Original Research

Changes in Physico-Chemical Composition in Groundwater under Area of Treatment Plant Operating in Natural Environment

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Abstract

This article introduces results of observations concerning changes in groundwaters located under the area of an exploiting plant-soil treatment plant. The research period included months from December 2008 to December 2009. In this period authors analyzed water samples from piezometers located around and directly on the irrigated area. Water samples were collected one a month. Each sample was analyzed for the following pollution indexes: BOD_5, COD_{Cr}, total nitrogen, total phosphorus, total suspension. Groundwaters were collected from the existing piezometric net (P1-P3) that was installed before main exploitation and from the complementary net (P4-P6) completed in 2008. Research showed that composition of groundwater located directly under the irrigated area declined in quality. The highest pollution indexes were observed in piezometer No. 4 for almost all indices. Research and direct observations showed improper exploitation of the treatment plant caused by overloading the irrigated area with high pollutant loads, resulting in decreasing treatment capability. For the purpose of regeneration of soil profile, further operation of the treatment plant should be verified in regard to decreasing single doses of sewage.

Keywords: piezometers, groundwater, pollution indexes, exploitation

Introduction

Within terrain without a central sewage system the treatment of even small amounts of waste effluent is a significant issue.

When building a local sewage treatment plant the complexity of the wastewater treatment processes should be taken into account [1].

Country terrains lacking in central sewage systems may determine a threat to groundwater in the event when local solutions of effluent treatment are improperly designed and exploited [2-4].

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This is observed, above all, by tank unsealing (cesspools and non-flow-through pits), as well as faeces disposal onto the adjacent field eluding liquid waste disposal stations adapted for sewage collection. Such activities aim at reducing costs connected with sludge and sewage removal.

The appropriate solution for collection and treatment of wastewater in rural areas should not only feature the high treatment operation and low costs of both construction and operation, but also a positive impact on the surrounding landscape [1, 5].

The Ordinance of the Minister of the Environment [6] determines conditions that shall be fulfilled in the course of entry of treated effluents to water and soil environment, and therefore it constitutes a legal regulation for home

Table 1. An average composition of household waste after mechanical treatment brought into plant-soil treatment plant in research period December 2008-December 2009.

Research period December 2008-December 2009	Pollution indicators				
	BOD_5	COD_{Cr}	Total nitrogen	Total phosphorus	Total suspended solids
	$mgO_2 \cdot dm^{-3}$	$mgO_2 \cdot dm^{-3}$	$mgN \cdot dm^{-3}$	$mgN \cdot dm^{-3}$	$mg \cdot dm^{-3}$
	188.62	497.92	79.65	10.42	167.77

sewage treatment systems. However, despite the fulfilment of such requirements, improper exploitation may harm quality of shallow-lying waters under the irrigated surfaces.

Sewage treatment in facilities working in a natural environment constitutes the alternative to traditional solutions of the following type: infiltrating drainage, sand filters, low-loaded activated sludge, etc.

Plant-soil-land filters are an extremely cheap solution because raw materials may be acquired from the natural environment (filling material and flora). Treatment processes in such treatment plants are extensive [7-9].

The characteristic feature of land filters is an artificial sealing in the form of soil that is put on the construction site of such a facility [10]. Soil filters are solutions using natural water-and-soil conditions in location of the treatment plants. After a previous mechanical treatment, waste effluents are directly released into the soil profile. Within such solutions, operating errors may result in an insufficient sewage treatment in the profile and effluent infiltration into groundwater shallow-lying relatively under the irrigated surface [5, 10, 11].

The systems have a lot advantages, including low construction and operating cost, high reduction of pollution indicators, and ease of integration into the surrounding landscape. Despite these benefits, irrigation regime and the quantities of effluent doses that may be released into the filter surface shall be absolutely observed.

Both in Europe and other parts of the world a huge number of Constructed Wetland systems have been designed for water pollution control purposes. They have been built as vertical or horizontal subsurface flow beds as well as hybrid systems (combinations of vertical and horizontal flow systems). The most common filling media are fine gravel or coarse sand [10, 12]. However, this type of object yields satisfactory results only for TSS (total suspended solids) and oxygen indices expressed as BOD_5 and COD [11]. Recent years have brought a new type of filling that improves operation over a longer period of time and protects the bed from clogging [13-15].

In 1996 a plant-soil treatment plant was put into operation in Brzeźno. Its long-standing monitoring spans the period of covering grains with manganese dioxide and the years of real exploitation, and also a period of intensely overloading the bed with waste effluent. Within terrain of the treatment plant a piezometer network has been installed with the aim of controlling waters lying under the irrigated surface [16].

The objective of this article is to show the direction of change that occurred in the course of a multiannual exploitation of the facility and the attempt to determine the influence of this form of sewage treatment on shallow-lying groundwater.

Research Methodology

Monitoring the composition of subterranean waters lying within the treatment plant and its surroundings was conducted in the period December 2008 to December 2009, and covered physicochemical analyses of the composition of wastewater after the mechanical treatment and the adduction to the facility and also the composition of subterranean waters.

A plant-soil treatment plant built for country residential development in Brzeźno constituted the research subject. Its long-standing exploitation and multiannual observations determined the choice of this treatment plant as a research subject. Household waste, which is collected throughout the sewerage network from the adjacent village, is subjected to a mechanical treatment in two three-chamber septic tanks of 55 m^3 capacity.

An average composition of household waste brought into the plant-soil treatment plant in Brzeźno within the research period is shown in Table 1. Average quantities of pollution indicators in wastewater treated in the facility differed considerably from parameters of a typical household wastewater provided in literature. Attentions shall be paid to high concentrations of total nitrogen and total phosphorus. This, probably, may be connected with a considerable part of waste effluents delivered to the examined facility using a gully emptier fleet [3].

After mechanical treatment the wastewater is pumped into a dosing-and-accumulating tank located within the treatment plant. A 110 m^3 tank after its filling, throughout a lifting device, feeds a ditch supplying wastewater into chosen sectors. The sewage collection sector was designed as a dyked and flat surface where poplar trees and grass mixture were planted.

Twenty-one sectors were prepared for year-long sewage collection. A single irrigation dose equal to 97 mm for each sector was provided in this facility.

Waste effluents are released into each sector every 21 days, regardless of the season. After passing through the soil filter at a depth of around 1.0 m, treated waste effluents are collected by a drainage system and then discharged into the point of disposal.

Table 2. Physicochemical composition of groundwater collected from piezometers before plant treatment operation [3].

Indices	Unit	P1	Quality class	P2	Quality class	P3	Quality class
pH	-	7.0	I-III	7.35	I-III	6.7	I-III
COD_{Mn}	mgO_2/dm^3	4.1	-	4.3	-	4.2	-
Ammonium nitrogen	$mgNH_4/dm^3$	0.31	II	0.4	II	0.32	II
Nitrate nitrogen	$mgNO_3/dm^3$	0.45	I	0.82	I	1.34	I
Nitrite nitrogen	$mgNO_2/dm^3$	0.00	I	0.043	II	0.054	III
Chlorides	$mgCl/dm^3$	122.0	II	47.0	II	22.0	II
Calcium	$mgCa/dm^3$	191.5	III	144.0	III	79.2	II
Magnesium	$mgMg/dm^3$	27.5	I	16.3	I	10.3	I
Sulphates	$mgSO_4/dm^3$	335.0	IV	230.0	II	116.0	II
Total solids	mg/dm^3	1065.0	-	694.0	-	394.0	-
Lead	$mgPb/dm^3$	0.018	II	0.1585	V	0.0495	II
Cadmium	$mgCd/dm^3$	0.00	I	0.00	I	0.00	I
Chromium	$mgCr/dm^3$	0.00	I	0.0045	I	0.0015	I
Total quality class			IV		V		III

A diagram of the treatment plant along with the location of measurement points is shown in Fig. 1.

Before putting the facility into operation, controlling boreholes were carried out (before the treatment plant and within terrain of a planted irrigation) [17]. When drilling, water samples were collected. An average physicochemical composition of groundwater collected during drilling is shown in Table 2.

Quality of groundwater before the treatment plant is characterized by water collected from the first drilling (P1). This sample is characterized by a high concentration of sulphates, whereas in subsequent drilling P2 the highest concentration of lead of all observed ones was registered. Water from piezometer No. 3 was of purity class III [17].

In 2008, within the terrain of the treatment plant in Brzeźno, a supplementary network consisting of three piezometers numbered P4-P6 was installed (Fig. 1 presents the location of piezometers). Piezometers were made of pipes with a diameter of 110 mm, to a depth 3.0 m.

Additional piezometers were supposed to supplement the existing piezometer network, and thereby give a detailed picture of quality changes of water lying under the treatment plant.

A structural diagram of piezometers (P4, P5, and P6) is shown in Fig. 2. Pollution indicators, which were marked in water samples collected during boring in 2008, are shown in Table 3.

Samples of groundwater from piezometers P1-P6 were taken monthly in the research period December 2008-December 2009.

Analyzed samples marked the following pollution indicators:

- BOD_5 (using OxiTop)
- COD_{Cr} (using MerckTest and spectrophotometer Photolab Spectral WTW, mineralization)
- Total nitrogen (using MerckTest and spectrophotometer Photolab Spectral WTW, mineralization)

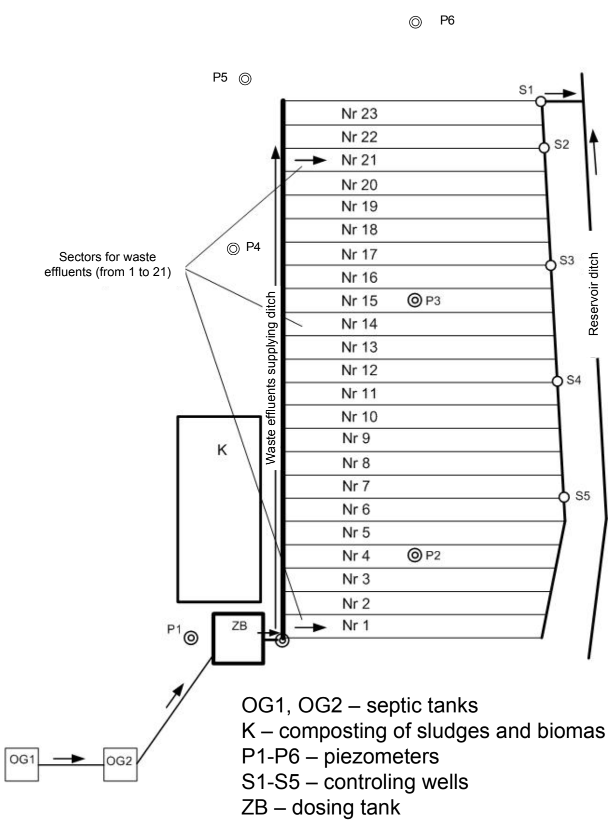


Fig. 1. Schema of treatment plant working in natural environment.

Table 3. Average physicochemical composition of groundwater sampling after 10-year-long operation [21].

No.	Indicator	Unit	P4	Quality class	P5	Quality class	P6	Quality class
1	pH	-	6.9	I-III	6.8	I-III	6.8	I-III
2	Conductivity	µS/cm	1030.0	II	450.0	II	515.0	II
3	Chlorides	$mgCl/dm^3$	144.0	II	47.3	II	87.7	II
4	Nitrate nitrogen	$mgNNO_3/dm^3$	<0.113	I	<0.113	I	<0.113	I
5	Sulphates	$mgSO_4/dm^3$	234.0	II	105.0	II	123.0	II
6	Sodium	$mgNa/dm^3$	138.0	II	11.4	I	39.5	I
7	Ammonium nitrogen	$mgNH_4/dm^3$	<0.03	I	0.134	II	<0.03	I
8	Nitrite nitrogen	$mgNNO_2/dm^3$	0.154	II	0.0088	I	0.0092	I
9	Potassium	mgK/dm^3	20.2	V	9.37	I-II	22.3	V
10	Magnesium	$mgMg/dm^3$	17.2	I	16.3	I	9.40	I
11	Calcium	$mgCa/dm^3$	162.0	III	90.1	II	86.6	II
12	Zinc	mg/dm^3	0.3807	I	0.3461	I	0.1076	I
13	Cuprum	mg/dm^3	0.1697	V	0.0743	IV	<0.004	I
14	Chromium	mg/dm^3	0.1434	V	0.0594	IV	0.037	II
15	Nickel	mg/dm^3	0.1042	V	0.0465	III	<0.006	I
16	Lead	mg/dm^3	0.2384	V	0.1249	V	0.0244	II
17	Cadmium	mg/dm^3	0.0053	IV	0.003	II	0.007	IV
Total quality class				V		V		IV

- Total phosphorus (using MerckTest and spectrophotometer Photolab Spectral WTW, mineralization)
- Total suspended solids (indirect method)

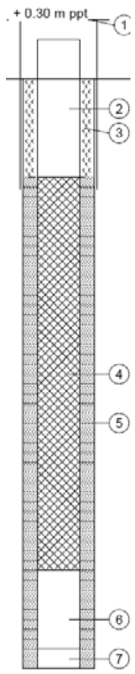
Analysis of Results

The dynamics of change in the concentration of chosen pollution indicator is presented graphically in Fig. 3.

Location of additional piezometers (P4-P6) was aimed at presenting the influence of improper exploitation of the treatment plant on quality of groundwater lying in the facility's surroundings. In piezometers established in 1996, months when the level of the water table was reduced to 2.5 m were observed. The lowest water table was observed in piezometers located directly on the surface irrigated with waste effluents (P2 and P3). A similar average depth as in piezometer number 2 was observed in hole number 5. During the research period the most shallow water table occurred in piezometer Nos. 1 and 4. Due to location of piezometers in P1, the influence of usage of adjacent terrain to the treatment plant on groundwater quality may be observed. Water quality in piezometer 4 present the influence of adverse exploitation (pouring sewage into the bed intended for sludge composting) on groundwater composition.

The highest pollution indicators were observed in the majority of cases for P4, except for TSS, the highest concentration of which occurred in P5.

BOD_5 values in water samples collected from piezometers throughout the majority of months of the year, maintained a low level reaching 0.5 $mgO_2 \cdot dm^{-3}$. In summer the rapid increase of BOD_5 for each piezometer, and then rapid



1 – casing length 0.80 m, diameter 160 mm PCV
2 – upfilter pipe length 0.70 m, diameter 110 mm PCV
3 – concreted sector
4 – net filter length 2.00 m, diameter 110 mm PCV
5 – gravel covered
6 – underfilter pipe length 0.50 m, diameter 110 mm PCV
7 – fuse length 0.10 m, diameter 110 mm, wood

Fig. 2. Constructional scheme of piezometer.

Table 4. Average composition of groundwater under terrain of plant-soil treatment plant in research period December 2008- December 2009.

No.	Pollution indicator		Average concentration						Quality water classes, values according to ordinance*		
			P1	P2	P3	P4	P5	P6	I	II	III-V
1	BOD_5	$mgO_2 \cdot dm^{-3}$	2.64	3.83	2.67	12.55	0.86	4.55	≤3	6	limit values not established
2	COD_{Cr}	$mgO_2 \cdot dm^{-3}$	74.45	87.33	93.89	125.92	112.46	119.15	≤10	≤20	
3	TSS	$mg \cdot dm^{-3}$	113.55	184.0	277.11	164.91	287.09	180.18	≤25	50	
4	Total nitrogen	$mgN \cdot dm^{-3}$	16.88	23.03	14.42	28.92	15.35	15.56	≤5	10	
5	Total phosphorus	$mgP \cdot dm^{-3}$	0.97	0.88	1.68	1.90	1.81	1.59	≤0.2	0.4	

*The Ordinance of the Minister of the Environment from August 20, 2008, in the case of superficial water quality classification [22, 23].

fall was observed. At the earliest (IV 2009) the increase of BOD_5 concentration for piezometer P4 located before the treatment plant was registered. In the case of P6, the maximum value of this indicator was observed in June 2009. As far as the remaining piezometers are concerned, along with the fall of the water table, an increase in BOD_5 value was observed.

Dynamics of the value change of COD_{Cr} had a course similar to all the piezometers. At the beginning of the research period, the highest concentration was observed, and then the concentration decreased. The TSS content in samples had a relation with table depth. Within the analyzed research period, for the lowest water table levels the highest suspension concentration was observed. The highest concentration of nitrogen value occurred in the waters of piezoemters P4 and P2. As far as the remaining piezometers are concerned, nitrogen concentration remained at a similar level (Table 4). The highest average concentration of total phosphorus occurred in the sample collected from piezometers P4. The maximum value of this indicator was observed in February in the waters of piezometer P2.

Discussion

Despite numerous operating errors, the plant-soil treatment plant in Brzeźno is still utilized. The treatment plant holds an official permit, valid until 31.12.2013, to discharge

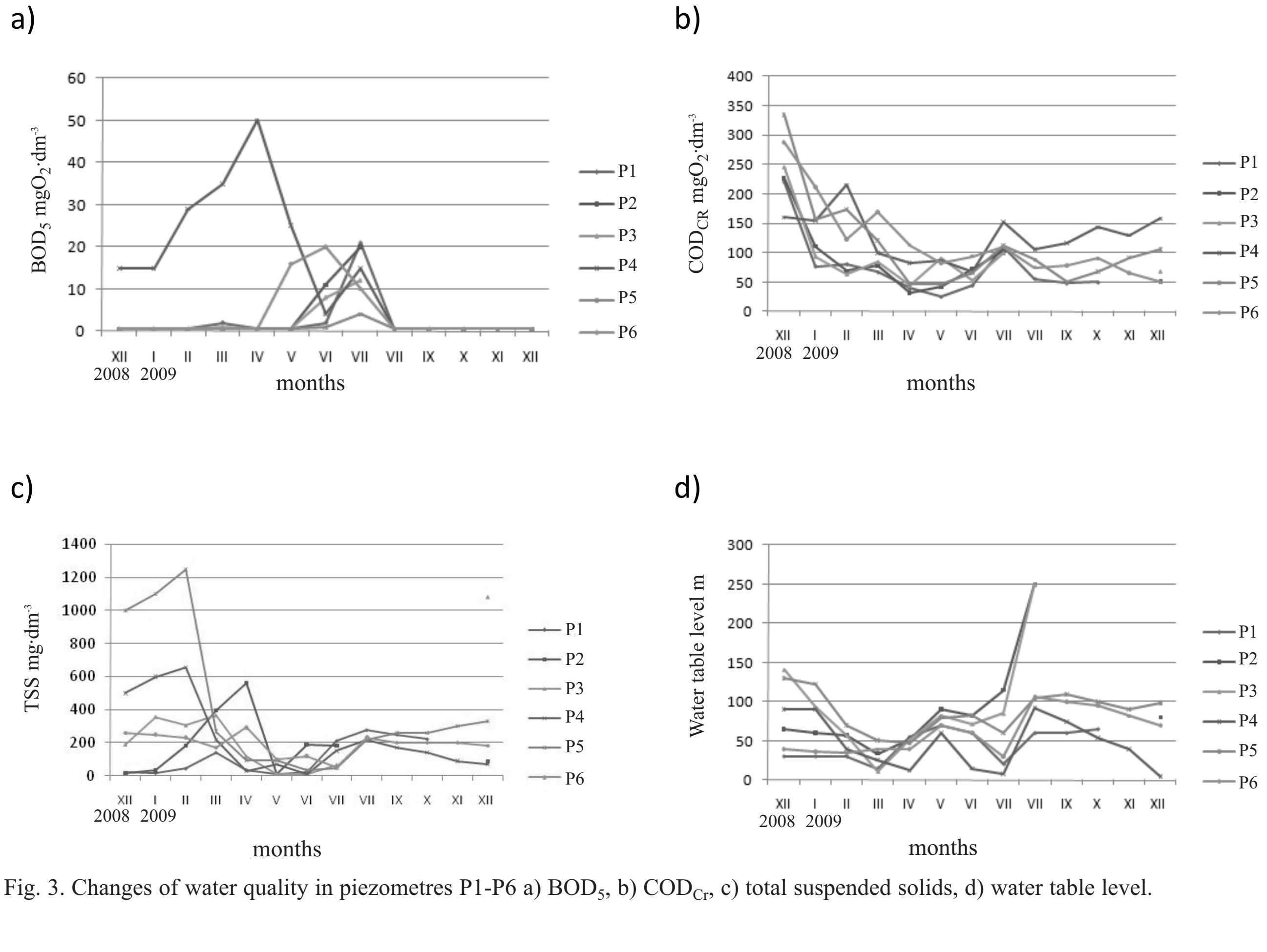


Fig. 3. Changes of water quality in piezometres P1-P6 a) BOD_5, b) COD_{Cr}, c) total suspended solids, d) water table level.

waste water effluents [3]. Onto the facility surface, not only waste effluents accumulated in a dosing-and-accumulating tank are released, but also waste effluents delivered from the adjacent buildings via means of a gully emptier fleet. An average composition of groundwater for the chosen pollution indicators is shown in Table 4.

Water from piezometer P4 located in the vicinity of the unlawful area of effluent discharge was characterized by the highest average pollutant concentration for BOD_5, COD_{Cr}, total nitrogen, and total phosphorus. Such high values of the indicators were the outcome of trickling of effluents through the soil profile directly to shallowly-lying groundwater. A multiannual exploitation, carried out very often along with omission of a proper irrigation schedule, caused groundwater deterioration. Currently COD values in waters collected from piezometers P1-P4 are several times higher than the values observed before putting the treatment plant into operation. All the piezometers are characterized by high values for TSS. The highest value was recorded for P5.

On account of the lack of limit values for analyzed pollution indicators in groundwater, in order to determine quality of waters under the irrigated surface, classification made out for the surface water was used. Although analyzed waters were subterranean ones, due to their physicochemical composition, they were categorized as unclassified ones.

Effluent treatment within soil environment is still one of the cheapest solutions of effluent utilization within terrain without a central sewage system. However, as observed in the course of a one-year observation, water environment quality regrettably deteriorated. On account of the specific construction of this facility, it is impossible to determine the load quantity that along with effluents has been brought into shallowly-lying groundwater [18-20].

The operating example of the facility indicates the elements that shall be thoroughly analyzed during designing and exploitation of similar facilities.

Conclusions

On the basis of our research the following conclusions were delineated:

- after a multiannual exploitation of the plant-soil facility, changes in the composition of groundwater lying under the irrigated surface were observed
- the highest pollution indicators within the analyzed research period occurred in piezometer 4 (a supplementary piezometer network) and concerned the following pollution indicators: BOD_5, COD_{Cr}, total nitrogen, and total phosphorus; this piezometer is located in the vicinity of the unlawful area of effluent discharge into the treatment plant's bed
- improper exploitation of beds, shown by overloading of effluents causes the potential lowering of the treatment capacity
- further utilization of the treatment plant's surface intended for treatment shall be verified, special attention shall be paid to new instructions for the exploited treatment plant, and effluent dosage shall be reduced with the aim of a self-regeneration of the soil profile.

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