Assessment of Groundwater Contamination in Municipal Solid Waste Landfill nearby Small Settlements

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Abstract. European North with a low population density and poorly developed transport infrastructure, it is difficult to organize waste removal and storage at large landfills, therefore many settlements have small landfills of municipal solid waste (MSW), and the practice of placing them in marshes is very common, which leads to the migration of pollutants into adjacent water bodies. Systematic monitoring of the environmental in the vicinity of such landfills is hampered by high costs of periodic water sampling and chemical composition analyses. It is possible to decrease the number of substances under analysis and thus reduce costs by determining the marker substances, the concentration of which in groundwater near the landfill has stable correlations with the content of other pollutants. The article provides results of cluster analysis made it possible to identify marker substances. To assess the extent of groundwater contamination at landfills of the Arkhangelsk region monitoring of solid waste landfills was organized, which included sampling and studying the chemical composition of the samples. The results of the study have shown that the dependences obtained are applicable for a large landfill in the capital of the region – the City of Arkhangelsk, while for landfills in small settlements the dependences need to be adjusted.

1. Introduction

European North with a low population density and poorly developed transport infrastructure, it is difficult to organize waste removal and storage at large landfills, therefore a small waste landfill is generated near almost every settlement, and the practice of placing them in swamps is very common. This leads to the migration of pollutants into adjacent water bodies.

The processes of sorption and desorption of pollutants by peat have not been studied enough yet. According to various authors, some substances are securely settled in peat, others are transferred by groundwater. Moreover, the effect of peat composition, temperature and other factors on the experimental results was not usually taken into consideration during the research [1, 2, 3, 4].

The study of the chemical composition of groundwater and the identification of specific pollutant substances will make it possible to establish the dependences necessary for predicting the distribution of pollutants at the base of the landfills of municipal solid wastes in small settlements.

2. Cluster analysis of pollutant concentrations

Analysis of the pollutant concentrations in 45 solid waste landfills around the world carried out by results of literature review showed that all pollutants are divided into 3 clusters (Figure 1). Cluster A includes heavy metal cations, many of which are highly toxic. Compounds of these metals are widely...
used in the chemical industry, galvanic production, etc. Their sources of waste are electrical products, such as lamps, batteries, etc.

Cluster B is represented by ammonium cations, alkaline and alkaline earth metals, as well as by sulfate, nitrate, chloride and phosphate ions. The salts generated from these ions are mainly soluble compounds. Sources of their presence in water can be natural minerals (calcite, apatite). They are contained in the products of the chemical industry; in particular, they are part of mineral fertilizers.

Cluster C represents organic compounds: oil products and phenols. The sources of oil products in groundwater are the effluents from industrial enterprises, petrol stations, and the landfills – containers with waste lubricants. Phenolic compounds can stem from industrial wastewater of the chemical complex enterprises. In addition, phenolic compounds are formed in natural conditions during the transformation of native aromatic compounds, mainly macromolecular (lignin) ones.

**Figure 1.** Scatter diagram with the correlations identified.

Within each cluster correlation analysis of pollutant concentrations was carried out that made it possible to identify marker pollutants: zinc (Zn), plumbum (Pb) and ferrum (Fe) in cluster A, which have the greatest number of links with other pollutants. Two statistically significant elements: Sodium (Na) and Potassium (K), were identified in cluster B. Correlation dependencies between marker pollutants and other substance were obtained for each cluster. For verification of the received dependences has been monitoring the composition of groundwater at the base of landfills of small settlements on the territory of the Arkhangelsk region.

3. **Organization of the experimental sites and sampling**

The organization of experimental sites and selection of samples were carried out at six sites of solid waste storage: sites 1, 2, 4, 5 are located in wetlands, and two areas 3, 6 - on clay soils (Figure 2a).

Wells were drilled at all sites, piezometers were installed, and monitoring of the chemical composition of groundwater was organized. The arrangement of piezometers is made taking into account the terrain, the direction of groundwater flow and the location of the nearest reservoirs. In addition to placing near the waste accumulators, piezometers are installed in the background areas that are not subject to man-made effects (Figure 2 d,e). The chemical composition of groundwater was determined in the Shared Equipment Center of NARFU by standard methods.
Figure 2. Locations of the test sites (a), a general view of the sites (b, c), peat sampling (d) an installation of a piezometer (e, f).

4. Results of the groundwater chemical composition study

Based on the analysis of scientific publications and established statistically significant correlations between the content of substances in groundwater, as well as identified marker substances, 16 substances were identified, the concentrations of which should be determined in groundwater at the base of the landfill: oil products, ammonium ion, potassium, sodium, magnesium, strontium, calcium, phenols, chloride-, nitrate-, phosphate-, sulfate-ions, plumbum, zinc, ferrum, mercury, as well as three indicators: COD, dry residue and pH (Table 1).

The results of determining the pollutant concentrations in groundwater at the base of landfill and the multiplicity of MPC exceedance are shown in comparative diagrams (Figure 3). The maximum permissible concentrations of pollutants in water are adopted as per the standard GN 2.1.5.1315-03*.

The chemical composition analysis revealed an increased content of phenols in all sites, ferrum – in 5 sites, ammonium ion – in 2 sites and potassium – in one site. The multiplicity of MPC exceedance for phenols was 11 ... 135, for ferrum – 2 ... 39, for ammonium ion – 2 ... 8. A significant pollutant MPC exceedance was detected at the sites located in swamps, which is apparently associated with delayed water exchange resulting in the accumulation of pollutants.
Figure 3. Multiplicity of MPC exceedance (logarithmic scale) in groundwater at the sites Nos. 1 (a), 2 (b), 3 (c), 4 (d), 5 (e), and 6 (f).
### Table 1. Concentration of pollutants in groundwater at the base of landfills according to the results of reconnaissance studies (mg/l).

| Parameter         | 1     | 2     | 3     | 4     | 5     | 6     | MSW landfill in Arkhangelsk |
|-------------------|-------|-------|-------|-------|-------|-------|-----------------------------|
| Oil products      | 0.018 | 0.114 | 0.013 | 0.231 | 0.008 | 0.027 | 0.743                       |
| Ammonium ion      | <0.1  | 3.1   | <0.1  | 12.0  | <0.1  | <0.1  | 186.1                       |
| Potassium         | 1.3   | 2.1   | 19.0  | 60.2  | 30.9  | 1.5   | 463.2                       |
| Sodium            | 2.8   | 16.6  | 8.7   | 86.5  | 3.3   | 1.6   | 939.7                       |
| Magnesium         | 4.0   | 1.4   | 29.5  | 26.9  | 41.2  | 4.4   | 135.5                       |
| Strontium         | <0.5  | <0.5  | <0.5  | <0.5  | <0.5  | <0.5  | -                           |
| Calcium           | 20.4  | 1.4   | 109.0 | 183.0 | 145.0 | 25.6  | 127.5                       |
| Total phenols     | 0.011 | 0.024 | 0.009 | 0.028 | 0.021 | 0.013 | -                           |
| Chloride ion      | 4.0   | 19.8  | 7.6   | 86.3  | 2.7   | 0.9   | 116.0                       |
| Nitrate ion       | <0.10 | <0.10 | 20.6  | 0.12  | <0.10 | <0.10 | 0.13                        |
| Phosphate ion     | <0.1  | <0.1  | <0.1  | 0.1   | <0.1  | <0.1  | -                           |
| Sulfate ion       | 0.7   | 17.2  | 47.5  | 4.2   | 1.6   | 0.7   | 123.7                       |
| Plumbum           | <0.005| <0.005| <0.005| <0.005| <0.005| <0.005| 0.026                       |
| Zinc              | 0.046 | 0.019 | 0.008 | 0.146 | 0.126 | 0.018 | -                           |
| Ferrum            | 3.2   | 0.2   | 0.4   | 11.7  | 0.6   | 0.6   | 2.5                         |
| Mercury           | <0.0001| <0.0001| <0.0001| 0.0003| <0.0001| <0.0001| 0.0030                     |

To verify the established correlation dependences, the statistical analysis included in addition to data from six sites the results obtained in 2006 during monitoring of a landfill with an area of 28.2 hectares in Arkhangelsk, located on a swamp with a 4-5 m depth [5].

Chemical analysis of groundwater samples taken near MSW landfill in the Arkhangelsk City has shown that the pollutants concentration at the landfill in the City of Arkhangelsk corresponds to the correlation dependences. An analysis of the data obtained in the experimental sites showed that the previously obtained correlation dependences of the concentration of pollutant substances Na → Mg, K → Mg, Pb → Fe and Zn → Fe are quite applicable to them (Figure 4 a, b, d, f): most experimental points are located within the limits of confidence probability (± σ). For the other substances, unsatisfactory convergence occurs, which is apparently related to the composition of the waste disposed at the landfills of small settlements.

5. Conclusions

Chemical analysis of groundwater samples taken near seven MSW landfills in the Arkhangelsk Region has shown that the pollutants concentration at the landfill in the City of Arkhangelsk corresponds to the correlation dependencies identified by the literature data, whereas for landfills in small settlements these dependencies should be specified.
Figure 4. Correlation dependences of pollutant concentrations. The green and purple lines indicate the MPC of the respective substances.

Legend:
- ○ MSW landfills in the world
- + Landfills under monitoring in Arkhangelsk region
- ▲ MSW landfill in the City of Arkhangelsk
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