Use of the MONERIS model for identification of sources of surface streams pollution by total nitrogen

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1 Introduction

The elevated amount of nutrients such as nitrogen in surface streams can result in environmental issues such as eutrophication of waters, growth of periphyton (Weitzel, 1979) and decrease of biodiversity (Carpenter *et al.*, 1998; Ledgard *et al.*, 1999; Di and Cameron, 2002)**.** The main aim of this contribution is to identify sources of surface streams pollution by total nitrogen. For this purpose, was used the GIS-oriented semi-empirical conceptual model MONERIS (Behrendt *et al.*, 2002, 2007).

2 Material and methods

Study area

In this study data in 20 river catchments located across the Slovak territory were analyzed. Figure 1 shows the location of investigated river catchments within the Slovak territory, the position of hydrological stations and water quality measurement points. Out of twenty, twelve river catchments have been used for the MONERIS model validation (marked as validation catchments).

Input data

In this contribution, the MONERIS model's input data has been aggregated for 2017. In the case of some static data (we assumed that they change from year to year very slowly and these differences can be neglected) that has not been possible to obtain for 2017, we used available dataset collected in the nearest possible year (e. g. CORINE Land Cover 2012 layer, data on wastewater treatment plants from 2016, etc.). In Table 1 are summarized some of the most important input data to the MONERIS model.

Validation of the MONERIS model

Model validation is done by graphical comparison of the modelled and measured total nitrogen in-river loads in $t \cdot y^{-1}$ at water quality monitoring places (Zessner *et al.*, 2011; Wenz, 2016). This is done using a scatter plot (Figure 2). Points (values in catchments) on scatter plot are clustered around a 1:1 line (perfect agreement) with two lines indicating 30% over- and underestimation (blue dotted lines). In this study, the performance of the MONERIS model is evaluated based on in-river loads from twelve river catchments (validation catchments, see Figure 1). It is because in modelled year (2017) data on water quality was available only in these catchments. In addition, four quantitative characteristics were used to statistically assess the MONERIS model performance: *the coefficient of determination (R^2), the Nash-Sutcliffe efficiency (NSE), the RMSE-observations standard deviation ratio (RSR), and the percent bias (PBIAS).*

The MONERIS model's emission pathways

Emission pathways used in this study are as follows: emissions via atmospheric deposition, subsurface flow, tile drainage systems, emissions from urban areas connected to sewer system, emissions from not connected urban areas, emissions via natural erosion and agricultural erosion, emissions via surface runoff, and emissions from point sources (nutrient emissions from WWTPs and industrial sources).

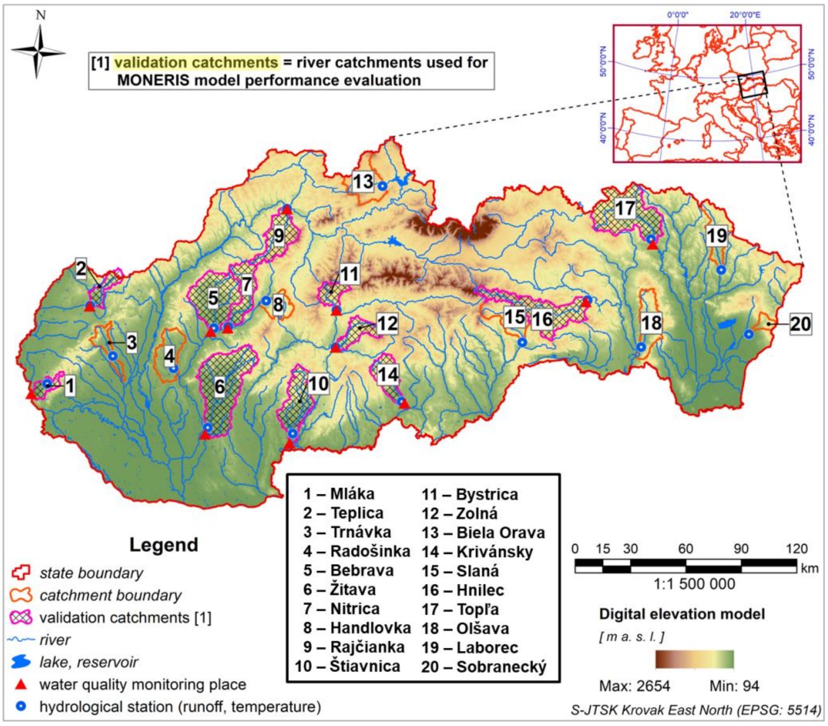

Figure 1: Localization of water quality measurement points, hydrological stations and investigated river catchments in Slovak territory.

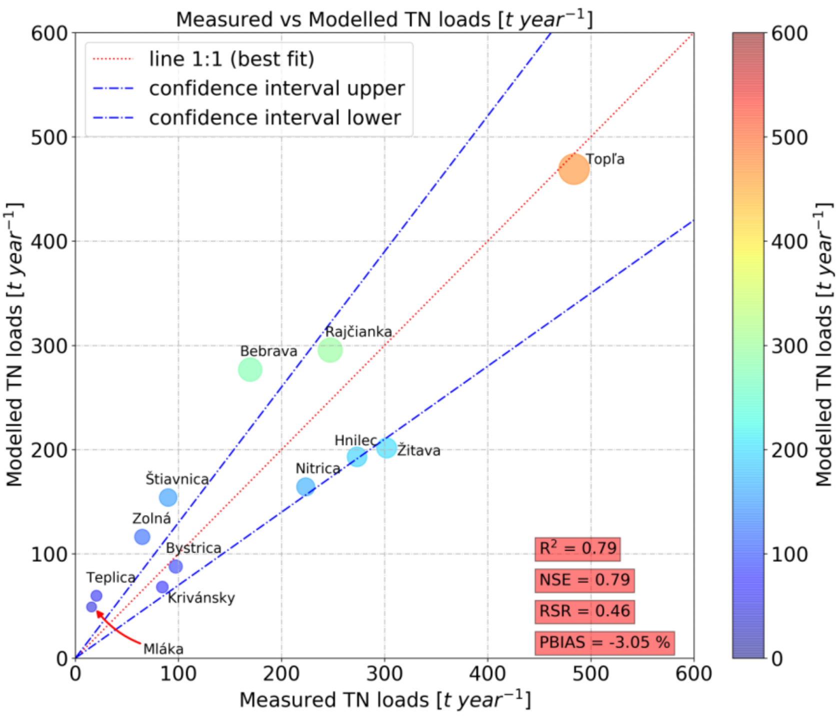

Figure 2: Measured versus modelled total nitrogen annual in-river loads based on data from validation catchments.

Table 1: Selected river catchment parameters – input data to the MONERIS model (explanatory notes on the next page).

catchment/ input data	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mláka	18.2	13.8	67.7	0.3	66.5	29.7	3.2	0.6	4.7	14.3	6.8	74.1	2.4	2 350	633.5	0.1	738.6	729.0	50.9	29.8
Teplica	62.2	6.9	30.5	0.7	0.7	54.1	45.0	0.1	1.1	7.5	0.0	91.4	6.9	1 500	684.3	0.5	699.3	643.7	50.9	16.9
Trnávka	48.8	14.8	35.2	1.0	0.1	90.4	9.2	0.0	0.5	38.5	18.5	42.5	6.6	1 500	617.8	0.4	806.1	641.1	40.3	103.0
Radošinka	72.0	7.3	20.3	1.3	2.2	95.7	1.6	0.5	0.2	82.3	11.3	6.2	17.1	1 500	570.6	0.4	763.9	580.6	45.9	0.0
Bebrava	39.4	5.2	54.9	2.5	0.1	80.1	18.0	1.8	0.1	40.9	24.6	34.3	27.7	2 200	693.7	2.9	568.2	633.3	62.3	53.4
Žitava	52.8	7.2	39.5	3.2	0.2	81.4	16.2	2.2	1.0	65.9	10.5	22.5	13.3	1 500	597.9	2.5	646.3	583.4	56.4	37.3
Nitrica	24.3	4.4	70.6	1.6	4.9	61.6	33.3	0.2	0.0	15.0	41.3	43.7	6.0	2 250	746.5	2.1	548.7	644.6	67.3	2.7
Handlovka	27.4	10.7	61.4	0.6	0.7	90.8	8.5	0.0	0.0	12.3	46.3	41.4	1.6	3 900	815.2	1.1	476.9	592.0	72.0	44.8
Rajčianka	26.4	6.9	66.0	1.4	0.0	61.0	38.6	0.0	0.3	6.6	35.5	57.6	5.4	4 500	830.6	4.3	510.9	675.9	87.0	7.4
Štiavnica	41.9	4.5	53.1	1.9	0.2	71.5	27.3	1.0	0.0	7.7	84.7	7.6	7.0	1 600	640.9	1.5	594.8	544.1	75.1	7.0
Bystrica	7.4	2.3	89.7	0.4	2.7	90.4	7.0	0.0	0.2	0.6	64.2	35.0	0.0	3 300	938.6	2.7	433.3	614.0	81.1	0.0
Zolná	35.6	3.4	60.8	0.4	2.3	90.5	7.2	0.0	1.6	18.6	57.1	22.7	2.9	2 000	742.3	1.5	454.8	524.6	73.7	0.2
Biela Orava	27.6	3.4	68.1	3.2	1.4	91.9	4.2	0.4	0.3	8.2	1.4	90.0	3.1	2 450	871.2	6.4	383.9	618.1	96.6	1.3
Krivánsky	33.4	7.2	58.4	2.7	20.2	75.7	4.2	0.0	1.1	23.6	19.1	56.2	6.5	1 400	670.7	1.3	501.2	548.0	70.4	17.8
Slaná	16.1	3.0	80.6	1.0	9.9	90.0	0.2	0.0	0.0	6.4	20.5	73.1	2.3	3 100	810.8	4.4	399.2	501.3	73.6	15.2
Hnilec	8.5	2.2	88.7	3.6	2.8	96.4	0.1	0.0	0.5	2.3	37.3	59.9	2.0	2 700	759.1	6.3	384.8	510.4	70.1	8.8
Topľa	31.5	3.7	64.1	5.3	3.6	85.5	10.9	0.0	0.4	5.7	15.2	78.7	7.0	1 400	697.2	5.3	535.9	569.4	82.7	12.3
Oľšava	38.8	4.2	56.6	1.0	0.1	75.2	24.4	0.3	0.9	5.6	53.8	39.6	10.8	1 500	638.8	1.4	569.0	539.1	66.0	3.7
Laborec	23.4	3.1	73.0	1.5	0.0	62.6	37.4	0.0	0.0	7.3	0.0	92.7	2.0	1 800	770.1	3.0	518.1	616.7	80.3	2.3
Sobranecký	23.6	6.0	70.1	0.2	0.0	77.3	22.7	0.0	0.0	23.9	60.5	15.5	2.6	2 650	779.4	1.5	631.1	572.9	68.6	0.0

Explanatory notes of the catchment characteristics in Table 1

1 = proportion of agricultural land (arable land, pastures) to the total are of the river catchment (%),
2 = proportion of urban areas to the total are of the river catchment (%),
3 = proportion of woodland and shrubland to the total are of the river catchment (%),
4 = water surface area (lakes, tributaries) (km^2),
5 – 8 = proportion of sandy (5), loamy (6), silty (7) and clayey (8) soil to the total area of agricultural land (%),
9 – 12 = proportion of unconsolidated rock areas near groundwater (9), unconsolidated areas far groundwater (10), consolidated areas with good permeability (11), consolidated areas with bad permeability (12) to the total area of the river catchment (%),
13 = drained agricultural land (km^2),
14 = N content in topsoil ($mg\ kg^{-1}$),
15 = long-term (1981 – 2017) annual precipitation ($mm\ y^{-1}$),
16 = long-term (2006 – 2017) annual discharge ($m^3\ s^{-1}$),
17 = long-term (2000 – 2017) annual NH4-N atmospheric deposition ($mg\ m^{-2}\ y^{-1}$),
18 = long-term (2000 – 2017) annual NO3-N atmospheric deposition ($mg\ m^{-2}\ y^{-1}$),
19 = long-term (2006 – 2017) annual nitrogen surplus on agricultural land ($kg\ ha^{-1}\ y^{-1}$),
20 = total nitrogen emissions (load) from WWTPs into tributaries ($t\ y^{-1}$) (data available for 2016 was used).

3 Results

Model simulation can be in general judged as satisfactory if NSE > 0.50, RSR < 0.70 and PBIAS is ± 70% (Moriasi *et al.*, 2007). Based on our results, R^2 has value 0.79, the NSE 0.79, RSR 0.46 and PBIAS about -3 % (Figure 2), can be concluded that the MONERIS model was successfully set up and shows a good model performance for total nitrogen water quality indicator. PBIAS -3 % suggests a small overestimation of in-river loads mainly in the case of smaller loads (e.g. the Trnávka and the Teplica river catchments). The possible reason for overestimation could be uncertainties in input data (e.g. groundwater residence time and nitrogen balance calculation) and also that the model is not able reflect the local situation in all the cases. Overestimation of emissions from point sources can be due by uncertainty in the calculation of the total nitrogen in-river loads from WWTPs (estimated values). Another parameter that has been also only estimated and could increase model uncertainty is number of inhabitants connected to septic tanks. We assumed that the rest of the inhabitants that are not connected to the sewer system are connected at least to septic tanks. Nowadays, this is still not in agreement with the real situation in Slovakia, particularly in small villages of marginal regions (in the southeast of central Slovakia and in the northeast of Slovakia).

Considering all river catchments together, the highest contribution on annual total nitrogen emissions has subsurface flow (62.2 %), followed by drainage systems (11.4 %) and point pollution sources (9.0 %). Surface runoff contributes by about 8 % and urban areas not connected to sewer system by slightly more than 4 %. Only small contribution on annual total nitrogen emissions (less than 4 %) have emission pathways as follows: agricultural erosion, urban areas connected to sewer systems, atmospheric deposition and natural erosion (Figure 3).

Comparing individual river catchments, subsurface flow is dominant emission pathway in 17 of 20 river catchments (Figure 4, Table 2). In three of the twenty river catchments the highest contribution on overall total nitrogen emissions was not via subsurface flow pathway. For example, in the Mláka river catchment, the most nitrogen emissions entry surface streams via point sources (~41 %). This is also the case in the Trnávka river catchment where even ~62 % of overall total nitrogen emissions are caused by point sources. Point sources contribute significantly also in the Handlovka river catchment (29.6 %). In contrast, in the Radošinka river catchment, total nitrogen emissions entry surface streams mostly via drainage systems (59 %). With respect to diffuse sources, in addition to subsurface flow emission pathway, in investigated catchments located in mountainous regions also surface runoff contributes to a higher extent. This is possible to see in river catchments as follows: the

Biela Orava (18.1 %), the Sobranecký (18.0 %), the Bystrica (16.7 %), the Laborec (16.0 %), the Slaná (12.8 %) and the Rajčianka (11.0 %) river catchments (Table 2) It has been already mentioned that in the Radošinka river catchment the highest contribution on overall nitrogen emissions is accounted for drainage systems. This is the second most important emission pathway also in the Bebrava river catchment where it contributes by 27.7 %. These catchments are followed by the Krivánsky (17.5), the Teplica (16.0 %), the Trnávka (15.7 %), the Oľšava (15.2 %), the Žitava (15.1 %), the Nitrica (13.1 %), the Štiavnica (11.6 %), and the Zolná (8.4 %) river catchments. In these river catchments, drainage systems are also the second most important contributor of nitrogen emissions in 2017. Negligible contribution have natural erosion and atmospheric deposition pathways. In the case of the first mentioned pathway, the contribution is in all catchments less than 1 % while in the case of atmospheric deposition it is below 2 %. Agricultural erosion contributes significantly only in the Radošinka river catchment (15.8 %) and it is also the fourth highest contributor of nitrogen emissions in the Žitava river catchment (7.1 %). From urban areas emission pathway, the highest contribution is in the case of not connected urban areas, this is mostly the case in the Mláka river catchment where even 22.6 % of overall nitrogen emissions are caused by not connected urban areas (Table 2).

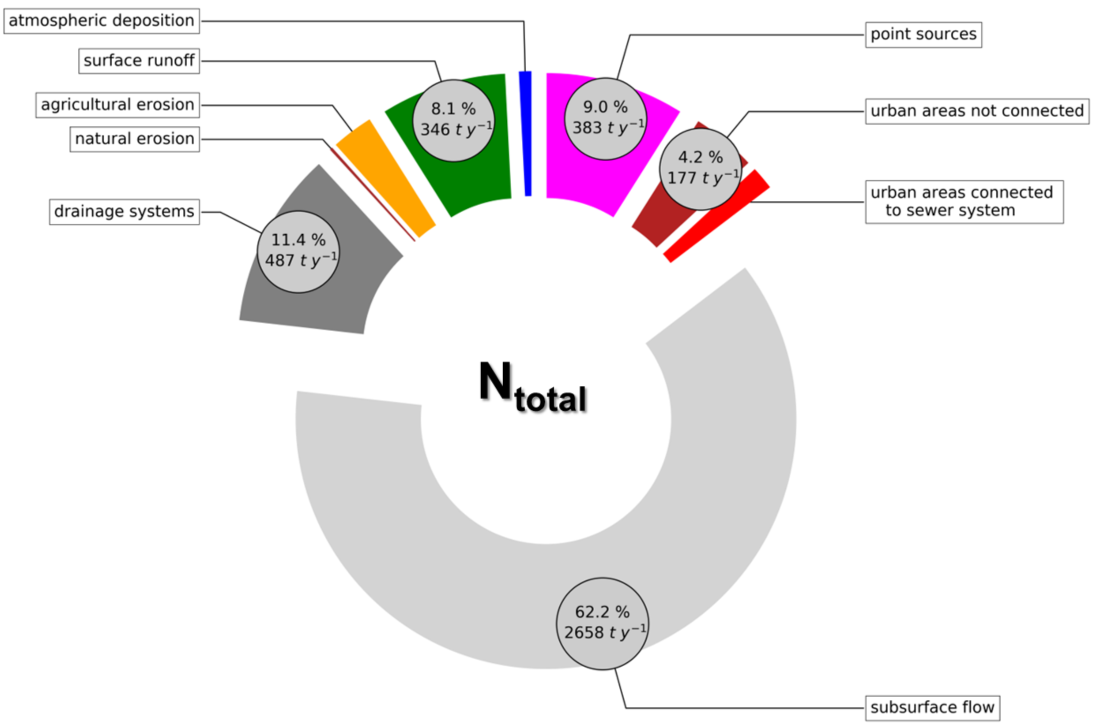

Figure 3: Proportion of emission pathways on annual total nitrogen emissions in all investigated catchments in 2017.

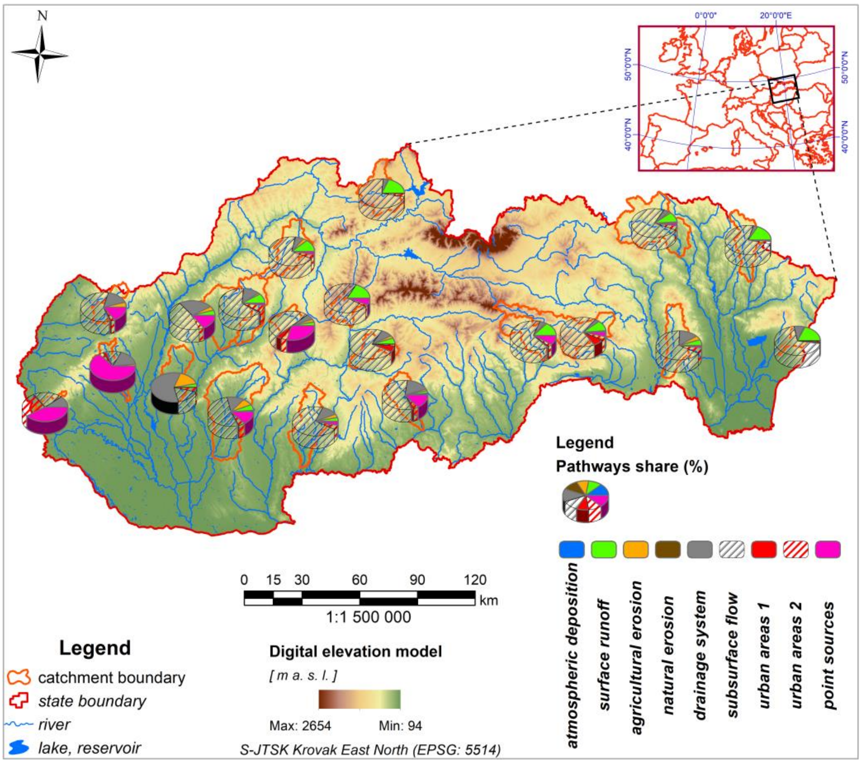

Figure 4: Proportion of emission pathways on overall total nitrogen emissions in investigated catchments in 2017. Urban areas 1 = urban areas connected to sewer system, urban areas 2 = urban areas not connected to sewer system.

4 Summary

Identification of sources of surface streams pollution by total nitrogen in twenty middle-sized river catchments within Slovak territory was the prior aim of this paper. For this purpose, we used the GIS-oriented MONERIS model. Model validation was performed by comparison of the modelled and measured total nitrogen in-river loads in $t \cdot y^{-1}$ in 2017. In this way, four quantitative characteristics were used as follows: coefficient of determination (R2), Nash-Sutcliffe efficiency (NSE), RMSE-observations standard deviation ratio (RSR) and percent bias (PBIAS). Good model performance concluded that the MONERIS model has been successfully set up and only slight overestimation of the modelled in-river loads has occurred. The MONERIS model simulation indicates that the main source of total nitrogen pollution in surface streams within Slovak territory is the subsurface flow. In investigated catchments it contributes by ~62 % on overall total nitrogen emissions. The second emission pathway, that contributes also significantly, is the drainage systems pathway (~11 %). It is followed by point pollution sources (~9 %), surface runoff (~8 %) and not connected urban areas pathways (~4 %). Negligible contribution on overall total nitrogen emissions have emission pathways such as agricultural erosion, urban areas not connected to sewer system and urban areas connected to sewer system, atmospheric deposition and natural erosion.

Different results of the proportion of emission pathways on overall total nitrogen emissions in individual river catchments are primarily caused by variability in input data – river catchment parameters. Thus, similar patterns is possible to find in river catchments with similar conditions. Another important factor is the nature of the model that is used for this type of analysis. In this case, the MONERIS model is the balance model and it is also not able to reflect the local situation in particular river catchment in all the cases. In the context of total nitrogen, it is for Slovakia in general possible to recommend measures that may improve water quality in surface streams. They are a decrease of nitrogen surplus on agricultural land and reduction of nutrients originating from point pollution sources.

Table 2: Proportion of emission pathways on overall total nitrogen emissions in investigated river catchments in 2017.

catchment/ pathway	atmospheric deposition	surface runoff	agricultural erosion	natural erosion	drainage systems	subsurface flow	urban areas connected to sewer system	urban areas not connected	point sources
Mláka	0.4%	0.1%	0.2%	0.0%	10.2%	23.9%	1.2%	22.6%	**41.4%**
Teplica	0.7%	0.9%	4.1%	0.1%	16.0%	**59.2%**	1.5%	3.2%	14.4%
Trnávka	0.7%	0.0%	1.6%	0.0%	15.7%	13.6%	2.7%	3.7%	**62.1%**
Radošinka	1.0%	2.9%	15.8%	0.1%	**59.0%**	16.6%	0.7%	4.0%	0.0%
Bebrava	0.8%	4.3%	3.6%	0.2%	27.7%	**44.7%**	0.6%	3.9%	14.2%
Žitava	1.2%	5.1%	7.1%	0.2%	15.1%	**52.5%**	1.1%	5.2%	12.5%
Nitrica	0.9%	8.6%	1.4%	0.2%	13.1%	**66.1%**	1.2%	6.7%	1.7%
Handlovka	0.4%	3.2%	2.6%	0.1%	5.2%	**49.6%**	4.4%	5.0%	29.6%
Rajčianka	0.5%	11.0%	3.4%	0.2%	6.9%	**71.2%**	0.6%	4.1%	2.3%
Štiavnica	0.8%	3.3%	3.1%	0.3%	11.6%	**73.1%**	0.6%	4.0%	3.2%
Bystrica	0.4%	16.7%	0.2%	0.3%	0.0%	**74.5%**	0.0%	1.9%	5.9%
Zolná	0.2%	5.3%	2.4%	0.2%	8.4%	**76.3%**	5.3%	1.8%	0.2%
Biela Orava	1.0%	18.1%	1.1%	0.2%	4.0%	**72.2%**	0.5%	2.7%	0.4%
Kriviánsky	1.7%	1.9%	1.6%	0.2%	17.5%	**57.9%**	2.0%	4.2%	12.9%
Slaná	0.4%	12.8%	1.3%	0.2%	4.7%	**68.2%**	1.4%	2.8%	8.2%
Hnilec	1.2%	9.4%	0.6%	0.4%	3.3%	**70.3%**	7.2%	3.8%	3.7%
Topľa	1.0%	9.1%	1.4%	0.2%	4.4%	**77.4%**	0.8%	3.5%	2.2%
Oľšava	0.5%	4.9%	4.0%	0.1%	15.2%	**68.1%**	0.3%	5.1%	1.8%
Laborec	0.8%	16.0%	0.8%	0.2%	3.7%	**74.6%**	0.4%	2.3%	1.1%
Sobranecký	0.3%	18.0%	1.2%	0.0%	8.8%	**69.4%**	1.2%	1.1%	0.0%

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