Drinking water pollution and its impact on the population in the Russian Federation

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Abstract. The paper shows the spatio-temporal analysis of changes in quality and safety indicators of drinking water supply systems for the period 2010-2018. It is found that for the period 2010-2018 on the territory of the Russian Federation, the shares of water supply systems (public by 13.11% and non-public by 11.69%), water sources (surface by 11.04% and underground by 13.13%) and facilities for transporting utility and drinking water (water pipelines by 21.27%) that do not meet sanitary epidemiological requirements has decreased. The share of the urban population provided with quality drinking water increased by 0.68%, while the share of rural population decreased by 2.91%. For the period 2010-2018 the increase in the indicator of life expectancy of Russian population from 68.94 to 72.91 years was recorded. It is shown that the most problematic areas are in the North Caucasian and Southern Federal Districts. The total contribution of indicators characterizing the sanitary and epidemiological well-being of the territories was 375.2 days (1.03 years). At the same time, the contribution of indicators of the quality and safety of utility and drinking water supply was 9.2 days (2.45% of the group of indicators of sanitary and epidemiological well-being of territories or 0.69% of the entire set of indicators of the environment).

1. Introduction

Water is a vital strategic resource and the provision of the population with a sufficient sanitary and high-quality water is one of the urgent problems in the world. The problems of depletion and pollution of water resources are a matter of serious concern.

Two-thirds of the global population lives in the areas with water shortages for one month or more than a year. About 500 million people live in the areas where water consumption is twice the renewable water resources. The UN report on the state of the global water resources emphasizes that “... the demand for water is growing rapidly: by 2050 it should increase, in general, by 55.0%. If the situation does not change, then by 2030 the global deficit of water resources on the planet will reach 40.0%” [1].

Taking into account the importance of efficient water use and the relationship between water resources and the environment, the UN General Assembly proclaimed 2018–2028 as the International Decade for Action “Water for Sustainable Development” [2].

The problem is not only the sufficiency of water resources, but also the quality of water in them. The process of pollution of water sources, ineffective and unsustainable methods of management and exploitation of water resources, climate change and other factors limit the ways and scope of their use [1].
According to the results of Russian research in 2014–2018 more than 5.0% of drinking water samples exceeded hygienic standards for a number of substances: bromine, manganese, strontium, chloroform, etc. It is proven that the non-standard quality of drinking water contributes to additional cases of morbidity (1 201.3 cases per 100 thousand of the total population) and mortality (10.9 cases per 100 thousand population) of the population associated with the quality of public drinking water supply systems [3].

In a number of territories of the Russian Federation, the increased levels of the risk of additional cases of morbidity associated with the quality of drinking water in the drinking water supply systems are formed, where the migration of chemical compounds from natural sources (geochemical provinces) makes the main contribution to the excess of hazard index (HI) [4].

According to Adimalla N et al. in some areas of India, mainly of agricultural type, there are increased levels of nitrates, the content of which in drinking water is 3.96 times higher than the levels established by WHO, while the greatest risk is the child population with a high risk of developing methemoglobinemia [5]. Increased levels of nitrates in drinking water negatively affect vulnerable populations, but there is evidence that concentrations 12.0 times lower than recommended safe levels can have long-term negative health effects in the form of increased risk of cancer morbidity and mortality [6]. Being one of the most important socially significant diseases in many countries, oncological diseases decrease the life expectancy of the population.

In a systematic review on the health effects of nitrates in drinking water, it was shown that the most stable links are formed between the oral intake of nitrates with drinking water and the development of diseases such as colorectal cancer, thyroid disease and congenital defects of the central nervous system [7].

The non-standard quality of drinking water is caused not only by the content of nitrates in drinking water, but also by metals. In addition to the migration of metals from soil to water sources due to erosion of rocks and soils, soil looseness, an initially high natural content of chemical elements in water sources (geochemical provinces), pollution of drinking water with metals can occur during the process of water treatment and transportation of drinking water through the distribution network [8]. The technical condition of the water distribution network can also become an additional factor in the increase in morbidity associated with the quality of drinking water supplied by centralized treatment and delivery systems.

The levels of pollutants in drinking water recommended by WHO do not take into account the possible synergistic effect between them when combined with drinking water. According to Wasana H M S et al. even if all the established safe standards for the content of pollutants in drinking water are observed, damage to the kidney tissue of experimental animals is possible, which is explained by the synergism of a number of parameters of drinking water (fluoride, cadmium, water hardness, etc.) [9].

In a study by Shaider L. A. et al. it is found that the quality of drinking water supply, which is available to different groups of the population, depends on the socio-economic standard of living, which can potentially be reflected in the differences in the levels of morbidity, mortality and life expectancy [10].

Surface water resources of the Russian Federation comprise 10.0% of the world river runoff or about 4.3 thousand km³/year (for one inhabitant of the country - about 30.2 thousand m³/year). Groundwater resources on the territory of the Russian Federation present almost 400.0 km³ per year including about 34.0 km³ per year suitable for use [11].

Despite the wide range of water resources, in the Russian Federation there are problems associated with the irrational use of water resources, the presence of a shortage of water resources in certain regions of the country, as well as anthropogenic and natural pollution of water bodies. The applied water treatment technologies do not always allow bringing the drinking water supplied to the population using public water supply systems to the standard quality, including due to the lack of monitoring for a number of priority substances in certain territories.

The quality and safety of public water supply systems will partly determine the current levels of
morbidity and mortality associated with the ingested water factor, which will ultimately affect the integral indicator of population health - life expectancy.

The increase in life expectancy to 78 years is one of the key tasks in the framework of the national development goals of Russia until 2030. In this regard, the search for the causes and conditions for the formation of increased levels of morbidity and mortality of the population, including from certain factors of the environment and lifestyle is the most pressing research area.

2. Purpose
The purpose of this research is to assess the contribution of indicators reflecting the qualitative and quantitative characteristics of public drinking water supply to the change in life expectancy of the population of the Russian Federation against the background of a set of determinants of the environment and lifestyle.

3. Materials and methods
The data on indicators of the environment and lifestyle, including the indicators of sanitary and epidemiological well-being of territories, were obtained from the forms of statistical accounting of state statistical bodies for the period 2010-2018 for all constituent entities of the Russian Federation, as well as departmental statistical forms.

The indicators of the environment and lifestyle were selected according to the modern concepts of the influence of these factors on the indicators of morbidity and mortality of the population at various levels of validation. In addition, it was taken into account that the studied indicators should be widely represented in the data of statistical reporting (for the maximum number of subjects of the Russian Federation. The total number of analyzed indicators was 148 units, divided into 7 groups (socio-demographic, sanitary-epidemiological, economic indicators, as well as indicators characterizing the lifestyle of the population and the health care system).

In order to compare the territories (federal districts) of the Russian Federation in terms of a set of indicators characterizing the quality of the water supply system, average rank values were used for the average annual growth rate of these indicators. It was supposed that the lower quality of water supply systems in the federal district formed a lower average rank value.

Due to the presence of multiple correlations between the determining indicators, the exploratory factor analysis was used to reduce the dimension of the input data. In the case of a gap (omission) in the data, the values for the previous year were substituted. In the absence of these data, the average value for a number of observations was substituted.

In order to take into account the multiple multifactorial effects of the indicators of the environment and lifestyle on life expectancy, the method of the construction of neural networks was used. During the study, many neural networks were built with various numbers of inner layers and neurons. As a result, the optimal network (with the maximum value of the determination coefficient) with two inner layers containing 8 and 3 neurons, respectively, was selected for the analysis. The difference between the predicted values of life expectancy, calculated using the predicted and actual values of the indicators, was used as a measure for the assessment of the number of years of survival (or non-survival) associated with sanitary-epidemiological, socio-economic and other determinants. The predicted changes in the indicators of the environment and lifestyle were calculated by a scenario in which the indicators changed by 2024 according to the current trends in their change, and for certain indicators - based on the target values approved in the national projects of the Russian Federation.

The construction of a set of neural networks with a different number of inner layers and neurons was performed using a script developed by the authors in the RStudio software product (“neuralnet” package). Network training was carried out on the basis of retrospective data of the analyzed indicators for the regions of the Russian Federation for 2010–2018. The formation of the data array and the subsequent descriptive analysis of the considered indicators was carried out in the MS Excel 2010 software package.
4. Results

In general, the analysis of the quality indicators of drinking water supplied to the public drinking water supply system showed that the situation related to the provision of the population with safe and high-quality drinking water improved. Thus, the share of public drinking water supply sources that did not meet the requirements of sanitary and epidemiological legislation in the Russian Federation as a whole decreased by 13.11% compared to 2010 (the average annual rate of decline was 1.73%). Among the federal districts, the share of such sources decreased in the Central Federal District (36.65%), at the same time, the largest growth was recorded in the North Caucasian and Southern Federal Districts (+76.03 and +58.09%, respectively).

The share of non-public water supply sources that did not meet sanitary and epidemiological requirements in the Russian Federation as a whole decreased by 11.69% compared to 2010, the average annual rate of decline was 1.27%. At the level of federal districts according to this indicator, the most favorable trend was found in the Far Eastern, Volga and Northwestern Federal Districts (−39.19, −38.88 and −38.88%, respectively).

In general, in the Russian Federation for the dynamic studied period, the share of water sources of non-standard quality, both surface (−11.04%) and underground (−13.13%), decreased. The share of surface water sources that did not meet sanitary and epidemiological requirements decreased everywhere in all federal districts, with the exception of the Southern Federal District, where the share of such sources increased by 30.42%. The share of groundwater sources of non-standard quality decreased most of all in the Central Federal District (−36.77%). In the North Caucasus, South and Ural Federal Districts, the share of such water sources increased by 89.89, 60.02 and 44.81%, respectively.

In comparison with 2010, the share of water pipelines that did not meet sanitary requirements decreased by 21.77% in 2019, the average annual rate of decline was 2.91%. Similar trends were in federal districts, except for the North Caucasian and Southern Federal Districts, where, on the contrary, the increase in the share of water pipelines that did not meet sanitary and epidemiological requirements was recorded by 21.44 and 11.36% relative to 2010, respectively.

The final indicator of the effectiveness of the control measures carried out in relation to the quality and safety of drinking water is the “share of the population provided with pathogen-free drinking water”. In relation to the urban population for the period 2010–2018 this indicator increased by 0.68%, the average annual growth rate was 0.09%. At the same time, the share of the rural population provided with pathogen-free drinking water decreased by 2.91% compared to 2010 (the average annual rate of decline was 0.32%). At the level of federal districts, the proportion of the urban population provided with pathogen-free drinking water increased relative to 2010 in all federal districts, except for the Central and Ural districts (−1.34 and −0.25%, respectively). The opposite situation was in the rural population provided with pathogen-free drinking water: only in the Central and Ural federal districts there was an increase in this indicator in 2010 by 11.74 and 1.65%, respectively.

According to the values of average ranks of all analyzed indicators reflecting the quality of utility and drinking water supply, the most prosperous territories were in the Central, Siberian and Northwestern Federal Districts (the values of average ranks: 6.0, 5.29 and 4.86, respectively). The smallest values of average ranks, and, accordingly, having negative tendencies towards the deterioration of the sanitary-epidemiological situation, were in the Southern and North Caucasian federal districts (values of average ranks: 3.14 in both federal districts) (figure 1). At the same time, life expectancy of the entire population in 2018 had the highest values in the North Caucasian Federal District. Moreover, seven of the top ten constituent entities of the Russian Federation with the highest level of life expectancy were in the North Caucasus and Southern Federal Districts.
Figure 1. Map of federal districts of the Russian Federation, distributed by the values of average ranks of quality indicators of public utility and drinking water supply.

The integral indicator of population health is life expectancy. For the period 2010–2018 on the territory of the Russian Federation, the life expectancy of the entire population increased by 3.97 years (5.76%), the average annual growth rate was 0.7%. During the studied period, at the federal district level, the highest growth rates of life expectancy were in the Far Eastern and Northwestern Federal Districts - 0.82 and 0.78%, respectively, where life expectancy in 2018 was 70.2 years and 73.3 years. At the same time, the highest values of life expectancy were in the North Caucasian, Central and Southern Federal Districts (76.25, 74.01, 73.54 years, respectively) (Figure 2).

Figure 2. Dynamics of changes in the indicator of life expectancy by federal districts of the Russian Federation for 2010 and 2018, years

Legend: RF – Russian Federation; CFD – Central federal district; NWFD – Northwestern federal district; SFD – Southern federal district; NCFD – North Caucasian federal district; PFD – Privolzhsky federal district; UFD – Ural federal district; SFD – Siberian federal district; FEFD – Far Eastern federal district.

The result of the use of neural network modeling of the environmental and lifestyle factors that probably affect the indicator of life expectancy, was a quantitative assessment of the change in the indicator of life expectancy from each determinant factor included in the analysis under given scenario conditions.
It was found that the contribution of indicators related to the quality of utility and drinking water supply was 9.2 days (2.45% of the group of indicators of sanitary and epidemiological well-being of territories or 0.69% of the total set of 148 indicators of the environment and lifestyle).

The group of sanitary and epidemiological indicators reflecting the effectiveness of control, supervisory and preventive measures in relation to objects that are the sources of the environmental pollution (water, air, soil, etc.), had 53 indicators, including 7 indicators characterizing the quality of water supply systems. The general increase in life expectancy of the entire population of Russia from the indicators of this group can probably amount to 375.2 days (1.03 years), which in share terms determines 28.32% of the total increase in life expectancy associated with the entire set of the environmental and lifestyle factors (Table 1). If the target values of indicators of national and federal projects are reached, as well as the changes in other indicators in accordance with the established trend by 2024, the total increase in life expectancy may be 1,325.0 days (3.63 years) for the entire population of the Russian Federation.

### Table 1. The contribution of groups of factors of the environment and lifestyle to the indicator of life expectancy in accordance with the dynamics of their change by 2024, as well as upon reaching the selected target indicators of national projects, days (%)

| Group of indicators | General increase in life expectancy | Days (years) | Contribution (%) |
|---------------------|-------------------------------------|-------------|------------------|
| Group of indicators of socio-demographic sphere | 396 (1.09) | 29.9 |
| Group of indicators of sanitary and epidemiological state of the territories | 375 (1.03) | 28.3 |
| Group of indicators characterizing the lifestyle of the population | 310 (0.85) | 23.4 |
| Group of indicators of economic sphere | 169 (0.46) | 12.8 |
| Health system indicators group | 75 (0.21) | 5.6 |
| Total | 1325 (3.63) | 100.0 |

5. **Conclusion**

The research results showed that:

1. For the period 2010-2018 on the territory of the Russian Federation, there was a decrease in the share of water supply systems (in public by 13.11% and in non-public by 11.69%), water sources (in surface by 11.04% and in underground by 13.13%) and water pipelines that did not meet sanitary and epidemiological requirements (by 21.27%). The share of the urban population provided with quality drinking water increased by 0.68%, while the rural population decreased by 2.91%. At the same time, the indicator of life expectancy of the population of the Russian Federation increased from 68.94 to 72.91 years;

2. The analysis of the indicators of the quality of utility and drinking water supply at the level of federal districts by the average values of the growth rates of indicators showed that in the territories of the North Caucasus and Southern Federal Districts, the increase in the abnormal quality of drinking water was found. Thus, the share of public drinking water supply sources that did not meet the requirements of sanitary and epidemiological legislation for the period 2010-2018 increased by 76.03 and 58.09%, respectively. At the same time, in the subjects of these federal districts, the highest values of life expectancy were recorded for the period 2010-2018 (76.25 and 73.54 in 2018, respectively). The result probably indicates that in these territories, other determinants of the environment and way of life have or compensate the greater effect on the indicator of life expectancy of the population;

3. The predicted increase in life expectancy according to a given scenario (reaching the target indicators of national projects and changes in indicators in accordance with the registered trends by 2024) is 1,325.0 days (3.63 years). The total contribution of indicators characterizing the sanitary and
epidemiological well-being of the territories was 375.2 days (1.03 years). At the same time, the contribution of the indicators of quality and safety of utility and drinking water supply was 9.2 days (2.45% of the group of indicators of sanitary and epidemiological well-being of territories or 0.69% of the total set of indicators of the environment and lifestyle).

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