-effect relationship between various indicators of the regional economic system from the point of view of the integration of human activity and the environment of the region. This model describes the observed system or process through the aspects of pressure, state, implements the concept of causality: human activity puts "pressure" on the environment and changes its quality and quantity of natural resources ("state"). The social system responds to these changes through environmental, general economic and industry reactions (social and public reactions). Currently, the PSR model has been transformed by expanding the Pressure (P) component to the Driving Forces (Driving) level Force , DF) (Surendra, Kalu, 2023; Zhang, Wang, Xiong, 2023), which includes not only the classic characteristics of anthropogenic impact on the ecosystem of the Russian Economic Zone (RSES), but also indicators characterizing the development of its economy and social subsystem, which, in essence, are the source and generator of the indicated impact. The object of this study is the sustainability of the ecosystem of the Khanty-Mansi Autonomous Okrug - Yugra (KhMAO-Yugra), which provides at least a third of the total oil production in Russia. Assessing the sustainability of the ecosystems of resource-oriented regions, whose economies are dominated by the mining industry, is of great importance. Oil and gas production is an industry with a high level of negative impact on the environment. The natural and climatic features of the okrug reduce the natural capacity of the natural environment for self-restoration and increase the negative impact of the economy on the ecosystem. Along with this, Khanty-Mansi Autonomous Okrug - Yugra is characterized by steady population growth, more than 80% of whom live in urban settlements. Thus, there is also a significant negative anthropogenic impact on the region's ecology. Based on the above, the authors believe the topic of this study is relevant.

Driving Forces - State - Response (DFSR) model. Force – State – Response , DFSR) between 2013 and 2023.

The novelty of the work is the development of a system of indicators of the DFSR model , adapted to the specifics of the research object, the application of the method of weighing information entropy and the method of taxonomic indicator for assessing the weighting coefficients of the indicators for determining the index of environmental sustainability of the region.

2 MATERIALS AND METHODS

The DFSR model consists of three hierarchically organized levels. The top level is the target level—the environmental sustainability index. Below that is the level of model components that describe the resilience of the regional ecosystem. The final level is the level of indicators that aggregate the components. The component level includes three aspects that influence the IEI: "Driving Forces (DF)," "State (S)," and "Response (R)." "Driving Forces" brings together indicators characterizing the socioeconomic development of the region and the anthropogenic impact on its ecosystem. "State" includes indicators representing the current state of the ecosystem as a result of the "Driving Forces" component. "Response" encompasses indicators reflecting the response of regional society to changes in the regional ecosystem and the parameters for its restoration. Thus, the structure of the DFSR model forms the IEI based on the principle of "driving forces for regional ecosystem development—changes in the state of the regional ecosystem—solutions to associated problems." The question "what happened" is answered by the S component indicators, which reflect physical and biological changes or trends in the ecosystem, as well as the state of corresponding trends in the region's socioeconomic development. The DF component indicators, related to both the region's socioeconomic development and human-induced environmental changes, answer the question "why this happened." For example, intensive exploitation or overuse of natural resources leads to their depletion and deterioration of environmental quality; thus, the S indicators measure the overall anthropogenic pressure on the ecosystem. The R component indicators characterize society's response to emerging environmental problems, answering the questions "what has been done" and "what should be done," thereby illustrating the efforts being made to resolve these problems and assessing the implementation of existing environmental policies for the sustainable development of the region. Based on the logic of the DFSR concept, improving environmental conditions and environmental management will contribute to the environmentally sustainable development of both the ecosystem and the region as a whole.

Table 1 presents the components of the DFSR model and their corresponding indicators, which, in the authors' opinion, reflect the environmental sustainability of the development of the region under consideration – the Khanty-Mansiysk Autonomous Okrug-Yugra. The "+" and "-" signs characterize the positive and negative impact of the table indicator on the sustainability of the region's ecosystem. The selection of indicators was carried out taking into account the results of previous studies on this issue (Aleshnikova, Burceva, 2023; Zhang , Wang , Xiong , 2023; Yuqing , Yongchao , Jingliang , Ruirui , 2020) and the specifics of the Khanty-Mansiysk Autonomous Okrug-Yugra RSES.

Table 1 : Components and indicators of the DFSR model for assessing the sustainability of the Khanty-Mansi Autonomous Okrug-Yugra ecological system.

j	DFSR model component	DFSR component index	Indicator influence sign
1	Pressure , P)	GRP per capita of the region, million rubles/person (DF 1)	+
2		Level of urbanization of the region, % (DF 2)	-
3		Population density of the region (people/km2) (DF 3)	+
4		Specific water intake for production needs, million cubic meters/million rubles of GRP (DF 4)	-
5		Water consumption for domestic needs per capita, million cubic meters/per thousand people (DF 5)	-
6		Specific discharge of polluted wastewater per unit of GDP, thousand m3 / million rubles of GRP (DF 6)	-
7		Specific volume of pollutant emissions into the atmosphere, thousand tons/million rubles of GRP (DF 7)	-
8		Specific volume of produced associated petroleum gas, million tons/million rubles of GRP (DF 8)	-
9		Specific area of oil-contaminated lands formed per year, ha/million rubles of GRP (DF 9)	
10		Specific volume of all types of generated production and consumption waste per GRP, million tons/million rubles (DF 10)	-
11		Energy intensity of GRP, thousand tons of equivalent fuel/million rubles (DF 11)	-
12	State, (S)	Water resources per capita, million m3 per year per person). (S 1)	+
13		BOD_5 – biochemical oxygen consumption for 5 days, mg/l at a temperature of 20 ^{0}C, mgO_2/dm^3, (S 2)	-
14		COD – chemical oxygen demand for the neutralization of difficult-to-oxidize organic substances, mg/l, (S 3)	-
15		Quality of surface waters in the region according to UKIZV, (S 4)	+
16		Drinking water quality - the proportion of water samples unsatisfactory in terms of sanitary and chemical indicators, %. (S 5)	+
17		The share of urban population living in cities with high and very high levels of air pollution, % (S 6)	-
18		Population morbidity caused by emissions of pollutants into the atmosphere per 1000 people (S 7)	-
19		Specific area of oil-contaminated lands at the end of the year, ha/million rubles of GRP (S 8)	-
20		The share of buried and recycled consumption and production waste from their total volume at the end of the year, %. (S 9)	+
21		The share of unprocessed extracted associated petroleum gas from its total volume, % (S 10)	-
22	Response, (R)	The share of treated water discharged into reservoirs from fresh water intake in the region, % (R 1)	+
23		The share of recycled water supply and repeated water supply from the total volume of water consumption in the region,%. (R 2)	+
24		The share of captured pollutants from the total volume of their emissions, % (R 3)	+
25		The share of processed associated petroleum gas from its total volume, %. (R 4)	+
26		The share of all types of waste rendered harmless, processed and transferred for storage from the total volume of waste, % (R 5)	+
2		The share of cleaned and	+

7		reclaimed oil-contaminated lands from those available at the end of the year in the region, %. (R 6)	
28		The share of the area of new forest plantations in the total forest area of the region, %. (R 7)	+
29		The share of current expenditure on environmental protection of the region from the GRP, %. (R 8)	+
30		The share of total costs for major repairs of fixed production assets for environmental protection in GRP, %. (R 9)	+

Note: compiled by the authors based on the data obtained during the study

The quality of surface water (S4) in the region is quite low, due to the nature of taiga wetlands with their characteristic acidic soil reaction, as well as intensive hydrocarbon extraction. Between 2013 and 2023, pollution levels fluctuated between pollution classes 4 and 5. Therefore, to account for the impact of this indicator on the stability of the region's ecosystem in terms of water resources, the authors used the ratio of the annual averaged specific combinatorial water pollution index for the region. (UKIZV) to the value of this indicator, corresponding to the middle of the 2nd class of water pollution.

The set of values of the DFSR model indicators (Table 1) at any moment in time " t " from the observed interval [t_0, T] determines the position of the considered regional ecosystem in a certain area of J -dimensional space ($J = 30$).

To ensure comparability of the DFSR model indicators (Table 1), their values are normalized. There are many methods for standardizing the values of indicators or factors - the extreme difference method, the logarithmic function transformation method, the z-score normalization method, etc. (Lobkova, 2019; Yuqing , Yongchao , Jingliang , Ruirui , 2020; Nadtoka , Vinogradov , 2014). In this work, the simplest, but quite popular and widely used in various fields of research method of extreme differences was used. To standardize the values of indicators that have a positive impact on the ecological sustainability of the regional ecosystem, i.e. having the "+" indicator influence sign in Table 1, a dependence of the form is used (Yuqing , Yongchao , Jingliang , Ruirui , 2020; Nadtoka , Vinogradov , 2014):

$$r_j(t) = \frac{x_j(t) - x\min_j}{x\max_j - x\min_j}; x\max_j = \max_{t=t_0}^{T}\left(x_j(t)\right); x\min_j = \min_{t=t_0}^{T}\left(x_j(t)\right) \quad (1)$$

For indicators that negatively affect the ecological sustainability of the region's ecosystem (sign "-" in Table 1), the following expression is used:

$$r_j(t) = \frac{x\max_j - x_j(t)}{x\max_j - x\min_j}. \quad (2)$$

Here $x_j(t)$ is the value of the j -th indicator for the year " t " .

The VC values of the indicators presented in Table 1 were calculated using the information entropy weighting method (IEWM) (Li, Su, Wei, 2019; Surendra , Kalu , 2023; Zhang, Wang, Xiong, 2023), which, as an assessment of the coefficients of variation of the indicator values, refers to objective VC assessment methods. Subjective methods combine the professional knowledge and experience of experts, as well as the hierarchical process analysis (AHP) (Saati, 2022; Vygodchikova, 2024). Objective methods neutralize the influence of the opinions and qualifications of the involved experts on the VC values, which increases the objectivity of VC assessments.

The entropy measure of uncertainty of alternative states of an object, developed by K. Shannon, has been adapted to calculate weighting coefficients in index systems (Mao , Deng , 2022). The idea is that higher variability, i.e. lower "entropy", of an indicator's values means that it is more important and should receive greater weight compared to other indicators. Then the entropy or entropy function of the j -th indicator is determined by the expression (Zhang, Wang, Xiong, 2023 ; Yuqing , Yongchao , Jingliang , Ruirui , 2020 ; Mao, Deng, 2022):

$$H_j = -\frac{1}{\ln T}\sum_{t=t_0}^{T}\left[R_j(t)\cdot \ln R_j(t)\right], \quad (3)$$

where $R_j(t) = \frac{r_j(t)}{\sum_{t=t_0}^{T} r_j(t)}$ and

$R_j(t) = 0 \rightarrow \ln R_j(t) = 0$.

The variability of the values of indicator j is greatest when the value of H_j is least, and if indicator j is part of a composite index, then its "objective" importance, or its weighting coefficient W_j, can be quantified by the relationship (Laslett, Urmee, 2020):

$$W_j = \frac{1 - H_j}{J - \sum_{j=1}^{J} H_j}. \quad (4)$$

The weighting coefficients W_j have the following property: $\sum_{j=1}^{J} W_j = 1.$

The assessment of the region's IEU is carried out based on the assumption that the range of values of the DFSR model indicators (Table 1) is limited by their minimum and maximum possible values, fixed in the interval [t_0, T].

TOPSIS method is implemented according to the following algorithm (Hwang, Yoon, 1981; Lobkova , 2019; Yuqing , Yongchao , Jingliang , Ruirui , 2020):

1. A set of indicators/metrics is developed that describe changes in the observed system or object.

2. The values of the indicators are standardized and weighting coefficients are calculated for them.

3. A comprehensive index of regional ecosystem sustainability is determined based on the distances from the current state of the region's ecosystem to the "ideal positive solution"—the upper pole (PIS)—and the "ideal negative solution"—the lower pole (NIS). The implementation of point 1 is presented in Table 1. Point 2 is implemented using the extreme difference method and the MVIEP.

When implementing point 3 of TOPSIS, the following procedures are performed (Hwang, Yoon, 1981; Lobkova , 2019; Yuqing , Yongchao , Jingliang , Ruirui , 2020):

1. A matrix of weighted values of indicators is formed (Table 1), the elements of which are determined by the expressions:

$$Y_j(t) = W_j \cdot Z_j(t); Z_j(t) = \frac{z_j(t)}{\sqrt{\sum_{t=t_0}^{T} z_j^2(t)}}, \quad (5)$$

where $z_j(t)$ is the value of the j -th indicator calculated depending on the indicator of its influence on the stability of the regional ecosystem (Table 1) at time " t ":

- the indicator " j " has a positive effect: $z_j(t) = x_j(t)$;
- the indicator " j " has a negative impact: $z_j(t) = \left[x_j(t)\right]^{-1}$

2. Based on the values of $Y_j(t)$, the characteristics/coordinates of PIS and PIS are determined for the moment in time " t ":

- upper pole:

$$Y_j^+(t) = \left\{\max Y_j(t) \middle| t = t_0, ..., T\right\} = \left\{\max Y_j(t) \middle| Y_1^+(t), ..., Y_J^+(t)\right\}. \quad (6)$$

- lower pole:

$$Y_j^-(t) = \left\{\min Y_j(t) \middle| t = t_0, ..., T\right\} = \left\{\min Y_j(t) \middle| Y_1^-(t), ..., Y_J^-(t)\right\}. \quad (7)$$

3. The Euclidean distance from the position of the region's ecosystem at time " t " to the formed upper and lower poles is determined (Hwang, Yoon, 1981; Lobkova , 2019; Yuqing , Yongchao , Jingliang , Ruirui , 2020):

- distance to the upper pole

$$D_j^+(t) = \sqrt{\sum_{j-1}^{J} \left(Y_j^+(t) - Y_j(t)\right)^2} \quad (8)$$

- distance to the lower pole

$$D_j^-(t) = \sqrt{\sum_{j=1}^{J} \left(Y_j^-(t) - Y_j(t)\right)^2} \quad (9)$$

4. For the moment of time " t ", the index of sustainability of the regional ecological system IEU(t) is calculated:

$$\text{ИЭУ}(t) = \frac{D_j^-(t)}{D_j^+(t) + D_j^-(t)}. \quad (10)$$

It is proposed to determine the level of sustainability of the region's ecosystem based on the classification proposed in the works (Zhang, Wang, Xiong, 2023; Yuqing , Yongchao , Jingliang , Ruirui , 2020; Alferova, 2022) (Table 2).

Table 2: Ranges of IEU values (t) and estimated levels of sustainability of the Khanty-Mansi Autonomous Okrug-Yugra ecosystem.

Interval of values of IEB(t)	Stability region	Degree of stability
0 – 0.1	VI	Absolutely unstable state
0.1 – 0.25	V	Unstable state
0.25 – 0.5	IV	A state with signs of instability
0.5 – 0.75	III	The state is close to stable.
0.75 – 0.9	II	Steady state.
0.9 – 1.0	I	High level of stability.

Note: compiled by the authors based on sources (Zhang, Wang, Xiong, 2023; Yuqing , Yongchao , Jingliang , Ruirui , 2020; Alferova, 2022)

The empirical basis for this study is departmental documents on environmental protection , publicly available statistical data presented on the websites of Rosstat, the Ministry of Natural Resources and Environment, and the Federal State Budgetary Institution "Hydrochemical Institute." All cost indicators are adjusted to comparable prices of 2013.

3 RESULTS AND THEIR DISCUSSION

The calculated values of the VC indicators (4) and components of the PSR model for assessing the environmental sustainability of the Khanty-Mansi Autonomous Okrug - Yugra are given in Table 3.

Table 3: Components and indicators of the DFSR model for assessing the environmental sustainability of development in the Khanty-Mansi Autonomous Okrug – Yugra.

Component of the DFPR model	VK component	DFPR component indicator	VK indicator
Driving forces (DF)	0.3631	DF 1	0.03269
		DF 2	0.02944
		DF 3	0.03327
		DF 4	0.03587
		DF5	0.03427
		DF6	0.03605
		DF7	0.03263
		DF 8	0.03423
		DF 9	0.03373
		DF 10	0.03325
		DF 11	0.02766
Condition, (S)	0.3305	S 1	0.0361
		S 2	0.0267
		S 3	0.0285
		S 4	0.0342
		S5	0.0347
		S6	0.0326
		S7	0.0355
		S 8	0.0338
		S 9	0.0327
		S 10	0.0357
Reaction, (Response, R)	0.3064	R 1	0.0365
		R 2	0.0364
		R 3	0.0307
		R 4	0.0285
		R5	0.0358
		R6	0.0341
		R7	0.0351
		R 8	0.0343
		R 9	0.0352

Note: compiled by the authors based on the data obtained during the study

The value of the VC (Wj) and the significance of the corresponding j-th indicator of the PSR model depend on the magnitude of the gaps in its values, which characterizes the amount of information this indicator possesses for the model. Thus, the lower the entropy value Hj (4), the greater the value of Wj (5), and vice versa. The weighting coefficients of the PSR model components were determined using the composite index scheme, i.e., they represent the sum of the VC of the indicators aggregated by the component. The highest calculated VC value is for the Pressure component, and the lowest for the Response component. The average VC value of the Response component indicators is the highest – CPR(Wj) = 0.03405, followed by the average of the State component CPS(Wj) = 0.03305 and the Pressure component CRP(Wj) = 0.03301. In this case, the variation coefficients νSj, characterizing the variability Wj of the values of the component indicators, differ significantly νPj = 0.076, νSj = 0.095, νRj = 0.08. Thus, the most significant for the sustainability of the ecosystem are changes in the indicators of the components "Response" and "State". Among these indicators, the most significant are R1 - (WR1 = 0.0365), R2 - (WR2 = 0.0364), S1 - (WS1 = 0.0361) and P6 - (WP6 = 0.0361). The least significant are the indicators S2 - (WS2 = 0.02666), P11 - (WP11 = 0.02766), S3 - (WS3 = 0.02845), R4 - (WR4 = 0.02851).

Figure 1 shows the calculated values of the IEU(t) (10) for the Khanty-Mansi Autonomous Okrug-Yugra from 2013 to 2023 and the boundaries of the two closest ecosystem stability areas (Table 3): V – unstable state; IV – state with signs of instability.

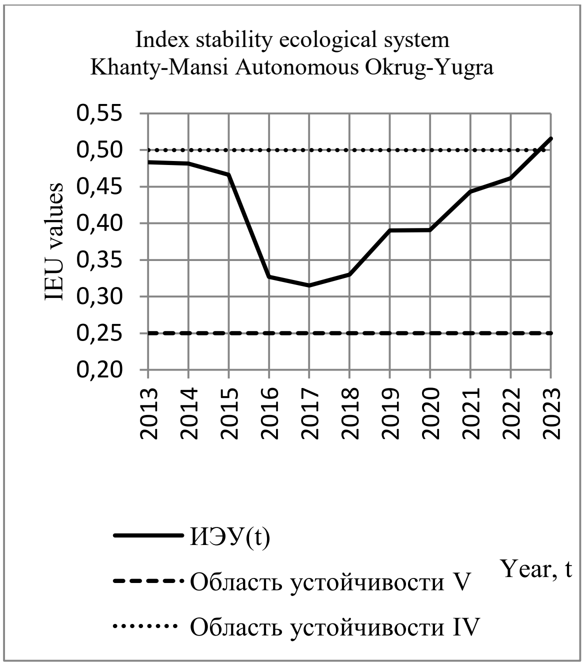

Figure 1: Changes in the values of the sustainability index of the ecological system of the Khanty-Mansi Autonomous Okrug – Yugra from 2013 to 2023. Note: compiled by the authors based on the results of this study.

The calculated IEI(t) values for the Khanty-Mansi Autonomous Okrug – Yugra lie in region IV, i.e., the ecosystem state shows signs of instability. These values are characterized by two trends – a downward and an upward trend. Between 2013 and 2017, the IEI(t) values decreased by 35%, demonstrating a downward trend. From 2017 to 2023, the IEI(t) values have been steadily increasing, with minor declines in growth rates in 2019 and 2022. The authors believe that the dynamics of the IEI(t) values (Figure 1) are due to the fact that the district's economy is export-oriented and highly sensitive to changes in foreign policy. In 2014, external sanctions were imposed on the Russian oil-producing sector, which led to a decrease in its attention to the district's environmental issues due to a decrease in revenues from oil sales. However, by 2017, the region's subsoil users and administration had adapted to the imposed sanctions, and the ESI(t) values began to increase. A localized decline in the ESI(t) value in 2022 was due to the imposition of additional external sanctions. However, the accumulated experience of joint efforts between oil producing companies and the district administration to adapt to external sanctions pressure ensured the district's continued improvement in environmental safety.

4 CONCLUSIONS AND SUMMARY

A quantitative assessment of the ecosystem sustainability of the Khanty-Mansi Autonomous Okrug - Yugra from 2013 to 2023 was conducted using the regional environmental sustainability index, developed based on the Pressure-State-Response model, adapted through the developed system of its indicators and components, reflecting the specifics of anthropogenic impact on the region's ecosystem. The TOPSIS method was used to calculate the regional ecosystem sustainability index. The weighting coefficients of the DFSR model indicators were determined using the information entropy weighting method. The level of sustainability of the Khanty-Mansi Autonomous Okrug - Yugra ecological system during the considered time period was determined taking into account the classification of the states of large systems, which are described by a fixed set of values for the indicators of their elements. Based on the calculated IEI values, it was established that the level of environmental sustainability of the Khanty-Mansi Autonomous Okrug - Yugra ecosystem from 2013 to 2023 is classified as "State with signs of instability." Moreover, from 2013 to 2017, the IEI values were characterized by a downward trend, with values declining by 35%. Since 2018, the IEI values have steadily increased, reaching a level where the region's ecosystem corresponds to a "near-sustainable state." Thus, applying the above-mentioned set of methods and models for retrospective assessment of the sustainability of a region's ecological system—the region's IEI values—allows us to identify trends in IEI value change, which is relevant for analyzing the effectiveness of organizational and technical solutions developed and applied in this area by the regional administration and the main actors in its economic system.

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