Evaluation of the Impact of Old Refuse Dumps for Industrial Wastes on Groundwater Quality and Sanitation of Dumps

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Abstract: The demand for comprehensive monitoring of hazardous wastes at dumps and landfills using a network of monitoring wells constructed in the sanitary protection zones is proved in this paper. The quality of drainage water entering the environment from old landfills and dumps is reported. The effect of pollution on groundwater quality in technological accumulations of industrial wastes of an old landfill of a machine-building plant is studied. The method for assessing the security conditions of pressure water depending on filtration duration of contaminated water from the first aquifer to the pressure horizon for an aquiclude distributing these horizons is shown. The flow rate of polluted water in a stratum under the action of natural underground water flow is calculated. The area of possible soil and water pollution with time is calculated with allowance for soil porosity. The isolation scheme for a landfill having no basic isolation is elaborated. The sanitation method for old landfills and industrial dumps is shown. An alternative to the old landfills with the controlled pollutant leaks is presented.

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1. Introduction

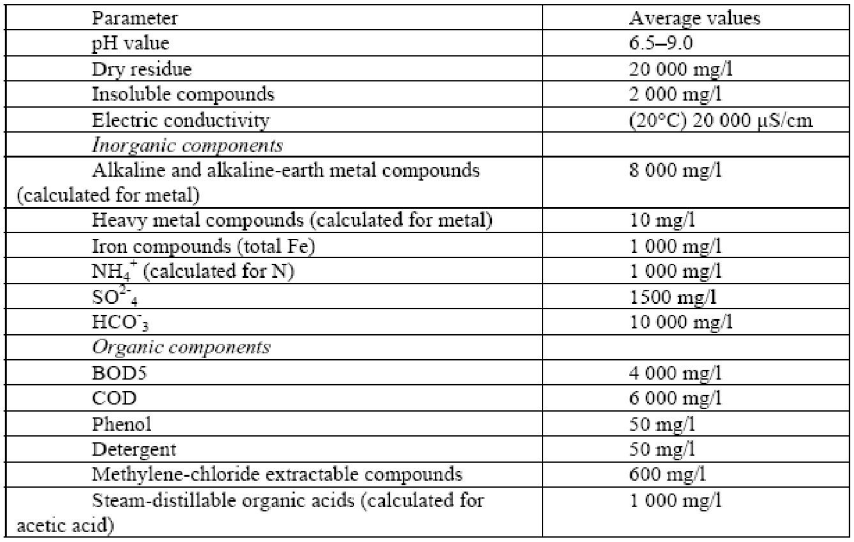
The papers published by different researchers who have studied all the aspects of burial of solid domestic and industrial wastes at landfills demonstrate that there is both significant surface pollution of soils over vast territories and groundwater and soils more than 20 m deep. It has been found that water percolating through the landfill body is also a source of pollution of surface water with Fe, Ba, Cr, P, Ti, Ni, nitrates, ammonia, and chlorides (2–100 MAC). In addition, the pollutants contain Co, W, Mo, V, Pb, Zn, Li, Sr, etc. (MAC exceeded by several times). These waters are toxic for living organisms and hazardous for the environment; hence, the landfill body should be protected (shielded) well. The efficiency of screening surfaces of the dump can be calculated using specialized models [1]. Various types of upper and lower coatings (shields) at landfills and dumps have been described in literature (e.g., [2]). Wastes containing organic components, oils and oil products, acids and alkali, and exchange cationites (e.g., calcium cation) affect the material that the dump screen is made of. The compatibility of the material of the landfill screen and the waste composition is tested at the laboratory using various techniques [3]. The effect of the washed-out components on permeability of clays shielding the landfill body was evaluated in different studies [4]. A significant increase in permeability of certain types of clays when exposed to various neutral engine oils and alkaline organic liquids has been observed in these studies. In some cases, the permeability increased to such extent that the material no longer complied with the requirements imposed to the coatings. The quality of groundwater around dumps and landfills must be systemically monitored. The comprehensive monitoring of hazardous waste disposals and assessment of the degree of wash-out and emission of pollutants from wastes at the landfills (hydrological, hydrochemical, impermeability of wells, etc.) are performed using monitoring wells that are constructed in the sanitary protection zone of a landfill [5]. At least four monitoring wells need to be constructed. One well needs to be arranged upstream of the dump, while the remaining three wells need to be located downstream, around the dump borders. It is most reasonable to determine the positions of the control wells in accordance with the evaluation of plots after the work is done. During the work, the directions of breaks along which the pollutants can migrate are revealed, and the optimal arrangement of the control wells is determined. One well should be placed in an area that is not exposed to the dump in order to find out whether or not the pollution observed is caused by another source. The dump owner is in charge for collecting and analyzing water samples. Water sampling and analyzing is carried out according to the established procedure [6]. The quality of groundwater must be in compliance with the drinking water standards. Additional tests for content of phenols, sulfates, manganese, sodium, chlorine, heavy metals, etc. are to be conducted in order to determine the general criteria of water quality.

The studies at one of the industrial landfills in Vologda have demonstrated that the condition of the network of monitoring wells is unsatisfactory, which causes the permeation of the main pollutant (oil products) to the first-aquifer groundwater through the space around pipe. The content of oil products in water collected from the wells in the dump center and in the southeastern part of the landfill was 2.1 and 2.4 mg/l, respectively. Pollutants at amounts being higher than the MAC value for ammoniacal nitrogen, nitrate nitrogen, and iron were detected in the second aquifer at a distance of 50 m from the western and southwestern borders of the landfill.

The percolating water at dumps is formed under the action of atmospheric precipitation and groundwater. The composition of this water depends on the type of wastes stored. While the percolating water from and industrial waste landfills contain the same compounds as the wastes do, the domestic waste dumps are characterized by predominant washing out of fermentation and putrefaction products. Special critical assessment should be performed for old dumps where the domestic and industrial wastes have not been separated (while it is common to sort wastes nowadays). The substances formed during anaerobic fermentation can interact with toxic substances from the industrial wastes, resulting in dissolution of the latter substances (e.g., via complex formation).

The microbiological processes and chemical reactions between the components of domestic wastes cause significant pollution of the percolating waters. The composition of pollutions in percolating waters depends on the phase of fermentation of materials and substances in the landfill (dump) body and significantly depends on the period they have been buried at the landfill. Table 1 lists various parameters of waters percolating from the landfills and dumps of domestic wastes.

Table 1. Quality of drainage waters at the landfills (dumps) of domestic wastes (6–8 years after the wastes were buried) [7]



Parameter	Average values
pH value	6.5–9.0
Dry residue	20 000 mg/l
Insoluble compounds	2 000 mg/l
Electric conductivity	(20°C) 20 000 μS/cm
Inorganic components	
Alkaline and alkaline-earth metal compounds (calculated for metal)	8 000 mg/l
Heavy metal compounds (calculated for metal)	10 mg/l
Iron compounds (total Fe)	1 000 mg/l
NH_4^+ (calculated for N)	1 000 mg/l
SO_4^{2-}	1500 mg/l
HCO_3^-	10 000 mg/l
Organic components	
BOD5	4 000 mg/l
COD	6 000 mg/l
Phenol	50 mg/l
Detergent	50 mg/l
Methylene-chloride extractable compounds	600 mg/l
Steam-distillable organic acids (calculated for acetic acid)	1 000 mg/l

2. Methods

1. To ascertain the main features of formation of groundwater in this area.
2. To distinguish groundwater horizons differing by hydrodynamic conditions.
3. To elaborate a network of monitoring and control wells in the sanitary protection area of the landfill.
4. To determine the directions of groundwater flows.
5. To assess the flow rates of groundwater and the degree of pollutant spread.
6. To evaluate quality of water sampled from the wells.
7. To elaborate the scheme of landfill sanitation.

3. Main part

The landfill of industrial wastes of one of machine-building plants in Vologda is studied in this paper. The landfill localizes within the plant territory. In geomorphological terms, it is the southwestern end of vast terraced alluvial-lacustrine Prisukhonskaya lowland. The area occupied by the landfill is located at the top lacustrine-glacial terrace of this lowland. The absolute altitudes of the terrace lie within 140–150 m; it was formed in the Early Valdai period (49–38 thousand years ago). The terrace is characterized by flat, weakly dissected relief with closed swamped depressions, some of which have no surface runoff.

Before the industrial wastes started to be buried, some engineering preparation of the plot was conducted. It consisted in the removal of the soil and vegetation layer and organization of drainless area on the surface of mainland soils. The abandoned pits located at the plot, where clay for brick production had been previously obtained, were used.

A total of 120 000 tons of petroleum- and oil-containing phase have been buried at the plant landfill during more than 40 years. Since it started to be used in 1972, the landfill area has been increased to 8 ha; the thickness of accumulated wastes reaches 5 m, while the total weight is over 150 000 tons, including II and III hazardous wastes (chromium-containing lapping compound and break-in sludge from the ball-bearing department; sludge from oil remover and sludge collector; grinding and thermal sludge). The following wastes have also been buried at the landfill: solid domestic wastes (rags, leather cuttings), rubber and plastic wastes, spent sandpaper and abrasive band, abrasive wastes. The amount of wastes brought annually to the landfill is over 8 000 tons. The formation of groundwater containing oil products has been observed as early as in the 1970s. Today, there is a control network consisting of 22 monitoring wells, which allows one to monitor the conditions of groundwater within the landfill.

There have been several ponds for liquid waste storage (up to 5 m deep) within the landfill area; only two still exist today. The main one is located in the center of the landfill (S = 0.5 ha); the second one is partially covered with wastes and local soil and localizes in the southwestern part of the dump. Density stratification of liquid wastes takes place in the storage ponds; the system is separated into three layer:

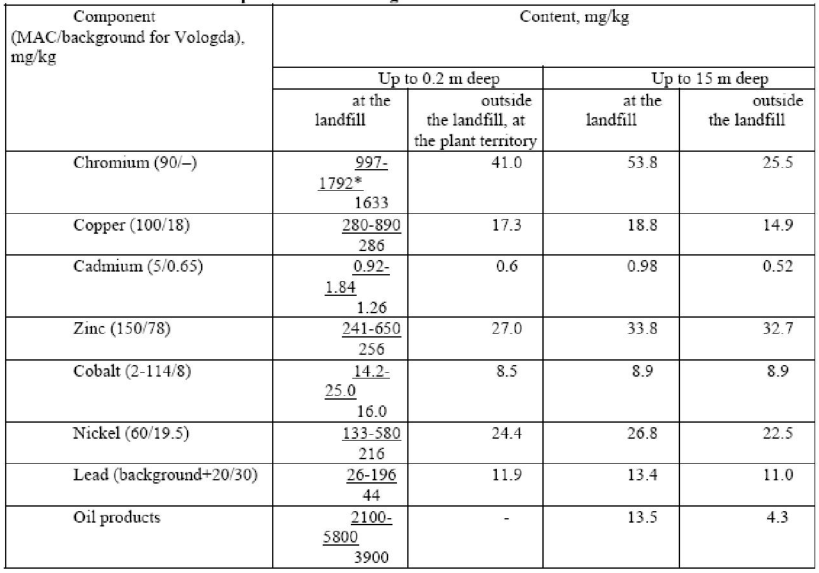
the top layer, up to 15 cm – poorly separable emulsion of oil products, water, and mechanical impurities (up to 5%); the amount of oil products and impurities decreases with depth;

middle layer, up to 3 m – clarified water contaminated with oil products and suspended matter (Cr^{3+} and Fe^{3+} content in the collected samples of this layer was 4.8 and 31 mg/l, respectively);

the bottom layer – the bottom sediment consisting of 70% solid phase impregnated with oil products up to 15% (1.2–1.8 g/cm^3 density). Iron content in the solid phase reaches 18%.

The degree of soil contamination within and beyond the landfill is shown in Table 2.

Table 2. Content of pollutants in technogenous accumulations at and outside the landfill



Component (MAC/background for Vologda), mg/kg	Content, mg/kg			
	Up to 0.2 m deep		Up to 15 m deep	
	at the landfill	outside the landfill, at the plant territory	at the landfill	outside the landfill
Chromium (90/–)	997-1792* 1633	41.0	53.8	25.5
Copper (100/18)	280-890 286	17.3	18.8	14.9
Cadmium (5/0.65)	0.92-1.84 1.26	0.6	0.98	0.52
Zinc (150/78)	241-650 256	27.0	33.8	32.7
Cobalt (2-114/8)	14.2-25.0 16.0	8.5	8.9	8.9
Nickel (60/19.5)	133-580 216	24.4	26.8	22.5
Lead (background+20/30)	26-196 44	11.9	13.4	11.0
Oil products	2100-5800 3900	-	13.5	4.3

* Numerator: the minimum – the maximum value; Denominator: the average value of an indicator.

The area under study belongs to the Northern Dvina artesian basin. The main features of groundwater formation at this territory are determined by the following factors:

– prevalence of precipitation over evaporation;

– significant thickness of Quaternary deposits mostly of argillaceous composition and the presence of inter-moraine loamy sand and sand lenses of different thickness;

– relatively weak dissection of the relief.

The presence of a thick (up to 5 m) technogenous layer and storage ponds (5 m deep;

mirror surface 0.7 ha) affects the formation and behavior of the first aquifer.

Four horizons of groundwater that differ in hydrodynamic bedding conditions are distinguished in a hydrogeological profile:

– first unconfined aquifer;

– second weakly confined inter-moraine aquifer;

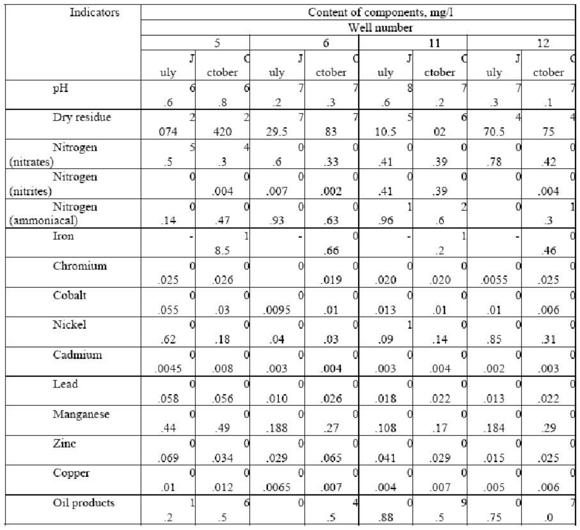
– third confined inter-moraine aquifer;

– fourth confined aquifer of pre-Quaternary deposits.

Water-bearing deposits of the first aquifer (groundwater) include the covering, lacustrine-glacial, lacustrine-paludal and moraine loamy sands, and technogenous waste accumulations. The thickness of soils above the moraine is characterized by leakage factors of 0.0004–0.004 m/day. The leakage factor of moraine loamy sands at depths up to 10 m lies within 0.001–0.01 m/day; deeper than 10 m it is 0.0001–0.01 m/day. The occurrence depth of the aquifer varies from 0.57 m in the dump center to 3 m on its western margin and 4.4 m in the eastern direction outside the dump. The groundwater flows in two main directions: north- and southeastern. The special hydrodynamic mode of the landfill territory is associated with the presence of storage ponds, which facilitates the formation of a "water dome" and creates conditions for spreading of the groundwater flow in other directions (northern and western) as well. The flow rate is 0.3 m/day. The minimal and maximal levels of groundwater were observed in July and November, respectively; the latter ones coincide with an increase in the amount of atmospheric precipitation. The gas fluctuations within the levels can be as high as 5 m. In terms of their chemical composition, horizon I waters are magnesium/sodium hydrocarbonate, low salinity, and very hard. The chemical composition of the first aquifer within the dump has significantly changed since 1972: a 4-fold increase in dry residue; a 3-fold increase in contents of magnesium, chlorides, and sulfates; and a 10-fold increase in calcium content were observed. Contamination of waters of the first aquifer with oil products and heavy metal ions was noted (Table 3).

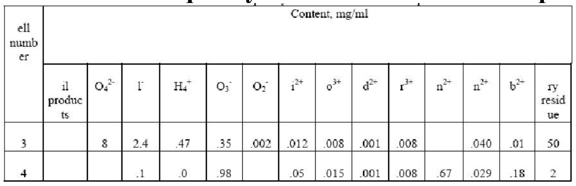
Wells 5 and 6 (in the landfill center), as well as 11 and 12 (at a distance of 40 m southeastwards outside the landfill) were established in 1986. Today, the condition of the network of monitoring wells is unsatisfactory, which causes permeation of the main pollutant (oil products) to the groundwater of horizon I through the near-pipe space. New wells were drilled in 1995; groundwater was tested in these wells immediately after they had been opened (the contents of oil products were as follows: 2.1 mg/l for the well in the dump center and 2.4 mg/l for the well in the southeast part of the dump). In order to assess the degree of pollution spreading in space, wells 33 (60 m northwards from the landfill) and 34 (120 m southeastwards from the landfill) were drilled and water sampled from these wells was analyzed (Table 4).

Table 3. Quality of water sampled from the wells



Indicators	Content of components, mg/l							
	Well number							
	5		6		11		12	
	July	October	July	October	July	October	July	October
pH	6.6	6.8	7.2	7.3	8.6	7.2	7.3	7.1
Dry residue	2074	2420	729.5	783	510.5	602	470.5	475
Nitrogen (nitrates)	5.5	4.3	0.6	0.33	0.41	0.39	0.78	0.42
Nitrogen (nitrites)	0	0.004	0.007	0.002	0.41	0.39	0	0.004
Nitrogen (ammoniacal)	0.14	0.47	0.93	0.63	1.96	2.6	0	1.3
Iron	-	18.5	-	0.66	-	1.2	-	0.46
Chromium	0.025	0.026	0	0.019	0.020	0.020	0.0055	0.025
Cobalt	0.055	0.03	0.0095	0.01	0.013	0.01	0.01	0.006
Nickel	0.62	0.18	0.04	0.03	1.09	0.14	0.85	0.31
Cadmium	0.0045	0.008	0.003	0.004	0.003	0.004	0.002	0.003
Lead	0.058	0.056	0.010	0.026	0.018	0.022	0.013	0.022
Manganese	0.44	0.49	0.188	0.27	0.108	0.17	0.184	0.29
Zinc	0.069	0.034	0.029	0.065	0.041	0.029	0.015	0.025
Copper	0.01	0.012	0.0065	0.007	0.004	0.007	0.005	0.006
Oil products	1.2	6.5	0	4.5	0.88	9.5	0.75	7.0

Table 4. Water quality in wells outside the dump



ell number	Content, mg/ml												
	il products	O_4^{2-}	l^-	H_4^+	O_3^-	O_2^-	i^{2+}	o^{3+}	d^{2+}	r^{3+}	n^{2+}	n^{2+}	b^{2+}	ry residue
3		8	2.4	.47	.35	.002	.012	.008	.001	.008		.040	.01	50
4			.1	.0	.98		.05	.015	.001	.008	.67	.029	.18	2

The data listed in Table 3 demonstrate that pollution with oil products does not occur for the main directions.

Thus, the polluting effect of the landfill is mostly confined to its area with an insignificant increment along its perimeter. Glacial loamy sands act as an aquiclude for the horizon; however, due to the presence of sandy lenses (hydrogeological windows), the flow from the first aquifer to the second one is 5 m^3/day per 1 ha / 0.5 mm of the layer). Spreading of contaminated water in a stratum induced by natural flow of groundwater takes place at a rate

$$V = k \cdot i, \quad (1)$$

where k is the leakage factor, m/day;

i is the natural flow gradient.

k = 0.01 m/day, i = 0.023.

$$V = 0.01 \cdot 0.023 = 0.00023 \text{ m/day}.$$

The actual rate of groundwater flow determined in the wells using the method of charged body V_a=0.3 m/day. This difference is caused by the existence of frost-shattered fractures and sand interlayers in the top section of the profile.

During 40 years that the landfill has been used, the pollution can theoretically spread over a distance of 8760 m:

$$L = \frac{V \cdot t}{n}, \quad (2)$$

where t is the duration of exploitation of the landfill (days);

n is the active porosity of rocks.

In fact, the concentration of the main pollutants (oil products, chromium, iron) at a distance of 120 m from the landfill lies within the allowable range, which is attributed to the ability of soils to retain many ionic compounds of microelements.

The second aquifer occurs in fluvioglacial deposits of Moscow glaciations mostly with sand and sandy loam composition. The thickness of the water-bearing masses fluctuates between 4 and 17 m. The leakage factor varies from 0.71 to 24 m/day. The second aquifer lies at depths of 6–10 m in the southwestern part of the plant territory and 16–18 m in the northern part. Within the landfill area, this horizon was not observed up to the depth of 25 m. The second water-bearing horizon occurs at a distance of 50 m from the western and southwestern margins of the landfill. The second water-bearing horizon is confined (magnitude of pressure is 6–10 m). The flow moves in the northeastern direction and is caused by the existence of the discharge of the aquifer (the deeply entrenched valley of the Vologda River) in the northern part. The second aquifer lies 4–8 m lower than the first aquifer; their levels coincide very rarely. The aquifer is not naturally protected against pollution. The second aquifer contains amounts of pollutants (ammoniacal nitrogen and iron) higher than the MAC.

The third aquifer is confined to the poorly defined fluvioglacial and glacial lacustrine deposits of the Dnieper glaciation period. The lithological composition of water-bearing rocks is diverse: fluvioglacial deposits consist of sand-gravel materials, sands of different grain size, and loamy sands. The maximum thickness is 30–40 m (most typically, 5–20 m). The roof of the aquifer system hypothetically lies near the plant at a depth from 30 to 60–70 m. The leakage factor varies from 0.1 to 24 m/day.

The aquifer system is of great practical significance for drinking water supply in Vologda. It is exploited by a number of wells (in most cases, along with the pre-Quaternary system). In terms of natural conditions, this aquifer is conventionally protected. No data on its pollution have been reported.

The fourth aquifer is the main aquifer used for water supply. It is represented by the water-bearing Permian-Triassic complex occurring at a depth of 85–95 m. Waters are confined. The magnitude of pressure is 70 m. Groundwater is fresh with 0.5 g/l mineralization. The chemical composition of waters in the aquifer complies with the standard requirements to drinking water. The direction of the groundwater flow is southeastern. In terms of natural conditions, this aquifer is conventionally protected.

Let us assess the conditions of protection of confined waters based on the duration of filtration of polluted water from the first aquifer to the confined aquifer per aquiclude distributing these horizons. Filtration duration t depends on aquiclude thickness m_O and leakage factor k and is determined using the formula:

$$t = \frac{{m_0}^2 \cdot n}{k \cdot \Delta H \cdot 365}, \quad (3)$$

where n is the active porosity of waterproof rocks (let us assume it to be 0.05);

ΔH is the difference between exceeding of the levels of the first aquifer and the confined one, m;

365 is the number of days per year.

Based on the hydrogeological conditions of the region, we use the following values: m_O=78 m, k = 0.001 m/day, ΔH = 20 m. Hence, t = 41.7 years.

Having compared this figure with the duration of exploitation of the dump (over 40 years), we arrive at conclusion that there is a probability that the landfill can contaminate the confined aquifer. There is a demand for sanitation due to the fact that the structure and use of the landfill do not comply with the current normative documents and the landfill may pollute groundwater.

It has been demonstrated above that there was no high-quality general and surface isolation at the landfill. Monitoring of groundwater near the landfill has demonstrated that pollutants present in landfill wastes had a negative effect on groundwater quality.

It has been found out that there was no drainage network and percolation waters were not collected in the landfill territory (which had no general isolation). When the level of groundwater is high, the base of the landfill is washed-out by it, resulting in penetration of the percolate to groundwater. The presence of chemical pollutants was detected in groundwater near the landfill.

In order to eliminate complications of the environmental situation and to avoid further pollution of groundwater, the following scheme of landfill sanitation is proposed.

The sanitation technology includes the following measures:

- Applying surface isolation, providing the technical elements to remove precipitation (broadening of the drainage ditch around the landfill).
- If necessary, arranging a gas collection system (increasing the number of plots, sites where pipes are mounted).
- Upgrading and adapting the existing pits to collect drainage water with allowance for the surface isolation system being reconstructed.
- Recultivation measures.

Elements of sanitation:

1. Raising banks and shaping.
2. Surface isolation system:
   a) construction of the combined layer;
   b) construction the mineral layer of surface.
3. Dehydration of the landfill surface.
4. Gas collection.
5. Collection of drainage water.
6. Coverage of entire landfill and road construction.
7. Recultivation measures.

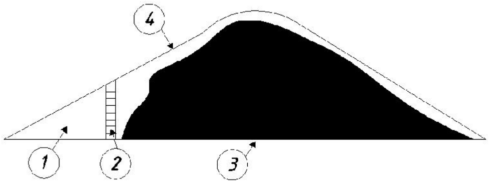


Fig. 1. Scheme of sanitation. Systemic profile: 1 – preliminary bank, 2 – clay cap, 3 – landfill body, 4 – isolation.

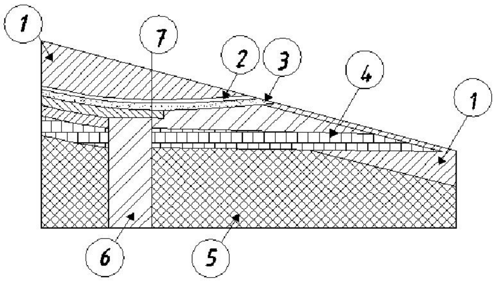


Fig. 2. Scheme of sanitation. Detail: preliminary bank:1 – recultivated soil, 2 – 0.1 m thick seepage layer, 3 – 0.2 m thick dehydrating layer, 4 – balancing layer, 5 – preliminary bank, 6 – ~1 m thick clay layer, 7 – the axis of pit edge.

The approximate size of the isolation layers used for sanitation are as follows: 100 cm thick surface soil layer; 10 cm thick percolation layer; 20 cm thick dehydrating and polymeric layers; 50 cm thick mineral densifier; ~50 cm thick balancing and decontamination layers. The ditches around the landfill with an isolating clay layer are broadened (Fig. 3).

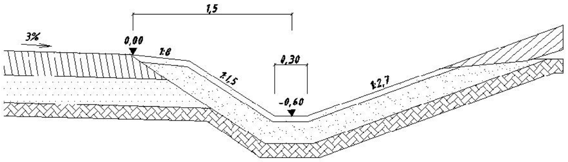


Fig. 3. Profile of the reconstructed water-removing ditch (surface drainage) along the perimeter of the landfill.

As demonstrated above, the first stage comprises surface shaping (relocation of material) followed by construction (if necessary) of the balancing layer (sludge interlayer) to ensure gas passage: approximate size 80 x 250 mm. The average leakage factor of soil k = 0.005 m/s. Sludges of noble metals with particle size up to 11 mm can be used to make the balancing layer. The compaction degree should be high ≥ 95 %, which is very difficult to achieve in practice. The compaction degree that is attained is usually ~86–88%; the balancing layer in this case acts as the base layer. The average permeability increases to $k = 5 \times 10^{-5}$ m/s. After the balancing layer is built, a double mineral layer of the clay compaction layer is built within the entire construction area.

The average leakage factor of soil increases to $k = 5 \times 10^{-9}$ m/s. The drainage and recultivation layers are subsequently placed. The areas covered with a recultivation layer are typically treated with an anti-erosion solution. The final works usually include construction of industrial roads and ditches around the landfill and construction of the fence. Planting vegetation is the final stage of sanitation measures.

4. Summary

Leakage of pollutants from the body of a landfill (and especially a dump) is inevitable. However, the landfill site should be constructed in such a manner so that a leakage did not cause an unacceptable risk. Slow controllable leakage is allowed: in case of this leakage, the environment is to be able to assimilate safe amounts of pollutants. This is particularly valid for heavy metals. Thus, waste fixation enables one to convert them to a non-leachable form, reducing the rate of supply of pollutants to the environment. The awareness of the fact that leaks from landfills are inevitable should change the paradigm of using dumps and landfills [8]. An alternative to the old landfill sites with controllable leakages is the landfills that can be regarded as storage sites until the technical and economic conditions will make it possible to recycle the wastes being stored. It was mainly grinding sludge containing valuable components and raw material that were buried at the landfill studied in this work. This sludge can be recycled to obtain coagulants and reagents for purifying industrial sewage water or can be used as additives to raw material and construction materials [9, 10].

5. Conclusions

1). Concentrations of the main pollutants (oil products, chromium, iron) outside the landfill (at a distance of 120 m) lie within the range of MAC values, which can be attributed to the ability of soils to retain ionic compounds of microelements.

2). Chemical pollutants were detected in groundwater near the landfill and at its border.

3). The polluting effect of the landfill is mostly confined to its area with an insignificant increment along its perimeter.

4). There is a probability that the landfill contaminates the confined aquifer. The structure and exploitation of the landfill do not comply with the current normative documents. The landfill may cause groundwater pollution; hence, sanitation is required.

5). The scheme of landfill sanitation has been elaborated.

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