# SLUDGE EFFECT ON GROUNDWATER QUALITY
## *Notekūdeņu duļķu iedarbība uz pazemes ūdeņu kvalitāti*

**A. Gontaszewska, A. Kraiński**
Instytut Budownictwa, Uniwersytet Zielonogórski, ul. Z. Szafrana 2, 65-516 Zielona Góra, Poland

**Abstract**
*The influence of sludge on the groundwater's quality has been shown on the bases of the agricultural exploitation of the sludge from a sewage-treatment plant. Little thickness of unsaturated zone (8.8 m) is not effective protection against the infiltration of the pollution from the surface. Unsaturated zone consist of sand of permeability coefficient k=0,68 m/h. The time of the vertical infiltration into the aquifer has been estimated at t=14,4 days. The investigations carried out during fertilization with the sludge have revealed an undoubted increase in the concentration of some ions as well as the increase in pH of the groundwater. The increase in the amount of some ions (e.g. $N\text{-}NO_3$, $SO_4$, Zn) as well as detergents indicates the possibility (as function of time) of reaching higher values than the ones permissible for drinking water. The phenomenon of the increase in the concentration of the particular ions will be accelerated after depletion of sorption of the soil in the unsaturated zone. The time can be estimated for not more than several years, taking into account a small area of the fertilized fields and high contents of "pollution" in the sludge (the total of the heavy metals reaches up to 1,5 g/kg)*
**Keywords:** *sewage sludge, groundwater quality, pollution, sludge exploitation.*

The sludge of the Gubin-Guben sewage-treatment plant is used in field fertilizing in the area of Brzozów, West Poland (fig.1). To evaluate the influence of the agricultural application of the sludge some geological research has been carried out and a local monitoring network has been made in two stages [7]. The compositions of the underground water and the sludge are analysed within the monitoring of the environment, which includes mainly the influence of the sludge on the underground water quality, each three months. The paper presents the analysis of the relation between the underground water quality and the composition of the sludge.

The geological structure of the region of the sludge application has been recognised in details to the depth of 15m under the ground level. There are sand deposits in the subsoil. It should be connected with the glacial outwash of Weichsel glaciation [4]. The thickness of the outwash series exceeds 15m. It consists mainly of medium and coarse sands and locally fine sand and sand gravel mix. In the southern part of the region there are loamy sands of the thickness up to 3m. down from the surface of the area.

In the bottom of the fluvioglacial deposits occur glacial drift, which can be connected with Saale glaciation [5,6,8]. The top surface of the glacial drift is irregularly distributed in the geological space (fig.2 and fig.3). This is probably partly the result of the glacitectonical distortions connected with the presence of the glacier front of Brandenburger glaciphase in the northern part of the region.

A single water bearing layer of the Quaternary level occurs in the subsoil of the described area. The water level stabilises at the depth 0.91 – 12.81m. under the ground level. The falls of the water level vary (fig.1), which results from the elevation of the loamy subsoil (and the water level) in the line of the holes VI – IV. The thickness of the aeration zone south from the holes VI-IV increases from about 6–7m to nearly 11-13m. (fig.3) with the mean value (from the piezometers in the fertilized area) m. = 8.81m. The values of the filtration coefficient oscillate in the range from k=0.075m/h up to k=1.98m/h, with the mean value k=0.63m/h (forn=24). It is also characteristic (in the majority of the holes) that the values of the filtration coefficient increase with depth.



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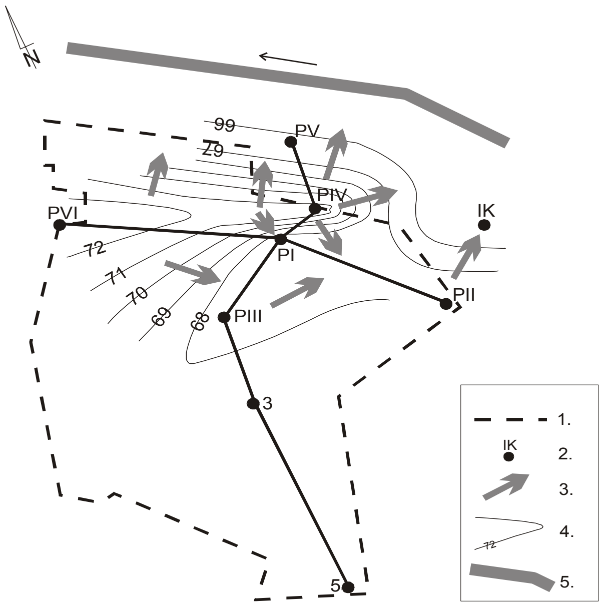


Fig. 1. Situation map of the region of sludge application. Explanation: 1- region's boundary; 2 – point of water uptake; 3 – groundwater flow; 4 – hydroisohypse; 5 - river

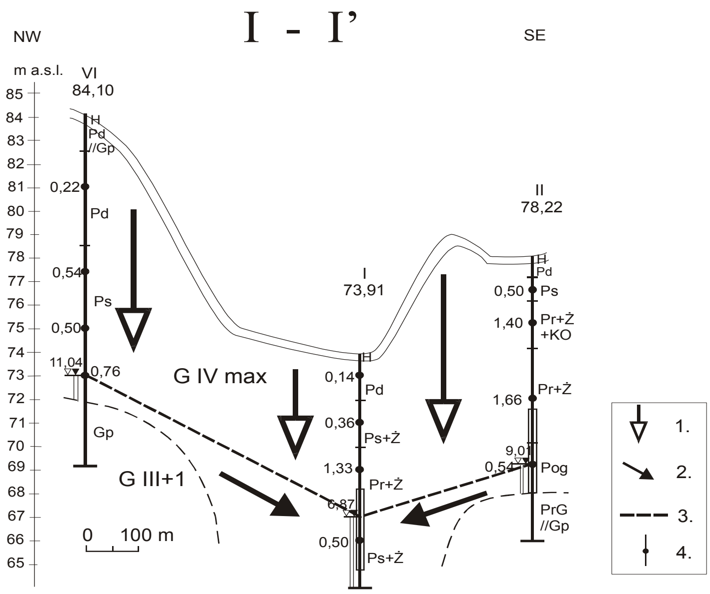


Fig.2. Geological Section I - I

Explanations: 1 - infiltration of pollution in the aeration zone; 2 - water flow in the water bearing layer; 3 - underground water level; 4 – filtration coefficient (m/h)

The thickness of the aeration zone in the recognised (northern) part of the area amounts from about 1m. (holes II and VI) up to several meters (3 and IV). The values of the filtration coefficient amount from k=0.14m/h to k=1.87m/h. The mean value k=0.68m/h (for n=11) is congruent with the calculated value of the filtration coefficient for the aeration zone. Periodical variations of the water level depend exclusively on the meteorological conditions (rainfalls) and amount from 0.49m (hole III) to 1.88m. (I).

Assuming the above mean values of the parameters of the aeration zone, the time of vertical infiltration through the zone can be calculated [10] (time of the shift of compounds from the sludge to the underground water level) which means that chemical compounds can be shifted from sludge to water bearing layer within two weeks.



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The results of the 2001-2002 research of the sludge of the Gubin-Guben sewage-treatment plant are presented in tab.1

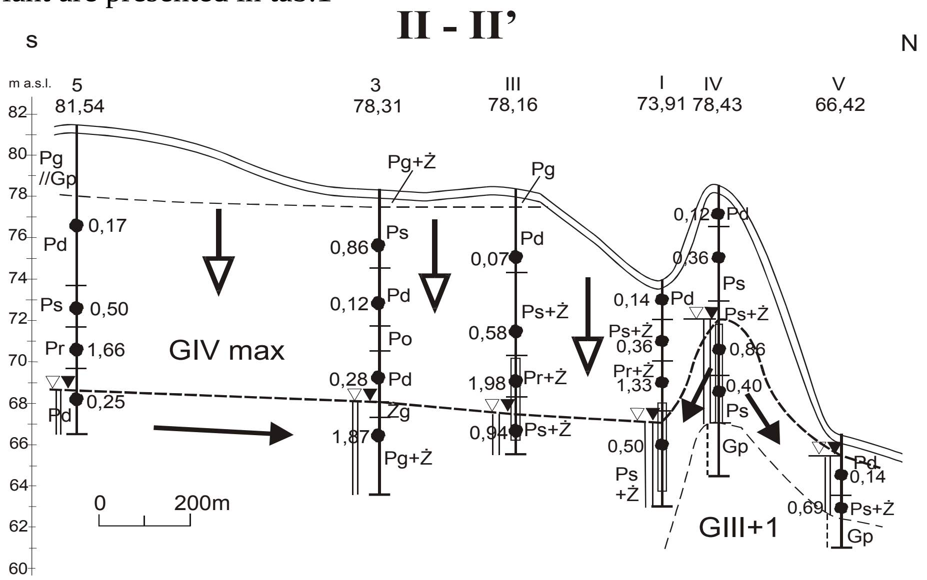


Fig.3. Geological Section II – II. Explanations – see fig.2.

The values of the particular physicochemical parameters vary considerably, e.g. the content of zinc ranges from 3801170mg Zn/kg s.m. High pH of the sludge: from 10.5 to 12.1, which may limit considerably the mobility of metal ions [18]. The typical range given in the table comes from [11] and comprises the results derived from 156 sewage-treatment plants during the years 1993-2000.

Table 1.

**The results of the examination of the sludge of the Gubin-Guben sewage-treatment plant**

| indicator | unit | 14.02.01 | 29.05.01 | 15.09.01 | 11.12.01 | 26.03.02 | 31.05.02 | 10.07.02 | mean values | typical range |
|---|---|---|---|---|---|---|---|---|---|---|
| humidity | % | 72,6 | 69,2 | 73,4 | 68,8 | 69,9 | 48,3 | 69,4 | 67,40 | - |
| organic matter | % | 48,2 | 47,0 | 47,4 | 36,0 | 43,4 | 75,0 | 49,9 | 49,56 | 50,62 |
| reaction | pH | 12,1 | 12,1 | 10,6 | 11,9 | 11,9 | 10,5 | 11,3 | 11,49 | 6,5-7,5 |
| nitrogen | % | 2,39 | 2,65 | 2,75 | 3,00 | 3,40 | 4,20 | 4,7 | 3,30 | 3,53 |
| phodphorus | % $P_2O_5$ | 1,10 | 1,3 | 1,11 | 1,28 | 1,50 | 2,05 | 2,45 | 1,54 | 3,01 |
| calcium | % CaO | 6,3 | 6,1 | 11,1 | 6,3 | 6,20 | 7,9 | 8,4 | 7,47 | 3,31 |
| potassium | %$K_2O$ | | | 0,05 | | | 1,20 | 1,20 | 0,82 | 0,4 |
| magnesium | %MgO. | 0,54 | 0,6 | | 0,9 | 0,78 | 0,9 | 1,10 | 0,80 | 0,72 |
| zinc | mgZn/kg | 167 | 208 | 1170 | 688 | 414 | 38 | 187 | 410 | 1350 |
| copper | mgCu/kg | 95 | 97 | 31 | 250 | 290 | 197 | 81 | 149 | 147 |
| lead | MgPb/kg | 22 | 45 | 200 | 85 | 83 | 60 | 14 | 73 | 47,5 |
| chromium | MgCr/kg | 8,2 | 6,7 | 13 | 15 | 42 | 23 | 13 | 17 | 175 |
| nickel | mgNi/kg | 9,3 | 11 | 24 | 21 | 22 | 22 | 7 | 17 | 30 |
| cadmium | mgCd/kg | 1,0 | 0,8 | 4 | 8 | 2 | 1 | 1 | 2,5 | 3,3 |

The sorption features of the glacial outwash deposits have been described in [1], as has been the influence of anthropo-pression on the underground water in [9, 13-15, 17] as well as problems connected with heavy metals in sewage, their migration and forms of occurrence [2, 3, 17, 19]. Data derived from piezometers PI, PII, PIII and a test well (IK), which is localized in the north of the area, have been used for the analysis of variation in the chemical composition of underground water resulting from the sludge fertilization.

The features of the underground water derived from the piezometer PVI have been assumed to be the hydro-geo-chemical background (so, the composition of the underground water corresponding to the composition before the sludge fertilization). It is should be mentioned, however, that the piezometer was produced in 2002.



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It results from the comparison of the values that:

- pH of the underground water has increased from 6.7 to 6.8;
- oxidizing abilities of water has decreased from 6.5 – 3.5 mgO2/dm3;
- the content of ammonia nitrogen has increased from 0.19 – 0.60 mgNH4/dm3;
- the content of sulphate has increased from 40 – 90 mgSO4/dm3;
- the content detergents has increased from 0.0015 – 0.0320 mg/dm3;
- the content of zinc has increased from 0.07 – 0.30 mgZn/dm3;

Table 2.

**Statement of the mean values of indicators in the water of the local monitoring network**

| | P I | *P II* | P III | IK | ***mean values*** | ***P VI*** | ***increase (%)*** |
|---|---|---|---|---|---|---|---|
| **pH** | 6,6 | 6,8 | 6,8 | 6,9 | ***6,8*** | ***6,7*** | ***1,2*** |
| **oxidization** | 3,8 | 3,7 | 2,9 | 4,2 | ***3,7*** | ***6,5*** | ***-78,1*** |
| **basis** | 1,7 | 2,4 | 1,8 | 2,6 | ***2,1*** | ***4,8*** | ***-126,3*** |
| **Ca** | 80,7 | 88,3 | 76,5 | 102,0 | ***86,9*** | ***80,1*** | ***7,8*** |
| **Mg** | 11,5 | 17,1 | 11,6 | 14,9 | ***13,8*** | ***18,2*** | ***-32,0*** |
| **Fe** | 2,84 | 1,98 | 3,35 | 0,28 | ***2,12*** | ***0,61*** | ***71,2*** |
| **Mn** | 0,36 | 0,89 | 0,55 | 0,17 | ***0,49*** | ***0,15*** | ***69,4*** |
| **N-NH4** | 0,64 | 0,78 | 0,58 | 0,26 | ***0,57*** | ***0,19*** | ***66,4*** |
| **N-NO2** | 0,06 | 0,09 | 0,08 | 0,08 | ***0,08*** | ***0,35*** | ***-358,1*** |
| **N-NO3** | 17,06 | 12,21 | 12,19 | 17,45 | ***14,73*** | ***1,13*** | ***92,3*** |
| **PO** | 0,11 | 0,08 | 0,13 | 0,52 | ***0,21*** | ***0,13*** | ***38,2*** |
| **Cl** | 34,1 | 34,2 | 26,4 | 34,1 | ***32,2*** | ***38*** | ***-18,0*** |
| **$SO_4$** | 84,1 | 97,0 | 87,1 | 120,0 | ***97,1*** | ***40*** | ***58,8*** |
| **K** | 17,8 | 13,2 | 6,6 | 20,5 | ***14,5*** | ***9,8*** | ***32,6*** |
| **detergents** | 0,035 | 0,038 | 0,023 | 0,015 | ***0,028*** | ***0,001*** | ***96,4*** |
| **Zn** | 0,416 | 0,358 | 0,091 | 0,508 | ***0,343*** | ***0,071*** | ***79,3*** |
| **Cu** | 0,013 | 0,012 | 0,009 | 0,013 | ***0,012*** | ***0,028*** | ***-138,1*** |
| **Pb** | 0,014 | 0,010 | 0,011 | 0,014 | ***0,012*** | ***0,026*** | ***-112,7*** |
| **Cr** | 0,008 | 0,007 | 0,005 | 0,006 | ***0,007*** | ***0,008*** | ***-23,1*** |
| **Ni** | 0,013 | 0,013 | 0,009 | 0,011 | ***0,011*** | ***0,020*** | ***-76,9*** |
| **Cd** | 0,001 | 0,002 | 0,001 | 0,002 | ***0,002*** | ***0,002*** | ***-21,5*** |

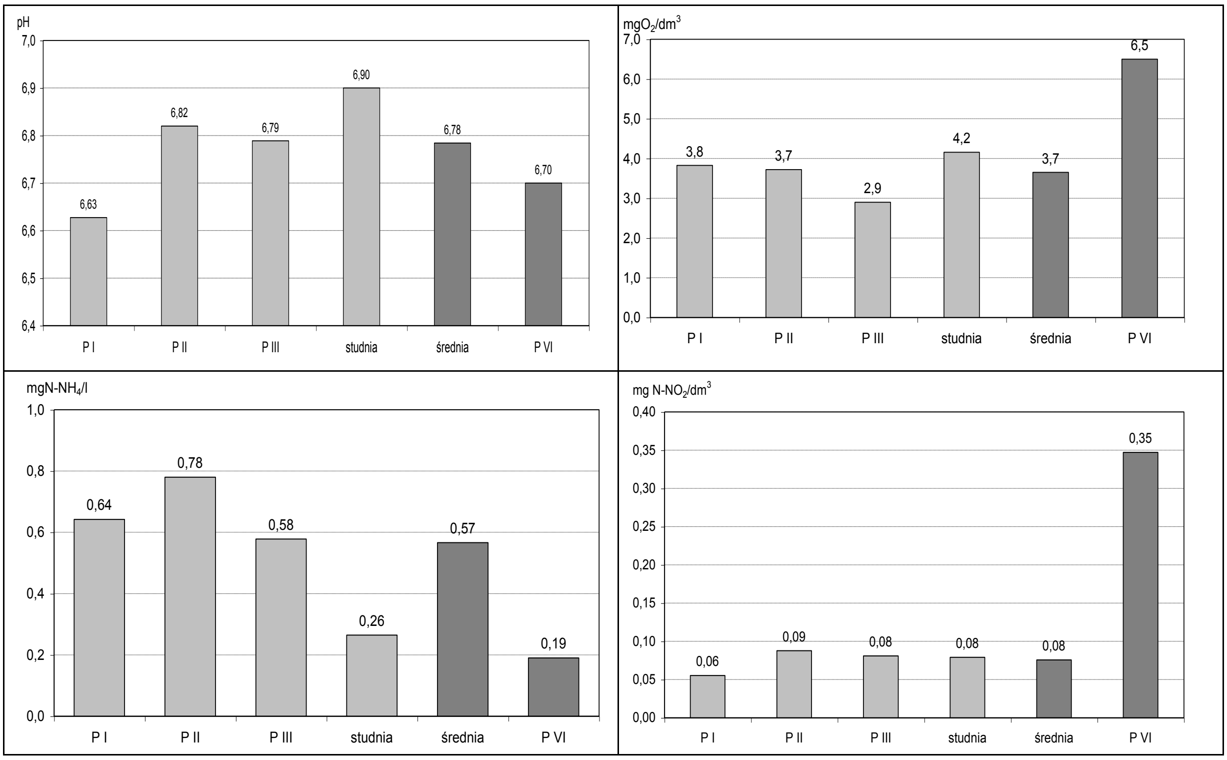


Fig.4. Comparison of mean value of some parameters in piezometers and well with hydrogeochemical background



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But there is a slight decrease in the number of ions Cu, Pb, Cd and Ni. It has been probably caused by the improvement in sorption features of the ground because of the increase in pH reaction [18]. The received mean results have been compared to the values derived from the piezometer PVI. The credibility of the comparison is considerably lowered (among others) because of there's only one measurement for piezometer PVI situated at the edge of the fertilized area and a forest and it may not illustrate well the hydro-geo-chemical background. It's remarkable that the contents of: iron, manganese, ammonia, nitrates, phosphates, sulphates and detergents increase in water, with the simultaneous decrease in its alkalinity and the number of magnesium ions, nitrites, sodium and all the heavy metals, except for zinc.The decrease in the content of heavy metals ions may be attributed to the deterioration of their mobility caused by increase in pH. Also compositions between values of the particular physicochemical parameters of the sludge and underground water within fertilized area (fig.5).

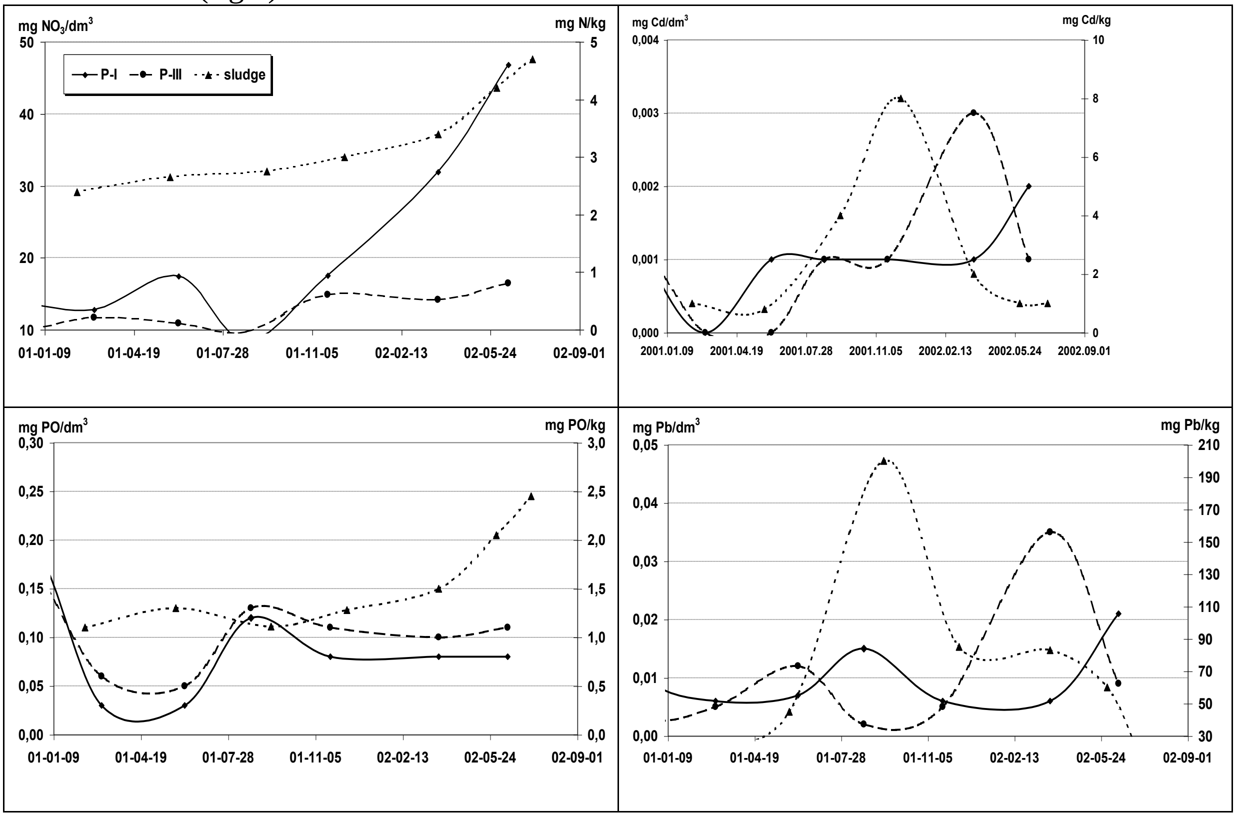


Fig.5. Comparison of contents the selected parameters in the underground water and the sludge

A close relationship between the composition of the sludge and the composition of the underground water is visible in piezometer PI. The highest correlation (r) has been found between the content of the nitrogen in the sludge and the content of the nitrogen nitrate in the underground water (0.95) and between the contents of zinc (0.73) and potassium (0.90) in the sludge and the underground water. Relationships between the contents of the particular ions in underground water from piezometers and the test well, situated in the close neighbourhood of the area fertilized with the sludge, have also been found. The relationships, best visible for piezometer PI, indicate a common source for a considerable part of ions Cl, SO4, NH4, Cu, Ni, Cr, Zn and detergents. The values of correlations between the contents of the particular ions in piezometers PI, PII, PII and the test well are presented in tab.3.

It results from the carried out analysis that the examined sludge applied to agriculture has a negative influence on quality of underground water. A recurring several times increase



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in content of zinc ions, ammonium nitrate and nitrogen nitrate as well as the content of detergents has been recorded for a number of cases. The increased content of ammonium nitrate exceeds even the standards for drinking water. The pollution with heavy metals has not been found to be hazardous, which may be initially attributed to the high value of the sludge pH. Although, it can be just time delay, until the soil's sorptive capacity is depleted.

Table 3.

**Values of the correlation coefficient (r) between the selected ions in the local monitoring network**

| **Ions** | **PI** | **PI + PIII** | **PI + PII + PIII + test well IK** |
|---|---|---|---|
| Cl-$SO_4$ | 0.92 | 0.70 | 0.60 |
| $NH_4$-$NO_2$ | 0.87 | 0.69 | 0.58 |
| $NH_4$-det | 0.45 | 0.27 | 0.39 |
| $NH_4$-Ni | 0.74 | 0.68 | 0.51 |
| $NH_4$-Cu | 0.94 | 0.84 | 0.71 |
| $NO_2$-Cu | 0.91 | 0.84 | 0.62 |
| Cu-Ni | 0.65 | 0.60 | 0.49 |
| Cr-Ni | 0.77 | 0.66 | 0.59 |
| Zn-Cl | - | 0.65 | 0.45 |

The paper presents only a part of the results of the examinations, which has been carried out for two years now. The short time of the observations does not allow a full evaluation of the influence of the sludge agricultural application on the underground water quality. However, a considerable influence of high pH of the sludge on the content of ions of heavy metals in the underground water is recorded, since the high pH results in a decrease in the number of heavy metals. The variations in the water quality within the mean values of parameters are considerable and may exceed 100%. It may also be concluded that after the depletion of the sorptive capacity of the soil in the unsaturated zone the composition of water does not deteriorate. The essential limitation of the presented analysis is the lack of the reliable data on the hydro-geo-chemical background and the values of the natural variations of the parameters within a year and a couple of years.

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