DIFFUSE POLLUTION OF WATER PROTECTION ZONES IN LJUBLJANA, SLOVENIA

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ABSTRACT

Ljubljana, the capital of Slovenia, lies in the area rich with both surface and groundwater. Ljubljana's citizens have been supplied with untreated, even not disinfected groundwater, for more than 110 years uninterruptedly. Two aquifers, Ljubljansko polje and Ljubljansko barje, represent drinking water resources for almost 300.000 inhabitants. The major part of the vulnerable Ljubljansko polje aquifer, the area under investigation, providing water supply for 90% of the whole population, lies beneath urban and agricultural areas. The waterworks are surrounded by large protection areas to avoid bacteriological and chemical pollution. Agricultural activities are supposed to be the main diffuse sources of nitrate in the groundwater that is a source of drinking water in Ljubljana. To verify this presumption we checked the results of nitrate concentrations from various sampling points, measured in different laboratories from 1992-2002. Analysis results form a basis for our future research work, oriented towards the investigation of nitrogen isotopes as indicators of nitrate sources.

KEYWORDS: aquifer, drinking water, groundwater, nitrate

INTRODUCTION

The urban area of the Ljubljana City spreads between two main rivers – the Ljubljanica, named after the town, the centre of which it flows through, and the Sava, which is the main Slovenian river discharging also the Alpine mountains in the north-west of the country. The urban and agricultural area between the two rivers is a living and working place for almost 15% of Slovenian inhabitants and the main groundwater resource at the same time. The Ljubljansko polje aquifer covers approximately 95 square kilometres and represents one of the main groundwater reservoirs in Slovenia. It was formed in Pleistocene and Holocene when the flow dynamics of the Sava made great changes and deposited up to 100 m deep layers of gravel and sand.

The Ljubljanica's riverbed is not permeable and only the Sava river water and local precipitations contribute to groundwater storage. The Sava river flows from the northwest to the east side of the Ljubljansko polje. The river flow oscillates from 40 m^3/s-700 m^3/s. The estimated average groundwater flow through the sandy aquifers reaches 3 m^3/s, the estimated groundwater velocities reach some ten meters per day. The hydraulic conductivity of the Ljubljansko polje aquifer is very high, from 10^{-2} m/s in the central part to 3-7 x 10^{-3} m/s on the borders of the field and 1-5x10^{-4} m/s at the foot of the hills[1]. These natural circumstances - high velocities and quite high groundwater flow – have enabled the preservation of groundwater quality at quite a high level - up to the present.

Mean annual precipitation for the period 1981 – 1990 was 1351 mm per year. The precipitation is the lowest in the winter and early spring, and the highest from June to November. In the summer, the majority of precipitation falls as heavy rainfall.

Two recharging components of the Ljubljansko polje groundwater, i.e. the local precipitation and infiltrated Sava river, are exposed to different sources of contamination because they originate from different parts of hydrological circle. Direct infiltration of precipitation makes the aquifer vulnerable to contamination by pollutants flushed through soils. Recent results[2] show that local land use is reflected in the intensified groundwater pollution, whereas the river water quality has improved during the last decades.

Figure 2 shows typical groundwater level oscillation in the Ljubljansko polje aquifer. Two maximums are usually observed, the primary in late autumn and the secondary in early summer.

Agricultural activities with excessive use of fertilisers and pesticides as well as other human activities as leakage from the sewer system, road accidents, industrial zones with insufficient emission control, expansion of existing physical planning areas, illegal waste deposit sites, excavation of gravel and the resulting decreasing depth of the unsaturated zones may be a serious threat towards a safe drinking water supply. Despite the permanent threat, basic microbiological and chemical parameters of the groundwater are within the limits prescribed by the Regulations on Health Requirements for Drinking Water and EU Directives, with the exception of pesticides.

Nitrate, another important pollutant, is an interesting object of investigation, because the changes in its concentration in Ljubljansko polje groundwater have been observed. However, nitrate concentrations do not exceed national drinking water standards (50 mg NO_3/l) and are in average less than 25 mg NO_3/l. The aim of the analysis was to emphasise the risk that nitrate represents and to outline the main sources causing the increase of nitrate concentration before it is to late. The results should form the basis for remedial measures leading to the improvement of groundwater quality.

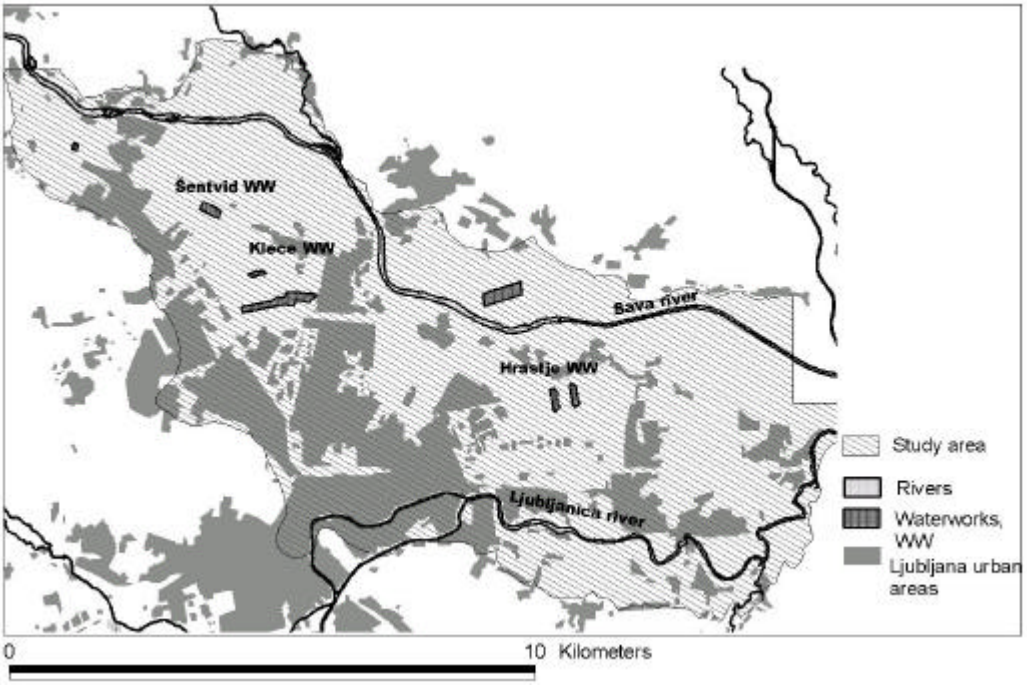

Fig.1. Map of the study area – Ljubljansko polje aquifer.

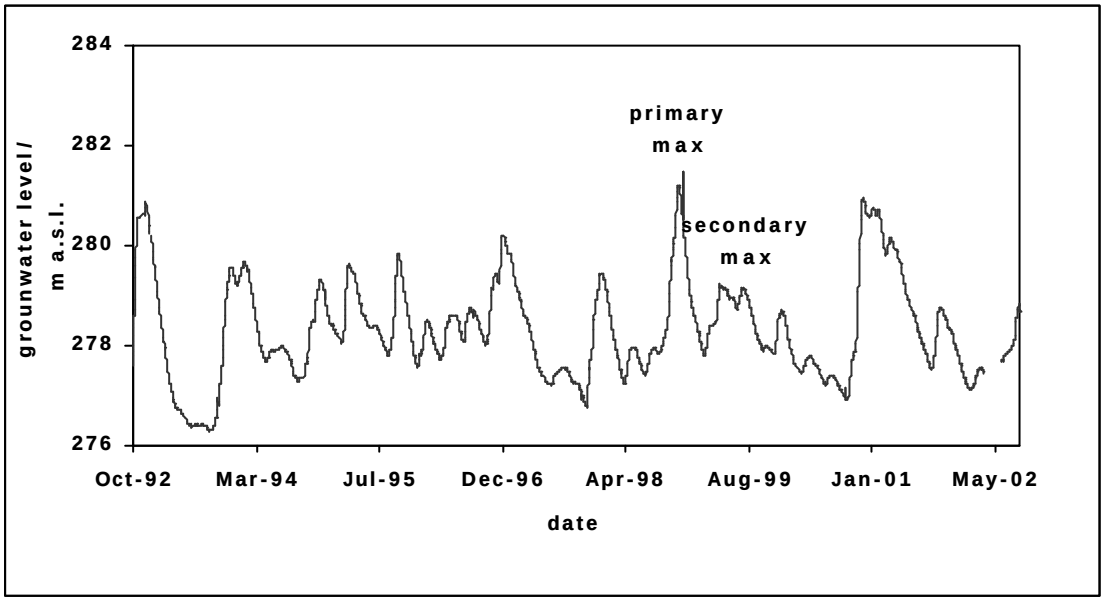

Fig.2. The series of groundwater level values at the observation point Vodovodna (G.K.x=5461832, G.K.y=5104093) from 1992-2002.

RESULTS AND DISCUSSION

The Ljubljansko polje groundwater exhibits certain local characteristics as a result of land use and features of the natural supply of the aquifer; these characteristics can be detected only with a sufficient number of appropriate sampling sites.

Many research activities and a few parallel monitorings of water status (on state[3] and municipality level[4] and as internal monitoring of water company[5]) were performed in the last decades in order to establish a comprehensive overview of water quality and the assessments of physical, chemical and microbiological quality of groundwater. The purpose of such testing is primarily to enable early detection of trends of individual types of pollution, but at the same time these tests, which in comparison with regular analysis of the network address a considerably wider extent of tested parameters, can also serve to detect sudden local pollution. In this review all available results of nitrate concentration from 1992-2002 were used.

The sampling points of research activities were active wells of the public water supply system, the industrial and private wells and the wells, continuously used as groundwater level observation points.

Possible sources of nitrate contamination include manure, commercial organic and inorganic fertilizers and also waste water from residential septic systems, untreated waste water, leaching in the environment, and natural organic material in soils.

Figure 3 shows nitrate concentrations throughout the study area, as a result of interpolation method of the average values at individual sampling points. The main characteristics of nitrate concentration disposition are low values at the observation points along the Sava river banks. The average concentration of nitrate in the Sava river water is less than 7 mg NO_3/l. When one goes away from the main infiltration areas along Sava river towards the middle of the aquifer, the nitrate concentration slowly increases.

The area on the left river bank, with the waterworks in the close vicinity of Sava river, is overgrown with forest and low underbrush. In that part of the aquifer the lowest nitrate concentration has been observed, not exceeding 12 mg $N0_3$/l. The nitrate concentration is generally lower and comparable to nitrate concentration in river water. The area is uninhabited and relatively undisturbed.

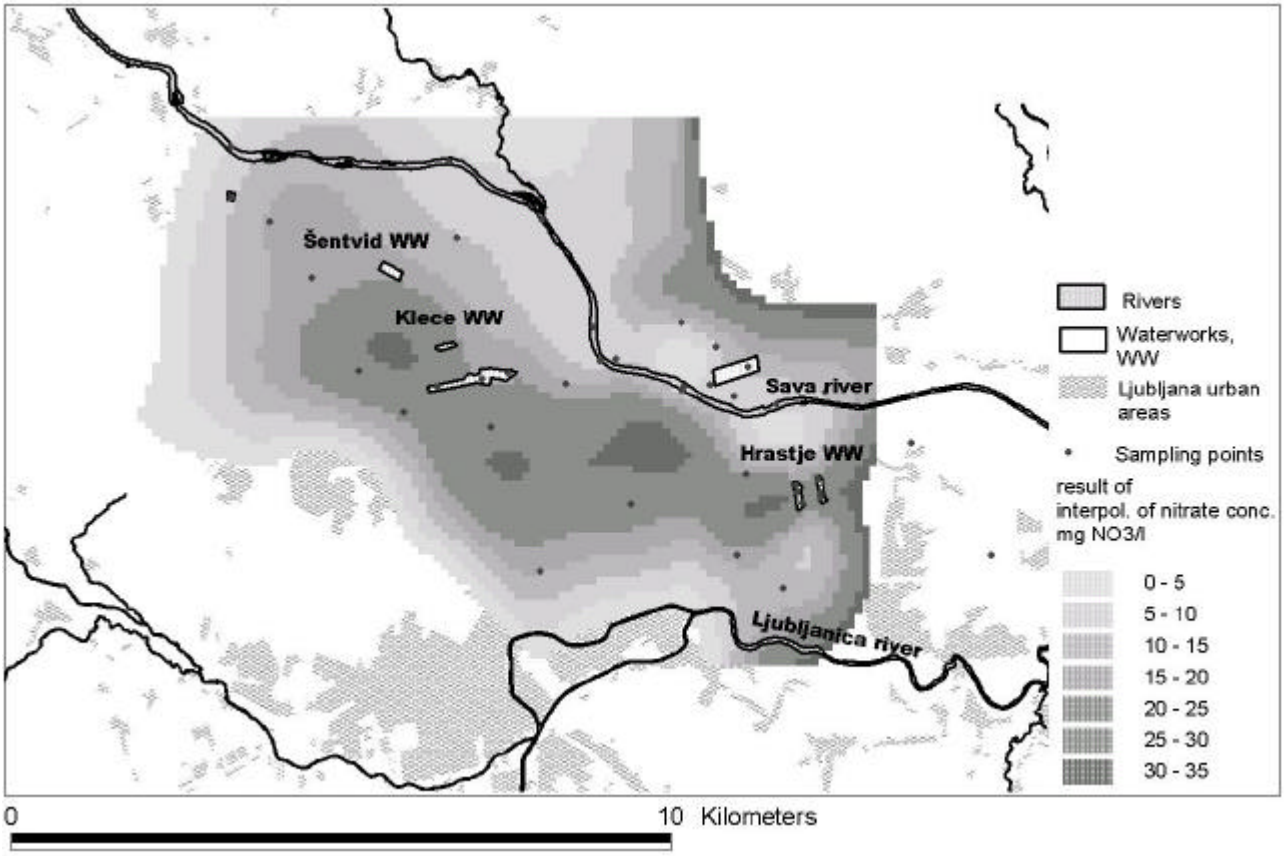

Fig.3. Distribution of nitrate through the Ljubljansko polje aquifer using SPLINE interpolation method.

The nitrate concentration in one of the wells of the waterworks that is situated in the north west side of the Ljubljansko polje aquifer (Sentvid waterworks) is comparable to the concentration of the nitrate in the middle of the main Ljubljana's waterworks (Klece waterworks), as shown in Figure 4. The capture zones cover the area towards the Sava river, where agriculture is the most probable source of nitrates. The concentrations are still not high, but higher than along the Sava river. From time to time the concentration time series shows deviation from the average values. To understand the phenomena two competitive effects have been taken into account. The first, causing the increase of the concentration, can be the pollutant being flushed from the surface into the aquifer with the precipitation. The second, causing the decrease of nitrate concentration, is the dilution of the contaminant, caused by high precipitation amounts. This can be the reason for extreme minimum value in May 1998 when the 77 mm of rain fell 5 days before the sampling. The effect of decreasing concentration with increasing groundwater level is also anticipated.

The time series for any observation point in the upper area of the aquifer shows that the average nitrate concentration is primarily defined by situation position of sampling point. The influence of the annual changes caused by groundwater level, amount of precipitation and season can be expected, but the concentration depends basically on the location, where the sample is taken. The same can be concluded for most of the basic physical and chemical parameters, like conductivity or concentration of basic anions and cations.

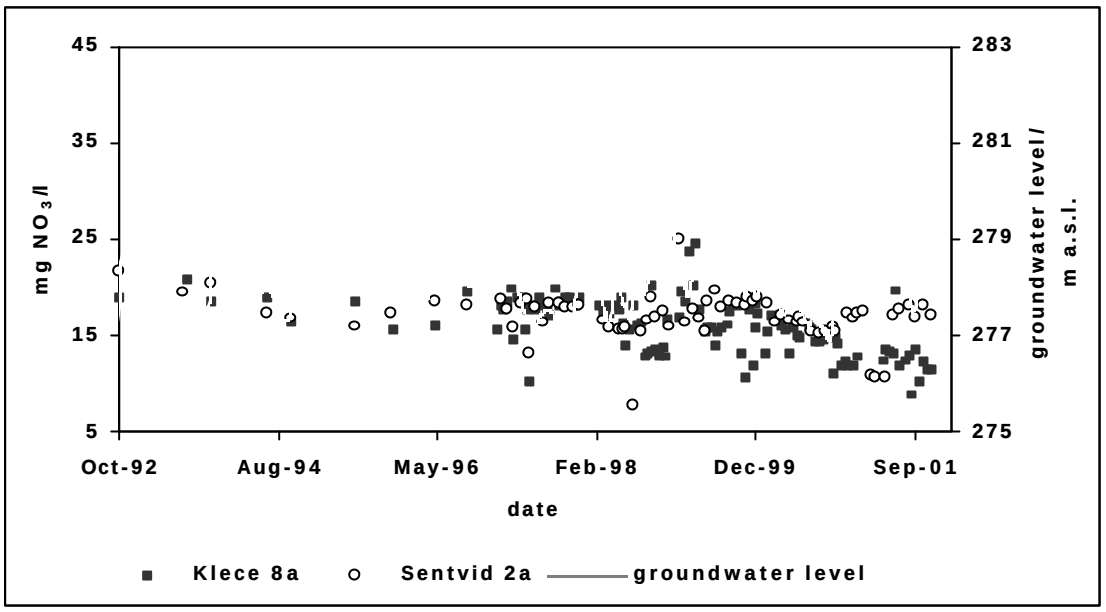

Fig. 4. The nitrate concentration time series for two active wells of the Klece and Sentvid waterworks. Comparison with groundwater level oscillations.

Figure 3 shows higher concentration of nitrate on the west side of Klece waterworks and towards south. The city area is urbanised, therefore it is expected that the main reason for high nitrate concentrations is the influence of the septic systems.

At down gradient area from Klece towards Hrastje waterworks in Figure 3 a cloud is observed, lying close to the right Sava river bank, where the concentration of nitrate is higher. The dark grey area coincides with the part of the city, where approximately 100 houses are not connected to the central septic system. The septic tank effluents are let out into environment. The unsaturated zone of the aquifer is only few meters deep, which makes the groundwater quality more vulnerable.

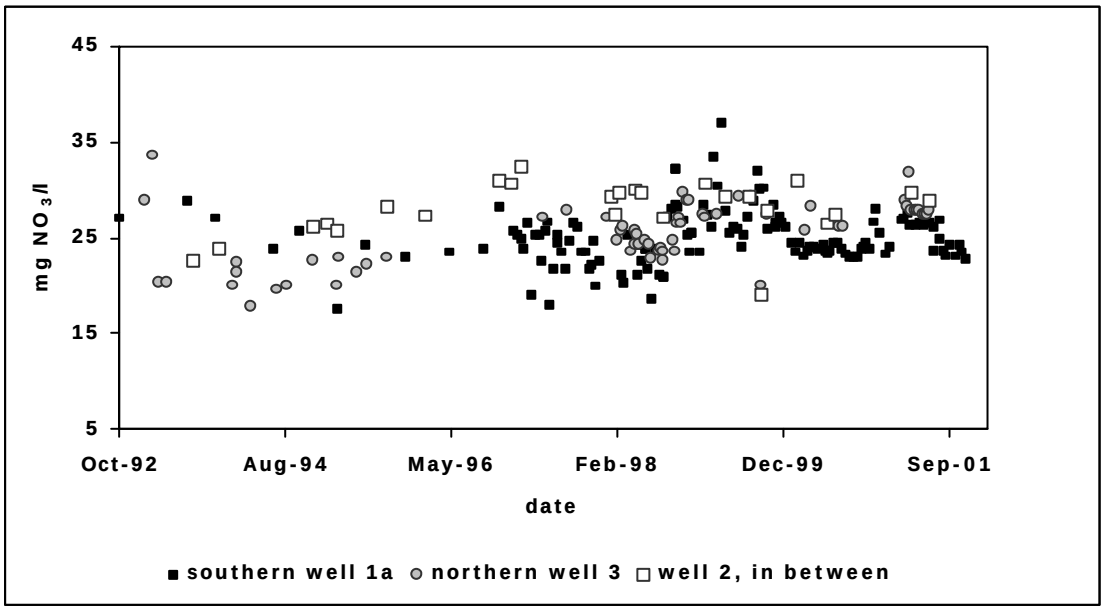

Fig. 5. The nitrate concentration time series for three active wells of the Hrastje waterworks.

The land on the west side of the Hrastje waterworks is primarily agricultural. The agriculture chemicals certainly attributed to higher nitrate concentrations, but the septic system cannot be excluded as an important anthropogenic source.

Finally, the nitrate concentration in the Hrastje waterworks wells are shown in Figure 5. The nitrate concentration of three active wells out of nine, labelled by 3, 2 and Ia, as they follow from the north to the south, are shown. Ten years ago the northern wells were less polluted with nitrate as southern part of the waterworks, but the nitrate concentration at the north

increased by 10 mg NO_3/l in the last decade. The concentration series still shows increasing values. The most probable sources are septic tank effluents in the capture zones that caused the upstream cloud of higher nitrate concentration values.

CONCLUSIONS

The average nitrate concentrations in the Ljubljansko polje groundwater are still not an object of serious concern, but the groundwater quality can be kept at the same level or can be improved only if appropriate immediate remedial measures are taken. Otherwise the demands arising from the Water Framework Directive (2000/60/EC) will hardly be reached.

The groundwater quality varies rapidly through the region. Agriculture is the main source of nitrate pollution, but the discharges from urban areas without sewerage systems or discharges from the sewerage system that is not tight could also contribute to the lowering of the groundwater and drinking water quality.

The agricultural activities in Slovenia have been more controlled and directed lately. It is expected that reimbursements for the loss of income due to limitations of agricultural activities in areas overlying the water resource will be introduced. This will be an additional expense that will also be reflected in the price of water, as well as will be the cost for the processes of construction of missing residential septic systems and the cost of reconstruction of the old ones.

To investigate nitrate sources in detail a nitrogen isotope study has been performed. The review was the first step of the study that has already started. It is expected that nitrogen isotopes will be used as useful qualitative indicators of different nitrate sources in the Ljubljansko polje aquifer.

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