Assessment of regions' socio-economic development based on non-metric data

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***Abstract* — Assessment of socio-economic development of both separate territories and countries as a whole, comparison of the received estimations to identify the development disproportions, lacks, and gaps, application of the best practices to decide the revealed problems promotes the development of balanced state regional development policy. Quite common tasks of such assessment are the ranking of regions and their grouping according to some generalized socio-economic development characteristics. The solution to these problems is complicated by the use of a set of indicators of non-numerical nature because traditional statistical methods are unsuitable for their processing. The paper considers the solution to the problem of constructing a consensus rank based on Kemeny's median. To solve the problem of grouping regions, an approach is proposed based on the picture of regions in the space of partial consensus rankings for economic and social development separately, with the subsequent detection of object stratification in this space. The practical implementation of the proposed approach according to partial rankings is given. A heuristic algorithm was used to construct Kemeny's median. The obtained grouping of the regions of Ukraine reproduced as a whole their order following the resulting consensus ranking. Comparison of the obtained results with the known results of solving such tasks, calculated on the set of metric indicators also showed their consistency.**

***Keywords: socio-economic development, region, non-metric indicators, ranking, grouping, Kemeny's median*.**

INTRODUCTION

The regional structure of each country is a complex entity, which is determined by a large number of different characteristics. Assessing both individual components of socio-economic development of regions and its level in general, are important tasks of modern regional policy, as their solution helps to identify regional disparities and gaps in the individual territorial units' development, to establish imbalances, inequalities, and stratification based on selected characteristics. The obtained results allow us to reflect the significance of the interrelations of the studied processes and phenomena, to provide information on the differences of socio-economic development of the regions in a concentrated form by grouping or ranking them. Smoothing interregional socio-economic differentiation, identifying and ensuring a balanced trajectory of regions' sustainable development are the content of modern regional development strategies of most countries, including Ukraine, which is reflected in the regional development programs [1, 2].

Therefore, among the tasks of assessing the regions' socio-economic development should be noted the tasks of grouping and ranking of regions based on a set of initial indicators. The solution to these problems is complicated by the multidimensionality of their description and the multifaceted effect of the initial indicators on the final result. Indicators measured on non-metric scales can also be used for individual components. In particular, such data may be the results of expert surveys or ratings formed by various government institutions. Under such conditions, the use of traditional statistical methods is limited due to the inadmissibility of many mathematical procedures for processing non-numerical data. Therefore, it is necessary to use special tools that take into account indicators of different nature in the final result.

LITERATURE REVIEW

Addressing issues related to the assessment of regional development is reflected in a significant amount of scholars' research. At the same time, there is a variety in the targets and tasks that are solved through the study, in data processing techniques, in sets of initial indicators. One of the most common approaches is the use of a composite index of socio-economic development, which is developed by a full reduction of selected indicators. The comprehensive index assessment technology is presented in articles [3, 4] for interstate comparisons of socio-economic development. Papers [5 – 10] present an assessment of regional imbalances and measure the relative backwardness of regions at the country level. In papers [11 – 14], in addition to calculating the numerical values of the composite index and ranking regions by this indicator, the use of scales to determine the socio-economic development level is proposed. Besides the traditional approach of determining intervals of equal length for each level, original techniques have been used. In particular, to reach this purpose, Rahaman and Ray [12] proposed to use deprivation index, average deprivation index, and composite development Index. Paper [13] described an iterative procedure to identify the levels' bounds of the region's socio-economic development scale.

The use of multidimensional statistical analysis methods, in particular, cluster analysis [15 – 19], is quite common for solving the problems of grouping regions by socio-economic development indicators. This also addresses the issue of identifying factors that, on the one hand, determine the disparities between different cluster formations and on the other hand, describe the similarities within the identified clusters. Less common is the use of multidimensional scaling methods, which allows both the grouping of regions in the space of latent indicators by the characteristics of socio-economic development and the ranking of objects under observation by some generalized characteristics [20 – 24].

The combination of methods of multidimensional statistics with fuzzy multiple models, in particular, the use of fuzzy clustering methods and fuzzy Klassen techniques for grouping regions by indicators of socio-economic development, is reflected in the articles [25 – 28].

Stankovich with co-authors proposes to use Data Envelopment Analysis (DEA) base on linear programming

techniques [29]. The application of this method allowed us to assess the effectiveness of socio-economic development and to form recommendations for the use of best practices in the formation of the state policy of regional development.

These approaches are based on the use of quantifiable indicators. However, very often the source data can be indicators that are non-metric, for example, are the results of pairwise comparisons of regions, expert surveys, or rankings for some characteristics. Under such conditions, the use of quantitative methods is incorrect and this leads to the use of methods of non-metric statistics. At the same time, the task of constructing a generalized ranking of regions and their grouping (clustering) remains relevant. Issues of ranking data processing in the construction of consensus ranking are presented in [30 – 36]. Among the methods that are used in the processing of ordered data, it is worth noting the method of Kemeny's median, Litvak's method, Cook-Seyford's method, Condorcet's method, the Borda's method. However, these methods were practically not used to solve the problems of regional development assessment.

Summarizing the presented results, we can conclude that, despite a large number of developed approaches to assessing the components of regional development, presented in the scientific literature, the issue of taking into account indicators of non-metric nature is given insufficient attention.

The purpose of the study is to solve the problem of ranking and grouping regions based on indicators of non-metric nature.

Problem Description and Methodology

Let's consider the problem of designing a generalized ranking of a set of objects in the presence of partial rankings for this set of objects (in our case, regions) for some set of indicators. So, all source data are data of non-metric nature.

Let's use the notation:

$R=\{r_i\}$, $i=1..m$ – a set of objects for which the problem of designing a generalized (consolidated, consensus) ranking is solved; m - number of objects;

$\Omega=\{\Omega_j\}$, $j=1..n$ – a set of non-metric indicators, measured on an ordinal scale, which determines the partial rankings of the studied objects; n – number of indicators; subset $\Omega^{(E)}\subset\Omega$ consists of indicators, that characterize regional economic development, a subset $\Omega^{(S)}\subset\Omega$ – characterize the social sphere of regional development.

$X=\{x_{ij}\}$, $i=1..m$, $j=1..n$ – a matrix that expresses a set of partial ranks of objects under study, created on the selected set of indicators Ω; x_{ij} – the rank of object r_i measured by Ω_j. In this case, we assume that the value of the indicator is smaller x_{ij} means the higher rank of the object r_i, that is, the highest is rank 1, the lowest is rank m. In this context, the expression $x_{ij}<x_{kj}$ means, that the object r_i dominates the object r_k, or $r_i \succ r_k$ by Ω_j; if $x_{ij}=x_{kj}$, then the objects r_i and r_k are equivalent in the ranking by the indicator Ω_j, i.e. $r_i \sim r_k$.

The problem is to create a generalized ranking of the set of objects R from the initial data represented by the matrix X. Usually such a problem is solved concerning some optimality criterion, which will determine the "best" ranking among all ones. This criterion can be a criterion for the minimum total distance from the optimal (consensus) ranking to all rankings, which are given by the initial data.

Denote by X_j – ranking by the j-th indicator Ω_j: $X_j = \{x_{1j}, x_{2j}, \dots, x_{mj}\}^T$, and by $X^* = \{x_1^*, x_2^*, \dots, x_m^*\}^T$ – required consensus ranking. The distance between the two rankings X_i and X_j is shown by the expression:

$$d(X_i, X_j) = \sum_{k=1}^{m} |x_{ki} - x_{kj}| \quad (1)$$

So, the task of finding a consensus ranking can be written as follows:

$$d(X^*, X) = \sum_{i=1}^{m}\sum_{j=1}^{n} |x_i^* - x_{ij}| . \to min \quad (2)$$

$$\begin{cases} X^* = \Delta \cdot U; \\ \delta_{ij} \in \{0; 1\}; \\ \sum_{i=1}^{m} \delta_{ij} = 1; \\ \sum_{j=1}^{m} \delta_{ij} = 1; \\ U = \{1,2, \dots, m\}^T; \end{cases} \quad (3)$$

Tasks (2) – (3) is a linear integer programming problem with dichotomous variables and corresponds to the assignment problem. Its solution can be obtained, in particular, by the Hungarian method or branch-and-bound method [37-40]. However, the search for a solution is significantly complicated with the increasing dimension of the task and the fact that the desired resulting ranking can have related ranks - when several objects are assigned the same rank values.

Let's consider finding a consensus ranking by calculating Kemeny's median using a heuristic algorithm [41]. To do this, it needs to construct for each ranking X_k the matrix of paired comparisons $P^{(k)}$, which elements are determined by the rule:

$$p_{ij}^k = \begin{cases} -1, & x_{ik} > x_{jk}; \\ 0, & x_{ik} = x_{jk}; \\ 1, & x_{ik} < x_{jk}; \end{cases}, \quad (4)$$

$k=1..n$; $i,j=1..m$.

Then expression (1) takes the form:

$$d(X^*, X) = \sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{n} |p_{ij}^* - p_{ij}^k|. \quad (5)$$

Suppose that in the ranking X^* the relation of advantage $r_i \succ r_j$, is satisfied, i.e., $p_{ij}^* = 1$. We write the loss matrix V, which elements are calculated by the formula:

$$v_{ij} = \sum_{k=1}^{n} |p_{ij}^* - p_{ij}^k| = \sum_{k=1}^{n} |1 - p_{ij}^k|, \quad (6)$$

$i, j=1..m$.

Next step, for each row of the matrix V, the total amount of losses is calculated using the formula:

$$v_i = \sum_{j=1}^{m} v_{ij}, \quad (7)$$

$i=1..m$, which serves as a basis for finding a consensus ranking. To do this, we find the smallest value of the vector of total losses, followed by the removal of the corresponding object from further consideration. Next step, the matrix V is reduced by recalculating its values by removing the elements

of the matrix corresponding to the object removed from consideration, and the process is repeated [42].

It is possible that, during such a ranking process, the next step will obtain several minimum values of total losses for the reduced in this step loss matrix. This means that the respective objects (regions) must receive the same rank, i.e., the given algorithm uses ordering with related ranks.

To assess the importance (weight) of each of the partial ordinal indicators Ω_j, j=1..n, we can use the absolute value of Spearman's rank correlation coefficient: the higher the value, the more the resulting consensus ranking X^* agrees (coincides) with the partial ranking X_j, j=1..n.

The coordinated ranking obtained as a result of the above heuristic algorithm allows identifying the place of each region in their general structure. But the ordinal scale doesn't allow to determine the degree of difference between studied objects, so this ranking doesn't provide information on the value of differences between regions by the socio-economic development level. The use of a composite index to estimate such differences will not give the desired result, because the addition and multiplication (magnification) of ordinal quantities don't make sense.

We propose to use the grouping of regions based on such considerations. For each group of rank indicators $\Omega^{(E)}$ and $\Omega^{(S)}$ the partial consensus ordering X_E^* and X_S^*. is constructed. Next, the studied objects are depicted in the space of partial consensus rankings and their natural stratification is identified. This allows establishing a regional structure by identifying clusters of regions, to identify gaps in their socio-economic development but doesn't allow to measure the extent and magnitude of such gaps, which is a common disadvantage of using ordinal data.

Results and Discussions

Consider the problem of consensus ranking on a case of Ukraine's regions according to the approach proposed. As initial data, we choose non-metric indicators that reflect the partial rankings for individual components of socio-economic development: Ω_1 – Economic and social cohesion; Ω_2 – Economic efficiency; Ω_3 – Investment and innovation development and foreign economic cooperation; Ω_4 – Financial self-sufficiency; Ω_5 – Development of small and medium business; Ω_6 – Labor market efficiency; Ω_7 – Infrastructure development; Ω_8 – Renewable energy and energy efficiency; Ω_9 – Availability and quality of services in the field of education; Ω_{10} – Social protection and security; Ω_{11} – Rational use of nature and quality of the environment.

In this case, the first six indicators reflect the economic development of the regions, ie, is a subset of $\Omega^{(E)}$, and the next five characterize the social sphere and is a subset of $\Omega^{(S)}$. The use of ranking data, in this case, is justified, because each of the presented sets of indicators is an integral latent characteristic of the relevant component of regional development and is reflected by a set of quantitatively measurable indicators.

Initial data are the outcomes of rating assessment of Ukraine's regions on a selected above set of indicators for 2019 presented by the Ministry for Communities and Territories Development of Ukraine [43].

For the convenience of representation of regions at carrying out calculations, we will assign to each region the corresponding code (Table I).

TABLE I. Correspondence between the name of Ukraine's region and its code designation

Code	Region	Code	Region
r_01	Vinnytsia	r_13	Mykolaiv
r_02	Volyn	r_14	Odesa
r_03	Dnipro	r_15	Poltava
r_04	Donetsk	r_16	Rivne
r_05	Zhytomyr	r_17	Sumy
r_06	Zakarpattia	r_18	Ternopil
r_07	Zaporizhzhia	r_19	Kharkiv
r_08	Ivano-Frankivsk	r_20	Kherson
r_09	Kyiv	r_21	Khmelnytskyi
r_10	Kyrovohrad	r_22	Cherkasy
r_11	Luhansk	r_23	Chernivtsi
r_12	Lviv	r_24	Chernihiv

The initial values of the partial ratings of socio-economic development of the regions according to the selected system of indicators for calculations are presented in Table II.

TABLE II. Initial data to make the calculation

Region	Indicators' values										
	Ω_1	Ω_2	Ω_3	Ω_4	Ω_5	Ω_6	Ω_7	Ω_8	Ω_9	Ω_{10}	Ω_{11}
r_01	8	1	16	5	15	6	10	13	12	3	11
r_02	11	20	1	24	16	22	18	6	9	4	4
r_03	2	2	6	3	21	2	2	7	20	7	17
r_04	23	17	14	2	24	23	22	24	7	21	24
r_05	19	13	19	12	14	13	24	3	10	12	13
r_06	1	22	8	22	9	21	11	15	24	22	2
r_07	7	4	9	20	22	15	17	20	22	11	14
r_08	3	14	20	13	18	9	14	19	23	6	15
r_09	13	3	5	1	12	1	7	12	2	9	23
r_10	21	10	2	15	2	14	5	4	4	18	21
r_11	24	24	22	4	23	24	21	23	8	20	22
r_12	4	12	11	7	10	7	12	10	14	23	7
r_13	12	7	4	10	19	4	9	5	18	19	19
r_14	5	18	17	18	8	8	6	8	6	15	16
r_15	9	6	7	6	20	18	20	18	15	14	6
r_16	15	9	24	16	13	12	4	1	21	2	5
r_17	22	21	13	17	11	16	13	17	5	8	18
r_18	14	15	21	9	7	19	3	21	17	13	1
r_19	16	16	10	8	1	5	19	16	1	1	20
r_20	10	8	3	23	5	20	23	2	16	17	12
r_21	20	23	23	11	4	10	16	9	13	16	8
r_22	18	5	15	19	17	3	15	14	3	10	10
r_23	6	11	18	21	3	11	1	22	19	5	3
r_24	17	19	12	14	6	17	8	11	11	24	9

Calculate the Kemeny's median for Ukraine's regions. To do this, we use the heuristic algorithm for its calculation. The results of the calculations are presented in Table III.

TABLE III. KEMENY'S MEDIAN X^*

Region	Consensus rank	Region	Consensus rank	Region	Consensus rank
r_01	3	r_09	1	r_17	18,5
r_02	14	r_10	5	r_18	13
r_03	2	r_11	24	r_19	4
r_04	23	r_12	6	r_20	16
r_05	18,5	r_13	11	r_21	16
r_06	22	r_14	9,5	r_22	9,5
r_07	21	r_15	12	r_23	7
r_08	20	r_16	8	r_24	16

The total distance of the obtained consensus ranking from the partial rankings according to the initial indicators, calculated by the formula (2), is d_1=1604. For comparison, the total deviation from the generalized rank, built on the results of ranking based on the total sum of ranks is d_2=1610. The last value is a larger one, and therefore indicates a poorer quality of ranking. Also, we note, that the results of this ranking, presented in Table IV, differ from the result presented in Table III.

TABLE IV. RANKING RESULTS BASED ON THE TOTAL AMOUNT OF INITIAL RANKS

Region	Consensus rank	Region	Consensus rank	Region	Consensus rank
r_01	3	r_09	1	r_17	18,5
r_02	14	r_10	5	r_18	13
r_03	2	r_11	24	r_19	4
r_04	23	r_12	6	r_20	16
r_05	18,5	r_13	11	r_21	16
r_06	22	r_14	9,5	r_22	9,5
r_07	21	r_15	12	r_23	7
r_08	20	r_16	8	r_24	16

Analysis of the ranking obtained allows us to conclude that the highest rating has such objects: Kyiv (r_09), Dnipropetrovsk (r_03), Vinnytsia (r_01), and Kharkiv (r_19) regions, the lowest rating have Donetsk (r_04), Zakarpattia (r_06), and Luhansk (r_11) regions. This result is consistent with the previously obtained results of ranking Ukraine's regions on the comprehensive index, which was calculated from a set of socio-economic development metric indicators [13].

We calculate the values of Spearman's rank correlation coefficients between the initial partial rankings X_j, j=1..11, and the consensus ranking X^*. The results are shown in Table V.

TABLE V. THE VALUES OF THE SPEARMAN CORRELATION COEFFICIENT BETWEEN THE INITIAL PARTIAL RANKINGS AND THE CONSENSUS ONE

Initial partial rankings										
X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
0,25	0,59	0,25	0,26	0,33	0,74	0,57	0,36	0,23	0,42	-0,02

Thus, the calculated consensus ranking is most consistent with the rankings obtained by indicators: Ω_6 – Labor market efficiency; Ω_2 – Economic efficiency; Ω_7 – Infrastructure development. It can be concluded that these indicators have the greatest weight in the construction of Kemeny's median.

Next, we calculate consensus rankings X_E^* and X_S^* for the subset of economic development indicators $\Omega^{(E)}$ and the subset $\Omega^{(S)}$. The results of the calculations are presented in Tables VI and VII.

TABLE VI. KEMENY'S MEDIAN X_E^*

Region	Consensus rank	Region	Consensus rank	Region	Consensus rank
r_01	4	r_09	1	r_17	21,5
r_02	20	r_10	7	r_18	14,5
r_03	2	r_11	24	r_19	5
r_04	23	r_12	3	r_20	10
r_05	18	r_13	6	r_21	21,5
r_06	18	r_14	11	r_22	16
r_07	13	r_15	8	r_23	9
r_08	12	r_16	18	r_24	14,5

TABLE VII. KEMENY'S MEDIAN X_S^*

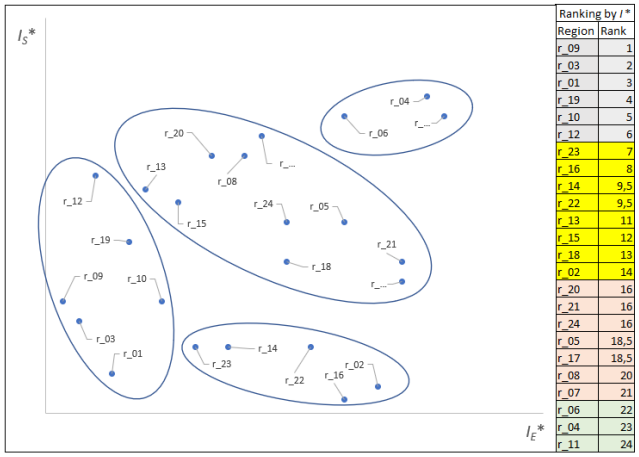
Region	Consensus rank	Region	Consensus rank	Region	Consensus rank
r_01	3	r_09	8,5	r_17	10
r_02	2	r_10	8,5	r_18	11,5
r_03	7	r_11	22,5	r_19	13
r_04	24	r_12	18	r_20	19,5
r_05	14,5	r_13	17	r_21	11,5
r_06	22,5	r_14	5	r_22	5
r_07	21	r_15	16	r_23	5
r_08	19,5	r_16	1	r_24	14,5

As follows from the presented results, the structure of ranking has a different appearance for ranking by economic development and social development. According to the ratings of economic development indicators, the best ones are Kyiv (r_09), Dnipropetrovsk (r_03), Lviv (r_12), Vinnytsia (r_01), and Kharkiv (r_19) regions. This result coincides with the result obtained for the whole set of indicators. The represented regions have a well-developed industry. Donetsk (r_04), Zakarpattia (r_06) and Luhansk (r_11) regions have the lowest ratings. Even though Donetsk and Luhansk regions are also regions with developed industries, at present, due to objective reasons, the enterprises of these regions do not work at full capacity. According to the information provided by the State Statistics Service of Ukraine, there was a reduction in industrial production, reduced investment, reduced export transactions, increasing tax debt in the Zakarpattia region during 2019 [44], which negatively affected their rating.

Because of social development, the best regions are Rivne (r_16), Volyn (r_02), and Vinnytsia (r_01) regions. Industrialized regions, leaders in economic development, have slightly lower ratings in social development, primarily due to the low level of environmental management in terms of environmental quality. Donetsk (r_04), Zakarpattia (r_06) and Luhansk (r_11) regions have the lowest ratings. Despite the positive dynamics of employment, these regions have some of the highest unemployment rates, as well as low ratings on "Renewable Energy and Energy Efficiency" and "Social

Protection and Security", which led to overall low ratings of social development.

Next step, we group the regions in the space of consensus ratings of economic and social development. The results are shown in Figure 1. The right part of the figure shows the ranking of regions in descending order of their consensus rating.



Ranking by I^*	
Region	Rank
r_09	1
r_03	2
r_01	3
r_19	4
r_10	5
r_12	6
r_23	7
r_16	8
r_14	9,5
r_22	9,5
r_13	11
r_15	12
r_18	13
r_02	14
r_20	16
r_21	16
r_24	16
r_05	18,5
r_17	18,5
r_08	20
r_07	21
r_06	22
r_04	23
r_11	24

Fig. 1. Grouping regions in the space of partial consensus ratings' scales

Based on the obtained results, it can be concluded that Ukraine's regions may be divided into four groups, which correspond to their natural stratification in the space of partial consensus rating scales. The first group consists of Kyiv, Dnipropetrovsk, Vinnytsia, Kharkiv, Kirovohrad, and Lviv regions. They are characterized by both quite high ratings for each of the partial rank scales and the overall rating, which can be seen in their image on the right part of Figure 1. The second group contains five regions: Chernivtsi, Rivne, Odesa, Ternopil, and Volyn regions. They are characterized by a high rating of social development and average values of the rating of economic development. In the consensus rating, these regions are located in the middle part of the scale. The third group consists of 10 regions: Mykolaiv, Poltava, Ternopil, Kherson, Khmelnytskyi, Chernihiv, Zhytomyr, Sumy, Ivano-Frankivsk, Zaporizhzhia regions, for which they have average ratings on both partial scales. These regions are also located in the middle part of the consensus ranking. And the last group consists of three regions that have the lowest ratings for both components of socio-economic development. These are Donetsk, Luhansk, and Zakarpattia regions. On the scale of the consensus rating, they are also located in the zone of the lowest values.

The approach presented illustrates the possibility of obtaining groupings, which allowed us to identify the regions' structure based on the set of non-metric indicators. Note that the results obtained in general, correlate with the grouping results obtained by applying cluster analysis technology based on a system of metrics [17]. Thus, the application of the presented approach, which is based on the construction of Kemeny's median, allows solving the problems of ranking and grouping of a set of objects on a collection of non-metric indicators.

CONCLUSION

Structural deformations of the economy, caused by both destabilizing external disturbances and the instability of the internal environment, lead to an increase in the disproportion of socio-economic development of regions and can cause progressed depression in some areas.

To develop effective measures to address the disparities in regional development, it is necessary to apply new approaches to modeling socio-economic situations, in particular, solving the issues of ranking and grouping of regions. The problem is complicated in the case when the initial data are indicators of non-metric nature, which often happens when processing expert data, ranking results, survey data, etc. Such data have the use of limited mathematical tools for their correct processing. One way to obtain a general rank is to calculate Kemeny's median as a consensus rank for all data, which can be reduced to the problem of integer programming. However, under conditions of large dimensionality, the solution to such a problem causes certain computational difficulties, so heuristic algorithms are used to find Kemeny's median.

The peculiarity of processing rank data allows to identify the objects' ordering under observation but doesn't allow to measure the differences between various objects, which complicates their structuring. The solution to this problem is possible by constructing partial rankings and images of the studied objects in the appropriate scale space.

These methods are used to solve the problem of ranking and grouping of Ukraine's regions by non-metric indicators of socio-economic development, which are partial ratings presented by the Ministry for Communities and Territories Development of Ukraine. Comparison of the results of grouping with the location of the regions on a consensus scale showed their consistency. Also, the results calculated are following similar results obtained based on quantifiable indicators and presented in other publications. This shows the favor of the tools used.

The results of the calculations can be taken into account for assessing the state of regions' socio-economic development and creating a set of measures in the implementation of regional development strategies to overcome interregional socio-economic differentiation.

The direction of further studies is the application of methods of comprehensive index assessment technology to identify the level of socio-economic development with the use of non-metric indicators.

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