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Article

The environmental assessment of the residential area of the small town based on snow-dirt sludge composition data

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Abstract. This paper presents the results of developing an approach to assessing the environmental state of residential areas in towns based on snow-dirt sludge (SDS) composition data. The study was conducted on the example of small and medium-sized towns of the Sverdlovsk region: Alapaevsk, Kachkanar, and Serov. The towns differ in their industrial specialization. The study focuses on dissolved forms of urban pollutants, including Pb, Mn, Ni, Cu, Zn, Co, Cr, and Fe. The total pollution index Z_c was calculated for SDS samples. Various approaches to calculate Z_c were tested, where the background concentration of an element was taken as: (1) the minimum concentration of the element in undisturbed snow in town, (2) the minimum concentration of the element in SDS in the city, (3) the maximum permissible concentration (MPC) of the element in water, and (3) the concentration of the element in snow at the SDS sampling site. The approach to calculate Z_c applying background concentration of the element in snow at the SDS sampling site proved most effective for assessing SDS pollution levels. This method enables to characterize the local natural and anthropogenic processes of migration and accumulation of pollution. The SDS may be used as an independent geochemical indicator of the urban environment. The data obtained significantly enhance the understanding of pollutant migration and accumulation in urban areas.

Keywords: urban environment, multi-storey buildings (MSB), detached houses development, residential construction, snow, pollution, metals, background concentration

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Научная статья

Оценка экологического состояния селитебной территории малого города на основе данных о составе снегогрязевой пульпы

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Аннотация. Приводятся результаты разработки подхода к оценке экологического состояния жилой зоны города на основе данных о составе снегогрязевой пульпы (СГП). Исследование проведено на примере малых и средних по численности городов Свердловской области: Алапаевск, Качканар и Серов, различающихся промышленной специализацией. В работе рассматривались поллютанты городской среды в водорастворимой форме: Pb, Mn, Ni, Cu, Zn, Co, Cr и Fe. Рассчитывался суммарный показатель загрязнения Z_c в СГП. Тестировались различные подходы к расчету Z_c, в которых в качестве условной фоновой концентрации элемента использовалась: минимальная концентрация элемента в снеге в городе, минимальная концентрация элемента в СГП в городе, предельно допустимая концентрация (ПДК) элемента в воде водных объектов, концентрация элемента в снеге на площадке отбора СГП. Лучше всего показал себя подход, учитывающий концентрацию поллютантов в снеге на пробной площадке. Этот способ позволяет характеризовать локальные процессы миграции и накопления загрязнения природно-антропогенного характера. СГП может рассматриваться как отдельный независимый геоиндикаторный объект городской среды. Полученные данные существенно дополняют картину миграции и накопления поллютантов в урбанизированной среде.

Ключевые слова: урбанизированная среда, многоквартирные дома, малоэтажная застройка, снег, загрязнение, металлы, условная фоновая концентрация

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Introduction

According to state statistics, one third of Russia's population lives in small and medium-sized cities[1]. Most industrial production is concentrated there. The pollution of such cities is typically related to the activities of city-forming industries (Novikova and Cherey, 2014). The environmental monitoring is often not conducted in such towns[2] as it requires time and human resources[3]. Moreover, small and medium-sized towns remain inaccessible for the public environmental control. The industrial environmental control and monitoring, as well as urban hygiene monitoring and control, focus on narrow tasks. At the same time, the environmental state of the residential area of the city is defined by the emissions from the stationary and the diffuse pollution sources, as well as the state of urban infrastructure and the compliance with the rules for improvement and maintenance of territories[4].

The lack of state environmental monitoring and the limited scope of the existing environmental monitoring in small and medium-sized cities result in disproportion in the socio-economic development of the country, as well as within the regions[5]. The issue of environmental quality assurance is exacerbated by the lack of the high quality medical care, the absence of medical personnel, and its insufficient qualification in small and medium-sized cities. Knowledge of the migration and accumulation of potentially harmful substances in urban landscapes is necessary to ensure public safety during natural and anthropogenic emergencies and accidents.

The extraction of mineral raw material and its processing, metallurgy, metalworking, and mechanical engineering are the main industries located in small and medium-sized cities of the Sverdlovsk region. The environmental state of these cities is considered to be of critical concern. Approximately 70% of the Sverdlovsk region's residents live in areas with unfavorable environmental quality (Krichker and Shimova, 2018).

A cost-effective solution for obtaining reliable information about the environmental state of small and medium-sized cities may be realized applying various types of deposition media in urban geochemical studies, such as snow, road dust, gully pots sediments and snow-dirt sludge (SDS) (Seleznev et al., 2019; Vlasov et al., 2023). These environmental compartments integrate pollution over time and space. The research programs and methodologies for obtaining the environmental data are well-developed (Bezberdaya et al., 2024; Lapteva and Shishkin, 2010; Lebedev and Agafonova, 2017;). Snow is the most studied and frequently used object for environmental monitoring. The snow cover remains for a

[1] Results of the All-Russian Population Census 2020. V. 1. Population size and distribution. Web page. URL: https://rosstat.gov.ru/storage/mediabank/Tom1_tab-10_VPN-2020.xlsx (accessed: 19.03.2025).

[2] Ural Department for Hydrometeorology and Environmental Monitoring. Web page. URL: http://svgimet.ru/?page_id=181 (accessed: 10.10.2024).

[3] State report on the state of the environment in the Sverdlovsk region in 2023, 2024.

[4] U.S. Environmental Protection Agency. Web page. URL: https://www.epa.gov/nps/nonpoint-source-urban-areas (accessed: 10.10.2024).

[5] Index of Quality of the Urban Environment. Web page. URL: https://xn----dtbcccdtsypabxk.xn--p1ai/#/methodology (accessed: 10.10.2024).

long time in most part of Russia and accumulates atmospheric pollutants. When the snow melts, the pollution moves with the water into the soil (Saet et al., 1990). The snow is mixed by vehicle wheels and pedestrians with loose material of the contemporary surface deposited sediments, road dust, forming SDS (Seleznev et al., 2019; Seleznev et al., 2024). The SDS accumulates on roads, sidewalks, driveways, and it is stored into piles on lawn areas and curbs. SDS is an environmental compartment that has received relatively little attention in urban environmental studies.

The objectives of the study are to develop and test an approach for assessing the environmental state of urban residential areas, using the composition of SDS as an indicator.

Materials and methods

Characteristics of the studied cities

The study was carried out on the example of Sverdlovsk region of Russia in the small towns of Alapaevsk (population of 35934 people) and Kachkanar (36563) and the medium-sized town of Serov (92349)[6]. The cities are located in the temperate continental climate zone on the eastern slope of the Ural Mountains. Alapaevsk and Kachkanar are located in the Middle Urals, and Serov in the southern part of the Northern Urals (Kobysheva, 2001). The natural conditions of the towns are similar.

The cities differ in their industrial specialization. The main industries in Alapaevsk are machinery, woodworking, and agriculture. The metallurgical plant in Alapaevsk was closed in 2018. Kachkanar Mining and Processing Plant is one of the largest mining companies in Russia. It is the main supplier of vanadium raw materials (Melchakov et al., 2018). Metallurgy is the main industry in Serov.

According to an assessment of the total pollution index Z_c of soils with heavy metals and metalloids, the environmental situation in Alapaevsk is characterized as hazardous (Kasimov and Vlasov, 2018). The total concentration of pollutants of the 1st to 3rd environmental hazard classes reaches 19 points in several parts of Kachkanar; it corresponds to the permissible pollution level (Menshikova et al., 2019; Rossman and Koroleva, 2016). The total pollution index is within the acceptable pollution level for soil in Serov[7].

The residential areas of small and medium-sized cities consist of neighborhoods with multi-storey apartment buildings (MSB), as well as low-rise housing, represented by private detached houses with property area. The areas occupied by MSB and low-rise housing neighborhoods are approximately equal.

Research program

A sampling grid of ten sites for snow and SDS sampling was established in each city according to the methodology described in the Order of the Ministry of Natural Resources and Environment of the Russian Federation No. 524 dated July 30, 2020[8]. Five sampling sites were located in the MSB area, and five in the area of the low-rise buildings. The sampling site in the MSB area represented a landscape microcomplex, including a residential building and the adjacent territory of both the inner courtyard and frontage of the city block. The microcomplex consisted of connected functional landscape zones: lawn, playground, parking lot, driveway, sidewalk, and street (road) (Seleznev et al., 2024; Yarmoshenko et al., 2020). The sampling site in MSB area was adjacent to the city's street network. The site in the low-rise buildings zone is also represented by a microcomplex of interconnected parts of the frontage zone (road, driveway, and green areas) and the courtyard (Seleznev et al., 2024).

One sample of snow and one sample of SDS were collected at each sampling site. The snow and SDS samples were taken from the courtyard in the MSB area. In the low-rise buildings area, the samples were collected from the frontage part. There is no SDS formed in the courtyards of low-rise buildings area in winter; this area is completely covered with snow and in summer is used, usually, for gardening. The intensity of vehicle traffic in the courtyard areas in the zones of MSB and low-rise buildings is quite low. The undisturbed snow cover was taken from lawns and playgrounds. In the MSB

[6] Population of the Russian Federation by municipalities. Web page. URL: https://rosstat.gov.ru/compendium/document/13282 (accessed: 20.03.2025).

[7] Analysis of Soil Quality in the City of Serov and Serov District Based on Control Data in 2022. Web page. URL: https://xn--112-hddo8cng.xn--p1ai/novosti/informatsiya-ot-rospotrebnadzora/analiz-kachestva-pochvy-na-territorii-g-serova-i-serovskogo-rajona-po-dannym-kontrolya-za-2022-god/ (accessed: 28.05.2024).

[8] Order of the Ministry of Natural Resources and Environment of the Russian Federation No. 524 of 30.07.2020 “On Approval of requirements for observations of the state of the environment, its pollution”.

area, SDS samples were collected from driveways, parking lots, and piles of snow. The SDS samples in the low-rise buildings area were taken from the roads and snow and SDS piles along them. Snow and SDS sampling were conducted during the period of maximum snow accumulation in March 2024.

The snow sample was collected using a sampling device made in the form of a plastic tube with a 10 cm diameter. The snow core sample was taken from the full depth of the snow cover. The grass, debris, and soil was removed from the bottom of the snow core during the sample collection. The snow sample collected at the sampling site represented the combined sample of snow taken from 3-5 sampling points (cores). The SDS sample collected at the sampling site was combined with SDS taken from 3–5 points at the site[9]. The SDS sample was collected using a shovel made of stainless steel (Seleznev et al., 2019, 2024). Snow and SDS samples were collected in clean 5 liter plastic buckets with lids. The contamination of the sample material from other samples was excluded. The buckets with the samples were stored in the refrigerator at a temperature of −4 °C. Sample preparation and chemical analysis were carried out at the chemical analytical center of the Institute of Industrial Ecology of the Ural Branch of the Russian Academy of Sciences accredited in the Russian System for Accreditation of Chemical Laboratories.

The samples were melted at room temperature for 24 hours. After melting, the sample volume was measured. The pH and Eh were determined in the samples using the portable instruments according to the instructions provided by the manufacturer. The pH was measured with portable pH-meter PH600 (Milwaukee, USA), and Eh was determined with portable Eh-meter ORP-200 (HM Digital, South Korea). After that the sample was filtered through the prepared paper filters "blue tape" with a pore size of 2 μm. The filter preparation consisted of rinsing it with distilled water and drying it. The SDS samples were filtered without shaking. Filtration of the samples was accelerated using a vacuum filtration device based on a battery of parallel-connected Buchner flasks with funnels. The filtrate from the snow and SDS sample was transferred into 1.5-liter bottle (to determine cation and anion composition of the sample) and 50 ml test tube (for determining metal content). The content of Na^+ and K^+ in the filtrate from the snow and SDS sample was measured using the flame photometry[9], content of Cl^- – titration[9], CO_3^- and HCO_3^- – potentiometric titration[10], and SO_4^{2-} using photometry[9]. The content of Ca^{2+}, Mg^{2+} and metals was determined by inductively coupled plasma mass spectrometry (ICP-MS) on the ELAN 9000 mass spectrometer (Perkin Elmer, USA) using method CV 3.18.05-2005[11].

Pollution degree assessment

The concentration coefficient K_{ci} of the *i*-th element in the snow sample was calculated according to the equation:

$$K_{c\,i} = \frac{C_i}{C_{background\ i}},$$

where C_i is the concentration of the *i*-th element in the sample, $C_{background\ i}$ is the reference background concentration of the *i*-th element.

Based on the calculated concentration coefficient the total pollution index (Z_c) was calculated for the snow and SDS at each sampling site (n is the number of elements):

$$Z_c = \sum_{i=1}^{n} K_{c\,i} - (n-1).$$

The Z_c was calculated taking into account elements which concentrations in the sample was 20% higher than the concentration in the reference background sample. The calculation was performed for typical urban pollutants in dissolved form (Pb, Mn, Ni, Cu, Zn, Co, Cr, and Fe), for which the maximum permissible concentrations (MPC) in environmental components have been established according to

[9] RD 52.04.186-89. Guidelines for the control of atmospheric pollution: date of introduction 1991-07-01.

[10] GOST 31957-2012. Water. Methods for determination of alkalinity and mass concentration of carbonates and hydrocarbonates, method A.

[11] CV 3.18.05-2005. Water quality. Method for measurement of elemental composition of drinking, natural, waste water and atmospheric precipitation by inductively coupled plasma mass spectrometry.

Russian Hygienic Standards and Requirements for Ensuring Safety and (or) Harmlessness of Environmental Factors for Human Health SanPiN N 1.2.3685-21[12].

Table 1 shows the reference background concentrations tested to calculate K_c for snow and SDS. The Z_c pollution categories corresponding to the Table 2 (Saet et al., 1990) were plotted on the city's map (Figs. 4–6).

Results

In total 60 combined samples of snow and SDS were collected in residential areas of the cities. One sample was taken per 1 km^2 in Alapaevsk and Serov, while two samples per 1 km^2 were collected in Kachkanar (Seleznev et al., 2024).

Physico-chemical properties of snow and SDS

The mineralization (calculated as the sum of primary cation and anion concentrations) of the SDS samples corresponded to fresh water for two samples, one from Alapaevsk and one from Kachkanar. For the remaining samples, the mineralization corresponded to ultra-fresh water. The pH and Eh values for snow and SDS are shown in Figure 1. In Alapaevsk, snow is characterized by the neutral pH values, while SDS shows properties from alkalescent to alkaline. In Kachkanar, both SDS and snow has alkalescent properties. In Serov, both SDS and snow show alkalescent and alkaline properties. The abnormal pH or Eh values were not found in snow and SDS in the studied cities. The pH, Eh, and mineralization in snow and SDS do not differ significantly within the area of the given city. They do not differ significantly between the areas of low-rise buildings and MSB.

Table 1. Reference background concentrations for snow and snow-dirt sludge to calculate K_c.

Method	Object of study	Reference background concentration	The point on the map	Figure
1	Snow or SDS	Minimum element concentration in snow in the city	Z_c in snow and SDS at the sampling site	4**A**, **B**, **C**
			Maximum Z_c in snow or SDS at the sampling site	4**D**, **E**, **F**
2	Snow or SDS	MPC in surface water bodies[12]	Maximum Z_c (selected between Z_c for snow and SDS) at the sampling site	5
3	SDS	3a. Minimum concentration of the element in SDS in the city	Z_c in SDS at the sampling site	6**A**, **B**, **C**
		3б. Concentration of the element in snow at the sampling site	Z_c in SDS at the sampling site	6**D**, **E**, **F**

[12] SanPiN N 1.2.3685-21. Russian hygienic standards and requirements for ensuring safety and (or) harmlessness of environmental factors for human health.

Table 2. Categories of pollution according to the pollution index Z_c (Saet et al., 1990).

Pollution category	Z_c *value*
Permissible	< 32
Moderately polluted	32–64
Harmful	64–256
Extremely polluted	> 256

Content of chemical elements in snow and SDS

Figs. 2 and 3 show the mean concentrations of metals in snow and SDS. The metal concentrations were below the detection limit in a part of samples: Mn (one snow sample), Cr (18 snow and 11 SDS), Ni (11 snow and one SDS), Cu (one snow and one SDS), Zn (one SDS), Co (26 snow and six SDS), and Fe (22 snow and three SDS). The number of samples with metal concentrations below the detection limit is significantly higher in snow than in SDS.

The pH and the content of pollutants in dissolved form in snow and SDS in the cities were compared with the literature data (Table 3) (Bełcik et al., 2024; Chand et al., 2024; Engelhard et al., 2007; Kravchuk, 2019; Kuoppamäki et al., 2014; Sakai et al., 1988; Tigeev et al., 2021). The pH values are similar to the pH values obtained in the other studies for the other cities (Romanova and Korolev, 2019; Zubkova et al., 2022).

The metal content in snow and SDS is significantly lower than MPC level in the studied cities. The water soluble phase in the SDS has a metal content that is several times higher than in the snow. In addition, the extremely low concentrations of Pb, Co, and Ni were observed in comparison with the other cities (Table 3). The Cr content in snow and SDS is significantly lower in Alapaevsk and Kachkanar than in the other cities; the Cr concentrations in snow and SDS in Serov are similar to those in the other cities in the world. The Cu content in SDS in the studied cities is several times higher than in snow, however it is similar to the concentration in snow in some other cities of the world. The concentrations of Mn and Zn in snow are lower than in SDS, and they are also similar to the content of these elements in the other cities. The Fe content in SDS is significantly higher than in snow in Kachkanar and Serov, it may be attributed to industrial activities.

The obtained reference background concentrations for the studied cities are significantly lower than the MPC level (up to several orders of magnitude for individual metals) (Table 4).

Assessment of the total pollution index

Table 5 presents the number of samples in cities that belong to different pollution categories based on the various reference background concentrations (see Table 1). Figure 4 shows the Z_c values obtained using the minimum pollutant concentration in the snow sample in the city as the reference background level. Using MPC as the reference background concentration allows obtaining the permissible pollution category for snow and SDS in the cities based on Z_c (Fig. 5). Fig. 6 shows the distributions of Z_c in SDS in the cities, calculated using the various kinds of the reference background. The large portion of samples is in the moderately polluted and harmful categories.

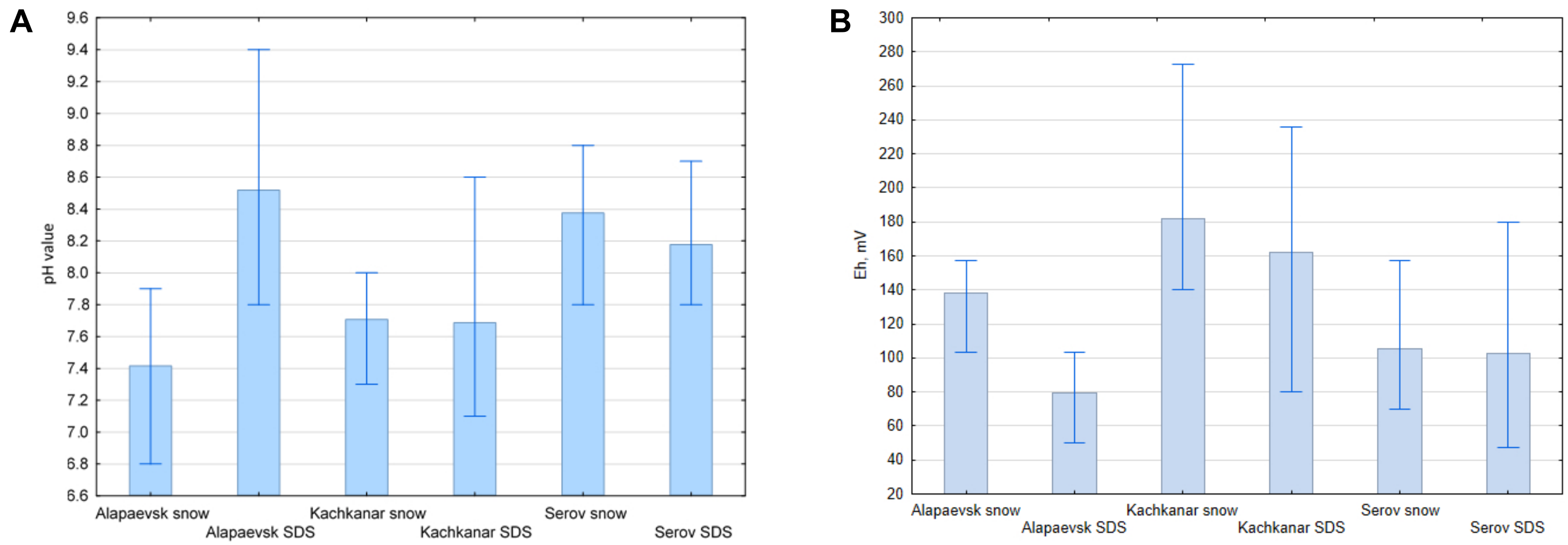

Fig. 1. Values of pH (**A**) and Eh (**B**) in snow and snow-dirt sludge samples in the studied towns (mean, whiskers – minimum and maximum values).

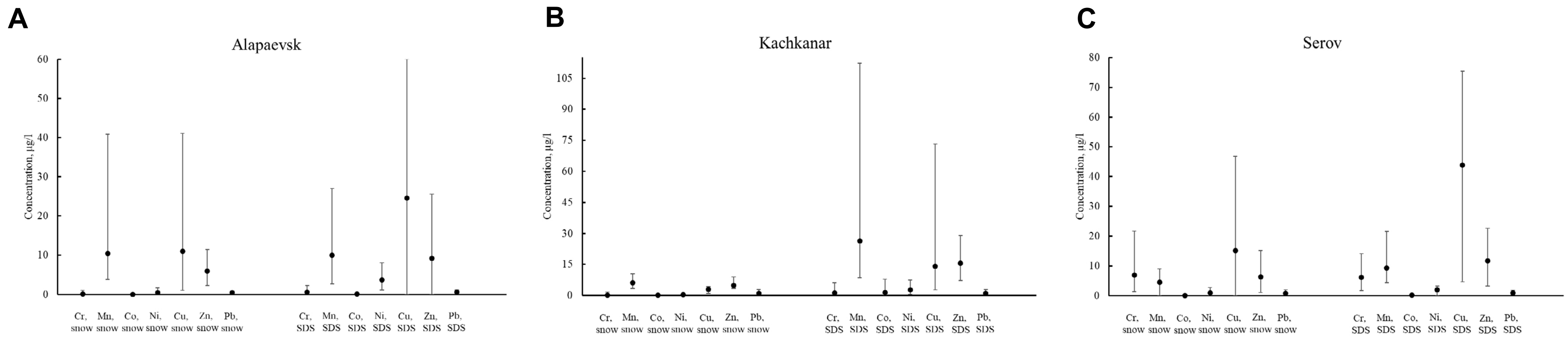

Fig. 2. Mean, minimum and maximum concentrations of metals in snow and snow-dirt sludge samples in Alapaevsk (**A**), Kachkanar (**B**) and Serov (**C**).

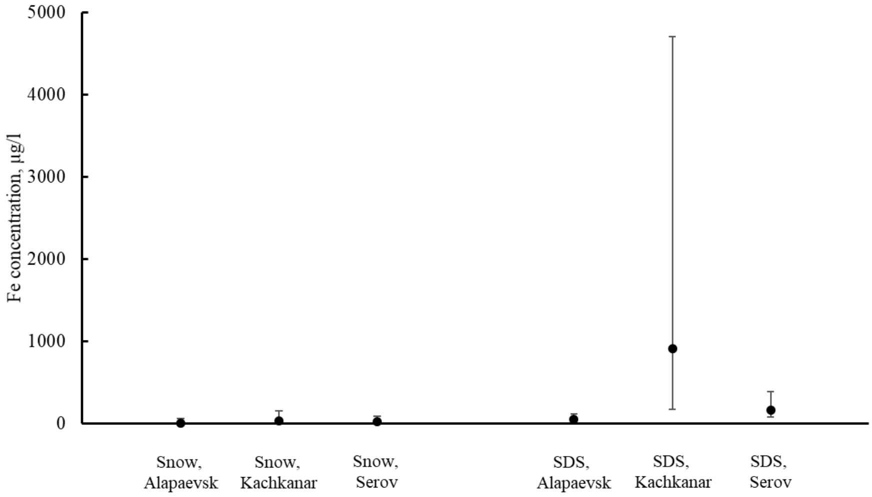

Fig. 3. Mean, minimum and maximum Fe concentrations in snow and snow-dirt sludge samples.

Discussion

The sampling grid of the current study is irregular, however it is consistent with the regulatory documents[13] and RD 52.04.186-89[14], thus it may be applied for other small cities. The number of sampling sites per km^2 of the grid is consistent with the density of sampling sites of the other studies (Kosinova et al., 2023; Lukyanov et al., 2022). The number of samples collected is sufficient to assess the environmental state of the residential area in small and medium-sized city in the cold season.

The physico-chemical properties of snow and SDS in the cities depend on the content of the industrial emissions. In Serov, the snow and SDS contain the substances used in the technological cycles of metallurgical plants, such as soda ash. The Cr supply in the dissolved phase from the atmosphere may be associated with emissions from metallurgical plants. High Fe concentration in SDS in Serov and Kachkanar is due to the use of solid material of mining sludge and metallurgical slag for road filling and the use as construction material (as well for road construction). The physicochemical properties of the environment, particularly the alkaline pH, contribute to the formation of dissolved Fe in these cities. Thus, the stationary pollution sources do not significantly alter the environmental state in the studied cities (for example, the Kachkanarsky Ore Mining and Processing Plant and the Nadezhdinski Metallurgical Plant in Serov).

The water-soluble phase of SDS may additionally be enriched with potentially harmful substances due to mixing with surface deposited sediments in an urban area. The SDS is a mixture of various sizes solid particles and water in a solid state. The liquid phase of SDS represents the total amount of soluble pollutants that have been precipitated from the atmosphere and are present on surfaces during the warm season. These pollutants are associated with surface sediments. The constant intermixing of SDS during the cold season homogenizes its composition within the area where it is formed, as well as within the larger parts of the urban area. The SDS "preserves" the pollution of the urban area that accumulates during both warm and cold seasons. The sampling of the SDS during the period of maximum snow accumulation may characterize the total pollution in the dissolved phase. The application of the standard methods of chemical analysis for SDS allows obtaining the results comparable with data on composition of chemical elements in snow.

We used the standard indicators of urban pollution in the current study – heavy metals widely distributed in urban environmental compartments. The assessment of the pollution degree using the Z_c index is a standard procedure. However, an issue arises regarding which reference background

[13] Order of the Ministry of Natural Resources and Ecology of the Russian Federation from 30.07.2020 № 524, 2020 “On approval of requirements for observations of the state of the environment and its pollution”.

[14] RD 52.04.186-89. Guidelines for the control of atmospheric pollution.

Table 3. Acidity level and content of pollutants in snow in water-soluble phase in different cities of the world.

City, country	Year of the study	pH	Concentration, m								Economic specialization
			Pb	Mn	Cr	Ni	Cu	Zn	Co	Fe	
Tobolsk, Russia	2021	6.0	–	–	–	–	–	–	–	–	Oil and gas processing, electric power
Tyumen, Russia	2019	–	15.0	–	7.3	28.6	11.5	–	–	–	Oil and gas processing
Sapporo, Japan	1988	8.5	34.1	513	9.3	–	37.6	53.0	–	–	IT
Muroran, Japan	1988	6.2	23.9	205	7.8	–	7.2	55	–	–	Metallurgy, oil processing, mechanical engineering
Asahikawa, Japan	1988	5.8	9.0	52	4.0	–	7.2	24	–	–	Agriculture, pulp and paper industry, mechanical engineering, metallurgy
Riga, Latvia	2024	–	23.4	276.0	15.6	10.8	58.2	327.0	3.8	27.8	IT, food production, pharmaceutical, metallurgy
Białystok, Poland	2024	–	38.9	–	283.3	21.4	239.4	1412.6	–	–	Food production, electrical engineering
Lahti, Finland	2014	6.6	1.0	9.6	1.3	1.4	3.3	-	0.6	–	Woodworking, textile, footwear, glass production, food production
Innsbruck, Austria	2007	–	16	–	–	–	0.02	0.1	–	–	Tourism

Table 4. Reference background concentrations and MPC levels of metals.

City	Concentration, m							
	Pb	Mn	Cr	Ni	Cu	Zn	Co	Fe
Minimum in snow in the city								
Alapaevsk	0.26	6.26	1.06	0.51	1.00	2.20	0.10	57.14
Kachkanar	0.42	3.32	1.70	0.38	3.68	3.59	0.11	71.80
Serov	0.49	2.38	4.63	0.36	1.69	1.84	0.13	51.47
Minimum in SDS in the city								
Alapaevsk	0.36	12.54	1.06	3.72	2.99	2.11	0.14	51.27
Kachkanar	0.27	8.50	1.25	0.93	2.69	9.13	0.21	175.03
Serov	0.50	11.20	1.74	1.95	42.05	10.48	0.13	84.35
MPC in surface water bodies[15]								
	10	100	50	20	1000	5000	100	300

concentration of an element should be used for the pollution assessment procedure. Technogenesis started long before the foundation of the towns in the studied area; thus it is difficult to find the background site which has not been anthropogenically altered. Residential areas are usually located within the sanitary protection zones of enterprises in small industrial towns. Residents in areas with low-rise houses use their household land to grow food for their own consumption.

The SDS is not typically used as the sampling object in urban geochemical studies because the reference background object could not satisfactory defined for such an artificial component. The reference background object should characterize the territory where the SDS forms. When calculating Z_c, the concentrations of elements in the sample that are higher than the background level should be taken into account. The K_c = 1.2 taken is used in the long-term practice of regional urban geochemical studies, the results of which are published in State Reports "On the state and environmental protection in the Sverdlovsk region (Russia)". The categories of SDS pollution by Z_c value are used to measure snow pollution by other researchers as well (Vasilychuk et al., 2023).

In this study, the following objects were tested for suitability as a reference background: minimum concentration of the element in snow in the city (Table 1, Method 1), MPC of the element in water of water bodies (Table 1, Method 2), minimum concentration of the element in SDS in the city (Table 1, Method 3a), concentration of the element in snow at the SDS sampling site (Table 1, Method 3b). The results of the assessment were applied to the city maps (Figs. 4–6).

The tested reference background objects have their own shortcomings. The minimum concentrations of various elements may be found in different samples. It is difficult to perceive the varied distribution of Z_c over the urban area in Fig. 4. But it is close to the real environmental situation in the city.

The assessment of the maximum value of Z_c in snow or SDS at the sampling site relative to MPC (Fig. 5) allows obtaining the permissible category of pollution for the city area. The MPC of elements in water-soluble phase is not related to lithological and geochemical characteristics of the city area. The resulting permissible values of Z_c do not reflect the geochemical state in the study area, do not show the geochemical anomalies associated with the main stationary sources of pollution in the city.

[15] SanPiN N 1.2.3685-21. Russian hygienic standards and requirements for ensuring safety and (or) harmlessness of environmental factors for human health.

Table 5. Number of samples in cities that belong to different pollution categories depending on used reference background concentration.

City	Object of study / reference background concentration (from Table 1)	Number of samples in pollution category Z_c, %		
		Permissible	Moderately polluted	Harmful
Alapaevsk	Snow / MPC in water	100	0	0
	SDS / MPC in water	100	0	0
	Snow / min element concentration in the sample of snow in the city	80	20	0
	SDS / min element concentration in the sample of snow in the city	90	10	0
	SDS / min element concentration in the sample of SDS in the city	50	20	30
	SDS / element concentration in snow at the sampling site	80	20	0
Kachkanar	Snow / MPC in water	100	0	0
	SDS / MPC in water	100	0	0
	Snow / min element concentration in the sample of snow in the city	100	0	0
	SDS / min element concentration in the sample of snow in the city	80	10	10
	SDS / min element concentration in the sample of SDS in the city	50	40	10
	SDS / element concentration in snow at the sampling site	60	30	10
Serov	Snow / MPC in water	100	0	0
	SDS / MPC in water	100	0	0
	Snow / min element concentration in the sample of snow in the city	90	10	0
	SDS / min element concentration in the sample of snow in the city	100	0	0
	SDS / min element concentration in the sample of SDS in the city	20	70	10
	SDS / element concentration in snow at the sampling site	60	30	10

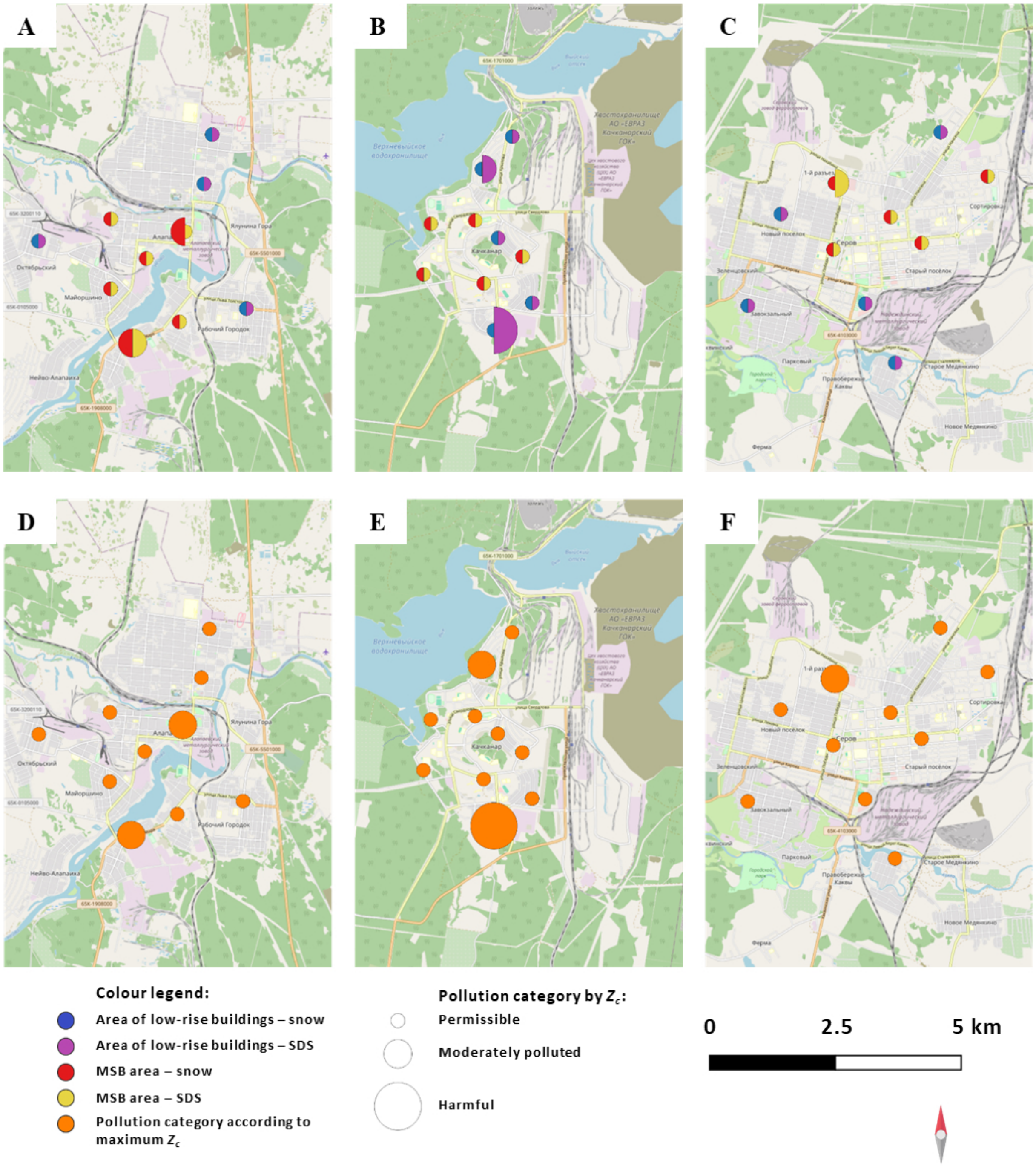

Fig. 4. Categories of pollution of snow and snow-dirt sludge by Z_c at sites (**A** –Alapaevsk, **B** – Kachkanar, **C** – Serov) and categories of site pollution by the maximum Z_c value chosen between Z_c in snow and snow-dirt sludge (**D** – Alapaevsk, **E** – Kachkanar, **F** – Serov).

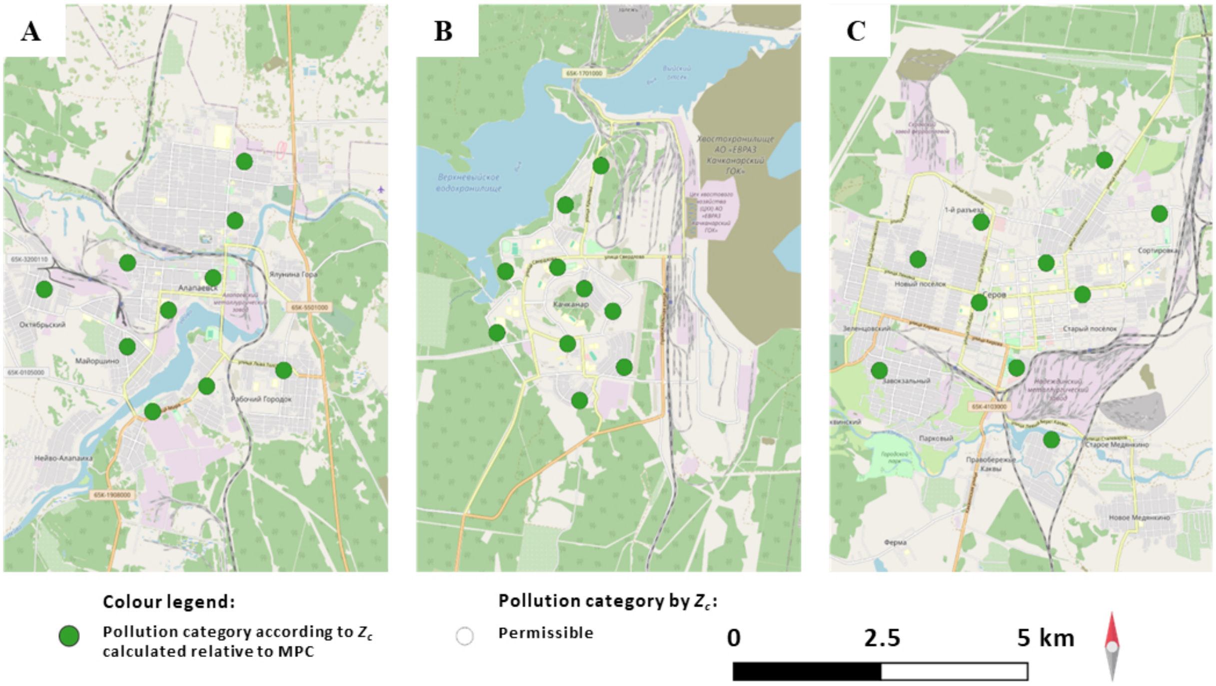

Fig. 5. Distribution of Z_c in snow and snow-dirt sludge calculated relatively to MPC: **A** – Alapaevsk, **B** – Kachkanar, **C** – Serov.

The selection of the reference background concentration for a particular area is determined by local features of its development, a complex of processes of anthropogenic geochemical alteration, geological conditions, wind rose and natural climatic conditions. The SDS represents a heterogeneous, anthropogenically modified object, a deposition medium. The undisturbed snow is a "natural accumulating object" that accumulates pollution from the atmosphere layer by layer during the cold season. Therefore, from the point of view of linking the background object with the characteristics of the territory and taking into account emissions from stationary and non-point sources of pollution, the most relevant approach will be to use the snow at the same sampling site as a reference background object for the SDS at the site (Fig. 6).

Conclusion

The study developed an approach to assess the environmental state of a city based on SDS composition data. When determining the degree of SDS pollution in the city, snow at the sampling site should be used as the reference background sample. The concentrations of pollutants in the reference background object reflect the current environmental and geochemical state of the city. The pollution assessments of urban areas obtained will make it possible to characterize the processes of geochemical transformation of the environment occurring in cities. This method is the most convenient and provides information on local migration and accumulation processes of pollution of both natural and anthropogenic origins occurring in the studied area. The SDS represents an independent geoindicator object. This is the first application of SDS in urban geochemical studies.

Independent monitoring of the state of the environment in low-rise urban areas makes it possible to identify areas of pollution and plan measures to reduce human impact. The data obtained significantly complements and details the pattern of pollutant migration and accumulation in the urban environment. The results of the study may be used by the companies conducting environmental monitoring, environmental services, management and maintenance, control authorities, and the Ministry of Emergency Situations during the elimination of the consequences of accidents and emergency situations in small cities with industrial facilities.

Fig. 6. Z_c distribution for snow-dirt sludge taking into account as a reference background the minimal pollutant concentration in snow samples for each city (**A** – Alapaevsk, **B** – Kachkanar, **C** – Serov) and concentrations in snow at the same site (**D** – Alapaevsk, **E**– Kachkanar, **F** – Serov).

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