ENVIRONMENTAL SAFETY

ЕКОЛОГІЧНА БЕЗПЕКА

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ANALYSIS OF URBANIZATION IMPACT ON THE DYNAMICS OF EMERGENCIES AND RISKS FOR POPULATION IN UKRAINE

К.А. Васютинська, С.В. Барбашев, С.Ю. Смик. **Аналіз впливу урбанізації на динаміку надзвичайних ситуацій та ризиків для населення в Україні.** Урбанізація в поєднанні з індустріалізацією та економічними структурними змінами викликає негативні процеси у всій системи «місто – навколишнє природне середовище» і, таким чином, стає важливим фактором формування стану екологічної небезпеки території. Мета роботи полягала у визначенні взаємозалежності між демографічними змінами і особливостями, що відображають характер урбанізаційних процесів в Україні, та динамікою показників природної та техногенної небезпеки. Показано, що наслідки урбанізації для зміни рівнів безпеки міських територій практично не вивчались. Дослідження динаміки надзвичайних ситуацій різного генезису за період 1989 – 2017 роки, актуальні в плані вивчення основних чинників природної і техногенної небезпеки, а також мають практичне значення для розроблення інструментів управління ризиками на урбанізованих територіях. Для дослідження використані методи статистичного, порівняльного та графічно-аналітичного аналізу. Показано, що стрімке скорочення чисельності загального населення України, поряд із чисельністю міських мешканців, є провідним чинником зменшення надзвичайних ситуацій природного та техногенного походження. Встановлена поліномна функціональна залежність між нормалізованими показниками природно-техногенної небезпеки і щільністю населення з високим коефіцієнтом кореляції (R^2=0,94). Оцінені ризики життю та здоров`ю населення та досліджені їх зміни за означеними роками. Відсутність сполучення між ризиками втратити життя та здоров`я та індивідуальними ризиками загибелі свідчить про неоднозначний вплив на них демографічних та урбанізаційних процесів. Показане, що індивідуальний ризик проявляє меншу залежність від нормалізованого показника щільності населення, ніж ризик потерпіти від надзвичайних ситуацій (НС). Тренди обох ризиків мають протилежній характер, а тенденції змін в області дуже малих та дуже великих нормалізованих значень щільності населення зворотно пропорційні. До основних причин недооцінки ризиків надзвичайних ситуацій урбанізованого середовища віднесені спосіб врахування НС в Україні, недосконалість регіональних та міських баз даних, недооцінювання малих і середніх катастроф та локалізованих явищ. Розроблена методологія врахування демографічних особливостей та темпів урбанізації як визначальних факторів формування стану екологічної безпеки. Запропоновані практичні рекомендації щодо управліннями надзвичайними ситуаціями в місті та мінімізації ризиків від надзвичайних ситуацій із врахуванням особливостей урбанізації в Україні.
Ключові слова: урбанізація, статистичні дані, екологічна безпека, надзвичайна ситуація, ризик

K. Vasyutinska, S. Barbashev, S. Smyk. **Analysis of urbanization impact on the dynamics of emergencies and risks for population in Ukraine**. Urbanization combined with industrialization as well as economic structural changes causes negative processes in the whole system "City – Environment". And, thus, it becomes an important factor in shaping the state of the ecological danger of the territory. The purpose of the work was to determine the interdependence between demographic changes and characteristics that reflect the nature of urbanization processes in Ukraine, and the dynamics of indicators of natural and man-made danger. The article shows that the consequences of urbanization for changing the levels of safety of urban areas have not been studied in practice. The study of the dynamics of emergencies of different genesis for the period 1989 – 2017 years, relevant in terms of studying the main factors of natural and man-made danger, and also have practical implications for the development of risk management tools in urban areas. They are also of practical importance for the development of risk management tools in urban areas. Methods of statistical, comparative and graphical-analytical analysis are used for research. It is shown that the rapid reduction of the population of Ukraine, along with the number of urban residents, is a leading factor in reducing natural and man-made emergencies. The polynomial functional dependence between normalized indicators of natural and man-made danger and population density with high correlation coefficient ($R^2 = 0.94$) is established. It was assessed the risks to life and health of the population and studied their changes over the years. The absence of connection of the risks of losing life and health and individual risks of death indicates an ambiguous impact of demographic and urbanization processes on they. It is shown that the individual risk is less dependent on the normalized indicator of population density than the risk of suffering from emergency situations (ES). Trends of both risks are the opposite. The tendency of changes in the field of very small and very large normalized values of population density are inversely proportional. The main reasons for underestimating the risks of emergencies in the urban environment include the way of taking in account of the emergency in Ukraine, the imperfection of regional and urban databases, the underestimation of small and medium-sized disasters and

localized phenomena. The methodology of taking into account demographic peculiarities and the rates of urbanization as the determinants of the formation of the state of ecological safety is developed. Proposed practical recommendations for emergency management in the city and minimization of emergencies from the point of view of the specifics of urbanization in Ukraine.

Keywords: urbanization, statistical data, ecological safety, emergency, risk

Introduction. The main process that determines the deleterious changes in the natural environment is the rapid urbanization that has become global. Anthropogenic impact on the elements of the environment consists of complex and ambiguous processes and phenomena that change the boundaries of sustainability of natural ecosystems and the biosphere as a whole. The active manifestation of technogenesis is connected with the high level of urbanization of the territory of Ukraine. According to him, the total area of cities and towns is 19 thousand km^2 or 3 % of the territory of the state with a concentration of the population of about 70 % [1, 2].

Urbanization, combined with industrialization and economic structural changes, causes negative processes throughout the system "City–Environment". They can be reduced to two directions:

Environmental degradation of the internal urban environment causes deterioration of the conditions of the inhabitants of the city, increases the level of environmental hazard for their life and health.

The expansion of cities and the formation of urban agglomerations lead to the expansion of suburban natural areas, changing the nature of the use of biological resources. In general, this violates the constancy of natural complexes, causes and potentiates dangerous phenomena, which, in turn, adversely affect the state of the ecological danger of the urbecosystem.

Hence, urbanization can be considered as an important factor in the formation of the state and the determination of the level of environmental hazard of the urbecosystem. Coordination of economic development and pollution of the environment is the basis of the concept of sustainable urban development. In addition to pollution, urbanization creates serious environmental problems not only in terms of exacerbation of technogenic danger in cities with the concentration of dangerous objects of industry, energy, transport. In urbanized areas, due to a sharp increase in the area of impenetrable surface, the initiation of natural-type emergencies such as flooding, karst, subsidence, etc., may be initiated. The reduction of suburban ecosystems, deforestation, changes in the nature of land use lead to forest and peat fires, floods, and hurricanes. Climate change is a significant threat, which is entirely related to the city's "breathing" and significant greenhouse gas emissions.

Thus, a detailed analysis of the risks of emergencies of different genesis, man-caused accidents and natural disasters must be carried out in relation to the dynamics of demographic changes and urbanization processes.

Analysis of recent research and publications. In recent decades, urban development has been linked with the achievement of social, economic and environmental sustainability. The policy of sustainable development of urban areas includes environmental protection, ecological planning of land management, housing construction and other aspects of the well-being of the growing population. This approach was called "sustainable urbanization" [3]. Safety is the basis for life, health, sustained social relations, freedom of choice and action, and human life must be healthy, productive and harmonious with nature [4]. The problem of sustainable urban development is an integral part of addressing global security challenges related to climate change, the use of organic fuels and greenhouse gas emissions, the rapid reduction of natural landscapes, and others [5]. In urban landscapes, the area of impenetrable surface has been sharply increased, which is an important indicator of the quality of the environment. It has been shown that the disturbance of water drain contributes to the risk of cities in remote sensing [6]. Therefore, the dimensions of the area of impenetrable surface should be taken into account in risk management systems for negative events.

Despite the fact that the effects of urbanization on the environment and natural resources have been researched for many countries of the world, changes in the levels of safety of urban areas have not been practically evaluated.

Methods of statistical and analytical assessment of the consequences of emergencies are investigated in Ukraine [7]. But the impact of urbanization processes on the state of ecological safety of the country has not been studied. It was established that the number of emergency situations (ES) of tech-

nogenic and natural origin is correlated so that 1.3 natural disasters belong to one technogenic emergency station [8]. Among the natural disasters most often are meteorological, geological and hydrological emergency and fire. The results of the analysis fully correspond to the tendencies of weathered climate change, as shown by numerous foreign studies [3, 5, 6].

Thus, the study of the dynamics of emergencies of technogenic and natural type in relation to demographic changes are relevant in terms of studying the main factors and patterns of the ES to develop risk management tools in urban areas.

The purpose of the article is to determine the interdependence between demographic changes reflecting the nature of urbanization processes in Ukraine and the dynamics of indicators of natural and man-made danger.

Materials and methods. Methods of statistical and comparative analysis are used in this work. Data on the number of available general and urban population of Ukraine from 1989 to 2017 were collected from statistical annual reports and ballots for the specified period [1, 2].

General and regional indicators of environmental safety were collected from the annual "Analytical review of the state of technogenic and natural safety in Ukraine" for the period 1992 – 2016 [9], and data for 2017 – on the basis of "Information and analytical certificate of emergencies in Ukraine in 2017" on the site of the State Service of Ukraine for Emergencies [10].

For the comparability of the obtained results, the normalization of data was carry out on the base of equations (1) and (2).

For a positive indicator:

$$r_{ij} = \frac{\{x_{ij} - \min(x_j)\}}{\{\max(x_j) - \min(x_j)\}}. \tag{1}$$

For a negative indicator:

$$r_{ij} = \frac{\{\max(x_j) - x_{ij}\}}{\{\max(x_j) - \min(x_j)\}}, \tag{2}$$

where x_{ij} – the value of j on the number of years i, $\max(x_j)$ and $\min(x_j)$ that are the maximum and minimum values of the indicator from all years.

Graphical analysis and normalization of statistical data was performed using the Python Panda library, DataFrame series, version v0.22.0. Also used is the function – trend line of software MS Office Excel in the diagrams, which corresponds to the reliability of the approximation of statistics data to the regression equation.

Presentation of the main material. In Ukraine the nature of urbanization, which is quantitatively characterized by a change in the percentage of urban population, differs from many other countries in the world by the following features.

Ukraine as an independent state has gained independence, being highly industrialized, well-developed and urbanized. The level of urbanization at the time of 1989 reached 67.27 %. During the years of independence, this level was maintained and increased by approximately 1.03 times, to 69.26 % [2].

Along with the slow growth of urbanization in Ukraine, the total population is rapidly decreasing (Fig. 1). And over the past 28 years it was almost 10 million. This trend is also typical of the urban population, whose number has decreased by 1.2 times – from 34869.2 thousand to 29357.7 thousand [1]. In the regional context, the regions of fast "negative" growth are the most industrially developed. These are Dnipropetrovsk, Kharkiv, Odessa regions. According to 2017 [2], population growth is diagnosed only in following regions of Ukraine: Transcarpathian, Rivne, Lviv, and Kyiv. But the last two expands more at the expense of migration processes than natural growth.

Between urbanization and the state of the environment there are complex multielement links, the study and consideration of which is necessary for the achievement of sustainable urbanization, preservation of the natural environment.

On the one hand, the scale of urbanization has increased the risks and vulnerability of the population to the dangers of natural or man-made origin. The magnitude of their impact on cities and other areas has grown. This clearly demonstrates the growth of material damage from catastrophic events [9]. However, the rapid decline in population density, including urban, affects the dynamics of manifestations of dangerous events.

The statistical analysis of man-made and natural manifestations of emergency situations (ES) in accordance with demographic changes over the past 20 years has been carried out. Since previously [8] the interdependence of natural and man-made ES was studied, the authors considered the patterns of manifestation of the sum of dangerous events.

On the basis of the calculated specific indicators of the number of emergency situations, according to the corresponding population per year and their normalized by the equation (1) values, a graphical analysis of their dynamic changes for the period 1997 – 2017 (Fig. 2) was conducted.

Trend lines for dynamic changes in the specific indicator of the total number of emergencies (Z_t) over the years (trend line regression equation Z_t: $y=0.0491x^2-1.7444x+19.017$, $R^2=0.90$) and the specific indicator of natural and man-made ES (Z_{nt}) (the regression equation of the trend line Z_{nt}: $y=0.0101x^2-0.7424x+1398$, $R^2=0.70$ has a polynomial character, and high correlation coefficients indicate a steady reduction in the number of emergencies over the past 20 years.
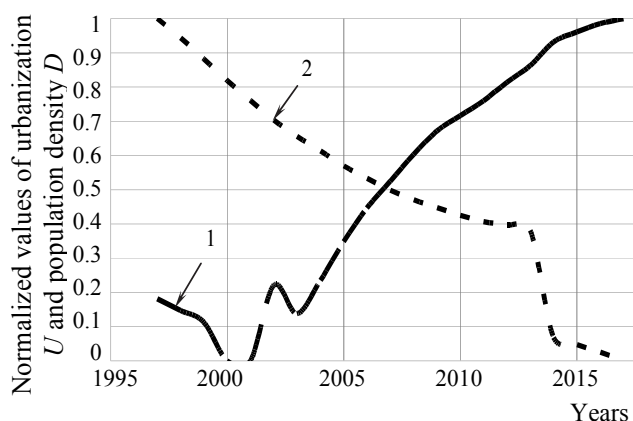

Fig. 1. Urbanization dynamics of URB and population density D on normalized values for the period 1989 – 2017: Urb (1) and D (2)
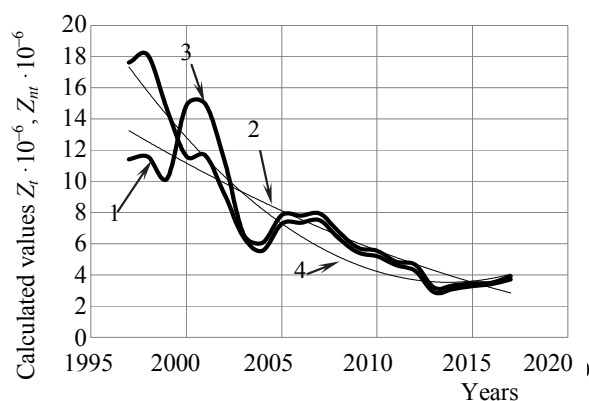

Fig. 2. Dynamics of changes calculated according to the population, the values of the total number of emergencies Zt, and the number of emergencies of natural and man-made nature of Zt for the period 1997–2017: Z_t (1); trend line Z_t (2); Z_{nt} (3); trend line of Z_{nt} (4)

However, the dependence of the factor of urbanization on the main indicators of ecological danger is not simple. Reducing the number of emergencies can not clearly indicate changes in the level of environmental safety. Natural disasters, as well as man-made accidents, are highly probable and have a cyclic nature, which require more than twenty years of research. The nature of their changes over the years (Fig. 2) is more likely to indicate the dependence on the decline in population density due to falling birth rates and active migrations that prevail over the pace of urbanization throughout the designated period.

The functional dependence of the normalized values of the number of emergency situations on the population density for the specified period is determined (Fig. 3).

It should be noted that the coefficient of correlation of the indicator of natural and man-made disasters (the regression equation of the trend line Z_{nt}: $y=1.3849x^2-0.4169x+0.0484$, $R^2=0.94$) is higher than in the case of the total number of disasters (regression equation of the trend line Z_t: $y=0.5351x^2+0.3738x-0.0139$, $R^2=0.72$). The lines Z_t and Z_{nt} practically coincide in the area of low population density and significantly diverge at their high values.
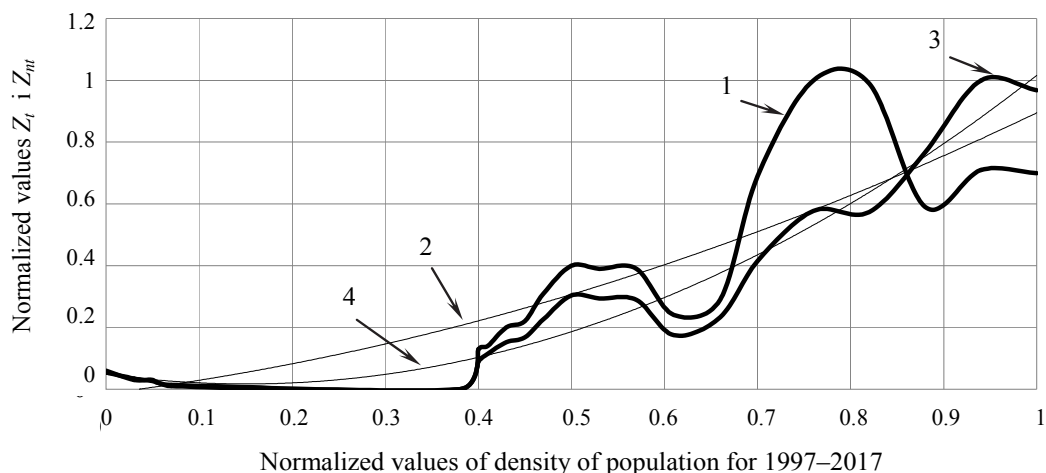
Fig. 3. Functional dependence of the total number of emergencies of natural and man-made nature on the density of the population by the normalized values: Z_t (1); trend line Z_t (2); Z_{nt} (3); trend line of Z_{nt} (4)

This shows the growing influence of social factors on the nature of the manifestation of dangers. Such a fact should be taken into account when organizing appropriate rescue measures in places of high concentration of the population, namely in cities and large settlements.

A risk analysis was conducted to assess the vulnerability of the population in the context of urbanization. The risk of suffering from any type of emergency (R_t) is calculated as the total number of deaths and injuries per year, according to the population of this year. Similarly calculated individual risk of death (R_i) (Table 1).

Table 1

Indicators of risk of loss of life and health from natural and man-made emergencies and individual risks for the period 1997 – 2017

Year	Emergency risk $R_t \cdot 10^{-5}$		Individual risk R_i 10^{-6} per year	
	R_t		R_i	
	calculated value	in a normalized form	calculated value	in a normalized form
1997	5.82	0.561	8.66	0.501
1998	8.61	1	10.34	0.684
1999	6.25	0.629	6.9	0.309
2000	5.04	0.439	10.69	0.722
2001	5.69	0.541	11.58	0.819
2002	4.49	0.352	10.81	0.735
2003	5.14	0.455	8.02	0.431
2004	5.82	0.561	8.86	0.523
2005	4.35	0.330	9.72	0.617
2006	3.25	0.157	10.03	0.650
2007	4.29	0.321	13.24	1
2008	3.35	0.173	12.72	0.944
2009	4.07	0.286	7.75	0.402
2010	2.46	0.033	7.89	0.417
2011	2.94	0.109	7.78	0.405
2012	2.55	0.047	6.61	0.278
2013	2.44	0.030	5.57	0.165
2014	2.25	0	6.69	0.287
2015	2.82	0.090	5.66	0.174
2016	4.67	0.381	4.30	0.026
2017	2.51	0.041	4.06	0

Changes in R_t and R_i indexes have been traced for the last 20 years in accordance with the dynamics of urbanization (Fig. 4).
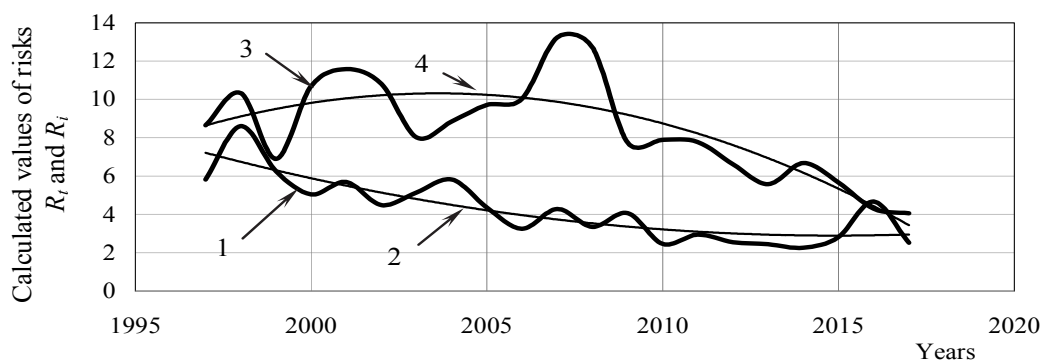

Fig. 4. Dynamics of risks to suffer or perish from emergency situations Rt, and individual risk of death of Ri during 1997 – 2017: Rt (1); trend line Rt (2); Ri (3); trend line of Ri (4)

The trend line of risk dynamics R_t over the years has a higher correlation ($y=0.013x^2–54.38x+54796$, $R^2=0.727$) than the line of trend of individual risk changes R_i ($y=–0.0383x^2+0.583x+8.1015$, $R^2=0.64$).

It should be noted that in no case of emergency, the value of the minimum risk of death (provided $R_i<10^{-8}$ for Ukraine [10]) is not achieved. The values of individual risks are within the maximum permissible risk ($R_i<10^{-5}$).

It's clear that the risk of suffering from emergencies is higher, but also do not exceed the threshold of 10^{-5}. The high rates of individual risks R_i do not coincide with years of R_t risk. Their "outbreaks" are observed both with a significant number of victims (for example, in 1999 – 2002), and with the trend of decreasing the total number of victims (for example, for the period 2006 – 2008) [9, 10].

The lack of a connection of the risks of losing life and health and individual risk of death indicates a mixed impact of demographic and urbanization processes on their (Fig. 5).
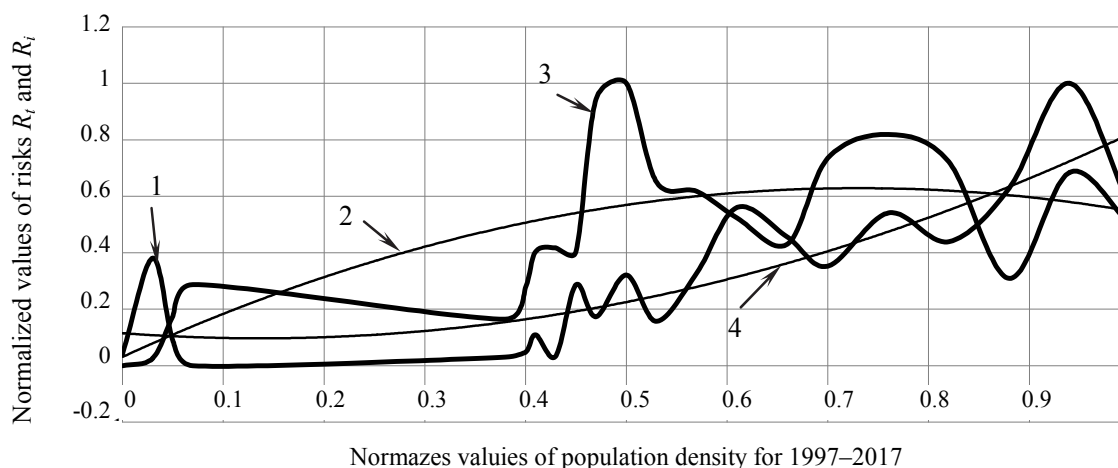

Normazes valuies of population density for 1997–2017

Fig. 5. The functional dependence of the normalized risks of suffering and death from emergency situations Rt, and individual risk of death Ri from the population density during 1997 – 2017: Rt (1); Rt (2); Ri (3); Ri (4)

Graphic analysis has shown that individual risk is less dependent from the normalized population density (for the equation of the trend line R_t: $y=–1.1203x^2+1.6369x+0.031$, the correlation coefficient $R^2=0.50$) than the risk of suffering from emergencies (for the equation of the trend line R_i: $y=0.9726x^2–0.2662x+0.1152$, the correlation coefficient $R^2=0.69$). It is important to note that the trends of both risks are the opposite, and trends in very small (<0.05) and very large (>0.85) normalized population density values are inversely proportional.

Results. The methodology of taking into account the demographic features and the rates of urbanization as determinants of the formation of the state of ecological safety allows identifying important aspects of achieving sustainable urbanization, reducing the risks and vulnerability of the population to various hazards of natural or man-made origin.

Insufficient emphasis on urban research on the risks of natural disasters and man-made accidents does not allow for an analysis according to the characteristics of urbanization processes. In Ukraine, there are no litigation databases of all types of origin for urban and rural population. It is likely that reducing the vulnerability of urban residents to emergencies can be explained by increased organization and better financing of emergency services of the State Service of Ukraine for Emergency Situations as well as modernization of technical facilities.

Thus, the level of risk of natural disasters and man-made disasters related to urbanization is underestimated for the following reasons.

The methodology of data collection based on regional and urban databases shows that data for small and medium-sized disasters is often lacking at all.

Significant difficulties in assessing urban risks arise when the most of the emergencies and associated losses are frequent but small (for example, localized karst phenomena, landslides, flooding, etc.).

Negative processes can cover only part of the urbanized area, which only complicates the assessment.

Local socio-economic factors, the readiness of the rescue services of the State Service of Ukraine for Emergency Situations, their material equipment, significantly affect the number of victims (dead and injured), and the extent of damage.

Secondary effects from emergencies are not taken into account. For example, the effects of damage to transport and communication infrastructure, loss of production, failures of life support systems for citizens, outbreaks of infectious diseases, and others. Such "secondary" unrecorded losses can significantly exaggerate direct and total material damage from emergency situations that are taken into account in statistical and analytical materials [9, 10].

Therefore, a set of objective and subjective factors shapes the risks of emergencies, where the vulnerability of cities to natural disasters and man-made disasters can differ significantly from one another and from a nation-wide level.

On the basis of the conducted researches it is possible to make a number of practical recommendations for developing a program of adaptation of urban systems and population for natural disasters and man-made disasters:

The scientific basis of the program should be risk analysis, taking into account all the features of the sources of hazards in their interaction.

The priority of the program is the methodology of taking into account demographic peculiarities and pace.

Cities, urban agglomerations and isolated areas with high population density are high risk objects. They need special systems for forecasting and organizing security events.

When assessing the risks of emergencies, it is necessary to assess the degree of modification of the environment, which creates a new danger and increases the manifestations of both natural disasters and man-made disasters.

The growing pace of urbanization requires the use of modern tools for environmentally-oriented urban planning and scientific and technological innovation.

Conclusions. The methodology of taking into account demographic peculiarities and the rates of urbanization as the determinants of the formation of the state of ecological safety is developed. Analysis of the dynamics of indicators of natural and man-made hazards showed that there are complex multielement links between urbanization and the state of the environment. Their consideration is necessary to achieve sustainable urbanization, as well as to reduce the risks and vulnerability of the population to various dangers of natural or man-made origin.

The method of taking into account emergency situations in Ukraine leads to underestimation of important factors of the formation of hazards of natural and man-made nature. Hence, the tendency of reduction of them can not unequivocally testify to the corresponding increase of the level of environ-

mental safety. The assessment of the dynamics of emergencies should take into account the peculiarities of demographic and urbanization processes in Ukraine that affect statistical and analytical data.

The risk analysis of the dynamics of catastrophic events was carried out to assess vulnerability of the population in the conditions of urbanization. It is shown that a set of objective and subjective factors generates the risks of emergencies, where the vulnerability of cities to natural disasters and man-made disasters can differ significantly from one another and from a nation-wide level.

The practical recommendations that have been developed establish the need for risk-oriented strategies to mitigate the effects of man-made disasters and adaptation programs to natural disasters both at the national level and at the levels of local self-government.

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