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Impact of wastewater from pig farm lagoons on the quality of local groundwater

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ABSTRACT

The objective of this study was to determine the degree of contamination of the shallow groundwater and the quality of drinking water, on the locations of three pig farms employing liquid manure cleaning systems, in lagoons without hydroisolation for storing wastewaters.

For the purpose of monitoring the quality of shallow groundwater and its level, ten piezometers were installed on three pig farms, whereas the quality of drinking water was followed using samples from the local wells.

The minimum fluctuations of shallow groundwater level were measured in the reference piezometers, whereas the highest variations (up to 4.19 m) were detected in the piezometers drilled near the lagoons, indicating the infiltration of water from the lagoon. A significant correlation ($P < 0.001$) between the amount of rainfall and the level of water in the piezometers, indicates the possible penetration of the pollutants from the earth surface to the groundwater. The measurements encompassed the physico-chemical parameters that characterize pig farm wastewater, viz. organic and suspended matter and dry matter. The results of measuring the parameters of wastewater, solid manure, and lagoon sediment indicate that efficient water purification occurred in the lagoons under natural conditions. The organic matter content in the lagoons was reduced by 85–90%, dry matter by 56–69%, suspended matter by 94–96%, total P by 31–50%, total N by 39–55%, Cu by 69–85%, and Zn by 83–89%. The results also show that most of the metals settled on the bed of the lagoon, reducing thus the risk of contamination of surface water and groundwater.

The investigation showed large variations in the parameters of shallow groundwater on the locations of the farms. The concentrations of NH_4^+-N in water of the reference piezometers ranged between 0.02 and 1.52 mg/L, while in the piezometers close to the lagoons they were up to 52.6 mg/L. The content of total N in the reference piezometers was between 0.14 and 22.4 mg/L, while in the piezometers close to the source of contamination it reached 90.4 mg/L. Also, at one of the farms the amounts of P and Cl^- measured in the piezometers close to the lagoon were up to 7 and 5 times higher than in the reference piezometer. The correlations between electrical conductivity (EC) and Cl^-, SO_4^{2-}, Na^+, K^+, between total N and NH_4^+-N, NO_3^--N and organic N by Kjeldahl (ONK) and various metals in the shallow groundwater, indicate their common origin from farm wastewaters.

On the other hand, the results clearly indicate that there was no degradation of the quality of the drinking water in the deeper layers, and none of the drinking water quality parameters showed significant variation during the investigation period. This is explained by the presence of 4–6 m thick clay layer between the lagoon and the drinking water aquifer.

Overall, this study clearly shows that the pollution of shallow groundwater on the farms is of a local character, and that here is no significant pollution of groundwater sources, despite the fact that farms employing liquid manure cleaning systems have been in operation for many decades.

1. Introduction

Intensive animal husbandry presents a potential risk of pollution of groundwater (Bartelt-Hunt et al., 2011; Cho et al., 2000; Kuderna and Blum, 1998; Kunz et al., 2009; Lee et al., 2010), and this may be especially important in areas where drinking water supply is based on groundwater abstraction. On the territory of the

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Province of Vojvodina (northern part of the Republic of Serbia), the only resource of drinking water for both households and industry are groundwaters. In view of the fact that the soil in Vojvodina is of an exceptionally high quality, agricultural production and raising of domestic animals are the most important branches of the economy in the region. As a result of these activities the wastewater and animal manure generated on the farms are characterized by high organic loads, with high contents of nutrients (Petersen et al., 2007; Lee et al., 2010), suspended solids and high level of microbial population (Chelme-Ayala et al., 2011), Na^+, K^+, Cl^- and $SO_4{}^{2-}$ (Krapac et al., 2002), and metals such as Zn, Cu (Petersen et al., 2007) and Ca, Mg, Fe, Mn (Sánchez and González, 2005).

The characteristics of liquid pig manure/slurry vary highly depending on the amount of water used to clean the stable and the kind of pits used to collect the slurries (Sánchez and González, 2005), animal feeding habits, zone climatology (González-Fernández et al., 2008), as well as the number of animals on the farm, their health state, feed composition (Suzuki et al., 2010), means used for cleaning, washing and disinfection, and the sort of drugs used for animal treatment and prevention from diseases. A consequence of the penetration of organic matter and ammonia to the groundwater can be the development of anaerobic conditions, whereas an increased content of nitrates can be a potential threat to human health. On the other hand, the presence of heavy metals in wastewater may lead to their accumulation in the surface layers of shallow groundwaters. The threat of the accumulation of heavy metals in the soil irrigated with wastewater, their appearance in plants, and the potential inclusion into the food chain, have been also pointed out in the study by Kiziloglu et al. (2008). Besides, the management of animal wastes, which assumes their collecting, storing, treatment, and potential utilization, may be a potential source of contamination of the environment. Once contaminated, groundwater is hard to regenerate, and because of that it is of crucial importance to ensure continuous monitoring of its quality.

Monitoring the state of wastewater and manure from pig farms gives a survey the parameters needed for the assessment of the contamination of shallow groundwater in the vicinity of the source of pollution, as well as for the evaluation of potential contamination of groundwater that is used as drinking water.

Previous investigations showed that the lagoons and pits for storing wastewaters and manure have a negative influence on the quality of groundwater because of the infiltration of $NO_3{}^-$, $NH_4{}^+$, and Cl^- from the surface and subsurface soil layers (Bartelt-Hunt et al., 2011; Cho et al., 2000; Krapac et al., 2002). The storage and spreading of fertilizers can also result in the contamination of drinking water due to the leaching of the pollutants (e.g. $NO_3{}^-$) to the aquifer (Bonton et al., 2010). Brainwood et al. (2004) found that the reason for higher contents of $NO_3{}^-$ and $PO_4{}^{3-}$ in groundwater was that the water in farm dams was contaminated by the manure containing $NO_3{}^-$, $PO_4{}^{3-}$, toxic metals, and bacteria.

The aim of this study was to assess the pollution of the shallow groundwater and the drinking water on the location of three pig farms that use liquid manure cleaning system and the lagoons without hydroisolation for storing wastewaters. It is worth mentioning that this is the beginning of the investigation into the influence of pig farms on the quality of groundwater in the Republic of Serbia, as the farms under study were among the first to use piezometric measurements for monitoring the penetration of wastewaters from the lagoons to groundwaters.

2. Materials and methods

2.1. The study area

For the purpose of monitoring the influence of pig farms on the quality of phreatic water it was of interest to know the hydrogeological conditions on a wider area of the investigated location related to the depths from about 2 to 80 m.

The wider area around the Vrbas municipality water source does not include any natural streams or other recharging surface water. Due to their hypsometric positions, the Danube-Tisa-Danube Canal (DTD) and the Great Backa Canal do not generally flow in a hydraulic connection to the aquifer, and are not a source of groundwater recharge. Practically, there are two dominant recharge sources for the groundwater in central Backa and beyond: local infiltration of water from precipitation and regionally, tapping from the north, from the recharge zones of the Telecka plateau. Research in this area (Rakic, 2009) suggests that the general direction of ground water flow in Backa is from the north to the south of Backa.

Although, poorly water-permeable clayey sediments, the uncontrolled exploitation of groundwater from the wells (large water consumption on the farms) may essentially affect the natural condition of the groundwater.

The investigation was carried out on three selected pig farms of different capacities, located in the area of South Backa of the Province of Vojvodina, denoted as FA, FB and FC (Fig. 1). The recipients of the wastewaters from these farms are surface waters that are directly or indirectly connected with the Great Backa Canal, as part of the DTD Hydrosystem. The average annual production on farm FA is 3000 livestock units (1 LU = 500 kg live weight), on farm FB 6500 LU, whereas the capacity of farm FC is 10,500 LU. All three farms use liquid manure cleaning systems, hence the wastewaters besides urine and faeces contain also pigsty washing water and disinfection agents, as well as dissipated feed, etc. As a result, the water consumption is high, and amounts on average (calculated on the annual level) 530 m^3/day on farm FA, 375 m^3/day on farm FB, and 1100 m^3/day on farm FC.

2.2. Disposition and location of the piezometers and drinking water wells

The effect of the farms and wastewater from the lagoons and sewage on the quality of the shallow groundwater was monitored using 10 piezometers, drilled to a depth of 10 m. Spatial distribution and the location of the particular piezometric boreholes have been done by taking into account the potential sources of contamination (earth lagoons with no hydroisolation, solid manure stores, internal sewerage system, pens for pigs) (Fig. 1), as well as the direction of groundwater movement. Thus, on each farm, two piezometers were installed close to the lagoons and solid manure stores at a distance of 28–105 m from the pollution source (on farm FA: FAP1 and FAP2, on farm FB: FBP2 and FBP3 and on farm FC: FCP2 and FCP4). On farm FC, because of its larger area, another piezometer (FCP3) was installed between the pigsties, close to the supply well for groundwater used for animal needs. Also, the reference piezometers (FAP3; FBP1; FCP1), were installed on each farm on the site which was the least or not at all exposed to the negative influence of the farm. The screens in the piezometers were located at approximately the same depth on all the farms. The water capture interval for piezometers at FBP2, FCP2 and FCP3 was 5.25–8.25 m; at FAP1, FAP3, FBP3, FCP1 and FCP4 5.30–8.30 m; at FBP1 5.50–8.50 m, and at FAP2 it was 6.20–8.20 m. The borehole diameter along the whole length is 146 mm. The depth of each borehole was 10 m and in each of them a 10-m piezometric structure consisting of a settler (1 m), screen (3 m), an overfilter PVC tube (4 m), and a steel pipe (2 m) was installed. The piezometer tip was protected by a metal cap, to prevent contamination. Similar boreholes were also used in the study by Holz (2009) to monitor the changes in the quality of groundwater under the influence of different contaminants.

In order to assess the degree of contamination of the drinking water aquifer on the farms, we monitored the quality of water from