GENERAL PROBLEMS OF THE MODERN RESEARCH AND INNOVATION OLICY

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SOCIAL RESILIENCE AND VULNERABILITY: A NOVEL METHODOLOGY FOR IDENTIFYING BIFURCATION POINTS

Introduction. *The persistence of systemic destabilizing forces in socio-economic development has complicated the implementation of policy mechanisms aimed at strengthening territorial social resilience.*

Problem Statement. *In contemporary contexts, macroeconomic shocks have heightened social vulnerability. Enhancing social resilience is thus essential to improving quality of life, mitigating social inequality and tension, and increasing citizen satisfaction — constituting a vital mechanism for reducing the adverse effects of such shocks.*

Purpose. *This study is aimed to identify bifurcation points within the resilience — vulnerability continuum of social systems — specifically zones of vulnerability, safety margins, and resilience — under conditions of transformational change, using the Carpathian region as a case study.*

Materials and Methods. *Bifurcation points of territorial social resilience have been determined using a dynamic equilibrium framework. Threshold vectors have been derived based on normal, lognormal, and exponential distributions of primary data using the maximum–minimum approach.*

Results. *Thresholds for each indicator of all social resilience components have been identified in terms of marginal and optimal levels. The upper threshold for the employment rate of the population aged 15—70 has been found to be 69.0%, with a lower optimal threshold of 63.7%; in contrast, Ukraine's employment rate in 2021 was 55.7%. Indicators of demographic security have shown critical trends: for example, in 2021, Lviv Oblast reported 170.1 children per 1,000 residents, which was 48.2 fewer than the lower optimal threshold.*

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Conclusions. *The identified bifurcation points in territorial social resilience underscore the urgent need to establish a modern social development model grounded in digital transformation, equitable access to social services and benefits, robust social protection, and inclusive civic participation.*

Keywords: resilience, territory, vulnerability, Ukraine, shocks, war, social domain, thresholds, bifurcation, vector.

It is impossible to establish effective management processes, create a high level of competitiveness of domestic industrial and economic complexes, and build a strong national economy without a reliable social base. Ensuring the social resilience of the country and its regions is a fundamental prerequisite not only for improving the well-being of the population but also for minimizing the social vulnerability of certain categories of the population and territories, reducing social tension, and increasing the level of satisfaction of citizens' interests.

Critical periods of society's development determine socio-economic, demographic, and environmental transformations that necessitate a revision of traditional ideas about the formation of principles and methods, as well as approaches to ensuring socio-economic resilience of the territory as a new paradigm of progress and revival of the country. Social resilience also implies a focus on human development, preserving the stability of socio-cultural systems and ensuring fair distribution of benefits and equal access to social services.

On the one hand, innovation and technological processes contribute to the competitiveness of a country, region, or territory and reduce the social vulnerability of the population. Structural sectoral transformations and focus on a high-tech economic system are triggers of economic progress and, consequently, an increase in the population's income as an existential indicator of social resilience. On the other hand, economic growth leads to an increase in the use of natural resources, which causes environmental pollution, especially in areas with low levels of development. The deepening of social inequality in Ukraine is formalized in the growing differentiation of the population by living standards, social exclusion, limited or unequal access to social goods and resources, limited needs, and failure to realize one's social rights. Overcoming the identified destructive influences objectively requires substantiation of scientific and applied provisions for the development of information and analytical frameworks for the study of social resilience in the spatial and temporal context.

The problem of weakening social resilience of the population, as well as the realization of its threats, is systemic and complex and has a high degree of social significance, as it directly affects the quality of life and demotivates people to live in the respective territory and realize their economic potential. For these reasons, the issue is actualized in research on economy and social policy. For example, S. Bayramova [1] considers social resilience as a threat to the preservation of human potential in terms of youth. Another study (I. Burov [2]) analyzes the consequences of reducing the level of resilience of the social system, in particular in terms of external labor migration. A. Kuzior et al. [3] go further and actualize the need to address the problems of social resilience from the point of view of deteriorating quality of life and complicated reproduction of human potential. As a result, threats from the social sphere are transformed into a plane where a decrease in labor productivity becomes their main consequence. However, this is not the only economic consequence if the labor market as a whole is destabilized (K. Lindgren, M. Österman [4]). Thus, synergistic effects develop problems of social protection → social security → employment → labor productivity → income → reproduction → social resilience → economic security, etc.

It is important to note that the problems of social resilience are aggravated in times of crisis. In the case of Ukraine, it was first the COVID-19 pandemic (P. Kaczmarczyk [5]; M. Farias, J. Leite [6]) and later the large-scale war (O. Cheromukhina [7]; S. Semiv et al. [8]). Such circumstances are not trivial and require specific attention (in terms

of developing and implementing mechanisms, tools, and means of state regulation of the economy and social and economic policy).

Meanwhile, the state's influence will not be effective if its objects are not clearly defined and identified. The research results show that the following of them are important in terms of the social resilience of the population: demographic component (Yu. Kharazishvili [9]), impeccable social and labor relations (O. Pankova, O. Kasperovich [10]), and standard and quality of life (E. Tate [11]). However, we consider this list to be incomplete and require additional inclusion and consideration of environmental issues, food security, and causality at the intersection of social resilience and social vulnerability.

Social vulnerability is not only a characteristic of the intensification of social risks and the spread of such forms of vulnerability as poverty, social exclusion, discrimination, etc. but also a precondition and consequence of the development of depressive processes in cities and territories. Hence, particular attention should be paid to preventing manifestations of social vulnerability in the form of "crossing" the critical limits of key indicators — characteristics of social resilience and stability (the so-called bifurcation points). It should be noted that to date, a comprehensive methodology for analyzing social vulnerability has not yet been developed and needs to be generalized from the methodological approaches to the analysis of social challenges and threats (M. Gall [12]), summarizing the state of development of social infrastructure, in particular in areas with a lower level of socio-economic development (U. Ivaniuk [13]), researching social innovations and their impact on the quality of life (O. Ilyash et al. [14]), studying the environment of social vulnerability of the population as a whole (O. Mulska et al. [15]) and its environmental factors and aspects in particular (O. Mulska et al. [16]), classification of characteristics of the quality of social and labor relations and employee protection (O. Novikova, L. Shamileva [17]), effects of natural disasters (D. Yoon [18]) and geophysical environment of the population (J. Ran et al. [19]), and research of social aspects of ensuring industrial and technological development and economic security of the national economy (O. Ilyash et al. [20]).

On the other hand, the elevation of this problem to the rank of strategic priority, requiring focus within a separate vector of state and regional policy, is caused by its growth in the system of global management of social progress. We are talking about the aggravation of the problems of deteriorating socio-economic conditions, increasing stratification of the population by living standards, and social exclusion. Meanwhile, Ukraine belongs to countries with extremely high social vulnerability and economic instability. According to ILO criteria, it is a country with a high poverty rate and a large share of the informal economy. Therefore, in the mainstream of further development of the theoretical, methodological, and applied foundations of the causality of social resilience and social vulnerability, as well as solving their most acute and urgent problems, it is important to summarize the results of scientific research that analyzes the impact of weakening social resilience on the deformation of the labor market structure (R. Boschma et al. [21]), the increase in unemployment of young people (J. Jongh [22]; S. Lee et al. [23]), the decrease in employment and the spread of unemployment among all segments of the population (E. Kalu et al. [24]), the transformation of employment problems into acute social challenges and threats, in particular in the context of a full-scale war (T. Pham et al. [25]; S. Syrtseva et al. [26]), and loss of human resources as a result of migration (T. Vasyltsiv et al. [27]).

The problem of social vulnerability and, conversely, aspects of ensuring social resilience, given their social significance, have always been in the focus of scientific discourse. Therefore, a wide range of recommendations has been developed for the development and implementation of a balanced social policy, in particular to counteract global social challenges of humanity (B. Danylyshyn, I. Bohdan [28]), reduce unemployment and improve the characteristics of social and labor rela-

tions (H. Mykhalchenko [29]), improve the institutional environment in the labor market (J. Kim et al. [30]), retain and efficiently use intellectual and human resources (R. Lupak et al. [31]), balance supply and demand in the labor market (T. Markefke, R. Müller-Rehm [32]; J. Wrench [33]), reduce the level and solve the problem of social vulnerability of the population actively involved in migration processes (O. Mulska et al. [34]), and improve working conditions and transition to freelancing and digital employment as effective tools for providing jobs, employment, and income (N. Shpak et al. [35], S. Hamideh [36], Halkiv et al. [37]).

Despite these and other developments, there is an objective need for further improvement of both theoretical, methodological, and applied foundations for identifying bifurcation points in the characteristics of the social vulnerability of the population (and hence the socio-economic system of the territory, region, and country), and for substantiating mechanisms and means of policy to strengthen the social resilience of the population by counteracting its social vulnerability. Due to this approach, the state policy on overcoming the social vulnerability of the population will be systemic and formed and coordinated at the central level of government, since it will continue to have its logical and problematic purpose and functional continuation at the regional level. In particular, it can be in the form of a relevant regional program for overcoming the challenges of social vulnerability of the population in the conditions of war and post-war recovery. Its provisions should be based on a holistic conceptual framework and combine most elements of the regional social policy in Ukraine.

Social vulnerability is studied through a gradation of levels of social resilience in the form of identification of bifurcation points, which is a structural and compositional characteristic of the state of the economic system and reflects the functioning of such areas as *the quality of social and labor relations, the standard of living, and demographic, environmental, and food security*. This list can be supplemented or refined both by components and by individual indicators. Social resilience, in turn, is a subsystem of a higher-level system — economic security, which is achieved through a level of development and economic security that fully meets the needs of the population and the territory as a whole.

There is no single commonly accepted system of social resilience indicators in the scientific discourse, in particular, the base of reliable statistical information is limited, and data on the same indicators is statistically limited, often contradictory or inconsistent. The lack of necessary statistical data complicates the process of building a universal methodology for analyzing social resilience using temporal and spatial approaches. Therefore, the possibility of a full accounting of the components of social resilience is an existential criterion for the development of an information and analytical system for the study of social resilience.

The assessment of social vulnerability of the population provides for the following *principles* of forming a system of indicators for monitoring social resilience:

- *comprehensiveness:* consideration of all significant indicators of social resilience that characterize the impact of factors on the state of the system;
- *systemic nature:* each component and indicator impact the system of social resilience (vulnerability as a whole) in particular and in interaction with other components or indicators;
- *hierarchy:* ranking of factors by importance — from general (components) to specific (indicators);
- *adequacy:* formation of the optimal set of indicators that reflects the real state of the system;
- *unambiguity:* avoiding semantics and ambiguity in the process of interpreting primary information, in particular, dividing indicators into stimulants and destimulants;
- *continuity:* ensuring the possibility of clarifying and adding new indicators to the system; developing special calculation methods to obtain new indicators that characterize the state of the system.

In terms of R&D development of the methodology for studying social resilience, and most often social security, the principle of accessibility is commonly used. It implies the inclusion of only those indicators that can be calculated based on the available statistical reporting and data accounting system. However, the principle of accessibility in this interpretation contradicts the principle of continuity and makes it impossible to further develop the methodology for assessing social resilience, vulnerability, or security.

Considering the mentioned principles, the system of indicators for assessing social resilience can be represented by the formula-function (1). Figure 1 shows the decomposition of social resilience using the systemic-structural approach.

$$f(SS) = (QSLR_t^n, LL_t^n, QSI_t^n, DS_t^n, ES_t^n, PS_t^n), \quad (1)$$

where $QSLR_t^n$ is the quality of social and labor relations in the region n in period t; LL_t^n is the standard of living in the region n in period t; QSI_t^n is the quality of social infrastructure in the region n in period t; DS_t^n is the demographic security in the region n in period t; ES_t^n is the environmental security in the region n in period t; PS_t^n is the food security in the region n in period t.

The definition of social resilience as the ability of the system to maintain dynamic equilibrium ("homeostasis" approach) allows us to calculate empirical indicators within the bifurcation points in the form of marginal and optimal thresholds. This approach assumes that the emergence of new threats changes the previous state of the system, which may also be within acceptable limits (state of dynamic equilibrium).

Thus, social resilience enters a new state with different characteristics from the previous one, while not only the structure of the system (composition of elements) changes but also the systemic links between indicators and the strength of the impact of structural components on the system as a whole. Therefore, homeostasis determines, on the one hand, the ability of the system to maintain resilience in dynamics to ensure optimal functioning, and, on the other hand, the resistance of the socio-economic system to new challenges and threats.

Threshold vectors are defined for each indicator of social resilience: (1) *lower marginal — upper marginal;* (2) *lower optimal — upper optimal*. The vector of optimal values characterizes the permissible interval of values — *safety margin* — when crossing the thresholds does not mean a violation of the homeostasis state (Fig. 2). Violation of marginal thresholds can lead to a loss of resistance or complete social instability. Therefore, the approach of empirical indicators of social resilience to the vector of lower marginal thresholds indicates the transition of the system from a state of equilibrium to vulnerability, and to the upper ones — a state of uncertainty. Interestingly, there is a neutral relationship in the range of optimal thresholds. The range above the upper optimal threshold is determined by a positive inverse relationship, which leads to either social resilience in dynamic equilibrium or instability due to unreasonable growth of empirical indicators, which contradicts sustainable development. The inverse relationship (the lower vector) leads to a weakening of social security, the spread of social vulnerability, and, consequently, the destruction of the dynamic equilibrium of the social system as a whole. The main postulate of guaranteeing social resilience is ensuring that it is within the optimal range (within the "homeostatic equilibrium") rather than maximizing its level (increasing the composite index).

Bifurcation points are identified according to three types of initial data distribution: *normal, lognormal, and exponential*. The normal distribution is typical for most indicators of social resilience and is characterized by a standard density of data scattering. Formulas (2—3) are used to construct the *marginal thresholds* of the normal distribution indicators, and formulas (4—5) are used for the *optimal thresholds*.

$$a_l^{lim} = \beta - \tau\sigma; \quad (2)$$

$$a_h^{lim} = \beta + \tau\sigma; \quad (3)$$

$$a_l^{opt} = \beta - \sigma; \quad (4)$$

$$a_h^{opt} = \beta + \sigma, \quad (5)$$

Component I "Quality of social and labor relations"

Catalysts

- Employment rate of the population aged 15—70, % of the total population of the corresponding age
- Recruitment rate, % of the average number of employees
- Number of individual entrepreneurs, per 1,000 population
- Employment of the unemployed rate*, %

Regressors

- Loss of working time rate, %
- Workload per vacant workplace, persons
- Informal employment rate, % of the employed population
- Share of employees working in hazardous conditions, % of the average number of employees
- Unemployment rate of the population aged 15—70, % of the total population of the corresponding age
- Forced part-time employment rate, % of the average number of employees
- Employee dismissal rate, % of the average number of employee

Component II "Standard of living"

Catalysts

- Average monthly nominal wage, EUR, on average per full-time employee
- Amount of pension benefits, EUR, per EUR 1,000 of GRP
- Disposable income, EUR, per capita
- Internet coverage, % of the total population
- Average amount of state assistance, EUR:
  – to low-income families
  – unemployment allowance
- State budget expenditures, EUR, per capita, on:
  – health
  – social protection and social security
  – education
- Average amount of benefits and subsidies (non-cash) for housing and communal services, electricity, and fuel, EUR, per one household
- Average monthly pension for all categories of pensioners, EUR
- Average monthly pension to wage ratio, %

Regressors

- Consumer price index, % to previous year
- The share of total household expenditures on food, %, per one household per month
- Old housing stock, total area of residential premises, m^2 per 1,000 population
- The share of wages in total household income, %
- Subsistence minimum to average monthly wage ratio
- Wage arrears per full-time employee, EUR
- Number of people with average per capita equivalent total income per month below the actual subsistence level, % of the total population
- The decile coefficient of differentiation of total income of the population

Component III "Quality of social infrastructure"

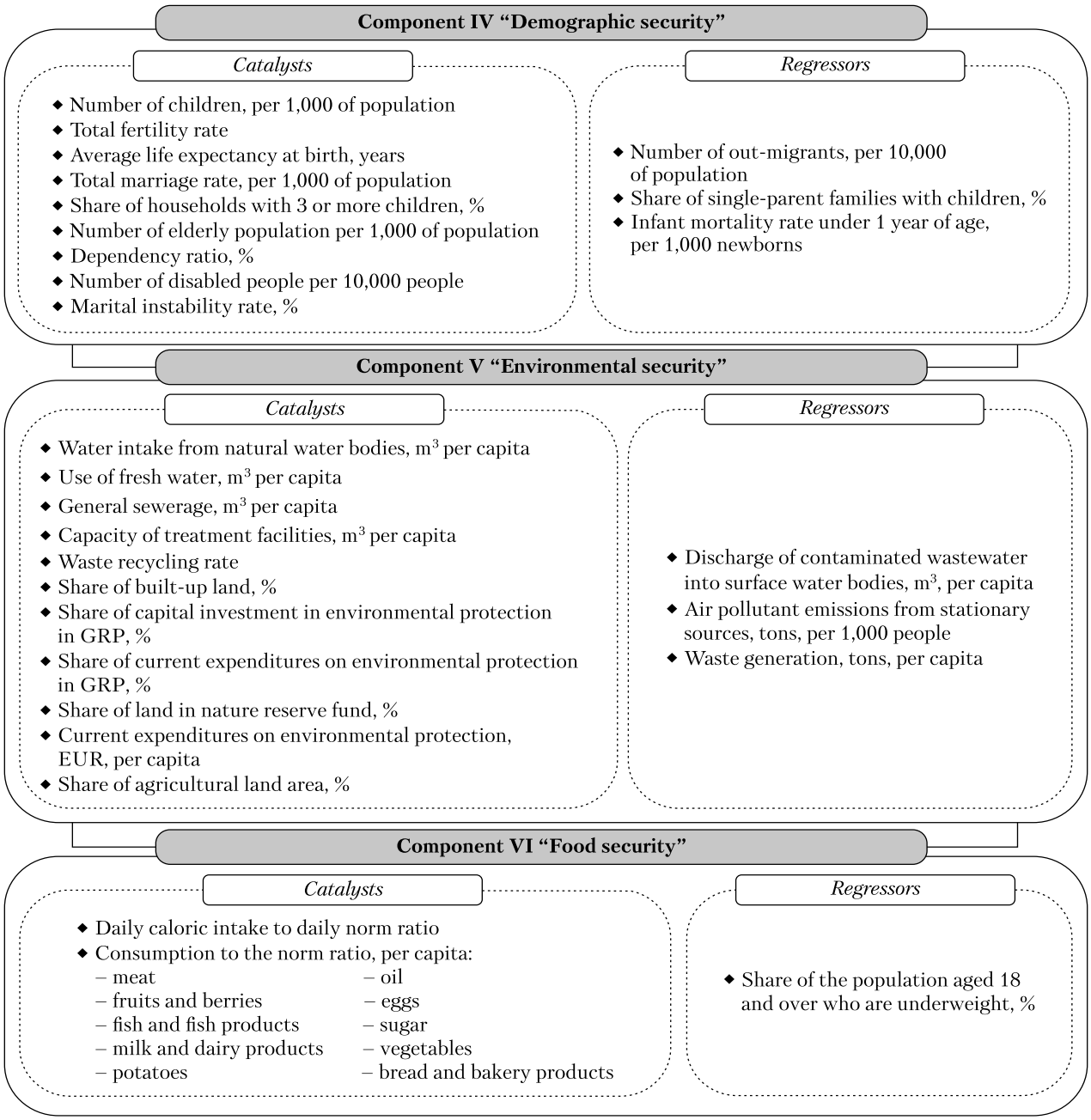
Catalysts

- Coverage of children with preschool educational institutions, % of the number of children of the corresponding age
- Share of households with no persons working, %
- Share of households with, %:
  – housing equipped with water supply and sewerage
  – convenient access to public transport
- Number of hospital beds, per 1,000 population
- Number of visits per shift at outpatient facilities, per 1,000 population
- Coverage of the population with medical personnel, persons, per 100,000 population
- Housing stock per capita, m^2 of the total area
- Number of teachers at HEIs of the 3rd and 4th accreditation levels, persons, per 1,000 students
- Number of research and teaching staff with a PhD and doctoral degree, per 100 postgraduate students
- Share of population living in an overcrowded housing, %
- Share of the population over 6 years of age with higher education, %
- Number of beds in residential care homes for the elderly and people with disabilities, per 100,000 population
- Number of institutions, per 100,000 population:
  – general secondary education
  – higher education

Regressors

- Number of crimes, per 1,000 population
- Morbidity rate, number of newly registered cases of diseases per 1,000 population

a



b

Fig. 1. Decomposition of social resilience: a systemic and structural approach

Note: *indicates the share of unemployed persons recruited by employment centres as % of total registered unemployment.

where a_l^{lim} is the lower marginal threshold; β is the average value of the indicators in the dynamic series; τ is the Student's *t*-test; σ is the standard deviation; a_h^{lim} is the upper marginal threshold; a_l^{opt} is the lower optimal threshold; a_h^{opt} is the upper optimal threshold.

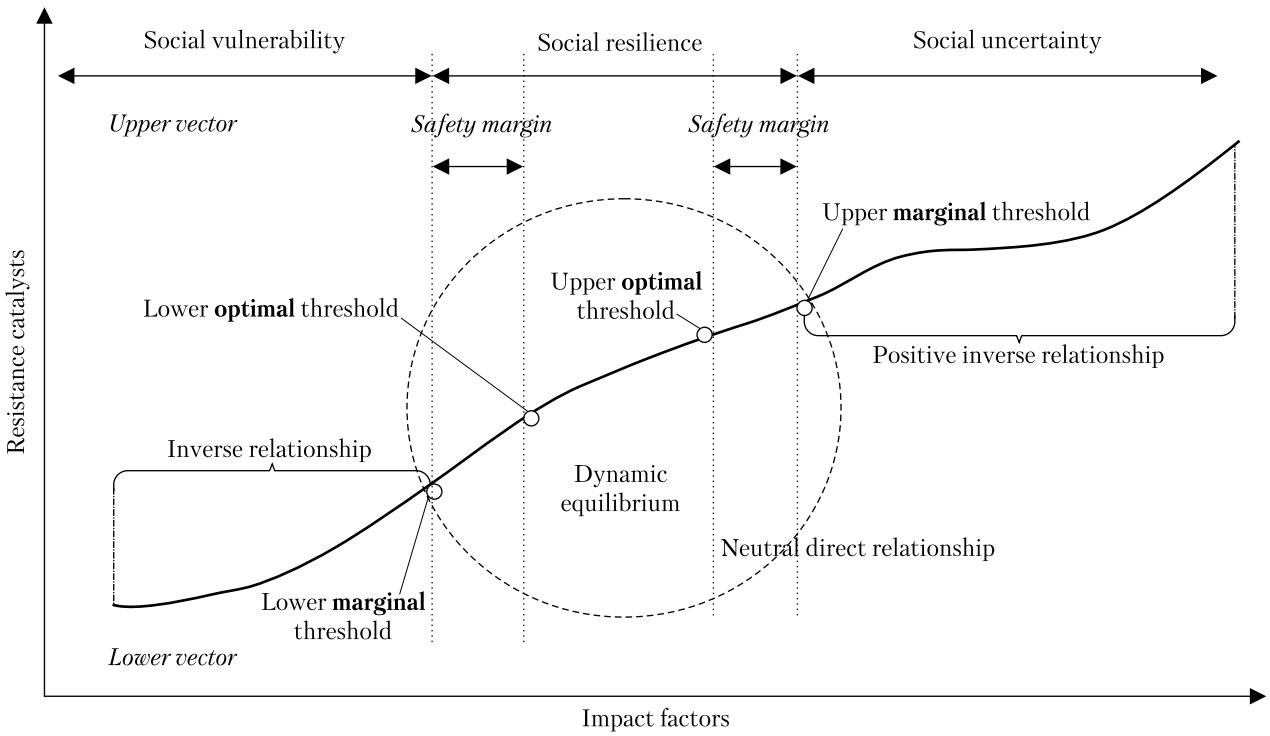


Fig. 2. Identification of bifurcation points in the social resilience-vulnerability system

The lognormal distribution is typical for indicators characterized by significant dynamic changes, which are also determined by the influence of other indicators. This is caused by the fact that the distribution of indicators is not symmetrical about their central axis, so the logarithmization of such values can have both positive and negative values. The lognormal distribution is typical for such indicators as the average monthly nominal wage; disposable income; subsistence minimum to average monthly wage ratio; the average amount of state social assistance to low-income families; the average amount of benefits and subsidies (non-cash) for housing and communal services, electricity, fuel; the share of single-parent families with children; the share of households with 3 or more children; emissions of pollutants into the air from stationary sources.

Formulas (6—7) are used to construct the *marginal thresholds* of the social resilience indicators of the lognormal distribution, and formulas (8—9) are used for the *optimal thresholds*.

$$a_l^{lim} = \beta - \tau\sigma / k_{as}; \quad (6)$$

$$a_h^{lim} = \beta + \tau\sigma; \quad (7)$$

$$a_l^{opt} = \beta - \sigma / k_{as}; \quad (8)$$

$$a_h^{opt} = \beta + \sigma, \quad (9)$$

where k_{as} is the skewness.

The exponential distribution is peculiar to indicators that are continuous and independent in nature, and the rate of their change is permanent. Indicators such as workload per vacant workplace and discharge of contaminated wastewater into surface water bodies are determined by an exponential distribution. The *marginal thresholds* for the exponential distribution indicators are calculated using formulas (10—11), and the *optimal thresholds* are calculated using formulas (12—13).

$$a_l^{opt} = \beta - \sigma / k_{as}; \quad (10)$$

$$a_h^{opt} = \beta + \sigma; \quad (11)$$

$$a_h^{lim} = \beta; \quad (12)$$

$$a_l^{lim} = \beta - \sigma / k_{as}. \quad (13)$$

The article aims to identify bifurcation points in the resilience-vulnerability social system (zones of vulnerability (danger), safety margin, and social resilience) in the context of transformational changes (a case study of the Carpathian region).

Based on the research findings, thresholds for each indicator across all components of social resilience have been defined along two vectors — marginal and optimal (Tables 1—6). The study has revealed that the upper marginal threshold for the employment rate among the population aged 15—70 is 69.0%, while the lower optimal threshold is 63.7%. For comparison, the employment rate in Ukraine in 2021 was 55.7%, which is 5.7 percentage points below the lower marginal threshold. The upper optimal threshold for the number of individual entrepreneurs per 1,000 population is 308.3, whereas between 2010 and 2021, this indicator in Ukraine did not exceed 41.5. The marginal threshold for the unemployment rate among the population aged 15—70 (as a percentage of the corresponding age group) is 10.9%. In 2021, Ukraine approached this threshold, with an official unemployment rate of 9.9% (though expert estimates suggest significantly higher values), while Zakarpattia Oblast exceeded the threshold with an unemployment rate of 11.1%.

A comparative analysis of actual and threshold indicator values reveals a critical situation in the *standard of living* component (Table 2), particularly regarding average monthly nominal wages, the average monthly pension across all pensioner categories, and disposable income. In 2021, the deviation from the lower optimal threshold amounted to EUR 1,909 for average monthly wages, EUR 586 for pensions, and EUR 1,059 for dispo-

Table 1. **Vector of Thresholds of Indicators of the Quality of Social and Labor Relations**

Indicators	Vector			
	Marginal		Optimal	
	Lower	Upper	Lower	Upper
Employment rate of the population aged 15—70, % of the total population of the corresponding age	61.37	68.97	63.71	66.63
Recruitment rate, % of the average number of employees	31.52	48.63	36.79	43.37
Employee dismissal rate, % of the average number of employees	18.42	15.01	17.37	16.06
Number of individual entrepreneurs, per 1,000 population	130.61	387.22	209.57	308.27
Informal employment rate, % of the employed population	20.71	13.63	18.53	15.81
Share of employees working in hazardous conditions (end of year), % of the average number of employees	22.83	20.21	21.13	22.14
Loss of working time rate, %	14.20	6.63	12.20	9.29
Employment of the unemployed rate, %	39.06	67.72	47.88	58.90
Workload per vacant workplace, persons	10.65	1.44	7.51	3.58
Unemployment rate of the population aged 15—70, % of the total population of the corresponding age	10.89	6.50	9.54	7.85
Forced part-time employment rate, % of the average number of employees	31.05	18.91	27.31	22.64
Component indicator of thresholds	**0.602**	**1.000**	**0.690**	**0.819**

Source: calculated by the authors.

sable income. The consumer price index in Ukraine reached 110.1% in 2021, exceeding the lower optimal threshold by 8.8 percentage points. The upper optimal threshold for this index is set at 88.01%. Notably, from 2010 to 2021, Ukraine did not exhibit a downward trend in the consumer price index within the specified range. Furthermore, unemployment benefits in the oblasts of the Carpathian region in 2020—2021 and 2016—2017 were 2.8 and 5.4 times lower, respectively, than the lower and upper optimal thresholds.

As a complex and multidimensional determinant, the *quality of social infrastructure* refers to the overall effectiveness, accessibility, and condition of essential services and facilities that support population well-being and economic stability, including healthcare, education, public safety, housing, and social services. As a component of social vulnerability, the quality of social infrastructure also reflects the objective living conditions and activity environment of the population. Notably, the threshold values for the indicators

Table 2. **Vector of Thresholds of Living Standard Indicators**

Indicators	Vector			
	Marginal		Optimal	
	Lower	Upper	Lower	Upper
Average monthly nominal wage, on average per full-time employee, EUR	2207.57	2909.96	2423.69	2693.84
Amount of pension benefits, per EUR 1,000 of GRP	10.69	15.81	12.26	14.23
Disposable income, per capita, EUR	3419.28	4806.14	3846.01	4379.42
Consumer price index, % to previous year	111.91	77.39	101.29	88.01
Share of total household expenditures on food, per one household per month, %	19.37	15.20	18.09	16.48
The decile coefficient of differentiation of the total income of the population	3.81	2.36	3.36	2.80
Old housing stock, total area of residential premises, m^2 per 1,000 population	52.21	36.52	47.38	41.35
Internet coverage, % of the total population	82.50	97.20	86.40	91.40
The share of wages in total household income, %	18,32	16,45	17,74	17,02
Subsistence minimum to average monthly wage ratio	0.26	0.04	0.19	0.11
Average amount of state assistance to low-income families, EUR	456.18	795.26	560.51	690.92
State budget expenditures on education, per capita, EUR	101.64	560.42	235.56	419.26
State budget expenditures on health, per capita, EUR	91.19	199,14	175.66	184.69
State budget expenditures on social protection and social security, per capita, EUR	272.09	583,.49	367.91	487.68
Average amount of benefits and subsidies (non-cash) for housing and communal services, electricity, and fuel, per one household, EUR	24.60	27.65	25.54	26.71
Unemployment allowance, per capita, EUR	277.12	471.28	336.86	411.54
Average monthly pension for all categories of pensioners, EUR	264.48	1372.42	709.58	1049.14
Wage arrears, per full-time employee, EUR	17.41	0.12	12.09	5.44
Number of people with average per capita equivalent total income per month below the actual subsistence level, % of the total population	10.30	7.46	9.42	8.33
Average monthly pension to wage ratio, %	28.91	70.55	42.08	62.57
Component indicator of thresholds	**0.675**	**1.000**	**0.748**	**0.857**

Source: calculated by the authors.

within this component differ significantly from the actual statistical data for the oblasts of the Carpathian region (Table 3). For instance, in 2021, the preschool enrollment rate — as a percentage of children of the corresponding age — was 38.5 percentage points below the upper marginal threshold in Lviv Oblast and 45.5 percentage points below it in Ivano-Frankivsk Oblast. The situation is particularly critical with regard to the housing stock per capita (m^2 of total area): in 2021, this value was 25.9 m^2 in Chernivtsi Oblast and 26.5 m^2 in Zakarpattia Oblast, falling short of the upper marginal threshold by 14.0 m^2 and 13.4 m^2, respectively. Threshold values for the share of the population aged 6 and older with higher education also highlight structural disparities. In 2021, the national average was 21.9%, compared to 14.4% in Zakarpattia Oblast and 25.8% in Lviv Oblast — figures that remain well below the lower optimal threshold of 39.8%.

Negative trends in the main demographic determinants (fertility, mortality, migration, marriage) in all regions of Ukraine, including the Carpathian region, have led to a significant weakening of the territory's capacity for self-reproduction of the population in the required amount. The obtained

Table 3. **Vector of Thresholds of Social Infrastructure Quality Indicators**

Indicators	Vector			
	Marginal		Optimal	
	Lower	Upper	Lower	Upper
Number of crimes, per 1,000 population	16.71	5.28	13.19	8.80
Coverage of children with preschool educational institutions, % of the number of children of the corresponding age	78.71	92.50	82.40	89.50
Morbidity rate, number of newly registered cases of diseases per 1,000 population	792.26	514.04	706.65	599.65
Share of households with no persons working, %	25.53	32.21	27.58	30.15
Number of hospital beds, per 1,000 population	4.72	11.08	6.67	9.12
Number of visits per shift at outpatient facilities, per 1,000 population	193.33	248.92	210.44	231.82
Coverage of the population with medical personnel, per 100,000 population	879.60	1794.20	1161.01	1512.78
Number of beds in residential care homes for the elderly and people with disabilities, per 100,000 population	100.51	144.81	114.14	131.18
Number of general secondary education institutions, per 100,000 population	29.27	51.40	36.08	44.59
Number of higher educational institutions, per 100,000 population	0.83	2.34	1.29	1.88
Housing stock per capita, m^2 of the total area	34.02	42.51	37.24	39.90
Number of teachers at HEIs of the 3rd and 4th accreditation levels, per 1,000 students	79.57	154.25	102.55	131.27
Number of research and teaching staff with a PhD and doctoral degree, per 100 postgraduate students	201.74	347.13	246.48	302.40
Share of population living in an overcrowded housing, %	47.00	60.16	51.05	56.11
Share of households with housing equipped with water supply and sewerage, %	67.00	90.31	74.18	83.14
Share of households with convenient access to public transport, %	78.05	94.78	88.31	89.61
Share of the population over 6 years of age with higher education, %	35.31	49.79	39.77	45.34
Component indicator of thresholds	**0.611**	**1.000**	**0.717**	**0.861**

Source: calculated by the authors.

thresholds of the demographic security indicators demonstrate critical demographic trends (Table 4). For example, the number of children per 1,000 population in 2021 in Lviv Oblast was 170.1, i.e. 48.2 people less than the lower optimal threshold. A similar situation is observed in other oblasts of the Carpathian region of Ukraine, where the differentiation between the upper optimal threshold and actual data reached 47 persons. For the oblasts of the Carpathian region as border areas, where the intensity of external migration is the highest among other regions of Ukraine, it is important to adhere to a special type of demo-reproduction with the following key features: preservation of quantitative and development of qualitative characteristics of the population, increase in active life expectancy, progressive gender and age structure, optimal balance of internal and external migration processes, strengthening of the role of the family institution, and increase in social responsibility for the life and health of the population. Instead, the opposite trend is observed in the region. For example, the number of out-migrants exceeds the upper marginal threshold 2 times in Zakarpattia Oblast and 3.5 times in Lviv Oblast, while the national average exceeds it 3.7 times. The marriage instability rate in 2021 in Ukraine was 6.96 percentage points higher than the upper optimal threshold.

Maintaining environmental safety indicators within their optimal thresholds is essential for ensuring ecological balance and protecting both the environment and the overall living conditions of the population. Consequently, systematic monitoring of environmental safety metrics relative to permissible limits can support the development and implementation of forward-looking policies aimed at reducing the population's social vulnerability to environmental hazards and the impacts of natural disasters. In 2021, freshwater use in Ukraine was 17.64 m^3 per capita, significantly below the lower optimal threshold of 29.45 m^3 (Table 5). The capacity of wastewater treatment facilities in Zakarpattia Oblast that year was 36.4 m^3, falling

Table 4. **Vector of Thresholds of Demographic Security Indicators**

Indicators	Vector			
	Marginal		Optimal	
	Lower	Upper	Lower	Upper
Number of children, per 1,000 of population	214.28	227.29	218.29	223.29
Number of elderly population per 1,000 of population	251.39	204.82	237.06	219.15
Dependency ratio, %	55.95	45.81	52.83	48.93
Total fertility rate	1.56	2.89	2.55	2.68
Infant mortality rate under 1 year of age, per 1,000 newborns	8.33	5.02	7.31	6.04
Average life expectancy at birth, years	77.96	82.15	79.25	80.86
Number of out-migrants, per 10,000 of population	127.73	34.36	99.00	63.09
Total marriage rate, per 1,000 of population	4.19	8.65	5.56	7.27
Share of single-parent families with children, %	11.58	2.60	7.72	5.30
Marital instability rate, %	61.28	25.75	50.35	36.68
Number of disabled people per 10,000 people	470.88	401.49	449.53	422.84
Share of households with 3 or more children, %	2.48	6.06	3.58	4.95
Component indicator of thresholds	**0.629**	**1.000**	**0.723**	**0.829**

Source: calculated by the authors.

short of the lower optimal threshold by 7.24 m^3. By contrast, the corresponding figures in Lviv and Ivano-Frankivsk Oblasts exceeded the upper optimal threshold by a factor of two. The upper threshold for the share of built-up land is 10.9%, which is 4.4 percentage points higher than the national average reported in 2021. The situation appears particularly critical in regard to current expenditures on environmental protection: between 2010 and 2021, Ukraine's spending did not exceed EUR 21.0 — except in 2011, when it reached EUR 25.1 — compared to an optimal threshold range of EUR 23.43—37.54. Additionally, in 2021, emissions of pollutants into the atmosphere from stationary sources were three times above the lower marginal threshold in Lviv Oblast and 12.7 times above in Ivano-Frankivsk Oblast.

Food security as a component of social resilience demonstrates the state of the system in which the food independence of the territory is ensured and the physical, economic, and social access of the population to sufficient nutritious and safe food, in accordance with the recommended dietary and nutritional standards, is guaranteed. The results of the thresholds of the component indicators (Table 6) show that the consumption of milk and dairy products, eggs, fish, vegetables, and fruits in Zakarpattia Oblast is within the acceptable range (from 0.7 to 0.85). Meanwhile, meat consumption to the norm ratio per capita and oil consumption to the norm ratio per capita exceed the upper marginal threshold by 30.0 percentage points. In Ivano-Frankivsk Oblast, the upper marginal thresholds were exceeded for the consumption of oil, potatoes, sugar, and bread and bakery products; in Lviv Oblast — for sugar, oil, and potatoes; and in Chernivtsi Oblast — for sugar, oil, and bread and bakery products, with exceedances of appro-

Table 5. **Vector of Thresholds of Environmental Security Indicators**

Indicators	Vector			
	Marginal		Optimal	
	Lower	Upper	Lower	Upper
Water intake from natural water bodies, m^3 per capita	37.40	59.42	44.17	52.64
Use of fresh water, m^3 per capita	22.88	44.22	29.45	37.65
General sewerage, m^3 per capita	33.50	53.41	39.63	47.28
Discharge of contaminated wastewater into surface water bodies, m^3 per capita	6.07	1.04	3.03	2.08
Capacity of treatment facilities, m^3 per capita	38.04	56.36	43.68	50.72
Air pollutant emissions from stationary sources, tons per 1,000 people	10.72	2.00	6.37	3.65
Waste generation, tons per capita	9.31	3.65	7.57	5.39
Waste recycling rate	0.22	0.52	0.31	0.43
Current expenditures on environmental protection, per capita, EUR	12.15	48.82	23.43	37.54
Share of capital investment in environmental protection in GRP, %	0.23	0.89	0.43	0.69
Share of current expenditures on environmental protection in GRP, %	0.69	1.77	1.02	1.44
Share of land in nature reserve fund, %	2.49	5.69	3.48	4.71
Share of built-up land, %	3.92	10.87	6.06	8.73
Share of agricultural land area, %	73.54	79.08	75.24	77.38
Component indicator of thresholds	**0.410**	**1.00**	**0.564**	**0.766**

Source: calculated by the authors.

ximately 25—30 percentage points. It is worth mentioning that the oblasts of the Carpathian region of Ukraine do not exceed the marginal and optimal thresholds of the share of the population aged 18 and over who are underweight, %.

The decline in the population's income triggered the spread of social vulnerability in the Carpathian region of Ukraine. The real income of the part of the population that had savings and stable jobs decreased significantly due to inflation and the devaluation of the national currency. For example, in 2022, inflation was about 30%, while for food and food services it was more than 50%, and the level of devaluation of the national currency was about 50%, despite the implementation of stabilization tools by the National Bank of Ukraine and the Cabinet of Ministers of Ukraine [38].

Table 6. **Vector of Thresholds of Food Security Indicators**

Indicators	Vector			
	Marginal		Optimal	
	Lower	Upper	Lower	Upper
Daily caloric intake to daily norm ratio	0.70	1.00	0.80	0.90
Share of the population aged 18 and over who are underweight, %	2.03	0.90	1.68	1.25
Consumption to the norm ratio, per capita:				
meat	0.70	1.00	0.80	0.90
milk and dairy products	0.70	1.00	0.80	0.90
eggs	0.70	1.00	0.80	0.90
fish and fish products	0.70	1.00	0.80	0.90
sugar	0.70	1.00	0.80	0.90
oil	0.70	1.00	0.80	0.90
potatoes	0.70	1.00	0.80	0.90
vegetables	0.70	1.00	0.80	0.90
fruits and berries	0.70	1.00	0.80	0.90
bread and bakery products	0.70	1.00	0.80	0.90
Component indicator of thresholds	**0.677**	**1.000**	**0.776**	**0.884**

Source: calculated by the authors.

The problem of social vulnerability, especially the spread of financial and material poverty, has become more acute as real incomes in national currency have almost halved. According to the World Bank, the share of the population in Ukraine living below the poverty line has increased from 2% to over 25% since the beginning of the full-scale war [39], and by the end of 2023, the share of the population in Ukraine living below the poverty line could increase to 55% [40]. The most significant effects of poverty are recorded in rural areas [41].

The lack of adequate social security is the bifurcation point of the spread of poverty among the most vulnerable categories of the population in 2023. In 2023, no increase in the minimum income (in 2022, it was $167) and the subsistence minimum ($65) is envisaged. The UN study shows that 44% of Ukrainian households cannot afford the most basic necessities, and the share of households with insufficient food consumption has increased to 30% [42].

Socio-economic disparities, social uncertainty, and the war in general have led to a critical weakening of the demographic resilience and security of all regions of Ukraine — a bifurcation point in the midst of instability. According to the EU Council's projections, Ukraine's population could decline by 24—33% as a result of the war and depending on its duration [43]. This threat is confirmed by the decline in the number of people living and working in Ukraine today, as the population has decreased by 6.7 million people since the beginning of the war [44]. Moreover, the gender and age structure of the population has changed, and the share of young people and people of childbearing age has decreased significantly [45].

It is worth mentioning that the full-scale war and its negative consequences have only exacerbated the demographic problems that have been accumulating for a long time, in particular, *the decline in the population of Ukraine* due to higher mortality than fertility rates; *high mortality rates among men of working age* (life expectancy for men is almost 10 years lower (65.1 years) than for wo-

men (74.4 years)) [46]; *population aging* (the share of people under the age of 17 in the country's resident population in 2021 amounted to 17.9%, which is 2.5 percentage points less than in 2019).

A particular problem that has arisen in the context of the war is *the protection of childhood*. A large share of children in Ukraine (more than 7.5 million) has been suffering from the consequences of war [47]. Protection of education is an important marker of the social and psychological stability of children in wartime (after they are physically safe from hostilities). All facilities providing education — children's development centers, kindergartens, schools, gymnasiums, universities — must be safe. Orphans, whose number is growing, require special attention (according to the National Social Service of Ukraine, as of August 1, 2022, more than 3,200 children were left without parental care [48]).

CONCLUSIONS

Socio-economic and socio-political transformations in Ukraine have resulted in the emergence of new socio-humanitarian and economic threats. The full-scale war has further disrupted the functioning of regional socio-economic systems, intensifying existing challenges and generating additional risks to the social security of the Carpathian region. Ongoing threats to social development — driven by the spread of destructive dynamics across both internal and external environments — have led to declining living standards, the devaluation of education, reduced human capital reproduction, the erosion of social stability, increased social vulnerability, and, ultimately, the distortion of the broader social system.

This study has examined social vulnerability through the lens of social resilience, emphasizing the identification of safe operational boundaries for the system. At the conceptual stage, thresholds for catalysts, regressors, and key components were determined, enabling the delineation of "zones of vulnerability" and the "safety margin" through comparison with composite indicators. For each social resilience metric, threshold vectors have been established — specifically, lower and upper marginal thresholds, as well as lower and upper optimal thresholds. The findings have indicated that surpassing these thresholds does not necessarily disrupt systemic equilibrium but instead reflects the region's capacity to sustain a functional margin of resilience in response to external stressors.

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СОЦІАЛЬНА СТІЙКІСТЬ vs ВРАЗЛИВІСТЬ: НОВАТИВНА МЕТОДИКА ІДЕНТИФІКАЦІЇ ТОЧОК БІФУРКАЦІЇ

Вступ. Системні дестабілізуючі впливи на розвиток соціально-економічних відносин ускладнюють імплементацію механізмів політики забезпечення соціальної стійкості територій.

Проблематика. Макроекономічні шоки в умовах сьогодення призводять до посилення соціальної вразливості населення, екзистенційним механізмом мінімізації наслідків яких є забезпечення соціальної резильєнтності території як передумови підвищення якості життя, зниження соціальної нерівності й напруги та зростання рівня задоволеності інтересів громадян.

Мета. Ідентифікація точок біфуркації у соціальній системі «стійкість-вразливість» (зон вразливості (небезпеки), запасу міцності та соціальної резильєнтності) в умовах трансформаційних змін (на прикладі областей Карпатського регіону).

Матеріали й методи. Розрахунок емпіричного показника точок біфуркації соціальної стійкості території виконано на основі підходу динамічної рівноваги, побудову векторів порогових значень – відповідно до нормального, логнормального, експоненціального розподілу вихідних даних на основі методу екстремумів.

Результати. Визначено порогові значення кожного індикатора усіх компонент соціальної резильєнтності за двома векторами — граничним та оптимальним. Встановлено, що верхньою граничною межею рівня зайнятості населення у віці 15—70 років є 69,0 %, а нижнім оптимальним порогом — 63,7 % (в Україні у 2021 р. рівень зайнятості склав 55,7 %). Емпіричні показники порогів індикаторів компоненти «Демографічна безпека» демонструють критичні демотенденції (кількість дітей, у розрахунку на 1 тис. населення, у 2021 р. у Львівській області становила 170,1 осіб, що на 48,2 особи менше, ніж нижній оптимальний поріг).

Висновки. Встановлені точки біфуркацій соціальної стійкості території дозволили констатувати, що існує необхідність побудови сучасної моделі розвитку соціальної сфери на засадах цифровізації, рівного доступу до соціальних послуг та благ, високого рівня соціального захисту, безперешкодної участі усіх членів суспільства у життєдіяльності громад.

Ключові слова: стійкість, територія, вразливість, Україна, шоки, війна, соціальна сфера, пороги, біфуркація, вектор.