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Assessment of trace elements pollution in snow piles removed from residential areas in Perm, Russia

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Abstract: Atmospheric deposition, vehicular transportation and de-icing agents are major sources polluted snow in urban. This study investigates the current trace elements concentrations of snow and de-icing using ICP-MS, and phytotoxicity using three vascular plants in snow. The study assesses the contamination, classification and phytotoxicity of snow quality removed from roads of residential areas and piled on children's playgrounds in residential territories. The research found that according to Russian environmental quality standard for water has been identified the exceeding trace elements in snow by W, Se, Mn, Cu, V, Mo, Ni and Zn. The pollution indices (*PLI, CF* and *Zc)* were identified pollution level of snow piles from moderate contamination to very high contamination. Based on average germination index values for *Sinapis alba* L., *Lepidium sativum* L., and *Triticum aestivum* L., the degree of inhibition in snow piles varied from no inhibition to strong inhibition. The trace elements content in de-icing "Galit A" and salt sand mix are defined in the following descending order: Zn > Mn > Ba > V > Rb > Sr and Mn > Ba > Cr > V > Sr > Ni, respectively. High concentrations of trace elements in snow piles are a source of environmental pollution. To prevent snow storage and disposal in residential areas should be involved in future studies of environmental pollution and circular economy, so that environmental managers can reduce threats to the environment and public health, as well as initiate circular economy projects in urban areas.

Keywords: contamination level, de-icing agents, phytotoxicity, pollution sources, snow quality

INTRODUCTION

In winter, roads, pavements, and adjacent areas maintenance to ensure practicability and safety involves snow removal by means of various de-icing agents. Two main ways are used globally for de-icing: mechanical way (sand, crushed stone, rock crumbs) to increase friction, and chemical way (reagents containing Na, K, Mg salts with various additives) [Gerasimov, Chugunova 2015; Xu *et al.* 2021]. In Canada only, about 5000.00 Gg of road salt are used annually in China – 600.00 Gg in year, in Sweden –150.00 Gg in year [Antonson *et al.* 2021; Rødland *et al.* 2020]. There are other known innovative methods that are less commonly applied due to their high cost: construction of roads with solar panels (USA), thermal water pipes under urban streets (Iceland), "heated sand" technology (Scandinavian countries), electric roadbed heating technology – "underfloor heating effect" (China), etc. [Lai *et al.* 2015].

In northern Swedish cities, roadside snow piles during the winter period had the following concentrations (in $\mu g \cdot dm^{-3}$): Cd = 0.43, Cu = 303, Pb = 41.9, Zn = 817 (in Luleå); Cd = 1.87, Cu = 905, Pb = 165, Zn = 3150 (in Umeå) [Vijayvan *et al.* 2019]. Snow collected from the Stockholm port area into the snow piles showed critical concentrations of Zn when compared to stormwater standards (average concentration measured in snow pile samples was 84 $\mu g \cdot dm^{-3}$ while the allowable standard value was 30 $\mu g \cdot dm^{-3}$ [Vijayvan *et al.* 2021].

In Russian cities, excessive use of de-icing agents on pavements and pedestrian paths, as well as storage of contaminated snow from roadways and residential parking lots on lawns, has been widespread in recent years [Gerasimov, Chugunova 2015; Malysheva *et al.* 2018]. In Perm, snow and soil cover of roadside lawns and squares contain significant concentrations of Ni, As, Zn, Cu, Co, Pb, W, Cr, and Sb [Voronchikhina *et al.* 2014]. At the same time, none of the studies have considered urban snow dumps collected from adjacent territories as a potential contamination source for playgrounds. Due to snowmelt, soils accumulate pollutants contained in snow piles. The soils of Perm snow piles after snow melt are noted by increased concentrations of Cu, Zn, Pb, Cd, and Hg, and some sites have demonstrated exceedances of these heavy metals relative to Russian standards [Shishkin, Lapteva 2009].

Waste management issues and circular economy in Russia are actively developing at the moment [Fedotkina *et al.* 2019]. The disposal of snow piles in residential areas, contamination of the environment with trace elements is considered one of the main environmental risks [Smol *et al.* 2020]. In this area, the circular economy may be associated to reduce trace elements pollution in soil, groundwater, and surface water. High concentrations (in mg·kg^{-1}) of As up to 9.11, Ni up to 70.02, Cu up to 48.78, Cd up to 0.83, Pb up to 23.39, and Zn up to 143.71 were found in soils after melting snow piles at playgrounds in residential area of Perm [Ushakova *et al.* 2022]. This fact allows us to consider snow piles as potential sources of trace elements in the soils of children's playgrounds, as well as the surrounding area. The greatest danger to human health and life, especially for children, is posed by excessive concentrations of heavy metals in the environment, which can enter the human body through the respiratory and digestive tracts or through the skin [Dixit *et al.* 2015; Zgłobicki *et al.* 2020]. Trace element levels in snow piles collected from road are formed as a result of road treatment with de-icing agents and the influence of vehicular transportation. Therefore, snow piles should be considered as the sources environmental pollution. The aim of this study was: (i) to assess the geochemical impact of contaminated snow stored on children's playgrounds of home territories, and to substantiate the need for a more detailed study of the organisation of removal and disposal of snow masses from home territories; (ii) to reveal the main sources of trace elements in the snow cover of adjacent territories; (iii) to assess the contamination of snow piles; (iv) to evaluate the phytotoxicity of heavy metal in snow using the three vascular plants: *Triticum aestivum* L., *Sinapis alba* L., and *Lepidium sativum* L.

STUDY MATERIALS AND METHODS

STUDY AREA

According to the municipal contract in the winter period of 2018/2019 on the territory of the Industrialny City District (Rus. Industriál'nyy rayon) of Perm, contractors used the following de-icing agents: sand and salt mixture, "Galit A" and crushed marble, among which the preference was given to the "Galit A". The use of sand and salt mixture is most effective at low temperatures (below −30°C). According to the official data of Perm city administration, in December 2019 in the Industrialny City District of Perm, 47 Mg of de-icing agents were used over the weekend alone due to intensive snowfall and subsequent glaze. Taking into account the length of roads in Perm, 20.00 Gg of de-icing agents are used annually [Voronchikhina *et al.* 2014].

The authors analysed the content of snow piles in adjacent territories, formed from the snow that was removed from the roadway and pavements and stored on the lawns and playgrounds of the Industrialny City District of Perm (Fig. 1).

The samples were collected at 10 points (T1–T10) in residential area (Fig. 1). Three samples of snow (T11–T13) were collected as conditional background samples in forest-park zones, distant from the local influence of large industrial enterprises and highways. The background concentrations of elements were obtained by averaging the concentrations of elements in three background points within the study area. Based on own procedure the contaminated snow was sampled layer-by-layer on the cleared wall of the snow pile all the way down at the point of its maximum thickness. Snow samples were taken with a plastic scoop, placed in plastic buckets, the average weight of field samples were 3 kg. The sampling was conducted at the end of the season of stable snow cover before snowmelt (last decade of March 2019).

GEOCHEMICAL ANALYSIS AND CONTAMINATION LEVELS

The snow samples were melted at room temperature. Subsequently, the snow meltwater was filtered through ash-less "blue ribbon" filters (2–3 μm pore size) to separate the dissolved phase and the solid phase. All samples were analysed at the "Centre for Collective Use of Unique Scientific Equipment of Perm State National Research University" (Rus. Centr kollektivnogo pol'zovaniya Permskogo gosudarstvennogo nacional'nogo issledovatel'skogo universiteta). The content of trace elements (Li, Be, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Rb, Sr, Zr, Mo, Cd, Sn, Sb, Cs, Ba, W, Tl, Pb, and Bi) in the snowmelt samples after filtering was determined by mass spectrometry using Bruker Aurora M90 (ICP-MS) instrument. Depending on the concentration of chemical elements, typical measurement errors (relative standard deviation – *RSD*) are in the following ranges: <0.001 μg·dm^{-3} – *RSD* 15–10%; 0.001–0.1 μg·dm^{-3} – *RSD* 10–5%; 0.1–1.0 μg·dm^{-3} – *RSD* 5–3%; >1 μg·dm^{-3} – *RSD* 3%. Meltwater acidity (pH) was determined by potentiometric method.

Taking into account the fact that snow meltwater is involved in recharging of surface water bodies, element concentrations in snow meltwater were compared with average global concentrations of dissolved trace elements in river water and with Russian maximum acceptable concentrations of hazardous substances in waters of water bodies of fishery importance (MAC_f) [Gordeev, Lisitzin 2014].

Evaluation of trace element composition of snow was conducted using the contamination factor (*CF*) (which allowed us to evaluate the pollution of environmental objects for a single element, taking into account its background value), pollution load index (*PLI*), and the total pollution index *Zc*.

The pollution load index (*PLI*) is calculated based on the potential contribution of all elements using the contamination factor (*CF*) values, following the Equation (1):

$$PLI = \sqrt[n]{(CF1 \cdot CF2 \cdot CF3 \cdot \ldots \cdot CFn)} \tag{1}$$

where: n = the number of studied elements.

The following gradation was used for the pollution load index identification: $PLI < 1$ indicated no pollution, $PLI = 1$ indicated baseline level of pollution, $PLI > 1$ indicated deterioration of site quality [Tomlinson *et al.* 1980].

The value of *CF* was calculated from the Equation (2) [Hakanson 1980]:

Fig. 1. Location map of snow sampling points T1–T13 (57°58'32" N; 56°11'44" E); source: own elaboration

$$CF = \frac{C_S}{C_B} \quad (2)$$

where: C_S = a heavy metal concentration in the analysed sample and C_B = the geochemical background concentration of an element in snow meltwater.

The interpretation of results of trace element composition analysis of dissolved phase of snow meltwater (excluding the solid phase of snow) was conducted using the *CF* evaluation results that were classified as follows: $CF < 1$ indicated low contamination, $1 \le CF < 3$ – moderate contamination, $3 \le CF < 6$ – considerable contamination, and $CF \ge 6$ – very high contamination.

The total geochemical load was evaluated based on the total pollution index *Zc* of snow piles [SAET *et al.* 1990], following the Equation (3):

$$Zc = \sum K_c - (n - 1) \quad (3)$$

where: K_c = the ratio of heavy metal concentration (C_S) to its background value (C_B) in the snow sample, n = the number of chemical elements with $K_c > 1.5$.

According to SAET *et al.* [1990], we used five contamination categories to identify the level of trace element contamination: $Zc < 32$ – low contamination, $32 \le Zc < 64$ – moderate contamination, $64 \le Zc < 128$ – high contamination, $128 < Zc \le 256$ – very high contamination, $Zc > 256$ – extremely contamination.

The effect of snowmelt phytotoxicity on seed germination, root length and germination index was estimated for three vascular plants (wheat *Triticum aestivum* L., mustard *Sinapis alba* L., and garden cress *Lepidium sativum* L.). Researches show that the amount of different seeds in phytotoxicity generally varies from 10 to 30 and mostly in triplicate [BARAN, TARNAWSKI 2013; BOŻYM *et al.* 2021; LAMHAMDI *et al.* 2011; MAÑAS, DE LAS HERAS 2018]. In this study, twenty seeds of each plant variety in three replicates were placed at an equal distance from each other in the middle of the test plate (Fig. 2). The phytotoxicity test results were based on the 4-day measurements (at 25 ±1°C) of delay or absence of seed germination and root growth of selected higher plants species exposed to pollutants in the snow dumps (compared to the control samples, germinated in distilled water). Seeds were considered germinated when the root and shoot lengths were more than 1 mm.

The number of germinated seeds and root length were considered as measurement parameters. Relative seed germination (*RSG*), relative root growth (*RRG*) compared to control (distilled water), and germination index (*GI*) were calculated

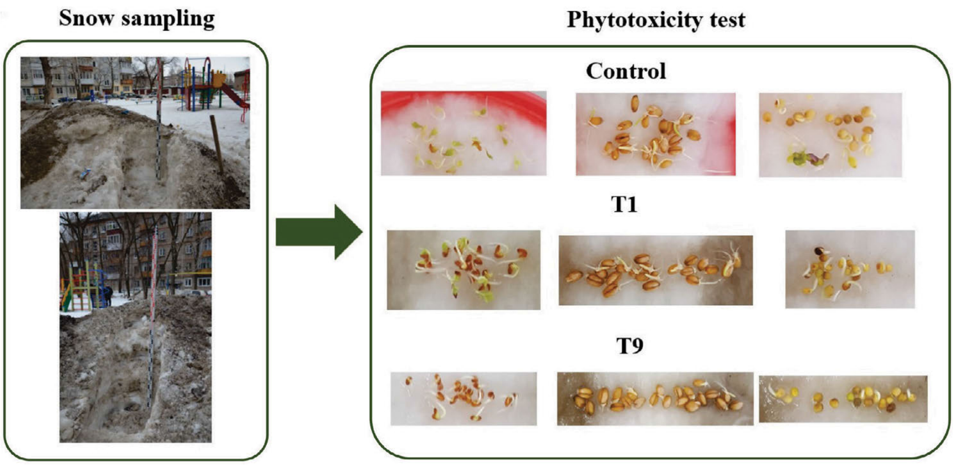

Fig. 2. Test trial under the laboratory conditions; source: own elaboration

according to the Equations (4–6) [MIAOMIAO *et al.* 2009; PAMPURO *et al.* 2017]:

$$RSG(\%) = \frac{number\ of\ seeds\ germinated\ in\ sample\ extract}{number\ of\ seeds\ germinated\ in\ control} 100 \quad (4)$$

$$RRG(\%) = \frac{root\ length\ in\ sample\ extract}{root\ length\ in\ control} 100 \quad (5)$$

$$GI(\%) = \frac{RSG \cdot RRG}{100}\ 100 \quad (6)$$

Based on the germination index value, phytotoxicity can be classified as follows: 90% > *GI* > 110% – "no effect/non-toxic", *GI* ≤ 90% – inhibition, *GI* ≥ 110% – stimulation [CZERNIAWSKA-KUSZA, KUSZA 2011]. According to the literature data [PINHO *et al.* 2017], the degree of inhibition can be classified as follows: *GI* ≥ 80%: no inhibition; 60% ≤ *GI* < 80%: mild inhibition; 40% ≤ *GI* < 60%: strong inhibition; *GI* < 40%: severe inhibition.

RESULTS AND DISCUSSION

CONCENTRATIONS OF TRACE ELEMENTS IN SNOW

Statistical data on the content of trace elements in snow piles collected from the adjacent territory and placed on children's playgrounds are presented in Table 1. In general, all measured trace elements significantly varied in concentrations from <0.01 μg·dm^{-3} (Ag) to 332.25 μg·dm^{-3} (Sr), with standard deviation of 0.01 and 78.78 μg·dm^{-3}, respectively. The pH value of snow meltwater at the background sites varied from 5.3 to 7.3 with an average value of 6.5. Snow meltwater within the area of high-rise buildings had neutral and slightly alkaline reaction ranging from 7.18 to 7.90 with an average value of 7.57. The alkalization is caused by the influence of de-icing agents, motor transport operation, and carbonate dust typical for urban development.

Taking into account the fact that meltwater is involved in recharging of surface waters, geochemical background features of the territory was evaluated based on comparing average values of trace element content in snow piles and snow cover of the background areas with average global concentrations of dissolved

Table 1. Summarised data on the concentrations of trace elements in samples of snow piles at playgrounds in the Industrialny City District of Perm

Element	Min.	Max.	Mean	*SD*	*CV* (%)	Back-ground	MAC_f
	μg·dm^{-3}						
Li	1.42	3.27	2.27	0.62	28	1.21	80
Be	0.28	0.30	0.30	0.01	2	0.29	0.3
V	0.33	5.36	1.79	1.36	76	1.54	1
Cr	4.99	7.64	6.24	0.83	13	5.14	20
Mn	2.77	115.80	30.22	37.17	127	6.39	10
Co	1.55	2.21	1.89	0.20	11	1.85	10
Ni	4.11	19.67	10.15	4.06	40	8.46	10
Cu	4.21	8.57	6.10	1.65	27	4.86	1
Zn	3.40	17.35	7.28	3.99	55	8.51	10
Ga	0.30	0.42	0.37	0.03	8	0.31	–
Ge	0.70	0.92	0.79	0.08	10	0.75	–
As	0.94	3.44	1.83	0.87	48	1.09	50
Se	0.34	37.23	10.03	10.68	107	4.34	2
Rb	1.16	3.97	2.34	0.96	41	1.10	100
Sr	77.84	332.25	161.41	78.78	49	46.65	400
Zr	0.02	0.13	0.06	0.04	63	0.05	70
Mo	0.69	3.51	1.59	0.93	58	1.05	1
Ag	< 0.01	0.02	0.01	0.01	30	0.01	–
Cd	0.11	0.29	0.2	0.05	24	0.24	5
Sn	1.2	42.68	16.45	10.80	66	12.95	112
Sb	0.18	1.55	0.64	0.42	65	0.33	–
Cs	0.08	0.20	0.13	0.03	24	0.11	1000
Ba	13.04	50.74	32.71	13.22	40	7.06	740
W	0.07	6.79	3.81	2.14	56	0.36	0.08
Pb	0.09	0.18	0.14	0.02	18	0.15	6
Number of samples	10					3	–

Explanations: *CV* = coefficient of variation, *SD* = standard deviation, MAC_f = Russian maximum acceptable concentrations of hazardous substances in waters of water bodies of fishery importance.
Source: own study.

trace elements in river waters [GORDEEV, LISITZIN 2014]. The mean values of elements at T1–T10 and conditionally background concentrations T11–T13 of most of the studied elements in snow meltwater from playground areas (Tab. 1) are significantly higher than mean global concentrations of dissolved trace elements in river waters. Thus, the W content exceeds average global concentrations by 127 times, Ni – by 20 times, Sn – by 41 times, Cd – by 10 times, and Co – by 10 times (Fig. 3). At the same time, background concentrations have similar distribution of elements exceeding average global concentrations of dissolved trace elements in river water as those from the territory of children's playgrounds, where an excess of the following elements was recorded: Sn (32 times), Ni (16 times), W (12 times), Cd (10 times).

ECOLOGICAL RISK ASSESSMENT OF THE TRACE ELEMENTS IN SNOWMELT

In snow meltwater of playground areas, we found that W exceeded fishery standards up to 84.9 times, Se – up to 18.6 times, Mn – up to 11.6 times, Cu – up to 8.6 times, V – up to 5.4 times, Mo – up to 3.5 times, Ni – up to 1.9 times, Zn – up to 1.7 times. In Sweden, snow meltwater is considered wastewater which has certain quality standards [VIJAYVAN *et al.* 2019]. Thus, in Swedish stormwater quality guidelines, the following concentrations are recommended: Cd – 0.45 μg·dm^{-3}, Cu – 30 μg·dm^{-3}, Ni – 20 μg·dm^{-3}, Pb – 10 μg·dm^{-3}, Zn – 90 μg·dm^{-3} [ALM *et al.* 2010]. Comparison of the studied meltwater with stormwater quality standards showed no exceedances.

The calculated *PLI* values ranged from 2.5 to 6.3. According to collective results of the elements concentration analysis, the snow meltwater was highly contaminated at the sampling point T9 (Tab. 2). The highest *CF* values were noted for W and Mn. Snow piles at sampling points T9 and T8 were identified as highly contaminated. At the same time, all sampling points, except for T5, were characterised as highly contaminated based on the *CF*. Average concentration values of W, Mn, Ba, Sr at the polluted snow locations significantly exceeded their conditionally background concentrations. At the same time, a very high level of contamination by Se is noted only at the sampling point T3.

According to the total pollution index *Zc*, the studied sites had low and medium levels of pollution. The strongest

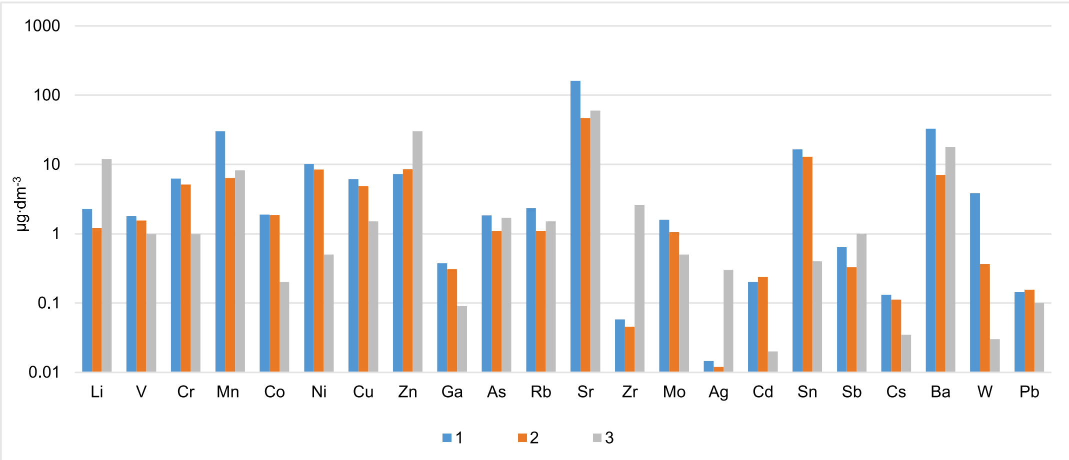

Fig. 3. Concentrations of trace elements in the dissolved phase of snow piles meltwater: *1* = average values in snow piles, *2* = background concentrations, *3* = global average concentrations of dissolved trace elements in river water; source: own study

Table 2. Trace element pollution levels of snow piles (T1–T10) on playgrounds in the Industrialny City District of Perm

No.	Height of snow piles (m)	Contamination factor (*CF*)			*PLI*	*Zc*
		CF ≥ 6	3 ≤ *CF* < 6	1 ≤ *CF* < 3		
T1	0.91	–	W_6	Sb–Ba–Sr–Li	2.9	9.0
T2	1.40	W_{11}–Mn_8–Ba_6	Sr_4	Rb–Sb–Se–Li–Mo–As	4.5	32.8
T3	1.41	W_{11}–Se_9–Ba_7	Sr_4–$(Sn–Rb)_3$	Ni–Li–Zn–Cs–Cu–V–Cr–Mo	3.4	37.7
T4	1.05	W_6	Ba_4	Se–Sr–Sb	4.9	14.1
T5	1.10	–	–	Ba–Sr	4.5	3.9
T6	1.70	W_{16}–Mn_{10}	Sb_5–$(Ba–V)_4$	Zr–Rb–Sr–Li–Se–Cu–Sn–Mo	2.5	44.2
T7	1.11	W_9	–	Ba–Sb–Se–Mn–Sr–Rb	3.1	16.1
T8	1.25	W_{19}– Ba_7–Mn_6	Sr_5–Mo_3–As_3	Rb–Li–Se–Cu–Ni	5.7	43.0
T9	1.09	$(W–Mn)_{18}$– Sr_7	Ba_5–Rb_4–As_3	Li–Mo–Zr–Cu–Sn	6.3	56.6
T10	1.58	W_9–Ba_6	Sr_4	Sb–Li–Rb–As	5.7	20.1

Source: own study.

pollution was noted at T3 (56.6), which corresponded with a moderate level of pollution. Sampling points T2, T3, T8 and T6 also fell into the category of moderate pollution level.

SNOW PHYTOTOXICITY

Two dicotyledons (*Sinapis alba* L. and *Lepidium sativum*) and one monocotyledon (*Triticum aestivum* L.) showed significant variation in *GI* values relative to controls after being exposed to pollutants present in snowmelt (Fig. 4). These values in snowmelt ranged from 40 to 126% for *L. sativum*, 23 to 204% for *S. alba*, and 23 to 119% for *T. aestivum*. The latest plant showed the highest sensitivity to contaminants, as 90% of analysed samples caused growth inhibition for this plant. Growth inhibition was also observed in more than 60% of the tested samples of *S. alba*. and *L. sativum* showed a varied response to pollutants: *GI* values greater than 110% (stimulation) were found in 38% of the snowmelt samples, and *GI* values between 90 and 110% (no effect) and less than 90% (inhibition) were found in 31% of the samples.

Significant inhibitory effect was found at T3, T1, and T8 with average *GI* values of 41%, 56%, and 59%, respectively. Stimulating effect was observed at T9 and T5 with average values of 123% and 130%, respectively. The most pronounced root growth in *L. sativum*, being 158% higher than the control, was observed in snow water at T9. An even higher positive effect on plant development (234% higher than the control) was observed in *S. alba* at the sampling point T5. At the same time, background sampling points T11–T13 in park areas were characterised by slight inhibitory effect with average *GI* values ranging from 64 to 86%.

The phytotoxicity test results corresponded with the chemical data, *GI* values showed a variety of effects in snow meltwater that ranged from growth inhibition to growth stimulation. Based on average *GI* values for the three test objects, the degree of inhibition in snow meltwater ranged from no inhibition to strong inhibition. Test sites T3, T1, and T8 are characterised by strong inhibition, and T6 and T2 – by mild inhibition. At the same time, exposure to snow meltwater showed opposite results for *L. sativum* and *T. aestivum*. Studies of Arif *et al.* [2016] and of Ciesielczuk *et al.* [2017] indicate adverse effects on root growth under different conditions depending on element concentrations. Since elements with similar physico-chemical properties can substitute each other in enzymatic pathways and receptor proteins, they compete for absorption, transport, and accumulation [Czerniawska-Kusza, Kusza 2011]. This study revealed that highest concentrations studied trace elements in snow piles for most elements (W, Mn, Ba, Sr, Se) levels were belonged to very high contamination (*CF* < 1) and for Sb and V was significant (3 ≤ *CF* < 6). According to Adamakis *et al.* [2012] confirm the toxic properties of W in plants, as they showed a number of effects at morphological, cytological and gene levels. Therefore, W should be considered as any heavy metal having a wide range of effects on plants. In combination with elevated concentrations of Mn, Cu, Ni, Mo Cr, etc., a stimulating or inhibitory effect on plant seedlings or roots can be observed [Arif *et al.* 2016; Singh *et al.* 2016; Yadav 2010].

Accumulation of trace elements from contaminated snow in urban soils in alkaline environment is characteristic of cationic elements (Zn, Cu, Ni, Sn, Mn). This result is in agreement with works by Menshikova and Zhdakaev [2017], and Khayrulina [2019] show that soils in longstanding urban residential development areas in Perm Krai contain elevated concentrations of Zn, Cu, Hg, Cd, As.

Anionic elements in contaminated snow (Mo, W, Se, V, Sb), in accordance with their geochemical features, migrate in an alkaline environment and affect the composition of surface water and groundwater, as well as bottom sediments of water bodies, where they may accumulate in case of decreased pH. Cationic elements Sr, Li, Ba, Rb also migrate with the aqueous medium. Thus, chloride ion in snow meltwater can also contribute to leaching of heavy metals adsorbed by soil particles [Reinosdotter, Viklander 2005].

ENVIRONMENTAL IMPLICATIONS

In Perm, about 30 Gg of sand-salt mix and 8 Gg of technical salt (“Galit A” mineral concentrate) were used during the winter season of 2018/2019. According to data provided by the administration of the Industrialny City District of Perm, during

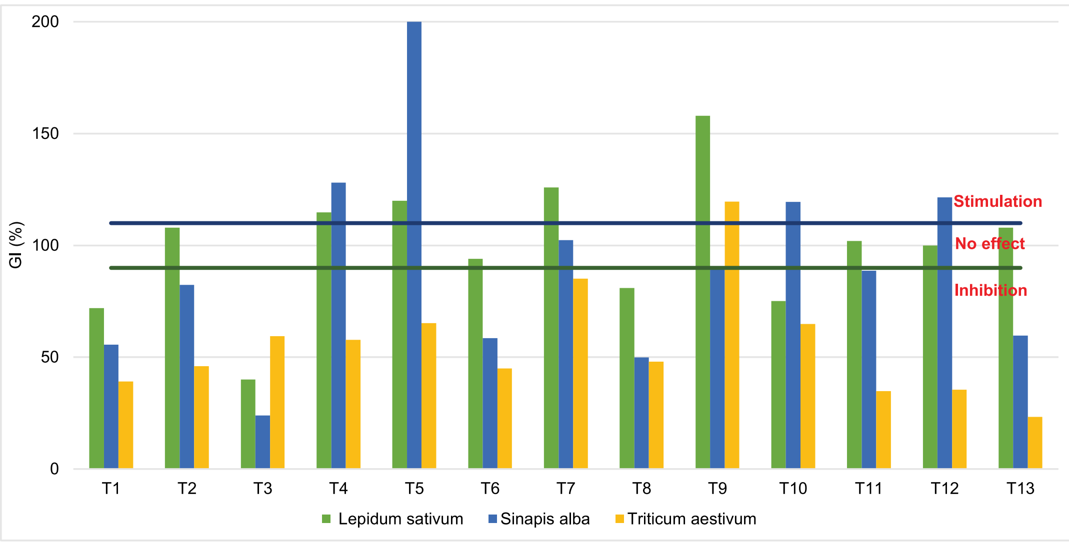

Fig. 4. Germination index values (*GI*, % of control) and effects of plant reaction in snowmelt; source: own study

heavy snowfall over the weekend in December 2019, 1880 m^3 of snow were removed from the district and 47 Mg of de-icing materials were used on dangerous road sections: descents, ascents, intersections, dangerous road turns, roads with the heaviest traffic, and pavements with a total area of 1.2 mln km^2. According to the quality certificate, the "Galit A" mineral concentrate contains up to 97% of sodium chloride; the remaining components are calcium ion, magnesium ion, sulphate ion, potassium ion, iron oxide, trace elements and water-insoluble sediment. The sand-salt mixture contains 75% of river sand and 25% of technical salt. The results of trace element analysis show significant concentrations of Co, Zr, Cr, Ba, Cu, Mn, Ni in the sand-salt mixture relative to "Galit A" (Fig. 5).

In order to minimise the impact of snow dumps on the soil and water environment and river systems, the implementation of stationary and mobile snow melting facilities is necessary. Snow removal to specialised landfills entails expensive transportation due to their remoteness from the city; it additionally increases the level of pollutant emissions from mobile sources. Currently, only Moscow has a sufficient network of stationary snow melting facilities (49 in total). In St. Petersburg, 11 stationary and 7 mobile snow melting facilities are in operation.

In Russian cities, management companies are responsible for the quality of winter cleaning of adjacent territories of high-rise residential buildings. Temporary placement of fresh snow in piles and heaps is allowed on all streets, squares, embankments, boulevards and garden squares on condition of its subsequent removal to specialised landfills or disposal sites, specified by regulatory documents. However, temporary storage of snow heaps in open territories is often long-term, taking the whole winter period until the onset of spring snowmelt, due to high cost of transportation of snow to specialised landfills.

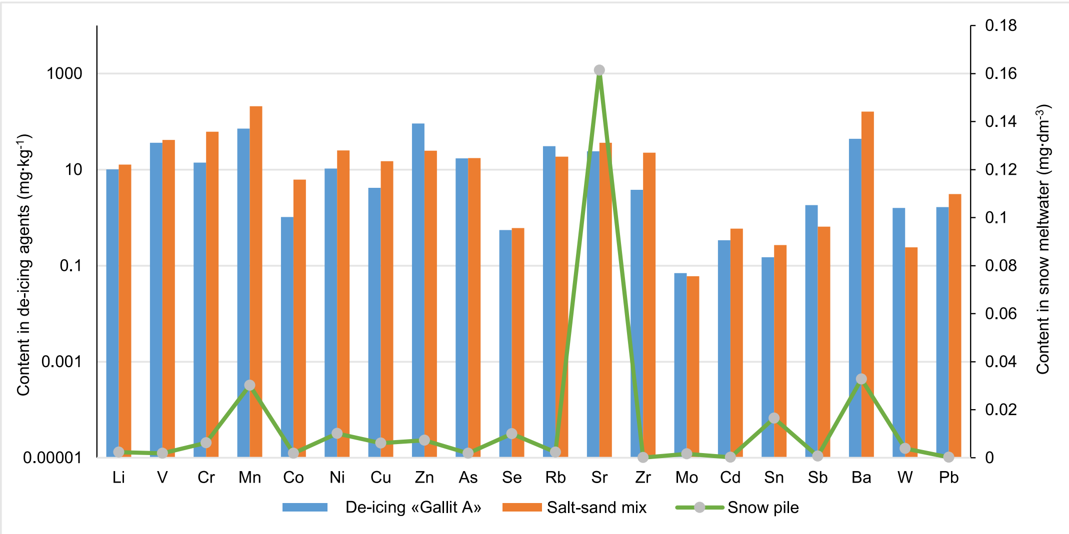

Fig. 5. Analysis of de-icing agent concentrations and average values of snow piles; source: own study

The concentrations of de-icing agents show significant excesses relative to the snow piles collected from the adjacent territory and placed on playgrounds. In the study area, a source of W, Mn, Ba, Sr, Se, Sb, and V (element concentrations exceeding background values) is the snow that comes off of mudflaps and other car parts in parking spaces within adjacent territories. Distribution of elements from the snow is associated with the use of de-icing agents on highways, pavements, and adjacent territories which adds to motor transport emissions and input of metals from the wear and tear of mechanical parts of cars. Thus, the source of Al, Zn, Ca, Cd, Co, Cu, Mn, Pb, W in the snow cover within the roadways is tires (including winter tires); Cd, Cu, Ni, Pb, Sb, Zn, Ba, Fe, Mo – brake mechanisms; Cr, Ni, Fe, Zn – engine and body wear; Pb – vehicle body paint; Cu, Ag, Ba, Cd, Cr, Co, Mo, Ni, V, Sb, Sr, Zn – engine emissions (including diesel); Al, Fe, Pb, Si, Sr, Ti can be found in the road surface (asphalt, bitumen) [Adamiec *et al.* 2013; Meland 2010; Müller *et al.* 2020].

Research results (Bäckström *et al.* [2004], Nelson *et al.* [2009]) show strong correlation between heavy metal mobilisation and de-icing. The mobilisation occurs during the winter period, which is contrary to most natural systems in boreal regions. Thus, heavy metal mobilisation was driven by salt content. Sodium chloride caused the greatest efflux of Cu, Zn and Pb. Magnesium salt had a greater effect on cadmium mobilisation.

Taking into account the long period of negative temperatures from October to March, with an average amount of precipitation of 263 mm for the whole winter period in Perm [Weather Atlas undated], it is necessary to consider using stationary and mobile snow melting facilities in city districts which should be strictly defined and equipped as recommended in foreign snow disposal guidance [Government of Ontario 2011].

Disposal of contaminated snow from adjacent territories to and within children's playgrounds is a gross violation of the Federal Law of the Russian Federation "On Production and Consumption Waste" [Rossiyskaya Federatsiya. Federal'nyy zakon… N 89-FZ] and other regulations for which liability is stipulated: from criminal liability to imposition of administrative fines.

CONCLUSIONS

The malpractice of removing polluted snow from roadways of adjacent territories onto lawns and playgrounds leads to the entry of significant concentrations of W, Mn, Ba, Sr, Se, Sb, and V (relative to background concentrations) into the environment of residential areas. Concentrations of W, Se, Mn, Cu, V, Mo, Ni, Zn in snow dumps significantly exceed the fishery standards for water. During snowmelt, meltwater is a potential pollutant of water and soil systems. The elemental composition of snow piles is due to the influence of operation of motor vehicle and winter road maintenance operations. At the same time, trace element analysis of de-icing agents shows considerable variations depending on their brand. Thus, the concentrations in the sand-salt mixture for Co – 6 times, Ba – 4 times, Mn – 3 times relative to the brand "Galit A". In "Galit A", however, the only significant concentration we found was that of Zn, exceeding the concentration in the sand-salt mixture by 4 times.

Placement of contaminated snow within adjacent territories enhances adverse effects and leads to negative environmental consequences: contamination of soils and natural waters, which inevitably affects public health. Development of strict regulations for residential areas on the use of de-icing agents and mandatory removal of contaminated snow from the roadway of adjacent territories to specialised landfills or stationary points for the disposal of snow serve as an effective solution for the aforementioned problems.

Review of the official websites of the subjects of the Russian Federation shows that there are currently two main types of violations in the use of de-icing agents in large cities: excessive use of those on pavements and pedestrian paths and storage of contaminated snow on lawns. An obvious way to normalise the situation is to strengthen the administrative control of management companies regarding the mandatory removal of contaminated snow from adjacent territories. Currently, helplines are available for citizens in almost all major cities. The construction of modern stationary and mobile snow removal facilities will also support the normalisation of the environmental conditions in cities.

When monitoring snow in urban areas, we recommend not to be limited to the standard list of heavy metals and arsenic, since the elemental load is caused by the influence of de-icing agents and the operation of motor vehicle and contains a wide range of different pollutants, whose toxicity can be demonstrated by bioindication methods.

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