https://doi.org/10.26565/2076-1333-2024-37-11
UDC 364.612(477.54-25+438.111)-787.5:656.025.2-021.161
Received 05 November 2024
Accepted 19 December 2024

Kateryna Kravchenko
PhD (Geography), Associate Professor, Kostyantyn Niemets Department of Human Geography and Regional Studies, V.N. Karazin Kharkiv National University, Svobody Sq., 4, Kharkiv, 61022, Ukraine
e-mail: kateryna.kravchenko@karazin.ua, https://orcid.org/0000-0003-4654-3185

RESEARCH OF URBAN AGGLOMERATIONS FROM THE POSITION OF A SYNERGETIC APPROACH

The article examines urban agglomerations as complex subsystems of the socio-geosystem, characterized by a set of synergetic properties: openness, dynamism, flexibility, hierarchy, and emergence, among others. Urban agglomerations evolve over time and change under the influence of internal and external factors. Their development is determined by various components, such as population dynamics, economic clusters, infrastructure development, investment, and innovation. The article emphasizes the necessity of a synergetic approach to research, which considers nonlinear interactions and emergent properties arising from complex systemic interconnections.

One of the key stages in the evolution of an urban agglomeration is the study of decision-making points in the development trajectory, or bifurcation points, where urban agglomerations can transform in different directions depending on demographic, economic, or technological changes. The study identifies numerous challenges faced by urban agglomerations, including social inequality, overburdened urban infrastructure due to excessive urbanization, and more.

The article describes three potentially possible scenarios for the development of urban agglomerations: sustainable development, conservation, and critical condition. Each scenario is determined by different levels of sensitivity and adaptation strategies in response to challenges arising in the context of urban agglomeration evolution.

The application of the synergetic approach in the study of urban agglomerations has been tested using self-organizing Kohonen maps and cluster analysis to examine the most dynamically developing urban agglomerations in Asia. Based on available data, nine clusters of Asian countries with similar urbanization trends have been identified, along with their respective challenges and development prospects. The conducted analysis of urbanization processes in Asian urban agglomerations highlights relevant globalization challenges that are expected to become pressing for many urban agglomerations worldwide.

Thus, ensuring the transition of urban agglomerations toward sustainable development requires an understanding of their complexity and synergetic nature, as well as the characteristics of transformation processes influenced by various factors.

Keywords: *urban agglomerations, synergetic approach, bifurcation points, phase transition, Kohonen map, cluster analysis*.

In cites: Kravchenko, K. (2024). Research of urban agglomerations from the position of a synergetic approach. *Human Geography Journal*, 37, 110-128. https://doi.org/10.26565/2076-1333-2024-37-11

Formulation of the problem. Human geography is a complex and rapidly evolving discipline, particularly in the contemporary context of globalization and the continuous intensification of socio-economic processes at various hierarchical levels. Due to its interdisciplinary nature, human geographical research has gained increasing relevance and depth, as it integrates traditional geographical methods and research approaches with innovative and original methodologies from both geography and other scientific fields. Undoubtedly, the more complex the research object, the broader the set of methods and approaches required for its comprehensive analysis. One of the dominant approaches that facilitates a deeper understanding of the mechanisms of self-organization and the evolution of socio-geosystems is the synergetic approach, which represents a specific form of the systems approach *(Niemets, 2005; Kravchenko, 2020).*

Urban agglomerations are complex, open, and dynamic formations that concentrate various socio-economic, demographic, and environmental processes, evolving under the influence of both internal and external factors. Their development is characterized by intensive urbanization, population growth, the transformation of urban and urbanized spaces, and the expansion of their functional roles. Thus, urban agglomerations not only serve as hubs of population concentration, economic activity, and innovation but also act as powerful "growth poles" for regions and countries worldwide.

Given the complexity and hierarchical nature of urban agglomerations as an object of human geographical research, as well as the necessity of analyzing their spatial structure and interconnections, it is crucial to employ systems theory and the synergetic approach as a methodological foundation for analysis, in combination with traditional geographical research tools *(Niemets, 2022; Kravchenko, 2020).* The synergetic approach to studying urban agglomerations enables a focused examination of their openness, dynamism, self-organization, resilience, adaptability, and development.

The importance of applying the synergetic approach in the study of urban agglomerations lies not only in enabling their analysis as complex territorial formations but also in forecasting their future development directions or potential for regeneration. This is achieved by considering the dynamic interplay between internal potential and external challenges *(Petlin, 2016; Niemets, 2023; Kravchenko, 2024).* Such an approach opens new perspectives for strategic management of urbanization processes, which is critically significant in the context of increasing instability and global challenges of the 21st century.

Analysis of Recent Research and Publications. A wide range of scientific studies has been dedicated to the phenomenon of synergy and synergetics as a scientific field. At the origins of this direction, it is essential to highlight the contributions of H. Haken and I. Prigogine, whose works introduced ideas on the interrelation between self-organization and information, the irreversibility of time, and the constructive role of chaos *(Prigogine, 1977; Haken, 2006).* Based on these concepts, the synergetic (dynamic) theory of information was formulated, and by the late 20th century, synergetic concepts of information synthesis, incorporating both quantitative and qualitative approaches, began to emerge. The most significant feature of this scientific development strategy is the gradual formation of the synergetic paradigm, which is particularly crucial in studying both social and natural systems characterized by large and increasingly intensive volumes of diverse information. According to I. Prigogine, development is only possible in a non-equilibrium system, where energy and matter gradients exist between the system and its external environment, facilitating material exchange processes that drive changes in both the system and its surroundings *(Prigogine, 1977).* Thus, the synergetic paradigm prevails in research on systems of various natures and origins.

The work of O. Vozniuk is dedicated to the application of the synergetic paradigm in analyzing the development of pedagogical science in Ukraine. The author considers synergetics as a methodological tool for understanding educational processes, emphasizing its significance in comprehending the self-organization of educational systems. Special attention is given to the nonlinearity of educational system development, which reflects their evolutionary dynamics, bifurcation processes in education that define transition points to new learning paradigms, and the self-organization of educational systems, contributing to their adaptability to societal changes. The author focuses on the synergetic analysis of educational systems, demonstrating how they evolve under the influence of internal and external factors. The researcher proposes a model of education synergization, which involves harmonizing traditional and innovative learning approaches. However, the study remains predominantly conceptual, with limited empirical verification of its conclusions *(Vozniuk, 2009).*

O. Shevchyk conducted research on synergetic problems in economics, addressing the emergence and development of the theory of "synergetic economics." The author emphasizes that instability and variability in socio-economic life have become permanent characteristics of modernity, necessitating new approaches to analyzing economic systems *(Shevchyk, 2014).*

C. Qu examines synergetics as an interdisciplinary field that studies the self-organization of complex systems. The author focuses on pedagogical synergetics, particularly in the context of fostering student motivation for educational and performing activities, developing creativity, and adapting arts education to a changing social environment. Key synergetic categories such as nonlinearity, bifurcation transitions, fluctuations, and chaos in educational processes are highlighted. However, the study is primarily theoretical, lacking empirical validation of the proposed concepts *(Qu, 2019).*

N. Hrazhevska considers the synergetic approach as a methodological foundation for analyzing nonlinear and non-equilibrium processes in economic system development. The author emphasizes that economic systems are not static but constantly evolving through stages of instability and self-organization. This approach serves as an alternative to classical deterministic models of economic development, which assume stable growth and equilibrium *(Hrazhevska, 2006).* The author particularly focuses on the mechanism of "order through chaos." A crucial element of this process is the phenomenon of self-organization—the ability of an economic system to adapt to changes through internal regulatory mechanisms. In this context, instability is not a negative phenomenon but rather a necessary condition for development. The author also highlights that the loss of stability in an economic system results not only from external influences (crises, globalization shifts, technological breakthroughs) but also from internal mechanisms of development. Random fluctuations play a significant role in this process, as they can substantially alter the system's development trajectory.

The study by A. Kniazevych et al. explores the formation and development of key principles of synergetics as a modern concept of self-organization and system development, emphasizing its significance for social science research. The authors argue that the principles of synergetics can help analyze patterns that determine natural crises in economics, governance, politics, and culture. As a universal research tool, the synergetic approach can be widely used for analyzing and modeling management situations across all models of societal organization *(Kniazevych, 2019).* In human geographical research, applying the synergetic approach enables a comprehensive analysis of the impact of various processes and phenomena, creating a holistic picture of spatial development.

K. Niemets extensively presents the use of the synergetic paradigm in studying geological and geographical systems. Specifically, the author views the synergetic approach as a concept that involves examining internal interactions within a system, its resources, mechanisms, and evolutionary potential. This is particularly important in human geographical research, as it allows for a comprehensive analysis of numerous factors and processes affecting the functioning of socio-geosystems. Since such systems are complex and heterogeneous, their study must include internal interconnections using various scientific approaches, aligning with the fundamental principles of synergetics, which emphasize the importance of interaction among system elements and their ability to self-organize. A significant contribution of K. Niemets's research is the analysis of socio-geosystem development through phase transitions at bifurcation points. The author highlights that at these points, the system must restructure its organization and transform its functions, altering its future development trajectory. This underscores the dynamic nature of socio-geosystems and the necessity of in-depth analysis of their evolution *(Niemets, 2005; Niemets, 2021).*

S. Pugach examines the synergetic approach in hu-

man geographical research as an essential methodological foundation for analyzing communication networks. The author argues that these networks are complex synergetic systems characterized by dynamics, instability, and evolutionary development. Pugach emphasizes that the synergetic approach focuses on internal system interactions, internal resources, and mechanisms that determine evolutionary potential. This enables the consideration of a broad range of factors influencing the functioning of communication networks within spatial environments. Thus, according to the author, synergetics is a crucial tool for studying complex, adaptive, and nonlinear processes in geographical systems *(Pugach, 2021).*

Focusing on urban agglomerations as integral subsystems of the socio-geosystem, the issue of synergetic development within these entities is currently most intensively explored in the works of urbanists and regional development specialists in China, driven by the exceptionally rapid growth of urban agglomerations in the country.

X. Lv and X. Mu investigate the evolutionary processes of urban agglomerations based on the synergetic approach and the law of urban scaling. The authors emphasize that cities, metropolitan areas, and urban agglomerations are complex, dynamic systems whose development occurs through mechanisms of self-organization, nonlinearity, and interconnections across different spatial levels. The synergetic approach is applied to analyze the multi-scale co-evolution of urban systems, allowing for the identification of developmental patterns, assessment of the spatial distribution of resources, and formulation of recommendations for regional planning. The authors consider urbanization processes as self-organizing phenomena with nonlinear dependencies among the indicators characterizing them (economic conditions, infrastructure development, environmental status, and innovation implementation). The urban scaling mechanism is presented as the interrelation between city size and its key characteristics through spatial autocorrelation analysis. According to the authors, the synergetic approach enables a comprehensive assessment of urban dynamics and the identification of key stability and development factors of urban agglomerations *(Lv, 2023).*

In the study by L. Wu et al., the mechanisms of urban agglomeration growth are presented based on the application of the synergetic approach. The authors view urban agglomerations as complex open systems that continuously evolve through the interaction of internal and external factors (particularly exemplified by urban agglomerations formed in the Yangtze River Delta). According to the authors, the key drivers of spatial organization are changes in population distribution, GDP, and industrial clusters, which act as order parameters in synergetic analysis. The development of agglomerations occurs through four types of interactions: internal synergy, point interaction, "ring-ring" synergy, and multi-ring synergy. During the self-organization process, urban systems transition between phases of instability and new order, forming multi-scale spatial structures that adapt to changing conditions. The study proposes a spatial synergy model that interprets how changes in development factors influence their evolution *(Wu, 2024).*

In the work of S. Wang, the synergetic approach is applied in the context of industrial agglomeration and urbanization interaction. The research is based on the concept of complex open systems, where urban agglomeration development depends on the interaction between industrial clusters and the level of urbanization in a given territory. The synergetic interaction between industrial clusters and urbanized areas is analyzed through a comprehensive model incorporating socio-economic development factors, spatial planning, and resource allocation. The order parameters for the self-organization of urban systems are determined by key indicators such as electricity consumption, water resources, social infrastructure, and economic efficiency. Based on the study results, it can be assumed that industrial clusters can act as catalysts for urban agglomeration development; however, the effectiveness of this process depends on the level of their synergetic interconnection *(Wang, 2021).*

The study by C. Wang and Q. Meng analyzes the role of the synergetic approach in urban agglomeration research, focusing on the Urban Economic Synergistic Development Network (UESDN). The research is based on the hypothesis that the synergetic approach envisions urban agglomerations not as isolated units but as interconnected nodes within a broader network. This interconnection facilitates a more efficient allocation of resources and enhances the overall economic functionality of cities and regions. The authors utilize systemic analysis methods to assess economic interactions between cities. This method quantitatively determines the strength and nature of these connections, emphasizing how specific cities act as "growth poles"— key centers in UESDN. The analysis is based on indicators such as city centrality, linkages between central cities of different hierarchical levels, and the role of individual centers in fostering economic interactions. Over the research period (ten years), the structure of UESDN transitioned from a node-based model to a more complex network structure, incorporating multiple urban centers, reflecting increasing urban interdependence and system evolution. According to the study results, the most influential factors in city network evolution are geographic location and the level of industrial development. However, the study does not mention factors such as the development of the tertiary sector and innovation, which, in our opinion, play a crucial role in the evolution of urban systems in the modern world *(Wang, 2020).*

The study by W. Wu et al. explores the environmental consequences of urbanization and urban agglomeration development using the Haken model. This work highlights the dynamic and interrelated nature of urbanization processes and environmental conditions through the lens of the synergetic approach. The application of the synergetic approach, as proposed by H. Haken, allows for the study of interactions among socio-geosystem subsystems in the dynamics of chaos and order. This comprehensive perspective helps researchers understand the evolution of urban agglomerations. In particular, the authors emphasize that despite extensive research on the interaction between society and the environment, insufficient attention has been paid to the synergetic effects of these interactions *(Wu, 2024a).*

Using the Haken model, this study quantitatively

assesses the synergy levels between urbanization and the environment in the Chengdu-Chongqing metropolitan area. It identifies interaction patterns through established order parameters and control variables, demonstrating how different factors influence the evolutionary trajectories of these subsystems. A significant methodological contribution of the study is the application of multidimensional spatial analysis methods to visualize and understand how synergy levels vary geographically within the metropolitan area. The spatial dimension is crucial for understanding how different urban districts may experience varying degrees of synchronization between economic development and environmental conservation. The study also emphasizes the necessity of integrating urbanization strategies with ecological considerations to promote sustainable development and achieve balanced urban growth based on the principles of sustainability. Thus, the synergetic approach serves as a powerful methodological tool for studying various systems, including metropolitan agglomerations. Its application enables the analysis of the current state of the system, its functions, the identification of bifurcation points, and the determination of managerial interventions necessary for system evolution and trajectory transformation towards sustainable development. Given that metropolitan agglomerations are complex subsystems of a socio-geosystem that evolve under numerous nonlinear interactions, exhibiting emergent properties and self-organization, the study of their dynamics requires effective multidimensional analysis methods *(Niemets, 2003; Niemets, 2023).*

Identification of previously unsolved parts of the general problem and the purpose of the study. In metropolitan agglomerations, the interaction of various components (economic, social, environmental, and innovative) leads to the formation of stable structures and new system properties that cannot be explained merely by the sum of their parts (emergence) (Fang, 2017; Fang, 2019; Kravchenko, 2024). From the perspective of the synergetic approach, agglomerations undergo instability phases (bifurcation points), where new equilibrium states and development trajectories are determined. These processes result from the interaction of society, business, urban infrastructure, the environment, and governance. Such interactions shape new patterns of development potential distribution, allowing the establishment of spatial regularities in the relationships among metropolitan elements and trends in future development.

Traditional socio-geographical multidimensional analysis methods include factor analysis (which identifies the primary factors influencing socio-geographical processes), cluster analysis (grouping socio-geographical objects based on similar characteristics), discriminant analysis (categorizing socio-geographical objects based on specific indicators), regression analysis (establishing dependencies among various socio-geographical categories or indicators), correlation analysis (determining interdependencies of socio-geographical indicators), principal component analysis (conducting analysis using generalized indices), and spatial analysis using GIS tools *(Niemets, 2005; Mezentsev, 2021).* Another effective research method is modeling the integral impact function, an original socio-geographical research method proposed by K. Niemets, which has been the subject of several studies *(Kravchenko, 2020; Niemets, 2022; Kravchenko, 2024).*

Considering the self-development capacity of metropolitan agglomerations, we propose using the Kohonen self-organizing maps (SOM) method for their multidimensional analysis. This method integrates elements of cluster analysis, factor analysis, and spatial visualization, thereby enabling the identification of development patterns and the prediction of possible evolutionary directions of metropolitan agglomerations. The relevance and feasibility of applying this method in socio-geographical studies of metropolitan agglomerations lie in its ability to establish complex development patterns, classify metropolitan agglomerations based on a wide range of criteria, visualize geospatial data, and forecast future development dynamics. Kohonen maps represent a self-learning and self-organizing neural network, thus embodying fundamental principles of synergetics such as self-organization, nonlinearity, adaptation, interdependence, and regularity (Figure 1).

Thus, the Kohonen map method is a practical methodological tool that implements synergetic principles in the analysis of multidimensional geodata and allows for the visualization and analysis of the self-organization features of socio-geosystems and their subsystems in human geography.

Presenting main material. System theory suggests analyzing urban agglomerations from the perspective of structural elements (population, economic clusters, infrastructure, innovation, etc.), functional connections (transport, communication, social networks), and regulatory mechanisms (local self-government, state policy, global trends). This approach allows for a deeper understanding of the mechanisms of self-regulation, adaptation, and development of metropolitan agglomerations. Urban agglomerations, as open systems, are in constant interaction with the external environment, manifested in the influence of global economic trends, international politics, technological levels, innovations, and global challenges. Their development can be viewed through the lens of synergetics, which helps to understand the mechanisms of their evolution and adaptation. Among the main synergetic phenomena observed in the functioning of metropolitan agglomerations are *(Kravchenko 2020; Niemets, 2022; Kravchenko 2024):*

- **nonlinearity**: This is evident in the complexity of predicting the development of metropolitan agglomerations, the impact of events and phenomena (such as the formation of a new "growth pole" or communication channel) on overall functioning, and the possibility of sharp changes in the development trajectory due to economic and social transformations.
- **self-organization**: Metropolitan agglomerations form and develop not only due to managerial decisions, but the agglomeration effect is largely driven by internal systemic processes, such as population migration to the central city, changes in the spatial organization of production, infrastructure development, etc. In some cases, processes like suburbanization or gentrification arise spontaneously, reflecting cities' adaptation to new socio-economic realities.
- **presence of fluctuations, bifurcation points, and**

phase transitions: Critical moments in the development of agglomerations can be caused by economic crises, catastrophic natural or anthropogenic events, the implementation of innovations, and smart technologies. In bifurcation points, different scenarios may occur: system transformation—either degradation or evolution, the decline of certain areas, or conversely, their rapid development due to innovative solutions.

- **adaptability**: Metropolitan agglomerations are flexible and change their structure according to the external environment and global challenges.
- **hierarchical structure**: Metropolitan agglomerations have a complex structure: a core, internal and external zones of the agglomeration, and peripheral satellite cities that interact with one another. The relationships between different hierarchical levels (microdistricts, cities, megacities) determine the development dynamics of agglomerations and their integration into broader regional and international processes.
- **dynamism**: Metropolitan agglomerations exhibit rapid changes in their internal structure, which may be driven by internal urban processes (such as changes in functional zoning or demographic shifts) or external impulses (economic crises, environmental catastrophes, political transformations).
- **resilience**: The resilience of metropolitan agglomerations is determined by their ability to maintain essential functions even during internal and external crises. The recovery and development of agglomeration systems depend on their ability to effectively utilize internal resources, attract external investments, create favorable conditions for entrepreneurship, and ensure the quality of life for the population.

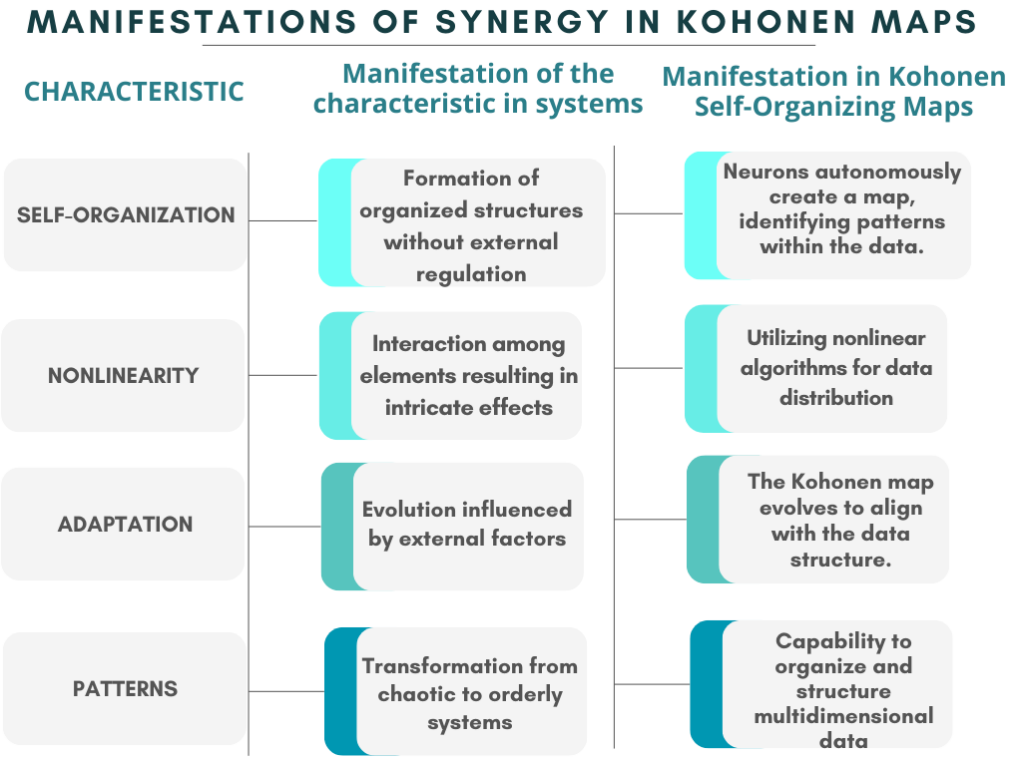


Fig. 1. Manifestations of synergy in Kohonen maps
(created by the author to Hushchyn, 2021; Kuzmenko, 2022)

This approach allows for the analysis of metropolitan agglomerations as living systems that are constantly changing and adapting to new challenges. Based on system theory and considering the aforementioned synergetic properties of metropolitan agglomerations, we will examine the structure of their evolution (Figure 2).

The scheme of the evolution of urban agglomerations demonstrates its evolution through the transition through key stages, each of which has its own characteristics, influencing factors and possible development scenarios. At the initial stage, the agglomeration exists as a relatively stable structure with established connections that ensure the stability of the functioning of the economy, social relations and infrastructure. It is a powerful system with intensive interconnections, is a concentration of economic activity in the "growth poles" and is characterized by relative demographic stability. At this stage, the system is in a state of moderate stability, which can last for a long time in the absence of fluctuations and intense dynamics of internal or external factors.

Subsequently, a stage of accumulation of changes and intense fluctuations occurs, which is accompanied by a complication of the agglomeration structure. Urbanization and expansion of city boundaries create new spatial and economic challenges, the so-called "growth poles" appear, which form points of active development. At the same time, the infrastructure becomes more complicated, there is a need for its adaptation to new conditions. This stage is accompanied by growing instability, since development is uneven, and the system begins to accumulate internal tension.

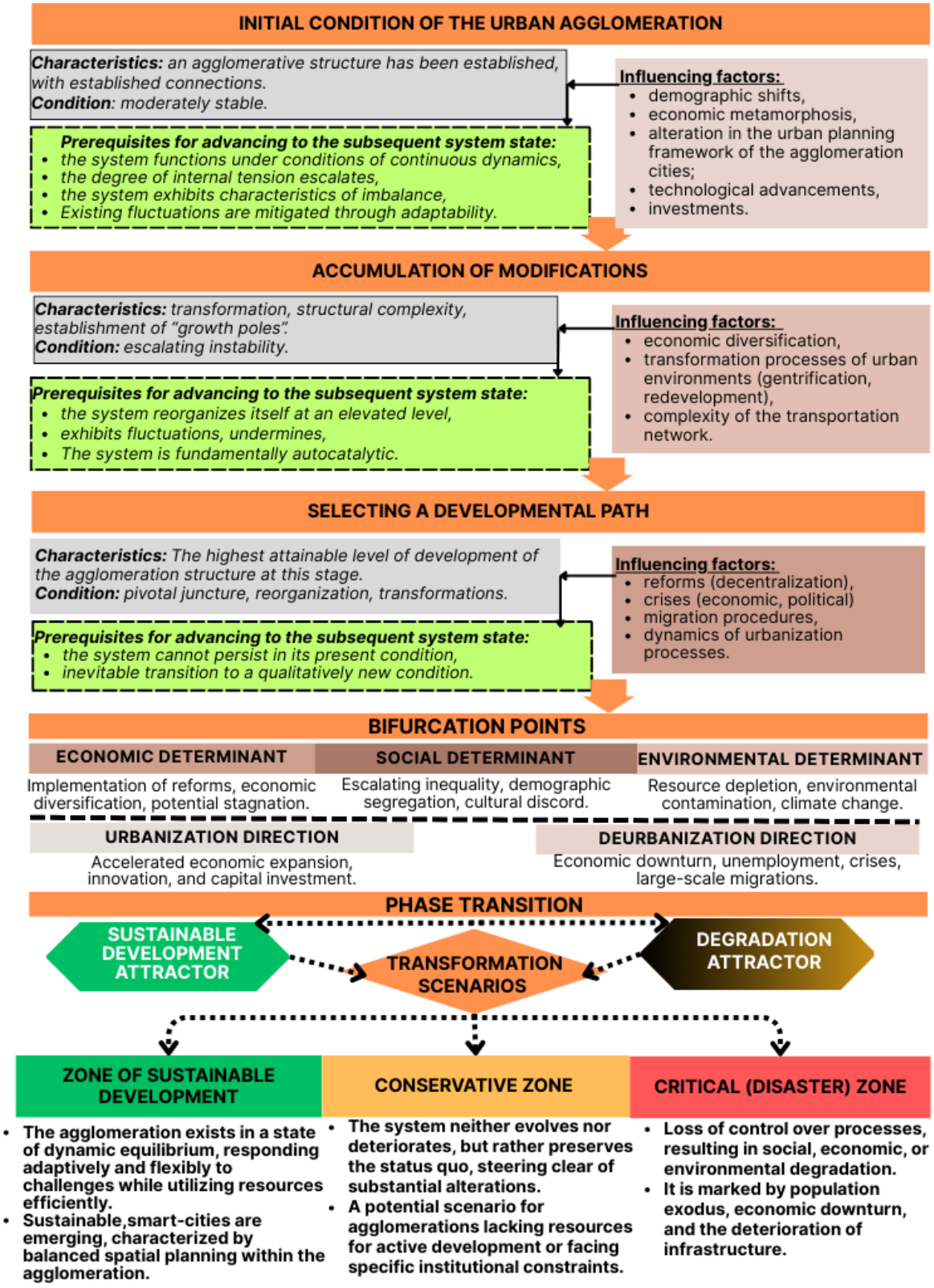


Fig. 2. Evolution of urban agglomerations *(created by the author)*

At the next stage, the agglomeration reaches a critical point - choosing the path of further development. This is a crucial phase when the system reaches the limit of its capabilities at the current level and requires radical changes. At this point, there is a need to revise urban policy, spatial planning and the economic model. Internal tension reaches a peak, which can either cause reorganization of the system or become a prerequisite for its decline. The conditions of continuous dynamics, growing imbalance and the need for adaptive mechanisms determine the further fate of the agglomeration.

The urban agglomeration falls into bifurcation points - moments when the system is forced to move to a new level of organization or undergo destructive chang-

es. This process is influenced by various determinants, among which it is worth noting: economic, social and environmental. As a result of the action of determinants, the development of the urban agglomeration can be stimulated, or the emergence of crisis phenomena is possible. Thus, at the next stage, a phase transition occurs, which determines further transformations of the urban agglomeration. In the future, the system, depending on the intensity and nature of the influence of certain determinants, moves in the direction of urbanization or deurbanization. If the system adapts to the existing challenges, it progresses in the direction of further urbanization, which is accompanied by economic growth, the emergence of innovative sectors of the economy, and the complication of the agglomeration structure. Otherwise, the direction of deurbanization may be determined, which will lead to economic recession, increased unemployment and mass migrations due to the loss of the attractiveness of the urban agglomeration. As a result, the system transforms according to the attractor of sustainable development, or the attractor of degradation.

Depending on the chosen direction and the action of the attractor, the system may end up in one of three zones. In the conservative zone, it maintains the status quo without significant changes, which is typical for urban agglomerations with limited resources. In the critical zone, the risk of degradation increases due to loss of control over economic or social processes, which can lead to decline and prolonged crises. If the agglomeration undergoes successful adaptation, it enters the zone of sustainable development, where a flexible response to challenges occurs, efficient use of resources is implemented, and a stable dynamic model of the urban agglomeration is formed.

Thus, in general, three scenarios of the evolution of an urban agglomeration are possible. The first is sustainable development, in which urban agglomerations use adaptive policies, develop smart technologies and creative clusters, and implement balanced spatial planning. The second is conservation, when the city functions within its capabilities without radical changes. The third is degradation, which involves the loss of control over urban processes, socio-economic decline, and population decline.

We will test the theoretical and methodological apparatus of the study on materials from countries in the world's regions, in particular, based on current urban studies - on the example of Asian countries. To typify the countries of the region according to the characteristics of urbanization processes and the development of urban agglomerations, taking into account available statistical data from official sources (World Bank.., UN Population Division.., European Commission), 15 indicators were selected: the share of the population living in urban settlements in 2000, 2023 and 2050 (%); growth rates of the share of the population living in urban settlements in 2000-2023 and 2023-2050 (%); the share of the population living in urbanized areas in 2023 (%); the share of the population living in cities with a population of at least 50 thousand. people with a population density of over 1,500 people per km² in 2020 (%); population density in urban settlements in 2015 (people per km²); share of urban areas in the total area of countries in 2023 (%); share of urban population living in urban agglomerations with different population sizes - less than 300 thousand people, from 300 to 500 thousand people, from 500 thousand to 1 million people, from 1 to 5 million people, from 5 to 10 million people, 10 million people and more, in 2015 (%). The indicated statistical indicators were normalized by linear scaling and converted into indices from 0 to 1 according to formula 1:

$$I_j = \frac{X_{i,j} - X_{\min,j}}{X_{\max,j} - X_{\min,j}} \quad (1)$$

where Ij is the index of the j-th indicator (the index has an amplitude from 0 to 1);

$X_{i,j}$ – current value of the j-th indicator;

$X_{мах,\ j}$ – the largest value of the j-th indicator in the observation series;

$X_{min,\ j}$ – the lowest value of the j-th indicator in the observation series.

Next, the clustering of the countries of the region was carried out according to the similarity of urbanization processes and the development of urban agglomerations using two methods - statistical (cluster analysis) and neural network (Kohonen self-organizing maps, SOM - Self-Organizing Maps). Considering the available statistical data from official sources, a statistical database was created with data from 47 Asian countries. Figure 3 presents the dendrogram of clustering and the Kohonen self-organizing map of Asian countries based on the similarity of urbanization processes and the development of metropolitan agglomerations. Figure 4 shows the component distribution maps for each individual indicator on the Kohonen map (Component Planes) and the clustering statistics (Cluster Statistics).

Based on cluster analysis using the distance measure 2.3, six clusters of Asian countries can be distinguished based on the similarity of urbanization processes and the development of urban agglomerations. Similar to the results of cluster analysis, nine clusters of Asian countries can be distinguished based on the similarity of urbanization processes and the development of urban agglomerations, and by editing the distance measure using cluster analysis, we will also form 9 clusters (Table 1).

According to cluster analysis and Kohonen's self-organizing map, cluster 1 includes countries where the average level of urbanization is about 62.8% in 2023, and the urbanization rate throughout the 21st century is quite high and constantly increasing (in 2000-2023 - 11.7%, in 2023-2050 - 18.2%), 74.0% of the urban population is expected by 2050; the exception is Armenia, where in 2000-2023 there were negative urbanization rates. The share of urban areas in the total area of the countries is low (2.0%), but the density of the urban population is high (about 3 thousand people per km2, in Mongolia - almost 6 thousand people per km2). The countries of this cluster have one of the highest shares of the urban population living in urban agglomerations with a population of more than 1 million (53.7% of the urban population), while only urban agglomerations with a population of 1-5 million are represented among the million-plus cities. Almost all the rest of the urban population lives in small cities with a population of less than 300 thousand people (43.2%).

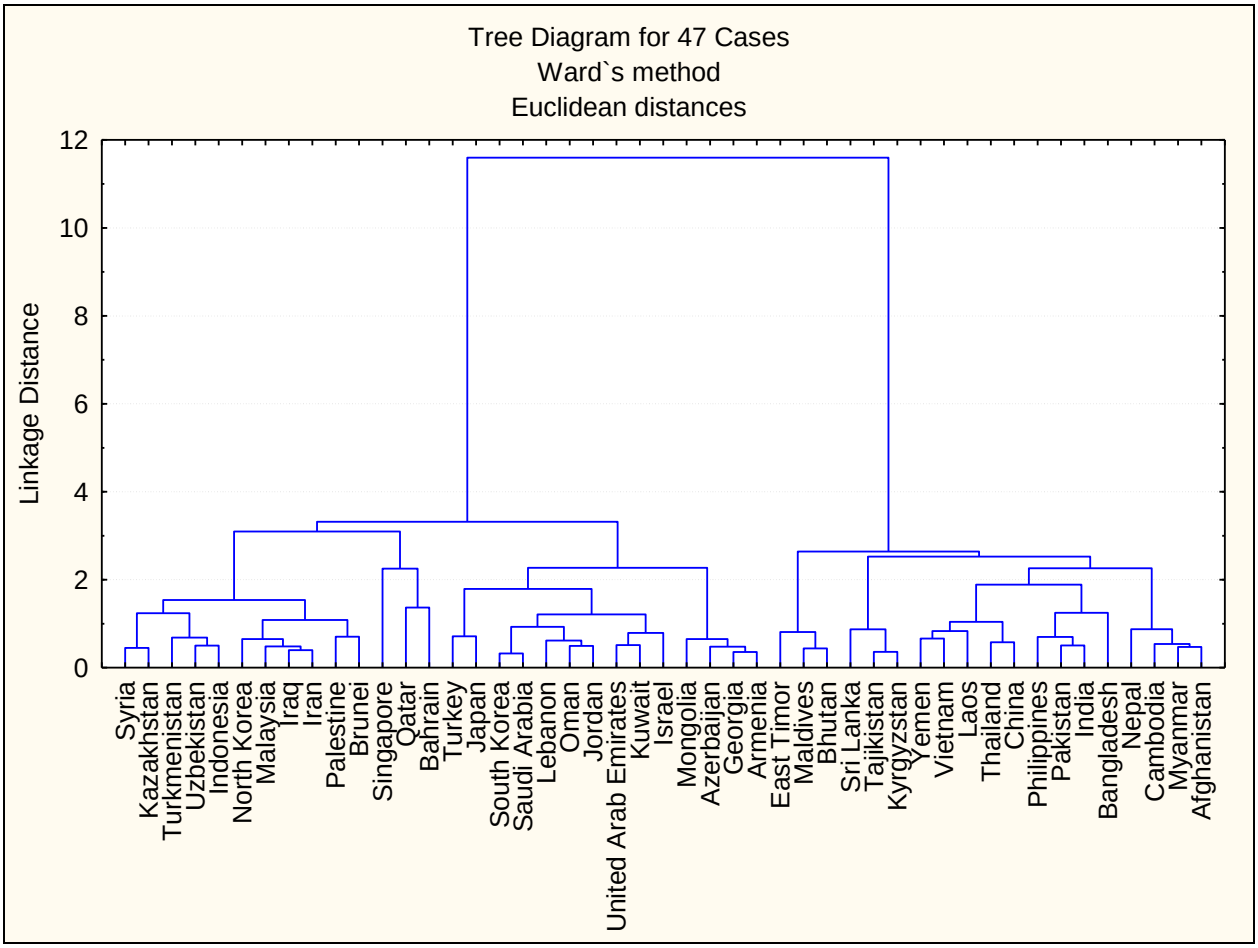


Fig. 3. Dendrogram of clustering of Asian countries by similarity of urbanization processes and development of urban agglomerationsin the first half of the 21st century *(created by the author on the results of cluster analysis)*

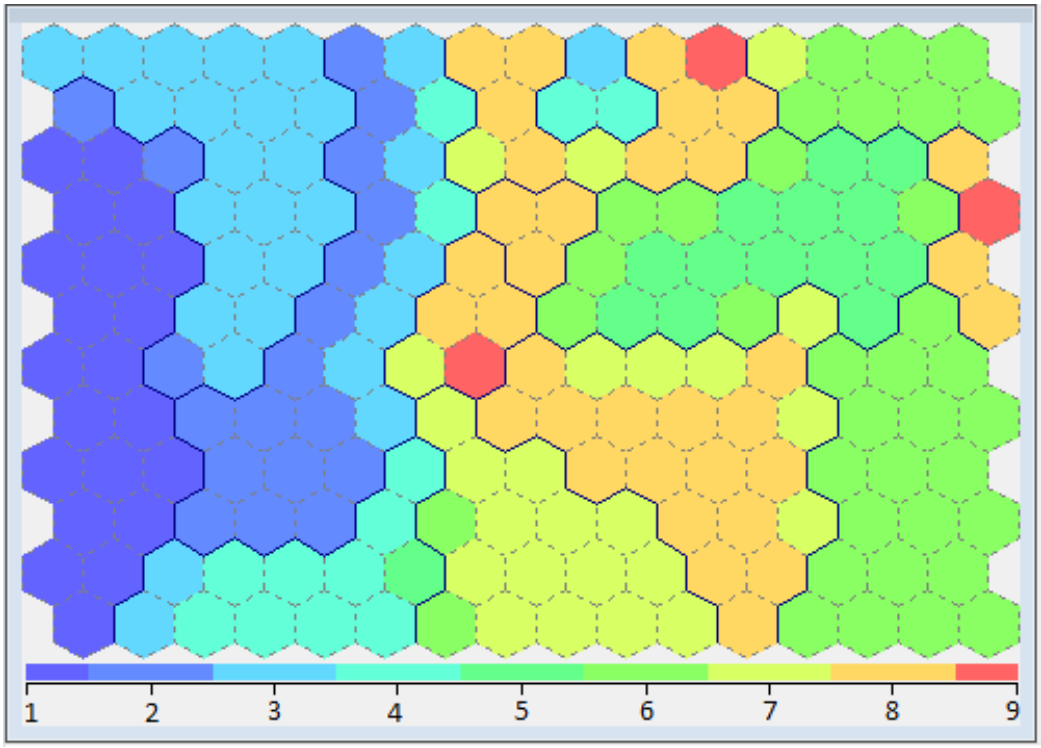


Fig. 4. Kohonen self-organization map of Asian countries according to the similarity of urbanization processes and development of urban agglomerationsin the first half of the 21st century (neural network model)

Таблиця 1

Comparative characteristics of clusters of Asian countries bysimilarity of urbanization processes and development of urban agglomerationsin the first half of the 21st century *(created by the author)*

Cluster analysis	**Kohonen's self-organizing map**
Cluster 1	
medium-urbanized countries, which are characterized by fragmented urban development, uneven development of urban infrastructure, but have potential for growth (Armenia, Georgia, Azerbaijan, Mongolia)	
Cluster 2	
highly developed countries with strong urban systems and dominance of large cities, where cities are centers of technology and finance	
Israel, Kuwait, UAE, Jordan, Oman, Lebanon, Saudi Arabia, South Korea, Japan, Turkey	Israel, Kuwait, UAE, Saudi Arabia, South Korea, Singapore, Lebanon, Japan
Cluster 3	
a heterogeneous group of countries with an active transition to an urban society, but with a fragmented urban structure	small countries with unique challenges, where urbanization is closely linked to political and geopolitical aspects (Bahrain and Brunei are oil countries, Palestine is in a state of political instability and military conflict)
Brunei, Palestine, Iran, Iraq, Malaysia, North Korea, Indonesia, Uzbekistan, Turkmenistan, Kazakhstan, Syria	Brunei, Palestine, Bahrain
Cluster 4	
least urbanized countries with significant growth potential but a weak infrastructure base	
Afghanistan, Myanmar, Cambodia, Nepal	Afghanistan, Bhutan, Cambodia, East Timor, Maldives, Nepal
Cluster 5	
countries with strong demographic potential, where urbanization is developing rapidly through industrialization, and cities are centers of economic growth	
Bangladesh, India, Pakistan, Philippines, China, Thailand, Laos, Vietnam, Yemen	Bangladesh, China, India, Indonesia
Cluster 6	
countries with economies focused on urban centers, where urbanization is close to its maximum	a heterogeneous group of countries where urbanization is shaped by external factors: conflicts (Syria), dependence on oil (Qatar)
Bahrain, Qatar	Qatar, Turkey, Philippines, Syria
Monocluster 7	**Cluster 7**
Singapore is a city-state with complete urbanization and an extremely high concentration of urban population	a heterogeneous group of countries with significant economic potential but limited freedom to develop cities (North Korea has a unique urbanization model)
	Iran, Iraq, Jordan, Kazakhstan, Malaysia, North Korea, Oman
Cluster 8	
small countries with limited resources for urbanization, where cities are concentrated on the coasts or in the mountains	countries in the stage of active transition to an urban society with significant internal challenges: rapid migration to cities (Vietnam, Thailand), social problems (Yeomen), political instability (Myanmar)
Bhutan, Maldives, East Timor	Uzbekistan, Vietnam, Yemen, Thailand, Pakistan, Myanmar
Cluster 9	
the most backward in terms of urbanization countries, where urbanization is only beginning to develop	
Kyrgyzstan, Tajikistan, Sri Lanka	Turkmenistan, Tajikistan, Kyrgyzstan, Sri Lanka, Laos

As for cluster 2, according to the results of the cluster analysis, it includes countries with a fairly high level of urbanization (the average level is 88.6% in 2023, in Kuwait – 100%). The average growth rate of urbanization, which tends to slow down (10.3% in 2000-2023, 5.0% in 2023-2050), is expected to be 92.9% of the urban population by 2050. These countries have one of the highest shares of the urban population living in urban agglomerations with a population of more than one million (52.3% of the urban population), while all urban agglomerations with a population of more than one million are represented among the agglomerations with a population of 1-5 million, 5-10 million, 10 million and more people, and 7.3% of the urban population lives in megacities (with a population of 10 million and more). Megacities are found in Japan and Turkey. The share of small cities is the lowest (only a third of the urban population lives in cities with a population of less than 300 thousand people). The average share of urban areas in the total area of the countries is (7.1%), but there are significant differences between countries: from 0.4% in Saudi Arabia to 18.3% in Lebanon. The population density in urban areas is high (more than 3 thousand people per km2, in Kuwait - about 5 thousand people per km2). According to Kohonen's self-organizing map, cluster 2 countries have the highest level of urbanization

(91.1% in 2023, in Kuwait and Singapore - 100%), the lowest urbanization growth rates, which also tend to slow down (5.2% in 2000-2023, 3.5% in 2023-2050), since almost the entire population already lives in cities, 94.1% of the urban population is expected in the cluster countries by 2050. The highest share of the urban population lives in urban agglomerations with a population of one million (64.6% of the urban population), while all urban agglomerations with a population of one million are represented among the million-plus cities. Megacities (with a population of 10 million or more) are only found in Japan, and they are home to almost half of the country's total urban population (the highest figure among the countries in the region). In the cluster countries, only a quarter of the urban population lives in cities with a population of less than 300,000. The share of urban areas in the total area of the countries is high (16.2%), but there are significant differences between the countries: Singapore is a city-state, 63.2% of which are urban areas, and in Saudi Arabia, urban areas occupy only 0.4% of the country's area. Very high population density in urban areas (about 4.5 thousand people per km2, in Kuwait - about 5 thousand people per km2, in Singapore - more than 12 thousand people per km2).

As for the countries of cluster 3, according to the results of the cluster analysis, it includes countries with a medium level of urbanization (66.0% in 2023 - from 50.5% in Uzbekistan to 79.1% in Brunei). The urbanization rates of countries throughout the 21st century have been quite high and are constantly increasing (in 2000-2023 - 14.4%, in 2023-2050 - 17.1%), 76.7% of the urban population is expected by 2050. The countries of the region are also characterized by a low share of urban areas in the total area of the countries (4.4%), with the exception of Palestine (27.1%). High urban population density (about 2.5 thousand people per km2, from 1.0 thousand people per km2 in Uzbekistan to almost 6 thousand people per km2 in North Korea). The cluster represents all urban agglomerations by population (from less than 300 thousand to 10 million people and more), but small ones prevail (with a population of less than 300 thousand people, where 61.2% of the urban population lives, and in Brunei 100%). According to the analysis using the Kohonen self-organizing map method, the cluster countries have a high level of urbanization (82.2% in 2023). Average and stable urbanization rates throughout the 21st century (in 2000-2023 - 6.9%, in 2023-2050 - 7.4%), 88.1% of the urban population is expected by 2050, and the highest share of urban areas in the total area of the countries is 24.2%, in Bahrain - 41.8%. The urban population density is high (about 2.5 thousand people per km2). There are no urban agglomerations with a population of more than one million in the cluster countries. Small cities predominate in the cluster countries (82.1% of the urban population lives in urban agglomerations with a population of less than 300 thousand people, and in Brunei - 100%). This is the highest indicator in Asia.

According to the results of the cluster analysis, cluster 4 countries have the lowest level of urbanization (26.6% in 2023), a projected increase in the level of urbanization to 41.7% in 2050, and the highest expected rates of urbanization (57.8% in 2023-2050, in Nepal - 70.7%). Among urban agglomerations, the categories with a population of less than 300 thousand people (54.6% of the urban population) and 1-5 million people (39.4%) prevail. The share of urban areas in the total area of the countries is the lowest (1.2%, in Afghanistan - 0.6%), and there is a high population density in urban areas (more than 2 thousand people per km2). According to the results of the study using the Kohonen self-organizing map, the cluster countries have the lowest level of urbanization (32.2% in 2023), and the projected increase in the level of urbanization is 45.8% in 2050, very high and stable urbanization rates throughout the 21st century (46-47% in 2000-2050, in Nepal - 60-70%). Among urban agglomerations, the categories with a population of less than 300 thousand people (76.7% of the urban population) and 1-5 million people (19.7%), and in Bhutan, East Timor and the Maldives, the entire urban population lives in small cities (with a population of less than 300 thousand people). The lowest share of urban areas in the total area of the countries (1.5%, in Bhutan – 0.1%), and the highest population density in urban areas (about 5.5 thousand people per km2, in Bhutan – almost 10 thousand people per km2, in the Maldives – almost 12 thousand people per km2).

According to the results of the cluster analysis, cluster 5 mainly includes countries with a fairly low level of urbanization (44.3% in 2023, from 36.4% in India to 64.6% in China). According to calculations, the projected growth in the level of urbanization is about 60.5% in 2050 (in all countries the urban population will prevail, in China – 80%), very high urbanization rates are observed with a tendency to slow down (51.3% in 2000-2023, 38.1% in 2023-2050). An increase in the rate of urbanization will be observed only in India, Pakistan and the Philippines. The cluster countries represent all urban agglomerations by population size (from less than 300 thousand to 10 million people and more), while the urban population is distributed relatively evenly across different types of cities. The highest share of the urban population living in megacities (with a population of 10 million or more) is 13.7%, the average share of urban areas in the total area of countries is (8.6%), but with significant internal contrasts: from 0.2% in Laos to 43.8% in Bangladesh. The density of the urban population is high (more than 2.5 thousand people per km2), also with significant differentiation between countries: from less than 1.0 thousand people per km2 in Bangladesh to more than 6.0 thousand people per km2 in Yemen.

According to Kohonen's mapsthe level of urbanization is below average (50.0% in 2023, from 36.4% in India to 64.6% in China), the projected increase in the level of urbanization to 66.0% in 2050 (the urban population will prevail in all countries, in China - 80%), the highest rates of urbanization, but with a tendency to slow down (55.6% in 2000-2023, 34.4% in 2023-2050). The exception is India, where an increase in the rate of urbanization will be observed. The cluster countries represent all urban agglomerations by population size (from less than 300 thousand to 10 million people and more). The highest share of the urban

population living in megacities (with a population of 10 million people or more) is 16.8%, and the share of urban areas in the total area of countries is high (14.7%, in Bangladesh – 43.8%). Average urban population density (less than 2 thousand people per km2, in Bangladesh - less than 1 thousand people per km2).

Cluster 6, according to the results of the cluster analysis, includes countries characterized by the highest level of urbanization (94.6% in 2023, in Qatar – 99.4%), these countries are also characterized by the lowest and stable growth rates of urbanization (2-2.4% in 2000-2050), since almost the entire population already lives in cities, and 96.5% of the urban population is expected by 2050. However, among the countries in the cluster there are no million-strong urban agglomerations, the entire urban population lives in urban agglomerations with a population of less than 1 million people, and small cities predominate, in which half of the urban population of the countries lives. The highest* share of urban areas in the total area of the countries is 23.8%, but in Bahrain it is 41.8%, the population density in urban areas is high (more than 3.5 thousand people per km2). According to the results of the analysis using the Kohonen map method, the level of urbanization can be described as "above average" (70.6% in 2023, from 48.3% in the Philippines to 99.4% in Qatar). The countries of the region are characterized by average urbanization rates, which are projected to almost double (in 2000-2023 – 9.5%, in 2023-2050 – 16.1%). It is clear that the pace of urbanization in Qatar is low and constantly slowing down, because almost the entire population already lives in cities, according to forecasts, 79.8% of the urban population is expected by 2050 (in Qatar - 99.7%). In general, there is a low share of urban areas in the total area of the countries (3.7%) and a high density of the urban population (more than 3 thousand people per km2). Urban agglomerations of the countries of this cluster by population belong to the range of 5-10 million people, while the distribution of the urban population by urban agglomerations of different populations is quite even. Megacities (with a population of 10 million people or more) are in the Philippines and Turkey; they are home to a quarter of the entire urban population of these countries, and a third of the urban population lives in urban agglomerations with a population of more than 1 million, and another third - in cities with a population of less than 300 thousand. persons.

Regarding cluster 7, the results of the cluster analysis show a monocluster, which includes the city-state of Singapore (with a population of 5.9 million people as of 2023), where, accordingly, there is 100% urban population, there are no rural areas (but in addition to urban areas, which make up 63.2% of the total area of the country, there are nature reserves and reserve areas, the highest density of urban population is more than 12 thousand people per km2. However, we see a diametrically different situation according to the analysis using the Kohonen map method. In the countries of this cluster, the level of urbanization is above average (75.6% in 2023, from 58.2% in Kazakhstan to 92.0% in Jordan), there are quite high and stable urbanization rates throughout the 21st century (in 2000-2023 - 14.8%, in 2023-2050 - 11.7%), There is a significant increase in the pace of urbanization, which is typical for Kazakhstan, North Korea and Iraq. 83.9% of the urban population is expected by 2050. As of now, the share of urban areas in the total area of the countries is very low (1.6%) and the density of the urban population is high (about 3.5 thousand people per km2). The cluster countries are dominated by small cities (with a population of less than 300 thousand people, where 52.3% of the urban population lives), but more than a quarter of the population lives in urban agglomerations with a population of more than one million.

According to the results of the cluster analysis, cluster 8 contains countries with a low level of urbanization (39.6% in 2023), and a projected increase in the level of urbanization to 51.8% in 2050, the highest rates of urbanization with a tendency to slow down (53.2% in 2000-2023, 31.1% in 2023-2050).

In the countries of this cluster, 100% of the urban population lives in urban agglomerations with a population of less than 300 thousand people. Here, the share of urban areas in the total area of the countries is very low (1.7%), as cities are concentrated on the coasts or in the mountains, where the growth potential of urban areas is limited. The highest urban population density is about 9 thousand people per km2, in the Maldives – more than 11.5 thousand people per km2. According to the results of constructing Kohonen maps, it was found that the cluster countries have a rather low level of urbanization (42.3% in 2023, the urban population slightly exceeds the rural population only in Thailand and Uzbekistan. The projected increase in the level of urbanization to 57.5% in 2050 (the urban population will prevail in all countries, except Myanmar), very high and stable rates of urbanization (37.5-38.0% in 2000-2050). In Vietnam,Yemen and ThailandThe pace of urbanization will slow down significantly by the middle of the 21st century, as it was very high in the first quarter of the century. All urban agglomerations are represented by population (from less than 300 thousand to 10 million people and more), with small cities (with a population of less than 300 thousand people) dominating, where almost half of the entire urban population lives, a third of the urban population lives in urban agglomerations with a population of more than one million (36.1%). Megacities (with a population of 10 million people and more) are only in Pakistan, where more than a third of the entire urban population of the country lives. The share of urban areas in the total area of the countries is low (3.8%, in Yemen and Myanmar - less than 1%), the density of the urban population is high (about 2.5 thousand people per km2, in Yemen - more than 6.0 thousand people per km2).

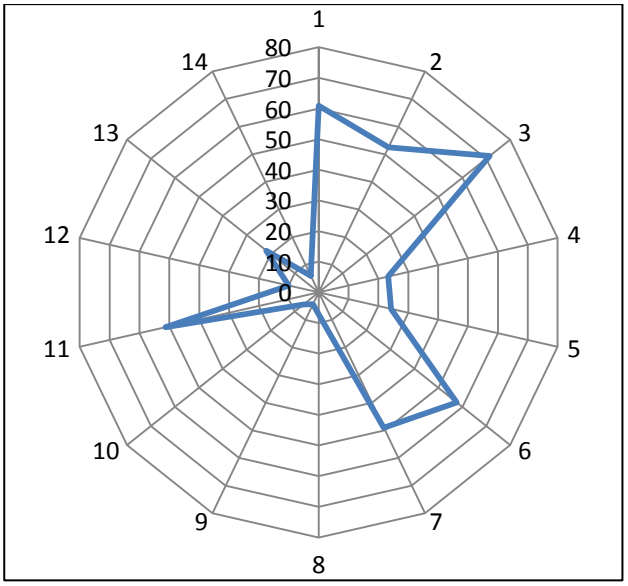
According to the results of the cluster analysis, cluster 9 includes countries with a very low level of urbanization (28.4% in 2023), and the projected growth of the level of urbanization is about 42.7% in 2050. Extreme increase in the pace of urbanization (from 6.1% in 2000-2023 to 52.9% in 2023-2050). Urban agglomerations are represented only by small and medium-sized cities (68.2% of the urban population lives in cities with a population of less than 300 thousand people, another 31.8% - in cities with a population of 500 thousand - 1 million people). The share of urban

areas in the total area of the countries is low (3.2%), the lowest urban population density is less than 1 thousand people per km2.

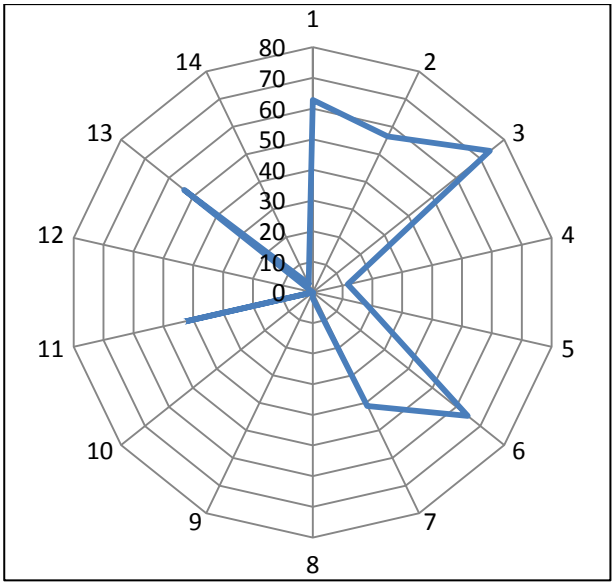
Regarding the Kohonen map study, it is worth noting the very low level of urbanization (35.5% in 2023, from 19.2% in Sri Lanka to 54.0% in Turkmenistan), the projected increase in the level of urbanization to 50.5% in 2050 (mainly due to Turkmenistan, where 68.9% of the urban population is expected by 2050), and a doubling of the urbanization rate (from 22.0% in 2000-2023 to 46.3% in 2023-2050). The exception is Laos, where the urbanization rate will decrease, as it was extreme in the first quarter of the century (74.0%). Urban agglomerations of the countries of this cluster are represented only by small and medium-sized cities (69.7% of the urban population lives in cities with a population of less than 300 thousand people, another 30.3% - in cities with a population of 500 thousand - 1 million people. The share of urban areas in the total area of the countries is low (2.1%), the lowest urban population density (slightly more than 1.5 thousand people per km2) is in Tajikistan - less than 700 people per km2.

To identify and characterize clusters using the neural network method, we will analyze the Kohonen self-organizing map (Fig. 4), component distribution maps (Component Planes) (Fig. 6), and clustering parameters for it (Cluster Statistics) (5).

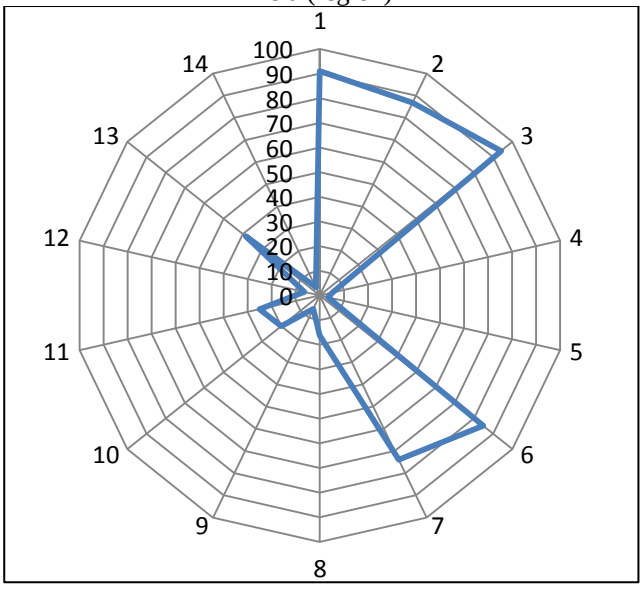
Analysis of the results of the association of Asian countries by the degree of the distance measure "Amalgamation schedule" shows that the most similar Asian countries in terms of the characteristics of urbanization processes and the development of urban agglomerations are Saudi Arabia and South Korea (united at a distance of 0.3245427), Armenia and Georgia (0.3550720), Kyrgyzstan and Tajikistan (0.3602163), Iran and Iraq (0.3983423). The largest distance at which all Asian countries are united into one cluster is 11.59886. This is a fairly large distance (in Europe it was 5.432524), which indicates a very differentiated situation with urbanization processes and the development of urban agglomerations in Asia.



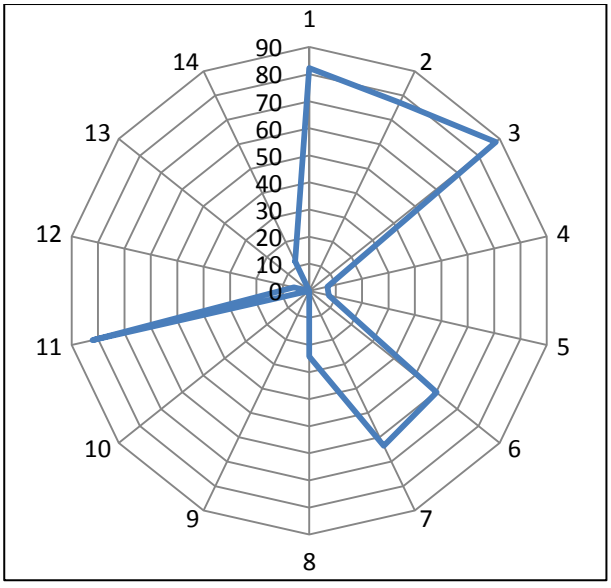
Asia (region)



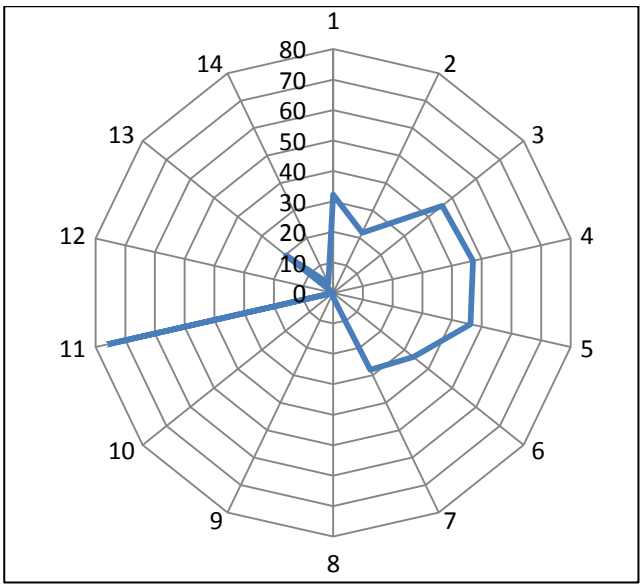
cluster 1



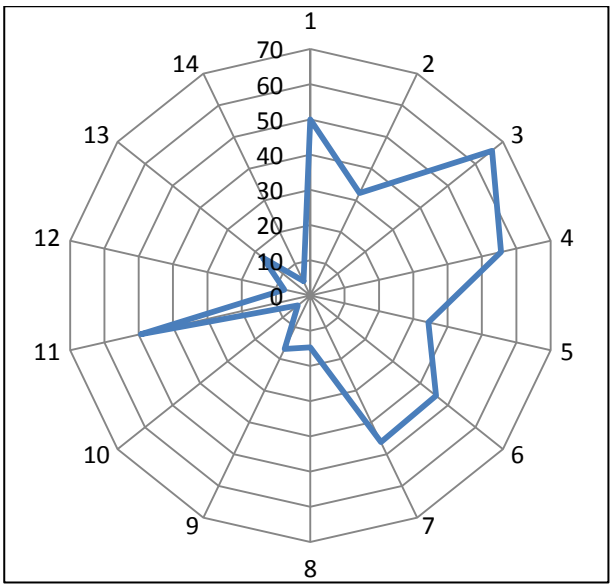
cluster 2



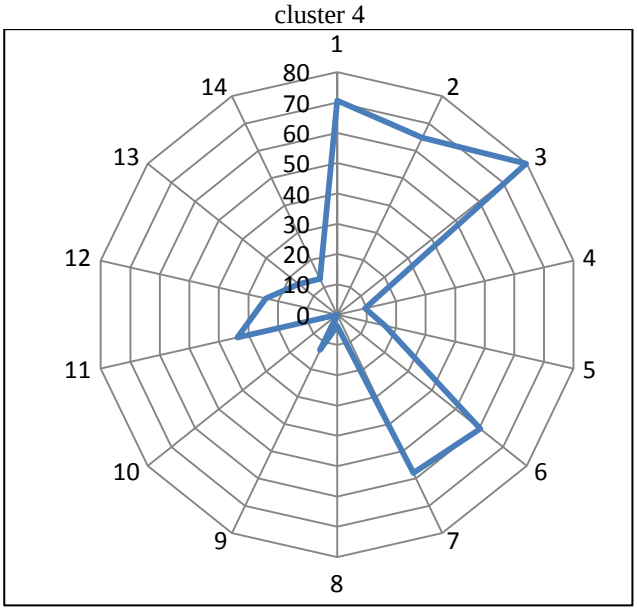
cluster 3



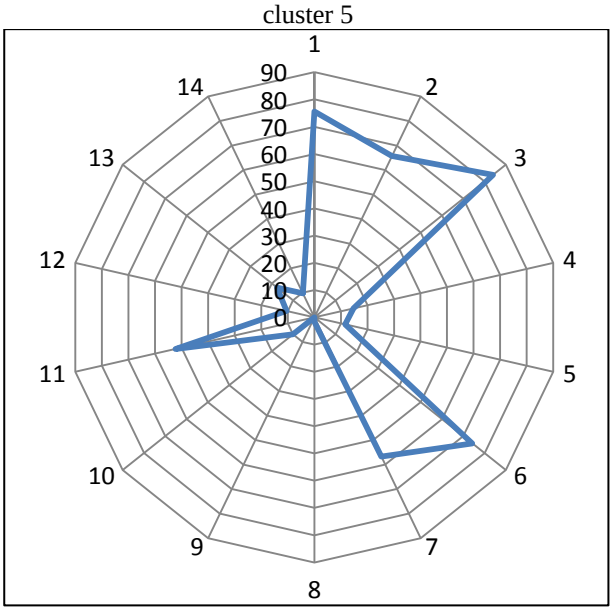
cluster 4



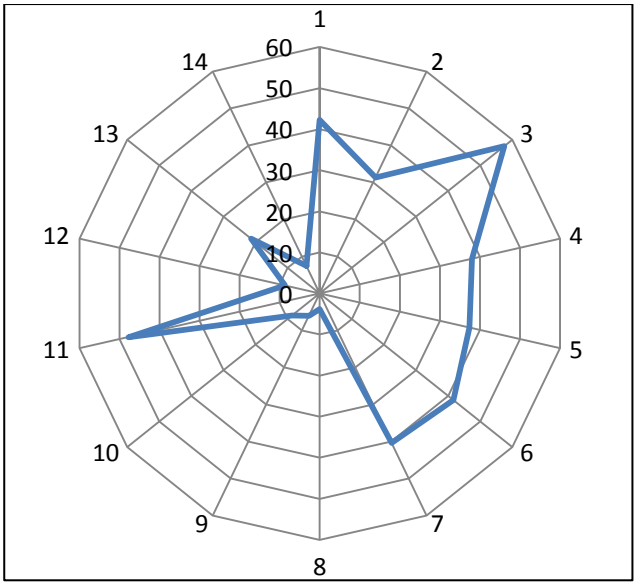
cluster 5



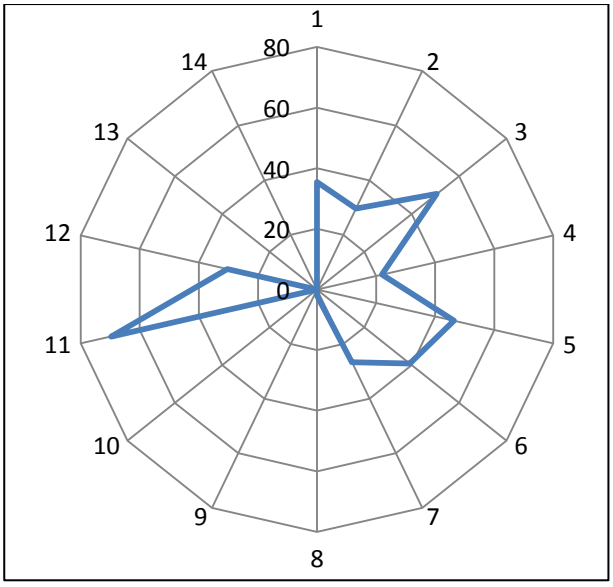
cluster 6



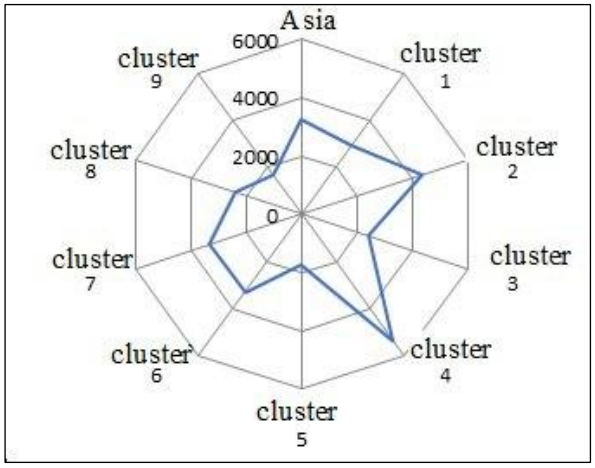
cluster 7



cluster 8



cluster 9



Urban population density, people per km2 (2015)

1 – share of the population living in urban areas, % (2023);
2 – share of the population living in urban areas, % (2000);
3 – share of the population living in urban areas, % (2050);
4 – urban population growth rates, % (2000-2023);
5 – urban population growth rate, % (2023-2050);
6 – share of the population living in urbanized areas, % (2023);
7 – share of the population in cities with a population of over 50 thousand people and a density of over 1,500 people/km2, % (2020)
8 – share of urban areas in the total area of countries, % (2023);
9 – share of the urban population living in urban agglomerations with a population of 10 million people or more, % (2015);
10 – share of the urban population living in urban agglomerations with a population of 5-10 million people, % (2015);
11 – share of the urban population living in urban agglomerations with a population of less than 300 thousand people, % (2015);
12 – share of the urban population living in urban agglomerations with a population of 500 thousand - 1 million people, % (2015);
13 – share of the urban population living in urban agglomerations with a population of 1-5 million people, % (2015);
14 – share of the urban population living in urban agglomerations with a population of 300-500 thousand people, % (2015)

Fig. 5. Characteristics of the region and clusters of Asian countries by similarity of urbanization processes and development of urban agglomerations, identified by the neural network method *(created by the author)*

We see that the composition of the clusters identified using cluster analysis and the neural network method (SOM) differs significantly (only the first cluster completely coincides). In addition to the difference in the methods themselves, which has already been mentioned, it should also be noted the very heterogeneous situation with urbanization processes and the peculiarities of the development of urban agglomerations in Asia - the spread of indicator values among Asian countries sometimes ranged from 0 to 100% (Fig. 7).

Regarding the countries of East Asia (China, Japan, South Korea, and others), it is worth noting the rapid urbanization in China (urban population growth from 20% in the 1980s to over 60% today); the formation of globally significant megacities (Tokyo, Shanghai, Seoul, Beijing); the development of metropolitan agglomeration corridors (Yangtze River Delta, Tōkaidō); planned creation of new cities and districts (especially in China); high-tech urban solutions, the spread of the "smart city" concept with artificial intelligence technologies, "green" cities, "garden cities," and vertical urbanization; the aging population problem in the cities of Japan and South Korea; and ecological challenges. Southeast Asia (Thailand, Malaysia, Philippines, Indonesia, Vietnam, and others) is characterized by population concentration in coastal megacities (Jakarta, Ho Chi Minh City) with the risk of flooding, an expressed "urban primacy system" (Bangkok, Manila, Jakarta), uneven development of urban infrastructure and transportation problems (Jakarta is the most congested city in the world), high population density, a mixture of traditional and modern elements in urban life, and the rapid transformation of agro-production areas into urban ones. South Asia (India, Pakistan, Bangladesh, and others) is characterized by large-scale migration from rural areas to cities, the formation of massive agglomerations (Delhi, Mumbai, Karachi, Dhaka), monocentric megacities with chaotic development, the spread of informal slums (shanty-towns), sharp socio-economic contrasts in cities, problems with providing basic urban infrastructure (lack of sewage systems, water supply), and the significant role of the informal economy. In the countries of Western Asia (Persian Gulf), rapid urbanization is linked to the oil boom, the creation of ultra-modern cities "from scratch" (Dubai, Abu Dhabi), a high share of foreign labor in the cities, the implementation of innovative urban planning technologies, ambitious infrastructure projects (cities of the future, utopian cities, artificial islands, skyscrapers, floating city projects), ecological sustainability challenges in a desert climate, and the influence of religious and cultural factors on urban architecture. Central Asia (Kazakhstan, Uzbekistan, and others) is undergoing the transformation of post-Soviet cities, uneven urbanization of territories, growth of capital agglomerations, and the preservation of traditional elements in urban planning. Many Asian cities are becoming pioneers in implementing innovative technologies, vertical urbanization, and sustainable development.

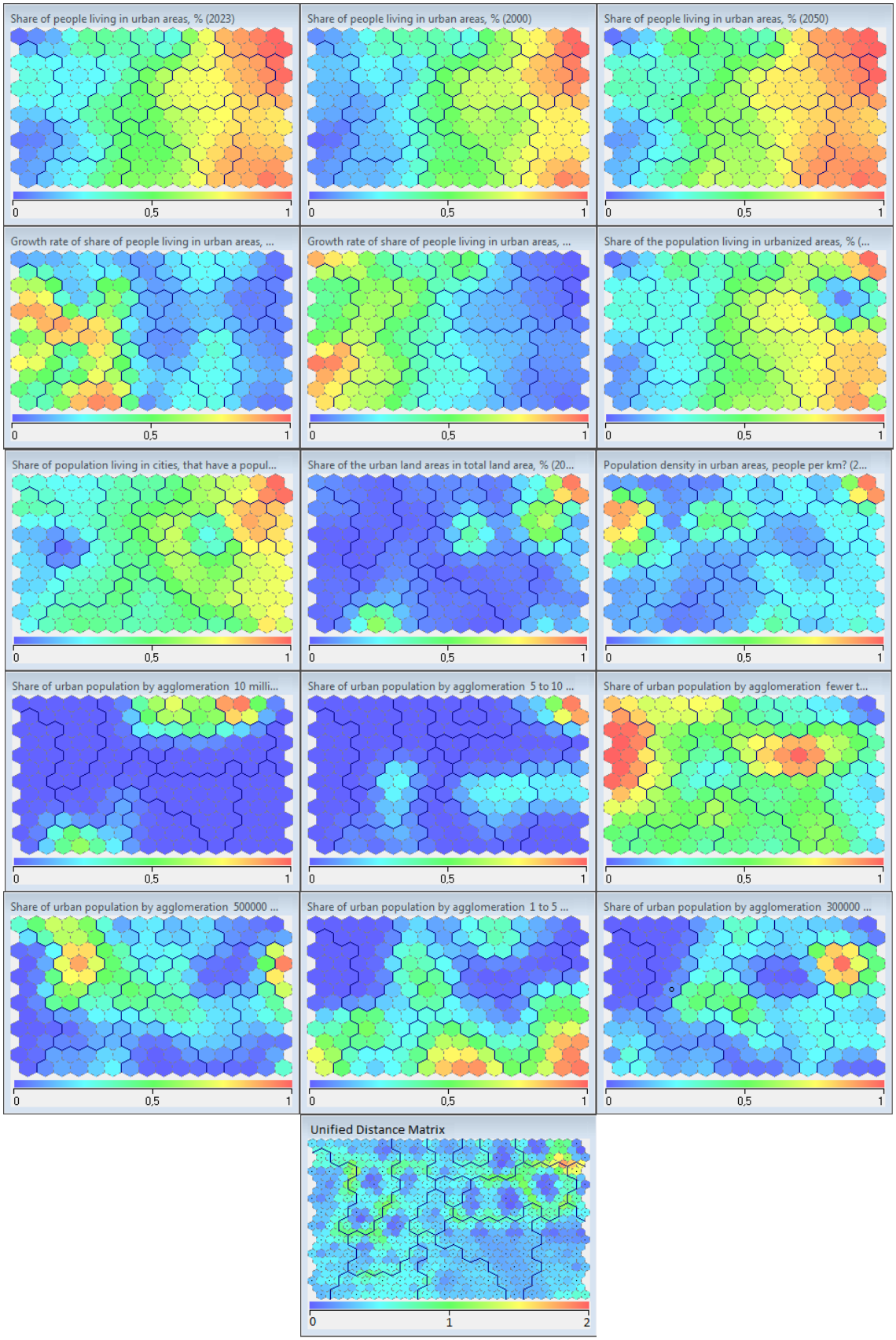
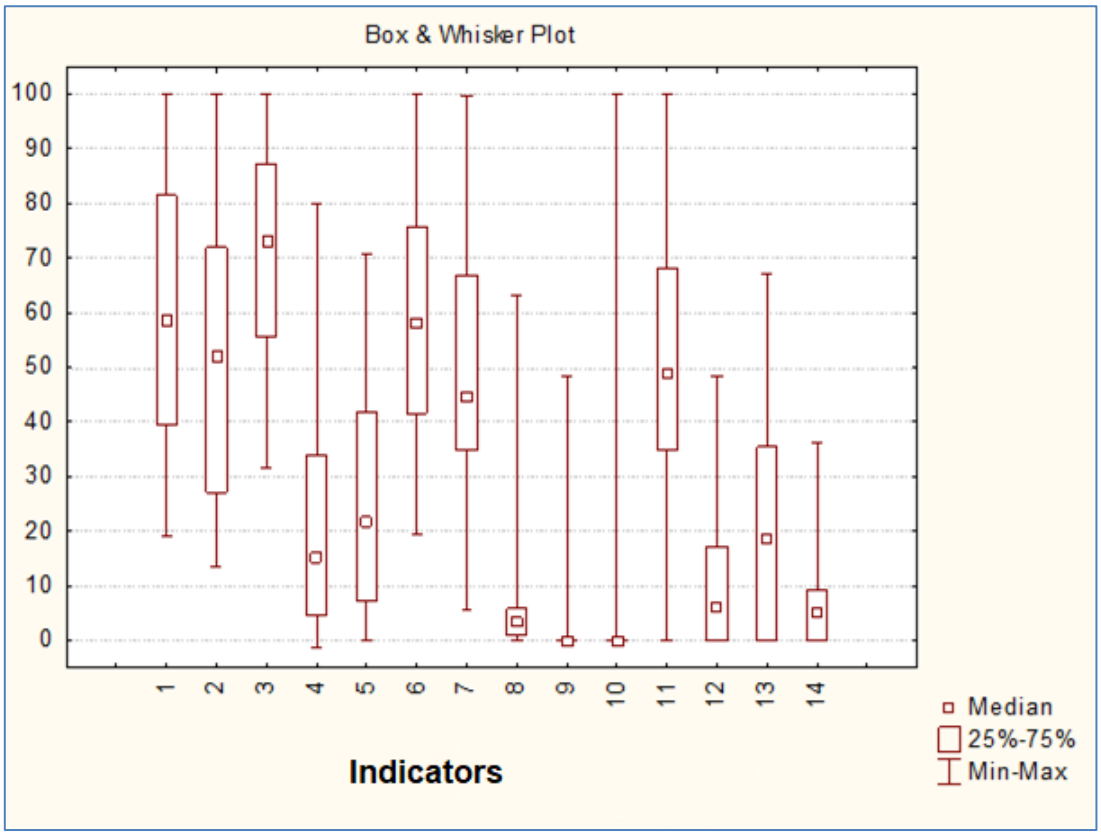


Fig. 6. Component maps (distribution of each individual indicator on the Kohonen map) and distance matrix Asian countries by similarity of urbanization processes and development of urban agglomerations (neural network model)



1 – share of the population living in urban areas, % (2023);
2 – share of the population living in urban areas, % (2000);
3 – share of the population living in urban areas, % (2050);
4 – urban population growth rates, % (2000-2023);
5 – urban population growth rate, % (2023-2050);
6 – share of the population living in urbanized areas, % (2023);
7 – share of the population in cities with a population of over 50 thousand people and a density of over 1,500 people/km2, % (2020)
8 – share of urban areas in the total area of countries, % (2023);
9 – share of the urban population living in urban agglomerations with a population of 10 million people or more, % (2015);
10 – share of the urban population living in urban agglomerations with a population of 5-10 million people, % (2015);
11 – share of the urban population living in urban agglomerations with a population of less than 300 thousand people, % (2015);
12 – share of the urban population living in urban agglomerations with a population of 500 thousand - 1 million people, % (2015);
13 – share of the urban population living in urban agglomerations with a population of 1-5 million people, % (2015);
14 – share of the urban population living in urban agglomerations with a population of 300-500 thousand people, % (2015)

Fig. 7. Range of indicator valuesurbanization processes and development of urban agglomerations in Asian countries *(created by the author)*

General trends in urbanization processes and the development of metropolitan agglomerations in Asia include the rapid growth of cities (the region houses the largest urban agglomerations in the world; it is predicted that by 2050, Asia's urban population will grow to 3.5 billion people) and the highest urbanization rates globally, the development of megalopolises, and hyper-concentration of population in them (Tōkaidō, Yangtze River Delta, Beijing-Tianjin, Indian Megalopolis), a high level of socio-economic differentiation (a strong contrast between rich and poor areas in cities), environmental problems, and innovations in urban planning (development of "smart" and "green" cities, garden cities, cities of the future, artificial intelligence in urban management, etc.).

The study of urban agglomerations in Asia reveals several key trends that may be relevant to the global urbanization process. In particular, the metropolitan agglomerations of the region demonstrate the highest growth rates in the world, accompanied by excessive population concentration in megacities (Tōkaidō, Yangtze River Delta, Indian Megalopolis, etc.). At the same time, significant socio-economic differentiation is observed between different city districts, leading to new globalization challenges, which necessitate the implementation of innovations in urban planning, including the development of "smart" and sustainable cities.

Cluster analysis of Asian countries based on the intensity and nature of urbanization processes reveals significant intra-regional differentiation. For example, Saudi Arabia and South Korea exhibit similar urban agglomeration development trends despite being geographically located in different subregions.

An important stage influencing the qualitative transformation of urban agglomerations is bifurcation points – critical moments after which the system may evolve in different directions. In Asia, such points have occurred and will occur in the future due to demographic changes,

economic recessions, technological upturns, and innovation breakthroughs. Accordingly, possible development scenarios for the urban agglomerations of the region include opportunities for sustainable development (balanced city growth), a conserved state (a state of stability without significant positive or negative dynamics), and a critical state – excessive urbanization leading to social tension, environmental depletion, and infrastructure overload.

Thus, the analysis of urbanization processes in the urban agglomerations of Asia demonstrates not only complex contemporary challenges that will become relevant for many countries around the world over time but also opportunities for overcoming them and developing management scenarios for these complex systems.

Conclusions. Urban agglomerations are complex, open, and dynamic subsystems of the socio-geosystem that dynamically respond to changes in both the external and internal environment. Their development is not a linear process but depends on a range of internal and external factors that can either accelerate or, conversely, slow down transformational changes. From a synergetic approach, urban agglomerations should be considered as open, adaptive, and non-linear systems capable of self-organization, restructuring, and improving their structure. One of the key features of agglomeration development is their tendency for qualitative transformations through phase transitions, which determine the further evolution and potential growth vector. These transitions can be either evolutionary, occurring gradually, or revolutionary, when external or internal factors provoke radical changes in the socio-economic structure of the urban system.

The study of urban agglomerations in Asia, the most dynamically evolving region in the world, using cluster analysis methods and the Kohonen self-organizing map, reveals several key trends that will be relevant to the global urbanization process in the future. In particular, Asia demonstrates the highest urban agglomeration growth rates in the world, accompanied by hyper-concentration of the population in megacities (Tokaido, Yangtze River Delta, Indian Megalopolis, etc.). At the same time, significant socio-economic differentiation is observed between different city districts, leading to new challenges, which necessitate the implementation of innovative solutions in geo-urbanistics and urban planning, particularly the development of urban agglomerations based on the concept of sustainable development, which should be the key driver of modern urban transformations.

Thus, the development of urban agglomerations in the 21st century should be based on a balance between economic growth, ecological security, and social equity. Considering synergetic principles, the basics of system analysis, forecasting bifurcation points, and implementing adaptive management strategies will ensure the stability and dynamic development of urbanized areas. Important tasks for future research in this area include the development of methods for forecasting phase transitions, assessing the effectiveness of contemporary urban models, and identifying optimal mechanisms for managing dynamic environments in the context of global changes.

References:

1. European Commission. European Union Open Data Portal. Retrieved from https://data.europa.eu/en
2. Fang, C. et al. (2019). Modeling regional sustainable development scenarios using the urbanization and eco-environment coupler: Case study of Beijing–Tianjin–Hebei urban agglomeration, China. Sci. Total Environ. 689, 820-830.
3. Fang, C., & Yu, D. (2017). Urban Agglomeration: An Evolving Concept of an Emerging Phenomenon. Landsc. Urban Plan, 162.
4. Haken, H. (2006). Information and Self-Organization A Macroscopic Approach to Complex Systems. Berlin-Heidelberg: Springer, 258 p.
5. Hrazhevska, N.I. (2006). Financial support for marketing in the innovative activities of corporate enterprises. *Bulletin of the Ukrainian Academy of Banking*, 2, 139-143 [in Ukrainian].
6. Hushchyn, I.V., Kyrychok, O.V., & Kuklin, V.M. (2021). Vstup do metodiv orhanizatsii ta optimizatsii neyiromerezh [Introduction to the methods of organizing and optimizing neural networks]. Kharkiv: V.N. Karazin Kharkiv National University Press, 152 [in Ukrainian].
7. Kniazevych, A., Dmytruk, V., & Hrynokh, N. (2019). The synergetics as a concept of social development. *Visnyk Natsionalnoi akademii kerivnykh kadriv kultury i mystetstv*, 2, 77-81.
8. Kravchenko, K., Niemets, K., Sehida, K., Niemets, L., & Suptelo, O. (2020). Approaches of determining the boundaries of agglomerations (basic case of Kharkiv region). *Human Geography Journal*, 28, 5-16 https://doi.org/10.26565/2076-1333-2020-28-01
9. Kravchenko, K. (2024). Human-geographical research perspectives of urban agglomerations: Understanding sustainability in the context of adverse external impact. *Ekonomichna ta Sotsialna Geografiya*, 92, 77-92. https://doi.org/10.17721/2413-7154/2024.92.77-92 [in Ukrainian].
10. Kuzmenko, I.R., & Telnova, H.V. (2022). Kohonen map tools for clustering countries by economic growth level and neoclassical factors. *In Proceedings of the XIII International Scientific and Practical Internet Conference "Finance, Accounting, and Taxation: Theory and Practice"*. Kyiv: NAU, 121-124.
11. Lv, X.; Mu, X. (2023). Investigating the Synergistic Evolution Mechanism of Multi-Scale Cities: A Case Study of Three Urban Agglomerations in Eastern China. *Buildings*, 13, 1197. https://doi.org/10.3390/buildings13051197
12. Mezentsev, K. (Ed.). (2021). Methods of socio-geographical research: Educational and methodological publication. Kyiv: Phoenix Publishing, 100 [in Ukrainian].
13. Niemets, K.A. (2005). Information interaction of natural and social systems: monograph. Kharkiv: Eastern re-

gional center of humanitarian and educational initiatives, 428 [in Ukrainian].
14. Niemets, K., Kravchenko, K., Kandyba, Y., Kobylin, P. & Morar, C. (2021). World Cities in Terms of the Sustainable Development Concept. *Geography and Sustanability*, 2(4), 304-311.
15. Niemets, L.M. (2003). Sustainable development: human-geographical aspects (on the example of Ukraine): monograph. Kharkiv, Fact, 383 [in Ukrainian].
16. Niemets, L.M., & Mezentsev, K.V. (Eds.) (2023). Information: nature, human, society (human-geographical aspects): collective monograph. Kharkiv, V.N. Karazin Kharkiv National University, 408 [in Ukrainian].
17. Niemets, L., Kravchenko, K., Sehida, K., Telebienieva, I., & Kliuchko, L. (2022). Informational and synergetic component of human-geographical research in the scientific heritage of Kostiantyn Niemets. *Visnyk of V.N. Karazin Kharkiv National University, Series «Geology. Geography. Ecology»*, 57, 153-172. https://doi.org/10.26565/2410-7360-2022-57-12
18. Petlin, V.M. (2016). Theory of natural territorial systems: In 4 volumes. Vol. 3: Entropic and synergetic foundations of organization, classification and typology, variability, self-regulation and self-organization. Lviv: Ivan Franko National University of Lviv, 540 [in Ukrainian].
19. Prigogine, I., & Nicolis, G. (1977). Self-Organisation in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations. New York, London, Sydney, Toronto: J. Wiley & Sons, 1977. 491 p.
20. Pugach, S.A. (2021). Communication networks of the region: theory, methodology, practice of socio-geographical research. Kyiv, Taras Shevchenko National University of Kyiv, 200 [in Ukrainian].
21. Shevchyk, O.H. (2014). The problem of synergetics in economics: Modern scientific research. *Scientific Journal of NPU named after M.P. Drahomanov. Series 18: Economics and Law*, 24, 18-24 [in Ukrainian].
22. Qu, G. (2019). Synergetic approach: Essence and characteristic features of application in scientific research on the pedagogy of art. *Naukovyi chasopys Ukrainskoho derzhavnoho universytetu imeni Mykhaila Drahomanova. Seriia 14. Teoriia i metodyka mystetskoi osvity*, 27, 127-130. https://doi.org/10.31392/NPU-nc.series14.2019.27.20 [in Ukrainian].
23. United Nations Population Division. Retrieved from https://population.un.org/dataportal/home
24. Vozniuk, O.V. (2009). Development of domestic pedagogical thought: Synergetic approach: Monograph (P.Yu. Saukh, Ed.). Zhytomyr: Zhytomyr Ivan Franko State University Publishing, 184 [in Ukrainian].
25. Wang, C., & Meng, Q. (2020). Research on the sustainable synergetic development of Chinese urban economies in the context of a study of industrial agglomeration. *Sustainability*, 12(3), 1122. https://doi.org/10.3390/su12031122
26. Wang, C., Mao, G., & Hsu, W.-L. (2021). Synergy effect of regional industrial agglomeration and urbanization. *Sensors and Materials*, 33(2), 727-737. https://doi.org/10.18494/SAM.2021.3039
27. World Bank. Retrieved from https://data.worldbank.org
28. Wu, L.; Huang, Y.; Cheng, Q. (2024a). Growth Motivation of Urban Agglomeration in Multiscale Spatial Structures from the Perspective of Synergy Theory. *Sustainability*, 16, 6190. https://doi.org/10.3390/su16146190
29. Wu, W., Huang, Y., Zhang, Y., & Zhou, B. (2024). Research on the synergistic effects of urbanization and ecological environment in the Chengdu–Chongqing urban agglomeration based on the Haken model. *Scientific Reports*, 14, 117. https://doi.org/10.1038/s41598-023-50607-1

Катерина Кравченко
к. геогр. н., доцент кафедри соціально-економічної географії і регіонознавства імені Костянтина Нємця, Харківський національний університет імені В.Н. Каразіна, майдан Свободи, 4, м. Харків, 61022, Україна
e-mail: kateryna.kravchenko@karazin.ua, https://orcid.org/0000-0003-4654-318,5

ДОСЛІДЖЕННЯ МІСЬКИХ АГЛОМЕРАЦІЙ З ПОЗИЦІЇ СИНЕРГЕТИЧНОГО ПІДХОДУ

У статті розглянуто міські агломерації як складні підсистеми соціогеосистеми, які характеризуються комплексом синергетичних характеристик: відкритість, динамічність, гнучкість, ієрархічність, емерджентність тощо. Міські агломерації еволюціонують протягом періоду існування та змінюються під впливом внутрішніх і зовнішніх чинників. Їх розвиток обумовлюється впливом різних складових, таких як динаміка чисельності населення, економічні кластери, інфраструктурний розвиток, інвестиції та інновації. У статті наголошується на необхідності синергетичного підходу до досліджень, який враховує нелінійні взаємодії та властивості, що виникають з комплексу складних системних взаємозв'язків. Одним із ключових етапів еволюції міської агломерації є вивчення точок вибору траєкторії розвитку або точок біфуркації, у яких міські агломерації можуть трансформуватись в різних напрямках залежно від демографічних, економічних або технологічних змін. В роботі охарактеризовано численні виклики, з якими стикаються міські агломерації, зокрема соціальна нерівність, перевантаження міської інфраструктури через процеси надмірної урбанізації, тощо.

В статті охарактеризовано три потенційно можливі сценарії розвитку міських агломерацій: сталий розвиток, консервація та критичний стан, кожен з яких визначається різними рівнями чутливості та адаптаційних стратегій до викликів, що постають у контексті еволюції міської агломерації.

Використання синергетичного підходу у дослідженні міських агломерацій апробовано при використанні методу самоорганізаційних карт Кохонена та кластерного аналізу для дослідження міських агломерацій Азії як таких, що найбільш динамічно розвиваються. На основі наявних даних визначено 9 кластерів країн Азії, які характеризуються схожими тенденціями урбанізаційних процесів, охарактеризовано проблеми та перспективи їх розвитку. Проведений аналіз урбанізаційних процесів у міських агломераціях Азії виявляє актуальні глобалізаційні виклики, які у перспективі стануть актуальними для багатьох міських агломерацій світу. Таким чином, для забезпечення переходу міських агломерацій до стійкого розвитку

важливим є розуміння їх складності та синергетичної природи, особливостей трансформаційних процесів під дією різноманітних чинників впливу.

Ключові слова: *міські агломерації, синергетичний підхід, точки біфуркації, фазовий перехід, карта Кохонена, кластерний аналіз.*

Список використаної літератури:

1. European Commission. European Union Open Data Portal. URL: https://data.europa.eu/en
2. Fang, C. et al. (2019). Modeling regional sustainable development scenarios using the urbanization and eco-environment coupler: Case study of Beijing–Tianjin–Hebei urban agglomeration, China. Sci. Total Environ. 689, 820-830.
3. Fang, C., & Yu, D. (2017). Urban Agglomeration: An Evolving Concept of an Emerging Phenomenon. Landsc. Urban Plan, 162.
4. Haken, H. (2006). Information and Self-Organization A Macroscopic Approach to Complex Systems. Berlin-Heidelberg: Springer. 258 p.
5. Гражевська Н.І. Фінансове забезпечення маркетингу в інноваційній діяльності корпоративних підприємств / Н.І. Гражевська // Вісник Української академії банківської справи. – 2006. - № 2. – С. 139-143.
6. Гущин І.В. Вступ до методів організації та оптимізації нейромереж: навчальний посібник / І.В. Гущин, О.В. Киричок, В.М. Куклін. – Х: ХНУ імені В.Н. Каразіна, 2021. – 152 с.
7. Kniazevych, A., Dmytruk, V., & Hrynokh, N. (2019). The synergetics as a concept of social development. *Visnyk Natsionalnoi akademii kerivnykh kadriv kultury i mystetstv*, 2, 77-81.
8. Kravchenko, K., Niemets, K., Sehida, K., Niemets, L., & Suptelo, O. (2020). Approaches of determining the boundaries of agglomerations (basic case of Kharkiv region). *Human Geography Journal*, 28, 5-16. https://doi.org/10.26565/2076-1333-2020-28-01
9. Kravchenko, K. (2024). Human-geographical research perspectives of urban agglomerations: Understanding sustainability in the context of adverse external impact. *Ekonomichna ta Sotsialna Geografiya*, 92, 77-92. https://doi.org/10.17721/2413-7154/2024.92.77-92
10. Кузьменко І.Р., Тельнова Г.В. Інструменти карти Кохонена для групування країн за рівнем економічного зростання та неокласичними чинниками // Матеріали XIII Міжнародної науково-практичної інтернет-конференції «Фінанси, облік та оподаткування: теорія і практика ». – К.: НАУ, 2022. – С.121-124.
11. Lv X.; Mu X. (2023). Investigating the Synergistic Evolution Mechanism of Multi-Scale Cities: A Case Study of Three Urban Agglomerations in Eastern China. *Buildings*, 13, 1197. https://doi.org/10.3390/buildings13051197
12. Методи суспільно-географічних досліджень: навчально-методичне видання / за ред. К. Мезенцева. Київ: Видавництво «Фенікс», 2021. 100 с.
13. Нємець К.А. Інформаційна взаємодія природних і соціальних систем: монографія / К.А. Нємець. –Харків, Східно-регіональний центр гуманітарно-освітніх ініціатив, 2005. – 428 с.
14. Niemets, K., Kravchenko, K., Kandyba, Y., Kobylin, P., & Morar, C. (2021). World Cities in Terms of the Sustainable Development Concept. *Geography and Sustanability*, 2(4), 304-311.
15. Нємець Л.М. Стійкий розвиток: соціально-географічні аспекти (на прикладі України): монографія / Л.М. Нємець. – Харків, Факт, 2003. –383 с.
16. Інформація: природа, людина, суспільство (суспільно-географічні аспекти): колективна монографія / за ред. Л.М. Нємець, К.В. Мезенцева. – Харків: ХНУ імені В.Н. Каразіна, 202. – 408 с.
17. Niemets, L., Kravchenko, K., Sehida, K., Telebienieva, I., & Kliuchko, L. (2022). Informational and synergetic component of human-geographical research in the scientific heritage of Kostiantyn Niemets. *Visnyk of V.N. Karazin Kharkiv National University, Series «Geology. Geography. Ecology»,* 57, 153-172. https://doi.org/10.26565/2410-7360-2022-57-12
18. Петлін В.М. Теорія природних територіальних систем: у 4-х т. Т. 3: Ентропійно-синергетичні основи організації, класифікація і типологія, мінливість, саморегулювання і самоорганізація. Львів: ЛНУ ім. І. Франка, 2016, 540 с.
19. Prigogine I. (1977). Self-Organisation in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations / I. Prigogine, G. Nicolis. – New York, London, Sydney, Toronto: J. Wiley & Sons, 1977. – 491 p.
20. Пугач С.О. Комунікаційні мережі регіону: теорія, методологія, практика соціально-географічного дослідження. Київ: Київський національний університет імені Тараса Шевченка, 2021. 200 с.
21. Шевчик О.Г. Проблема синергетики в економіці: сучасні наукові дослідження. *Науковий часопис НПУ імені М.П. Драгоманова. Серія 18: Економіка і право*, 2014. Вип. 24, С. 18-24.
22. Цюй Г. Синергетичний підхід: сутність і характерні особливості застосування в наукових дослідженнях з педагогіки мистецтва. *Науковий часопис Українського державного університету імені Михайла Драгоманова. Серія 14. Теорія і методика мистецької освіти*, 2019. Вип. 27. С. 127-130. https://doi.org/10.31392/NPU-nc.series14.2019.27.20
23. United Nations Population Division Data Portal. URL: https://population.un.org/dataportal/home
24. Вознюк О.В. Розвиток вітчизняної педагогічної думки: синергетичний підхід: Монографія / за ред. проф. П.Ю. Сауха. – Житомир: Вид-во ЖДУ ім. І. Франка, 2009. – 184 с.
25. Wang, C., & Meng, Q. (2020). Research on the sustainable synergetic development of Chinese urban economies in the context of a study of industrial agglomeration. *Sustainability*, 12(3), 1122. https://doi.org/10.3390/su12031122
26. Wang, C., Mao, G., & Hsu, W.-L. (2021). Synergy effect of regional industrial agglomeration and urbanization. *Sensors and Materials*, 33(2), 727-737. https://doi.org/10.18494/SAM.2021.3039
27. World Bank Open Data. URL: https://data.worldbank.org
28. Wu, L.; Huang, Y.; Cheng, Q. (2024a). Growth Motivation of Urban Agglomeration in Multiscale Spatial Structures from the Perspective of Synergy Theory. *Sustainability*, 16, 6190. https://doi.org/10.3390/su16146190
29. Wu, W., Huang, Y., Zhang, Y., & Zhou, B. (2024). Research on the synergistic effects of urbanization and ecological environment in the Chengdu–Chongqing urban agglomeration based on the Haken model. *Scientific Reports*, 14, 117. https://doi.org/10.1038/s41598-023-50607-1

Надійшла 05 листопада 2024 р.
Прийнята 19 грудня 2024 р.