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IMPACT OF DIFFERENT PROPORTION OF AGRICULTURAL LAND IN RIVER CATCHMENTS ON NITROGEN SURFACE STREAMS POLLUTION

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Water quality is threatened particularly in regions where the agricultural landscape is prevailing. This study presents results of the comparison of yearly total nitrogen emissions and contribution of different emission pathways on this emissions into surface streams for three river catchments in Slovakia territory with the contrasting proportion of agricultural land to the total area of the river catchment. For nitrogen yearly emissions and pathways detection, the numerical model MONERIS has been used. Results indicate that in river catchments with a higher proportion of agricultural land higher contribution of nitrogen emission carried out mainly via groundwater (especially in lowland), but also via agricultural erosion and drainage system.

KEY WORDS: water quality, surface stream, nitrogen emission, MONERIS, river catchment

Introduction

The Water Framework Directive (European Community, 2000), that rules the current European water policy, defines water quality as the level of deviation from the type-specific 'reference conditions'. Water quality in surface streams can be expressed by physical, chemical and biological indicators and most often is affected by a combination of anthropogenic as well as natural factors, the relative influences of which change with temporal and spatial scale. Many studies refer that the water pollution problem is caused by changes in the composition of land use within a catchment as human activities increase (Amiri and Nakane, 2009; Boskidis et al., 2010).
Understanding the influence of river catchment parameters on time and spatial variability of nutrients concentrations is the basic requirement for effective water quality management, especially in regions where the agricultural landscape is prevailing (Hill, 1981; Sliva and Williams, 2001; Foley et al., 2011).
Agriculture is considered to be one of the most representative examples of a non-point source of surface streams pollution (Lam et al., 2010). The non-point source emissions that end up in surface waters have many different pathways: overland flow, groundwater flow, tile drainage, erosion, urban systems and atmospheric deposition, etc. Surface streams are polluted during more intensive rainfall mainly and in snowmelt period, thus during significant runoff events (Julínek and Říha, 2017; Halmová et al., 2019). The heightened amount of nitrogen in surface streams can result environmental issues such as eutrophication of waters, growth of periphyton, etc. (Weitzel, 1979) and decrease of biodiversity (Di and Cameron, 2002).
To effectively target pollution mitigation and remediation actions in regions with impaired water quality, a number of models have been developed (Rothwell et al., 2010). One of them is the MONERIS (MOdelling Nutrient Emissions into RIver Systems) model. This model calculates the emissions of nutrients (e. g. nitrogen) to the surface water by different pathways (Behrendt et al., 2007).
We used this model to calculate and compare yearly total nitrogen emission in tonnes per year [$t\ y^{-1}$] as well as in kg per hectare per year [$kg\ ha^{-1}\ y^{-1}$] among three middle-sized river catchments from different parts of Slovak territory with different proportion of agricultural land to the total area of the river catchment. Results of the model were used also for determination of the pathways with the most important contribution to the nitrogen emission in these catchments.

Material and methods

In order to fulfill the objectives of this contribution, there was necessary to handle several datasets from different sources and in diverse quality, as well. All these data were necessary as the input data to the MONERIS model in order to calculate yearly total nitrogen emissions (YTNE) and also to determine the proportion of different pathways on YTNE into surface streams in three river catchments.

MONERIS model is a semi-empirical conceptual model which allows quantification of nutrient emissions from point and diffuse pollution sources into surface streams (Behrendt et al., 2002; 2007; Schreiber et al., 2005). While the wastewater from municipal wastewater treatment plants and from industry is directly discharged into the rivers and is not difficult to identify them, diffuse emissions of pollutants into surface waters are caused by the sum of different pathways, which are realized by separate flow components. They can be divided to these main groups (Behrendt et al., 2007):

- input into surface water via atmospheric deposition,
- input into surface water via groundwater,
- input into surface water via tile drainage,
- input into surface water via paved urban areas,
- input into surface water by erosion,
- input into surface water via surface runoff (dissolved nutrients).

Basis of the spatial resolution is the analytical unit, thus sub-catchments in a river basin. It is possible to run the model in a spatial resolution of 1 km^2 (Behrendt et al., 2007), but due to the calibration needs, a minimum spatial level depends on accessible input data resolution. Water quality data in three river catchments were collected for the years 2008–2017. These catchments were selected from different parts of Slovakia territory and they represent different proportion of agricultural land to the total area of the river catchment. Data that changes dynamically in time and space such as precipitation, runoff or nitrogen balance we collected and processed for 2017. More detailed information about data used for this analysis is possible to find either in Table 1 or in the next paragraphs.

All data was distinguished into several categories as follows:

- data on physical geography, where we included mainly data on relief, land cover, soil, geology and climatology:
  - digital elevation model (NASA JPL, 2013) that has spatial resolution approximately 30x30 m; from this data also average angle of slope and average elevation were derived,
  - data on land cover derived from the CORINE Land Cover 2012 (CLC) (EEA and SAZP, 2012),
  - the additional dataset consists mainly on data about agricultural land use available from the Land Parcel Identification System layer (LPIS) (Ministry of Agriculture of the SR, 2017),
  - data on soil texture, soil losses, and nitrogen top soil content available from the European Soil Data Centre (European Commission, 2009, 2015, 2016a),
  - data on rocks permeability taken from the Global Hydrogeology Maps of Permeability and Porosity (Gleeson et al., 2018),
  - bonitized Soil-Ecological Units layer (BPEJ) (NAFC, 2017),
- data on precipitation, evapotranspiration, river discharge and the water temperature was provided by the Slovak Hydrometeorological Institute (SHMI),
- data on non-point pollution sources:
  - data on the consumption of industrial and organic fertilizers at the district level of Slovakia territory provided by the Central Testing and Control Institute of Agriculture,
  - data on gross nutrient balance at the district level of Slovakia territory according to Directive No. 151/2016 (the Ministry of Agriculture of the SR, 2016) provided by the Central Control and Testing Institute in Agriculture in Bratislava,
  - modeled data on wet and dry atmospheric deposition, reduced as well as oxidized, was provided by the European Monitoring and Evaluation Programme (MET Norway, 2019),
  - data on crops grown at district level of Slovakia (harvest area in hectares, total harvest in tonnes, harvest from one hectare in tonnes), data on livestock at district level provided by the Statistical Office of the Slovak Republic,
- data on point pollution sources:
  - data on important point pollution sources (The Ministry of Environment of the Slovak Republic, 2009) in Slovakia,
  - data on wastewater treatment plants in Slovakia territory (European Commission, 2016b),
  - data on the number of inhabitants connected to the sewer system and number of inhabitants connected to sewer system via wastewater treatment plants provided by the Water Research Institute in Bratislava,
- data on water quality: monthly data consist of concentrations in total nitrogen water quality indicator in the period 2008–2017 provided by SHMI (for the long term and seasonal statistic processing the whole dataset was used, for MONERIS model only data from 2017 was used),
- other data:
  - detailed boundaries of river catchments provided by the SHMI,
  - data on the number of inhabitants of Slovak municipalities and towns provided by the Statistical Office of the Slovak Republic,
  - data on drainage channels provided by the Hydromelioration state-owned enterprise.

Total nitrogen concentrations values lower than the limit of quantification were set to the half value of the quantification limit according to Government Regulation No. 201/2011 Coll (Government of the Slovak Republic, 2011). Fig. 1 shows localization of monitoring places for water sampling as well as boundaries of river catchments where analysis of river catchment parameters was done. Table 1 shows selected parameters of the river catchments that were also used as inputs in the MONERIS model.

For identification of land cover, we used datasets from EEA and SAZP (2012) and Ministry of Agriculture of the SR (2017). Based on these two data sources, we divided individual land cover categories into four groups as follows:

- agricultural areas: arable land and pastures,
- forest and seminatural areas,
- urbanized and technique areas,
- uncategorized: open pit mine, open land, glaciers, wetland, water surface area.

Group of agricultural areas consist only of two land cover categories – arable land and pastures – for two main reasons: in these areas the application of industrial and organic fertilizers is the highest one and therefore in catchments with a higher proportion of mainly these two land cover categories there is also a higher potential for nitrogen surface streams pollution; another reason is that Land Parcel Identification System (LPIS) layer, that we used mainly for identification of arable land and pastures, has higher spatial accuracy and reliability in comparison with CORINE Land Cover.

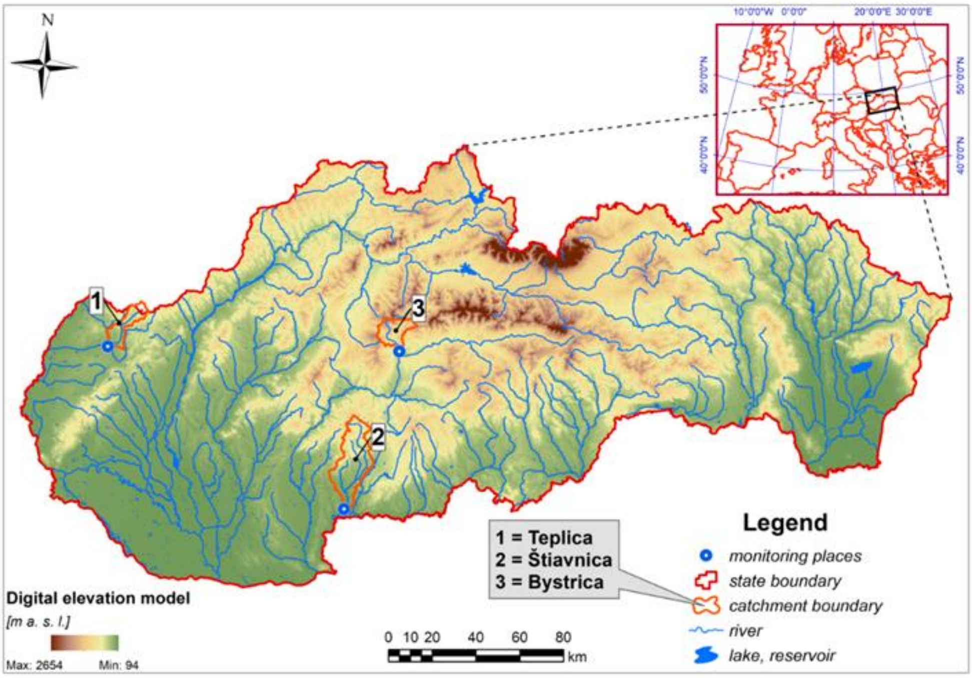

Fig. 1. Situation of evaluated river catchments in Slovakia territory and localities of water quality measurements.

Table 1. Summary of investigated catchments parameters

catchment parameter	unit	Teplica catchment	Štiavnica catchment	Bystrica catchment
size	km^2	152.6	445.7	158.9
average slope	%	12.4	15.9	46.9
agricultural land (AgL.)	km^2	94.9	186.5	11.8
proportion of AgL. to the total area of catchment	%	62.2	41.9	7.4
drained AgL	km^2	6.9	7.0	0.0
proportion of drained AgL to the total area of AgL	%	7.3	3.8	0.0
forest and seminatural area	km^2	46.5	236.7	142.6
urban area	km^2	10.6	20.1	3.7
uncategorized area	km^2	0.7	2.3	0.9
yearly precipitation	mm y^{-1}	559.9	706.0	957.2
average annual discharge	$m^3 s^{-1}$	0.2	1.2	2.5
average annual water temperature	°C	12.7	10.5	8.6
nitrogen balance on AgL. land	kg $ha^{-1} y^{-1}$	49.3	70.4	72.9
population	inhabitants	25 310	24 034	2 134
population connected to WWTP´s via sewer system	inhabitants	20 489	12 585	0.0

The basis for modeling of nitrogen emission pathways in the MONERIS model

In this paper, we focused mainly on differences in nitrogen emissions that entry surface streams via emission pathways that relate to the area of agricultural land: agricultural erosion and drainage systems. However, as it has been already mentioned, in the MONERIS model more than only these two emission pathways are present. Therefore, in the results of this work we present emissions from all emission pathways as they are available in the MONERIS model. A more detailed investigation of the contribution of other emission pathways will be performed in future work. Nevertheless, in this section, we will briefly explain which data are most relevant for the calculation of emissions via other emission pathways that are also important in regard to overall nitrogen emissions.

To calculate nitrogen emission via point sources, data on important point pollution sources and wastewater treatment plants has been used. Statistical data such as number of inhabitants and mainly number of inhabitants connected to a sewer system and connected to a sewer system with wastewater treatment plants are important for the calculation of nutrient emissions from paved urban areas. To calculate emission via groundwater, data on rock permeability, data on soils, and also data on nitrogen balance on the agricultural area was necessary to process. Geology or rock types are in the MONERIS model discriminate according to consolidation and groundwater level (Behrendt et al., 2007). It is an important parameter for the calculation of nitrogen retention in the unsaturated and saturated zone and then for calculation of nitrogen concentration in groundwater. Inevitable inputs for calculation of the contribution of surface runoff on overall total nitrogen emissions are land cover categories, river discharge, and precipitation. Surface runoff is calculated separately for different land cover categories. The basis for the surface runoff calculation is the specific runoff from these areas (Venohr et al., 2011). The basis for the calculation of emissions via natural and agricultural erosion creates data on soil losses, land cover, digital elevation model (slope), and N-content of topsoils. Emissions via drainage systems are calculated using data on drained agricultural area, data on precipitation, and nitrogen balance on agricultural land.

Results and discussion

Nitrogen concentrations, yearly emissions in t y^{-1} and kg ha^{-1} y^{-1} to the surface streams and proportion of emission pathways on YTNE in three river catchments with different proportion of agricultural land to the total area of the river catchment were analyzed. Table 1 gives a summary of the selected river catchment parameters.

Fig. 2 shows area of arable land and pasture (agricultural land) and also localization of till-drainage channels. Arable land is prevailed land cover category mainly in the Teplica river catchment and also in the south part of the Štiavnica river catchment. On the other hand, we can see only minimal area of arable land and just small area of pasture in the Bystrica river catchment.

We should notice that the Štiavnica river catchment area is approximately three times larger than the areas of rest two catchments. On the other hand, average elevation and average slope were the highest in the Bystrica river catchment.

In Fig. 3 is possible to see that total nitrogen concentrations in two out of three investigated river catchments are decreasing during 10-year period. It is noticeable mainly in the Teplica river catchment (nitrogen concentration have decreased from approximately 8 mg l^{-1} at the beginning of the period (2008) to around 4 mg l^{-1} at the end of period in 2017). In the Štiavnica river catchment, a decrease of about mg l^{-1} in the 10-year period was recorded. On the other side, in the Bystrica river catchment no trend in total nitrogen concentrations was detected.

Total nitrogen emissions into surface streams were calculated using the MONERIS model that simulated surface streams nitrogen emissions along 11 emission pathways as follows:

- atmospheric deposition,
- surface runoff,
- snowmelt,
- agricultural erosion,
- natural erosion,
- drainage systems / tile drainage,
- groundwater,
- urban areas connected to a separated sewage system,
- urban areas connected to a combined sewagesystem,
- urban areas not connected to a sewage system,
- point sources of nitrogen.

It is possible to display total emissions in tonnes per year as well as in kg per hectare per year and the proportion of each pathway on yearly total nitrogen emissions. Fig. 4 shows the total nitrogen emission in tonnes per year divided into above-mentioned 11 pathways. On the other hand in Fig. 5 it is possible to see area-specific nitrogen emission also divided into eleven pathways, but in kg per hectare per year. This kind of analysis is independent on the catchment size. The MONERIS model results show that the highest contribution on total nitrogen emission in all three catchments has groundwater pathway. Second important pathway in the Teplica and the Štiavnica river catchment is a drainage system and in all catchments also the contribution of nitrogen emissions from point sources. The contribution of surface runoff is not negligible mainly in the Bystrica river catchment. In the context of the proportion of agricultural land to the total area of the river catchment, we are focused to differences in nitrogen emissions originating from agricultural erosion. In case of a flat territory (lowland) also the existing drainage channels determine significantly the proportion of nitrogen emission to surface streams, what was confirmed also by the results of this study. Till-drainage network in the Teplica river catchment drains approximately 6.9 km^2, thus only slightly more than 7% of the total area of the river catchment. In the Štiavnica

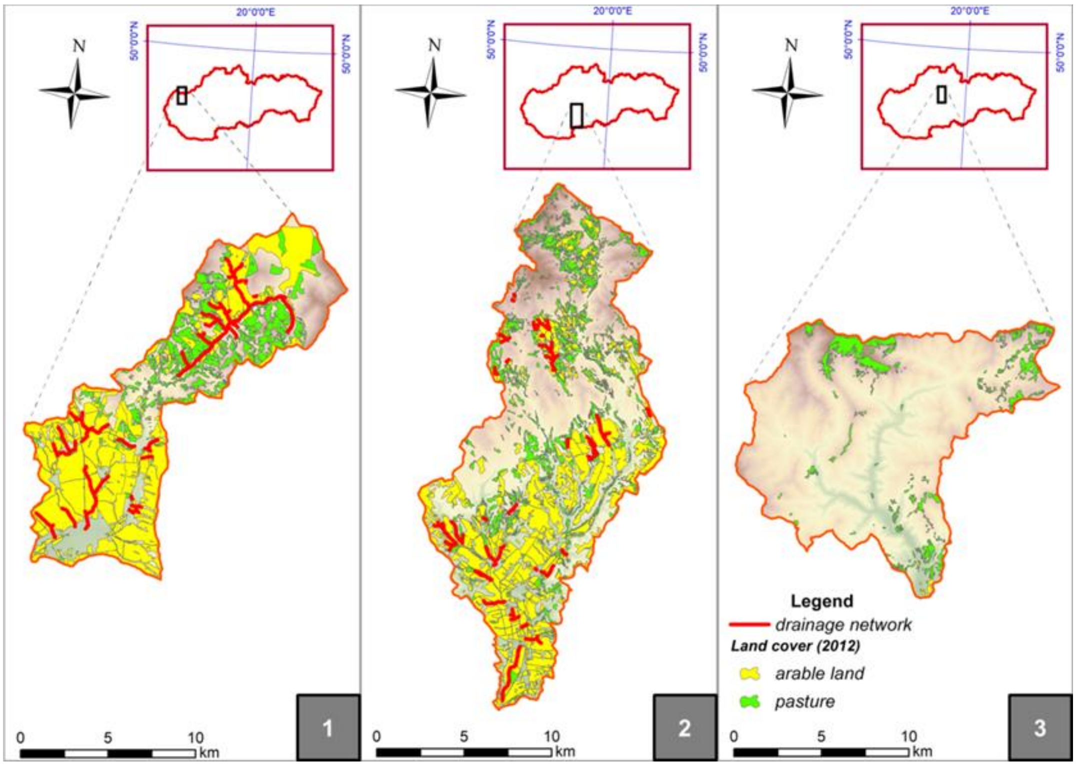

Fig. 2. Agricultural land cover categories and tile-drainage network in evaluated river catchments (numbers correspond with Fig. 1) on the background of digital elevation model (legend valid for all three maps).

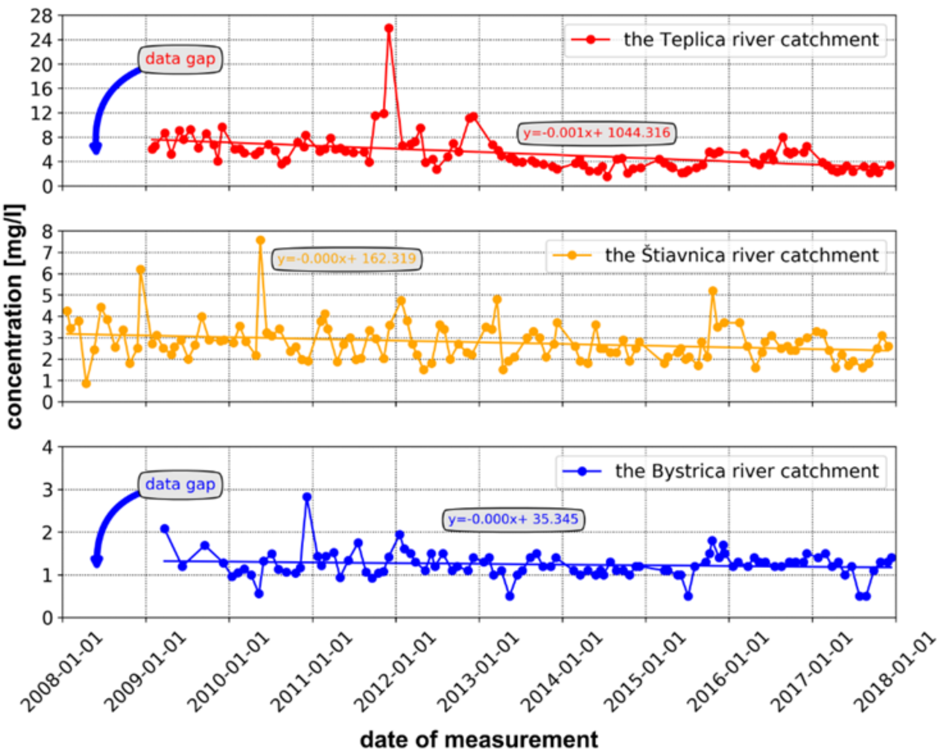

Fig. 3. Time series of total nitrogen concentrations in three investigated catchments in the period 2008–2017 (data with monthly time step collected from one location at the catchment outlet).

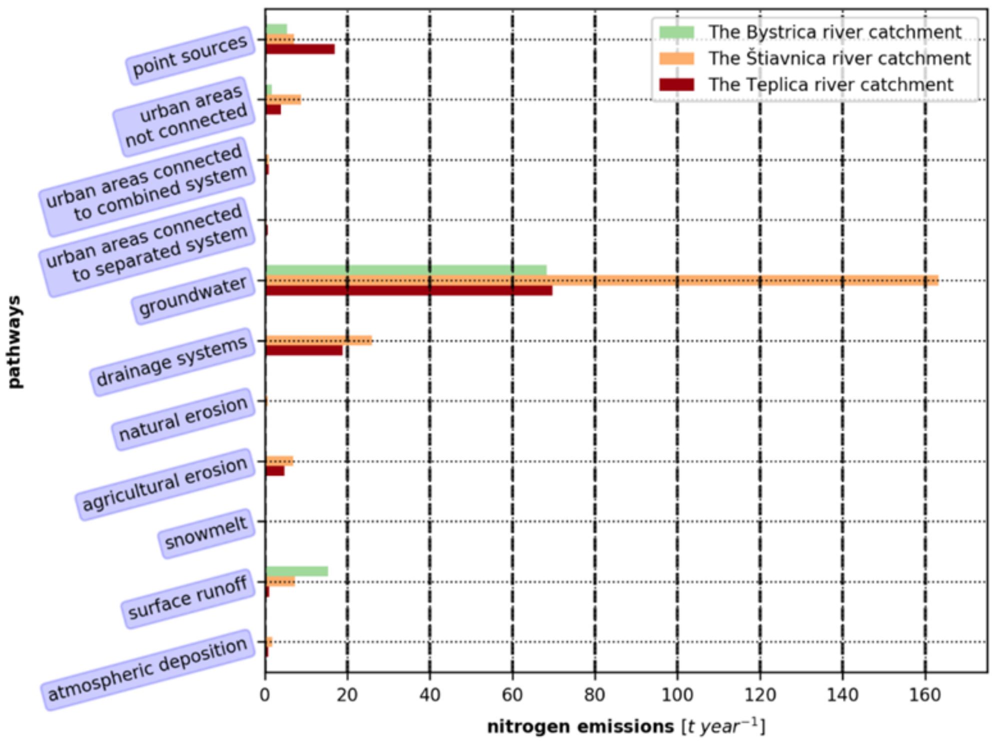

Fig. 4. Emissions of total nitrogen in three evaluated catchments via different pathways in tonnes per year by MONERIS model results.

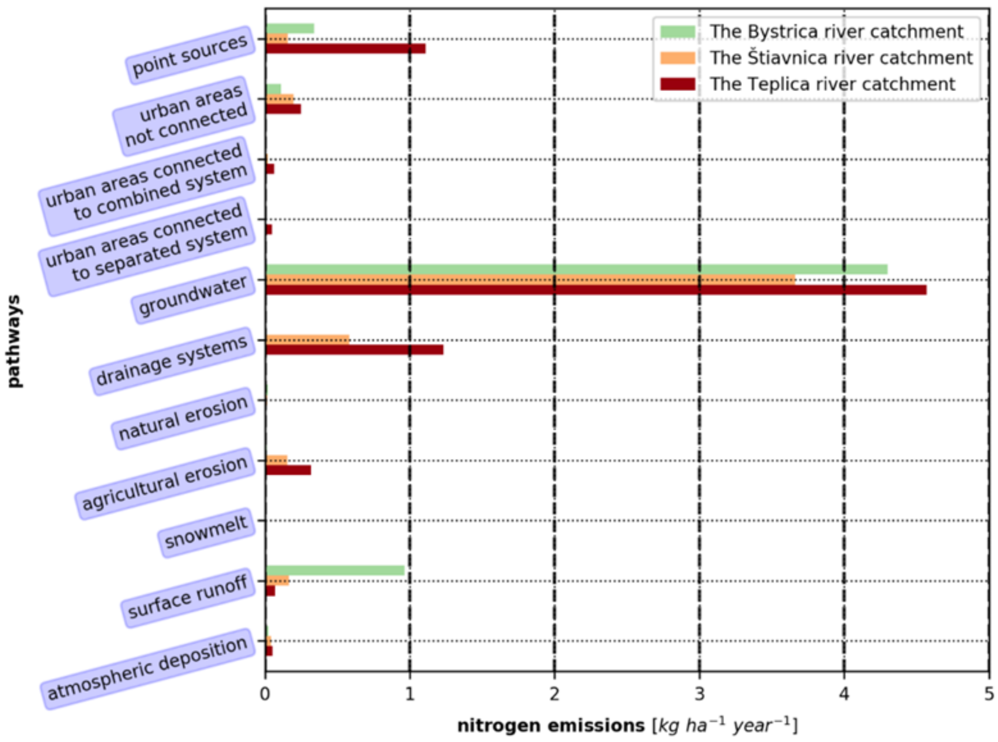

Fig. 5. Emissions of total nitrogen in three evaluated catchments via different pathways in kg per hectare per year by MONERIS model results.

river catchment proportion of drained agricultural land to the total area of agricultural land is only 3.8%. The highest contribution of drainage network on YTNE in tonnes per year was in the Štiavnica river catchment (26 t y^{-1}) (Fig. 4). On the other hand, area-specific nitrogen emission, which considering or eliminate river catchment size impact, was the highest in the Teplica river catchment (1.2 kg ha^{-1} y^{-1}) via the drainage system pathway (Fig. 5).

Another important pathway for nitrogen is erosion of nitrogen in particulate soil organic matter or sorbed on clays. It was confirmed that by soil erosion there are transported soil particles and also nitrogen which contributes to surface water contamination (Follett and Delgado, 2002). In the MONERIS model this process is represented by agricultural erosion pathway. Since the catchments have not the same size, graph that show proportion of agricultural erosion and drainage system pathway (in percentages) on YTNE was plotted and it shows detailed comparison of nitrogen emission carried out via these pathways in investigated catchments (Fig. 6).

In the Štiavnica and the Teplica catchments, contributions of nitrogen emissions via drainage network and agricultural erosion pathway have higher importance than in the Bystrica river catchment. At first, we focused on differences in yearly nitrogen emission via agriculture erosion as well as via the drainage system in t y^{-1} and kg ha^{-1} y^{-1} (Fig. 4 and 5) that were observed between the Štiavnica and the Teplica river catchments. Results in t y^{-1} are influenced with the fact that the Štiavnica river catchment is three times larger than the Teplica river catchment and therefore there is more total area of agricultural land, thus also more nitrogen sources (e. g. application of fertilizers). Comparison of emission in kg ha^{-1} y^{-1} allows us to compare differences in nitrogen emission more objectively (Fig. 5). This is also the case in Fig. 6 where is possible to see that the highest contribution on YTNE in agricultural erosion and drainage system pathways is in the Teplica river catchment (16%), thus in the catchment with the highest proportion of agricultural land to the total area of the catchment. On the other side, there is practically no contribution to the YTNE from these pathways in the Bystrica river catchment. In the Bystrica catchment there is no drainage network and only a small proportion of agricultural land, thus agricultural erosion and drainage system have only negligible contribution on overall total nitrogen emission into surface streams in this catchment. However, in this catchment surface runoff has a non-negligible (second highest one after groundwater pathway) contribution to overall YTNE (Fig. 5). It is probably results of high slopes in this river catchment and also a higher amount of yearly precipitation.

Summary of YTNE in all three investigated catchments offers Table 2. It is possible to see that nitrogen emission in t y^{-1} is the highest in the Štiavnica river catchment, thus in the largest river catchment in our study. On the other hand, area-specific emission in kg ha^{-1} y^{-1} is the highest in the Teplica river catchment, thus in the catchment with a higher proportion of agricultural land to the total area of the river catchment. In the Teplica river catchment, we can see also the highest contribution of agricultural erosion (4.1%) and drainage system (16%) pathways to the YTNE in comparison with the rest two catchments. These two emission pathways are related to the proportion of agricultural land in investigated areas. As was already mentioned, there is only small contribution from agricultural erosion and no contribution via drainage system pathway on YTNE in the Bystrica river catchment since there is no drainage network and only small area of agricultural land there.

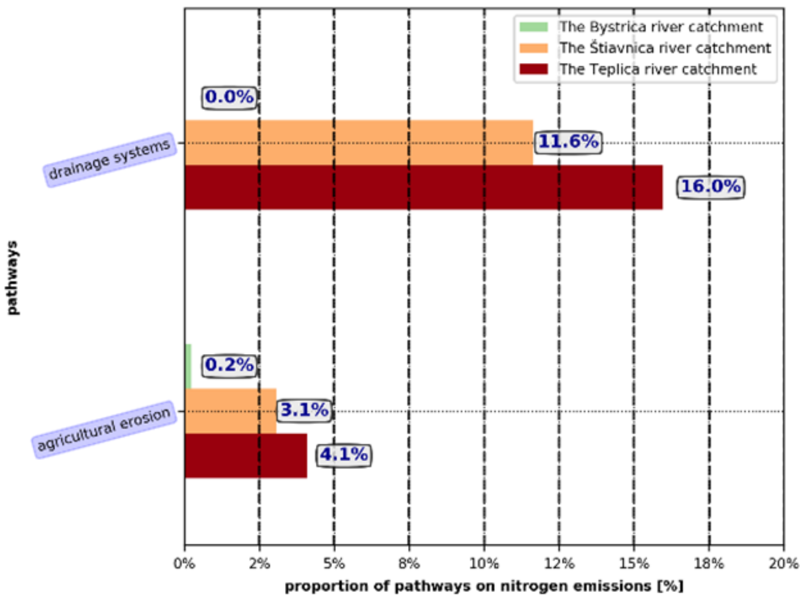

Fig. 6. Proportion of agricultural erosion and drainage system emission pathways on YTNE into surface streams in three evaluated river catchments by MONERIS model results.

Table 2. Yearly total nitrogen emissions (YTNE) via different pathways and proportion of each pathway on total emission in three investigated catchments

pathway	Teplica river catchment			Štiavnica river catchment			Bystrica river catchment		
	*	**	***	*	**	***	*	**	***
atmospheric deposition	0.1	0.8	0.7	0.0	1.9	0.8	0.0	0.4	0.4
surface runoff	0.1	1.1	0.9	0.2	7.3	3.3	1.0	15.3	16.7
snowmelt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
agricultural erosion	0.3	4.8	4.1	0.2	6.9	3.1	0.0	0.2	0.2
natural erosion	0.0	0.1	0.1	0.0	0.7	0.3	0.0	0.3	0.3
drainage systems	1.2	18.8	16.0	0.6	26.0	11.6	0.0	0.0	0.0
groundwater	4.6	69.7	59.2	3.7	163.2	73.1	4.3	68.3	74.5
u. a.(1) connected to separated system	0.0	0.8	0.6	0.0	0.5	0.2	0.0	0.0	0.0
u. a.(1) connected to combined system	0.1	1.0	0.8	0.0	0.9	0.4	0.0	0.0	0.0
urban areas not connected	0.3	3.8	3.2	0.2	8.9	4.0	0.1	1.8	1.9
point sources	1.1	16.9	14.4	0.2	7.1	3.2	0.3	5.4	5.9
TOTAL	7.7	117.9	100	5.0	223.3	100	5.8	91.7	100

(1) *u. a. – urban areas; * kg ha^{-1} y^{-1}; ** t y^{-1}; *** proportion in %*

Conclusion

In this contribution, we used the MONERIS model to simulate the nitrogen loads to surface streams in three river catchments with different proportion of agricultural land to the total area of them. There was determined also proportion of emission pathways on this emission. In the Teplica river catchment where around 62 % of catchment area is covered by agricultural land, long term median concentration of total nitrogen was four times higher than in the Bystrica river catchment where the proportion of agricultural land is only around 7%. Furthermore, emission of total nitrogen via the drainage system pathway in the Teplica river catchment was 16% of overall yearly total nitrogen emission. Drainage system pathway contributed 4.1% of YTNE. On the other hand, there was practically no contribution from above-mentioned emission pathways in the Bystrica river catchment. In the Štiavnica catchment (41.9% of the catchment area is covered by agricultural land), 11.6% of overall nitrogen emission carried out via drainage system and 3.1% via agricultural erosion. Most important nitrogen emission pathway in all three catchments was groundwater.

The MONERIS model is helpful tool for evaluation of proportion of emission pathways on total nitrogen emission in catchments, but it is very demanding to input data.

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References

Amiri, B. J., Nakane, K. (2009): Modeling the Linkage Between River Water Quality and Landscape Metrics in the Chugoku District of Japan, Water Resources Management. Springer Netherlands, 23(5), 931–956. doi: 10.1007/s11269-008-9307-z.

Behrendt, H., Kornmilch, M., Opitz, D., Schmoll, O., Scholz, G. (2002): Estimation of the nutrient inputs into river systems – experiences from German rivers, Journal of Material Cycles and Waste Management. Springer-Verlag, 107–117. doi: 10.1007/s10113-002-0042-3.

Behrendt, H., Venohr, M., Hirt, U., Hofmann, J., Opitz, D., Gericke, A. (2007): The model system MONERIS Version 2.0 User's Manual.

Boskidis, I., Gikas, G. D., Pisinaras, V., Tsihrintzis, V. A. (2010): Spatial and temporal changes of water quality, and SWAT modeling of Vosvozis river basin, North Greece, Journal of Environmental Science and Health Part A, 45, 1421–1440. doi: 10.1080/10934529.2010.500936.

Di, H. J., Cameron, K. C. (2002): Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies, Nutrient Cycling in Agroecosystems, 64(3), 237–256. doi: 10.1023/A:1021471531188.

EEA and SAZP (2012): CORINE Land Cover (CLC). European Environmental Agency. Slovak Environment Agency. COPERNICUS PROGRAMME – Copernicus Land Monitoring Service. Available at: <http://copernicus.sazp.sk/>.[Online: 15th-March-2020].

European Commission (2009): LUCAS 2009 TOPSOIL data. European Soil Data Centre (ESDAC), European Commission, Joint Research Centre. Available at: <https://lnk.sk/eE24>. [Online: 15th-March-2020].

European Commission (2015): SOIL EROSION BY WATER (RUSLE2015). European Soil Data Centre (ESDAC), European Commission, Joint Research Centre. Available at: <https://lnk.sk/bpLW>. [Online: 15th-March-2020].

European Commission (2016a): TOPSOIL PHYSICAL PROPERTIES FOR EUROPE (based on LUCAS topsoil data). European Soil Data Centre (ESDAC), esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre. Available at: <https://lnk.sk/pFX6>. [Online: 15th-March-2020].

European Commission (2016b): Urban Wastewater Treatment Plant. URBAN WASTEWATER TREATMENT PLANT REPORTED DATA – EUROPEAN COMMISSION urban wastewater website. Available at: <https://lnk.sk/vCH1>. [Online: 15th-March-2020].

European Community (2000): Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, Official Journal of the European Parliament. Brussels, Belgium, Official Journal of the European Parliament. doi: 10.1039/ap9842100196.

Foley, J. A. et al. (2011): Solutions for a cultivated planet, Nature. Nature Publishing Group, 478(7369), 337–342. doi: 10.1038/nature10452.

Follett, R. F., Delgado, J. A. (2002): Nitrogen fate and transport in agricultural systems, Journal of Soil and Water Conservation, 57(6), 402–408. Available at: <https://lnk.sk/cioL>. [Online: 15th-March-2020].

Gleeson, T. (2018): GLobal HYdrogeology MaPS (GLHYMPS) of permeability and porosity. Scholars Portal Dataverse. doi: doi/10.5683/SP2/DLGXYO.

Government of the Slovak Republic (2011): Govermment Regulation SR No. 201/2011 Coll., that rules technical specifications for chemical analysis and monitoring of water status. Available at: <https://lnk.sk/nyLT>.[Online: 15th-March-2020].

Halmová, D., Pekárová, P., Bačová Mitková, V. (2019): Long-term trend changes of monthly and extreme discharges for different time periods, Acta Hydr. Slov., 20(2), 122–130.

Hill, A. R. (1981): Stream Phosphorus Exports From Watersheds with Contrasting Land Uses in Southern Ontario, Journal of the American Water Resources Association. John Wiley & Sons, Ltd (10.1111), 17(4), 627–634. doi: 10.1111/j.1752-1688.1981.tb01269.x.

Julínek, T., Říha, J. (2017): Assessing stream water quality influenced by storm overflows from sewers., Pollack Periodica, 12(2), 117–128.

Lam, Q. D., Schmalz, B., Fohrer, N. (2010): Modelling point and diffuse source pollution of nitrate in a rural lowland catchment using the SWAT model, Agricultural Water Management. Elsevier, 97(2), 317–325. doi: 10.1016/J.AGWAT.2009.10.004.

MET Norway (2019): Modelled air concentrations and depositions. The Norwegian Meteorological institute and the European Monitoring and Evaluation Programme (EMEP). Available at: <https://lnk.sk/FT57>. [Online: 15th-March-2020].

Ministry of Agriculture of the SR (2017): LPIS - LAND PARCEL IDENTIFICATION SYSTEM. Ministry of Agriculture and Rural Development of the Slovak Republic. Available at: <https://lnk.sk/uTZ9>. [Online: 15th-March-2020].

NAFC (2017): BONITIZED SOIL-ECOLOGICAL UNITS. National Agricultural and Food Centre Lužianky. Available at: <https://lnk.sk/imF4>. [Online: 15th-March-2020].

NASA JPL (2013): NASA Shuttle Radar Topography Mission Global 1 arc second, distributed by NASA EOSDIS Land Processes DAAC. Available at: <https://lnk.sk/iD03>. [Online: 15th-March-2020].

Rothwell, J. J., Dise, N. B., Taylor, K. G., Allott, T. E. H., Scholefield, P., Davies, H., Neal, C. (2010): Predicting river water quality across North West England using catchment characteristics, Journal of Hydrol., 395 (3–4), 153–162. doi: 10.1016/j.jhydrol.2010.10.015.

Schreiber, H. et al. (2005): Nutrient emissions from diffuse and point sources into the River Danube and its main tributaries for the period of 1998–2000 – results and problems, Water Science and Technology. IWA Publishing, 51(3–4), pp. 283–290. doi: 10.2166/wst.2005.0602.

Sliva, L. and Williams, D. D. (2001): Buffer zone versus whole catchment approaches to studying land use impact on river water quality, Water Research. Pergamon, 35(14), 3462–3472. doi: 10.1016/S0043-1354(01)00062-8.

The Ministry of Environment of the Slovak Republic (2009): Water Plan of Slovakia. Available at: <https://lnk.sk/lpsX>.[Online: 15th-March-2020].

The Ministry of Agriculture of the SR (2016): Decree no. 151/2016 Coll. Decree of the Ministry of Agriculture and Rural Development of the Slovak Republic laying down details on agrochemical testing of soils and on the storage and use of fertilizers (In Slovak).

Venohr, M. et al. (2011): Modelling of Nutrient Emissions in River Systems - MONERIS – Methods and Background, International Review of Hydrobiology, 96(5), pp. 435–483. doi: 10.1002/iroh.201111331.

Weitzel, L. R. (1979): Periphyton measurements and applications, in Weitzel, L. R. (ed.) Methods and measurements of periphyton communities: A Review. American Society for Testing and Materials, 3–33. Available at: <https://lnk.sk/boHM>. [Online: 15th-March-2020].

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