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Research article

ASSESSMENT OF AEROGENIC RISKS FOR PEOPLE LIVING IN CLOSE PROXIMITY TO ULBA METALLURGICAL PLANT

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In this study, our aim was to assess public health risks caused by ambient air pollution in close proximity to production facilities of "Ulba Metallurgical Plant" JSC (JSC "UMP") located in Ust-Kamenogorsk, Kazakhstan.

The study relied on the health risk assessment methodology under exposure to chemical environmental factors.

Our research objects were chemical pollution in ambient air in close proximity to production facilities of "Ulba Metallurgical Plant" JSC and its effects on public health.

We assessed public health risks caused by chemical pollution in ambient air in close proximity to production facilities of JSC "UMP". The assessment relied on data obtained at monitoring posts of RSE "Kazhydromet" between 2018 and 2021. We identified six carcinogens in the analyzed area that created unacceptable public health risks. High non-carcinogenic risks were typically caused by exposure to particulate matter (dust), $PM_{2.5}$ *and* PM_{10}*, sulfur dioxide and sulfuric acid.*

Our assessment of non-accidental mortality risks caused by exposure to PM2.5 in ambient air established unacceptable relative risks (RR: 1.27–1.78), individual risks of non-accidental ($1.5–2.1\cdot10^{-3}$*) and cardiopulmonary mortality (between* $8.3\cdot10^{-4}$ *and* $1.0\cdot10^{-3}$*).*

Unfavorable meteorological factors and geographic location can promote high levels of ambient air pollution and created aerogenic health risks for people living in the analyzed industrial area.

The established risks require developing and implementing scheduled health-improving activities aimed at raising quality of the environment.

***Keywords**: metallurgical plant, risk assessment, public health, ambient air, pollutants, hazard quotient, hazard index, Ust-Kamenogorsk.*

At present, environmental protection and urban public health are given much attention all other the world due to the intensified urbanization and growing levels of pollution and emissions into ambient air [1]. There have been multiple studies that address effects produced by ambient air pollution on the human body [2].

Exposure to industrial emissions is known to induce varied adverse health outcomes [3, 4].

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Elevated levels of solid particles (dusts, $PM_{2.5}$, $PM_{10,}$), ozone and nitrogen oxide (dioxide) in ambient air result in high mortality rates among people living on a given territory [5–7].

Also, some research works have proven that levels and dynamics of pollutant concentrations in ambient air in big cities largely depend on meteorological conditions and a season [8, 9].

Similar studies have been accomplished in the Republic of Kazakhstan (RK) as well since intensified production and urbanization create elevated pollution levels in ambient air in various regions in the country. This, together with some local geographical, climatic and socio-economic peculiarities, causes negative health outcomes in population. Given that, it is extremely important to assess public health risks and health harm [10–14].

Experts have long established direct links between contents of adverse chemicals in ambient air (solid particles (dusts), $PM_{2.5}$, PM_{10}, nitrogen dioxide, sulfur dioxide, phenol, formaldehyde, arsenic, benz(a)pyrene and others) and incidence of respiratory and cardiovascular diseases, cancer incidence and mortality [15, 16].

Preliminary studies that examined public health depending on ambient air pollution were accomplished in the country in 2019 [17]. Following their results, it was recommended to perform more comprehensive examinations of public health depending on air pollution levels in some cities in the RK. Given that, the research works in the sphere continued, namely, health risk rates caused by exposure to ambient air pollution were determined in seven most significant industrial regions in Kazakhstan. The research works were accomplished within the project "The National program for implementing patient-specific and preventive medicine in the Republic of Kazakhstan" IRN OR12165486.

We have assessed aerogenic health risks for people living in close proximity to the production facilities of "Ulba Metallurgical Plant" JSC (hereinafter JSC "UMP") located in Ust-Kamenogorsk, the East Kazakhstan region, Kazakhstan. This article presents the assessment results.

The environmental situation in Ust-Kamenogorsk is influenced not only by industrial emissions but also by some other factors. The city is located in a secluded hollow and this prevents pollutants from dispersing. Meteorological conditions are often unfavorable there due to weak winds or their absence (it is total calm on approximately 98–100 days a year) and high air humidity due to frequent radiation and river fogs. Elevated levels of ambient air pollution occur in 80–90 % of days with fogs. According to the Republican State Enterprise "Kazhydromet" (RSE "Kazhydromet" for short), there have been persistently high levels of some pollutants in ambient air in Ust-Kamenogorsk including PM_{10}, sulfur dioxide, carbon oxide, nitrogen dioxide, hydrogen sulfide, and phenol. Sulfuric anhydride concentrations reach 4–5 daily average MPC[1].

The authors of the work [16] established that cancer incidence was by two times higher in Ust-Kamenogorsk than on average in the country and by 1.4 times higher than on average in the region. Deaths from cancer were by 1.9 times higher than on average in the republic. Cancer incidence was examined in dynamics; as a result, it was revealed that its growth amounted to 6.5 % in Ust-Kamenogorsk whereas it was 13.5 % in the republic. A relationship was suggested between cancer incidence and ambient air being polluted with adverse chemicals.

A separate study revealed that long-term living in Ust-Kamenogorsk led to developing skin pathologies and weakened immunity [18].

Therefore, according to data available in research works, high levels of chemical pollution in ambient air in Ust-Kamenogorsk occur due to its peculiar physical and geographical position and the synoptic situation. They cause elevated cancer incidence and weakened immunity among people living there.

All the above indicates the issue is topical for the examined area.

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[1] Monthly newsletter on the state of the environment. *RSE "Kazhydromet"*. Available at: https://www.kazhydromet.kz/en/ecology/ezhemesyachnyy-informacionnyy-byulleten-o-sostoyanii-okruzhayuschey-sredy/2018 (June 19, 2022).

In this study, our aim was to assess public health risks caused by ambient air pollution in close proximity to production facilities of "Ulba Metallurgical Plant" JSC (JSC "UMP") located in Ust-Kamenogorsk, Kazakhstan.

To achieve this, the following tasks were set:

1) To provide quantitative description of carcinogenic and non-carcinogenic public health risks depending on levels of ambient air pollution in the examined area relying on data collected at the monitoring posts of the RSE "Kazhydromet" regional office in Ust-Kamenogorsk;

2) To assess risks of non-accidental and cardiopulmonary mortality depending on $PM_{2.5}$ concentrations in ambient air;

Materials and methods. Our research objects were chemical pollution in ambient air in close proximity to the "Ulba Metallurgic Plant" production facilities and their impacts on public health in Ust-Kamenogorsk. Pollutant concentrations in ambient air were estimated as per data taken from the Information bulletins about the environmental situation issued by the RSE "Kazhydromet". We analyzed data collected over the last four years (2018–2021).

Ust-Kamenogorsk is one of the largest industrial centers in Kazakhstan. There are many working enterprises in the city and this leads to substantial chemical emissions into ambient air. "UMP" JSC is an established manufacturer of uranium, beryllium, tantalum and niobium products; it is among world's leading enterprises in the sphere. The enterprise is a part of the National Atomic Company "Kazatomprom" JSC. The production facilities are located in Ust-Kamenogorsk and border the production facilities of another company in the south-west. This company is Ust-Kamenogorsk lead and zinc plant that belongs to "Kazzinc", a large Kazakhstan manufacturer of zinc, lead, copper and precious metals. The closest residential areas near the production facilities of "UMP" JSC are those of Ust-Kamenogorsk. The distances from the residential areas to the boundaries of these production facilities are 890 meters in the west, 570 meters in the east and 290 meters in the south-east.

Emissions from the production facilities of "UMP" JSC, together with emissions from other enterprises in the city, make a certain contribution to the overall background pollution there. This background pollution is measured at seven monitoring posts that belong to the RSE "Kazhydromet" and are located at different points within the city. Three are in the closest proximity to the production facilities of "UMP" JSC.

Several chemicals are included into monitoring programs accomplished at these posts. They are solid particles (dusts); $PM_{2.5}$; PM_{10}; sulfur dioxide; carbon oxide; nitrogen dioxide; nitrogen oxide; phenol; hydrogen sulfide; hydrogen fluoride; hydrogen chloride; formaldehyde; chlorine; sulfuric acid and sulfates; lead; zinc; cadmium; copper; beryllium; ozone; ammonia. We took actual single maximum and average annual concentrations of the above-listed chemicals in ambient air to calculate aerogenic health risks. The data we used in calculations were collected in 2018–2021 and taken from the Information bulletins about the environmental situation issued by the RSE "Kazhydromet"[1].

Carcinogenic and non-carcinogenic health risks were assessed in accordance with the Guide R 2.1.10.1920-04 "Human Health Risk Assessment from Environmental Chemicals" (hereinafter the Guide R 2.1.10.1920-04)[2].

We did not calculate population carcinogenic risk levels since it was impossible to define a precise number of people exposed to emissions from the "UMP" JSC production facilities.

In this study, hazard quotients (HQ) and hazard indexes (HI) were applied to assess non-carcinogenic risk levels. They were calcu-

[2] The Guide R 2.1.10.1920-04. Human Health Risk Assessment from Environmental Chemicals (approved and validated by G.G. Onishchenko, the First Deputy to the RF Public Healthcare Minister and the RF Chief Sanitary Inspector on March 5, 2004). *KODEKS: electronic fund for legal and reference documentation.* Available at: https://docs.cntd.ru/document/1200037399 (June 18, 2022) (in Russian).

lated as per the formulas provided in the Guide R 2.1.10.1920-04[2].

We applied a more complicated scheme to calculate risks of mortality caused by exposure to average annual $PM_{2.5}$ concentrations in ambient air in Ust-Kamenogorsk, namely, a log-linear model as per the following formulas [19]:

$$R = \frac{RR-1}{RR} M\rho; \quad (1)$$

$$RR = \left(\frac{C+1}{C_0+1} \right)^{\beta}, \quad (2)$$

where RR is relative risk;

R is population risk;

$M\rho$ are background levels of non-accidental and cardiovascular mortality (we used official statistical data provided by the Republican State Enterprise “The Republican Center for Electronic Public Healthcare” of Ministry of Health of the Republic of Kazakhstan);

β is concentration – response factor (the average value is 0.15515);

C is $PM_{2.5}$ concentration;

C_0 is threshold concentration (it usually equals $7.5\frac{\mu g}{m^3}$);

M is background mortality (cardiopulmonary);

ρ is exposed population (the whole city population was considered in these calculations).

The analysis was based on available information including identified (current and established) concentration and background mortality. Typically, only PM_{10} concentrations have been determined in ambient air in the city; $PM_{2.5}$ concentrations were first registered in 2021 and have been identified ever since (Table 1).

Average annual $PM_{2.5}$ concentrations were calculated as per the method described in the work [19] relying on average annual concentrations of solid particles (dusts) provided in the Informational bulletins by the RSE “Kazhydromet”[1]. The following formula was used to calculate them:

$$PM_{2.5} = (0.33 - 0.36) \cdot TSP, \quad (3)$$

where TSP is total solid particles; (0.33–0.36) are recalculation quotients [19]. The quotient value 0.36 was used for the analyzed region given its climatic conditions.

The data on population numbers and population mortality were taken from the materials provided by the National Statistics Bureau of the Agency for Strategic Planning and Development of the Republic of Kazakhstan[3] and the Republican State Enterprise “The Republican Center for Electronic Public Healthcare” of Ministry of Health of the Republic of Kazakhstan[4].

Results and discussion. According to the research aim and tasks, we assessed public health risks depending on levels of ambient air pollution in close proximity to the production facilities of “UMP” JSC.

Table 1

Cancer incidence among population in Ust-Kamenogorsk estimated as per data on medical aid appealability (per 100 thousand people)

Regions	2018	2019	2020
The Republic of Kazakhstan (urban population)	952.1	899.6	876.5
The East Kazakhstan region (urban population)	1777.8	1713.5	997.8
Ust-Kamenogorsk	2576.4	2522.7	1710.3

Note: the data were provided by the Republican State Enterprise “The Republican Center for Electronic Public Healthcare” of Ministry of Health of the Republic of Kazakhstan[4].

[3] Demographic statistics. *Agency for Strategic planning and reforms of the Republic of Kazakhstan*. Available at: https://stat.gov.kz/region/264990/statistical_information/industry/6361 (June 18, 2022).

[4] Respublikanskii tsentr elektronnogo zdravookhraneniya [The Republican Center for Electronic Public Healthcare]. Available at: https://rcez.kz (June 18, 2022) (in Russian).

Carcinogenic and non-carcinogenic public health risks were assessed as per data taken from the Information bulletins issued by the RSE "Kazhydromet"[5].

Carcinogenic risks. The cancer incidence is high in the analyzed area (Ust-Kamenogorsk) with its rates being by 1.4 and 2.7 times higher accordingly than in the region and the republic as a whole (Table 1). Given that, it is obvious that carcinogenic health risks existing in the area should be assessed.

The quantitative description of carcinogenic risks was based on values of individual carcinogenic risks identified for six chemicals from the analyzed list since these chemicals have carcinogenic properties according to Table 2.4 in the Appendix 1 of the Guide R 2.1.10.1920-04[6]. Table 2 provides these values of individual carcinogenic risks.

Obviously, values of individual carcinogenic risks identified for cadmium, benz(a)-pyrene and arsenic fell within the range between $1.1 \cdot 10^{-4}$ and $8.6 \cdot 10^{-4}$, that is, they were acceptable for occupational groups and unacceptable for population at large. Such a risk requires developing and implementing scheduled sanitary activities in settlements.

Non-carcinogenic risks. In this study, we applied a hazard quotient (HQ) to assess non-carcinogenic health risks. This quotient is a ratio of a certain exposure level (concentration *C*) to a reference level of a certain chemical under acute (ARfC) and chronic (RfC) exposure (the formulas to calculate it are provided in the Guide R 2.1.10.1920-04)[6].

In case there is combined exposure to several chemicals, the total non-carcinogenic risk is described with a hazard index (HI).

Average daily and single maximum concentrations of pollutants that have been controlled in ambient air over the analyzed years are given as per data provided by the Information bulletin of the RSE "Kazhydromet"[5] (Table 3).

Figures 1 and 2 show the results obtained by calculating HQ and HI (respiratory organs being the target ones) under acute and chronic exposure.

HQ values identified for some chemicals under acute exposure were higher than a permissible (acceptable) risk level, which is equal to 1.0 or lower. Unacceptable acute inhalation risks were identified for exposure to sold particles (dusts), PM_{10}, $PM_{2.5}$ (2021); sulfur dioxide, hydrogen sulfide (2018); sulfuric acid and arsenic. The total hazard indexes (HI) identified for ambient air pollutants were high as regards respiratory organs being the target ones (Figure 1).

A similar picture was observed for chronic non-carcinogenic risk values. The total hazard index identified for major ambient air pollutants in Ust-Kamenogorsk was also high for respiratory organs as target ones (Figure 2).

Table 2

Individual carcinogenic risks in Ust-Kamenogorsk

Chemical	2018	2019	2020	2021
Formaldehyde	6.0E-05	6.6E-05	4.5E-05	3.9E-05
Cadmium	1.7E-04	1.4E-04	1.1E-04	4.5E-05
Lead	3.8E-06	3.7E-06	4.1E-06	1.7E-06
Beryllium	2.7E-07	2.7E-07	2.4E-07	1.7E-07
Benz(a)pyrene	6.2E-04	7.5E-04	7.5E-04	7.5E-04
Arsenic	8.6E-04	8.6E-04	4.3E-04	*

Note: * means that no data on a concentration were provided in the Information bulletin[5].

[5] Monthly newsletter on the state of the environment. *RSE "Kazhydromet"*. Available at: https://www.kazhydromet.kz/en/ecology/ezhemesyachnyy-informacionnyy-byulleten-o-sostoyanii-okruzhayuschey-sredy/2018 (June 19, 2022).

[6] The Guide R 2.1.10.1920-04. Human Health Risk Assessment from Environmental Chemicals (approved and validated by G.G. Onishchenko, the First Deputy to the RF Public Healthcare Minister and the RF Chief Sanitary Inspector on March 5, 2004). *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200037399 (June 18, 2022) (in Russian).

Table 3

Average daily and single maximum concentrations of pollutants in ambient air in Ust-Kamenogorsk

Chemical	Average daily concentrations (mg/m^3)					Single maximum concentrations (mg/m^3)				
	RFC, mg/m^3	2018	2019	2020	2021	ARFC, mg/m^3	2018	2019	2020	2021
Solid particles (dusts)	0.075	0.1262	0.109	0.0955	0.084	0.3	2.2	2	1	0.9
$PM_{2.5}$	0.015	*	*	*	0.025	0.065	*	*	*	0.88
PM_{10}	0.05	0.0475	0.05	0.0476	0.028	0.15	0.99	0.99	0.99	0.96
Sulfur dioxide	0.05	0.1183	0.09	0.1085	0.076	0.66	5.70	4.93	5.47	4.95
Carbon oxide	3	0.7403	0.68	0.6027	0.653	23	28.70	14.47	20.71	11.3
Nitrogen dioxide	0.04	0.0729	0.06	0.0438	0.036	0.47	0.56	0.77	0.42	0.29
Nitrogen oxide	0.06	0.0132	0.003	0.002	0.005	0.72	1.08	0.68	1.57	1.48
Ozone	0.03	0.0379	0.029	0.0411	0.06	0.18	1.37	0.16	0.15	0.14
Phenol	0.006	0.0016	0.001	0.0017	0.002	6	0.02	0.01	0.02	0.04
Hydrogen sulfide		*	*	*	*	0.1	1.05	0.19	0.16	0.063
Hydrogen fluoride	0.014	0.0069	0.007	0.0032	0.003	*	*	*	*	*
Chlorine	$2·10^{-4}$	$3.9·10^{-3}$	0.004	0.0052	0.007	0.2	0.07	0.09	0.07	0.09
Hydrogen chloride	0.02	0.0309	0.03	0.0665	0.057	2.1	0.15	0.15	0.22	2.1
Ammonia	0.1	0.0045	0.004	0.0029	0.002	0.35	0.054	0.19	0.06	0.06
Sulfuric acid	0.001	0.0143	0.014	0.0106		0.1	0.5	0.18	0.35	
Formaldehyde	0.003	0.0046	0.005	0.0034	0.002	0.048	0.07	0.06	0.03	0.01
Arsenic	$3·10^{-5}$	$2·10^{-4}$	$2·10^{-4}$	$1·10^{-4}$	*	*	*	*	*	*
Lead	$5·10^{-4}$	$3.1·10^{-4}$	$3.1·10^{-4}$	$3.4·10^{-4}$	$1.8·10^{-4}$	*	*	*	*	*
Copper	$2·10^{-5}$	$5.4·10^{-5}$	$5.6·10^{-5}$	$4.3·10^{-5}$	$1.8·10^{-5}$	*	*	*	*	*
Beryllium	$2·10^{-5}$	$1·10^{-7}$	$1.13·10^{-7}$	$1·10^{-7}$	$6.5·10^{-8}$	*	*	*	*	*
Cadmium	$2·10^{-5}$	$9.5·10^{-5}$	$7.5·10^{-5}$	$6.1·10^{-5}$	$2.4·10^{-5}$	*	*	*	*	*
Zinc	$9·10^{-4}$	$1.3·10^{-3}$	$1.2·10^{-3}$	$1.1·10^{-3}$	$4.3·10^{-4}$	*	*	*	*	*

N o t e : * means that no data on a concentration were provided in the Information bulletin[5].

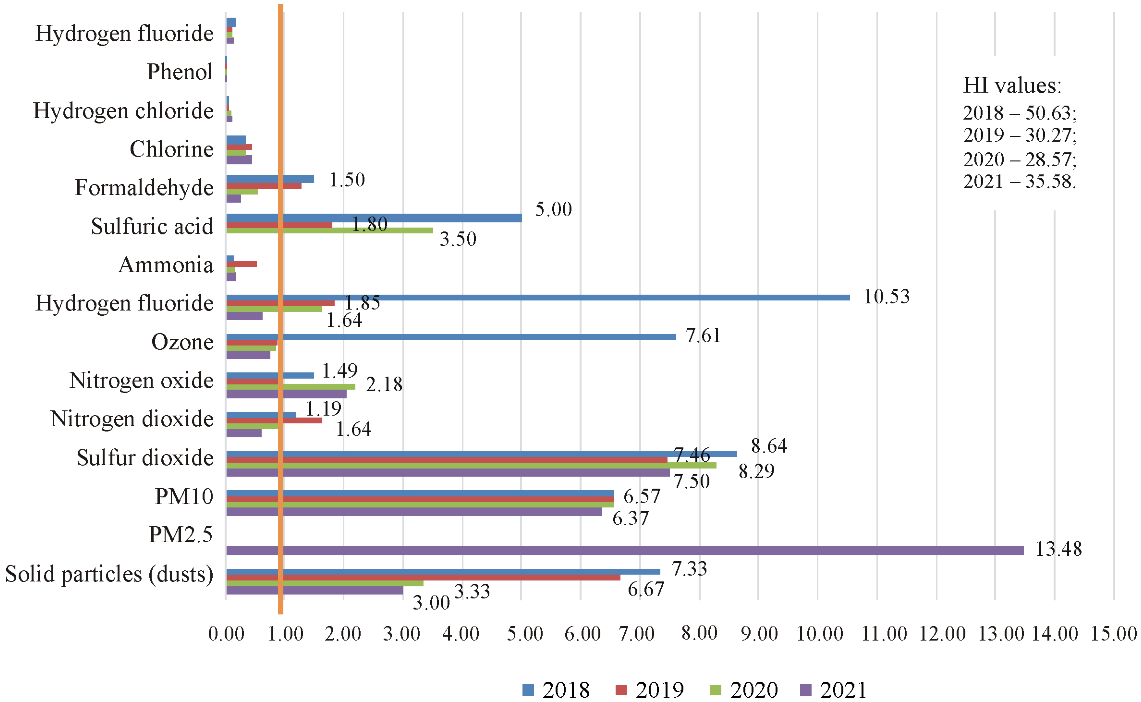

Figure 1. Hazard quotients (HQ) and hazard indexes (HI) under acute exposure (respiratory organs as target ones)

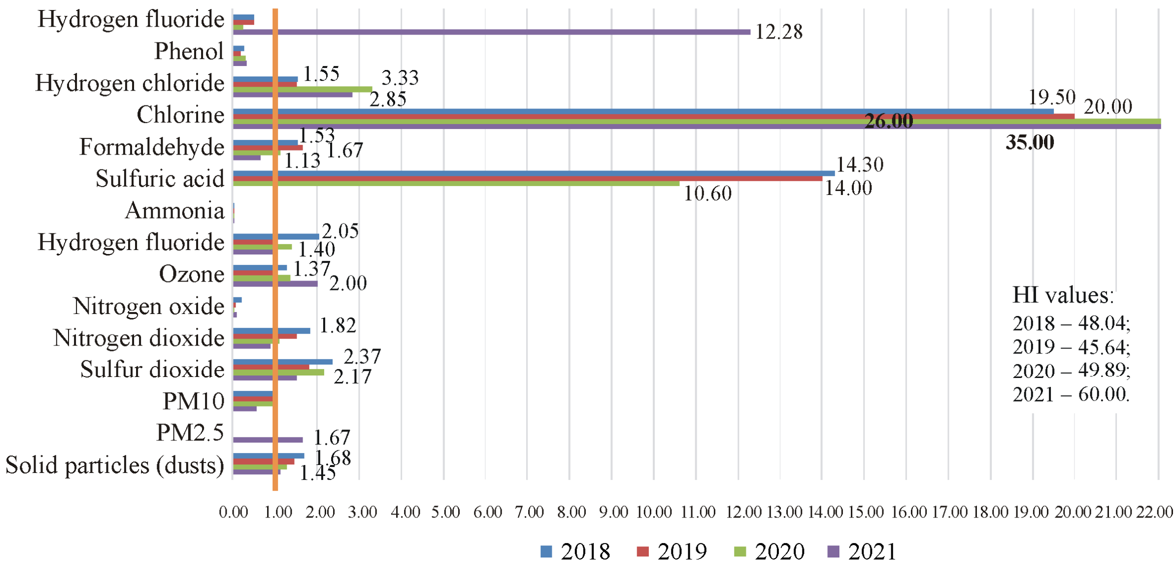

Figure 2. Hazard quotients (HQ) and hazard indexes (HI) under chronic exposure (respiratory organs as target ones)

The highest values of hazard quotients under chronic exposure were identified for chlorine and sulfuric acid and for such heavy metals as cadmium, arsenic and copper (Table 4).

HQ values for chlorine under chronic exposure were identified as high due to its low reference concentrations.

Hazard quotients for heavy metals identified in ambient air in concentrations equal to and / or higher than permissible risk levels indicate possible effects produced by emissions from the lead and zinc plant of the "Kazzinc" company.

The total hazard index identified for ambient air pollutants in Ust-Kamenogorsk was high for respiratory organs as target ones. Given the summation of these targeted effects on the body organs and systems, the identified heavy metals produce them on the kidneys, blood and the hormonal systems.

Therefore, the identified levels of acute and chronic non-carcinogenic health risks occur due to exposure to sulfur dioxide and sulfuric acid in ambient air in Ust-Kamenogorsk.

At the same time, when air humidity is high, sulfur dioxide increases a concentration of sulfuric acid as it is indicated by its abnormally high hazard quotients under chronic exposure. These chemicals are emitted from smoke plumes of enterprises powered by coal fuel and natural gas or are contained in exhausts from motor transport.

Table 4

Non-carcinogenic risks under chronic epxosure to heavy metals

Metal	HQ values			
	2018	2019	2020	2021
Arsenic	6.67	6.67	3.33	*
Lead	0.63	0.622	0.676	0.35
Copper	2.7	2.8	2.15	0.90
Beryllium	0.005	0.006	0.005	0.0033
Cadmium	4.75	3.75	3.05	1.20
Zinc	1.491	1.34	1.27	0.48
Hygienic standard	HQ ≤ 1.0			

Note: * means that no data on a concentration were provided in the Information bulletin[5].

Assessing risks of non-accidental and cardiopulmonary mortality depending on levels of ambient air pollution with $PM_{2.5}$. Our quantitative description of non-carcinogenic public health risks identified their high levels due to exposure to solid particles (dusts) and PM_{10} in ambient air in the analyzed city. PM_{10} produce certain effects on mortality, incidence of respiratory and cardiovascular diseases as well as on some other health indicators [19].

The WHO experts believe approximately 3.0 % of deaths from cardiopulmonary diseases and 5.0 % of deaths from lung cancer to be caused by exposure to particulate matter (PM). In different European regions, this share varies between 1 and 3 % and between 2 and 5 % accordingly. At the same time, some studies established that adverse effects produced by exposure to particulate matter $PM_{2.5}$ caused up to 3.1 million deaths and up to 3.1 % of lost years of healthy life all over the world [20].

Given all the above-stated, we assessed risks of non-accidental mortality in Ust-Kamenogorsk caused by exposure to ambient air pollution with $PM_{2.5}$ with their concentrations being calculated as per the formula (3).

Table 5 summarizes the results obtained by calculating risks of non-accidental mortality caused by ambient air pollution with $PM_{2.5}$ in Ust-Kamenogorsk over 2018–2020. Non-accidental mortality in 2021 was not calculated since we did not have any official background data on non-accidental and cardiovascular mortality in that year.

Non-accidental and cardiopulmonary mortality was rather high in 2018–2020 (Tables 5 and 6).

The data in Table 5 clearly show that a relative risk of the overall non-accidental mortality (*RR*) varied between 1.27 and 1.78 over the analyzed period whereas the actual pollution threshold was usually 7.5 $\frac{\mu g}{m^3}$, and a risk was determined at the above-mentioned levels. When calculating a population risk caused by exposure to $PM_{2.5}$ concentrations in ambient air in Ust-Kamenogorsk, we identified from 521 to 740 non-accidental deaths per year. This number was rather high and made a considerable contribution (up to 20 %) into the overall mortality in the analyzed city (Table 5).

Table 5

Risks of non-accidental mortality due to ambient air pollution with $PM_{2.5}$ in Ust-Kamenogorsk

Years	Calculated average $PM_{2.5}$ concentration (mg/m^3)	Average population number	Non-accidental mortality (number of deaths)	Relative risk, RR	Population risk, R	Additional deaths (AD)	Individual risk, IR $PM_{2.5}$
2018	0.045	342,422	3173	1.30	577	127	$1.7\cdot10^{-3}$
2019	0.039	344,953	3319	1.27	521	133	$1.5\cdot10^{-3}$
2020	0.344	347,480	4069	1.78	740	163	$2.1\cdot10^{-3}$

Table 6

Risk of cardiopulmonary mortality under exposure to ambient air pollution with $PM_{2.5}$ in Ust-Kamenogorsk

Year	Calculated average $PM_{2.5}$ concentration (mg/m^3)	Average population number	Cardiopulmonary mortality (number of deaths)	Relative risk, RR	Population risk, R	Additional deaths (AD)	Individual risk, IR $PM_{2.5}$
2018	0.045	342,422	1281	1.3	349	51	$1.0\cdot10^{-3}$
2019	0.039	344,953	1225	1.27	288	49	$8.3\cdot10^{-4}$
2020	0.344	347,480	1636	1.78	446	65	$1.3\cdot10^{-3}$

Individual risks of non-accidental mortality were above $1.0 \cdot 10^{-3}$ (Table 5); this meant they were unacceptable both for occupational groups and population at large. In case such a risk occurs, urgent sanitary activities are to be developed and implemented to mitigate it.

According to our calculations, a population risk of mortality from respiratory and cardiovascular diseases varies between 288 and 446 deaths per year. The number of additional deaths per each 10 μg/m^3 of $PM_{2.5}$ varies between 49 and 65 (Table 6).

To sum up, we assessed risks of mortality due to inhalation exposure to $PM_{2.5}$. The calculated individual risks of non-accidental and cardiopulmonary mortality were within the third (higher than $1 \cdot 10^{-4}$) and fourth ranges (higher than $1 \cdot 10^{-3}$). This requires developing and implementing sanitary activities.

However, as we assessed public health risks as per the data provided by the RSE "Kazhydromet", we established high health risks caused by exposure to pollutants in ambient air. High health risks were identified under exposure to particulate matter, sulfur dioxide, sulfuric acid and heavy metals.

Calculated risks of non-accidental and cardiopulmonary mortality caused by exposure to $PM_{2.5}$ turned out to be unacceptable.

These established high public health risks can be also associated with unfavorable meteorological conditions (calms, high air humidity etc.) and geographical peculiarities of the examined area.

Given all the above stated, our study has enabled us to make the following conclusions:

1. Six carcinogens out of the ambient air pollutants in the analyzed area were established to create unacceptable health risks for people living there (identified risks are between $8.6 \cdot 10^{-4}$ and $1.1 \cdot 10^{-4}$). These carcinogens are cadmium, lead, arsenic, formaldehyde, benz(a)pyrene, and beryllium.

2. Hazard quotients (HQ) calculated for solid particles, particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide, sulfuric acid and heavy metals (under chronic exposure) were higher than permissible (acceptable) risk levels. The total hazard index (HI) calculated for ambient air pollutants in the region was high for respiratory oirgans as target ones.

3. Individual risks of non-accidental and cardiopulmonary mortality caused by exposure to $PM_{2.5}$ were unacceptable for population at large (IR is higher than $1 \cdot 10^{-4}$).

4. High levels of health risks caused by exposure to ambient air pollution in the analyzed region can be also associated with its geographical location and unfavorable meteorological conditions (frequent calms and high air humidity).

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