Long term trend of water quality in the Bela river

P. Miklanek, M. Martincova, M. Dosa and P. Pekarova

Langzeittrend der Wasserqualität des Bela-Flusses

1 Introduction

Stream water quality is one of the central topics of the Water Framework Directive (WFD, 2000). The Directive focuses on preservation and improvement of the aquatic environments within the European Union mainly with respect to quality of all water bodies. The Directive declares the commitment of the EU member states to evaluate the long-term evolution of water quality in surface streams with respect to the type of a water body. In order to understand how surface water quality in catchments is affected by different land use patterns, it is essential to monitor water quality in 'reference basins' with respect to all possible factors controlling the chemical status of water. To separate the effect of anthropogenic activities on water quality from natural factors (e.g. lithology, land cover, climate, etc.), we need to monitor water quality in pristine catchments in order to obtain background values (concentrations).

Our objective is threefold: (1) to evaluate the water quality in the Bela River at the downstream sampling site located at Liptovsky Hradok for a period of 20 years (1991–2010), (2) to analyze long-term trends in the time series of water temperature and other selected water quality parameters and (3) to model the selected water quality parameters using multi-regression methods.

2 Data

The water quality in the Bela river basin is evaluated for the period 1991–2010. The data we present here were obtained from the database of the Slovak Hydrometeorological Institute (Fig. 1) for the sampling site at Liptovsky Hradok (Fig. 2). During the analyzed period, mean water temperature (Tw) was 7.2 °C, mean conductivity (EC) was as low as 12.19 mS/m, chloride concentration (Cl^-) was 4.04 mg/l

Zusammenfassung

Zur Klassifizierung des ökologischen Potenzials und des aktuellen Zustands von Oberflächengewässern ist die Kenntnis der Entwicklung der Wasserqualität in ungestörten Referenzgebieten und in anthropogen beeinflussten Einzugsgebieten wesentlich. In diesem Beitrag werden Gewässerqualitätsdaten des Flusses Bela in der Slowakischen Republik aus dem Zeitraum 1991 bis 2010 verwendet. Zuerst wurden Langzeittrends ausgewählter Qualitätsparameter analysiert. Die Signifikanzprüfung der Trends erfolgte mittels zweier nichtparametrischer Tests, dem Mann-Kendall-Trendtest und dem Sen's-slope-Test. Die Trends zeigen eine Verbesserung der Wasserqualität am Bela-Fluss. Darüber hinaus wurde mit Hilfe der Mehrfachregression eine Modellierung ausgewählter Gewässerqualitätsparameter durchgeführt.

Schlagworte: Bela-Fluss, Fließgewässerqualität, Mann-Kendall-Trendtest, Mehrfachregressionsanalyse.

Summary

Understanding how water quality evolves in undisturbed 'reference' catchments compared to catchments affected by anthropogenic activities is important with respect to a classification of the ecological potential and the status of surface stream waters. In this paper we use water quality data from the Bela River in Slovakia, covering a 20-year period (1991–2010). First, we analyzed the long-term trend of selected water quality parameters. Two nonparametric tests, the Mann-Kendall trend test and Sen's slope test, were used to assess the significance of the detected trends. The observed trends suggest that quality of water in the Bela River has improved over the course of the analyzed period. In addition, we applied multi-regression methods to model selected water quality parameters.

Key words: Bela River, stream water quality, Mann-Kendall trend test, multi-regression analysis.

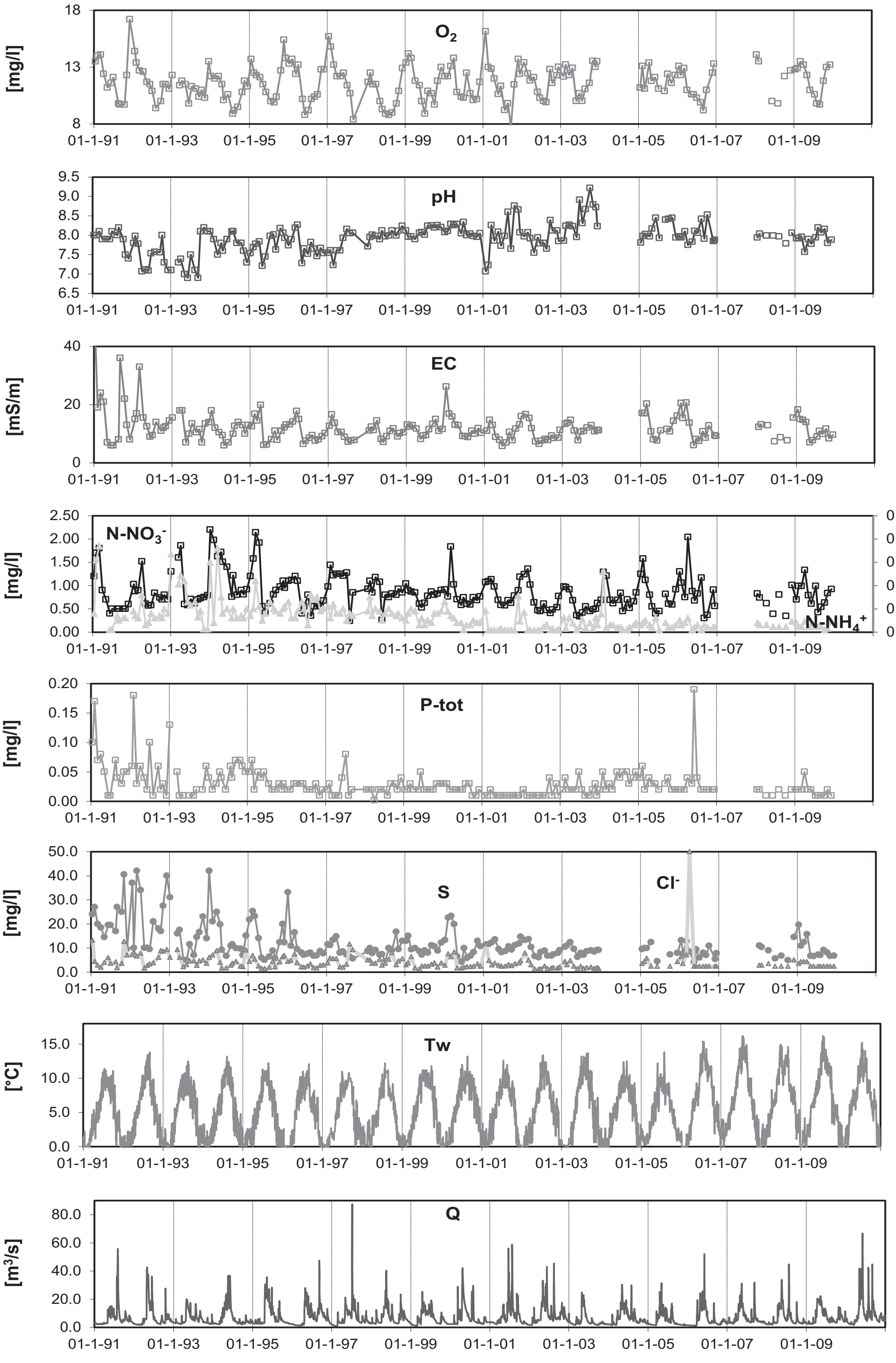

Figure 1: Concentrations of selected chemical and physical parameters in the Bela River at Liptovsky Hradok, period 1991–2010 (O_2 – oxygen, pH – acid-base reaction, EC – electric conductivity, N-NO_3^- – nitrate nitrogen, N-NH4$^+$ – ammonia, P-tot – total phosphorus, S – sulfate, and Cl^- – chloride are the once-per-month data, water temperature Tw was measured daily at 7 a.m., Q = average daily discharge

Abbildung 1: Konzentration ausgewählter chemischer und physikalischer Parameter des Flusses Bela bei Liptovsky Hradok für die Periode 1991 bis 2010. O_2 – Sauerstoff, pH – Wert, EC – elektrische Leitfähigkeit, N-NO_3^- – Nitratstickstoff, N-NH_4^+ – Ammonium, P-tot – Gesamphosphor, S – Sulfat und Cl^- – Chlorid wurden monatlich beprobt, Wassertemperatur Tw täglich um 7 h sowie Abfluss Q (Tagesmittelwerte) and sulfate concentration (S) was 12.74 mg/l. These values are relatively low (Kovacova & Veliskova, 2012; van Lanen & Dijksma, 2004; Kondratyev & Trumbull, 2012), documenting low pollution of the Bela river (Fig. 2). Mean monthly concentrations of the selected parameters are shown in Fig. 3.

3 Methods and results

3.1 Long term trends

The monthly series include seasonal (cyclic) component and therefore the time series of the mean annual concentrations were used to evaluate the long-term trends of the selected water quality parameters. The significance of the trends was calculated by the Mann-Kendall test and the magnitude of the linear trend was calculated by the non-parametric Sen's method (Mann, 1945; Kendall, 1975; Makesens, 2002). The results show (see Table 1) that the water quality in the Bela River improved over the period 1991–2009. This is indicated by the negative slope coefficient A for most parameters (Table 1).

In the case of ammonia (N-NH_4^-) and sulfates, the declining concentrations were found to be statistically significant at the $\alpha \leq 0.001$ level of significance. This decreasing trend can be attributed to the reduced agricultural activities in Slovakia and also in the lower portions

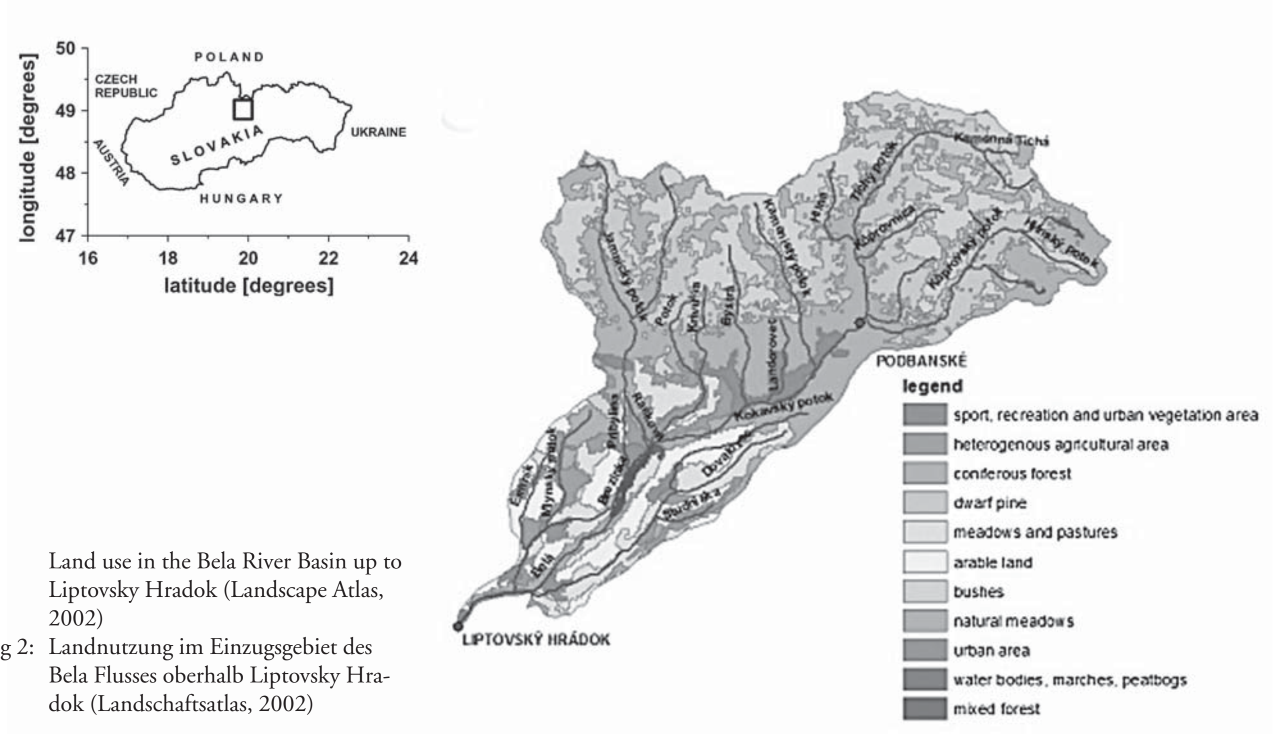

Figure 2: Land use in the Bela River Basin up to Liptovsky Hradok (Landscape Atlas, 2002)

Abbildung 2: Landnutzung im Einzugsgebiet des Bela Flusses oberhalb Liptovsky Hradok (Landschaftsatlas, 2002)

Table 1: Trend significance (S) – Mann-Kendall trend test, (A) nonparametric Sen's slope and (B) intercept estimates of a linear trend, period 1991–2009, ChSK-Cr – chemical oxygen demand

Tabelle 1: Trendsignifikanz (S) des Mann-Kendall-Tests, (A) Sen's-Steigung und (B) Achsabschnitt der Periode 1991 bis 2009, ChSK-Cr – chemischer Sauerstoffbedarf

Series	S	A	B	Series	S	A	B
EC		–0.077	12.62	N-NO3–	+	–0.009	0.92
pH	*	0.024	7.68	P tot	*	–0.001	0.04
Tw		–0.032	7.32	Cl–	**	–0.137	5.24
O2		–0.007	11.73	S	***	–0.397	15
N-NH4+	***	–0.006	0.12	NL		0.14	5.191
N-NO2–	**	0	0.01	ChSK-Cr		–0.353	13.45

(*** trend at $\alpha \leq 0.001$ level of significance, ** trend at $\alpha \leq 0.01$ level of significance, * trend at $\alpha \leq 0.05$ level of significance, + trend at $\alpha \leq 0.1$ level of significance, if the cell is blank, the significance level is greater than 0.1)

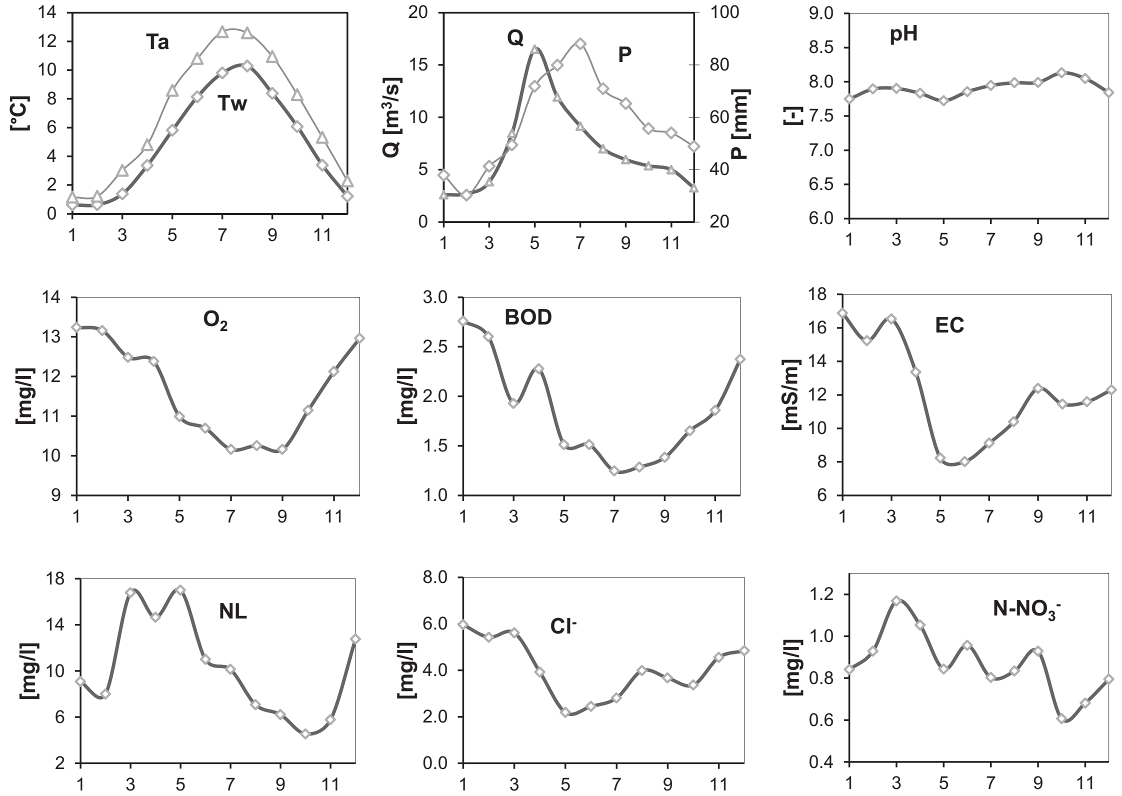

Figure 3: Mean monthly concentrations of selected parameters at Liptovsky Hradok, 1991–2005 (Ta – air temperature, Tw – water temperature, Q – discharge, P – precipitation, pH – acid-base reaction, O_2 – oxygen, BOD – biological oxygen demand, EC – electric conductivity, NL – insoluble matter, Cl– – chloride N-NO_3^- – nitrate nitrogen)

Abbildung 3: Mittlere monatliche Konzentration ausgewählter Parameter bei Liptovsky Hradok, 1991–2005 (Ta – Lufttemperatur, Tw – Wassertemperatur, Q – Abfluss, P – Niederschlag, pH – Wert, O_2 – Sauerstoff, BOD – Biol. Sauerstoffbedarf, EC – elektrische Leitfähigkeit, NL – ungelöste Stoffe, Cl– – Chlorid, N-NO_3^- – Nitratstickstoff)

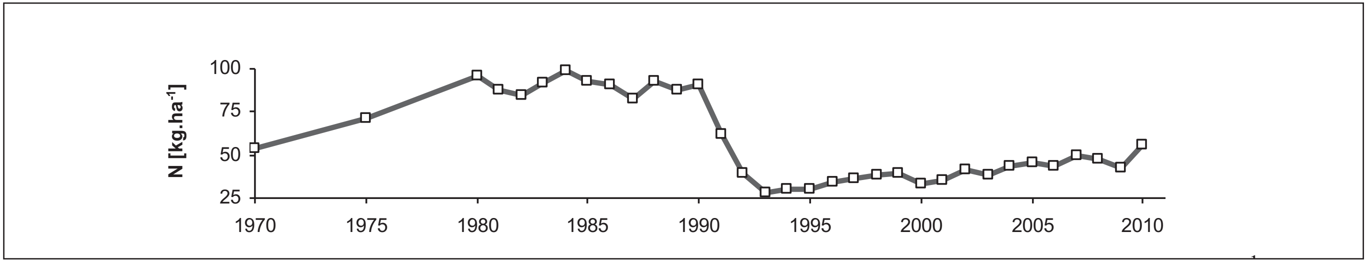

Figure 4: Mean doses of nitrogen fertilizers applied in agriculture in Slovakia in kg.ha^{-1} (Landscape Atlas, 2002)

Abbildung 4: Mittlere jährliche Gabe der landwirtschaftlichen Stickstoffdüngung in der Slovakei in kg.ha^{-1} (Landschaftsatlas, 2002)

of the Bela catchment. Figure 4 exhibits a significant decrease of nitrogen fertilizers after 1990. Similar development was observed throughout Eastern Europe (STÅLNACKE et al., 2003).

3.2 Empirical relations between selected water quality parameters

The cross-correlation matrix of the selected water quality parameters shows a strong relation (R = 0.96) of electric conductivity with Ca^+ Mg ions. Positive relations were found between electric conductivity and sulfates (0.69) and nitrates (0.59). A relatively significant negative correlation coefficient has been found between water temperature and electric conductivity (–0.65), and between discharge and conductivity (–0.61). It is related to the fact that during the high flow period the clean snowmelt water runs off. As a consequence we used non-linear multiple regression functions to indirectly estimate concentrations of the selected water quality parameter from discharge Q and stream water temperature Tw. For example, the following relation is valid for electric conductivity EC [mS/m]:

$$EC = 10.79 + \frac{11.17}{Q} - 0.747(Tw) + 0.03635(Tw)^2 \qquad (1)$$

For water hardness (Ca+Mg) in [mmol/l] we found the relation:

$$(Ca{+}Mg) = 0.779 - 0.06802\mathrm{In}(Tw+0.1) - 0.1288\ln(Q) \qquad (2)$$

For oxygen (O_2) in [mg/l] we found the relation:

$$O_2 = 13.39 - 0.0563Q - 0.0205(Tw)^2 \qquad (3)$$

These relations can be used to fill gaps in records with missing data. Another use of these statistical relations is for prediction of water quality parameters using discharge and water temperature scenarios related to climate change scenarios. The daily discharge and daily temperature can be used to complete the continuous daily series of selected parameters. Fig. 5 shows a comparison of the measured and modeled values of water hardness (Ca + Mg), electric conductivity, and oxygen. The observed data are once-per-month data, modeled values are based on equations (1), (2), and (3) and are calculated from mean daily values of Tw and Q.

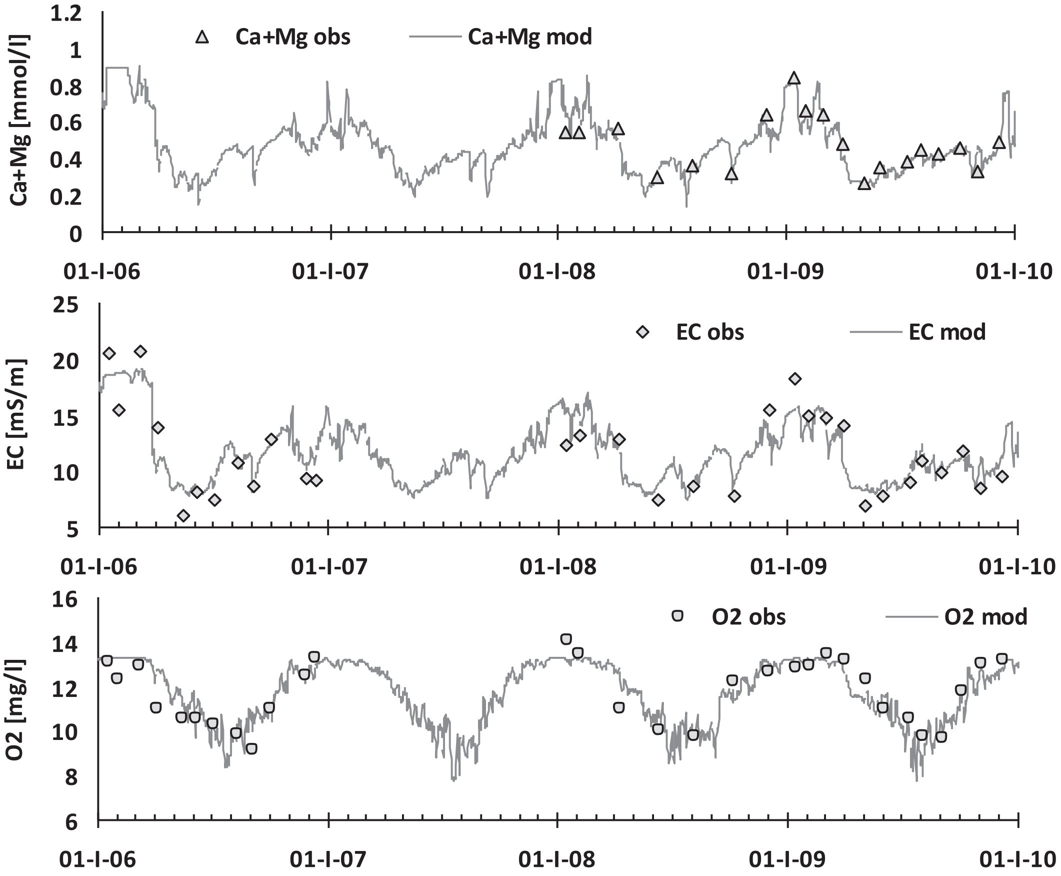

Figure 5: Comparison of the measured and modeled values of the water hardness (Ca + Mg), electric conductivity EC, and oxygen (O_2), Bela river, station Liptovsky Hradok, selected period 2006–2009

Abbildung 5: Vergleich der gemessenen und modellierten Werte für Wasserhärte (Ca + Mg), elektrische Leitfähigkeit EC und Sauerstoff (O_2) für den Fluss Bela bei Liptovsky Hradok für die Periode 2006 bis 2009

4 Conclusion

In terms of water quality, the upper Bela River (upstream the Podbanske station) can be considered a river with natural, anthropogenically unaffected chemical regime.

Further downstream, the quality of water in the Bela river is athropogenically affected. Nevertheless, the water quality (measured at the Liptovsky Hradok station) is quite good and has been improving over the last two decades (with respect to both physical and chemical parameters). We attribute the declining trend in nitrate, ammonia, total phosphorus, sulfate and chloride concentrations to lower fertilization rates in the arable areas downstream Podbanske.

The cross-correlation matrix revealed that the strongest correlation (0.96) is obviously between electric conductivity and water hardness (Ca + Mg). A relatively high negative correlation was found between water temperature and electric conductivity (–0.65), or discharge and electric conductivity (–0.61). A positive correlation was found between electric conductivity and sulfates (0.69), and nitrates (0.59).

We established mathematical relations to indirectly estimate the selected water quality parameter using only discharge and water temperature. The presented equations are suitable for estimation of missing data in time series, or to estimate water quality during runoff situations when water quality sampling is not possible due to inaccessibility of sampling sites or equipment failure.

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References

Landscape Atlas of SR (2002): Landscape Atlas of the Slovak Republic. (In Slovak.) Ministry of Environment SR, Bratislava.

KENDALL, M.G. (1975): Rank Correlation Methods. Griffin, London.

KONDRATYEV, S. & N. TRUMBULL (2012): Nutrient loading on the eastern Gulf of Finland (Baltic Sea) from the Russian catchment area. J. Hydrol. Hydromech., 60 (3), 145–151.

KOVACOVA, V. & Y. VELISKOVA (2012): The Risk of the Soil Salinization of the Eastern Part of Zitny Ostrov. J. Hydrol. Hydromech., 60 (1), 57–63.

MAKESENS (2002): MAKESENS 1.0, Mann-Kendall Test and Sen's Slope Estimates for the Trend of Annual Data, Version 1.0. Finnish Meteorological Institute.

MANN, H.B. (1945): Nonparametric Tests Against Trend. Econometrica, 13, 245–259.

STÅLNACKE, P., A. GRIMVALL, C. LIBISELLER, A. LAZNIK and I. KOKORITE (2003): Trends in Nutrient Concentrations in Latvian Rivers and the Response to the Dramatic Change in Agriculture. J. Hydrol., 283 (1–4), 184–205.

VAN LANEN, H.A.J. & R. DIJKSMA (2004): Impact of Groundwater on Surface Water Quality: Role of the Riparian Area in Nitrate Transformation in a Slowly Responding Chalk Catchment (Noor, The Netherlands). Ecohydrol. Hydrobiol.4 (3), 315–325.

WFD (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 Communities, L372.

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