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Integrated Assessment of the Impact on the Natural Environment Components from the Solid Domestic Waste Landfill of the City of Arkhangel'sk

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Abstract—The leachate generated by the solid domestic waste landfill in the city of Arkhangel'sk affects the natural waters of the swamp in the landfill location site. Based on the results from laboratory studies, the main pollutants brought by the landfill leachate were identified and quantitatively determined, and the environmental condition of the area adjacent to the landfill was characterized. The pollutant migration routes were determined. The contribution of the landfill leachate to the chemical composition of the natural environment components in the adjacent swamplands was determined, and the impact it exerts on the environmental condition of the area surveyed was assessed.

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INTRODUCTION

Waste disposal and utilization rank among the major environmental problems faced by the European part of the Russian North, including Arkhangel'sk oblast and its administrative center, the city of Arkhangel'sk [1]. Without a sanitary landfill meeting the sanitary-hygienic requirements in place, solid domestic waste (SDW) generated in Arkhangel'sk is landfilled.

Solid domestic waste landfills are powerful sources of contamination for natural environment components. Depending on the natural characteristics of the landfill location site, as well as on the specific climatic conditions and some other factors, wastes may undergo unpredictable physicochemical and biochemical transformations into harmful substances.

In our previous study [2] we described in detail the approaches to ecoanalytical assessment of the condition of the SDW landfill and adjacent areas in Arkhangel'sk, which take into account the natural and climatic characteristics of the region of interest. Here, we will briefly characterize the climatic and natural conditions, as well as some features of soils in Arkhangel'sk oblast, essential for the input of pollutants to the environment from the waste disposal sites.

The average annual temperature in Arkhangel'sk oblast is close to +5°C; it tends to decrease when moving southwest-northeastwards. The annual precipitation ranges from 400 mm at the White Sea coast to >500 mm some distance southwestwards.

The Arkhangel'sk oblast is characterized by a well-developed hydrologic network; it is crossed by one of the biggest rivers in the European North, Northern Dvina (with numerous tributaries of which Vychegda, Vaga, and Pinega are big rivers) flowing in the southeast to northwest direction. A lot of tributaries running from the watersheds between the nearly parallel big rivers constitute a very dense water network.

The soil conditions of Arkhangel'sk oblast exhibit a clear zonal pattern, with north- and middle-taiga subzones of the taiga zone characterized by podzolic soils. In the former subzone, gley-podsol soils occupy a large part of the watershed areas; there are swamp-podzolic soil and peat massifs as well. High swampiness (up to 25%) is typical for northern part of Arkhangel'sk oblast because of flat terrain, poor drainage conditions, and occurrence of waterproof clays of glacial origin. As to the Northern Dvina river basin, it is 8.5% swamped and more passable.

Assessment of the Natural Water Contamination by Landfill Leachate

Interaction of SDW with atmospheric precipitation results in formation of leachate containing numerous components arising from breakdown of substances. The amount and composition of the leachate vary with the plot area, amount of landfilled waste, and precipitation level. Especially vulnerable to contamination by leachate are active water exchange areas confined to the upper soil profile, above all groundwater [3].

The SDW landfill leachate has a complex chemical composition represented by organic and inorganic substances, which varies in each stage of the lifecycle of the landfill and significantly differs from that of industrial and municipal wastewater. The leachate contains toxic components, bioresistant impurities, and various microorganisms, in particular pathogens.

Monitoring of the condition of natural waters in the area affected by the Arkhangel'sk SDW landfill was carried out as prescribed by relevant recommendations and regulations [4–9]. To this end, a network of monitoring sites was established at which water samples were collected with intent to be subsequently subjected to the chemical and microbiological analyses.

With due regard to the geological and botanical characteristics of the natural environment within the area affected by the landfill, the monitoring sites were arranged exactly along the groundwater flow route. Specifically, monitoring sites were established around the SDW landfill perimeter, with a background site selected behind the embankment of the highway passing near the landfill, and two monitoring sites, at the landfill proper.

Also, additional monitoring sites were arranged with a view to assessing the groundwater condition at different distances from the landfill: within the groundwater flow section at a distance of 1000 m from the landfill, with the background monitoring site selected behind the embankment of the highway, and within the groundwater flow section originated from swamps near the Yuras river at a 3000–3500-m distance from the SDW landfill. For collection of natural waters samples, observation wells (1.5- and 2.5-m deep piezometers) and a pit at a depth of 0.5–0.7 m were specially installed at the monitoring sites.

Along with groundwater analysis, the water condition for Yuras river (the surface water source) was monitored at the groundwater inflow location site, 0.5 km downstream, as well as 0.5, 1 and 3 km upstream the river.

The surface water and groundwater samples were collected as prescribed by relevant standards [10, 11]. Natural water samples were taken twice a year (in the spring/summer and autumn seasons).

The following groups of indicators were used for assessing the impact exerted by the SDW leachate on the natural water.

(1) General chemical indicators of natural water quality: pH (potentiometric analysis), COD (titrimetric analysis), ionic composition (liquid ion chromatography/capillary electrophoresis), and dry residue (gravimetric analysis).

(2) The content of organic and inorganic pollutants: petroleum products (IR spectroscopy/fluorimetry), phenols (fluorometric analysis), heavy metals (X-ray fluorescence analysis/inversion voltammetry/atomic-absorption spectroscopy).

(3) Microbiological indicators: total coliforms, thermotolerant coliforms, coli fags, intestinal bacterial pathogens.

(4) Parasitological indicators: helminth eggs, cysts of intestinal pathogenic protozoa.

(5) Virological indicators: hepatitis A virus antigen, rotavirus antigen.

The samples of groundwater affected by the leachate from the SDW landfill, which were taken around its perimeter, are neutral (pH 6.5–7.5), and those collected from plots separated by a 1-km distance from the impact source, weakly acidic (pH 5.0–6.5). These are typical values for swamp waters, considering the presence of humic acids therein.

The degree of mineralization of the groundwater exhibits variability across the area surveyed. For example, the total salt content of the groundwater flowing west-eastwards (from the landfill to the surface water source) progressively decreases. The groundwater samples taken around the perimeter of the landfill and below the landfill foundation level are salty, with dry residue being up to 6.2 g l^{-1}. At the background monitoring site behind the road embankment, the underground water is characterized by a decreased average content of dry residue, 0.7 g l^{-1}, and is classed with natural waters having a relatively high salinity.

At a 1-km distance from the eastern border of the landfill (along the groundwater flow path), the salt concentration in the groundwater was reduced to 0.5–1.8 g l^{-1}. Like in the case of the background monitoring site, this water can be classed with waters having a relatively high salinity. The water samples collected at the background monitoring site located outside the groundwater flow section, are characterized by reduced average content of dry residue (up to 0.5 g l^{-1} maximum salt concentration).

The dichromate oxidizability (COD) of the groundwater samples taken around the landfill perimeter is estimated at 685 (O_2 mg) l^{-1} on the average, and this level may reach 2700 (O_2 mg) l^{-1}.

The COD for the samples taken at a 1-km distance, is 315 (O_2 mg) l^{-1} on the average, and it may reach 1305 (O_2 mg) l^{-1}. Such oxidizability levels are not typical for water available from natural sources [the 15 (O_2 mg) l^{-1} level is characteristic for COD of the water in heavily contaminated water bodies]. In the case of interest, high COD levels are associated with the specific composition of the peat-swamp soils in the area surveyed.

In this study we took advantage of the natural water classification scheme proposed by O. A. Alekin [12], in which waters are categorized depending on the dominating anion into carbonate (fresh and ultrafresh river waters and significant quantities of underground water), chloride (seawater and estuarine water, as well as underground water of saline soil areas), and sulfate (intermediate between the chloride and carbonate waters in terms of distribution and mineralization) groups.

The groundwater samples collected around the SDW landfill perimeter and at a 1-km distance from the eastern border of the landfill along the groundwater flow path and within the groundwater flow section belong to the chloride class sodium group, water type III ($Cl^- > Na^+$), with Cl^- and Na^+ dominating among the major ions.

The dominating ions for the swamp water in the area of interest can be arranged into the following series:

$$Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-, NO_2^- > PO_4^{3-}, Br^- > F^-$$
$$Na^+ > K^+ > NH_4^+ > Ca^{2+}, Mg^{2+}$$

Based on the natural water characteristics, three zones can be identified within the area surveyed.

Zone 1 is located directly around the perimeter and in the vicinity of the landfill. The landfill leachate exerts a direct impact on the swamp waters: It modifies their chemical composition and acts as a source of epidemiological risk.

Zone 2 is separated by a 1-km distance from the eastern border of the landfill along the groundwater flow path. The chemical composition of water in his zone differs from that of the water directly affected by the landfill leachate (the underground water is filtered through the mass of peat-swamp soils characterized by high sorption and buffer capacities).

Zone 3 incorporates the surface water of the natural water body, Yuras river.

Clear delineation of these zones is troublesome because of a variable composition of the landfill leachate and of the need to examine the “barrier” properties of high moor peat-swamp soils representative of the area of interest.

Peat is know to have a large specific surface area and high porosity (95%), and it was found [13] that, in the ability to treat polluted water, it can compete with other adsorbents provided low flow rates and small quantity of wastewater to be treated. Also, it was demonstrated [14] that peat can be used for pretreatment of heavily polluted landfill leachates.

Given below are the results from analysis of the groundwater samples collected at the monitoring sites arranged around the perimeter of the Arkhangel’sk SDW landfill.

Inorganic pollutants include Hg (up to 10.8 MPCs), Cd (up to 2.2 MPCs), Zn (up to 3.4 MPCs), Bi (up to 6.7 MPCs), Fe (up to 42 MPCs), and Mn (up to 118 MPCs). The Pb, Cu, Ni, Cr, and V levels do not exceed their corresponding MPCs. The inorganic, in particular, heavy metal pollutant speciation in the examined natural water containing humic acids is governed above all by complexing processes. However, estimation of the proportion of metal complexed with humus substances and of the stability constants for these complexes is complicated due to some specific features of humic acids [15]: variable composition, polydispersity, heterogeneity, and polyelectrolyte nature.

As regards organic pollutants, these groundwater samples contain petroleum products (up to 16 MPCs on the total petroleum products basis) and phenols (up to 624 MPCs on the volatile phenols basis).

The thermotolerant and total coliform levels in the groundwater samples collected around the landfill perimeter exhibited, respectively, 2400- and 240-fold excesses over the standard value established for the summer, most epidemiologically dangerous, season [16]. Comparison with the results of the previous microbiological examinations revealed significant deterioration of the groundwater quality in terms of these bacteria levels.

The groundwater samples collected at the monitoring sites located around the perimeter and at the foundation of the landfill do not meet the relevant hygienic requirements, which fact suggests that the SDW landfill of the city of Arkhangel'sk poses certain epidemiological risk. At the same time, in terms of the parasitological indicators, all the groundwater samples collected were compliant with the relevant sanitary requirements [17]; they did not contain helminth eggs and cysts of intestinal pathogenic protozoa, as well as hepatitis A antigen and rotavirus.

The groundwater samples collected at a site separated from the eastern border of the landfill by a 1-km distance along the groundwater flow path either did not contain most of microelements or contain them in amounts not exceeding the appropriate MPC levels due to filtration through the peat-swamp soil mass and to sorption processes.

The water of Yuras river, which receives the groundwater contaminated with landfill leachate, is fresh (average salinity 0.29 g l^{-1}l) and neutral (pH = 6.9–7.3) due to $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ hydrocarbonnates it contains. The dichromate oxidizability (COD), 72 (O_2 mg) l^{-1}, on the average, reaches 122 (O_2 mg) l^{-1} at the location site of the groundwater inflow into the surface water source, which is limited by a drainage ditch on the north. In terms of COD, river Yuras is a heavily contaminated water body; in accordance with Alekin's classification [12], its water belongs to the hydrocarbonate (calcium) type ($HCO_3^- > Ca^{2+} + Mg^{2+}$).

A low heavy metal content revealed for river Yuras water can be explained by distribution of the toxicant metal between the components of this aquatic ecosystem (metal species include those dissolved, sorbed and accumulated by phytoplankton, retained by bottom sediments, and adsorbed on the bottom sediment surface from the aquatic environment in soluble form or on suspended particles) [18].

The microelement concentrations and the major indicators of water quality for the location at which the groundwater and the drainage ditch water are discharged differ substantially from those for the downstream and upstream water at the background monitoring site. Hence, the groundwater and the drainage ditch water affect the water composition of the surface water source.

Assessment of the Soil Cover and Swamp and Forest Vegetation Contamination in the Area Adjacent to the Landfill

The matter flows in soil are involved with surface atmosphere, vegetation, and surface water, as well as with soil and ground water. Soil is able of actively transforming the incoming compounds whose migration ability it can either increase or decrease [19].

In swamplands of the European part of the Russian North, peat acts as a natural collector of pollutants contained in groundwater, which efficiently captures and immobilizes them [20]. Therefore, in assessment of the extent of the environmental impact exerted by the SDW landfill in the city of Arkhangel'sk, particular focus was placed on peat as one of the main components of the landscape in the region of interest. A variety of biogeochemical and migration processes proceed in peat, and it acts as a natural sorbent with respect to various substances.

The vegetation condition was monitored as prescribed by relevant methodical guidelines [21–23], as well as with the use of field survey techniques adopted in plant ecology, forest science, and soil science. The monitoring employed the "key sites" method for studying the soil and vegetation components on small representative plots which are characterized by an important parameter, the area of the association definition (0.5–0.75 ha in forest zones) [24].

The vegetation and soil condition was monitored at three key sites. One key monitoring site was established in a young shrub-sphagnum pine forest adjacent to the southeastern part of the landfill, which may affect the condition of not only vegetation in the landfill proper but also of the bird inhabitants of the landfill site. The second site was established in the middle part of the zone of landfill leachate flow towards river Yuras, in which peat undergoes major water saturation and subsequent transformation of high- to low-moor peat under wastewater exposure. The third site was established in the northeastern section of the landfill, in the middle part of the area enclosed by the border of the landfill leachate flow zone and the drainage channel, where a middle-aged shrub-sphagnum pine forest was formed.

Two background test plots, one at a 2-km distance from the eastern border of the landfill, and the other, at a 25-km distance from the city of Arkhangel'sk, were established with a view to assessing the aerogenic contamination of the soil and vegetation cover.

After a soil contamination event has occurred, the plants tissues accumulate toxic substances which further enter human body via trophic chains. Hence, chemical analysis is of critical importance for soils on which those plants are grown whose fruit species are used for food by the population.

Soil sample collection for the purpose of chemical analysis was carried out after the morphological characteristics of the soil were available for each of the soil profiles, as prescribed by the relevant standards [25, 26]. Soil samples were collected from different soil layers (corresponding to 0–5, 5–20, 20–40, and 40–80 cm in depth) in four soil profiles (up to 90–100 cm deep) at each of the key sites. Four soil samples taken from each of the soil layer were thoroughly mixed to form a composite sample.

For the groundwater monitoring sites being established, soils samples were additionally taken at the depths of 0.5, 1.5 and 2.5 m and subsequently subjected to analysis for the content of micro- and macroelements.

Sampling aimed to assess the soil and vegetation condition was undertaken once a year (in summer season, when both the vegetation cover and the epidemiological threat are at a maximum).

The impact of the SDW landfill on the soil cover of the adjacent area was assessed on the basis of the following groups of indicators.

(1) The pH_{KCl} indicator (potentiometric analysis).

(2) The content of inorganic and organic pollutants: heavy metals (X-ray fluorescence analysis/inversion voltammetry/atomic-absorption spectroscopy), petroleum products (IR spectroscopy/fluorimetry).

(3) Microbiological indicators: total microbial count.

(4) Parasitological indicators: helminth eggs and larvae (viable), cysts of intestinal pathogenic protozoa.

Because no calculation of the clarkes of elements for peat was undertaken, the generally accepted practice was applied. Specifically, the accumulation levels of elements in peats were assessed by comparison with the corresponding clarkes in soils; the ratio of the content of the element in the sample to its clarke in soil was determined. If considered as a geological formation, peat could be more reasonably characterized by comparison of the average abundances of elements in peat with the clarkes of these elements in the lithosphere. However, this approach is not quite correct in the case of peat with its organogenic origin.

The main criterion for hygienic assessment of the soil contamination by chemicals is the maximum permissible, or tentatively permissible, concentration of a substance in soil.

The chemical contamination level for soils is assessed using the indicators developed on the basis of complementary geochemical and geohygienic studies of environmental objects. These indicators include the chemical substance concentration coefficient K_c, which represents the ratio of the actual content of a substance in soil C_i, mg (soil kg)$^{-1}$, to the regional background content C_{bi}:

$$K_c = C_i/C_{bi}. \quad (1)$$

and the integrated pollution index Z_c, which represents the sum of the concentration coefficients of contaminating chemical elements:

$$Z_c = \Sigma(K_{bi} + \ldots + K_{bn}) - (n - 1), \quad (2)$$

where n is the number of the analyzed substances whose concentrations are to be summed.

The distribution pattern for the geochemical indices, derived from analysis of the soil samples collected at the soil monitoring sites, gives an insight into the spatial structure of contamination over the area surveyed and allows identification of zones that pose health risks for the population [27].

The integrated pollution index characterizing the severity of soil contamination with man-made pollutants was legislatively formalized and enjoys now widespread use as an integrated indicator [28].

With lacking information on the background concentrations of heavy metals in soils and vegetation for the Arkhangel'sk oblast, the present data on their content were compared with the clarkes of the elements, and the content of the total petroleum products, with their maximum permissible concentration in soil.

Using the monitoring data obtained, the peat samples collected at the groundwater monitoring sites being established can be characterized on the basis of the following pollution categories: "hazardous" at the landfill monitoring site; "extremely hazardous" (Z_c > 128) at the site established on the eastern tip of the landfill; "moderately hazardous" ($16 < Z_c < 32$) at the sites located around the perimeter and at a 2.5-km distance, respectively; and "permissible" ($Z_c < 16$) at the remaining monitoring sites [29].

Table 1. Indices of accumulation of microelements in peats within the surveyed area[a]

Element	n^a	F, % [b]	CC_{av} [c]	AC, %[d]
Hg	48	69	24.07	65
Cd	32	50	1.16	13
Pb	64	63	2.48	53
Zn	64	100	2.33	98
Cu	64	94	2.00	94
Ni	64	97	0.93	36
Co	64	84	1.62	84
V	64	52	0.40	22
Sr	64	98	0.31	0
Mn	64	97	0.21	0
Fe	64	73	0.18	0
Petroleum products	48	100	–	–

[a] n is number of the samples analyzed; [b] F, frequency of the element; [c] CC_{av}, ratio of the content of the element to its clarke; [d] AC, occurrence of above-clarke concentrations.

The largest contribution to soil contamination comes from hazard class 1 (containing Hg, As, Zn), hazard class 2 (containing Cu, Co), and hazard class 3 (petroleum products) substances.

The contamination density was at a maximum in the immediate vicinity of the eastern border and under the foundation of the landfill, which findings correspond to the data on migration of leachate pollutants along the groundwater flow path. In the adjacent area, the peat soil contamination level tended to decrease with increasing depth.

Correlation analysis of the soil samples collected at the groundwater monitoring sites allowed the As–Zn–Pb ($r > 0.9074$) and Cu–Ni–V ($r > 0.6157$) associations of elements to be identified within the surveyed area affected by the Arkhangel'sk SDW landfill, because the most significant positive correlations were revealed specifically between their concentrations in the peat-swamp soil.

It should be noted that the Cu, Ni, and V concentrations exhibit moderately positive correlations with Fe ($r > 0.3223$) irrespective of the soil depth at which these elements occur. The content of these same elements (Cu, Ni and V) in soil at different depths, starting from 1.5 m, exhibits a moderately negative ($r > 0.3184$) correlation with the content of Co. For the 0.5-m depth, a positive correlation ($r > 0.3640$) was identified, probably due to competitive sorption of these elements by the peat-swamp soil mass.

It was found that the peat soil is characterized by a highly nonuniform microcomponent distribution over both the area and depth.

It was of interest to compare the concentrations of the pollutants, revealed for the background monitoring sites and the sites selected within the area affected by the Arkhangel'sk SDW landfill. A comparable, and the highest, concentration of microelements and petroleum products was revealed for the soil in the test plots established for the purpose of monitoring of the soil cover and swamp and forest vegetation along the groundwater flow path in the immediate vicinity of the landfill. This fact was confirmed by the geological survey data on the groundwater flow path and the presumed influence of the landfill leachate on the groundwater and soil cover of the adjacent area.

The microelement composition of the soil in the background test plots differs from that in the areas affected by the leachate-contaminated groundwater and is characterized by reduced levels of all the microelements determined.

The correlation analysis of the soil samples collected at the soil and vegetation monitoring sites revealed the following association of elements within the surveyed area affected by the Arkhangel'sk landfill: Zn-Cu-Ni-Fe-V (the most significant positive correlations were identified between the content of these microelements in the peat-swamp soils. These data reflect those from analysis of the peat soil samples, collected at the groundwater monitoring sites, for the microelements determined.

It was also expedient to compare the average content of selected microelements (heavy metals) in soil of the area surveyed with that for the soil in Arkhangel'sk as estimated for 2007 [30]. It turned out that, on the average, the Hg, Cd, Pb, Zn, Cu, Ni, Co, and Mn levels in the peat soil of the test monitoring plots exceed those for Arkhangel'sk on the whole by factors of 48, 580, 35, 56, 160, 93, 86, and 71, respectively.

The geochemical assessment of the elemental composition of the peats was carried out using the following indicators [31]:

frequency of the element (the ratio of the number of samples in which the element was detected to the total number of the samples analyzed, %);

clarke of the concentration of the element (the ratio of the content of the element in the sample to the clarke of the element in soil); and

frequency of above-clarke concentrations (the ratio of the number of samples with above-clarke content to the total number of samples, %).

Table 1 lists the calculated frequencies, clarkes, and above-clarke concentrations which were used for estimating the element content in high-moor peats of the area surveyed (Table 2).

Using the calculated clarkes in the peat soils of the area surveyed, the elements were arranged in biogeochemical series based on individual test plots (TPs) of soil cover monitoring, located at three key sites: the site adjacent to the southeastern part of the landfill, which may affect not only the condition of vegetation of the landfill proper but also of the bird inhabitants of the landfill site (TP1); the site established in the middle part of the zone of landfill leachate flow toward the surface water course (TP2); and the site established in the northeastern section of the landfill, in the middle part of the area enclosed by the border of the landfill leachate flow zone and the drainage channel (TP3). Also, background test plots were established at a 2-km distance from the eastern border of the landfill and at a 25-km distance from the city of Arkhangel'sk (TP4k and TP5k, respectively):

TP1: $Hg_{19.92} > Cd_{5.20} > Pb_{3.06} > Zn_{2.85} > Cu_{2.12} > Co_{1.86} > Ni_{1.02} > V_{0.60} > Sr_{0.25} > Mn_{0.18} > Fe_{0.16}$

TP2: $Hg_{43.25} > Zn_{3.23} > Pb_{2.49} > Cu_{2.10} > Co_{1.48} > Ni_{0.97} > Sr_{0.52} > V_{0.45} > Mn_{0.30} > Cd_{0.28} > Fe_{0.19}$

Table 2. Classification of elements based on the degree of concentration in the high-moor peat within the surveyed area

Frequency (F) of element in high-moor peat	Accumulation of elements in peat with indicated intensity		
	vigorous ($CC_{av} > 0.3$)	strong ($0.3 > CC_{av} > 0.1$)	slight ($CC_{av} < 0.1$)
$F > 75\%$ Common elements	Zn, Cu, Ni, Co, Sr	Mn	–
$75\% > F > 50\%$ Medium-abundance elements	Hg, Cd, Pb, V	Fe	–
$F < 50\%$ Uncommon elements	–	–	–

TP3: $Hg_{37.42} > Pb_{3.99} > Cu_{2.47} > Zn_{2.31} > Co_{1.94} > Ni_{1.21} > V_{0.56} > Sr_{0.32} > Cd_{0.27} > Fe_{0.20} > Mn_{0.19}$

TP4k: $Hg_{4.92} > Cu_{1.97} > Zn_{1.81} > Pb_{1.44} > Co_{1.37} > Ni_{0.87} > V_{0.35} > Sr_{0.23} > Fe_{0.19} > Mn_{0.17} > Cd_{0.09}$

TP5k: $Hg_{14.83} > Zn.\,Pb.Co_{1.45} > Cu_{1.32} > Ni_{0.57} > Sr_{0.22} > Mn_{0.19} > Fe_{0.16} > V_{0.03} > Cd_{0.00}$

Using the integrated pollution indices $Z_{c,}$ it is possible to categorize the soil cover contamination level as permissible for the background test plots TP4k and TP5k ($Z_c < 16$) [29], as moderately hazardous for the TP1 test plot ($32 > Z_c > 16$), and as hazardous for the TP2 and TP3 test plots ($128 > Z_c > 32$).

Like in the case of the groundwater monitoring sites, the soil cover contamination in the test soil monitoring plots was contributed mostly by substances belonging to hazard class 1 (Hg, Pb, Zn), 2 (Cu, Co), and 3 (petroleum products).

The microbiological and parasitological examinations of the peat-swamp soils of Arkhangel'sk oblast were carried out jointly with the Center for Hygiene and Epidemiology, Federal State Healthcare Institution. Using the criteria provided in [29], the parasitological indices revealed for the soil samples collected at the groundwater monitoring sites allow them to be classed as "clean", and the samples collected at the landfill periphery, as "moderately hazardous."

Based on the content in the peat soils of the area adjacent to the landfill, the microelements can be arranged as follows:

Fe > Mn > Zn > Sr > Cu, V, Ni > Pb > Co > Hg, Cd.

Vegetation is most actively involved in migration and transformation of chemical compounds. The nutrient migration intensity is determined by the chemical composition of the plants. Examination of the elemental composition of the plants, which constitute a substantial part of biological matter cycles, is essential for more comprehensive characterization of the distribution of the chemical elements in natural and man-made landscapes.

Terrestrial plants have most of their mass (up to 90–95 on a percentage dry mass basis) constituted by carbon, oxygen, and hydrogen which they take up from air and water. The remaining 5–10% of the plant substance is accounted for by other elements (in particular, microelements) coming from the soil. The chemical elements are unevenly distributed in plant organisms. For example, the highest concentrations of microelements were detected in leaves and needles, and in grassy plants they are distributed more or less evenly [32].

The selective absorption of chemical elements by plants can be characterized by the biological absorption coefficient K_b, which represents the ratio of the content of an element in plant biomass to that in soil, as introduced by B.B. Polynov [33].

Due to selective absorption power possessed by plants, the content of elements in them is slightly different from that in soil. For the soil cover, as well as the swamp and forest vegetation monitoring sites, the distribution of microelements in plant tissues can be presented as follows:

$$Fe > Mn > Zn > Sr > Cu,Ni > Pb > Co.$$

The biological absorption coefficients are indicative of strong differentiation of the elements involved in biological migration. The intensity of the biological absorption of an element depends only slightly on its total content in soil because some microelements are weakly involved in biological processes, and soils can be dominated by species that are hardly accessible for plants.

Also, chemical elements can be delivered to plants, especially to their above-ground parts, by the aerogenic path. It must be stressed that the microelement composition of the swamp and forest vegetation generally reflects that of the soil cover.

CONCLUSIONS

Field and laboratory studies revealed a high buffer capacity of peat and demonstrated its environmental function of a natural barrier preventing the spread of pollutants contained in groundwater from the solid domestic waste landfill in the city of Arkhangel'sk. However, peat itself is becoming progressively more contaminated as time goes on, which may lead at some point to breakdown of the organic matter of peat and release of pollutants into the soil solution.

The results of the studies performed suggest a need for engineering and technical measures to be taken in order to prevent a negative impact on the natural environment components from the solid domestic waste landfill in the city of Arkhangel'sk.

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REFERENCES

1. *On the Condition and Protection of the Environment of the Russian Federation in 2006: State Report*, Trutnev, Yu.P. and Temkin, A.A., Eds., Moscow: Center for International Projects, 2007.
2. Bogolitsyn, K.G., Larionov, N.S., Bogdanov, M.V., and Fedina, Zh.T., *Ekol. Prom–st. Rossii*, 2007, January, p. 38.
3. Ignatovich, N.I. and Rybal'skii, N.G., *Ekol. Vestn. Rossii*, 1998, no. 1, p. 23; no. 2, p. 24; no. 3, p. 13.
4. *RD (Regulatory Document) 03-417-01: Methodical Recommendations on Drafting Safety Monitoring Project for Hydraulic Installations at Production Sites, Facilities, and Organizations Supervised by the State Committee of the Russian Federation for Supervision of Safe Working Practices in Industry and for Mine Supervision*, Moscow: Gosudarstvennyi Komitet Rossiiskoi Federatsii po Standartizatsii, Metrologii i Sertifikatsii, 1995.
5. *GOST (State Standard) R 22.1.08-99: Safety in Emergency Situations: Monitoring and Forecasting of Hazardous Hydrological Phenomena and Processes: General Requirements*, Moscow: Izd. Standartov, 1999.
6. *GOST R 22.1.07-99: Monitoring and Prediction of Dangerous Weather Phenomena and Processes: General Requirements*, Moscow: Izd. Standartov, 1999.
7. *SP (Code of Practice) 11-102-97: Engineering and Environmental Survey for Building Activities*, Moscow: Gosudarstvennyi Komitet Rossiiskoi Federatsii po Arkhitekture i Stroitel'stvu, 1997.
8. *SP 2.1.7.1038-01: Hygienic Requirements on Establishment and Maintenance of Solid Domestic Waste Landfills*, Moscow: Izd. Standartov, 2001.
9. *Instructions on Designing, Exploitation, and Remediation of Solid Domestic Waste Landfills*, Moscow, 1996.

10. *GOST R 51592-2000: Water: General Requirements for Sampling*, Moscow: Izd. Standartov, 2000.
11. *ISO 5667-11:1993: Water Quality: Sampling: Part 11: Guide on Groundwater Sampling*.
12. Alekin, O.A., *Osnovy gidrokhimii* (Fundamentals of Hydrochemistry), Leningrad: Gidrometeoizdat, 1970.
13. Ruel, M., Chornet, S., Coupal, B., Aitcin, P., and Cossette, M., in *Muskeg and the Northern Environment*, Radford, 1973, p. 221.
14. Rock, C.A., Greer, T.F., Fiola, J.W., and Woodard, F.E., *J. New Eng. Water Poll. Cont. Assoc*., 1985, vol. 19, p. 32.
15. Perminova, I.V., *Doctoral (Chem.) Dissertation*, Moscow, 2000.
16. *SanPiN (Sanitary Regulations and Standards) 2.1.5.980-00: Hygienic Requirements for Surface Water Protection*, Moscow: Ministerstvo Zdravookhraneniya i Sotsial'nogo Razvitiya Rossiiskoi Federatsii, 2000.
17. *SanPiN 3.2.1333-03: Prevention of Parasitic Diseases on the Territory of the Russian Federation*, Moscow: Gosudarstvennaya Sanitarnaya Inspektsiya Rossiiskoi Federatsii, 1999.
18. Budnikov, G.K., *Soros. Obraz. Zh*., 1998, no. 5, p. 23.
19. Alekseeva, A.S., *Cand. Sci. (Biol.) Dissertation*, Moscow, 2002.
20. Frostman, T.M., *Water Management*, 1996, January/February, p. 14.
21. *Metodika organizatsii i provedeniya rabot po monitoringu lesov SSSR (v ramkakh Mezhdunarodnoi sovmestnoi programmy po otsenke i monitoringu vozdeistvii zagryazneniya vozdukha na lesa v regione Evropeiskoi Ekonomicheskoi Komissii OON)* [The Methodology of Organizing and Carrying out the Work on Monitoring of Forests of the USSR (in the Framework of the International Cooperative Program on Assessment and Monitoring of Air Pollution Effects on Forests Launched and Operating under the Convention on Long-Range Transboundary Air Pollution of the UN Economic Commission for Europe UNECE)], Pushkino, 1987.
22. *Metodika organizatsii i provedeniya rabot po monitoringu lesov evropeiskoi chasti Rossii po programme ICP Forest (metodika EEK OON)* [The Methodology of Organizing and Carrying out the Work on Monitoring of Forests of the European Part of Russia under the ICP Forest Program (UN-ECE Methodology)], Moscow, 1995.
23. *Manual on Methods and Criteria for Harmonized Sampling, Assessment, Monitoring, and Analysis of the Effects of Air Pollution on Forests*, UNECE**,** Frankfurt, 1994.
24. Yashin, I.M., Shishov, L.L., and Raskatov, V.A., *Pochvenno-ekologicheskie issledovaniya v landshaftakh* (Soil and Environmental Studies for Landscapes), Moscow: Mosk. Sel'skokhoz. Akad. im. Timiryazeva, 2000.
25. *GOST 17.4.3.01-83: Nature Conservation: Soil: General Requirements for Sampling*, Moscow: Izd. Standartov, 1984.
26. *GOST 17.4.4.02-84. Nature Conservation: Soil: Methods for Sample Collection and Preparation for Chemical, Bacteriological, and Helminthological Analyses*, Moscow: Izd. Standartov, 1984.
27. *MU (Methodical Instructions) 2.1.7.730-99: Federal Health Regulations, Norms, and Standards of Hygiene: Hygienic Soil Quality Requirements for Populated Areas*, Moscow: Ministerstvo Zdravookhraneniya i Sotsial'nogo Razvitiya Rossiiskoi Federatsii, 1999.
28. Titova, V.I., Dabakhov, M.V., and Dabakhova, E.V., *Pochvoved*., 2004, no. 10, p. 1264.
29. *SanPiN 2.1.7.1287-03: Soil, Cleaning of Settlements, Domestic and Industrial Waste, Sanitary Soil Protection: Sanitary and Epidemiological Regulations and Standards*, Moscow: Ministerstvo Zdravookhraneniya i Sotsial'nogo Razvitiya Rossiiskoi Federatsii., 2003.
30. *Sostoyanie i okhrana okruzhayushchei sredy Arkhangel'skoi oblasti v 2007 godu* (The State and Protection of the Environment of the Arkhangel'sk oblast in 2007), Dolgoshchelov, L.G., Ed., Arkhangel'sk: Izd. Tsentr Gos. Med. Univ., 2008.
31. Kreshtapova, V.N., *Metodicheskie rekomendatsii po otsenke soderzhaniya mikroelementov v torfyanyh mestorozhdeniyakh Evropeiskoi chasti RSFSR* (Methodical Recommendations on Estimation of the Content of Microelements in Peat Deposits of the European Part of the Russian Federation), Moscow: Min. of Geol. SSSR, 1974.
32. Protasova, N.A. and Belyaev, B.A., *Soros. Obraz. Zh*., 2001, vol. 7, no. 3, p. 25.
33. Polynov, B.B., *Izbrannye trudy* (Selected Works), Moscow: Akad. Nauk SSSR, 1956.