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## ASSESSMENT OF TECHNOGENIC POLLUTANTS IMPACT OF THE URBAN ENVIRONMENT OF ZAPORIZHZHIA CITY ON HUMAN HEALTH OF THE SHEVCHENKIVSKYI DISTRICT

**Abstract.** The city of Zaporizhzhia has a large number of ferrous and non-ferrous metallurgy enterprises, machine-building and metalworking enterprises, construction facilities and the chemical industry, which leads to a high technogenic burden on the health of the city's residents. **The purpose of the article** is to establish the risks to the health of the population of the Shevchenkivskiyi district of Zaporizhzhia in the period 2019–2022 from air pollution by gaseous substances. The selected district is the largest in terms of area and population. At the same time, many industrial enterprises of the cities are located in the district: JSC Motor Sich, SE Zaporizhzhia Machine-Building Design Bureau “Progress” named after Academician O.G. Ivchenko, PJSC Zaporizhzhia Abrasive Plant, State Enterprise Research and Production Complex “Iskra”, Production Unit “Zaporizhzhia Oil Extraction Plant”. **Research methods.** The study used the general procedure of the Human Health Risk Assessment methodology developed and recommended by the US Environmental Protection Agency. We also used sanitary and hygienic, analytical and mathematical research methods. **The scientific novelty of the work** lies in the fact that for the first time a scientifically substantiated and provided riskometric assessment of the impact of technogenic pollutants of the urban environment on the human health of the Shevchenkivskiyi district of the Zaporizhzhia city. Scientific data on the patterns of formation of morbidity and mortality in the district's population as a result of industrial emissions into the air basin has been supplemented. **Conclusions.** It has been established that the results of calculations of hazard factors and indices in assessing the inhalation effects of pollutant emissions from industrial enterprises under chronic exposure in the Shevchenkivskiyi district of Zaporizhzhia for 2019–2022 indicate the presence of exceedances of safe levels. The total hazard indices for assessing the chronic inhalation effects of pollutant emissions from industrial enterprises in the study area are at an extremely high level. The individual carcinogenic risk of chronic exposure during the study period in the Shevchenkivskiyi district of Zaporizhzhia is at an average level.

**Key words:** atmospheric air, hazard coefficient, hazard index, individual carcinogenic risk, cancer, chronic exposure, technogenic pollutants, emissions.

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## ОЦІНКА ВПЛИВУ ТЕХНОГЕННИХ ЗАБРУДНЮВАЧІВ МІСЬКОГО СЕРЕДОВИЩА М. ЗАПОРІЖЖЯ НА СТАН ЗДОРОВ'Я НАСЕЛЕННЯ ШЕВЧЕНКІВСЬКОГО РАЙОНУ

**Анотація.** У місті Запоріжжя зосереджена велика кількість підприємств чорної та кольорової металургії, машинобудівних та металообробних підприємств, будівельних виробництв та хімічної промисловості, що призводить до високого техногенного навантаження на здоров'я мешканців міста. **Метою** наукової статті є встановлення ризиків для здоров'я населення Шевченківського району міста Запоріжжя у період 2019–2022 роки від забруднення атмосферного повітря газоподібними речовинами. Обраний район є найбільшим за площею та кількістю населення, що проживає у ньому. В той же час на території району розташовано багато промислових підприємств міст: АТ «Мотор Січ», ДП «Запорізьке машинобудівне конструкторське бюро «Прогрес» імені академіка О.Г. Івченка», ПрАТ «Запорізький абразивний комбінат», Казенне підприємство «Науково-виробничий комплекс «Іскра», Виробничий підрозділ «Запорізький олійноекстракційний завод». **Методи досліджень.** При виконанні дослідження було використано загальну процедуру методології оцінки ризику для здоров'я населення (Human Health Risk Assessment), розроблену та рекомендовану Агентством США з охорони довкілля. Також використовували санітарно-гігієнічні, аналітичні та математичні методи дослідження. **Наукова новизна роботи** полягає в тому, що вперше науково обґрунтована та надана ризикометрична оцінка впливу техногенних забруднювачів міського середовища на стан здоров'я населення Шевченківського району міста Запоріжжя. Доповнено наукові дані про закономірності формування захворюваності й смертності населення району внаслідок промислових викидів у повітряний басейн. **Висновки.** Встановлено, що результати розрахунків коефіцієнтів та індексів небезпеки при оцінці інгаляційних впливів викидів забруднюючих речовин від промислових підприємств при хронічному впливі в Шевченківському районі міста Запоріжжя за 2019–2022 рр. свідчать про наявність перевищень безпечних рівнів. Сумарні індекси небезпеки у досліджуваному районі знаходяться на надзвичайно високому рівні. Індивідуальний канцерогенний ризик при хронічній дії за досліджуваний період у Шевченківському районі міста Запоріжжя знаходиться на середньому рівні.

**Ключові слова:** атмосферне повітря, коефіцієнт небезпеки, індекс небезпеки, індивідуальний канцерогенний ризик, онкозахворювання, хронічний вплив, техногенні забруднювачі, викиди.

**Statement of the problem.** The emissions of stationary sources from industrial enterprises in the city of Zaporizhzhia contain a variety of chemical compounds [2]. Air pollution can cause specific, non-specific, acute and chronic effects on the human body. It can lead to an increase in the number of cases of hypertension, malignant tumours, and respiratory diseases [1].

Zaporizhzhia is one of the most urbanised, industrialised and environmentally unfavourable cities in Ukraine. The population of Zaporizhzhia lives in conditions of constant air pollution with harmful chemicals of man-made origin. The crisis of technogenic load on the city is exacerbated by the climatic features of the region and the existing buildings. The city of Zaporizhzhia is located in climatic conditions characterised by unfavourable conditions for the dispersion of harmful emissions (temperature inversions, calm weather, etc.), which leads to the accumulation of emissions from enterprises in settlements. The main enterprises of the city of Zaporizhzhia are located in the industrial area, which is located almost in the city centre, and air pollution over the main districts of the city occurs in almost any wind direction [7].

Analysing the emissions of pollutants into the air of Zaporizhzhia, we can testify to the excess of reference doses of the relevant chemicals.

The development of the city of Zaporizhzhia took place in such a way that the city's settlement areas were in close proximity to large industrial enterprises. Many residential buildings were located within the sanitary protection zones of industrial enterprises. The yellow-grey haze of smog is often observed over the city of Zaporizhzhia, which is formed as a result of emissions from industrial enterprises that are concentrated in a relatively small area. The undulating flat terrain with a tiered girder network worsens the ventilation of the city and the conditions for dispersing pollutant emissions [5].

The obtained results on hazard coefficients and indices, individual carcinogenic risks from air pollution in the Shevchenkivskyi district of Zaporizhzhia can be used in the activities of the State Institution "Zaporizhzhia Regional Centre for Disease Control and Prevention of the Ministry of Health of Ukraine", the Municipal Institution "Health Care Administration" of Zaporizhzhia City Council and the Department of Environmental Safety of Zaporizhzhia City Council.

**Analysis of sources and recent research.** The author of the article Max Roser [8] believes that researchers have long known that polluted air leads to a large number of premature deaths. But in the past, it was thought that the link between exposure and health outcomes was less strong. More recent studies have found that a certain level of exposure leads to more deaths than in previous studies. The incline of the exposure-response function is sharper than previously thought.

The article by Rybalova O. [6] and others notes that the city of Zaporizhzhia has a high air pollution index for five pollutants. The authors note that the value of the hazard index for getting a disease at this level of air pollution in Zaporizhzhia corresponds to class 4, which indicates a high level of danger. The authors of the article insist on further research of the state of atmospheric air and making the necessary managerial decisions on the implementation of environmental protection measures.

Pirogova I., Veremeienko G., Yanko S. in their article [4] believe that control over the state of atmospheric air is an important link in the environmental monitoring system. This, in turn, provides information on the level of pollution of the atmospheric air component, which directly and indirectly affects human health. According to the authors' calculations, the analysis of the correspondence between the production capacity in Zaporizhzhia and the levels of the comprehensive air pollution index showed that a sharp decline in production capacity leads to a decrease in the content of pollutants. However, the composite air pollution index is still at the level of elevated and hazardous air pollution.

According to P. Sicard and others [9], in order to achieve air quality standards and to mitigate the effects of air pollution, urgent action at all levels of government is required. In cities, there should be stricter air quality monitoring to reduce the impact of emissions, while implementing effective emission control policies that take into account regional socio-economic imbalances.

**Purpose, object, subject and methods of research.** Air pollution caused by stationary sources of industrial enterprises in the city affects the general health of the population. **The purpose of the research** is to establish the risks to the health of the population of the Shevchenkivskyi district of Zaporizhzhia in the period 2019–2022 from air pollution by gaseous substances. In accordance with this goal, the study was aimed at solving the

following **tasks**: to assess the toxicity of emissions and to form a list of priority air pollutants that characterise the impact on public health; to calculate non-carcinogenic risks by coefficients and hazard indices (HQ, HI) and individual and population carcinogenic risk (ICR, PCR) for the health of the exposed population exposed to air pollution in an industrial city for the period 2019–2022.

**The object of the study** is the impact of pollutant emissions on the formation of inhalation risk to the health of the population living in the area of stationary source emissions. **The subject of the study** are pollutants; health risks caused by inhalation exposure to polluted air (non-carcinogenic and carcinogenic risks).

**Research methods.** The study used the general procedure of the Human Health Risk Assessment methodology developed and recommended by the US Environmental Protection Agency. Risk assessment involves four interrelated stages, namely: hazard identification, exposure assessment, hazard characterisation (dose-response assessment), and risk characterisation, the methodology for which is described in [10, 3]. We also used sanitary and hygienic (to assess air pollution with harmful chemicals), analytical (to assess the toxicity of substances), and mathematical (probabilistic assessment to calculate the levels of risk to the health of the exposed population) research methods.

The scenario and characteristics of the impact of pollutants selected for the conditions of the Shevchenkivskiyi district of Zaporizhzhia are presented in Table 1.

Table 1

**Scenario and route of pollutant exposure**

Elements of exposure analysis	Exposure characteristics
Agents	chemical pollutants
Sources	emissions from stationary organised sources
The way of influence	inhalation (breathing air)
Exposure time	non-carcinogenic and carcinogenic effects
Geographical coverage	Shevchenkivskiyi district of Zaporizhzhia
Evaluation period	2019–2022
Type of exposure by contact time	chronic

The priority route of pollutant intake into the human body is the inhalation route, and the analysed environment is atmospheric air.

In order to determine the list of priority potentially harmful chemical compounds emitted by industrial enterprises, the most complete list of all chemicals that can affect humans in the study area was initially compiled. The following criteria for selecting priority pollutants were taken into account: assessment of the toxicity of pollutants that can affect public health; analysis of data on hazard parameters and “dose-response” relationships (reference concentrations; carcinogenic potential factors; current national standards: maximum permissible concentrations for maximum one-time and average daily concentrations (MPCm.o., MACa.d.), and estimated safe exposure levels (ESLs)); assessment of the direction of impact on organs and systems of the human body.

Taking into account the criteria for selecting priority pollutants emitted into the air by stationary sources of industrial enterprises, a list of priority pollutants for four years (2019–2022) was formed, necessary for further research to assess the risk to public health. The list includes 8 chemical compounds, including hydrogen sulphide, phenol, formaldehyde, and carbon disulfide, which are classified as hazard class 2 (highly hazardous substances); nitrogen dioxide, sulphur dioxide, and suspended solids, which are classified as hazard class 3; and carbon monoxide, which is classified as hazard class 4.

Among the priority pollutants, 1 of the chemicals has a carcinogenic effect. According to the IARC classification [11], formaldehyde belongs to the group of class 1 carcinogens (2A/B1), i.e. the most dangerous for humans. The following streets of the Shevchenkivskiyi district were selected for the study: intersection Kharchova-O. Porady (1), O. Porady-Magistralna (2), M. Koryshchenko (3), Peredatochna (4), O. Porady (5). Within a radius of 1000 m from these streets there are PJSC “Zaporizhzhia Oil and Fat Plant” and PJSC “Zaporizhzhia Abrasive Plant”.

The averaged levels of annual concentrations of pollutants for 2019–2022, which form exposure loads on the health of the population of the Shevchenkivskiyi district of Zaporizhzhia, were provided by the State Institution “Zaporizhzhia Regional Centre for Disease Control and Prevention of the Ministry of Health of Ukraine”.

Based on the calculated exposure levels, the risk characteristics for the Shevchenkivskiyi district from air pollution caused by industrial emissions

were established, which included non-carcinogenic and carcinogenic risks, namely, hazard coefficients for individual substances (HQ), hazard indices for a set of substances and total hazard indices (HI), individual (ICR) and population (PCR) risks.

**Summary of the main material.** The results of calculations of hazard ratios in assessing the inhalation impacts of pollutant emissions of industrial enterprises during chronic exposure on the studied streets in 2019–2022 indicate the presence of exceedances of safe levels ( $HQ > 1$ ) in some places of measurement of the receptor points (Fig. 1).

In the Shevchenkivskyi district, the average values of the hazard coefficients for chronic inhalation exposure in 2019 exceed the permissible level for all substances except carbon monoxide (except for the intersection between O. Porady and Magistralna streets, where the risk level is low), and are at the following levels: for dust – at a high level on Kharchova, O. Porady, Magistralna, Peredatochna streets; for sulphur dioxide, nitrogen dioxide, formaldehyde, phenol – at an average level on all studied streets of the Shevchenkivskyi district.

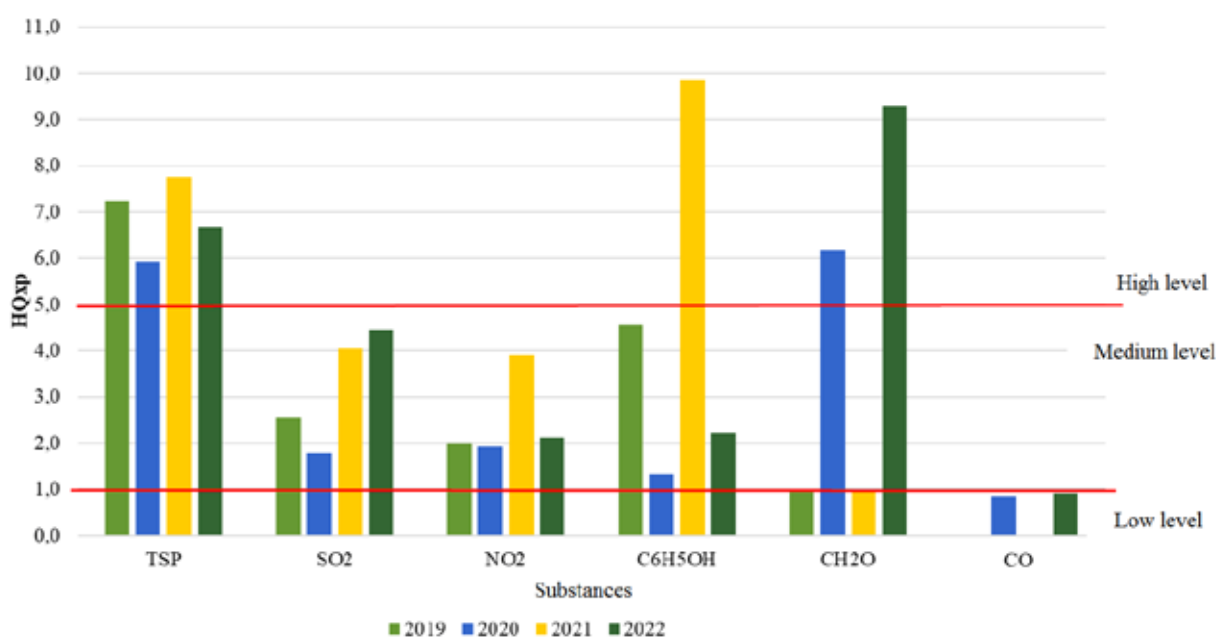
The average values of the hazard coefficients for lifetime inhalation exposure in 2020 exceed the permissible level for all substances except carbon monoxide and are at the following levels: for dust and formaldehyde – at a high level on Kharchova,

O. Porady, Mahistralna, Peredachna streets; for sulphur dioxide, nitrogen dioxide, phenol – at an average level on all studied streets of the Shevchenkivskyi district.

The average values of the hazard coefficients for chronic inhalation exposure in 2021 exceed the permissible level for all substances except carbon monoxide (except for the intersection between O. Porady and Magistralna streets, where the risk level is low), and are at the following levels: for dust and formaldehyde – at a high level; for sulphur dioxide, nitrogen dioxide (on O. Porady and Magistralna streets – high level), phenol (for Peredatochna street – extremely high level) at an average level on all studied streets of the Shevchenkivskyi district.

The average values of the hazard coefficients for chronic inhalation exposure in 2022 exceed the permissible level for all substances except carbon monoxide and are at the following levels: for dust and formaldehyde – at a high level on Kharchova, O. Porady, Magistralna, Peredatochna streets; for sulphur dioxide, nitrogen dioxide, phenol – at an average level on all studied streets of the Shevchenkivskyi district.

The results of the hazard indices calculations indicate the presence of exceedances of safe exposure levels ( $HI > 1$ ) for most priority pollutants for



**Fig. 1. Annual average values of hazard coefficients in the assessment of hazardous inhalation effects of pollutant emissions from industrial enterprises for the period 2019–2022 in the Shevchenkivskyi district of Zaporizhzhia**

chronic inhalation exposure in the studied areas in 2019–2022 (Fig. 2).

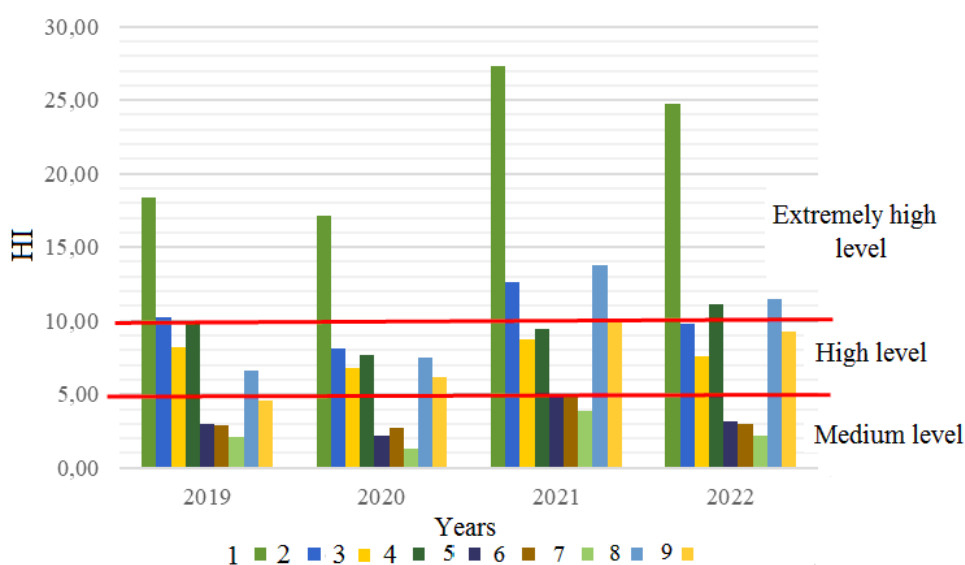
The results of the hazard indices calculations in the Shevchenkivskiy district in 2019 indicate an extremely high level of chronic inhalation exposure in the studied streets to the respiratory system (HI=16.17÷21.89) and cardiovascular system (HI=9.90÷10.65); at a high level are the effects on the number of additional cases of death (HI=8.63÷11.00) (an extremely high level is observed on Kharchova and O. Porady), congenital developmental defects (HI=7.38÷9.10), immune system (HI=4.00÷5.33), visual organs (HI=5.83÷8.17); at the medium level are the impacts on the central nervous system (HI=2.57÷3.82), circulatory system (HI=2.43÷3.71), parenchymal organs (HI=1.55÷2.83).

The results of calculating the hazard indices in 2020 indicate an extremely high level of chronic inhalation exposure to respiratory organs on the studied streets (HI=5.56÷18.10); at a high level – the impact on the cardiovascular system (HI=5.47÷9.97), the number of additional cases of death (HI=4.00÷8.81), congenital developmental defects (HI=7.87÷9.59), the immune system (HI=4.67÷7.67), and the organs of vision (HI=0.83÷8.75); at the medium level – impact on the central nervous system (HI=1.47÷3.03), blood

circulatory system (HI=1.36÷4.09), parenchymal organs (HI=1.83÷11.00) (extremely high level is observed on Peredatochna Street).

The results of calculations of hazard indices in 2021 indicate an extremely high level of chronic inhalation exposure in the studied streets to respiratory organs (HI=22.56÷33.76), cardiovascular system (HI=9.92÷19.43), visual organs (HI=8.23÷22.00); the impact on the number of additional deaths (HI=8.91÷10.09) is at a high level (extremely high level is observed on Magistralna, M. Koryshchenko and O. Parady streets), born developmental defects (HI=7.87÷9.59), immune system (HI=6.00÷12.00) (extremely high level is observed on Peredatochna, M. Koryshchenka and O. Porady streets); at the medium level – the impact on the central nervous system (HI=2.99÷11.83) (an extremely high level of HI=11.83 is observed for Peredatochna Street), circulatory system (HI=3.43÷6.48) (high level is observed on Magistralna, M. Koryshchenka and O. Porady streets), parenchymal organs (HI=1.83÷11.00) (extremely high level is observed on Peredatochna Street, HI=11.00).

The results of calculating the hazard indices in 2022 indicate an extremely high level of chronic inhalation exposure to respiratory organs on the studied streets (HI=19.91÷29,87) and the number



**Fig. 2. Annual average values of hazard indices in the assessment of chronic inhalation exposure of pollutant emissions from industrial enterprises for the period 2019–2022 in the Shevchenkivskiy district of Zaporizhzhia (1 – respiratory system, 2 – cardiovascular system, 3 – congenital developmental defects, 4 – additional cases of death, 5 – central nervous system, 6 – circulatory system, 7 – parenchymal organs, 8 – visual organs, 9 – immune system)**

of additional deaths ( $HI=7.13\div 16.27$ ), at a high level – the impact on the cardiovascular system ( $HI=6.54\div 10.72$ ), congenital developmental defects ( $HI=5.02\div 8.80$ ), immune system ( $HI=7.33\div 12.17$ ) (an extraordinary level is observed on M. Koryshchenka str. M. Koryshchenka Street), visual organs ( $HI=9.25\div 13.37$ ); at the average level – the impact on the central nervous system ( $HI=2.42\div 4.93$ ), circulatory system ( $HI=2.78\div 3.86$ ), parenchymal organs ( $HI=1.52\div 4.00$ ).

The greatest impact of pollutants is on the respiratory system. The main contribution to respiratory diseases in the population of the exposed area is made by dust (Total Suspended Particulates) and formaldehyde (Fig. 3). The share of formaldehyde is increasing with every year under investigation.

The results of calculations of individual carcinogenic risk for chronic exposure in the period 2019–2022 on the studied streets of the Shevchenkivskyi district of Zaporizhzhia are within the average risk level ( $10^{-4} < ICR < 10^{-3}$ , which is unacceptable for the population, typical for most large industrial cities) for chronic exposure (Fig. 4). The highest individual carcinogenic risk was  $2.98 \cdot 10^{-4}$  on Peredatchna Street in 2022;  $2.94 \cdot 10^{-4}$  on Mykola

Koryshchenko Street in 2021;  $2.86 \cdot 10^{-4}$  on Oleksii Porada Street in 2021;  $2.41 \cdot 10^{-4}$  on average in Shevchenkivskyi District in 2021.

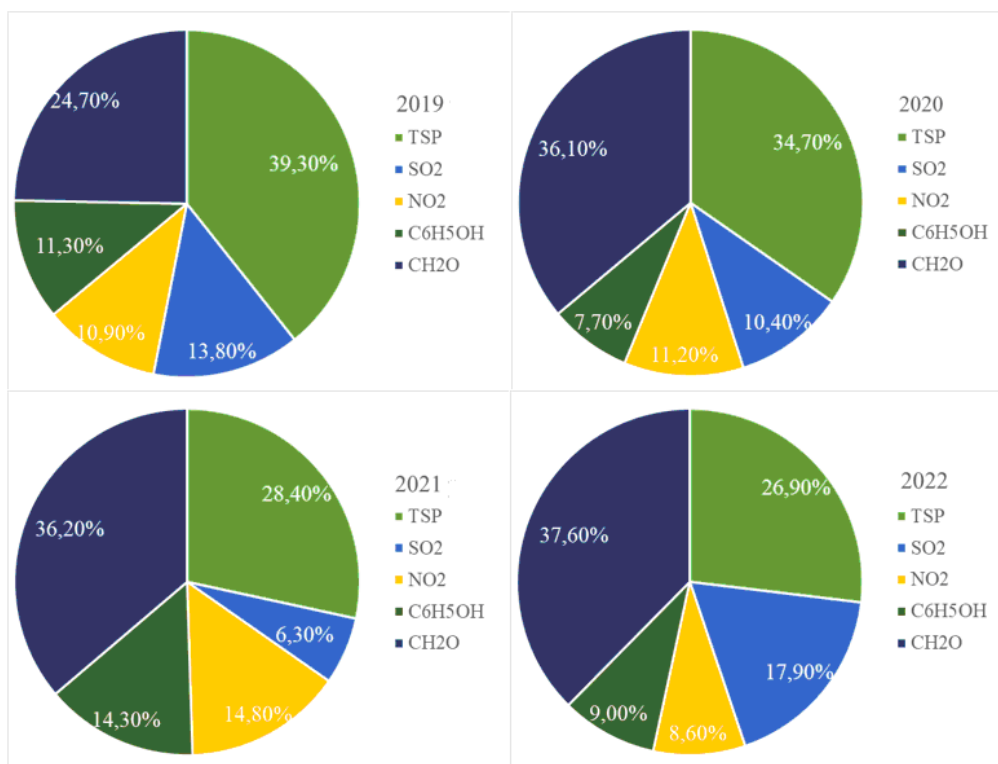
The population carcinogenic risk of PCR under chronic exposure in the Shevchenkivskyi district was 17 in 2019, 23 in 2020, 36 in 2021 and 34 in 2023, the number of additional cases of cancer during the lifetime of the population exposed to the concentration of the substance.

Taking into account the analysis of the public health risk assessment and based on the studies conducted to assess the public health risk in the Shevchenkivskyi district of Zaporizhzhia, it is necessary to develop and implement measures to manage the public health risk.

### Conclusions

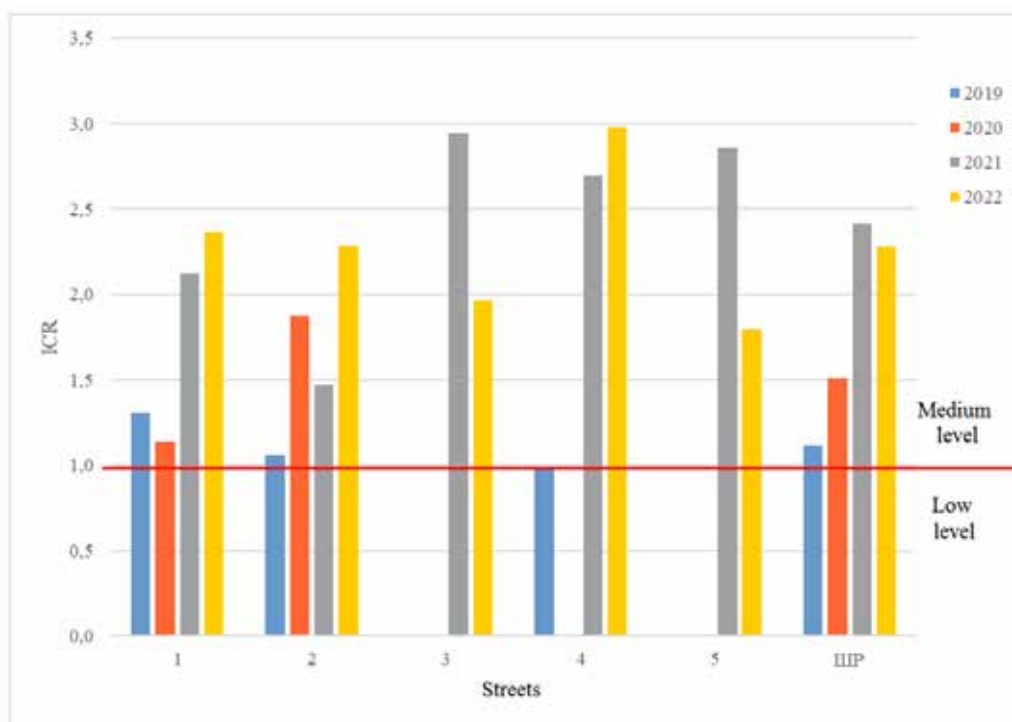
1. In the city of Zaporizhzhia, there is a high level of air pollution associated with significant concentrations of formaldehyde, nitrogen dioxide, phenol, hydrogen sulphide, and suspended solids. Polluted air has a negative impact on the health of city residents.

2. The results of calculations of hazard coefficients in assessing the inhalation effects of pollutant emissions from industrial enterprises



**Fig. 3. The share of pollutants affecting the respiratory system in the assessment of chronic inhalation exposure to pollutant emissions from industrial enterprises for the period 2019–2022 in the Shevchenkivskyi district of Zaporizhzhia**





**Fig. 4. Individual carcinogenic risk from formaldehyde under chronic exposure in the studied streets of the Shevchenkivskiy district of Zaporizhzhia in 2019–2022**

under chronic exposure on the studied streets for 2019–2022 indicate that safe levels are excessive ( $HQ > 1$ ) in some places where receptor points were measured and are at a high level for dust and formaldehyde.

3. The results of calculations of hazard indices indicate the presence of exceedances of safe exposure levels ( $HI > 1$ ) for most priority pollutants for chronic inhalation exposure in the study areas in 2019–2022 and are at an extremely high level for respiratory and cardiovascular systems, at a high level – for the number of additional cases of death, birth defects, immune system, and organs of vision; at an average level – for the central ner-

vous system, circulatory system, and parenchymal organs.

4. The results of calculations of individual carcinogenic risk for chronic exposure for the period 2019–2022 on the studied streets of the Shevchenkivskiy district of Zaporizhzhia are within the average risk level ( $10^{-4} < ICR < 10^{-3}$ , which is unacceptable for the population, typical for most large industrial cities) for chronic exposure.

5. The population carcinogenic risk of PCR for chronic exposure in the Shevchenkivskiy district is 17 in 2019, 23 in 2020, 36 in 2021 and 34 in 2023, the number of additional lifetime cancer cases per population exposed to the substance concentration.

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