Relationship between selected catchment parameters and nutrient concentrations in 15 river catchments in Slovakia

Cyril SIMAN, Institute of Hydrology SAS

Abstract

The elevated amount of nutrients in surface streams can result in environmental issues such as eutrophication of waters, growth of periphyton and decrease of biodiversity. To better manage water quality at a catchment scale, many studies have evaluated the influence of catchment characteristics (e.g. land-use types, land-use patterns, morphology, hydrology, soil type, soil texture, soil drainage, and geology) on river water quality. In this contribution we decided to examine relationship between eighteen river catchment parameters and nutrient concentrations in surface streams in 15 river catchments in Slovakia territory. The relationship between eighteen river catchment parameters and median concentrations in total nitrogen and total phosphorus water quality indicators we have evaluated using Spearman's correlation coefficient. Results indicate mainly impact of land cover, such as share of urban areas, agricultural land and woodland, and to some extent also rock permeability on water quality in evaluated catchments. With a higher share of rocks with good permeability, we have observed also higher median concentration in both total nitrogen as well as total phosphorus water quality indicators. This could be a consequence of lower residence time, therefore less time for denitrification process what can lead to higher concentrations of nutrients in surface streams.

Key words: water quality, total nitrogen, total phosphorus, surface streams, catchment parameters, Slovakia

Anotation: Water quality in surface streams is influenced by several factors that change over time and space.Understanding of these influences on catchment level is inevitably for improving water quality in surface streams. This contribution deals with the analysis of the relationship between selected river catchment parameters and total nitrogen and total phosphorus concentration in surface streams within catchments in Slovakia territory.

Abstrakt

Zvýšené množstvo živín v povrchových tokoch vedie k environmentálnym problémom, ako napríklad eutrofizácia vôd, rast vodného kvetu a znižovanie biodiverzity. Viacero štúdií potvrdilo kľúčovú úlohu parametrov povodia (ako napr. krajinná pokrývka, geomorfologické charakteristiky, druh pôdy a geologické zloženie) vo vzťahu ku kvalite vody v povrchových tokoch. V príspevku sme skúmali vzťah medzi 18-timi parametrami povodia a koncentráciou živín v povrchových tokoch v 15 povodiach na území Slovenska. Vzťah medzi 18-timi parametrami povodia a mediánovými koncentráciami v ukazovateľoch kvality vody celkový dusík a celkový fosfor sme ohodnotili prostredníctvom Spearmanovho korelačného koeficientu. Výsledky naznačujú významný vplyv krajinnej pokrývky, predovšetkým podielu urbanizovaných, ale aj poľnohospodárskych oblastí na celkovej ploche povodia, na kvalitu vody v hodnotených povodiach. Do určitej miery bol preukázaný aj vplyv priepustnosti hornín na koncentrácie živín. S rastom podielu plochy hornín s dobrou priepustnosťou bol pozorovaný trend rastu koncentrácie celkového fosforu, ale aj celkového dusíka v povrchových tokoch. Tento vzťah je výsledkom vplyvu priespustnosti hornín na dobu pobytu dusíka a fosforu v pôdnom a horninovom profile. Čím lepšia priepustnosť hornín, tým rýchlejšie dochádza k prieniku živín do podzemných a povrchových vôd a tým menej času zostáva na procesy (napr. denitrifikácia) vedúce k odbúravaniu a znižovanu koncentrácií týchto látok.

Kľúčové slová: kvalita vody, celkový dusík, celkový fosfor, povrchové toky, parametre povodia, Slovensko

Anotácia: Kvalita vody v povrchových tokoch je ovplyvnená viacerými faktormi, variabilnými tak v čase ako aj priestore. Pochopenie ich vplyvov na úrovni povodia je nevyhnutnou podmienkou na zlepšenie kvality vody v povrchových tokoch. Príspevok sa venuje analýze vzťahu medzi vybranými parametrami povodia a koncentráciami celkového dusíka a celkového fosforu v povrchových tokoch v 15-tich povodiach na území Slovenska.

1 Introduction

To better manage water quality at a catchment scale, many studies have evaluated the influence of catchment characteristics (e.g. land-use types, land-use patterns, morphology, hydrology, soil type, soil texture, soil drainage, and geology) on river water quality (Thornton and Dise, 1998; Jarvie *et al.*, 2002; Meynendonckx *et al.*, 2006; Davies and Neal, 2007; Onderka *et al.*, 2012; Zhou *et al.*, 2017; Elwan, 2018). One of the main causes of water quality deterioration, is leaching of nutrients, such as nitrogen or phosphorus, mainly from agriculture, into groundwaters as well as surface waters (Harding *et al.*, 1999; Hooda *et al.*, 2000; Di and Cameron, 2002; Wilcock *et al.*, 2006). The elevated amount of nutrients 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).

In this contribution, we have evaluated impact of source (e.g. land use) and transport factors (soil, geology, etc.) on water quality in surface streams in selected river catchments in Slovakia territory. In analysis we included also impact of soil structure and hydrogeology as well as impact of anthropogenic activity (represented by land use) on water quality. For this purpose we used multivariate statistic using Spearman's correlation coefficient.

2 Correlation analysis

2.1 Data and methods

For analysis of water quality in 15 river catchments, we have received monthly data on total nitrogen and total phosphorus concentrations in the period 2006 – 2017 from the database of Slovak Hydrometeorological Institute. Values that were lower than the limit of quantification we have decreased by half according to Government Regulation No. 201/2011 Coll. Then we have calculated a median value for both total phosphorus and total nitrogen water quality indicators. Figure 1 shows localization of water quality measurement stations as well as boundaries of river catchments where analysis of river catchment parameters was done. For evaluation of river catchment characteristics, we have used several types of data, most of them were freely available. First of all, we have processed Corine Land Cover [1] and Land Parcel Identification System [2] data in order to obtain a proportion of different types of land cover in river catchments. We evaluated also proportion of different soil types based on data on soil texture and soil losses from different types of land cover. Both datasets we have downloaded from the European Soil Data Centre [3, 4]. We created four soil types according to share of clay, silt and loam in a soil sample. Information about hydrogeology we derived from Global Hydrogeology Maps of permeability and porosity that was also available online [5]. Data on precipitation and evapotranspiration we have received from the Slovak Hydrometeorological Institute. Mean elevation and mean slope we derived from a digital elevation model in ArcMap. All data that are presented in this contribution were processed in Python and ArcMap. We have tested a normality of data samples using the Shapiro-Wilk test (Shapiro and Wilk, 1965). Table 1 shows that almost half of data samples are not normally distributed, therefore we have decided to use the Spearman's correlation coefficient (Spearman, 1904; Gauthier, 2001) that belongs among non-parametrical statistical methods. One of the advantages of the Spearman's correlation coefficient is that it is not that sensitive to extreme values (outliers) in comparison with the Pearson coefficient (Hauke and Kossowski, 2011) and in addition Spearman's correlation assesses monotonic relationships (whether linear or not). Therefore in all correlation graphs that are presented in this contribution Spearman's correlation coefficient was used. Figure 2 and 3 shows correlation matrix between all catchment parameters as well as between total nitrogen and total phosphorus concentrations with catchment parameters.

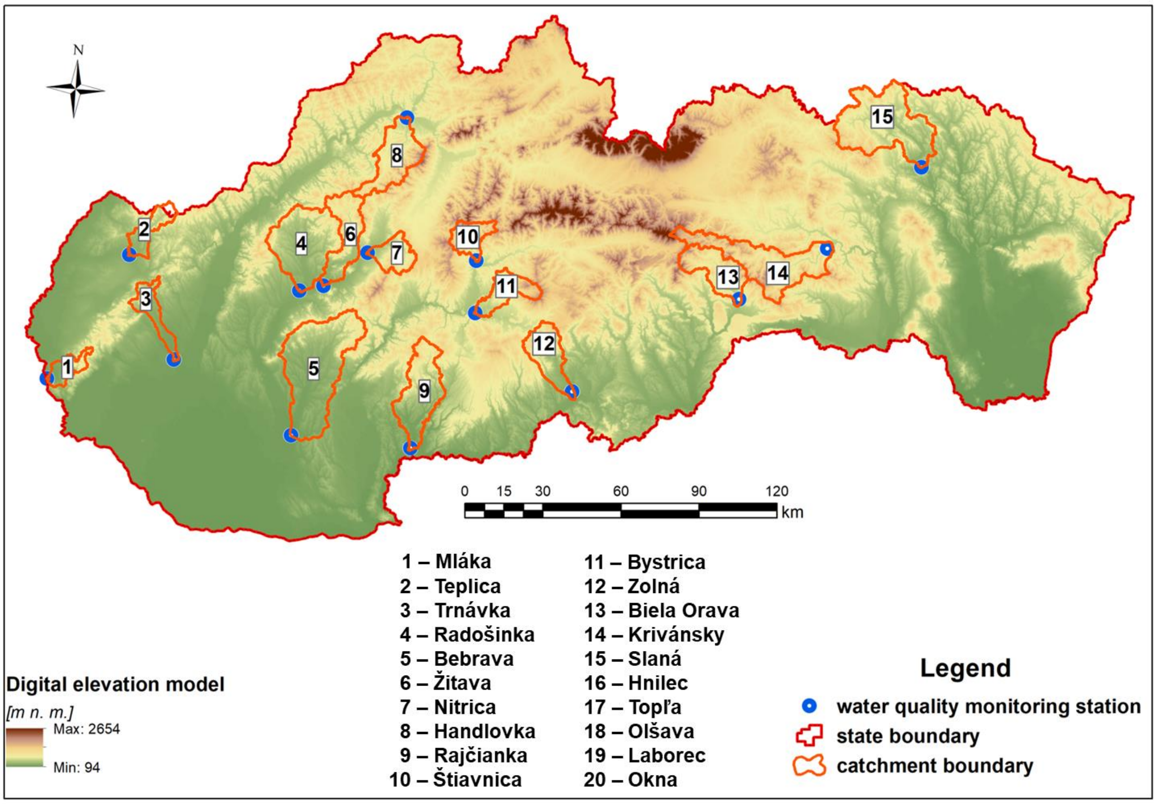

Figure 1: Localization of water quality measurement stations and evaluated river catchments in Slovakia territory.

Table 1: Short data description with result of Shapiro-Wilk test of normality of data sample.

data sample abreviation	***unit***	***short data description***	***p_value***	***H_0 hypothesis verification***
Ntotal	mg l^{-1}	median value [period 2006 - 2017]	0,081	reject H0 = not normal distributed data
Ptotal	mg l^{-1}	median value [period 2006 - 2017]	0,047	reject H0 = not normal distributed data
mean_elevation	m a. s. l.	derived from DTM raster layer	0,284	reject H0 = notnormal distributed data
mean_slope	%	derived from DTM raster layer	0,167	reject H0 = notnormal distributed data
agri_land	%	proportion of the land cover category	0,966	reject H0 = notnormal distributed data
urban_areas	%	proportion of the land cover category	0,033	reject H0 = not normal distributed data
woodland	%	proportion of the land cover category	0,698	reject H0 = notnormal distributed data
arable_land	%	proportion of the land cover category	0,048	reject H0 = not normal distributed data
sandy_soil	%	proportion of the soil texture category	0,000	reject H0 = not normal distributed data
loamy_soil	%	proportion of the soil texture category	0,024	reject H0 = not normal distributed data
silty_soil	%	proportion of the soil texture category	0,038	reject H0 = not normal distributed data
clayey_soil	%	proportion of the soil texture category	0,000	reject H0 = not normal distributed data
unconsolidated_rocks	%	proportion of the hydrogeology category	0,008	reject H0 = not normal distributed data
consolidated_rocks	%	proportion of the hydrogeology category	0,008	reject H0 = not normal distributed data
yearly_prec	mm yr^{-1}	median value [period 2006 - 2017]	0,422	reject H0 = notnormal distributed data
summer_prec	mm yr^{-1}	median value [period 2006 - 2017]	0,654	reject H0 = notnormal distributed data
evapotranspiration	mm yr^{-1}	derived from DTM raster layer [period 1981 - 2010]	0,205	reject H0 = notnormal distributed data
arable_land_losses	t ha^{-1} yr^{-1}	intersection of arable land and mean soil losses layer	0,998	reject H0 = notnormal distributed data
grassland_losses	t ha^{-1} yr^{-1}	intersection of grassland and mean soil losses layer	0,172	reject H0 = notnormal distributed data
nat_cov_land_losses	t ha^{-1} yr^{-1}	intersection of arable land and mean soil losses layer	0,222	reject H0 = notnormal distributed data

2.1 Results

In this contribution, we evaluated the relationship between river catchment parameters and median concentrations in total nitrogen and total phosphorus water quality indicator. Figure 2 shows the correlation matrix of Spearman‘s correlation coefficient that indicates connections among all river catchment parameters as well as between total nitrogen water quality indicator and river catchment parameters. The highest positive correlation coefficients between total nitrogen water quality indicator and river catchment parameters we have recorded in case of the proportion of urban areas to the total area of river catchment (0,9), evapotranspiration (0,89) and proportion of arable land to the total area of catchment (0,78). The significantly high correlation we have observed also in case of proportion of agricultural land (0,64) and proportion of unconsolidated rock (0,76) areas to the total area of the river catchment. The highest negative value was recorded in the mean slope of river catchment (-0,92) and almost the same in case of mean elevation of river catchment (-0,91). The significantly high negative value of Spearman’s correlation coefficient was recorded also in case of yearly and summer half precipitation (in both cases it was -0,85). Between total nitrogen median concentrations and proportion of consolidated rock areas to the total area of the river catchment, a quite strong negative correlation was observed (-0,76). The correlation coefficient between proportion of woodland areas to the total area of river catchment was -0,70. Figure 3 shows the same approach but in the case of total phosphorus water quality indicator. Basically we could observe very similar patterns like in case of correlation between total nitrogen and river catchment parameters. The highest positive correlation coefficient in the case of proportion of urban areas to the total area of river catchment. On the other hand, the highest negative value was recorded in the case of mean elevation of the river catchment. Figure 4 and 5 shows the relationship between total nitrogen as well as total phosphorus water quality indicator and selected river catchment parameters. Each correlation subplot shows not only magnitude but also the direction of the relationship, we depicted also regression and marginal histograms with kernel density fits (Rudemo, 1982). An important part of graphs is not only Spearman’s correlation coefficient itself but also p-value, based on which we can confirm or reject null hypothesis about the dependence of variables. On Figure 4 and 5 you can see correlation between water quality indicators (total nitrogen and total phosphorus) and proportion of agricultural land, urban areas, woodland areas, unconsolidated rock areas, consolidated rock areas and loamy soil areas to the total area of river catchments as well as long term yearly precipitation and long term yearly evapotranspiration within catchments. Based on results of correlation analysis that confirmed the highest influence of the proportion of urban areas to the total river catchments area on median total nitrogen and total phosphorus concentrations we decided to depict also another quantile characteristics of water quality data on Figure 6 and 7. These graphs show median as well as upper and lower quartile and decile in evaluated river catchments that are sorted descending by the proportion of urban areas to the total area of river catchment from left to right. We can see obvious decrease in all quantile characteristics with decrease in proportion of urban areas in river catchments.

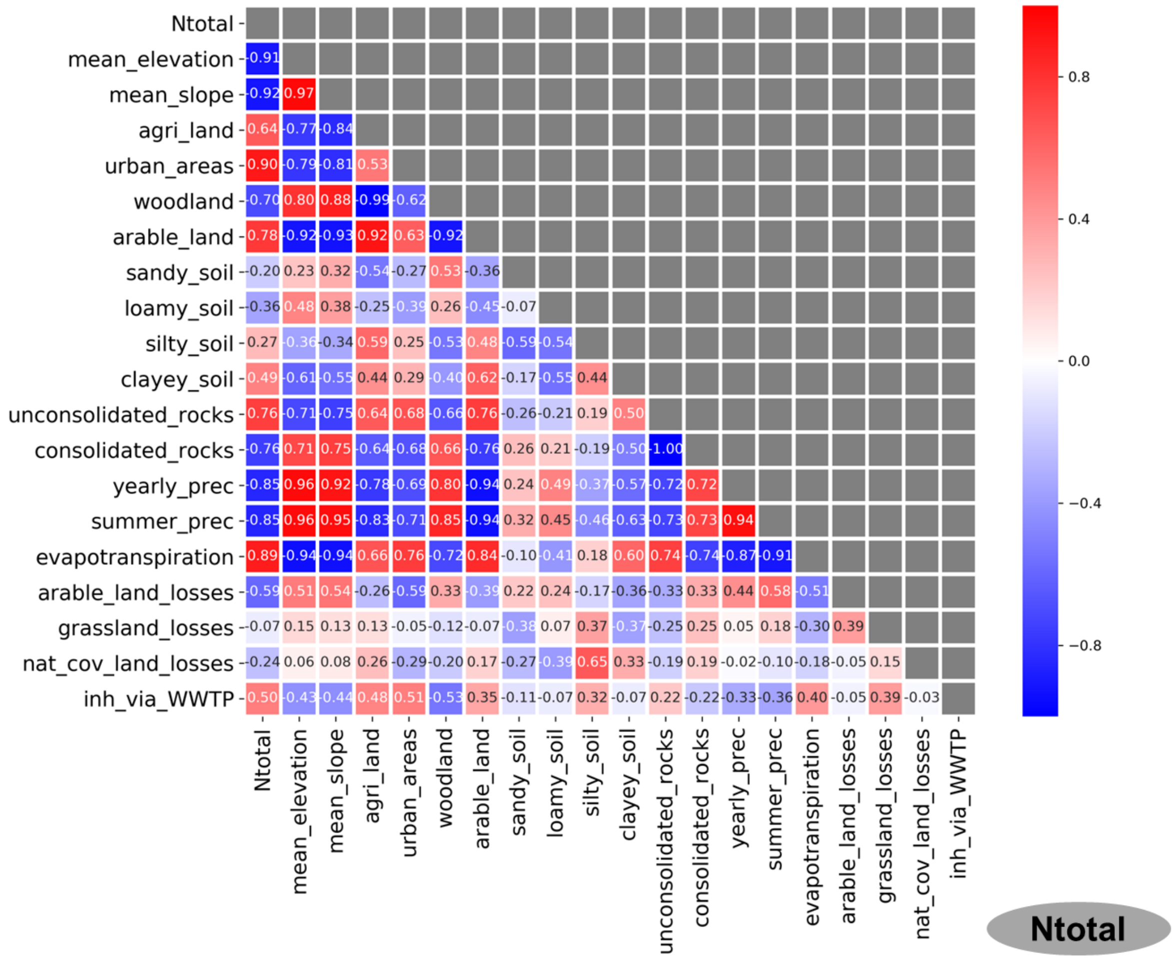

Figure 2: Spearman's correlation matrix between selected river catchment parameters and total nitrogen water quality indicator.

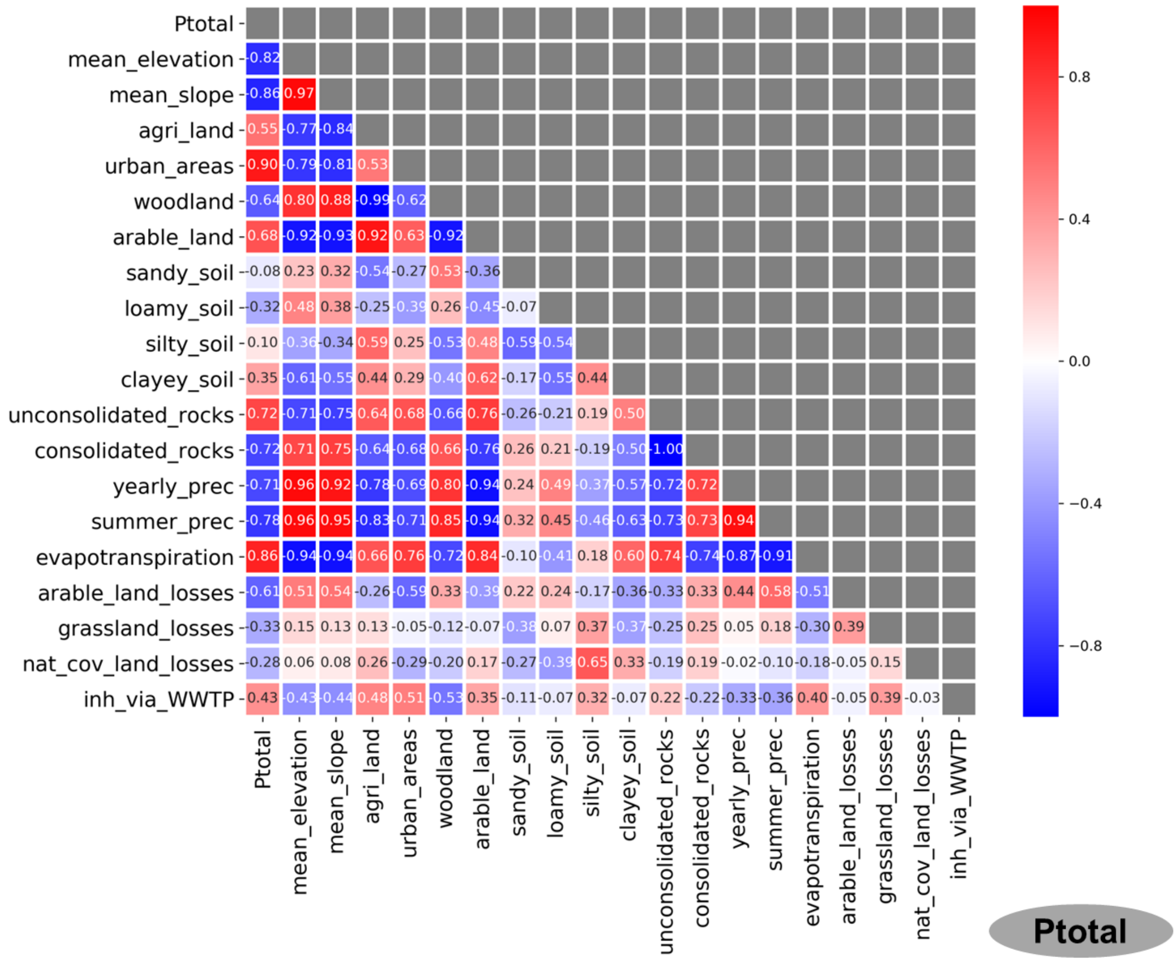

Figure 3: Spearman's correlation matrix between selected river catchment parameters and total phosphorus water quality indicator.

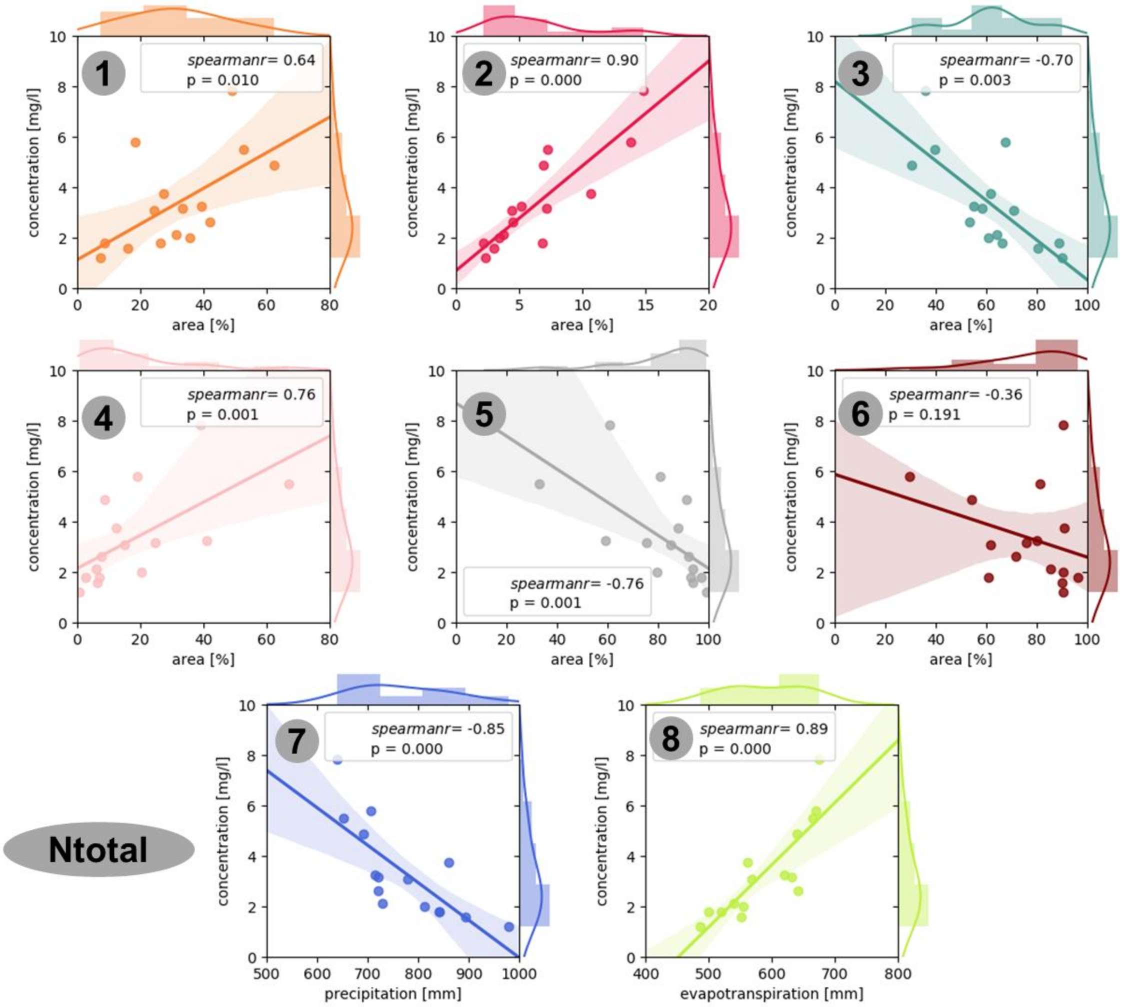

Figure 4: Spearman's correlation between selected river catchment parameters and median concentrations in total nitrogen water quality indicator (1 – agricultural land, 2 – urban areas, 3 – woodland areas, 4 – unconsolidated rock areas, 5 – consolidated rock areas, 6 – loamy soil, 7 – long term yearly precipitation, 8 – long term yearly evapotranspiration).

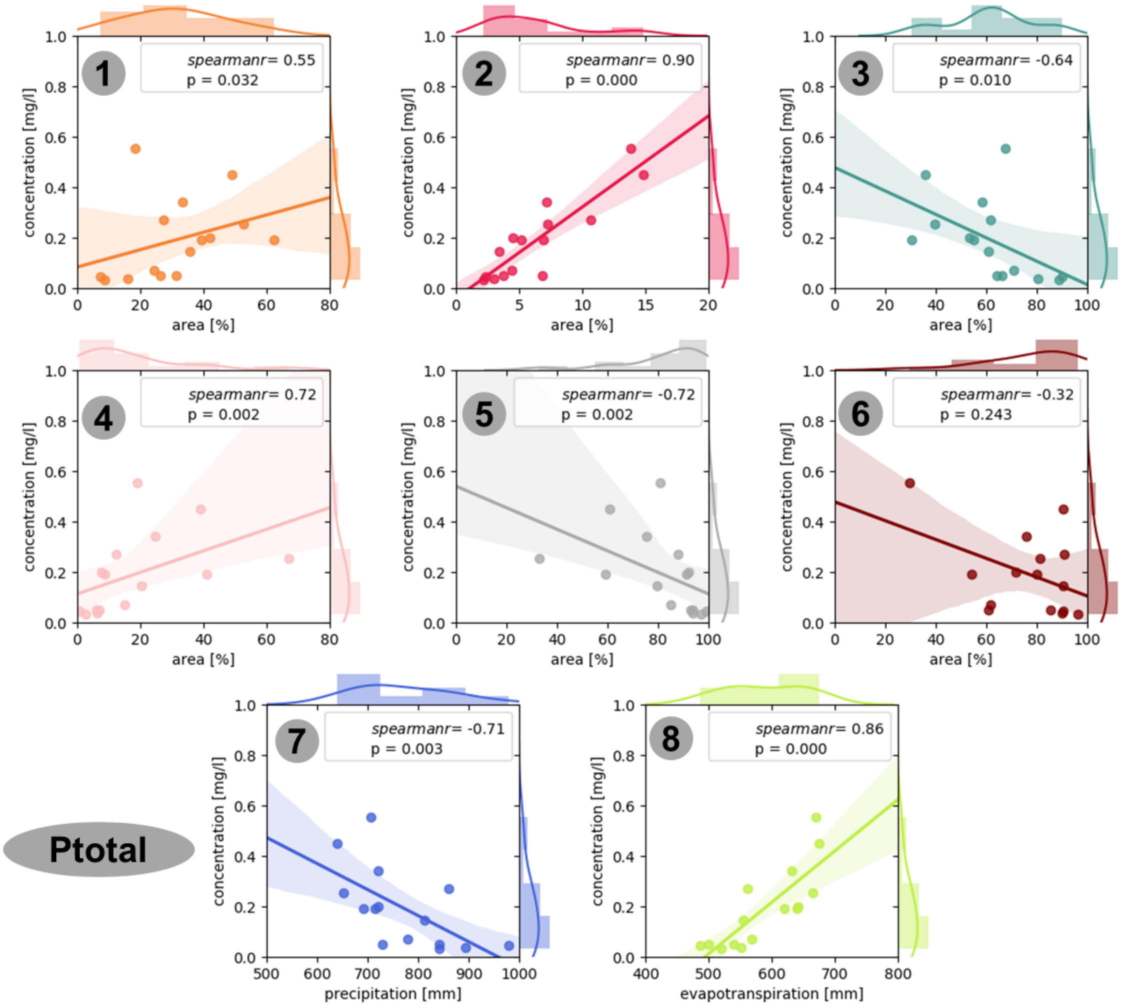

Figure 5: Spearman's correlation between selected river catchment parameters and median concentrations in total phosphorus water quality indicator (1 – agricultural land, 2 – urban areas, 3 – woodland areas, 4 – unconsolidated rock areas, 5 – consolidated rock areas, 6 – loamy soil, 7 – long term yearly precipitation, 8 – long term yearly evapotranspiration).

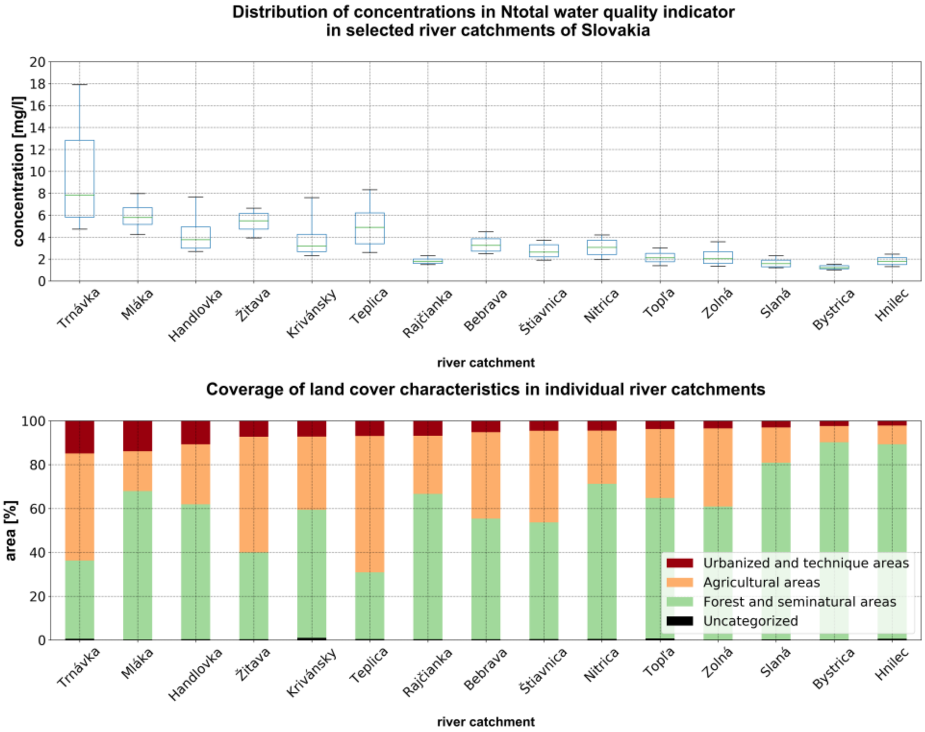

Figure 6: Total nitrogen concentrations in evaluated river catchments (above) and share of land cover categories on total catchment area (bottom) (sorted according Urbanized and technique areas descending from left to right).

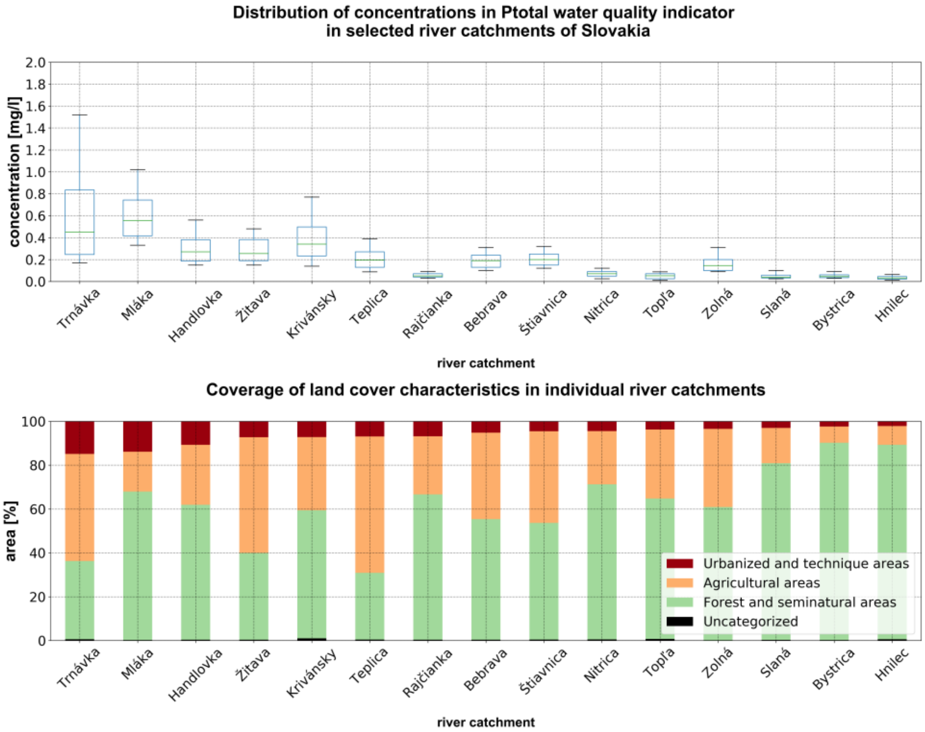

Figure 7: Total phosphorus concentrations in evaluated river catchments (above) and share of land cover categories on total catchment area (bottom) (sorted according Urbanized and technique areas descending from left to right).

2.2 Discussion

As have been mentioned in conclusion of work of Hauke and Kossowski (2011): ,,Make sure not to overinterpret Spearman's rank correlation coefficient as a significant measure of the strength of the associations between two variables", we have to be careful in the interpretation of results that we have presented in the previous paragraph. In addition, probably mainly in case of the relationship between nutrients concentrations and mean elevation, mean slope, long term precipitation and evapotranspiration we meet with the so-called spurious correlation. Pearson defined spurious correlations to be correlations caused solely by data transformations which do not reflect meaningful properties of the underlying data (Pearson, 1897). Spurious correlation can be also defined as a mathematical relationship in which two or more events or variables are associated but not causally related, due to either coincidence or the presence of a certain third, unseen factor (Simon, 1954; Benson, 1965; Kronmal, 1993; Brett, 2004). One of the main factors that we have identified to have an influence on water quality in Slovakia river catchment is the proportion of land cover categories to the total area of river catchment (Siman and Velísková, 2019). A lower proportion of urban areas to the total area of river catchment is in the mountainous regions of Slovakia territory, hence in river catchments with higher elevation, slope angle and annual precipitation and on the other hand with lower evapotranspiration. Despite we have observed high correlation coefficients between nutrient concentrations and above-mentioned parameters it is likely that only proportion of land cover such as urban areas can be pointed as main driver influencing nutrient concentrations in surface streams within evaluated catchments. Higher attention should be dedicated to impact of the proportion of consolidated and unconsolidated rock areas on nutrient concentrations. Some studies have investigated the influence of the hydrogeologic settings on the fate of nitrate in rocks with contrasting permeability (Orr *et al.*, 2016; Rivas *et al.*, 2017; Elwan, 2018). Hydrogeology has an impact on residence time that can be considered as the main important factor in improving water quality through denitrification (Fennessy and Cronk, 1997). Denitrification is the process by which nitrate is transformed through a series of microbial reduction reactions to gaseous nitrogen forms (Korom, 1992; Rivett *et al.*, 2007) and it was found to be the main process of nitrate attenuation in the subsurface environment (Rivett *et al.*, 2007). Many studies have shown that denitrification is influenced by catchment characteristics (e.g. soil and rock properties), most recent results of this relationship are available in Elwan (2018).

In this contribution, we have evaluated also the relationship between rock and soil structure on nutrient concentrations in surface streams. We have supposed that consolidated rock areas will have worse permeability than unconsolidated rock areas. Based on correlation analysis we have observed a quite strong relationship that indicates that with an increase of the proportion of unconsolidated areas to the total area of river catchments also increase in both total nitrogen as well as total phosphorus concentrations can be predicted. In the case of analysis of the relationship between soil structure and nutrient concentrations, the results were not that convincing. We expected, similarly like in the case of the impact of geology structure on water quality, that in catchments where soils with lower permeability (such as clayey or silty soils), are dominating soil type, lower concentrations of nutrients will be observed (in the context of impact on residence time and therefore denitrification process) and vice versa. The highest correlation coefficient was in the case of clayey coils (0,49) but the problem is that clayey soils have very rare occurrence in evaluated catchments. The same issue we observed also in case of sandy soils that occur almost exclusively in the southwest of Slovakia. Dominating soil type in the context of soil texture is loamy soil that consists of different size of grain and loamy soils can have therefore wide spectrum of features and also permeability. In addition, there are no big differences in the proportion of loamy soil to the total area of the river catchment since in most catchments loamy soil is dominated soil type.

3 Conclusion

In this contribution, we evaluated the relationship between selected river catchment parameters and nutrient concentrations in 15 river catchments located in Slovakia territory. We mostly analysed connections between median concentrations in total nitrogen and total phosphorus water quality indicators and proportion of land cover, rock and soil characteristics to the total area of river catchments as well as some geomorfometrical (mean elevation and mean slope) and climatological characteristics (yearly precipitation and evapotranspiration). We used Spearman's correlation coefficient that is used for not normal distributed data, it can catch also non-linear trends and it is not that sensitive to outliers. Our results suggest a significant negative impact of the proportion of urban areas to the total are of river catchment on nutrient concentrations and the similar impact can be seen also in case of proportion of arable land and agricultural land on nutrient concentrations. Proportion of woodland areas has comparable significant influence on nutrient concentrations, but on the other hand, this impact is positive. We have noticed also a strong correlation between proportion of consolidated as well as unconsolidated rock areas and nutrient concentrations in our catchments. In catchments where consolidated rock areas were dominating, lower nutrient concentrations occurred and vice versa. In the case of the influence of soil texture on nutrient concentrations, results were not so convincing. Likely because in Slovakia there are no so big differences in soils in the context of soil texture. In addition, the loamy soil that consists of different size of grain and has, therefore, a wide range of features, is very dominated soil type in Slovakia territory.

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4.2 Links to data

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[2] COPERNICUS PROGRAMME – Copernicus Land Monitoring Service. 2019. [online]. CORINE Land Cover, CLC 2012. [cit. 2019-10-08]. Available from: <http://copernicus.sazp.sk/>.

[3] TOPSOIL PHYSICAL PROPERTIES FOR EUROPE (based on LUCAS topsoil data). 2019. [online]. [cit. 2019-10-08]. Available from: <https://lnk.sk/pFX6>.

[4] SOIL EROSION BY WATER (RUSLE2015). 2019. [online]. Available from: <https://lnk.sk/bpLW>.

[5] GLOBAL HYDROGEOLOGY MAPS (GLHYMPS) OF PERMEABILITY AND POROSITY. 2019. [online]. Available from: <https://lnk.sk/chvR>.