

SNOW COVER AND GLACIERS

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SOIL CHEMISTRY DYNAMICS AT SNOW DISPOSAL SITES
IN YUZHNO-SAKHALINSK

V.A. Lobkina, A.A. Muzychenko, M.V. Mikhalev

*Far East Geological Institute, FEB RAS, Sakhalin Department,
25, Gorkogo str., Yuzhno-Sakhalinsk, 693000, Russia; valentina-lobkina@yandex.ru*

Soil chemistry dynamics at snow disposal sites in Yuzhno-Sakhalinsk has been monitored since 2013 to evaluate the contents of elements and physicochemical properties of soils. The measured element contents were compared with the respective approximate permissible concentrations for soils and background values. Four soil samples collected in 2013 at snow disposal site 2 in the southern part of Yuzhno-Sakhalinsk city contained abnormal concentrations of Ni, As, V, Cu, and Zn. More data were obtained from seventeen other soil samples taken in 2017: eleven samples at site 1 (northern part of the city), five samples at site 2, and one reference sample. The concentrations of chlorine, sulfate, sodium, and calcium ions exceeded the background values: Cl^- in eleven samples, SO_4^{2-} in nine samples, Na^+ in fifteen samples, and Ca^{2+} in fourteen samples. The concentrations of heavy metals (Pb, Zn, and Ni) analyzed in three samples were above the background (Pb) and the approximate permissible values (Zn and Ni). Soils sampled in 2018 contained Zn, Ni, Pb, As, and Cu exceeding the approximate permissible concentrations. The results of soil analysis demonstrate that soils at snow disposal sites and in their vicinities in urban areas can accumulate toxic chemicals and pose environment risks.

Geoenvironment, soil pollution, snow disposal site, artificial snow patch, Yuzhno-Sakhalinsk, Sakhalin

INTRODUCTION

Snow removed from streets in urban areas and stockpiled at disposal sites can form large snow bodies of mixed natural-anthropogenic origin. The actual Russian federal law lacks special regulations to control the negative effects of snow disposal on the environment. There is no special concept of an anthropogenic snow patch in the Russian scientific literature, though it is largely used in mass media. All issues concerning snow removal, storage, and disposal are a matter of urban development and are regulated at the municipal level [*Federal Law, 2018*].

The gap in the federal legislation for snow disposal management and mitigation of its negative environment impacts mainly results from the lack of data on these impacts. Unlike the natural snow patches, the snow removed from urban areas can be impacted by salts or other snow and ice control chemicals and airborne pollutants from vehicle exhaust, heat power production, etc. [*Tentyukov, 2007*]. The removed snow entrains sand, litter, and debris that are deposited on the ground or carried away with the meltwater as the snow melts. Thus snow melting leads to contamination of soils under disposal sites and in their vicinities and poses environment risks.

We study the impact of snow storage and disposal on the chemistry of soils at two sites in the northern and southern parts of Yuzhno-Sakhalinsk (Fig. 1). The two sites (18.6 Ha in 2017) can accom-

modate more than $1.5 \cdot 10^6 \text{ m}^3$ of snow for a winter season, which is a volume equivalent of the largest water reservoir in southern Sakhalin Island.

The snow stockpiled at disposal sites can stay there for four months after the end of the cleaning season (mid-April) till the following snow removal period. The long-term storage of snow at the northern site has produced perennially frozen soil (artificial permafrost) covered with a 3–5 m thick layer of sand, ground, and litter.

The study has several objectives: evaluating soil contamination from snow patches at the disposal sites; identifying chemicals in soils under snow and measuring their concentrations; comparing the measured concentrations with the background and approximate permissible values according to the actual norms [*Methodological Guidelines, 2018; Sanitary Norms and Regulations, 2018a; State Norms, 2018*]; tracing the paths of element migration from the snow patches.

METHODS

The chemistry dynamics of soils under the snow disposal sites in Yuzhno-Sakhalinsk was studied in samples from the snow patch base collected in three campaigns (stages).

Stage I (2013). Soils were sampled at four points of site 2 in the southern part of Yuzhno-Sakhalinsk (Fig. 1): two samples from different depths of a trench (0–10 cm and 10–30 cm), one sample from the snow

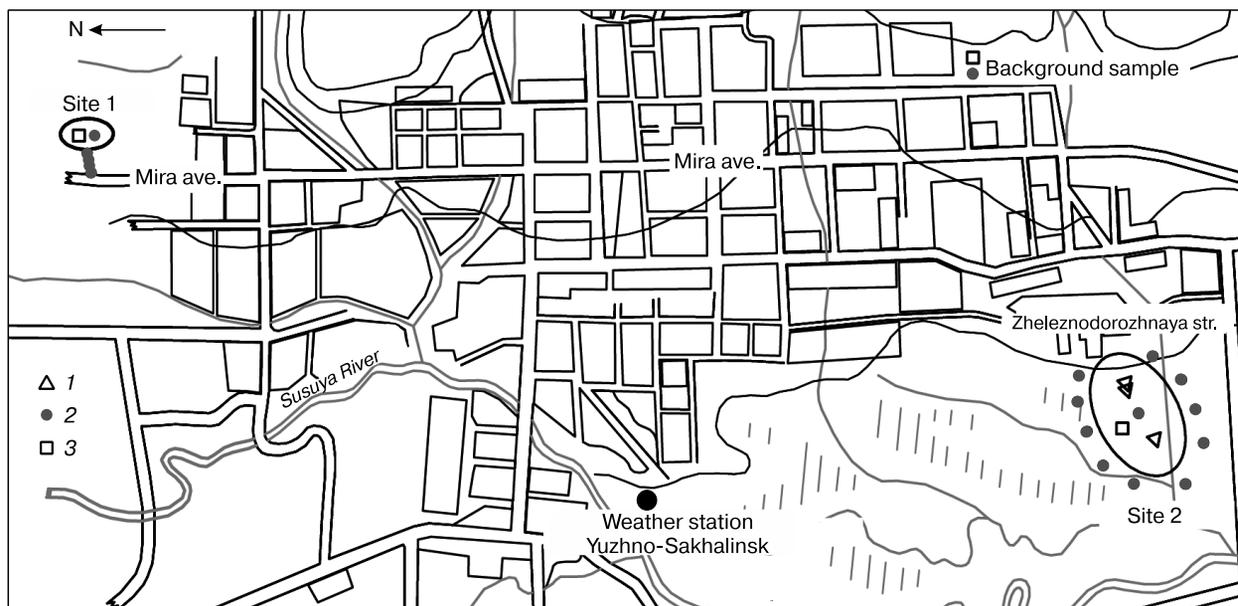


Fig. 1. Location of snow disposal sites in Yuzhno-Sakhalinsk.

1 – stage I (2013); 2 – stage II (2017); 3 – stage III (2018). Sampling points (surface areas of snow disposal sites are not to scale).

patch base (dry residue after snow melting), and a reference sample from outside the snow patch. The samples were analyzed for particle-size distribution, physical properties, major-ion chemistry, and trace-element composition. The analytical work was performed at the Analytical Center of the Institute of the Earth's Crust (Irkutsk) [Lobkina *et al.*, 2016]. Site 1 in the north of the city was not sampled in 2013 (Fig. 1).

Stage II (2017). Seventeen soil samples were collected (Fig. 2): five and eleven samples from sites 1 and 2, respectively, and one reference sample; fourteen samples were from depths of 5–15 cm below the

vegetation layer and two composite samples were from the patch base, including samples 12 and 11 at sites 1 and 2, respectively (Fig. 1); the reference sample (17) was taken near site 2, outside the disposal area. The sampling procedure followed the *State Standard* [2017]. Laboratory testing was performed at the *Sakhalinsky State Center of Agrochemical Survey*, Yuzhno-Sakhalinsk.

Soils at site 1 were sampled along a drain trench (Fig. 2, *a*, samples Nos. 13–16). Sampling all around the site perimeter was impossible because of the infrastructure. The trench was dug in 2013 to prevent swamping in the site area. It drains the greatest part

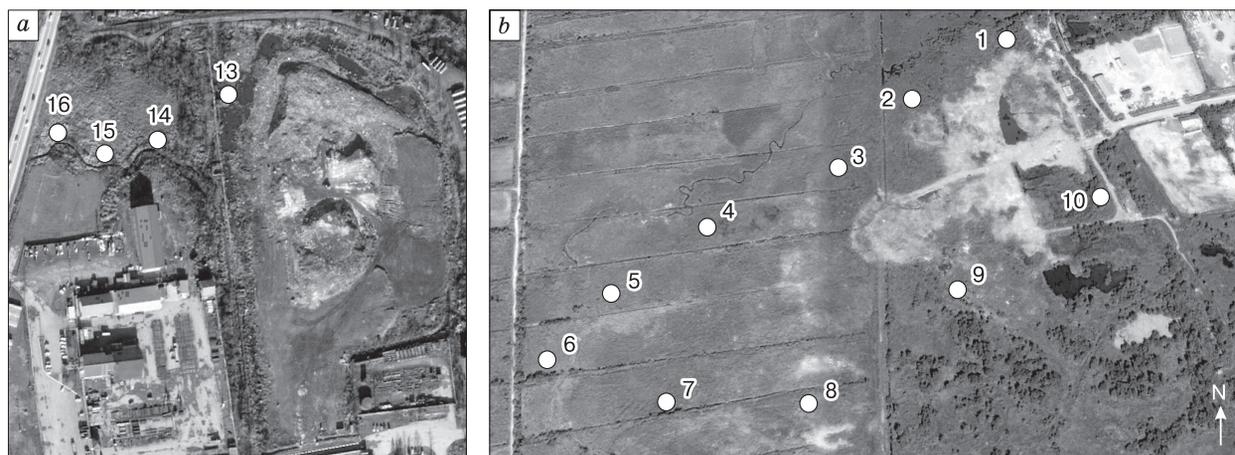


Fig. 2. Sampling points, stage II (2017):

a – site 1; *b* – site 2. 1–16 are sample numbers.

of meltwater from the northern part of site 1 and is presumably the main path of contaminants entrained with the surface runoff. Site 2 was sampled all around its perimeter (Fig. 2, *b*, samples Nos. 1–10) at roughly equidistant points.

Stage III (2018): four composite samples from the snow-ice surface at the two sites, collected in June and August, and one reference sample. The sam-

ples were analyzed comprehensively at the Laboratory of Analytical Chemistry of the Far East Geological Institute (Vladivostok).

RESULTS

Stage I (2013). The soil samples were grouped according to microstructure which allowed identify-

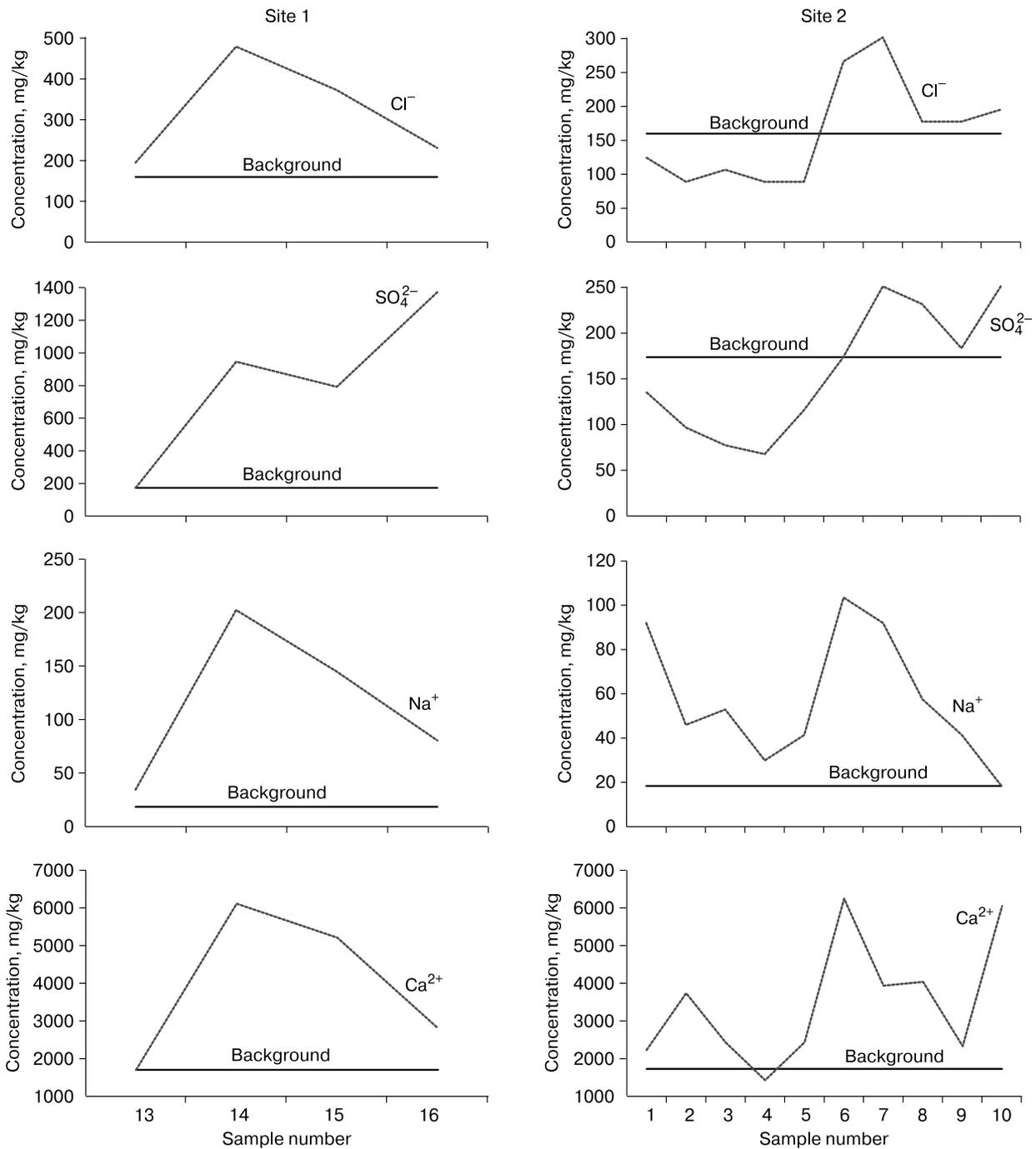


Fig. 3. Concentrations of Cl⁻, SO₄²⁻, Na⁺, and Ca²⁺ in soils at snow disposal sites, relative to the background values, stage II (2017).

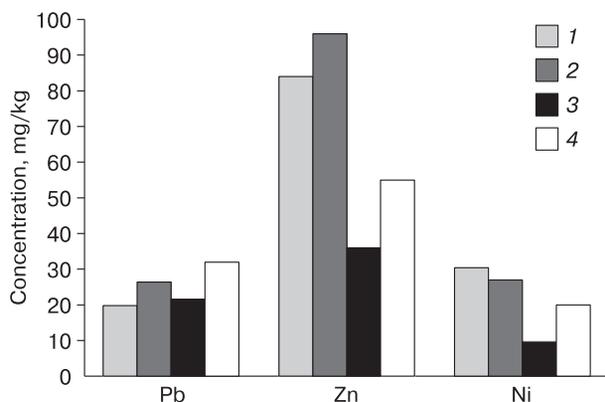


Fig. 4. Contents of heavy metals in samples relative to the background and APC values (stage II) [State Norms, 2018].

1 – site 1; 2 – site 2; 3 – background; 4 – APC.

ing the types of natural soils in the territory of site 2, while the bulk chemistry analysis of samples confirmed that samples from the snow storage site had particular compositions. The study revealed changes in mechanic properties of soils due to inputs of gravel and sand associated with snow removal from the urban territory and to road construction across the site.

The concentrations of minor and trace elements in soils exceed the approximate permissible values (APC), by factors of 2.4 for Ni, 4.8 for As, 1.2 for Cu, and 1.5 for Zn in all samples, as well as 1.1 for V (in one sample); Pb was within the APC level [Lobkina *et al.*, 2016]. The APC norm was chosen according to the scenario for the most vulnerable soils [State Norms, 2018; Sanitary Norms and Regulations, 2018a], because the assessment did not concern damage to soil as an environment object.

Stage II (2017). The concentrations of major ions measured in soils sampled along the drain trench at site 1 (Fig. 2, a) and along the boundaries of site 2 (Fig. 2, b) were as follows (Fig. 3):

(1) Cl^- was above the background in all samples at site 1 (by a factor of ≤ 3) and in five out of ten samples at site 2 (by a factor of ≤ 1.8);

(2) SO_4^{2-} was above the background in three out of four samples at site 1 and in four out of ten samples at site 2 (the excess reaching 5.5 and 1.5 times, respectively);

(3) Na^+ was above the background in all samples at site 1 and in nine out of ten samples at site 2 (by factors of 11 and 5.6 the greatest, respectively);

(4) Ca^{2+} was above the background in three out of four samples at site 1 and in nine out of ten samples at site 2 (by a factor of ≤ 3.6 in both cases).

The contents of major ions in samples from the snow patch base at sites 1 and 2 were as follows:

(1) 213 mg/kg Cl^- at both sites;

Table 1. Contents of elements in samples from surface snow-ice mass at disposal sites (stage III)

Sample	Element contents, mg/kg					
	Ni	Cu	Zn	Pb	As	V
Site 1	51.99	131.60	283.4	57.95	1.9	134.04
	42.45	58.41	179.0	24.24	3.42	100.24
Site 2	62.63	86.07	251.0	33.43	2.11	132.18
	69.02	61.72	183.1	29.11	3.02	140.48
Background	24.91	48.71	52.72	15.17	1.7	85.93
APC	20	33	55	32	2.0	150

Note: values in numerator and denominator are for June and August 2018, respectively.

(2) 183 mg/kg and 232 mg/kg SO_4^{2-} at sites 1 and 2, respectively;

(3) 34 mg/kg and 64 mg/kg Na^+ at sites 1 and 2, respectively;

(4) 4408 mg/kg and 3206 mg/kg Ca^{2+} at sites 1 and 2, respectively.

Three samples from the base of snow patches 1 and 2 and one reference sample (Fig. 4) were analyzed for heavy metals (Pb, Zn, Ni), and the resulting concentrations were above the background and APC values [State Norms, 2018] for Zn and Ni at both sites and for Pb at site 2.

The supernatant solutions of the samples had pH values varying from 5.77 to 7.26 at site 1 and from 5.88 to 8.16 at site 2, against a background of 5.25. The pH values of the composite samples from the patch base were 6.53 at site 1 and 8.12 at site 2.

Stage III (2018). The measured element concentrations exceeded the APC values in all samples: by factors reaching 3.5 for Ni, 4 for Cu, and 5.2 for Zn; Pb was 1.8 times the background value in two samples from both sites collected in June, while As was 1.7 times the background in one sample collected in August at site 1 and in both samples from site 2 (Table 1). The APC values are according to [State Norms, 2018; Sanitary Norms and Regulations, 2018a]. Vanadium did not exceed APC but was above the background in all samples, as well as Cr, Cd, Sb, Sn, Mo, Y, and Sc. The concentrations of Ni, Cu, Zn, and Pb were lower in August than in June (Table 1), due to downward infiltration of melt- and rainwater.

The reported results support the inference that soil at the sites of snow storage and disposal is prone to chemical contamination, which poses environment threats to people and infrastructure of urban areas.

DISCUSSION

The anthropogenic chemical load on a territory can be evaluated from the excess of element concentrations over the background values expressed as an enrichment factor [Revich *et al.*, 1982; Saet *et al.*,

Table 2. Total contamination (Z_c) for two sites

Sample number	Z_c	Sample number	Z_c
Site 1		Site 2	
14	20.0	1	5.3
15	14.8	8	4.9
16	12.4	10	4.2
13	2.1	2	3.7
Site 2		3	3.3
6	8.9	9	2.8
7	7.6	5	2.7

1990]. The enrichment factor KK is found as [Methodological Guidelines, 2018]:

$$KK = \frac{C}{C_b},$$

where C is the measured concentration of an element and C_b is the background value. Since the anthropogenic chemical anomalies are most often multi-elemental [Filimonova et al., 2015; Prosekin and Filimonova, 2017], the contamination is commonly evaluated as a total for a group of elements [Sanitary Norms and Regulations, 2018b]:

$$Z_c = \sum KK - (n - 1),$$

where Z_c is the total contamination with several elements (summed enrichment factors); n is the number of elements with $KK > 1$.

We estimated the total contamination Z_c of four elements analyzed at stage II, for all samples except for those from the patch base and the background sample (Table 2). The series of element concentrations, which are presented in the descending order in Table 2, allow tracing the paths of element migration: the higher the Z_c the greater the contamination at the respective point (Fig. 2).

The results confirm that most of contaminants at site 1 migrate along the drain trench. The Z_c values decrease from the patch toward the road side ditch which accommodates meltwater. They are the highest in sample 14 ($Z_c = 20.0$) at the trench head (Fig. 2, a). Further tracing of the contamination was obstructed by a motor road and buildings behind it.

At site 2, the contaminants mainly migrate toward points 6 and 7 (Fig. 2) down the general slope of the ground surface and reach the highest concentrations in sample 6 ($Z_c = 8.9$).

The Z_c value was impossible to estimate in sample 4, where only Na^+ was above the background, and in sample 5 it was the lowest over site 1 ($Z_c = 2.7$). The reason is that both samples were collected near an unnamed creek which may partly wash out the contaminants from the soil.

The problem of snow disposal is not a seasonal one. As the observations show, snow can survive the ablation season [Gensiorovsky et al., 2013], and the

elements may migrate during the most active melting of snow (latest March–April), as well as during the whole lifespan of the snow patches.

CONCLUSIONS

The sites of snow storage and disposal cause negative impacts on the environment. As our study has confirmed, melting of snow at the disposal sites leads to accumulation of contaminants in soils to the concentrations that exceed the background and approximate permissible values.

The highest concentrations of some elements recorded over the monitoring period markedly exceed the APC values, by factors of 3.5 for Ni, 4.8 for As, 1.1 for V, 4.0 for Cu, 5.2 for Zn, and 1.8 for Pb. Some major ion contents are times the background values: up to 3 times for Cl^- , 5.5 for SO_4^{2-} , 11 for Na^+ , and 3.6 for Ca^{2+} . The high contents of elements result from the use of salts during winter road maintenance operations in urban areas. The treated snow does not melt completely and is disposed at sites where it mixes with clean snow masses. The dissolved salts used for cleaning penetrate into soils and lead to its salinization. The same situation is observed in areas of petroleum development [Bryukhan and Lebedev, 2012].

When the snow disposal sites were created in 2010, the impact was limited to their surface areas: 3.3 Ha for site 1 and 6.0 Ha for site 2. However, the affected areas currently reach 8.0 Ha and 50.0 Ha for the two sites, respectively. They have expanded over the zones of contamination and swamping and are increasing progressively, as estimated from chemical analyses of soil samples. The calculations show the highest total amount of contaminants for sample 14 from site 1 ($Z_c = 20$) and sample 6 from site 2 ($Z_c = 8.9$). The main migration paths of chemicals from the sites follow the general natural slope of the area.

The influence zone of site 1 comprises trading and storage facilities and a part of a motor road along Mira avenue, which are exposed to the risks of flooding with meltwater and soil subsidence. A cellar of a storage facility was flooded in 2013. The water was drained then through a specially dug ditch, along which soil was sampled afterwards. The contaminants from site 2 discharge into the Susuya River. The pollution in the area of site 2 will preclude its further use for agriculture.

The snow disposal sites pollute the environment and disturb the sanitary setting in Yuzhno-Sakhalinsk. The formation of artificial permafrost at snow patches leads to swamping and water logging of soils. The snow patch surfaces are exposed to active solifluction processes in summer and autumn, which show up as viscoplastic or fluidal flow of soils. Other effects appear as frost heaving and subsidence pits in

light clay silt along the boundaries of the snow disposal sites.

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