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Methodological Issues of Assessing the Resilience of the Working-Age Population Against Negative Environmental Impacts*

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Abstract. The purpose for the research is to study the resilience of regional human population against environmental impacts based on evaluation of quality indicators of environmental living conditions and promotion of population's health on the one hand, and on population's mortality for a number of causes related to environmental degradation on the other hand. Indicators of environmental degradation may include expanding industrial production, energy consumption, population density, growing number of motor vehicles etc. The study is initiated by the trends of the second epidemiologic transition according to which diseases and causes of mortality are mostly attributable to endogenous factors related to natural ageing of a human body, its declining age-related vitality and resistance to adverse external impacts including environment. The novelty of the research lies in assessment of both population's resilience against this kind of impacts in regions with varied concentration of population and facilities used for economic purposes, and causes of morbidity and mortality from this type of impacts. The system approach used for the research helps both take into account the multicomponent influence of factors over a substantial period of time (a ten year period) and assess their cumulative impact on the sustainability of population's self-preservation behavior. According to the research results, highly industrialized regions strengthen the negative dynamics of working-age population mortality. The situation is different in less industrialized regions where the population is sufficiently adapted to environmental impacts. According to econometric estimates, causes of cancer mortality are closely correlated with respiratory diseases and indicators of environmental impact – environmental pollution with vehicle emissions (exhaust fumes). The research results can be used in justification and adoption of strategic solutions in creating "new quality" of life. The application of research results is focused on making decisions based not only on their interpretation, from the standpoint of improvement or deterioration of the regional situation, but also on the regional assessment of resilience of the human population to environmental impacts adversely affecting population's health.

Key words: assessment, industrialized regions, resilience, environmental impacts, causes of morbidity and mortality, working-age population.

Introduction

According to the principles of sustainable development adopted at the UN Conference on Environment and Development in Rio de Janeiro in 1992, "the country's socio-economic development must be focused on improving the life of all its citizens, preserving natural resources, increasing penalties for environmentally destructive activities". However, the current industry management structure in many regions has not only marked the nature and pace of economic development but also predetermined high human-induced load on the environment. A downward trend in living conditions and, as a result, in people's health is constantly increasing; this is particularly evident in industrialized regions. The understanding by local authorities and communities of this issue has caused environment and environment protection be among top priorities of Russia's development as they are essential in the process of establishing "new quality of life" which is focused on creating environment-friendly and comfortable living conditions for people, their work and recreation, as well as on increasing life expectancy and decreasing morbidity caused by unfavorable environment [15].

In general, the environmental impact on demographic processes is the manifestation of the influence of economic growth factors the indicators of which are industrial production, increase in the number of motor vehicles [24], level of energy consumption, rising population density [23], disposal of production and consumption waste [28], level of urban development and city density [22].

The degree of factor influence is determined by the intensity of their load on the environment. In this regard, we observe the reduction in the "biosphere[1] and environment[2] carrying capacity" and, as a consequence, the emergence of social risks, increase in population morbidity, reducing demographic and labor potential, reducing "quality" of the environment suitable for human activity.

Thus, creating favorable conditions for life and natural reproduction is currently of paramount importance, especially in densely populated regions with industrial production facilities as because human health is determined by three factors: heredity, quality of life and environment.

This issue has identified the main purpose for the present research focused on studying the viability (resilience) of the Russian working-age population against environmental impacts based on the evaluation of quality indicators of environmental living conditions on the one hand, and on population's mortality caused by disease and other factors, environment being among them.

The methodological framework of the research

Analysis of scientific literature has showed that the concept of "resilience" is used in a variety of subject areas and is considered as a state of an individual sphere of human activity. For example, Gavrikova A.V. introduces the concept of demographic resilience which is referred to as a state providing continuous renewal and growth of quantitative and qualitative demographic structures in relevant

[1] b*iosphere carrying capacity* – ability of a biosphere to restore its life-sustaining function depending on disturbing external – (the Sun and space) and internal factors of natural matter and energy cycle, human activity;

[2] *environment carrying capacity* – ability of the environment to digest, process wastes from a specific human activity within specific natural complexes and ecosystems; to level energy-related and physical production impacts by vital activity, natural matter and energy cycle in the structure of a natural complex differing form the structure and functions of a biosphere in a lower hierarchical level of system configuration.

historical and socio-economic conditions. According to the author, the most important components affecting demographic resilience are population dynamics, fertility, mortality, migration and social development of the population [5]. Gaifullin A.Yu. explores social resilience as a state of elements of the society in a certain area providing stability of functioning of the entire spatial social system and stable position of its actors, and counteracting internal and external threats in the long term [7]. Velichkovskii B.T. considers sustainability as a nation's viability through the correlation of social and biological mechanisms in the development of a demographic crisis and the changing health of the Russian population [3].

In the present study, sustainability is referred to as the ability of a system to be coincident in its characteristics before and after being exposed to a variety of factors and caused "shocks". From a theoretical point of view, the key role in human adaptation to changes belongs to external factors, while internal (social) factors no longer have a significant impact [14].

The methodological framework for studying the resilience of the working-age population against environmental impacts is based on key provisions of the general system theory including the study of population resilience within a population system and its ability to self-sustained development considered as a key property of resilience [17].

The concept of environment as a combination of artificial and natural biological, physical, chemical, and social factors able to have a direct and indirect impact on the state of abiotic and biotic components of a biosphere including human beings, was formulated by Burdin K.S. in 1985 [2]. This concept is consistent with the assertion that population's health is a more objective criterion for evaluating the environmental effects than a simple comparison of concentration of specific pollutants with environmental and health standards [18]. It may be concluded that health indicators integrally take into account the complex and combined effects including unidentified pollutants which affect the human body.

Zaitseva N.V., Trusova P.V., Shur P.Z. and others emphasize in their work that exposure of a complex of chemical factors of air pollution, traffic noise and the impact of negative lifestyle factors causes unacceptable risks to human health which increase when a person reaches the age of 47 and becomes critical at the age of 58 [21].

Along with this, human life expectancy depends on many other factors. Demography and medicine traditionally divide factors of mortality into two components: endogenous (internal causes) and exogenous (external causes) [27]. The first group includes natural causes of death – ageing, congenital defects and hereditary diseases. Exogenous factors are related to the influence of external environment. This group can include socio-economic factors, environment, and the effectiveness of the current healthcare system in the country.

According to the international statistical classification of diseases and health-related problems, external causes include road accidents, exposure to smoke, fire and flames, contact with venomous animals and plants, travelling and deprivation, alcohol intoxication, injuries from military actions, etc [13]. According to numerous experts, high mortality rate from circulatory diseases is related to the influence of psychological factors [4]. Velichkovskiy B.T. [3] identifies the "social stress" as a decisive factor in population's health, especially in the period of system changes in the country.

Until the beginning of the 19th century many scholars noted the predominance of exogenous factors over endogenous. However, in the middle of the 19th century, ideas about the nature of negative impacts of various factors on human health began to change. According to the concept of epidemiological transition by A.R. Omran [26], changes in the approach to determining the causes of morbidity and mortality [6] are due to the fact that the first place in the structure of the "new" pathology is occupied by diseases and causes of death primarily due to endogenous factors associated with natural ageing of a human body, its age-related decline of vitality and resistance to adverse external influences [9]. The latter is related to eco-biological causes including environment [6]. Later, this statement was presented in the report of the World Health Organization (WHO), which noted that the contribution of eco-biological factors in mortality rates is 20–30 % on the global average[10].

Methods

Assessment of population's resilience against environmental impacts was conducted based on the methodology of Interfax–Era Agency environmental and energy rating. The perk of such a technique consists in the use of the system approach for assessing the multidimensional impacts of environmental factors over a considerable period of time, which helps estimate their aggregate impact on population's health. Since sustainability in broad terms means the ability of a system to remain unchanged amid changes, the frequency and force of changes in homogeneous systems directly affect its stability and can be used for its evaluation. This assessment approach is based on the fact that external and internal impacts affect the system and its parameters deviate from their “standards”. When these impacts recede system parameters return to their normal level. Frequent changes in basic parameters reflect the system’s “sensitivity” to impacts, i.e., its instability. Accordingly, the system’s stability can be defined by low variation of its key parameters [20].

Based on this approach, in order to obtain correct assessment of population’s resilience against negative environmental factors one must use standard deviation values of the number of deaths among people of working age per 100 thousand people in this age category from its average long-term level as variation parameters. The resulting figure will be the parameter variation; its value will help compare the indicator in different regions interpreting them in terms of viability and resilience in Russia as a whole.

The higher is the variability variation of these indicators, the more unstable is the population system. Thus, high variation of population’s resilience indicates a significant risk to people’s health.

In order to quantitatively estimate the changes in population resilience in the Russian regions we used data of Rosstat on various causes of death of the working-age population over the period 2005–2014. As a result, we calculated the average long-term value level, the standard deviation and variation index according to the formulas below.

1. The mortality rate of the working-age population on average over 10 years is calculated by Formula 1:

$$CT' = 1/10 \sum_{1}^{10} CTt \, , \qquad (1)$$

where CTt – mortality of the working-age population in a particular year defined as the number of deaths among people of working age per 100 thousand people in a given age category;

10 – number of years.

The standard deviation in mortality of the working-age population which illustrates the annual deviation of average mortality rate from the average for a certain period of time is calculated according to Formula 2:

$$CT'' = \sqrt{1/10 \sum_{1}^{10} (CTt - CT')^{2}} . \qquad (2)$$

2. The population resilience index is calculated according to Formula 3:

$$V = CT'' / CT', \qquad (3)$$

where V – variation index of population’s resilience against negative factors.

The calculation was conducted for each constituent entity of the Russian Federation (except for the Republic of Crimea and the city of Sevastopol) over a ten year period.

After that we calculated the index of total environmental impact by indicators of exhaust fumes and pollutant emissions into the atmosphere. In order to assess the degree of human-induced load related to concentration of economic activities and population within settlements, we added indicators of building and road areas to the calculations.

Based on the obtained average estimations of environment indicators and road and buildings areas we carried out the assessment of environmental impact according to the following formula:

$$TE = EA / road + EI / AB , \qquad (4)$$

where TE – total environmental impact, tons/ha;

EA – average pollutant emissions from road vehicles within 10 years, thousand tons;

road – area of roads in an average of 10 years, thousand ha;

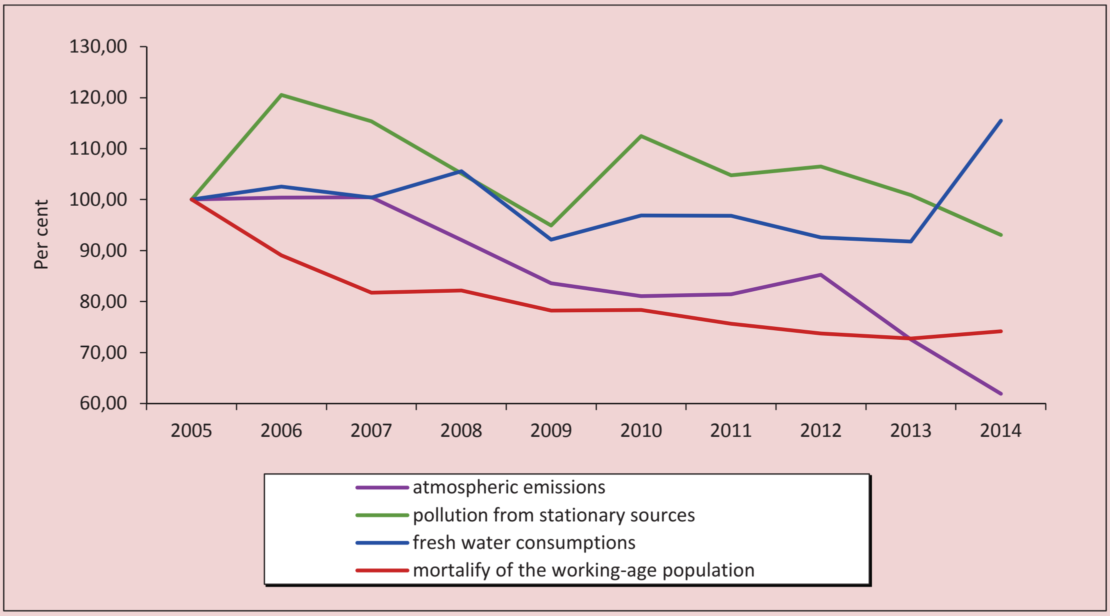
EI – pollutant emissions from stationary sources in an average of 10 years, thousand tons;

AB – built-up areas in an average of 10 years, ha.

Dynamics of socio-economic and environmental state of Russian regions are characterized by high differentiation which in the methodological context is quite difficult to measure when searching for a proper average trend by region. In this regard, analysis of correlation between the variation index of population's resilience (V) and total environmental exposure (TE) by region was carried out using the method of least squares. It seems that this method is the best for addressing the problem of smoothing experimental dependences and finding the average statistical patterns when studying time series with a considerable spread in values.

Analysis of the Russian regions' environment and the structure of mortality of the working-age population in the past decade mark an increased role of some factors and the reducing influence of others. Thus, if in the Soviet period capacity utilization was close to 100%, this mainly determined the state of the environment. However, amid the reforms of the 90-s, compression of industrial production volumes has ceased to have a dominant impact on the environment component. Factors associated with urbanization processes along with the related increase in the anthropogenic load on the environment in areas with dense economic activity and population began to come to the forefront by level of negative impact.

Figure 1. Performance of indicators of environment and mortality of the working-age population in Russia in 2005–2014, % (2005 = 100%)



Source: compiled according to the Federal State Statistics Service.

Despite the general trend of decreasing emissions into the atmosphere and reducing mortality (*Fig. 1*), air pollution in many regions of the Russian Federation is characterized as high, dangerous and very dangerous. This is evidenced by the annually published report of the Ministry of Natural Resources and Environment of Russia [11].

Experts note that air pollution is one of the key risk factors for human health [25] since the daily air consumption of an adult amounts to 12 m^3 [18]. This is evidenced by almost repeating trends in these two indicators up to 2013. At the same time, most common air pollutants are dust, nitrogen oxides, carbon monoxide, formaldehyde, hydrocarbons, and sulfur dioxide [8]. All these pollutant components form the base of exhaust fumes.

Analysis of the research results

Based on environmental variation indicators we assessed the degree of their influence on variation indicators of mortality of the working-age population for a number of causes. This approach helps evaluate the correlation between mortality of the working-age population on the one hand, with morbidity rates (tumors, infectious and parasitic diseases, circulatory diseases, digestive and respiratory diseases) caused by negative environmental impacts, on the

Results of correlation analysis of indicators of environmental impact and mortality from certain types of diseases

Causes of disease-related mortality	Total morality of the working-age population	Environmental impacts		
		Emissions	*Exhausts*	*Pumping*
	Correlation index (R)*			
External	0.88	0.43	0.41	0.48
Digestive	0.77	0.63	0.61	0.58
Respiratory	0.86	0.54	0.53	0.55
Circulatory	0.85	0.60	0.62	0.58
Cancerous	0.71	0.44	0.52	0.44
Parasitic	0.42	0.13	0.11	0.14

* Correlation between mortality of the working-age population and disease-related mortality.

other hand, and indicators characterizing the quality of environment determining population's health.

On order to determine the degree of correlation we constructed the correlation matrix (*Table*) between different causes of morbidity resulting in mortality of the working-age population including environmental impacts.

The correlation analysis concludes that the greatest contribution to mortality of the working-age population is made by external causes (R=0.88). The correlation between mortality and circulatory diseases (R=0.85), respiratory and digestive diseases is also high (0.86 and 0.77 respectively).

We managed to trace sufficiently close correlation between environmental impact and disease-related mortality rates. According to the table, the consequences of environmental pollution with exhaust fumes include mortality caused by circulatory (R=0.62), digestive (R=0.61) and respiratory diseases (R=0.53). Pollutant emissions into the atmosphere from stationary sources have the greatest impact on population mortality caused by digestive (R=0.63), respiratory (R=0.54) and circulatory diseases (R=0.60). The consequences of water pollution include mortality caused by digestive (R=0.58), circulatory (R=0.58) and respiratory diseases (R=0.55). The correlation index of indicators of environmental impacts and causes of mortality from parasitic diseases indicates lack of connection.

The contribution of external causes in the mortality rate of the working-age population amounted to 20%, circulatory diseases – 23%, respiratory diseases – 19%, digestive diseases – 16% (*Fig. 2*).

Environmental factors with the most negative impact on health include pollutant emissions from exhaust fumes into the atmosphere (*Fig. 3*).

Figure 2. Contribution of major diseases to the mortality rate of the working-age population, %

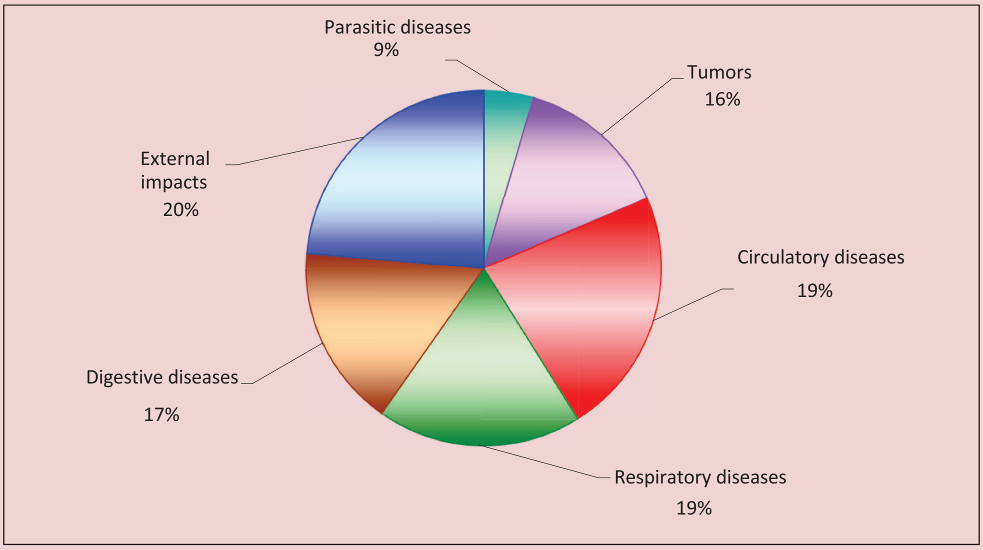
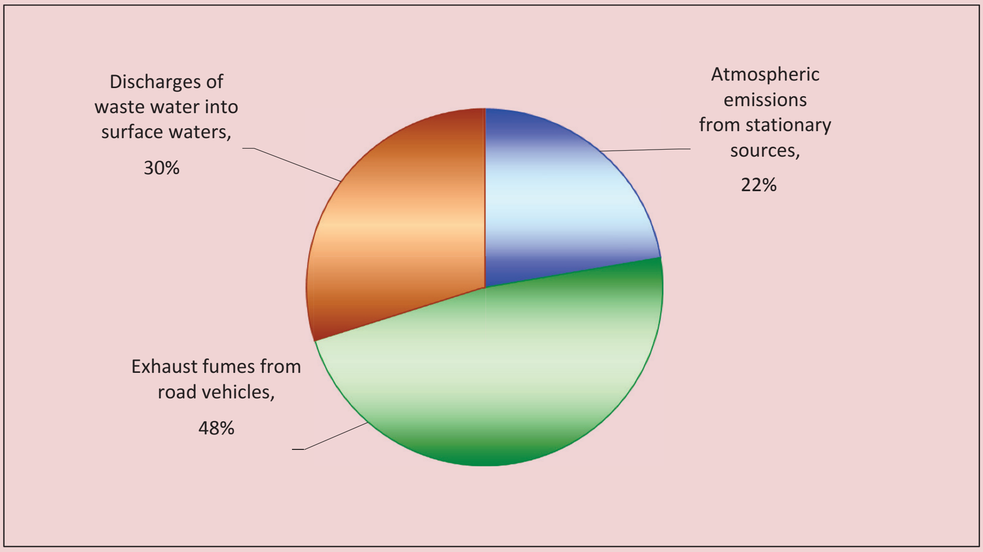


Figure 3. Contribution of negative environmental impacts to incidence of various types of diseases among working-age population, %



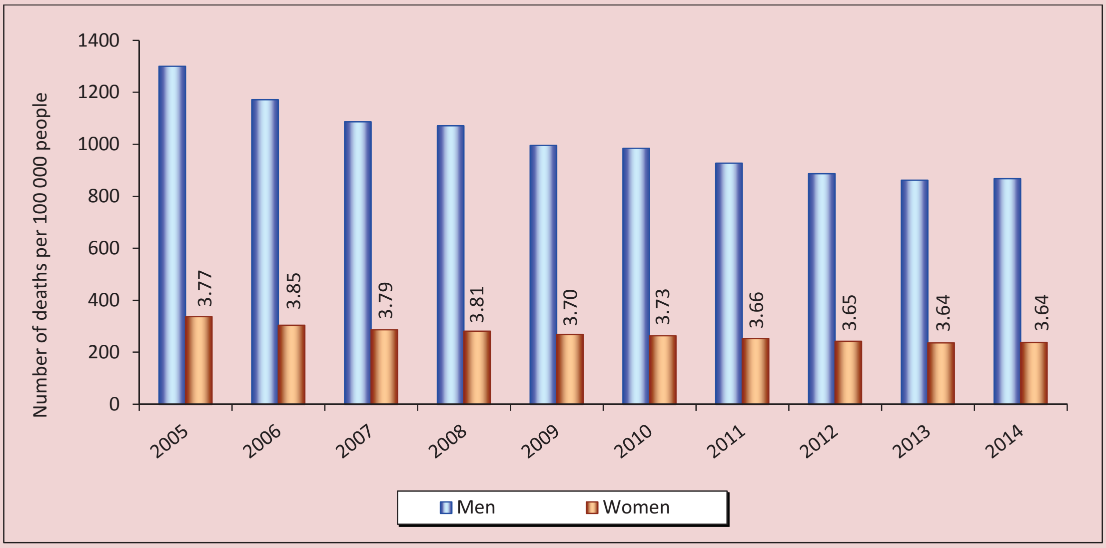
From the standpoint of gender, mortality caused by circulatory diseases among men of working age is much higher than that of women. The highest values of mortality index are characteristic of men aged 25–50, of women – aged 25–40 years. In general, during 2005–2014 the mortality rate in this age group increased by 1.6–2.4 times among men and 1.6–2.3 times among women [1].

During the analyzed ten-year period the mortality rate among men was more than three times higher than that of women (*Fig. 4*).

As for the territorial aspect, the negative environmental impact on health is particularly pronounced in densely populated regions with dense economic activity.

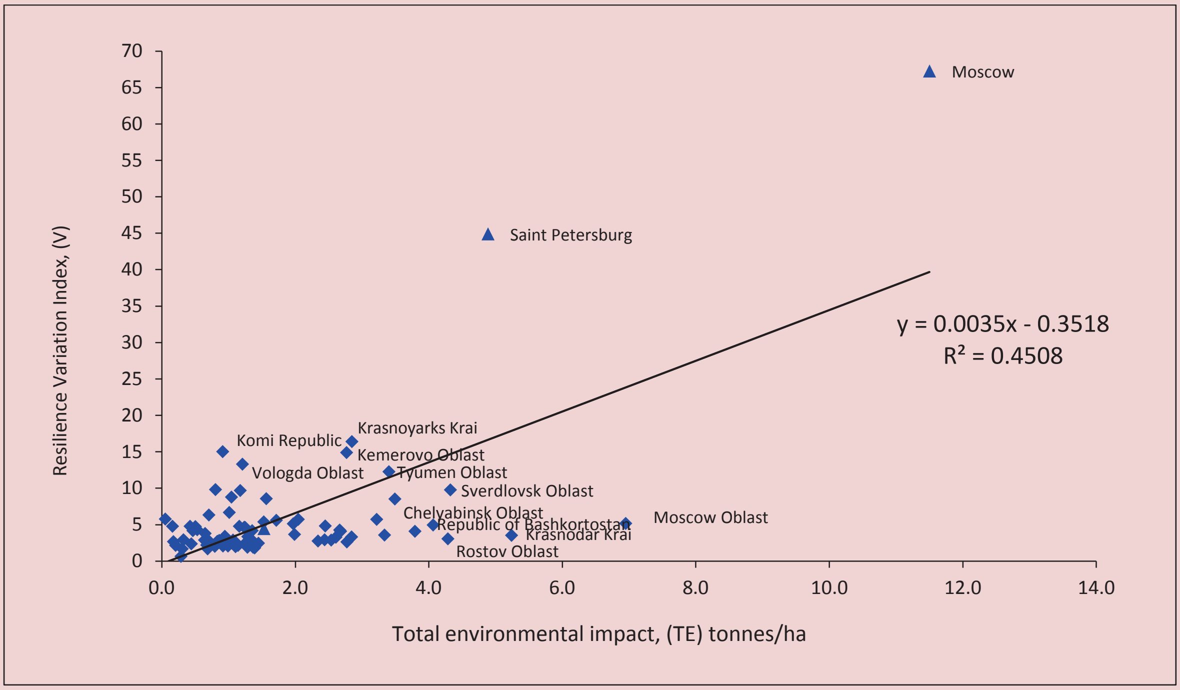
This is confirmed by the results of analysis of correlation between total environmental impacts and the variation index of population resilience in the regional breakdown, which is demonstrate in *Figure 5*. This is also confirmed by results of rating assessment of "the quality of life" in the Russian regions [19]. For example, regions such as Krasnoyarsk Krai, the Komi Republic, the Moscow and Sverdlovsk oblasts occupy leading positions in "economic development" by volume of production of goods and services. In these same regions the environmental situation is assessed as unfavorable: Krasnoyarsk Krai is ranked 85th, the Komi Republic – 82th, the Moscow Oblast – 65th, the Sverdlovsk Oblast – 69th. As for data on morbidity, in the group

Figure 4. Performance of the gender structure of mortality among working-age population in Russia in 2005–2014



Source: Demographic Yearbook of Russia. Rosstat.

Figure 5. Evaluation of the contribution to the total environmental impact to the resilience variation index in Russian regions, average of 2005–2014



of "morbidity" mortality of the working age population of the Moscow and Sverdlovsk oblasts are ranked 19th and 17th respectively by indicators of mortality of the working-age population. In other regions, the mortality rate is somewhat lower.

However, it should be noted that in these regions the population's resilience is much higher than in denser populated regions with denser economic activities, which include Moscow and Saint Petersburg. This may indicate that the role of anthropogenic factors in human activities increases significantly with the concentration of economic activities and population, becoming a greater threat to their health and life.

It should be noted that unfavorable environmental conditions in such cities as Moscow and St. Petersburg have an impact on the average general mortality in Russia to an extent that when removing these regions from the analysis list, statistical correlation between the index of total environmental impacts and the variation index of population's resilience . However, as noted above, the method of least squares helps not only narrow the regional differences, but also provide adequate average pattern in Russia.

According to analysis results, the contribution of the total environmental impact to resilience variation in average of 10 years amounted to 45% (*Fig. 5*), the resulting elasticity index indicates that with a 10% reduction in the total environmental impact population's resilience against negative environmental impacts will increase by 0.03%.

Conclusion

The obtained results help identify and better understand the important functional components in the development of population's health and living conditions, as well as its resistance to various negative impacts in regions with dense economic activity. Close correlation between environmental indicators and indicators of mortality characterizes a kind of "pressure" on population's health and their resilience against environmental factors. The possibility of using the proposed methodological tools of assessment by the governing bodies in decision-making helps make proper conclusions about the quality of environment in regions and its impact on population's health, and take effective measures to reduce the negative impact of environmental factors.

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