*Original Research*

# Influence of Leachate on Quality of Underground Waters

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**Abstract**

Evaluation of the influence of leachate on underground waters in the vicinity of a chosen landfill is examined in this paper. The purpose of the research was to give information on maximum pollutants concentrations which could penetrate ground and water subsoil and its influence on the area adjacent to the landfill. Scale and range of pollution in the examined area have been observed in 7 piezometer test wells and 4 nearest household wells and analogous parameters have been determined for leachate. To evaluate the influence of leachate on examined ground waters a method of multidimensional factor analysis with Varimax rotation was used.

**Keywords:** landfill, leachate, underground waters, factor analysis with Varimax rotation

## Introduction

On the basis of numerous studies it has been established that as a result of biochemical decomposition of organic substances and washing out of soluble mineral and organic fractions contained in waste material on a landfill site by precipitation and run-off waters, leachate is formed. Their physical and chemical composition is determined by, among other things, deposited waste type, their properties, and landfill operation time and type [1, 2].

In spite of many safety devices (subsoil sealing, drainage) leachate can get outside landfill area and penetrate the aquiferous layer. The results of pollution can be visible even at long distances from the landfill for many years [3].

Leachate's physical and chemical properties and water quality in the vicinity of many landfills have been examined and described in literature [4-6]. In spite of rich documentation, there are no complete data sets which would identify the most important parameters controlling the influence of leachate on water environment.

The purpose of the article is to evaluate the influence of leachate on ground waters in the vicinity of a chosen landfill.

## Material and Methods

The landfill under scrutiny has been in operation since 1984. Its area is approx. 35 ha and there are three disposal cells, out of which only one is presently being used (since 2002). By late 2004 the landfill had approx. 1.004.200 Mg of waste.

On the outskirts of the landfill there is a system of trim drainage ditches picking up precipitation waters from the area. A leachate drainage made of perforated PVC pipes of 110mm in diameter is also installed. Leachate waters are transfered to intermediate pumping stations situated around disposal fields from where they are transported to two storage reservoirs. Purifying accumulated leachate takes place in a treatment plant located within the landfill area.

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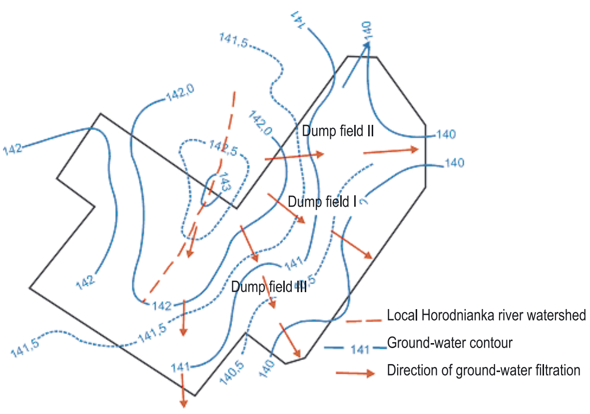


Fig. 1. Ground-water contour configuration on the landfill.

The hydrogeological structure of the area under examination has been determined on the basis of a network of drillings and archival materials. An area of 1500 m from the landfill has been examined. As a result of research and analysis of materials it has been found that in the area under examination quaternary formations dating back to Pleistocene are deposited. The free surface of ground waters is separated from the earth surface by a zone of aeration ranging in thickness from 0.95 m to 5.4 m, i.e. on ordinates approximately 139.0 m to 142.0 m above sea level. The landfill is underwashed by ground waters inflowing from the western direction. Ground waters from beneath the dump flow off mainly in northeastern, southeastern, and eastern directions (Fig. 1).

Table 1. Basic statistical parameters of dump leachate quality from the analyzed landfill site.

| Index | Unit | N | Mean | Total | Minimum | Maximum | Standard deviation |
|---|---|---|---|---|---|---|---|
| Reaction | pH | 30 | 7.9 | 235.9 | 6.1 | 9.8 | 0.8 |
| Temperature | $^0C$ | 30 | 15.2 | 457.2 | 2.0 | 24.1 | 6.2 |
| Electrolytic conduction | µS/cm | 30 | 21394 | 641816 | 1980 | 36000 | 9795 |
| Nitrite nitrogen | $mg/dm^3$ | 30 | 0.424 | 12.710 | 0.001 | 3.140 | 0.693 |
| Nitrate nitrogen | $mg/dm^3$ | 30 | 25.0 | 749.1 | 0 | 120.1 | 28.1 |
| Ammonium nitrogen | $mg/dm^3$ | 30 | 1381.07 | 41432.01 | 162.00 | 4520.11 | 1168.54 |
| Dissolved oxygen | $mgO_2/dm^3$ | 30 | 7.5 | 224.2 | 1.4 | 24.6 | 5.3 |
| $ChZT_{Cr}$ | $mgO^2/dm^3$ | 30 | 6813 | 204402 | 305 | 20100 | 5588 |
| Phosphates(V) | $mg/dm^3$ | 30 | 21.24 | 637.08 | 0 | 78.00 | 22.52 |
| Sulfates(VI) | $mg/dm^3$ | 30 | 55.0 | 1664.2 | 0 | 270.0 | 72.0 |
| Iron | $mg/dm^3$ | 30 | 8.33 | 249.9 | 1.81 | 21.00 | 4.63 |
| Free cyanides | $mg/dm^3$ | 30 | 0.045 | 1.339 | 0.001 | 0.160 | 0.050 |
| Calcium hardness | $mg/dm^3$ | 30 | 463 | 13897 | 10 | 3180 | 664 |
| Magnesium hardness | $mg/dm^3$ | 30 | 413 | 12397 | 9 | 1900 | 394 |
| Total hardness | $mg/dm^3$ | 30 | 876 | 26294 | 42 | 3658 | 863 |
| Chlorides | $mg/dm^3$ | 30 | 1516.8 | 45505 | 50 | 3775 | 886.2 |
| Boron | $mg/dm^3$ | 24 | 8.3 | 198.7 | 0.5 | 16.0 | 5.0 |
| General suspensions | $mg/dm^3$ | 30 | 689 | 20662 | 10 | 1700 | 479 |
| Dissolved substances | $mg/dm^3$ | 30 | 12102 | 363059 | 380 | 18060 | 4262 |
| Dry residue | $mg/dm^3$ | 30 | 12791 | 383721 | 1080 | 18520 | 4304 |
| Cadmium | $mg/dm^3$ | 14 | 0.0708 | 0.9916 | 0 | 0.19 | 0.0745 |
| Copper | $mg/dm^3$ | 14 | 0.216 | 3.0244 | 0.0244 | 0.98 | 0.239 |
| Zinc | $mg/dm^3$ | 14 | 1.106 | 15.4776 | 0.0186 | 2.21 | 0.660 |
| Nickel | $mg/dm^3$ | 14 | 0.364 | 5.099 | 0.07 | 1.3 | 0.321 |

Trim drainage ditches surrounding the landfill from the southeastern side are not a barrier for pollution migration from the landfill. The depth of trim drainage ditches is 1.5 m below ground level while the lower border of the aquiferous layer reaches more than 8 m below ground level. This means that waters from beneath the municipal landfill contaminated by leachate are not captured by the ditches and can freely migrate in eastern and southeastern directions.

Sands forming the first aquiferous layer are of highly varying depth of strata (0.7 m – 12.0 m), quite homogeneous granulation ($\varphi$ = 0.05 mm – 0.20 mm), and low water permeability coefficient $k=10^{-4} - 10^{-5}$ m/s. With such parameters and low hydraulic gradient values, characteristics for watershed and spring areas, ground waters flow at a speed of 10 to 50 m/year. Real speed of downflow as well as hydraulic gradient are variable and depend mainly on precipitation level.

## Results

For the purpose of research, 30 samples of leachate were taken within a 2-year period and selected physical and chemical indices for these samples have been determined. The purpose of the research was to give information on maximum pollution concentration which could penetrate ground and water subsoil and its influence on the area adjacent to the landfill. Table 1 presents basic statistical parameters of the leachate quality at the site.

Mineral composition is mainly influenced by content of chlorides, ammonia nitrogen, total hardness, magnesium hardness, calcium hardness, sulfates(VI), nitrate nitrogen and phosphates(V). Strongly connected with the pollution are electrolytic conduction, dry residue, and dissolved substances. On the basis of Table 1, the content of particular indicators of pollution in leachate can be ordered as follows:

*Cl > $N_{NH4+}$ > dry residue> dissolved substances> total hardness>calcium hardness> magnesium hardness> $SO_4^{2-}$ > $PO_4^{3-}$ > Fe > B > $N_{NO2^-}$ > CN> heavy metals*

Content of heavy metals in leachate can be ordered as follows:

*zinc > nickel > copper > cadmium*

The element that is most strongly present in leachate is zinc. Processes of leaching away of it are probably supported by good solubility of zinc compounds (except carbonates and hydroxides). At pH > 5 zinc migrates most often in a form of sulfate and chloride-complex compounds.

The above series are close to the ones obtained by Szymański in his study on leachate on Sianowo landfill of Koszalin [7].

Compared to leachate at other landfills in Poland, the leachate of the analyzed municipal landfill is characterized by lower concentrations of nitrate nitrogen, chlorides, dissolved substances, and zinc. For example, mean content of zinc in the examined landfill was 1.1055 mg/dm$^3$, while in Swojczyce landfill of Wrocław it was 12.0 mg/dm$^3$, and in Wola Zarczycka (landfill of Leżajsk (podkarpackie voivodeship)) it was 3.4 mg/dm$^3$. Higher values for the leachate on the landfill of this paper are in electrolytic conduction and iron [7]. The differences may be caused by different ways of using the landfills as well as their operation time.

## Discussion

Scale and range of pollution in the examined area have been observed in 7 piezometer test wells and 4 nearest household wells and analogous parameters have been determined for leachate. Location of measuring points is presented in Fig. 2.

Examined waters were characterized by varying concentrations of particular indicators of pollution depending on sampling point. To evaluate the influence of leachate on quality of underground waters the multidimensional factor analysis procedure has been used which describes the most important regularities existing in the analyzed sets of variables (Table 2). The basic idea of factor analysis (a.k.a. the main components analysis) is joining two correlated variables into one factor. The main purpose of using factor analytical techniques is to discover structure in relations between variables. Factor analysis has been carried out by means of one of the options in the Statistica program. The analysis

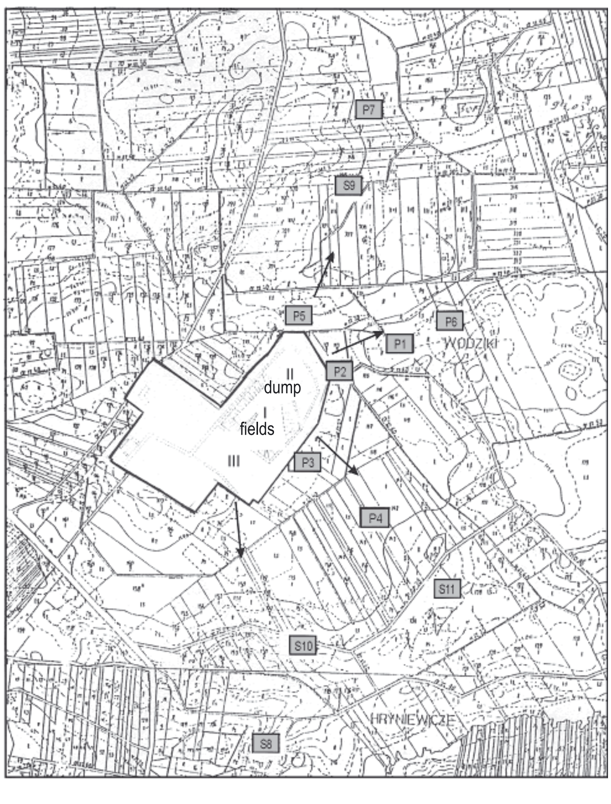


Fig. 2. Location of measuring points within area adjacent to the analyzed landfill.

of main components with Varimax rotation has been chosen as the procedure for isolating factors. The purpose of the rotation is to maximize the variability of a new factor with a simultaneous variance minimization around it. Subsequent factors are orthogonal and their analysis can be helpful in the classification of processes taking place in the examined waters. Because each factor is correlated with different variables, their analysis can allow evaluation of the significance of particular variables in quality forming of the examined waters. In the results interpretation, factors with correlation coefficient r >0.500 were considered substantial.

Additionally, in order to evaluate the interaction force of a particular factor in subsequent control points, mean factor loads have been calculated (Table 3).

Maps showing the influence of a particular factor in subsequent control points have been worked out on the basis of the calculated loads. The factor load distribution analysis has facilitated the interpretation of results obtained during the factor analysis, all the more so because they come from nine points situated unevenly on the examined area.

Ground water test results present 4 factors, describing 63.31% of appearing phenomena (Table 2). On the basis of the results analysis it has been stated that Factor 1 characterizes general pollutant indices, Factor 2 allows isolation of the pollutant characteristic for the landfill, Factor 3 shows the transition zone between the landfill and examined wells, and Factor 4 describes processes taking place with participation of iron compounds.

The first factor, explaining 32.28% of all variances, remains in high positive correlation with nitrate nitrogen, general suspensions, dissolved substances, and dry residue. Strong positive correlation, $|\pm 0.5| \leq r < |\pm 0.7|$,

Table 2. Factor analysis of chemistry of groundwaters in the area of municipal landfill – Varimax rotation version.

| Index | Factor1 | Factor2 | Factor3 | Factor4 |
|---|---|---|---|---|
| Reaction | -0.152 | -0.178 | -0.014 | 0.365 |
| Temperature | -0.334 | 0.427 | -0.147 | -0.557 |
| Electrolytic conduction | **0.654** | 0.172 | -0.104 | -0.276 |
| Nitrite nitrogen | -0.142 | -0.051 | -0.629 | -0.146 |
| Nitrate nitrogen | **0.736** | -0.032 | 0.003 | 0.037 |
| Ammonium nitrogen | 0.174 | 0.482 | -0.046 | 0.002 |
| Dissolved oxygen | -0.208 | **-0.614** | -0.032 | 0.367 |
| $ChZT_{Cr}$ | 0.448 | 0.214 | 0.114 | 0.024 |
| Phosphates(V) | -0.071 | 0.347 | 0.271 | 0.072 |
| Sulfates(VI) | 0.252 | -0.081 | -0.146 | -0.218 |
| Iron | 0.116 | 0.256 | -0.017 | **0.628** |
| Free cyanides | 0.205 | **0.557** | 0.204 | 0.104 |
| Calcium hardness | -0.144 | 0.131 | -0.157 | **0.715** |
| Magnesium hardness | 0.103 | 0.017 | **-0.845** | -0.120 |
| Total hardness | -0.035 | 0.116 | **-0.779** | 0.482 |
| Chlorides | **0.577** | -0.178 | 0.058 | 0.113 |
| Boron | -0.063 | **0.633** | -0.019 | 0.199 |
| General suspensions | **0.729** | -0.164 | -0.043 | 0.177 |
| Dissolved substances | **0.790** | 0.158 | 0.009 | -0.127 |
| Dry residue | **0.953** | 0.045 | -0.012 | -0.006 |
| Cadmium | -0.107 | **-0.636** | 0.066 | -0.030 |
| Copper | 0.102 | **-0.503** | 0.276 | -0.137 |
| Zinc | 0.001 | **-0.704** | 0.072 | -0.145 |
| Nickel | **0.504** | -0.30066 | 0.129 | -0.083 |
| % of variation | **32.28** | **14.40** | **9.25** | **7.38** |

also appears in electrolytic conduction, chlorides, and nickel (Table 2). On the basis of the map of distribution of factor values in alternate measuring points, presented in Fig. 3, we can conclude that they are general pollution parameter characteristic for both areas in the immediate vicinity of the landfill and areas in which households with dug wells are located. The distribution of the above-mentioned values allows us to determine an approximate border between landfill influence and pollution created by households.

The second factor, comprising 14.40% of global variability, shows positive correlation with boron and cyanides, and negative with dissolved oxygen, cadmium, copper, and zinc (Table 2). It describes conditions of occurrence of the heavy metals, boron, and cyanides depending on quantity of dissolved oxygen in water. High

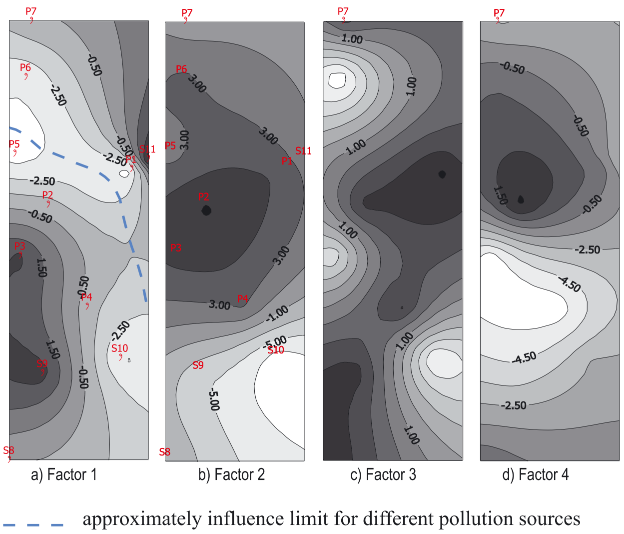


Fig. 3. Distribution of mean factor values in alternate measuring points near the analyzed landfill.

content of oxygen, i.e. oxidizing conditions, favors occurrence of cadmium, copper, and zinc in waters, simultaneously causing decrease in content of boron and cyanides in the waters. Factor value analysis in alternate points shows that heavy metals pollution concerns mainly waters in household wells, while the increase in boron and cyanide concentrations affects waters in the immediate vicinity of the municipal landfill (Table 3). The factor allows the isolation of parameters causing water pollution near the landfill and not appearing near other pollution objects, e.g. household buildings.

The third factor, describing 9.25% of all variances, negatively correlates with the value of nitrite nitrogen, magnesium hardness, and total hardness (Table 2). Its negative influence is best seen in the immediate vicinity of the landfill and in water in a dug well (point S10) (Table 2, Fig. 3). The factor exemplifies the transition zone (presence of $N_{NO2}$) between the landfill and examined household wells. Factor value distribution analysis enables us to determine the border between pollution from the dump and household buildings.

The fourth factor (7.38%) is positively correlated with iron compounds and calcium hardness and negatively with water temperature (Table 2). In waters polluted by organic compounds there can occur iron migration, mainly in the form of complex organic compounds. Processes described by the factor dominate in point P2 and they have the weakest influence in points P3 and P4 (Table 3).

## Conclusions

The four isolated factors have allowed us to determine the participation of examined variables in different processes taking place in ground waters. Analysis shows that waters near the landfill are characterized by increased concentrations of boron and cyanides, while waters in dug

Table 3. Factor values for alternate control points of ground-water in the area of municipal landfill.

| Location | Factor1 | Factor 2 | Factor 3 | Factor 4 |
|---|---|---|---|---|
| P1 | -3.728 | 4.533 | -1.107 | 0.014 |
| P2 | -1.062 | 7.251 | -0.612 | 2.747 |
| P3 | 2.706 | 5.530 | 2.923 | -6.099 |
| P4 | -1.028 | 3.063 | -0.623 | -6.100 |
| P5 | -4.087 | 2.390 | 1.204 | 1.102 |
| P6 | -3.258 | 3.410 | 3.930 | 0.326 |
| P7 | -0.740 | 0.000 | -0.145 | -2.603 |
| S8 | -0.474 | -1.140 | -1.013 | 0.267 |
| S9 | 2.982 | -4.390 | -0.761 | -4.121 |
| S10 | -3.633 | -8.401 | 3.609 | -2.461 |
| S11 | 4.146 | 1.206 | -0.365 | -2.622 |

wells are characterized by higher content of heavy metals: cadmium, copper, and zinc. Other studies [5, 7] show that the factor which limits the durability of metal-organic connections can be high concentration of chlorions and nitrate ions. The ions occurring in waters in dug wells can facilitate creation of soluble forms of heavy metal compounds with the ions. The increase in concentration of boron and cyanides reaches points P1 and P4, 260 and 400 m away from the dump, respectively. The given distances can describe approximate range of pollution from the leachate.

Analyses show that using factor analysis to interpret results allows to create synthetic measures describing the most important processes taking place in the examined ground waters. Detailed evaluation of factor values can be helpful in evaluating the range of pollution migration from landfill sites.

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