INFLUENCE OF LOCAL AND LARGE SCALE HYDROMETEOROLOGICAL FACTORS ON INTERANNUAL GROWNDWATER NITRATE REGIME IN RURAL SETTLEMENT

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ABSTRACT. Influence of local and large scale hydrometeorological factors on interannual growndwater nitrate regime in rural settlement. The study analyzes the spatial distribution of groundwater nitrate concentration in Siculeni, a rural settlement in Eastern Transylvania. The aim of the paper is to determine the factors influencing the inter-annual regime of groundwater nitrate concentration. In the analyze groundwater nitrate concentration and water table data are used from 23 sampling points and also precipitation data from Miercurea Ciuc meteorological station are processed. Based on combined cluster analyzes with geographical information system tools the role of point wise communal pollution sources on nitrate concentration are demonstrated, on the other hand the significant empirical relationship between precipitation and groundwater nitrate concentration is argued via introducing an intermediate variable, namely the groundwater table fluctuation. This emphasizes the fact that groundwater nitrate concentration is partly determined by communal local factors and also partly by large scale processes.

Keywords: groundwater nitrate concentration, water table variations, precipitation

1. INTRODUCTION

Increasing groundwater NO_3^- concentrations are generally attributed to anthropogenic sources including agricultural fertilizers, septic and other wastewater sources, livestock facilities, and atmospheric deposition (Böhhlke et al., 2002). Nitrate, the major form of nitrogen in oxidizing water, is not a direct toxic component. When somehow reduced to nitrite, it becomes a health hazard. In the gastrointestinal tract the reduction takes places, so nitrate is present in the range of 6-15 mg/l in the saliva of the organism (Tannenbaum, 1976). There are three potential health hazards related to the consumption of water high in nitrate:

- methemoglobinemia or blue baby syndrome. Most of the reported case involved infants in rural areas (Tannenbaum, 1976);
- potential formation of cancer-causing nitrosamines: reacts with secondary amines and amides present in food and water to form N-nitroso compounds, many of which are carcinogenic, strongly correlated with stomach cancer or Non Hodgkin limfoma. (NRC 1978);

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- elevated nitrate levels in drinking water further have been associated with neural tube defects, and spontaneous abortions (Dorsch et al., 1984; Fanet et al., 1987; CDC 1994 in Ruckart et al.2008).

Nitrate levels are higher in shallow wells and decrease as well depth increases. The shallow superficial aquifers are significantly higher nitrate polluted than the bedrock aquifers demonstrating the contributions of nitrate fertilizer (Rajagopal, 1989).

A study in Minnesota showed that nitrate concentrations at the water table are closely linked to seasonal recharge and with nitrogen fertilizer applications (Landon et al., 2011) Nitrate concentrations in well water were dependent on time, well depth, climate, and surface runoff. In some studies are shown that nitrate levels appear to be stable over a period of even 17 months (Ruckart et al. 2008).

In this study the dichotomy of recharge is going to be demonstrated and also some aspects of natural and anthropogenic phenomenon affecting directly or indirectly the nitrate regime is pointed out in the case of Siculeni village, Romania.

2. DATA AND METHODS

The measuring points consist of a series of observing wells drilled specially for this purpose (15) and few existing traditional wells used daily by locals (8). The observing wells were drilled with Ejikelkamp soil auger, and tubed with PVC pipes and filled on the outside with rounded shape gravels. The sample taking procedure consists of 3 pumping with 9 V battery run 1 inch diameter submersible pump. Before every water sample the observing wells were sucked out totally twice, for having a refreshed water sample. The distribution pattern of the observing wells takes into account the perpendicular street structure of the village Siculeni

The village itself is situated on the axe of the Upper Ciuc basin, an intra-mountainous depression drained by the Olt River, which flows on the western side of the village. The relief of the village is slightly flat, with a small slope from the NE to SE. see Fig. 1a. The Eastern side of the village consists of a wide debris slope of Frumoasa creek, which originates in the Ciuc Mountains and reaches the Olt River 2 km North of Siculeni village. This relief leads us to the presumption that the groundwater has a combined origin: partly from the Olt river-s alluvial groundwater system, partly from the debris slope groundwater system. This dichotomy is going to be reflected in the clusters and annual regime of measured parameters.

The village shows the regular pattern of the Transylvanian village, the households are lined up on the streetfront and almost every household has to deal with animal breeding (few cattle, sheep, poultry, and horses). Some newly built houses have no animals at all. Each household includes small vegetable gardens behind the houses and stables. 8 wells covers this vegetable garden area behind the houses, 12 wells are situated in the middle of the household, and 3 wells are in the village center, which on one side shows the urbanized face (no animals, plenty of shops, train station, blocks), but right behind the blocks is an area full of swine barns). One of drilled wells is in the very vicinity of this area.

The absolute altitudes of the wells were read from the 1:5000 scale cadastral maps. The water table depth was registered manually by a floating device. The nitrate concentration of the water samples were measured at the well with the Nitracheck 404 portable device, with a resolution of 1 mg/l. Three measurements were averaged on every water sample. The observation period is September 2007 – august 2008, during this period 29 samples were analyzed, on a weekly-biweekly basis.

Regional patterns in groundwater nitrate concentration interannual variability have been analyzed in clusters determined by K-mean method (MacQueen, 1967). The reason behind splitting the observed wells in 5 clusters based on the nitrate concentration is that spatially the wells are distributed in 4 districts, and the swine-barn area well had a distinctive regime with 10 times higher concentrations.

The daily precipitation data were used from the Miercurea Ciuc meteorological station, which is situated 6 km SE from the village.

The main statistical method in order to analyses the influence of local and large scale hydrometeorological factors on groundwater nitrate concentration consists in correlation analysis and linear regression analysis including the *b* (slope) coefficient estimation.

3. RESULTS

3.1 Spatial distribution of groundwater nitrate concentration

Local patters in groundwater nitrate concentration variability have been analyzed in clusters determined by K-mean method. The 23 samples are grouped into 5 clusters presented in Fig. 1b.

In order to interpret the mosaic-like spatial distribution of clusters *the distance of the samples from potential pollution source* points (e.g cesspits, manure heaps, stables, and pens) has been analyzed taking into account the *groundwater flow directions* drawn based on water table depth observations. The results are synthesized in Table 1.

Table 1: The Typology of the 5 nitrate-based clusters of wells

cluster 1.	at least 3 pollution sources, all in the 20 meter range
cluster 2	maximum 2 pollution sources, AND one of them is more then 40 m away
cluster 3	at least 2 pollution sources, all in the 30 m range
cluster 4	maximum 2 pollution sources, AND one of them is more than 30 m away
cluster 5	at least 3 pollution sources, all in the 15 m range

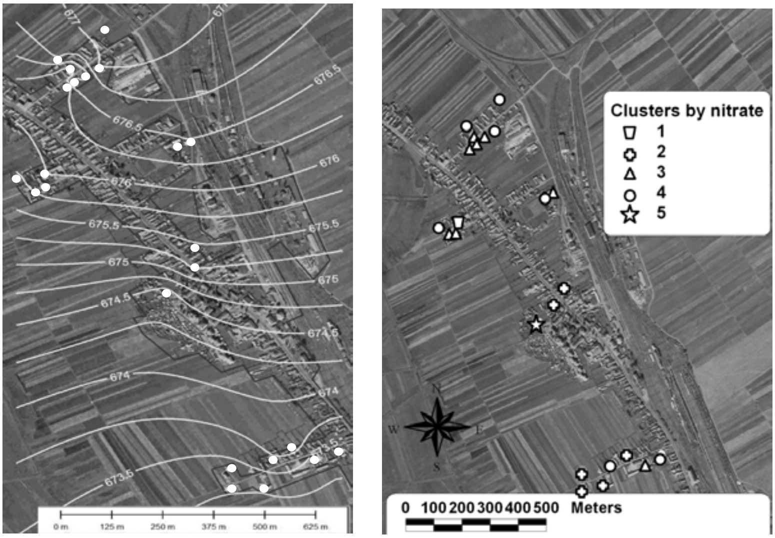

Fig. 1a. (left) shows the topography (m above SL) of the studied area; Fig. 1b. (right) the distribution of the groundwater nitrate concentration clusters in Siculeni

The variation of groundwater nitrate concentration over the year in the case of each cluster only taking into account the datasets without data gaps are shown in Fig. 2. The well of the cluster 1 represents relative high nitrate concentration (109 mg/l average) with also high standard deviation (± 30 mg/l) during the sampling period being located in between 2 households and a big barn in a range of 20 m. The wells from the cluster 2 show the lowest concentration, in average 20 mg/l and the lowest interannual variation (± 10 mg/l) being located in the village center, without animals, or they have max 2 pollution sources and at least one is more than 40 m away. The nitrate concentration of the cluster 3 indicates higher values, 83 mg/l average, and the standard deviation of values are higher as well (± 12 mg/l) than in the case of cluster 2. These have at least 2 pollution sources in the 30 m range.

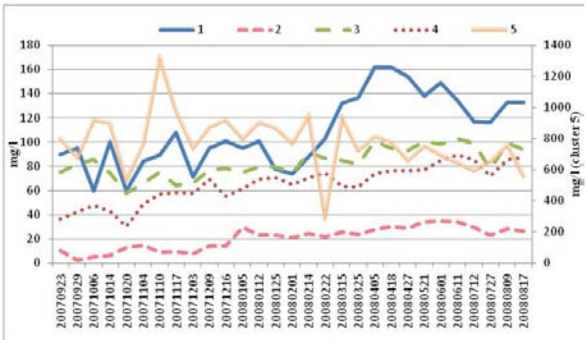

Fig. 2. The interannual variation of groundwater nitrate concentration in the case of the 5 clusters in Siculeni in the period of 09.2007 – 08.2008

Cluster 4 includes wells located mainly in the vegetable gardens, having average nitrate concentration value between values of cluster 2 and 3 (65 mg/l average), but having higher variability (± 16 mg/l). Cluster 5 is a special case showing very high nitrate concentration, 779 mg/l average with also considerable interannual variability (± 181 mg/l).

3.2 Dependency of nitrate concentration on hydrometeorological parameters

The dependency of groundwater nitrate concentration on precipitation intensity is influenced by complex factors, such soil characteristics, flow directions, thus the empirical relationship between the two parameters is determined by introducing a new attribute, namely the groundwater table depth.

Methodologically let us have an environmental variable, W, which is an indirect function of variable X through the intermediate variable Y: $W\{Y(X)\}$. In our case nitrate concentration, W, depends on the water table fluctuation, Y, which, in turn, depends on precipitation, X.

If the $W(Y)$ and $Y(X)$ functions are not too complicated (i.e. not especially non-linear), and ΔX changes of X are not too large, then both functions can be approximated by linear relationships within a narrow interval around their initial conditions: $W(Y) \approx Wo+(dW/dY).Y$ and $Y(X) \approx Yo+(dY/dX).X$. Having appropriate sets of observed or experimental data, the above derivatives can be determined by statistical estimates of regression.

If we wish to know the strength between the nitrate variation (ΔW) and the changes in precipitation (ΔX), we should apply the following simplified formula:

$$\Delta W = (dW/dY).(dY/dX).\Delta X, \qquad (1)$$

where the product of the derivatives can be estimated by the product of the corresponding regression coefficients.

Based on our statistical model in the first step significant correlation has been found between the groundwater table depth and sum of daily precipitation measured between the two sampling time in all cases. In all cases the precipitation dataset was the same, the relation with different strength comes from the diverse soil properties and possibly the dichotomy of the groundwater recharge pointed at the beginning of this article. The negative correlation describe the reasonable physics of the phenomena, namely the groundwater table depth decreases (groundwater level increases) in parallel with increase in precipitation amount, and conversely.

In the second step the linear relationship between groundwater nitrate concentration and groundwater table depth is quantified by correlation coefficients. In all cases statistical significance test has been elaborated at $p=0.05$. The results are presented in Table 2, consequently statistically significant correlation has been found between the two variables in the case of the clusters 1, 2, 3 and 4.

Table 2. Correlation coefficients (r) between variables, significance level at p=0.05 is 0.36 and changes in groundwater nitrate concentration with 1 mm precipitation changes

Clusters by groundwater NO_3^- concentration	r groundwater table depth and precipitation	r NO_3^- concentration and groundwater table depth	Changes in groundwater NO_3^- concentration in case of 1 mm precipitation changes (mg/l)
Cluster 1	-0.50	-0.61	0.31
Cluster 2	-0.46	-0.80	0.12
Cluster 3	-0.52	-0.66	0.15
Cluster 4	-0.47	-0.55	0.14
Cluster 5	-0.46	-0.04	-

Cluster 5 does not show significant relation because of the high anomaly in the NO_3^- concentration. In the following this cluster will be excluded from the analyses. The negative correlation indicates nitrate concentration increase in parallel with groundwater table depth decrease, namely with groundwater level increase, and conversely. Following the water table rise, the formerly leached nitrates from the semi dry soil solute into the groundwater. As the consequence groundwater nitrate concentration increases if precipitation increases.

As the second step of the statistical analysis the linear regression coefficient has been calculated between groundwater nitrate concentration - groundwater table depth and groundwater table depth - precipitation. The dependent variables are the groundwater nitrate concentration, and the groundwater table depth, respectively. The change in groundwater nitrate concentration in the case of 1 mm precipitation changes can be quantified as the product of the regression coefficients (Table 2). It should be mentioned that the impact of precipitation on groundwater nitrate concentration is differing in the case of the 4 clusters; the highest value is detected at Cluster 1, mainly caused by the strong relationship between the groundwater table and nitrate attributes. This is due to the fact that the cluster is represented by a single well, which shows relatively high concentrations – its average is twice higher than the threshold for drinking water. It has the biggest barn in the village in its 30 m range, so nitrate responds quickly to the water table fluctuation.

3.3 Large scale groundwater table depth variation

The spatial distribution of groundwater table depth is influenced by other parameters beside the precipitation like soil characteristics and hydrogeological conditions as well. In order to validate the empirical relationships presented above the variation of groundwater table depth has been analyzed separately.

Based on interannual variation of the groundwater table depth the 23 wells are grouped into 5 clusters also determined by K-mean method (Fig. 3a). The spatial distribution of the clusters is primarily determined by regime of the water table fluctuations and do not corresponds with the clusters in section 3.1. These clusters seem to be linked to the dichotomy of the groundwater recharge from the two systems which are interlinked under the village. The water table flow contour lines drawn in Fig. 3b. (Date: 27th of July 2008) exemplifies the phenomenon: the Olt alluvial groundwater system flows from NW-SE direction, the Frumoasa creek debris cone groundwater system flows from NE-E. Note that only the contours under the village should be taken into account, because of measured data. The contours outside the village area are the results of Kriging variograms and are not checked by observed data.

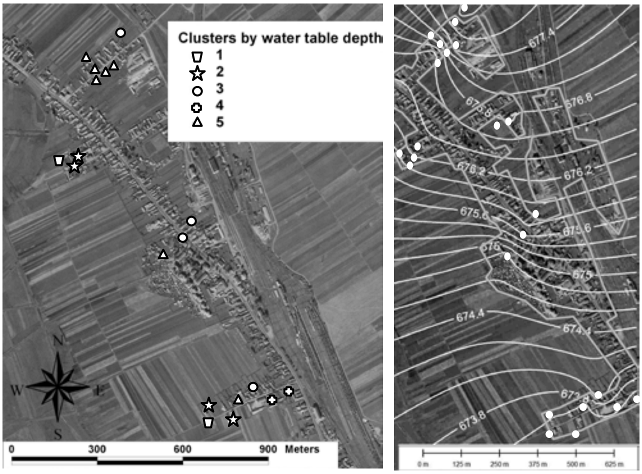

Fig. 3a. (left) The spatial distribution of the groundwater table depth clusters in Siculeni; Fig 3b. (right) The piezometric map of Siculeni village in 27.07.2008-waterheads in m above SL

Table 3. Correlation coefficients between variables, significance level at p=0.05 is 0.36

Clusters by groundwater table depth	**r NO_3^- concen-tration and ground-water table depth**
Cluster 1	-0.56
Cluster 2	-0.53
Cluster 3	-0.92
Cluster 4	-0.59
Cluster 5	-0.60

In this section the correlation coefficients between groundwater nitrate concentration and groundwater depth are also calculated, but at this time the wells are enrolled in groundwater table depth clusters. Table 3 shows the results. There have been found significant correlation between groundwater table depth and groundwater nitrate concentration.

4. CONCLUSIONS AND DISCUSSIONS

Nitrate concentration of groundwater generally increases in the warm period of the year.

The relation between the cluster’s location and its average nitrate concentration confirms the significant role of point wise pollution sources in groundwater nitrate variability.

In the section of 3.1 the local aspect of groundwater nitrate concentration has been argued. High resolution analyses in North Hungarian village also emphasized that extremely high nitrate concentrations under the settlements cannot be argued only with agricultural source nitrate diffuse leaching (Kerényi et. al

1998). In the same time in the section of 3.2 the strong correlation between nitrate concentration and groundwater table depth has been proved. The variation of groundwater table depth is controlled by large scale processes (including precipitation).As the consequence the fact that groundwater nitrate concentration is party determined by all local factors and also partly by large scale processes can be emphasized.

In the case of different clusters the strongest correlation (from Table 2) in Fig. 1b denotes the greater role of local factors (point wise pollutions), the strongest correlation (from Table 3) in Fig. 3a highlights the role of large scale nitrate leaching which has its origin in the diffuse sources in the E and NE of the village, where wide agricultural fields are situated. All the wells belonging to the cluster 3 (water table based clustering) has few communal potential pollution sources, so they relate strongly to the agricultural source of nitrate, thus the high correlation with the water table regime.

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