NITRATE VULNERABILITY AND CONCENTRATION OF GROUNDWATERS IN HUNGARY

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Abstract: The designation of nitrate sensitive areas requires to consider the properties of subsurface water and the soil, as well as their environmental setting and attention should be paid to the behaviour of nitrogen compounds in the specific environment.

In our opinion there are problems with the EU Nitrates Directive (91/676/EEC), for example the „one moment measure” or the uniform adaptation is the lack of a standard EU-wide sampling method. In our definition, those territories are vulnerable to nitrate pollution from agricultural sources where nitrate originates from agricultural activity and gets to the surface or to the uppermost layer of the geological media, and from where nitrates are washed down or into the geological media with a transporting medium (usually water) polluting the surface- or groundwater. About both the vulnerability of surface- and subsurface waters in Hungary maps were derived showing the risk areas. These maps can be used to plan for the preventive actions against nitrate pollution.

Beside the national level, our research was continued in the model area level too. We can follow spatial-temporal changes of the nitrate-ion concentration in the groundwater at that scale much better, so model areas and sampling points (monitoring wells) were chosen in the middle and eastern part of Hungary.

The conclusion of these measurements is that both the background values and the amount of anomalies varies with geological - morphological and meteorological factors. The vulnerability of surface covering sediments may be defined taking count all of these factors.

Key words: nitrate vulnerability, groundwater, Hungary

Introduction

Surface water vulnerability to nitrates is defined by the EU Nitrates Directive (91/676/EEC) and other legislation based on the 50 mg/l nitrates threshold (for drinking water more than 25 mg/l) and on the criteria that nitrates take part in eutrophization in still waters. Groundwaters containing more than 50 mg/l nitrates are also classified as vulnerable.

The problem with the definition formulated by the Directive is that it refers to a „one moment measure” of the water quality for determining vulnerability, and the vulnerability defined by the geological environment is not taken into account. The fact that at different points of a water body (even in the same geological environment) very different nitrate levels can be measured both in space and in time, is also not considered. Another problem in the uniform adaptation is the lack of a standard EU-wide sampling method.

Study area

Hungary is situated in the Pannonian Basin surrounded by the Carpathian Mountains chain. Most of Hungary’s surface is lowland (about 68%), 30% is covered by hills between 200 and 400 m-s and only 2% of the country rises above 400 metres. The surface of the country is mostly covered by young, sedimentary and volcanic rocks. Groundwater occurs in lowland- and hilly areas made up of loose sediments. It is virtually absent in mountain regions, at least it does not form an expansive, continuous table like in the basins filled with sediments (Rónai, 1956).

Apajpuszta model area

The model area is situated at the north part of the Danube Valley, in the middle part of the country. The area is part of the most typical saline depressions between the loess and sand dunes at Danube-Tisza Interfluwe. The total area is 50 km². Based on the lithological sections (from the results coming from the boreholes and the analysis of the samples) the model area is vertically segmented: above the gravelly sand there is sand and at the top clayey sediments are situated (Bakacsi, 2001). In the Danube Valley, above the unsaturated zone, often quite thick lime mud
accumulations appear. At the bottom of the saline lakes, situated in the depressions between the loess and sand dunes at Danube-Tisza Interfluwe, carbonate mud precipitate. In the glacial periods of the Ice Age, wind blew the different sediments at the actual places: sand building up the hills from the alluvial deposit of the Danube, loess from the boundary of the inland ice, and carbonates from the moulding carbonate rocks of the Transdanubian Mountains (Kuti et al., 2009a).

**Nyírőlapos (Hortobágy) model area**

This project deals with an area in the eastern part of Hungary at the Great Hungarian Plain, called Hortobágy. The modelling area has a size of 800 x 500 m. The surface is nearly flat and it is fall to the northwest with a gradient less than 0.001%. The geological underground is build by a riverine - alluvial formation from the Holocene and Pleistocene. The surface and near-surface formations are young, Holocene, or Pleistocene river, flood area formations. On the surface there is usually 2 m thick Holocene silty clay, which changes into clayey silt in some places. Under this layer there is a contiguous 1-1.5 m thick heavy silty clayey layer (Tóth and Kuti, 1998).

**Materials and methods**

The key element of nitrate leaching is if it reaches the surface or not. In this case, factors influencing the vulnerability are the permeability of the layers above the groundwater level, the depth of the groundwater, the organic matter content and the water behaviour of the soil.

Based on the above considerations, 1:100 000 scale maps were created for the assessment of potential nitrate leaching in soils in Hungary. Combining these information, a vulnerability map was derived showing the risk areas. This map can be used to plan for the preventive actions against nitrate pollution.

Beside the national level, our research was continued in the model area level too. We can follow spatial-temporal changes of the nitrate-ion concentration in the groundwater at that scale much better. Monitoring wells were established and sampled monthly from 1995 in different geological sites of the Great Hungarian Plain. Depth to the groundwater level was measured and the pH and conductivity were checked in the field. All water samples were analysed for the major components and for the micro-elements. Environmental factors such as pH and Eh having an effect on NO$_3$-ion concentrations measured in the groundwater were processed with multi-dimensional statistical methods.

The observation wells were sampled monthly. Depth to the groundwater was measured and the pH and conductivity were checked in the field. All water samples were analysed for the major components (Na+, K+, Ca++, Mg++, Fe++, NH$_4$+, Mn++, Cl–, HCO$_3$–, CO$_3$–, SO$_4$–, NO$_3$–, NO$_2$–, H$_2$SiO$_3$) and for the micro-elements (Cr, Zn, Co, Ni, Ba, Al, Cu, Sr, Mo, B, Pb, Cd, Li).

After a few years of sampling, a new method was tested in Nyírőlapos (Hortobágy) model area. Next to the existing observation wells two other were established in different depths, so we became able to check the chemical composition of the groundwater in different depths at the same location.

**Results and discussion**

The geological definition of nitrate sensitivity to agriculturally induced nitrate contamination was formulated upon our previous investigation results of similar nature. Accordingly, an area is sensitive to agriculturally induced nitrate contamination if the nitrate occurring on the surface or in the upper part of the geological medium as a result of some agricultural activities can pass by the assistance of a transmitting agent, mostly water washed down or washed in across the geological medium in the surface- or subsurface water and contributes to its contamination (Kuti et al, 2009b).

It has to be spoken of very sensitive and slightly sensitive areas if the trajectory of the wash down or wash in is practically without obstacle or if it is affected by some natural or geological factors (poorly permeable horizons, nitrate is filtered out of the liquid, long way of seepage, etc.), respectively. An aggravating factor concerning the protection or prevention of nitrate pollution is
when the surface water in the given area at risk was affected by eutrophication or if the nitrate content of the subsurface water’s uppermost horizon exceeds 50 mg/l below most of the surface in a freshly taken sample.

Following the definition of sensitivity an overview was made on the geological and pedological factors of sensitivity resulting in the methodological elaboration of the compilation of the maps illustrating wash down and wash in for surface- and subsurface waters, respectively with setting up the maps’ legend and finally, preparing the maps.

**Wash down**

Concerning wash down it has to be studied whether the nitrate pollution getting or present on the surface can reach the surface water (still- or running water) and how quickly and in what amount it can. Wash down can be expressed by the combination of the following factors: 1. slope conditions in the area (slope steepness), 2. the geological sequence on the surface (lithology), 3. the state of the surface cover in the area (surface cover), 4. the distance of the area from surface waters.

**Table 1**

Factors of wash down

<table>
<thead>
<tr>
<th>Slope steepness %</th>
<th>Superficial deposit</th>
<th>Sensitivity of the surface</th>
<th>Degree of sensibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>s &lt;2</td>
<td>h = sand</td>
<td>N = insensible</td>
<td>insensible</td>
</tr>
<tr>
<td>e1 2-5</td>
<td>kl = silt, loess</td>
<td>Gy = slightly sensible</td>
<td>slightly sensible</td>
</tr>
<tr>
<td>15-10</td>
<td>a = clay, solid rock, tuff</td>
<td>K = intermediately sensible</td>
<td>sensible</td>
</tr>
<tr>
<td>m &gt;10</td>
<td></td>
<td>É = sensible</td>
<td>very sensible</td>
</tr>
</tbody>
</table>

*Fig. 1. Map of the sensibility to wash down: 1. insensible; 2. slightly sensible; 3. sensible; 4. very sensible*
Concerning the distance from surface waters areas closer than 100 m, between 100 and 500 m and farther than 500 m are distinguished. The closer the given area to the water the higher the likelihood that contamination reaches it. Due to scale limits this factor is not considered on overview maps but it is vitally important in practical farming, a local factor that is needed to be taken invariably into account.

Concerning slope conditions flat, gently sloping, sloping and steep areas are distinguished. The steeper the slope the easier the pollution reaches the water i.e. the easier it is washed down.

Concerning the superficial deposits distinction is made between the sequences on which the water runs quickly or slowly off and on which it does not run off but infiltrates in them instead.

With regard to surface cover it is considered whether the surface of the specific area is open and if it is not what the type of the surface cover is.

The combination of all these elements (table 1) facilitates the compilation of the map representing the sensitivity to wash down. The specific elements are illustrated in an integrated way. Consequently, the sensitivity of the areas is presented from the insensible to the very sensitive ones (fig. 1).

Wash in

The key question of the sensitivity to wash in is whether nitrate can pass from the soil surface in the subsurface waters (mainly groundwater). Therefore in order to assume sensibility to wash in it has to be studied if the nitrate contamination getting or already present on the surface can reach the subsurface water (groundwater) at risk and how quickly and in what amount it can.

Wash in can be expressed by the combination of the following factors: 1. permeability of the sequence above the groundwater level, 2. groundwater depth below the surface, 3. organic matter supply of the soil, 4. water budget of the soil.

Concerning permeability permeable, slightly permeable, intermediately permeable and impermeable sequences are distinguished. Knowing the types of the disposition of the sequences above the groundwater table their permeability, thickness and bedding characteristics can be assumed. It is important since the same impermeable qualification must be assigned to the areas where impermeable layers cover the surface and to those where they occur below the surface but above the groundwater level.

With regard to the position of groundwater depth values < 1 m, between 1 and 2 m, between 2 and 4 m and > 4 m below the surface are considered. Groundwater closer than 2 m to the surface affects directly the surface. The depth < 1 m characterises virtually wetlands. In this case even the superficial sequences are frequently saturated with water. The groundwater table in the interval of 2-4 m can still have an indirect influence on the surface i.e. surface contaminations can still reach the water in this depth. The risk of their reaching the groundwater in more than 4 m depth is quite low and this water does not affect the surface at all. The organic matter supply of the soil is considered by the classification of its amount (t/ha) in the soil.

With regard to water budget it was considered whether it is absorbed and at which rate by the specific soil. Based on the numerical determination of water management parameters the Hungarian soils were assigned to the following 9 water management categories (Várallyay, 1980).

The legend of the sensibility to wash in was elaborated upon the combination of the four base maps (table 2) facilitating to compile the final map. The map features the area of Hungary illustrating the different categories of sensitivity to wash in (fig. 2). The four-component combined legend applied on the map represents finally the rate of sensitivity on the map such as insensitive, slightly sensitive, sensitive and highly sensitive.
### Table 2
Factors of wash in Permeability of the sequences above the groundwater table

<table>
<thead>
<tr>
<th>Permeability of the sequences above the groundwater table</th>
<th>Groundwater depth below the surface (m)</th>
<th>Organic matter supply of the soil (t/ha)</th>
<th>Water management of the soil</th>
<th>Classification of the rate of sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$z =$ strongly impermeable</td>
<td>4 = &gt;4</td>
<td>300 = &gt;300</td>
<td>$N =$ poor absorbing-, strong retaining capacity</td>
<td>insensitive</td>
</tr>
<tr>
<td>$k =$ intermediately impermeable</td>
<td>3 = 2-4</td>
<td>200 = 200-300</td>
<td>$Gy =$ intermediate absorbing-, good retaining capacity</td>
<td>slightly sensitive</td>
</tr>
<tr>
<td>$gy =$ poorly impermeable</td>
<td>2 = 1-2</td>
<td>100 = 100 200</td>
<td>$K =$ good absorbing-, good retaining capacity</td>
<td>sensitive</td>
</tr>
<tr>
<td>$a =$ permeable</td>
<td>1 = &lt;1</td>
<td>50 = 50-100 25 = &lt;50</td>
<td>$É =$ very high absorbing-, very poor retaining capacity</td>
<td>highly sensitive</td>
</tr>
</tbody>
</table>

**Fig. 2.** Map of the sensitivity to wash in:
1. insensible; 2. slightly sensible; 3. sensible; 4. very sensible

**Spatial-temporal changes of the nitrate-ion concentration in the groundwater**

For searching the spatial-temporal changes of the nitrate-ion concentration in the groundwater, model areas and sampling points were chosen in the middle and eastern part of Hungary. The circles mean the model areas and the quarters show the locations of the water sampling points. From those model areas two were chosen (Apajpuszta and Nyírőlapos/Hortobágy) to check the nitrate content of the groundwater using the results of the monitoring wells. The following results came from the analysis of the nitrate values:

- the nitrate content varies in wells next to each other: the nitrate content in the groundwater at a certain area cannot be estimated based on the sampling of one well (fig. 5);
- the results of the laboratory tests of continuous sampling campaigns justified also that the change in salt concentration may be accompanied by the modification in the nature of groundwater in certain extremely alkaline areas (fig. 6). It can be due with high probability to a horizontal change resulting from the fluctuation of the groundwater i. e. to the change in the direction of the groundwater flow. So the groundwater chemistry varies widely in space and time: the chemical composition of the groundwater cannot be estimated based on the sampling of one well:

- the variability of the nitrate content is seasonal, depends on the vegetation type and life cycle: the nitrate concentration in the groundwater at Nyrőlápos study area is high from July till October, and low in the other part of the year (fig. 7). The seasonal extremity in the nitrate concentration in the groundwater is strongly connected to the weather: when the yearly precipitation is high, the nitrate peak is lower.

Fig. 5. NO$_3^-$ concentration in two groundwater observation wells close to each others of the Apajpuszta model area

Fig. 6. Change in the nature of groundwater in the observation wells of the Nyrőlápos model area (Hortobágy)
Conclusions

We presented our definition for vulnerable territories to nitrate pollution and also the mechanism of the likely pollution was reconsidered upon all these factors and the conclusion was drawn that concerning sensitivity surface- and subsurface waters should be treated separately.

Other conclusion of these measurements is that both the background values and the amount of anomalies varies with geological-morphological and meteorological factors. The vulnerability of surface covering sediments may be defined taking count all of these factors.

Based on these results, the legislative nitrate vulnerability ranking of certain agricultural lands had to be redefined. Results indicate that, in contradiction to EU and Hungarian legislation, local environmental thresholds should be defined with respect to the local geochemical background.

Acknowledgements

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