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Baseline Survey for an Assessment of the Nitrate Problematic in Divjaka Region of Albania

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Abstract

The Republic of Albania is an official candidate for EU membership since 2014, whereas for the accession to the EU the whole EU legislation has to be implemented into Albanian law. Thus, the limit value of the nitrate concentration in groundwater is defined with 50 mg/l according to the EU Groundwater Directive. However, in a definite region in Albania that is called Divjaka area it is assumed that this limit value is exceeded due to intensive agricultural land use, whereas no measurements are currently available. Therefore, simulation results of the nitrogen discharge model EPIC are presented, including the annual nitrogen leaching and the nitrate concentration in percolation water. As the latter exceeded the limit value, the findings at least indicate the necessity to monitor groundwater quality as basis for further studies and potential measures to avoid pollution.

Keywords: groundwater, nitrate concentration, pollution, EPIC model.

1. Introduction

Drinking water of high quality is the basis for human health and well-being. Against this background, the European Union enacted laws to protect the water resources of its member states. The general legal framework is given by the EU Water Framework Directive (EU-WFD) [7]. According to the latter, surface water and groundwater should be of ‘good status’ with regard to both quantity and quality. The more specific EU Groundwater Directive defines threshold values that indicate a good chemical status of groundwater [8]. In order to assess the ‘good status’, EU member states have to establish monitoring programmes and implement programmes of measures to guarantee the required standard [3; 9].

The Republic of Albania – as an official candidate for EU membership – has to implement the whole EU legislation into national law. In general, no difficulties are expected regarding quantitative aspects, because the Albanian water resources of both surface water and groundwater are considerably larger than the amount that is used [10]. On the other hand, intensive agricultural land use is known to have the potential to deteriorate groundwater quality due to the input of nutrients. Nitrogen, for example, is essential for crop production. Hence, fertilizers containing nitrogen in the form of ammonium (NH_4) and nitrate (NO_3) are commonly applied to guarantee high and stable yields, thus securing food production for a growing population. Under certain circumstances, however, nitrogen leaching can cause groundwater pollution [4; 11].

According to the EU Groundwater Directive, the limit value of nitrate concentration is 50 $mg \cdot l^{-1}$. In a particular Albanian region named Divjaka area, it is assumed that this limit value is exceeded due to intensive agricultural land use. As no direct measurements of groundwater quality are available to date, estimating nitrogen leaching is the only way to obtain general information for further studies and discussion of potential measures.

Consequently, the main objective of the current study was to assess the amount of leached nitrogen as well as the nitrate concentration in percolation water in Divjaka area using a nitrogen discharge model (EPIC). Applying this model provided the possibility to consider plant requirements, crop rotations, soil properties, climatic conditions and optional irrigation according to local practices.

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2. Materials and Methods

2.1. Study site Divjaka area

Divjaka area (41°0'0''N and 19°30'0''E) covers four agro-environmental areas (Figure 1): A lagoon of 595 ha; aside, an area of 308 ha that is frequently flooded during winter season, characterised by salt affected soils, and used as pasture; an area of 4826 ha, where in the East hills reach about 20 m elevation; and an area of 3200 ha, where the altitude increases up to 3 m and groundwater is about 1.5 m below ground surface. 1800 ha of the last-mentioned area are used as agricultural fields. This part was considered for this study, mainly because it is intensively used and high amounts of fertiliser are applied on a sandy soil.

Weather data of the years 2008 to 2012 are shown in Table 1 and Figure 2. Mean annual precipitation was 992 mm, mean air temperature was 16.2°C.

Figure 1. Divjaka area, Albania

Table 1. Precipitation of the study area Divjaka

Year	2008	2009	2010	2011	2012	Average value
Precipitation in [mm]	738	1001	1291	1282	648	992

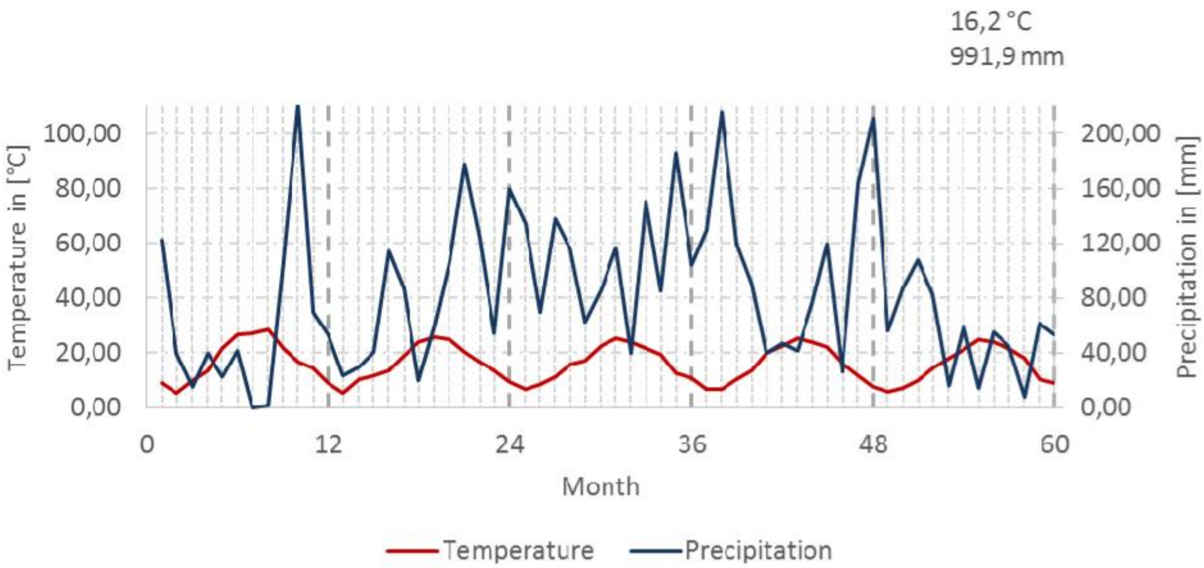

Figure 2. Air temperature and precipitation of Divjaka area (2008-2012)

2.2. EPIC – Nitrogen discharge model

EPIC (Environmental Policy Integrated Climate) is a mathematical simulation model for agricultural cultivation that enables assessing *"effects of management decisions on soil, water, nutrient and pesticide movements, and their combined impact on soil loss, water quality, and crop yields for areas with homogeneous soils and management."* [12]. Simulation results allow studying plant growth in relation to yield (from an economical point of view), in combination with impacts of specific land use scenarios on the environment [1; 12].

EPIC is composed of sub-models. The hydrology sub-model includes surface runoff, lateral subsurface runoff, snow melt, alterations in groundwater level, percolation, and evapotranspiration

(ET). Reference ET is computed based on weather data using the well-known model after Penman and Monteith. Actual ET is calculated considering both reference ET and soil water depletion. Crop water requirements are determined based on actual ET data and the leaf area index representing crop development. The nitrogen and phosphorus cycle are simulated using sub-models for mineralisation, immobilisation and denitrification. Nitrogen leaching is proportional to percolation and therefore depending on the amount of surface and lateral subsurface runoff. A sub-model for crop growth contains specific parameters for each crop. Nitrogen uptake is based on an optimum supply for the respective crop. The sub-model for tillage operations considers changing soil properties due to loosening of the upper soil layer [6].

2.3. Model input and simulations

Simulations were performed on a daily basis, the results averaged to annual values. Input data for the simulations included weather data, soil (hydraulic) properties, crop characteristics and crop rotations, and management data (tillage, fertilisation, irrigation).

Weather data, measured at a representative weather station, comprised solar radiation, air temperature, relative humidity, and wind velocity. According to the Albanian soil map [10], the prevailing soil type in the study area was sand with fractions of 90 % sand, 9 % silt, and 1 % clay; organic matter was smaller than 1 %. Soil hydraulic properties were estimated based on these data using a pedotransfer function after [2]. According to this, plant available water was 62 mm for a soil depth of 150 cm, and hydraulic conductivity at saturation was 17 $m \cdot d^{-1}$. These parameters indicate a low water storage capacity and a high permeability.

Two typical crop rotations of six and five years, respectively, were established based on information from the Directory of Agriculture in Lushnja (Figure 3).

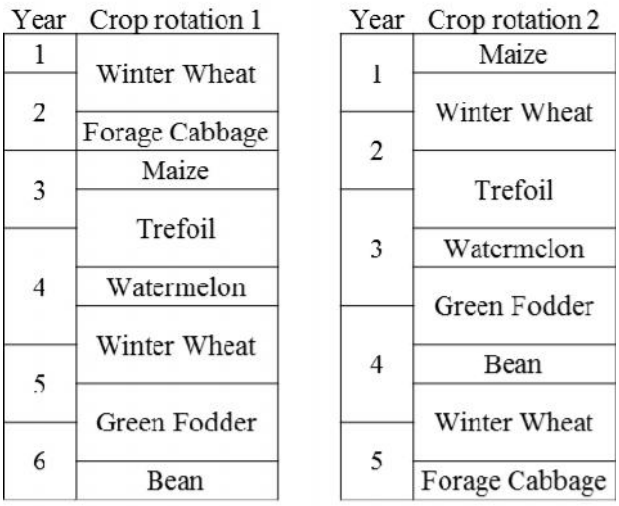

Figure 3. Crop rotations as model input

Irrigation and fertilisation were considered according to local practices; Table 2 gives an overview on the respective amounts. Nitrogen fertilisation includes all kinds of fertilisers; costumarily, chemical fertilisers as well as organic manure are applied in the region.

The entire simulation period was 12 years, in which the weather data (five years of measurements) were repeated in a loop. Each model run was then repeated five times, each time starting with another year, so that every crop was simulated based on the weather conditions at hand. Results of the five repeated runs were averaged in order to represent mean conditions rather than differences between single years. Thus, yields and output data represent average weather conditions.

Table 2. Typical crop rotations, nitrogen fertilisation and irrigation as input data for the model

Year	Crop rotation 1			Crop rotation 2		
	Crop	Fertilisation in [kg N/ha]	Irrigation in [mm]	Crop	Fertilisation in [kg N/ha]	Irrigation in [mm]
1	Winter Wheat	168		Maize Winter Wheat	316 168	5 *50
2	Forage Cabbage	176	4 *40	Trefoil	51	
3	Maize Trefoil	316 51	5 *50	Watermelon Green Fodder	102 176	1* 30
4	Watermelon Winter Wheat	102 168	1 *30	Bean Winter Wheat	51 168	2 *30
5	Green Fodder	176		Forage Cabbage	176	4 *40
6	Bean	51	2 *30			

3. Results and Discussion

Simulated average yields of the respective crops revealed differences between crop rotation 1 and 2 as well as compared to typical yields in Albania (Table 3). Substantial differences (larger than 20 %), however, can only be recognised for trefoil (not irrigated) in crop rotation 2 compared to the other values, and watermelon in crop rotation 1 compared to real yields. The other yield levels indicate plausible simulation parameters in general. However, it has to be noted that the presented quantities represent mean values with little statistical significance.

Comparing calculated actual ET (Table 4) to rainfall data (Table 1) confirms that the region is sufficiently supplied with water. However, the water storage capacity of the prevailing soil is poor, which is the reason why irrigation seems necessary in spite of the positive water balance.

Irrigation amounts were determined during the simulation by balancing rainfall, plant water uptake, and available soil water. When the computed water balance became negative, the model included irrigation up to the amounts given as input data (Table 2). Consequently, simulated (= “essential”) irrigation amounts could be smaller than the input value, as it was the case for maize and partly for forage cabbage (Table 5). Without over-interpreting the simulations, it can be concluded that irrigation of maize could be reduced without yield decrease, whereas for watermelon more irrigation might have increased the yield level of the simulation. However, further studies and adaptions of crop parameters are required to substantiate these findings.

Table 3. Average yield in dry matter

Crop	Simulated average yield in [t/ha]		Average yield in Albania in [t/ha]
	Crop rotation 1	Crop rotation 2	
Maize	6.1	6.1	5.1
Winter Wheat	3.6	3.6	3.0
Trefoil	3.0	2.3	3.0
Watermelon	2.9	3.3	4.1
Green Fodder	6.2	7.0	6.6
Bean	1.2	1.1	1.3
Forage Cabbage	4.1	3.6	4.2

Table 4. Actual evapotranspiration

Crop rotation	Average actual evapotranspiration in [mm/a]					
	2008	2009	2010	2011	2012	mean
Crop rotation 1	406	589	575	521	503	519
Crop rotation 2	391	563	546	499	485	497

Table 5. Irrigation amounts of irrigated crops: simulation versus (maximum) input data

Crop	Simulated irrigation amount in [mm]					Irrigation performed in Albania in [mm]
	2008	2009	2010	2011	2012	
Maize	4 x 50[1]	2 x 50	2 x 50	3-4 x 50[2]	4 x 50	5 x 50
Bean	2 x 30	2 x 30	2 x 30	2 x 30	2 x 30	2 x 30
Watermelon	1 x 30	1 x 30	1 x 30	1 x 30	1 x 30	1 x 30
Forage Cabbage	4 x 40	2 x 40	2 x 40	3 x 40	4 x 40	4 x 40

[1] The irrigation amounts four times 50 mm, which is in sum 200 mm in this vegetation period.

[2] The irrigation for crop rotation 1 is three times 50 mm and for crop rotation 2 four times 50 mm.

The presented quantities of rainfall and actual ET in combination with the poor water holding capacity and the large permeability of the soil indicate substantial deep percolation and, consequently, a high risk of leaching processes.

In fact, simulated amounts of percolation water were substantial in all years (Table 6). Because of the slightly smaller actual ET of crop rotation 2, its percolation amounts were larger. While water that percolates below the rooting depth contributes to groundwater recharge, it also might leach nitrogen, as illustrated in Table 7. It has to be noted that the annual mean quantities express only the dimension of nitrogen leaching. Details have to be investigated on time series with higher temporal resolution, because single events – for example, strong rainfall after fertiliser application – are known to have a substantial impact on percolation and leaching processes.

Simulated values of the nitrate concentration in percolation water were smaller in years with larger precipitation (Table 8), likely because of dilution. In general, nitrate concentrations exceeded the limit value of 50 $mg \cdot l^{-1}$ in all the years. From this follows that the presumed environmental conditions and management practices imply a certain risk of groundwater pollution. However, concretising this risk or quantifying contaminant loads requires further studies including, above all, more data.

Table 6. Percolation water

Crop rotation	Average percolation water in [mm/a]					
	2008	2009	2010	2011	2012	mean
Crop rotation 1	461	475	663	699	319	523
Crop rotation 2	476	501	693	732	337	548

Table 7. Nitrogen leaching

Crop rotation	Average nitrogen leaching in [kg/(ha.a)]					
	2008	2009	2010	2011	2012	mean
Crop rotation 1	158	128	104	152	67	122
Crop rotation 2	171	121	125	125	74	123

Table 8. Nitrate concentration in percolation water

Crop rotation	Average nitrate concentration in percolation water in [mgNO_3^-/l]					
	2008	2009	2010	2011	2012	mean
Crop rotation 1	154	118	74	124	87	111
Crop rotation 2	158	107	76	89	75	101

4. Conclusions

A simulation model was applied to estimate nitrogen leaching in an agricultural area in the republic of Albania. The basic water balance data included rainfall, calculated evapotranspiration, and soil hydraulic properties. Typical crop rotations and management practices (fertilisation, irrigation) were considered. A positive balance (rain minus evapotranspiration), and a soil with low water storage capacity and high permeability resulted in considerable amounts of percolation water during several years of simulation. Also nitrogen leaching could be verified. Simulated nitrate concentrations exceeded the limit value of the EU Groundwater Directive.

The simulation results at least indicate the necessity to monitor groundwater quality as basis for further studies and to avoid pollution.

Potential measures to prevent groundwater quality from deterioration might consider optimisation of irrigation, changes of crop rotations including catch crops, and adaptions of tillage operations. Besides that, adapting fertilising practices will be necessary with respect to the authorised maximum nitrogen amount of 170 $kg \cdot ha^{-1} \cdot a^{-1}$ according to the EU Nitrates Directive. In conclusion, it is obvious that harmful environmental impacts caused by agricultural land use should be reduced. At the same time, proper yields have to be guaranteed in order to maintain the basis for agricultural production. In this regard, simulating different scenarios by changing input data and can help understanding effects and adapting measures with respect to a sustainable and productive agriculture [5].

5. Acknowledgments

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