Integral Assessment of the Sustainability of Socio-Ecological and Economic Systems and the Quality of Life of the Population in the Regions of the Arctic Zone of the Russian Federation

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Integral Assessment of the Sustainability of Socio-Ecological and Economic Systems and the Quality of Life of the Population in the Regions of the Arctic Zone of the Russian Federation

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Abstract. The article deals with the integral assessment of the state and sustainability of socio-ecological and economic systems (SEES). The integral assessment of SEES, 9 regions of the Arctic Zone of the RF (AZR) and one region of the central Russia (Tver Region) is used as a foundation for the analysis of the state of SEES and the quality of life of the population, as well as the ability of SEESs to maintain their properties and quantitative characteristics in case of an external impact on the system or any intrasystem changes. Eight scenarios of impact on subsystems and systems as a whole at the regional level were developed to assess sustainability. The article presents the results of the evaluation of the quality of environment and the quality of life of the population in the regions in 2003-2015. The main goal of the study was to identify situations in which SEES, upon the impact assigned upon it, will not be able to maintain its properties and parameters and will move to another class, both in separate subsystems and as the whole system.

1. Introduction

The relevance of the research is conditioned by the need to develop the theory and practice of assessment of the state of complicated natural and social systems, their non-additive (emergent) properties, as well as systemic modeling of natural and social transformations of eco-, geo-, and social systems. The article examines the integral assessment of the state of the socio-ecological and economic system (SEES), the quality of life of the population and the sustainability of SEES. A conventional formula of such a system can be outlined as follows: SEES = biocommunities + physical-geographical environment (biotopes) + population + economics + social conditions (culture + politics + education +...). We understand the condition of SEES as a characteristic of the system at a certain point in time. The emphasis is placed on the comparative assessment of the quality of life in the regions of the Arctic Zone of the Russian Federation (AZR) in the period between 2003 and 2015 and its comparison with other regions of the Russian Federation (Tver Region, Russia).

The latest recommendations in the field of global, regional, economic and social development were specified in the work of the Commission of Stiglitz, Sen and Fitoussi [1-3]. To organize its work, the Commission was divided into three working groups, which studied, respectively, the traditional issues of GDP assessment, the quality of life issues and sustainability issues. The working groups made

recommendations on each of these areas [1], which became known as the 12 recommendations for fundamental change in the foundations of the state statistics in France and the rest of the world.

The peculiarity of the modern stage is not only substantiation of representative criteria or groups of criteria for the assessment of state of natural and socio-ecological and economic systems, but also the development of models of analysis and synthesis of indicators taking into account the use of non-complete, non-exact and non-numeric information on the criteria and priorities of the assessment [4, 5]. It is noted that it is difficult to apply mathematical modeling to such studies, and that the number of evaluation criteria is constantly increasing.

2. Materials and methods

In our publications on the results of integral assessment of the state of eco-, geo-, and sociosystems and their emergent properties [7-9] we noted that in case of single (direct and indirect), complex and multicriteria assessments of the state of systems, it is observed that the values received within the framework of indicator approach are incomparable, with one criterion (indicator) or a group of criteria the system falling into one class, and another (others) in another class (other classes). Thus, the interpretation of the results leads to uncertainty. We recommended to use multicriteria and multilevel estimations simultaneously, taking into account the modeling of evaluation priorities within the levels (subsystems) and between them on the basis of "*nnn*-information". Taking into account the multilevel structure (2-3 levels, in general) also simulates the emergence nature of the system, because it considers the non-equilibrium of criteria weight not only within the groups, but also between them. We recommend the following methods: The method of randomized aggregated indicators (MRAI) and its modern versions, which the authors called "ASPID-Methodology", i. e., methodology of analysis and synthesis of parameters in the context of information deficit, or APIS-methodology (Aggregated Preference Indices System) [4, 5].

At the modern stage, the level of foreign research is characterized by the accumulation of methodological and practical experience in the study of the state of complex systems in the nature and the society and their specific subsystems [10-13]. A popular method is the use of a spider chart ("rose chart" in the Russian literature), which combines into a single picture the information on a large number of indicators [10]. Other approaches involve the construction of complex indicators, which are a combination of the set of parameters used into a single composite sustainability indicator (CSI) [10], in which the parameters are taken into account with their weights reflecting the priority of each value.

In our approach, the stable state of the SEES of a region is characterized by the ability of the system to maintain its properties and regime parameters upon an external impact on the system or intrasystem changes which characterize the quality of life of the population of the region. Based on the definitions of the quality of life, the main objective of the integrated assessment may be to identify a set of natural, social and economic conditions that determine, to a greater or lesser degree, human health, both personal and social, and human needs, i.e., the match between the life environment of a healthy person and the person's needs.

The general basis for the construction of integrated indicators was described by us in numerous publications, including our works [6-9]. The works feature some schemes of the generation of integrated indicators, criteria, units and levels of assessment.

The scenarios for the assessment of the impact on each subsystem of the region SEES are described in detail in our work [7].

The environmental subsystem includes 8 parameters for evaluation: 1) emissions of polluting substances into atmospheric air from stationary sources (thousand tons); 2) capture of atmospheric pollutants from stationary sources (thousand tons); 3) fresh water consumption (million cubic meters); 4) the volume of the water circulating and used in a successive order (million cubic meters); 5) reforestation (thousand hectares); 6) fertilization on one hectare of agricultural crops seeding in agricultural organizations (tons); 7) discharge of polluted wastewater into surface water bodies (million cubic meters); 8) generation of production and consumption waste (thousand tons).

The economic subsystem includes 5 parameters for evaluation: 1) population (estimated at the end

of the year; thousand people); 2) number of unemployed (thousand people); 3) monetary income per capita in a month (rubles); 4) the number of residents with income below the subsistence minimum (as % of the total population); 5) the number of enterprises and organizations (pcs.).

The social subsystem includes 5 parameters for evaluation: 1) life expectancy at birth (number of years, the whole population); 2) number of registered crimes per 100,000 population; 3) the number of visits to museums per 1,000 population; 4) number of hospital beds (thousand); 5) number of preschool educational institutions.

All the indicators are selected from the data of the Federal State Statistics Service of Russia (Rosstat) website (collections "the Regions of Russia"). The calculation technology is based on the convolution of indicators at the first and second levels and identification of situations in which the SEES will not be able to preserve its properties and mode parameters (state class) with the specified hypothetical impact on it, considered as separate systems and as a whole. When planning scenarios of the deterioration of the situation in the subsystems at the first level of the convolution, the subsystems characteristics were set with due consideration for the various direction of the parameters. The state of the system and quality of life of the population of the region were evaluated for 5 grades (I – high; II – above average; III – average; IV – below average; V — low) in which it was in 2013. The proximity of the integral value to 0.0 corresponds to the high quality of life of the population, the proximity to 1.0, to the low quality.

3. Discussion of the results

The analysis of the obtained results brought us to the following primary conclusions. In 2003, the quality of life of the population of the key region (Tver Region) at the second level of the convolution was characterized by the value of the aggregated indicator (the integral indicator of the final level of convolution) of 0.64 (class IV, average); in 2013, the value was 0.57 (the borderline between classes III and IV). The change in the quality of life of the population, as it follows from the calculations, was most influenced by the economy (the integral index of the subsystem decreased by 18%). The contribution of the social subsystem was 6.7%, and that of ecological subsystem was 8.9%. In general, the period from 2003 to 2013 was found to be characterized by the improvement of social and environmental conditions.

The class boundaries for class III of the integral indicator of the ecological subsystem: 0.37-0.56; for class IV: 0.56-0.77. The hypothetical deterioration of only the ecological situation (parameters of the ecological subsystem) by 30% in all 8 parameters did not change the class of ecological state of the system. The integral indicator of the environmental subsystem in this case grew by 7.3% (from 0.41 to 0.44).

On the second level of convolution, in terms of the value of the aggregate indicator, the state of the SEES and the quality of life of the population moved from the borderline situation between III and IV classes in 2013 (0.57) to IV class (0.58). The change is generally negligible (1.8%), but it characterizes the transition of the system to a more senior class and should therefore be mentioned, as the system as a whole was found to be unable to fully preserve its characteristics and the quantitative values of its modes, and thus was vulnerable to the deterioration of the environmental situation (by 30%). A twofold hypothetical deterioration of only the environmental situation in all 8 parameters changes the value of the aggregated indicator of the ecological subsystem by 17% (0.48, III class; previous value 0.41, III class) and brings the quality of life on this subsystem to class IV (the width of the class interval being 0.56-0.77). The aggregate value of the standard of living increased by 3.5%. The aggregate value is characterized by class IV (0.59 being the left boundary of IV class; the value used to be 0.57, in the middle of the class). The borderlines of IV class for the aggregated indicator: 0.56-0.79.

Hypothetical deterioration 30% of only the economic situation in all 5 parameters changed the value of the aggregated indicator of the economic subsystem by 6.8% (from 0.59, the borderline between classes III and IV, to 0.63, which is IV class, closer to the left extremity), however, by the size of the aggregated indicator at 30% reduction in the economic performance, the quality of life class

changed only slightly, by 1.8% (0.57 in 2013 and 0.58 upon 30% deterioration). A twofold hypothetical deterioration of only the economic situation in all 5 parameters of the economic subsystem caused an increase in the integral indicator of the unit by 20% (0.71, IV class; the previous value was 0.59) with the width of the class interval of 0.59 to 0.81. This did not change the class of the integral indicator, but brought the system closer to the quality of life assessed by the economic subsystem as class V. In this case the quality of life, in terms of the aggregated indicator, deteriorated by 7% and was characterized by the aggregated indicator of 0.61 (class IV), the previous value being 0.57 (borderline value between classes III and IV), with the interval range of the aggregated indicator of class IV from 0.56 to 0.79.

Hypothetical deterioration 30% of only the social situation in all 5 parameters changed the value of the subsystem's aggregated indicator by 18.6% (the previous value of 0.70, which is IV class, changed to 0.83, which is V class, closer to the left extremity, with the interval range of class V of 0.80-1.00), however, in terms of the aggregated indicator, the quality of life changed only slightly, by 7% (0.57 in 2013 and 0.61 upon 30% deterioration of the social conditions). A twofold hypothetical deterioration of only the social sphere in all 5 parameters changes the class of the social subsystem integral index by 34.3% (0.94, V class, the previous value being 0.70). The quality of life of the population, in terms of the aggregated indicator, decreased by 21% (0.69, IV class, whereas in the past it was 0.57, i.e., the borderline value between III and IV classes), the width of the interval of class IV being 0.56-0.79.

It can be noticed that the most sensitive subsystem was the subsystem of the social environment. In its respect, the maximal increase of the effect from the impact, both on separate subsystems, and in general on the socio-ecological and economic system (second level), is observed. It is noticeable that after a 30% worsening of the situation the consolidated evaluation depends more on economic factors.

It is also of interest to consider simultaneously the possible decline in the quality of life across all the subsystems occurred at the same time. For this purpose, the aggregated indicator of the quality of life was calculated for the case of a hypothetical 30% deterioration of conditions in all the subsystems at the same time compared to 2013. In this case, the aggregate value is equal to 0.63 (IV middle class). Before the change it was 0.57 (borderline value between III and IV classes). The percentage value of the change was 10.5%. In the first approximation, this value corresponds to the sum of the percentage values of the changes in individual subsystems: 1.8+1.8+7.0. With a twofold hypothetical deterioration of the quality of life across all the subsystems at the same time, we get the aggregated indicator of 0.71 (IV right border). It was 0.57 (borderline value between III and IV classes). The percentage value of the change was 24%. Thus, in case of a twofold hypothetical deterioration of parameters we get a practically linear increase of the aggregated indicator and the transition of the quality of life from the borderline value between classes III and IV to class IV (closer to the borderline with class V). A twofold change of the situation in one of the subsystems towards the deterioration of the quality of life compared to 2013 results in an increase of the aggregated indicator of the environmental subsystem by 17%, of the social subsystem by 34% and of the economic subsystem by 20%. In terms of the aggregated indicator, a twofold change of the situation across all the subsystems simultaneously results in 24% increase of the aggregated indicator. This increase leads to a deterioration of the quality of life by approximately one class.

In some more complex examples, taking into account different weights of the parameters within subsystems and between them, the non-linear nature of the relations; non-complete, non-exact and non-numeric information on the priorities of assessment, multilevel information convolution is also introduced. The weighting factors are set on the basis of information deficit models [4, 5]. The comparison of the states of the systems on an integral basis gives an opportunity to quantify the spatial and temporal peculiarities of their dynamics and the degree of their transformation.

In [9] we noted the main drawback of experiments with hypothetical changes in the situation in the regions. This main disadvantage is in the fact that in a real-life conditions the simultaneous hypothetical change of load by 30%, 50%, doubling of the load, etc. within one of the sectors or in all the subsystems simultaneously is unlikely. Each parameter selected as a representative criterion will have its own pace and direction of changes. The situation is complicated by the fact that different

regions may have different rates and directions of such changes. Therefore, in the next phase of the research, it was necessary to examine the temporary change of each of 18 criteria, determining the trends for the regions. These results are described in [9] by the example of the Komi Republic in 2003-2013.

As expected, the analysis of the trends of changes in individual characteristics showed that the rate and direction of the changes were different. This conclusion was used in experiments with the regions of the AZR. As a result, it was found that 8 regions have a tendency towards the improvement of the quality of life of the population. Murmansk Region, the Komi Republic, the Khanty-Mansiysk Autonomous District of Ugra, the Sakha Republic (Yakutia): improvement of the quality of life of the population by 7-10%. Arkhangelsk Region, the Nenets Autonomous District, the Chukotka Autonomous District, and the Yamal-Nenets Autonomous District: improvement of the quality of life of the population by 10-12%. The quality of life remained unchanged in the Taimyr (Dolgano-Nenets) Autonomous District in the period from 2003 to 2005.

To compare the quality of life in the Arctic Regions of the Russian Federation with the regions of the Central Part of the Russian Federation, the quality of life of Tver Region population in 2003 and 2013 was considered. In terms of the aggregate indicator, in the period from 2003 (0.64) to 2013 (0.57) the quality of life of the population in Tver Region improved by 11%. This indicates that the quality of life in the regions under comparison was changing at similar rates.

4. Conclusion

In conclusion, we would like to mention the advantages of the use of the approach under consideration for the evaluation of the integrative properties of complex natural and social systems and the quality of life of the population. When building classification models, the researcher introduces the classes of the state of the system and the classes of the quality of life; uses axiological approach and axiometry (ecological qualimetry), substantiates the type of the integral indicator, solves the problem of normalization of raw data with due account of the type of relation (direct, reverse) and its non-linearity, takes into account the *nnn*-information (non-numeric, non-exact and non-complete) on the evaluation priorities; works with the evaluation scales of the necessary and sufficient evaluation criteria, although it can also use qualitative scales for evaluation; the researcher can introduce several levels of convolution of indicators, sets or models the weights (priorities) of evaluation within groups, subsystems (levels) and between them and can change them if necessary.

The use of models in a GIS environment allows to perform zoning of objects or territories by the values of their integral indicators; to trace the temporal dynamics and spatial differences of the integrated indicators, to make conclusions on the ability of the systems to maintain or change the class of their state (quality) in time. It was also discovered that SEES is able to maintain its properties and the properties of the subsystems or to change them when the "normal impact level" is exceeded.

5. Acknowledgements

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