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Social and hygienic problems and mortality of the population after the liquidation of a city-forming enterprise for the production of chemically hazardous substances (on the example of Usolye-Sibirskoye, Irkutsk region)

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Introduction. In Usolye-Sibirskoye, after the liquidation of the town-forming enterprise "Usoliekhimprom", the socio-economic and demographic situation sharply worsened, and environmental problems accumulated since the 30s of the twentieth century aggravated. For the period 1990–2019, the city's population decreased by almost 30%.

The study aims to conduct a comparative analysis of the mortality rate of the male and female population of Usolye-Sibirskoye, the Irkutsk Oblast and Russia and assess the contribution of a certain age and gender groups (children, working-age, and post-working age) to the formation of super-mortality in the population.

Materials and methods. The study base was the primary data of the Federal State Statistics Service (Table C-51 "The number of deaths by sex, age and specific causes of death" and 2PN "Population by sex and age"). We calculated the age-specific for 5-year age groups and age-standardized mortality rates from all causes of death separately for the male and female population of Usolye-Sibirskoye, Irkutsk Oblast and Russia for ten years (2010–2019) and traced them dynamics. Standardization was carried out by a direct method (the standard is the population of Russia according to the 2010 census). Considering the small population of the city and the resulting fluctuations in the mortality rate in individual years, to obtain stable indicators, we summarized the data on mortality for ten years (2010–2019) and calculated the average coefficients. We performed similar calculations for the region and country. We also assessed the contribution of certain age and gender groups (children, working and post-working ages) to the formation of excess mortality.

Results. During 2010–2019 among the male and female populations of Usolye-Sibirskoye, Irkutsk Oblast and Russia, there was a steady decrease in mortality, but in the city, higher rates and slower rates of their decline were recorded compared to the region and the country. As a result, at the end of the observation period, the gap between the city's mortality rate and the compared territories increased even more. The most significant demographic losses occurred in the working age, where the average mortality rate for men and women over ten years was 28 and 37%, respectively, higher than the regional and 1.8 and 2.2 times the national average.

Conclusion. *Thus, the main contribution to the excess mortality of the population of Usolye-Sibirskoye is made by men and women of working age (from 53.6% to 72.5% depending on the comparison area), which, on the one hand, maybe a consequence of the influence of harmful and dangerous working conditions. In combination with a polluted environment, on the other hand, it may be due to the termination of the operation of a city-forming enterprise and the inevitable increase in unemployment and socio-economic tension in these conditions.*

Ethics. The study was conducted in an ethical manner.

Keywords: *standardized mortality rates; excess mortality; working age; environment; harmful and hazardous working conditions*

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Introduction. Usolye-Sibirskoye is one of the oldest cities in the Irkutsk Oblast, founded on the banks of the Angara River in 1669 by the Yenisei Cossacks. They discovered a salt spring and built a brewhouse [1]. In Soviet times (1936), the Usoliekhimprom chemical enterprise began operating. It consisted of an acetylene complex (production of calcium carbide) and a chlorine complex (production of chlorine and its derivatives by diaphragm electrolysis of brine). From 1970 to 1998, a mercury electrolysis workshop worked at the enterprise. It dumped about 1461 tons of heavy metals into the environment, and 60 tons of it ended up in Angara [1, 2]. In the 1990s, the Usoliekhimprom enterprise entered a period of crisis. It continued to work, but the number of employees constantly decreased. As a result of bankruptcy on November 1, 2017, the company was finally liquidated. Since October 2018, an emergency regime was introduced in the city due to the discharge of chemically hazardous substances[1]. By order of the President of Russia V.V. Putin dated July 30, 2020, in Usolye-Sibirskoye, the local authorities took measures to solve environmental problems with the involvement of equipment and employees of the Ministry of Defense, management and representatives of Rosprirodnadzor, the Ministry of Emergencies, the Ministry of Health, Rosgvardia, Rostekhnadzor, Rospotrebnadzor, Rosatom State Corporation, Research Institute of Hygiene,

[1] Decree of the Governor of the Irkutsk Region dated December 21, 2008, No. 260-ug "On the introduction of a high alert mode of operation for the territorial subsystem of the Irkutsk Oblast of the unified state system for the prevention and elimination of emergencies".

Occupational Pathology and Human Ecology, and other organizations[2].

The environmental and technical supervision data in August 2020 at the industrial site show the mercury MPC in the ambient air exceeded 367 times, benzene — 5.2 times. In wastewater, the MPC of mercury exceeded 33 thousand times, oil products — 3 thousand times, iron — 190 times, copper — 22 times, phosphates — 5 thousand times, etc. [2]. Thus, tons of toxic substances of 1–3 hazard classes, including mercury and carcinogens [3]. At present, on the territory of the former Usoliekhimprom plant, all enterprises have ceased their activities, production processes have stopped, the equipment is dismantled. Elimination, disinfection, and neutralization of chemically hazardous substances in large quantities at the industrial site occur.

For a long time in Usolye-Sibirskoye there was an unfavourable demographic situation. In 1990 107 thousand people lived in the city; by 2020, the population decreased to 76.0 thousand people, i. e., the decrease was almost 30%[3].

The closure of the Usoliekhimprom chemical plant resulted in a sharp reduction in the number of employees and a massive population outflow. In the last decade, the highest migration outflow was from 2011 to 2015, when the population decline due to migration was 3–4 times higher than in the Irkutsk Oblast and ranged from 8% to 13% per year. In recent years, the negative migration balance has decreased to 4–5%, but it remains two times higher than the mechanical decline in the population in the region.

At the same time, we cannot rule out that an intensive decline in the population of Usolye-Sibirskoye was a consequence of migration and a high mortality rate in the city [4].

The study aims to conduct a comparative analysis of the mortality rate of the male and female population of Usolye-Sibirskoye, the Irkutsk Oblast and Russia and assess the contribution of a certain age and gender groups (children, working-age and post-working age) to the formation of super-mortality in the population.

Materials and methods. The study base was the primary data of the Federal State Statistics Service (Table C-51 "The number of deaths by sex, age and specific causes of death" and 2PN "Population by sex and age"). We calculated the age-specific for 5-year age groups and age-standardized mortality rates from all causes of death separately for the male and female population of Usolye-Sibirskoye, Irkutsk Oblast and Russia for ten years (2010–2019) and traced them dynamics. We considered the age structure of the population in Russia for 2010 (population census 2010) as the standard. Standardization was through the direct method.

We considered the relatively small population of the city of Usolye-Sibirskoye and possible strong fluctuations in mortality rates in individual years. Therefore, we also calculated the mortality rates averaged over 10 years (2010–2019) from all causes in aggregate for the enlarged age groups of children (0–14), working-age (15–59 (54)) and post-working age (60+(55+)) male and female population. We performed similar calculations for the Irkutsk Oblast and Russia as a whole.

To quantify the contribution of individual age and gender groups mortality to the overall male or female mortality (in the three above-mentioned age groups, and total for all ages) in the Usolye-Sibirskoye, Irkutsk Oblast and Russia, we calculated the number of deaths on average (2010–2019) according to standardized indicators:

$$ {}^{std}M_x = \frac{m_x^{std} \cdot P_x^{std}}{10000} \quad (1), $$

where ${}^{std}M_x$ is the number of deaths in a particular age group; mxstd is the standardized mortality rate, calculated for 10 thousand people in group x; x is age group (children; working age; post-working age); P_x^{std} is the population that we took as the standard.

We calculate the total number of deaths in each population (${}^{std}M$) as the sum of deaths in three age groups (${}^{std}M_x$):

$$ {}^{std}M = {}^{std}M_{0-14} + {}^{std}M_{15-59/54} + {}^{std}M_{55+/60+} \quad (2). $$

We estimated the difference in the total number of deaths in Usolye-Sibirskoye (when compared with the region or country) as an excess number of deaths if the obtained difference is positive:

$$ {}^{std}M^{excess} = {}^{std}M^{1} - {}^{std}M^{0} \quad (3), $$

where ${}^{std}M^{excess}$ is the total number of excess deaths when comparing two populations; ${}^{std}M^{1}$ is the total number of deaths in Usolye-Sibirskoye, and ${}^{std}M^{0}$ is the total number of deaths in the Irkutsk Oblast (Russia).

We estimated the excess number of deaths in each age group (${}^{std}M^{excess}$) in Usolye-Sibirskoye in comparison with the region (or country) in a similar way ***(formula 3)***.

At the next stage, we took excess mortality in general for all age groups (${}^{std}M^{excess}$) as 100% and assessed the contribution of each of the age groups to the total excess mortality:

$$ w_x = \frac{{}^{std}M_x^{excess} \cdot 100}{{}^{std}M^{excess}} \quad (4), $$

where w_x is the contribution of age group x to excess mortality when comparing two populations (%); ${}^{std}M_x^{excess}$ is the number of excess deaths in the age group when comparing the two populations.

The received contribution indicator makes it possible to judge the share of each of the age and gender groups in the excess demographic losses of the population of Usolye-Sibirskoye.

Results. Analysis of the dynamics of standardized mortality rates from all causes showed that throughout 2010–2019 in the city of Usolye-Sibirskoye, in comparison with the Irkutsk Oblast and Russia, mortality rates were higher among the male and female populations. It was especially significant in men ***(Fig. 1 and 2)***. In some years, the standardized mortality rate in the city was higher than in the region for the male population by 14.0–23.7%; in comparison with Russia by 40.3–58.5%. The differences ranged from 1.6 to

[2] Order of the President of the Russian Federation of July 30, 2020, No. 189-rp "On measures to prevent and eliminate environmental pollution in the urban district of Usolye-Sibirskoye, Irkutsk Oblast".
[3] Database "Indicators of municipalities" of the Federal State Statistics Service https://www.gks.ru/scripts/db_inet2/passport/pass.aspx?base=munst25&r=25736000 (Accessed: 02.08.2021)

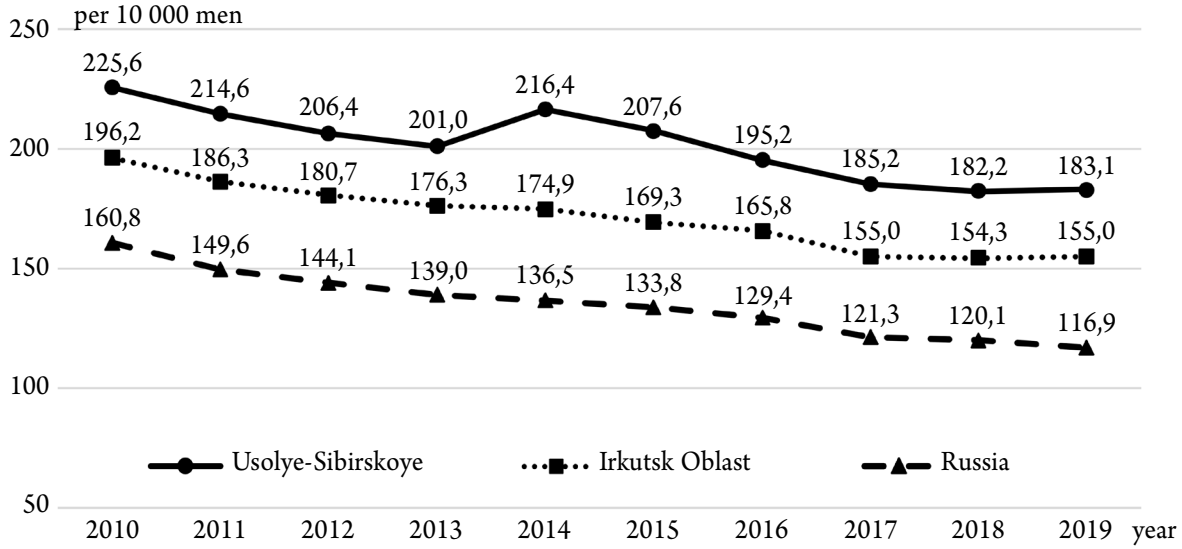

Fig. 1. Dynamics of the standardized mortality rates of the male population from all causes in aggregate in Usolye-Sibirskoye, the Irkutsk region and the Russian Federation in 2010–2019, per 10 000 men

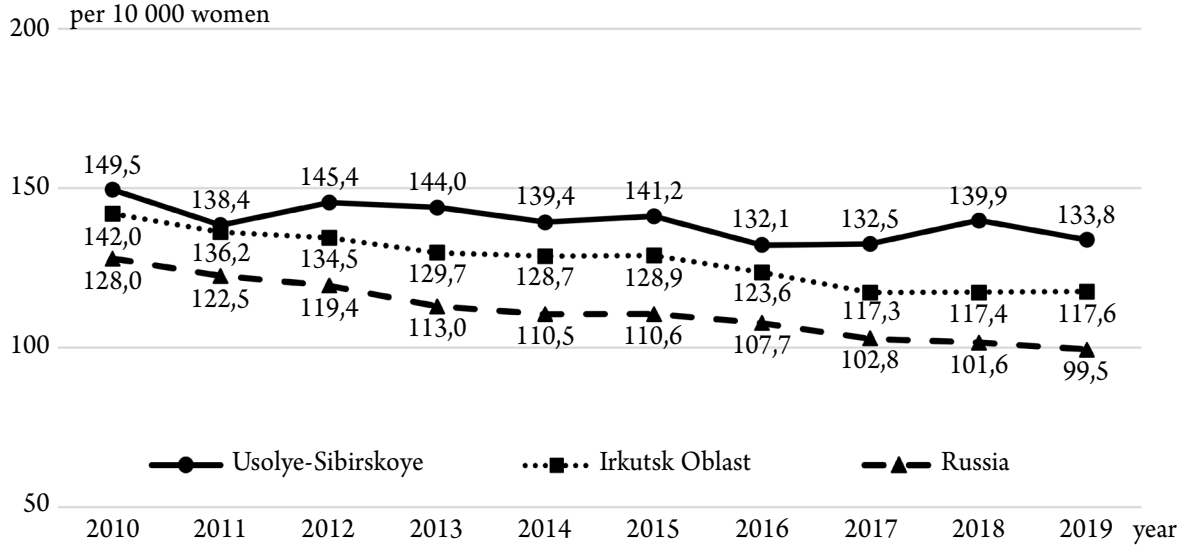

Fig. 2. Dynamics of the standardized mortality rates of the female population from all causes in aggregate in Usolye-Sibirskoye, the Irkutsk region and the Russian Federation in 2010–2019, per 10 000 women

19.2% among the female population and from 13.0 to 37.7%, respectively.

Throughout the studied decade, there was a clear tendency towards a decrease in mortality in all three populations. However, it was not always consistent in of Usolye-Sibirskoye. The standardized mortality rates for men decreased in Usolye-Sibirskoye by 18.8%, in the Irkutsk Oblast by 21.0% and in Russia by 27.3%.

The mortality rate among the female population also decreased, but, like in men, in Usolye-Sibirskoye, its decrease was the most minor (10.5%) compared with the Irkutsk Oblast (17.2%) and with Russia (22.8%).

The unequal rate of decline in mortality caused an even more significant gap in the mortality rate of Usolye-Sibirskoye population in comparison with the region and the country. In 2010, the age-standardized mortality rate for men in Usolye-Sibirskoye exceeded the similar regional indicator by 15.0%, and in 2019 the gap was 18.1%. Compared to Russia, it increased from 40.3% to 56.6%. For women, the difference in mortality rates compared to the Irkutsk Oblast was 5.3% in 2010, in 2019 — 13.8%. Compared to Russia, it increased from 16.0% to 34.5%.

The analysis of mortality performed according to standardized coefficients from 2010 to 2019 shows that higher mortality rates are recorded in Usolye-Sibirskoye compared to the Irkutsk Oblast and Russia as a whole, both in the male and female population. At the same time, the gap in mortality rates continues to grow. In connection with the above, it seemed important to determine which age groups of men and women make the most significant contribution to the excess mortality of the population of Usolye-Sibirskoye.

The city's relatively small population does not allow for in-depth analysis: when distributing by sex and individual age groups (children, people of working-age and post-working age), the number becomes insufficient to study mortality. We summarized the mortality data for 10 years (2010–2019) and calculated the average coefficients to obtain stable indicators.

In men, the standardized mortality rate averaged over ten years in the city of Usolye-Sibirskoye was 201.8 per 10

thousand and was higher compared with the Irkutsk Oblast by 17.6%, and with Russia by 49.5% ***(Table 1)***.

Analysis of mortality in individual age groups of the male population showed that in childhood (0–14 years), boys in Usolye-Sibirskoye had a mortality rate 3.6% higher than in the Irkutsk Oblast and 30.3% higher than in the Irkutsk Oblast, Russia.

At the working-age (15–59 years), the differences in mortality were most pronounced. The mortality rate among men in the city was higher than in the Irkutsk Oblast by 28.1% and almost two times (1.8 times) higher than in Russia. At the age over able-bodied (60 years and older), the excess mortality was 9.0% and 28.4%, respectively.

Differences in mortality rates among women when comparing Usolye-Sibirskoye with Irkutsk Oblast and Russia as a whole were less significant than among men ***(Table 1)***. The excess of the 10-year average for women in the city was 9.5% and 25.3%, respectively.

The analysis of mortality in certain age groups revealed tendencies similar to those for men. However, there were also some peculiarities. For girls (0–14 years old) in Usolye-Sibirskoye, the standardized coefficients were lower than in the Irkutsk Oblast by 32.1% and lower than in Russia by 17.4%.

An in-depth analysis showed that contradicting the general trend could be an insufficient number of observations in the study of mortality. On average, in the city during the studied period, from 450 to 600 girls and from 470 to 650 boys were born annually. During two out of ten years of observation, there was no single case of infant mortality among newborns (aged 0–364 days) in girls. Infant mortality has the highest rate compared to all other childhood one-year age groups. Therefore, the zero mortality rate in the first year of life strongly influenced the overall infant mortality rate (0–14 years) in these years and, accordingly, the rate averaged over ten years.

At the same time, in Usolye-Sibirskoye the stillbirth rate is 1.5–2.5 times higher than in the region and the country. Deaths occurring before delivery are not included in the infant mortality rate. It can mask the low viability of a significant proportion of newborns. Thus, the phenomenon of low infant and child mortality may be due to a higher stillbirth rate compared to the region and country.

In the working-age (15–54 years), the situation with the mortality rate of the female population in Usolye-Sibirskoye, like that of men, was highly unfavourable. The excess compared with the Irkutsk Oblast was 37.5%, and compared with Russia, the mortality rate was 2.2 times higher. In the post-working age (55 and older), the differences in mortality rates were 4.6% and 13.6%, respectively.

Based on the standardized mortality rates averaged over ten years, we calculated the contribution of individual age groups to the excess mortality of the male and female population of Usolye-Sibirskoye compared with the region and the country as a whole ***(Table 2)***.

To assess the contribution of individual age groups to excess mortality, the overall excess of male mortality in the

Table 1

Standardized mortality rates of the male and female population of Usolye-Sibirskoye, the Irkutsk Region and the Russian Federation on average for 2010–2019 (per 10 000 population of the corresponding sex and age)

Region	Age groups, y.o.			
	all ages	0–14	15–59(54)	60 (55) and older
Men				
Usolye-Sibirskoye	201.8	11.6	143.7	736.5
Irkutsk Oblast	171.6	11.2	112.2	675.5
Russia	135.0	8.9	80.0	573.8
Women				
Usolye-Sibirskoye	139.6	5.7	49.5	374.0
Irkutsk Oblast	127.5	8.4	36.0	357.6
Russia	111.4	6.9	22.7	329.2

Table 2

The contribution of certain age groups to the excess male and female mortality of Usolye-Sibirskoye in comparison with the Irkutsk region and the Russian Federation, %

Region	Age groups, y.o.			
	all ages	0–14	15–59(54)	60 (55) and older
Contribution of the age group to excess mortality in Usolye-Sibirskoye when comparing mortality rates to (%)				
Men				
Irkutsk Oblast	100.0	0.2	72.5	27.3
Russia	100.0	0.7	66.3	33.0
Women				
Irkutsk Oblast	100.0	–3.1	63.0	40.1
Russia	100.0	–0.6	53.6	47.0

city compared with the Irkutsk Oblast by 17.6% ***(Table 1)***, we take it as 100% and evaluate the contribution of each of the age groups. So, in 72.5% the reason for the higher mortality rate in Usolye-Sibirskoye was excess deaths in the working-age. At the same time, children and post-working age accounted for only 0.2% and 27.3% of additional deaths, respectively ***(Table 2)***.

Discussion. The study of the mortality rate in the male and female population in Usolye-Sibirskoye showed that during 2010–2019 the city recorded higher mortality rates from all causes combined with the Irkutsk Oblast and Russia. The most significant demographic losses occurred in the working age, where the mortality rate averaged over ten years for men and women was higher (28.1% and 37.5% respectively) than the regional indicator and 1.8 and 2.2 times higher than the national one. Thus, the excess mortality in Usolye-Sibirskoye was mainly due to the excess mortality of the working-age population. Its contribution to the overall excess of mortality in men in Usolye-Sibirskoye compared to the Irkutsk Oblast was 72.5% compared to Russia 66.3%. For women, respectively, 63.0% and 53.6%.

Our data are consistent with the results of other mortality studies carried out in Usolye-Sibirskoye in recent years [5,6]. They indicate higher mortality rates compared to the Irkutsk Oblast and other industrial cities of the region. However, the authors use non-standardized mortality rates for analysis in these studies. It significantly reduces the value of the data obtained, given the different age structures in cities. The paper by N.V. Neiman (1991) on oncological morbidity and mortality assessment in Usolye-Sibirskoye, carried out in the early 90s, stands out noticeably. This study showed that the standardized mortality rates from malignant neoplasms in Usolye-Sibirskoye exceeded the mortality rate of the Russian population by an average of 15% [7].

There were significantly more studies on the morbidity of various population groups in Usolye-Sibirskoye compared to the region and other industrial towns. For example, Malygina O.Yu. (1989) found that among children aged 1–3, fewer healthy ones, and more children with functional impairments[4]. Assessment of the health status of preschool children in Usolye-Sibirskoye revealed that 76.1% had morphological and functional abnormalities: from nose and throat, neuropsychiatric health, musculoskeletal system, functional cardiopathy, allergies. More than a third of the examined children (36.9%) had chronic diseases. In 38.1% of cases, there were signs of immunological deficiency [6].

Similar data on increased levels of primary and general morbidity was in the study of the health status of adolescents and adults [8–13].

The incidence rate among Usoliekhimprom JSC employees was significantly higher than the staff of the machine-building enterprise. The most frequent occurrences were the likelihood of developing a neurological syndrome, coronary heart disease, arterial hypertension, functional disorders of the gastrointestinal tract and liver. Female workers exposed to epichlorohydrin, and allyl chloride had a high prevalence of kidney and thyroid diseases, which are targets for exposure to these substances [6].

88% of Usoliekhimprom employees who underwent an in-depth medical examination due to chronic inhalation intake of mercury had impaired immunity due to professional contact [14].

Among the reasons for the formation of increased levels of morbidity and mortality in the city, the authors name the polluted environment and the long-term consequences of the impact of harmful production factors (workers of the city-forming enterprise during the period of its operation constituted a significant part of the able-bodied population of the city) [15–21].

An important direction for further research is long-term monitoring of the health status, including mortality, of the current residents of the city and the next generations to assess the consequences of the impact of occupational and environmental factors in the long term. The new Federal Register of Medical Death Documents can be used for this task. It is a component of the Unified State Health Information System (ЕГИСЗ), which will become operational in March 2022[5].

The results obtained indicate that high mortality rates in the city are the result not only of problems associated with the consequences of the production activities of the Usoliekhimprom enterprise and an environmental disaster. The children and the elderly, the most vulnerable groups when exposed to unfavorable external factors, but men and women of working age form the bulk of excess mortality. Therefore, we are talking (along with hygienic problems) about the burden of socio-economic and psychological issues that fall on the shoulders of the working-age population. We should also note the contribution to high mortality in Usolye-Sibirskoye of such a risk factor as mortality from causes caused by alcohol. In the Irkutsk Oblast, it remains at a high level (52.7 per 100 thousand of the population), significantly higher than the average value for the Siberian Federal District (33.9 per 100 thousand of the population in 2020). At the same time, the relationship between high mortality in working age and high alcohol consumption has now been sufficiently studied.

Conclusions:

1. In Usolye-Sibirskoye, over the past decade, mortality rates have been higher in the male and female population compared to the Irkutsk Oblast and Russia, and the gap in indicators is growing.

2. The most challenging situation in the town of Usolye-Sibirskoye with the mortality rate of the working-age population. In this age group, the 10-year average for men and women was 28.1% and 37.5% higher than that in the Irkutsk Oblast and 1.8 and 2.2 times higher than the national average.

3. Assessment of the contribution of individual age groups to the excess mortality of the male population in Usolye-Sibirskoye showed that the excess mortality in men compared with the Irkutsk Oblast by 72.5% is due to excess mortality in the working-age and by 27.5% increased mortality in children and past-working age. Women have additional demographic losses by 63.0% due to their working-age.

4. The study allows us to assume that the excess mortality of the male and female population of working age in Usolye-Sibirskoye is not only a consequence of the impact of a polluted environment and harmful working conditions, but can be caused by an increase in unemployment, poverty and socio-economic tension associated with the bankruptcy of the city-forming enterprise.

[4] Malygina O.Yu. Hygienic assessment of the influence of atmospheric pollution of a chemical plant on the health of the child population in the conditions of Eastern Siberia: Abstract of the dissertation of the candidate of medical sciences, Irkutsk, 1989.

[5] Federal Law of July 2, 2021, No. 358-FZ "On Amendments to Certain Legislative Acts of the Russian Federation." http://base.garant.ru/401422494/ (Accessed 11/08/2021).

5. A promising direction for further research is the study of mortality from individual causes in combination with an analysis of the socio-economic situation of the population as a basis for the development of a scientifically grounded system of measures aimed at preserving and strengthening the health and reducing mortality of men and women in Usolye-Sibirskoye.

6. In practical terms, when developing a regional demographic policy, the phenomenon of the excess mortality of the working-age population in Usolye-Sibirskoye is essential. It is necessary to ensure the adoption of additional measures to protect the health and improve the well-being of this category of citizens.

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