

The variability of surface water quality indicators in relation to watercourse typology, Czech Republic

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Abstract This paper examines the relationships between watercourse typology and selected indicators of long-term surface water quality for rivers in the Czech Republic. The parameters used to define watercourse typology are in accord with the Water Framework Directive 2000/60/EC outlined by the European Commission. The relationships were tested using descriptive and multivariate statistical analysis, namely cluster analysis and canonical correspondence analysis. It was found that only some of the typological parameters have a close association with

indicators of surface water quality. Specifically, the parameters of altitude and geology show clear relationships with pH, calcium content, and the saprobity index of macroinvertebrates. Conversely, parameters that are strongly influenced by anthropogenic pollution show weak relationships with indicators of surface water quality. These depend instead on the presence of pollution sources rather than on natural environmental conditions.

Keywords Water Framework Directive · Typology · Surface water quality · Reference conditions · GIS

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Introduction

Watercourse typology forms an important component of environmental water management legislation within the European Union, as defined by the European Commission Framework Directive on Water Policy. Typology is of fundamental importance with regard to differentiating adjacent water bodies and in establishing reference values for the ecological status of watercourses. In order to differentiate adjacent water bodies, the typology must be able to distinguish a single type of water body in order to effectively implement water management planning, monitoring, reporting, and administration (EC 2003). In order to establish reference values for monitoring and assessing the ecological status of watercourses (Hering et al. 2010), it is essential that the stream types represent

homogeneous categories of those natural characteristics that determine the basic biological, hydro-morphological, and chemical properties of the stream. The establishment of accurate reference values is fundamental to forming a system for monitoring, evaluating, and reporting on the ecological quality of the surface water (Sandin and Verdonschot 2006).

Determining reference values remains one of the tasks necessary for the implementation of the Framework Directive (WFD). The WFD allows different approaches for deriving reference conditions: (1) comparison with an existing undisturbed site, (2) historical data and information, (3) models, or (4) expert judgement (EC 2000). The common problem of analyzing and validating reference values for rivers in Europe is underpinned by a strong anthropogenic influence, which causes a fundamental difficulty for setting such values based on comparison with an undisturbed site (Bald et al. 2005; Muxika et al. 2007). For a number of streams, it is then very difficult, if not impossible, to identify locations that correspond to determined reference conditions. Reference conditions classified at the national scale are thus stemming from historical data and their application in geostatistic models. In order to determine the reference values accurately and interpret changes in the status of the various watercourses, it is fundamental to understand the intensity and character of the anthropogenic influence in relation to the typological characteristics of the particular watercourse to which the reference values are connected (Simpson et al. 2005; Verdonschot and Nijboer 2004).

This article aims to assess the extent to which the pollution load in surface waters is related to the typology of the various watercourses in the Czech Republic. The analysis focuses on a geostatistic evaluation of the spatial and functional relationships between typological parameters and selected indicators of long-term surface water quality. The variability of water quality indicators in relation to the typological category has been evaluated, as well as the functional and spatial relationships between the typological categories and indicators of surface water quality determined during a long-term monitoring program. To carry out the assessment, descriptive statistics have been applied (cluster analysis and canonical correspondence analysis) taking advantage of spatial analysis in the environment of geographic

information system (GIS). The assessment is based on data from the long-term monitoring of surface water quality between 1970 and 2009.

Methodology and data sources

Typology of watercourses in the Czech Republic

Watercourse typology necessarily reflects simplified natural conditions, based on parameters that influence the character and ecological status of aquatic ecosystems (EC 2000, 2003). The typology should have the minimum number of categories required to distinguish the various types of watercourse (Sommerhäuser and Pottgiesser 2004). In the Czech Republic, the new watercourse typology is based on four parameters: drainage basin, altitude, geology, and stream order (Langhammer et al. 2009). These parameters are further subdivided in order to maintain functional heterogeneity while still reflecting the minimum possible number of general categories. Therefore, parameter of drainage basin is subdivided into three categories, altitude into four categories, geology into two categories, and stream order into three categories (Table 1).

Czech typology applies drainage basin as a regionalization parameter instead of “eco-region” as defined by (Illies 1978). This is due to the combination of several factors. As a result of the specific geographical features of the Czech Republic, European eco-regions are practically identical to the main drainage divides within the Czech Republic. Studies examining the suitability of the eco-region parameter show that the boundaries between neighboring eco-regions are not sharp. Instead, they are composed of diffuse zones in which there is a mingling of those species that were supposed to determine the various boundaries. While testing the suitability of the eco-region parameter within the Czech Republic, Zahrádková et al. (2005) indicated that drainage basin provided a more useful basis for categorization in relation to the distribution of macro-invertebrates. The Czech Republic is divided into three drainage basins (Fig. 1). The drainage basin of the North Sea, including the Elbe Basin, corresponds closely to the eco-region of the Hercynian Mountains of Central Europe. The drainage basin of the Mediterranean Sea corresponds closely to the Pannonian eco-region. The drainage basin of the

Table 1 The resulting typological categories for watercourses and other bodies of water

Parameter	Number of categories	Category
Drainage basin	3	1. North Sea 2. Baltic Sea 3. Mediterranean Sea
Altitude	4	1. <200 m a.s.l. 2. 200–500 m a.s.l. 3. 500–800 m a.s.l. 4. >800 m a.s.l.
Geology	2	1. Crystalline and igneous 2. Sandstone, clay, Quaternary
Stream order	3	1. Streams (order 1–3) 2. Small rivers (order 4–6) 3. Large rivers (order 7–9)

Baltic Sea corresponds closely to the Central European lowland eco-region.

The altitude parameter within the typology expresses, among others, the basic climatic characteristics of the environment, namely temperature, its annual course, rainfall mean, distribution of discharge throughout a year, etc.. The parameter comprises of four categories: <200, 200–500, 501–

800, and >800 m a.s.l. The geology is classified into two categories that reflect different rock diagenesis and, therefore, divergent physical and chemical properties: metamorphic and igneous rocks, and sedimentary and Quaternary rocks. Watercourse size is defined by the relative stream order of Strahler, which is used as a proxy for the relative magnitude of water flow in a river

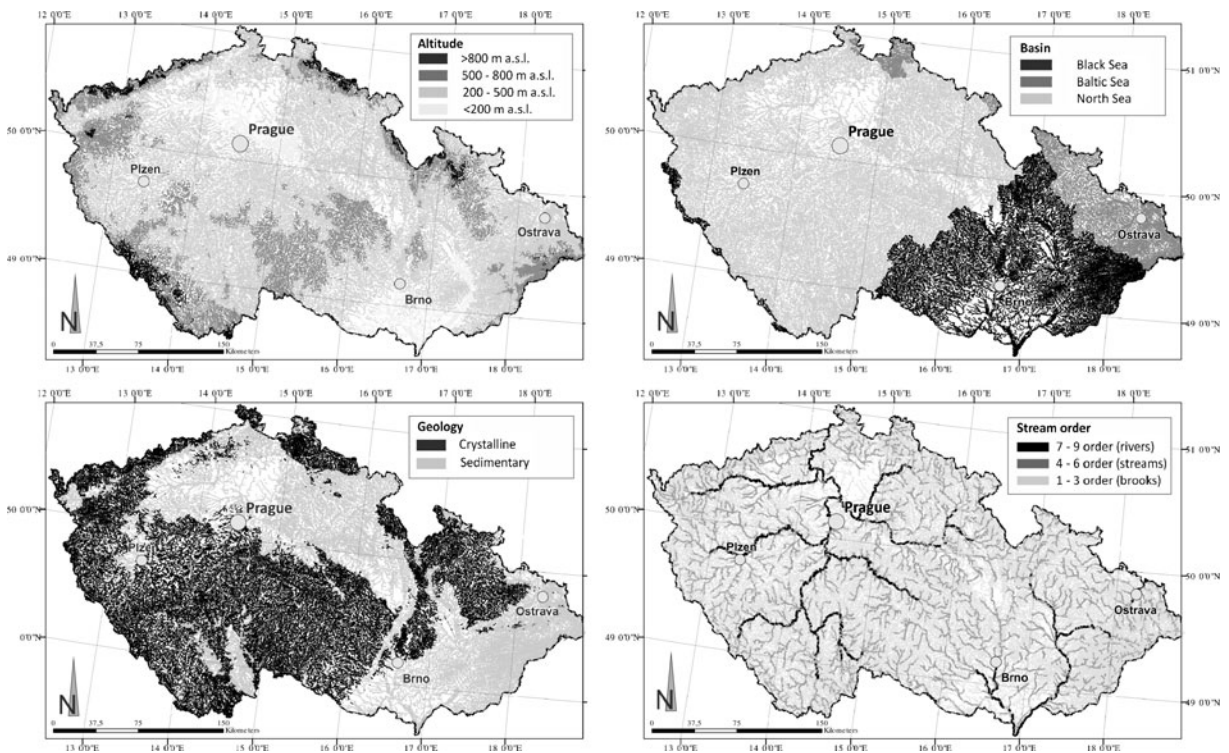


Fig. 1 Categorization of parameters for the typology of the Czech Republic

network and expresses relationships to other physical geographical parameters (Horton 1945; Strahler 1957; Hellweger and Maidment 1999). Following a quantitative analysis of river network data for the Czech Republic, where stream orders range from 1 to 9, stream orders were divided into three categories. The applied terminology also gives a clear indication of the size of the watercourse: stream (orders 1–3), small river (orders 4–5), and large river (orders 6–9).

The four categories described above comprise the typological division of the various watercourses in the Czech Republic. The underlying typology represents a zonal division derived from parameters that express regional variability of abiotic conditions, i.e., drainage basins, altitude, and geology. The zonal divisions form homogenous regions in term of physiographic characteristics inside the region that are maximally heterogeneous in relation to the adjacent zones. At this level of categorization, the river network is divided into a total of 21 basic zonal types of watercourse. The full range of zonal types of watercourse, including the parameter of stream order, comprises a total of 47 types.

Selected water quality indicators

Selected physical, chemical, and biological indicators were chosen in order to analyze the variability of typological parameters in relation to parameters of long-term surface water quality. These indicators reflect various sources of pollution and processes of contamination, in addition to showing the distribution of pollutants in time and space. At the same time, the chosen indicators provide sufficient coverage of monitoring data for the number and distribution of monitoring profiles and length of the monitoring period.

Of the basic physical and chemical parameters, the following were evaluated: water temperature and conductivity, pH, and the concentration of Ca. These provide information regarding the degree of acidity in the aquatic environment. Indicators biochemical oxygen demand (BOD₅) and chemical oxygen demand (COD) reflect the load of organic substances, while N-NO₃⁻ and P_{total} indicate essential nutrients. Of the hydrobiological parameters, indicators for chlorophyll and the saprobity index of macroinvertebrates were included. The values for selected indicators were expressed for individual profiles for the maximum

available time span during the reporting period; the arithmetic mean, median, minimum, and maximum.

The data source for long-term surface water quality was the Arrow Database (MZP 2010), which contains the results of surface water quality monitoring for the period 1970–2008. The monitoring networks are operated by the Czech Hydrometeorological Institute, the Water Board Authority, and the Agricultural Water Board Authority. The database comprises 2,527 monitoring profiles in a time series from 1970 to 2008. As the majority of the profiles represent various lengths of time, we have used a subset of 313 water quality monitoring profiles in which all the selected indicators were available for an identical time span.

The main source of spatial data was the GIS layer “Typology of Water Bodies” developed by the authors (Langhammer et al. 2009). This was accompanied by a segmental model of the various river networks, derived from a detailed digital elevation model (VUV 2009) and the database DIBAVOD (VUV 2010).

Assessment methodology

The following working hypotheses represent the starting point for the analysis:

1. Individual typological parameters have different influences on the quality of surface water.
2. Only some of the surface water quality indicators will show a relationship with the natural characteristics expressed in the typological parameters.
3. Indicators of water quality that reflect the direct anthropogenic burden of organic and inorganic substances will be practically independent of watercourse typology.

To verify these hypotheses, methods of descriptive and multivariate statistical analysis were used to assess the variability of the selected water quality indicators in individual typological categories and for the study of the relationships between long-term values of indicators of quality and categorized typological categories.

The basic characteristic variability of selected surface water quality indicators was for individual typological categories expressed through a box plot, which shows the mean, median, and variability values. Links between the values of water quality indicators and watercourse typologies were verified by canonical correspondence analysis (CCA). This

method is a tool to identify the relationship between two matrices, describing the same object (Ter Braak 1986). CCA is frequently used especially in ecology, where one matrix is a description of the nonliving environment at a particular location, while the second represents the species composition of the populations (Palmer 1993; McCune 1997). When applied to a selected data file, the typological parameters are used as explanations of changes in variables of long-term average values of surface water quality in individual profiles. The functional and spatial relationships of various indicators of water quality and typological parameters were then tested using cluster analysis. The assessment method used was that of agglomerative hierarchical clustering with single linkage as the aggregation method, while the Pearson correlation coefficient was used as a measure of similarity (Addinsoft 2010; Everitt et al. 2001).

Input data for statistical evaluation were generated using GIS analysis, where typological characteristics have been calculated from individual data layers for the quality measurement profiles (Fig. 2). The processing of input data, analysis, testing, classification, typology, and verification of results were

performed using the GIS software ArcGIS and MapInfo Professional. XLStat 2010 software was used for statistical analysis.

Results

Variability of water quality indicators with regard to typological parameters

Drainage basins

The parameter of drainage basin has only minimal potential for directly influencing the physiochemical indicators of surface water quality. The observed differences in mean values and variability of water quality indicators in relation to the regional breakdown of the drainage basins are mainly caused by the different characters of each individual region. The Elbe, Morava, and Oder River basins, which represent each major drainage basin, show significant differences in physical-geographical factors and also socioeconomic characteristics of land use. In turn, this affects the water quality (Fig. 3; Table 2).

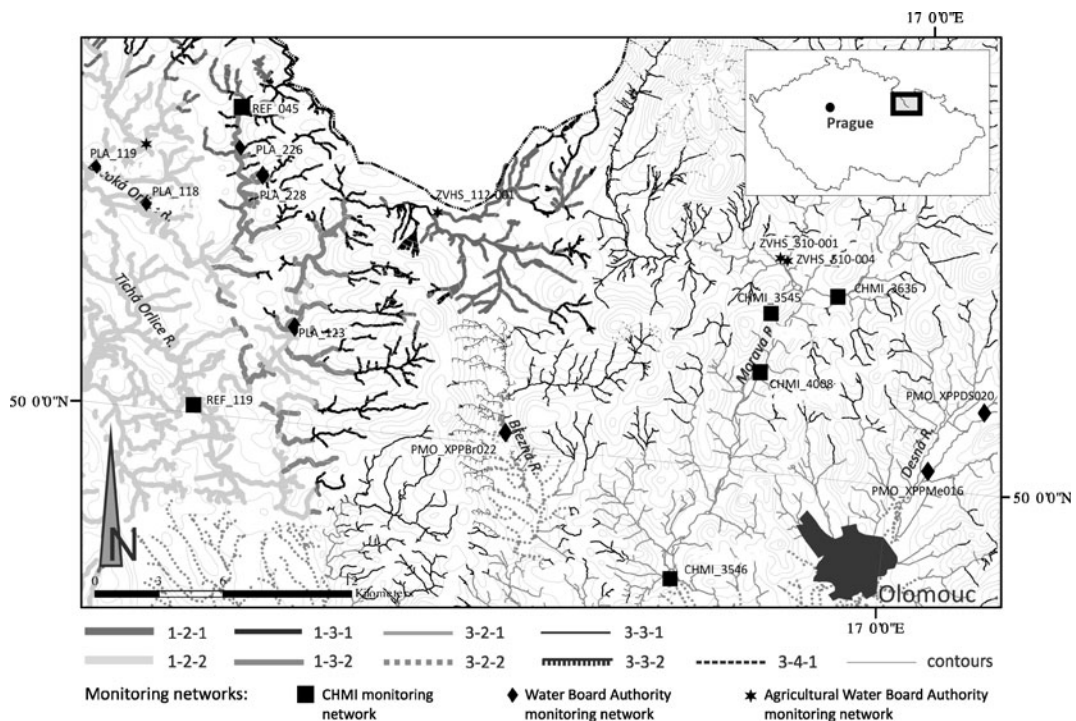


Fig. 2 Spatial link of information used for the analysis. The river network is classified according the typological parameters, the monitoring profiles contain information on long-term changes of surface water quality in monitoring networks

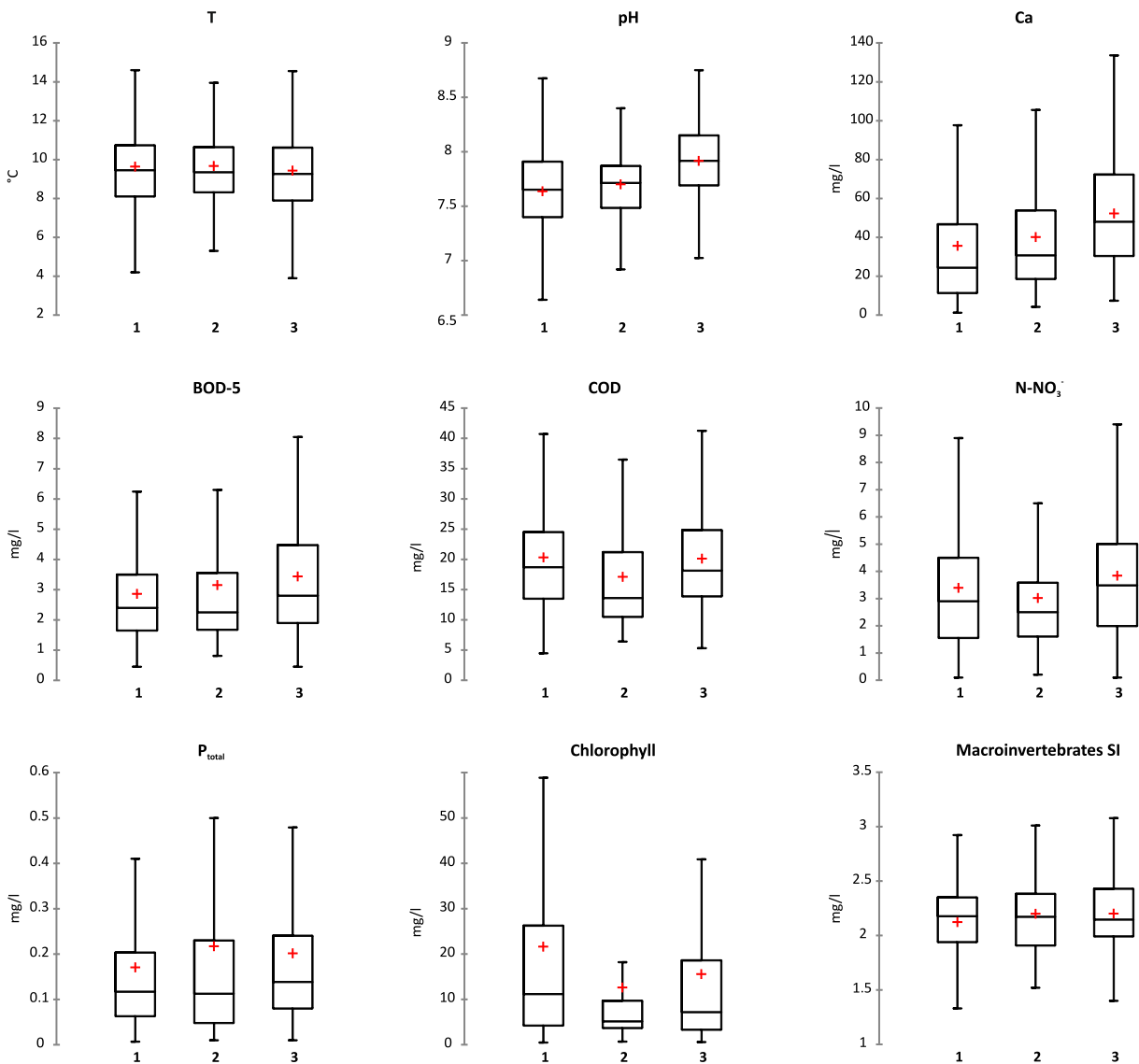


Fig. 3 Variability of selected water quality indicators in the category drainage basin (1- the North Sea, 2- Baltic Sea, 3- Black Sea). *T* water temperature, *pH* pH, *Ca* conductivity, *BOD5* biological oxygen demand, *COD* chemical oxygen demand, *N-NO₃⁻* nitrogen-nitrate, *P_{total}* total phosphorus, *chlorophyll* chlorophyll, *macroinvertebrates SI* saprobity index of macroinvertebrates

Among the most important differences in the physical-geographical factors is that of the underlying geology. This is reflected in pH values and calcium concentrations.

The Elbe River basin, which drains to the North Sea, exhibits higher acidity due to it being associated with the greatest concentrations of Paleozoic or igneous rocks. By

Table 2 The percentage of watercourse length within the geology categories defined according to the main drainage basins

Drainage basin	Crystalline and igneous rock (%)	Sedimentary and Quaternary rock (%)
North Sea (Elbe)	62.5	37.5
Baltic Sea (Oder)	44.8	55.2
Black Sea (Danube)	48.6	51.4
Total	57.0	43.0

Data from Langhammer et al. (2009)

contrast, the Morava River basin, which drains to the Black Sea, exhibits higher alkalinity due to the flysch range of the Outer West Carpathians having a significant proportion of sedimentary and Quaternary rocks.

Altitude

The effect of altitude on all the values and variability of surface water quality indicators is very pronounced for all the evaluated indicators (Fig. 4). Altitude directly affects climate conditions and the natural processes in water-courses which, in turn, influences water quality indica-

tors (water temperature, dissolved oxygen). In the higher altitude category, there is a lower natural average water temperature which has a positive effect on the oxygen balance and self-purification mechanisms within the watercourse. The relationship between altitude and the average long-term value indicators is therefore evident in those indicators that reflect the basic physical parameters and characteristics of the environment, e.g., temperature, conductivity, pH, calcium concentration, and biological indicators.

At the same time, however, the informative value of these relationships is rather obscured by the fact that

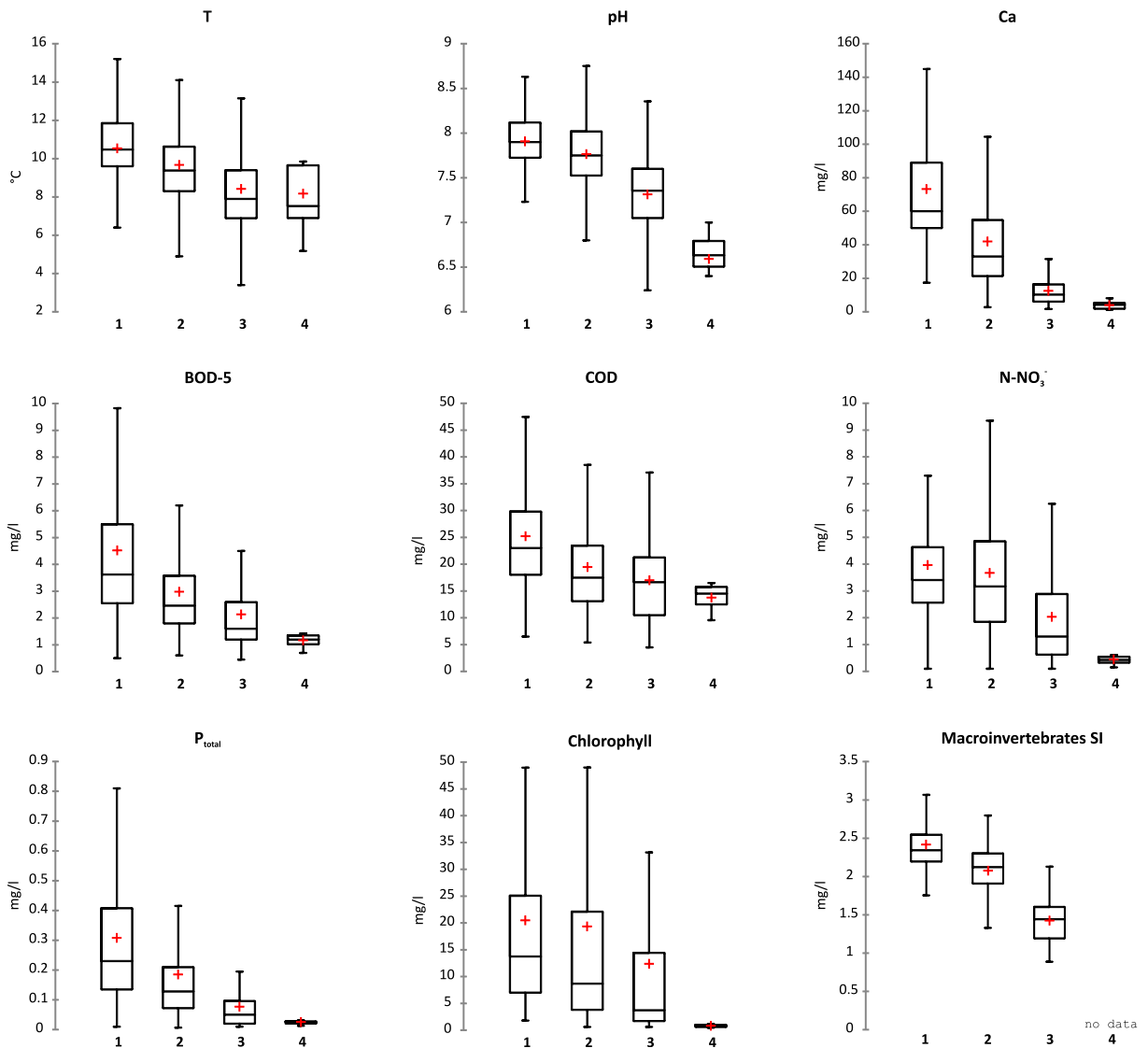


Fig. 4 Variability of selected water quality indicators in the category Altitude (1- 0–200 m a.s.l., 2- 200–500 m a.s.l., 3- 500–800 m a.s.l., 4- over 800 m a.s.l.)

altitude predisposes the character of land use in an area, and so it may be seen as indirect evidence for the intensity of anthropogenic activity (Bičík et al. 2001) with which the production of pollutants is tied. Vertical segmentation is evident in the variability of water quality indicator values, reflecting pollutants from anthropogenic sources. There is significantly less intense land use at higher altitudes in terms of population, industry, and agriculture. In addition, notable sources of direct contamination are generally not found at higher altitudes. This is expressed in a decrease in indicator values that reflect both direct and diffuse sources of surface contamination (BOD_5 , COD , $N-NO_3^-$, P_{total}).

Geology

The strength of the relationship between the substrate and the chemical condition of surface water is generally limited in densely inhabited areas. With regard to the types of geology, it is possible to expect causality only in those indicators that do not reflect anthropogenically derived pollutants. Of the evaluated indicators, it is primarily water pH and the total concentration of calcium that reflect either the acidity or alkalinity of the substrate.

Indicators that reflect the load of anthropogenic organic compounds (BOD_5 , COD) or nutrients ($N-NO_3^-$, P_{total}) from point and diffuse emission sources have, in contrast, minimal variability of values for loads in both categories of geological bedrock.

The significant influence of geology is also evident in the saprobity index of macroinvertebrates, both in terms of their obtained values and variability. The latter indicates the sensitivity of the communities to the different chemistry in the substrates. In the case of chlorophyll, the influence of the substrate is manifested by different variability, while mean values remain comparable for both kinds of substrate (Fig. 5).

Stream order

The influence of stream order is apparent primarily in a reduction in the variability of indicator values as a function of the increased stream order of the watercourse (Fig. 6). For most indicators, we observe the highest variability in the lowest stream order category, i.e., at springs and headwater streams. This corresponds to the high sensitivity of small watercourses to

changes in pollution load and the great variability in the environment of small streams, partly due to their large number compared to watercourses of higher stream order. Conversely, larger watercourses with higher values of relative stream order and stable anthropogenic pollution load show a lower level of variation.

Changes in load values in relation to stream order are most evident in the pollutant nitrogen-nitrate ($N-NO_3^-$), where a significant decrease in the average value and total variability with increasing categories of stream order is observed. This corresponds with the general nature of this pollutant, which is the dominant one for this indicator. Changes in the value of other load indicators in relation to stream order are limited.

Linkages between water quality indicators and typological parameters

The linkages among the values and variability of water quality indicators and the typological parameters reflect different functional relationships. The nature of these relationships is important in enabling verification of the homogeneity of the typology and particularly in designating a system of accurate reference conditions and in the interpretation of monitoring results.

The association between the indicators of water quality and individual typological parameters were evaluated using cluster analysis (CA). An overall assessment of the relationships between indicators of surface water quality and monitoring profiles was carried out using canonical correspondence analysis (CCA).

CCA was performed to indicate the potential links of selected water quality indicators with the typological parameters. The typological parameters were used as explanation for variables, represented by data on water quality indicators from individual monitoring profiles. In addition to CCA, a permutation test was performed which confirmed the existence of a linear relationship between the categories and the observed values for the measured profiles (Table 3).

The results demonstrate that only some of the typological parameters have a functional relationship with water quality indicators (Fig. 7). The relationship is apparent especially for geology and altitude, as for example with the concentration of calcium in the category geological bedrock or the

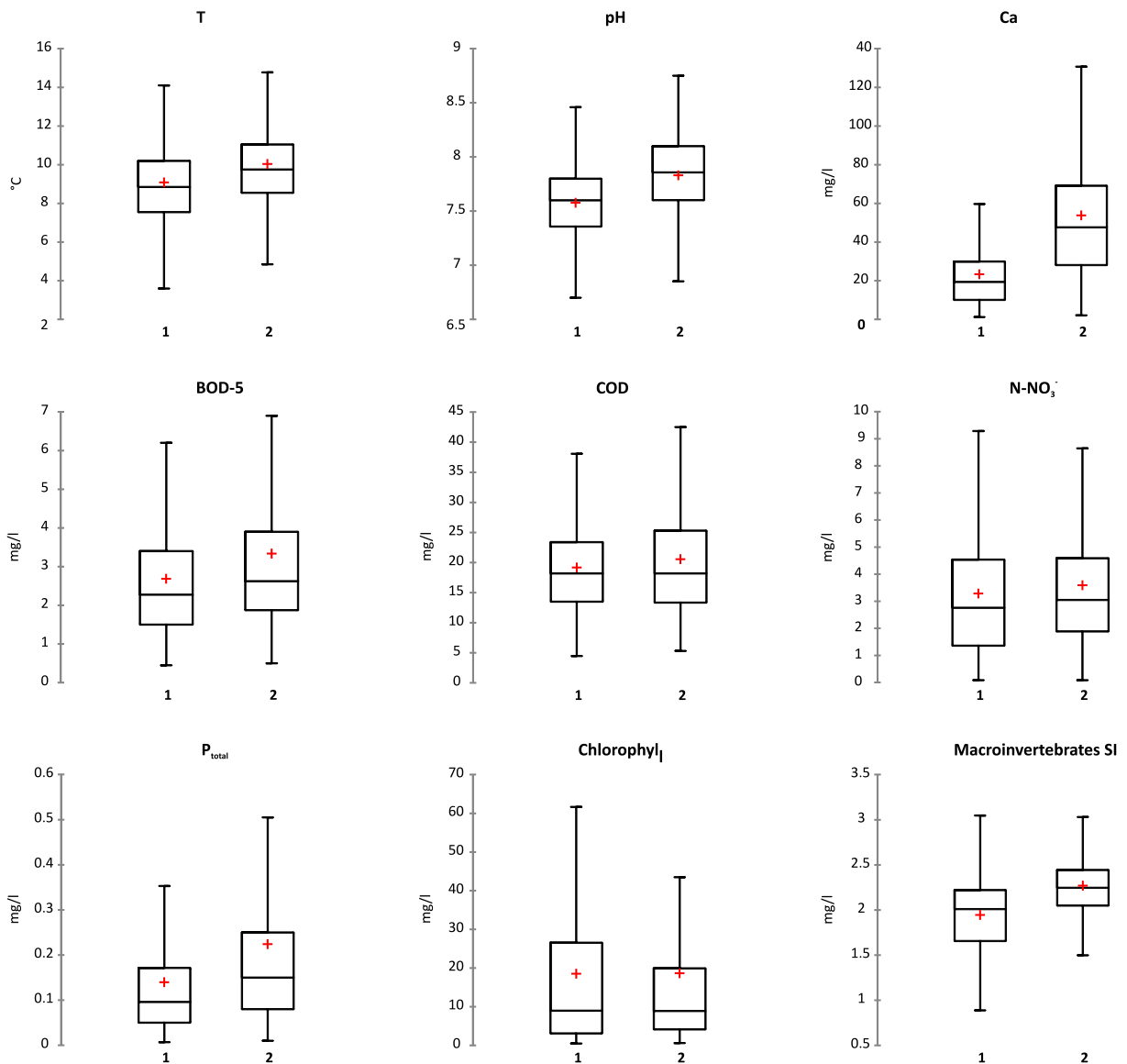


Fig. 5 Variability of selected water quality indicators in the category Geology (1- crystalline, 2- sedimentary)

saprobity index of macroinvertebrates with altitude. Conversely, the association between indicators of water quality and stream order parameters is negligible. Clearly, the relationships of some parameters reflect anthropogenic loads. For example, BOD₅ and total suspended particles in the parameter drainage basin reflect regional differences in watercourse load rather than a connection to natural factors.

The potential links between typological parameters and surface water quality indicators were

further tested by cluster analysis (Fig. 8). The association between pH and typological parameters is strong with regard to geology. It is also notable with regard to drainage basin, which demonstrates the influence of differences between the various geological bedrock within the individual basins. In contrast, there are no associations between pH and either altitude or stream order.

The distribution of mean values and spatial variability in concentrations of calcium is consistent with the distribution of pH values. The

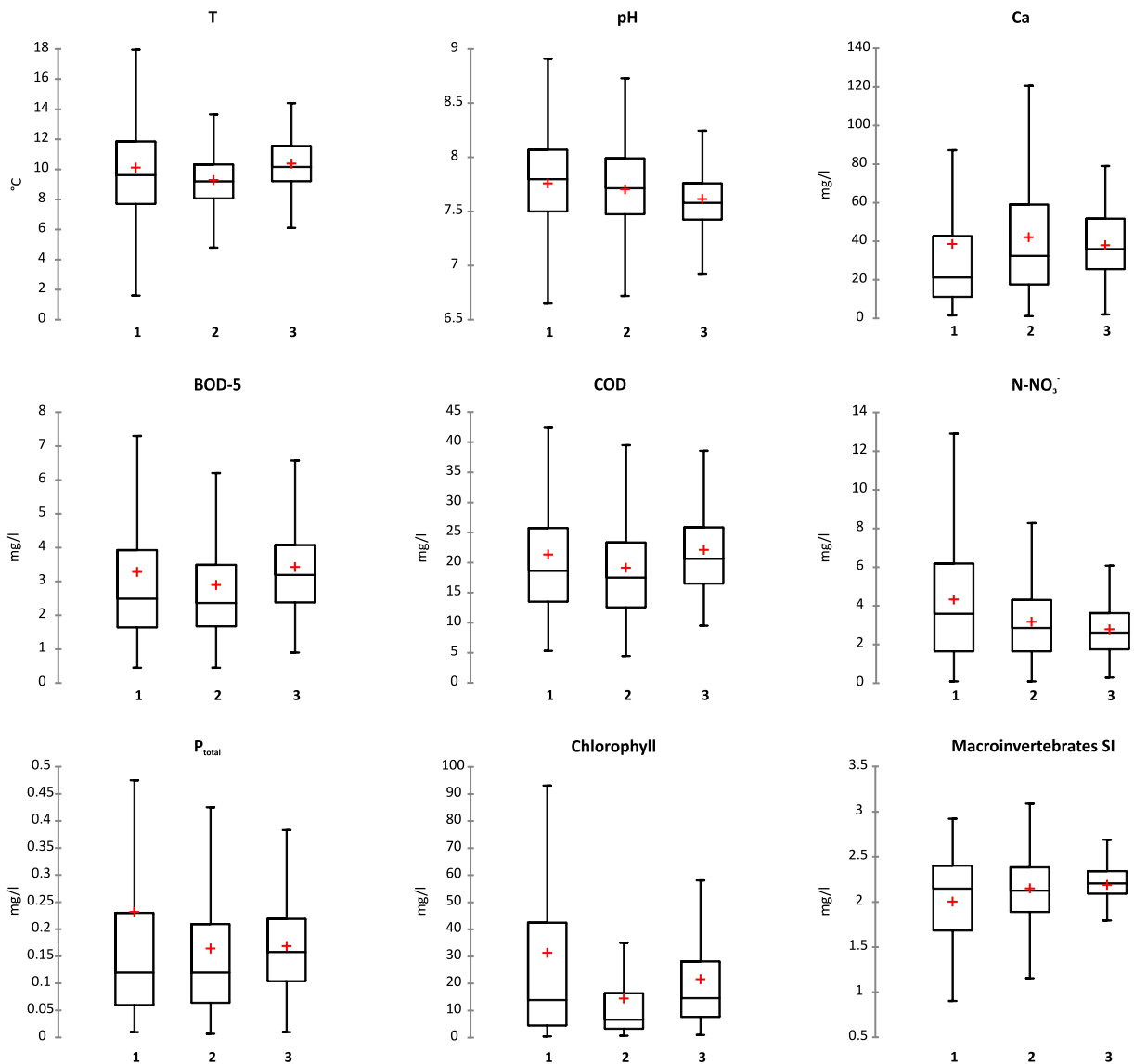


Fig. 6 Variability of selected water quality indicators in the category Stream order (1- Stream order 1–3, 2- Stream order 4–6, 3- Stream order 7–9)

strongest relationship of Ca concentration is again with geology. Average long-term concentrations of calcium are much higher for Quaternary and sedimentary rocks than for crystalline rocks. The notable relationship with drainage basin reflects the different geological structures within the main basins.

In the case of water quality indicators, which reflect anthropogenic load, relationships with typological parameters are negligible. The distribution of values for the concentration of water quality indicators and functional relationships are driven by the

distribution of anthropogenic sources of pollution, which here have stronger effect than natural environmental properties. For example, the results of cluster analysis indicate a very weak association between BOD₅ concentrations and typological parameters.

The absence of functional linkages with typological parameters is also typical for other parameters where the pollution level is driven by anthropogenic sources, be that industrial, municipal, or agricultural. This applies, for example, to the indicators of major nutrients that are expressed here in the parameters of total phosphorus and nitrate nitrogen. Although the

Table 3 Canonical correspondence analysis—value table and permutation test

	F1	F2	F3	F4
Regression coefficients:				
Basin	-0.384	-0.409	0.788	-0.357
Altitude	0.369	0.774	0.630	-0.201
Geology	-0.547	0.836	-0.203	-0.366
Stream order	0.447	-0.202	-0.089	-0.891
Contributions (objects):				
PH	0.087	0.150	0.187	0.003
CA	0.336	0.060	0.163	0.008
NL105	0.059	0.488	0.209	0.098
BSK5	0.001	0.020	0.020	0.148
CHSKCR	0.075	0.091	0.033	0.067
NNO3	0.016	0.001	0.079	0.458
PCELK	0.000	0.002	0.011	0.171
Chlorophyll	0.412	0.149	0.288	0.001
IS_BENTOS	0.013	0.038	0.011	0.045
Inertia:				
	Value	%		
Total	0.173	100.000		
Constrained	0.028	16.032		
Unconstrained	0.145	83.968		
Results of the permutation test:				
Permutations	500			
Pseudo F	0.382			
<i>p</i> value	<0.0001			
Alpha	0.050			

Test interpretation: Null hypothesis (*H0*) - the sites/objects data are not linearly related to the sites/variables data; Alternative hypothesis (*Ha*) - the sites/objects data are linearly related to the sites/variables data. As the computed *p* value is lower than the significance level alpha=0.05, one should reject the null hypothesis *H0*, and accept the alternative hypothesis *Ha*. The risk to reject the null hypothesis *H0* while it is true is lower than 0.01%

pollution in these indicators has different origin and spatial distribution, the resulting links to the physical-geographical features expressed in the parameters of typology are negligible.

The spatial variability of chlorophyll is significantly affected by the presence of nutrients, i.e., it largely corresponds to the distribution of nutrient sources, in particular nitrogen and phosphorus. Connections to parameters that reflect the variability of natural conditions, as shown in the results of the cluster analysis, are therefore not evident as in cases of the previously mentioned nutrients.

Spatial variability of values for the saprobity index of macroinvertebrates shows a rather significant relationship with geology. This reflects spatial variations in acidity, expressed as pH values. At the lower level of aggregation, there is evident but weak relation to the stream order.

Discussion

An evaluation of relationships between water quality indicators and typological parameters, using surface water quality data files from the long-term monitoring network in the Czech Republic, confirmed the hypothesis that only some of the indicators of water quality show a relationship with natural characteristics. The expression of typological parameters and some of the indicators of water quality, reflecting direct anthropogenic loads of organic and inorganic substances on the character of the natural conditions, expressed as typology, is practically independent. Complex parameters, expressing natural conditions such as altitude, stream order, or geology, are likely to have cross-effects on runoff and contamination transport processes.

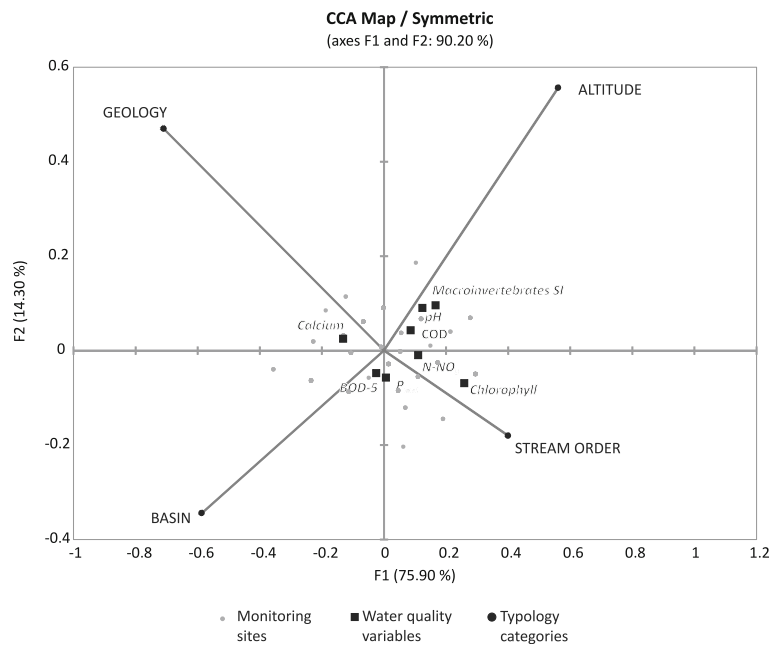
For correct interpretation of the ties between individual parameters of typology and indicators of water quality, it is important to ensure that the typology parameters are independent and have no significant cross-correlations. Typology parameters were therefore tested using the correlation analysis and principal component analysis to identify potential mutual relations.

The analysis results (Table 4, Fig. 9) show that the mutual links between the parameters of the typology are not significant. The two main components that explain 65% of the total variability of the dataset have the strongest link to the parameters of altitude (F1, Table 4) and stream order (F2, Table 4). This confirms the evenness of the distribution of variation among typology parameters and the heterogeneity of natural conditions. The independence of key typology parameters expressing physiography—altitude, geology, and stream order—implies that the potential cross-effects of selected parameters are marginal and thus ensures credibility of further testing of linkages between typology and water quality parameters.

Variability of water quality indicators

Among the *physiochemical parameters*, there are obvious differences with regard to the extent to which

Fig. 7 Canonical correspondence analysis displaying links between indicators of water quality typological parameters at monitoring stations of water quality monitoring networks. Typological parameters are used as an explanation of the variables, represented by data from water quality monitoring



the value of the given indicator is directly influenced by anthropogenic processes. Water pH, calcium, and acid-neutralizing capacity indicators, where a significant influence of natural factors can be assumed, confirmed significant spatial zoning. The values of these indicators are quite strongly associated with the spatial distribution of the geological bedrock.

In contrast, parameters reflecting *anthropogenic organic load* (BOD_5) and inorganic compounds ($N-NO_3^-$, total phosphorus) show that their spatial variability is mainly determined by the amount of anthropogenic pollution sources. This situation is similar for all indicators that show different mechanisms of pollution distribution, e.g., from point sources (BOD_5) and nonpoint sources ($N-NO_3^-$) and a combination of the two groups of emission sources (total phosphorus). Indicators reflecting primarily anthropogenic load are therefore not considered suitable as reference parameters for the verification of typological homogeneity.

Biological indicators very closely reflect the anthropogenic organic load within the watercourses. The results confirm the generally applicable connections between biological parameters of water quality and pollutants in the watercourse. This applies to both saprobic systems with links to the oxygen regime and organic pollution, as well as to the trophic system, tied to the presence of nutrients in the watercourse.

The saprobity index of macroinvertebrates is the only indicator in which there are clear, significant, spatial, and functional links to the category of geology, which indirectly reflects the level of acidity within the aquatic environment.

Relationships between typological parameters and indicators of water quality

The undertaken analysis has confirmed that individual typological parameters reflect the quality of surface waters differently. The parameters with the strongest links to water quality are altitude and geology. The direct influence of stream order can be observed with some of the indicators, while drainage basin is without significant impact. There is a very sensitive relationship between physiographic characteristics of the environment, physiochemical parameters, and the biological condition of the watercourse. A number of authors (e.g., Giller and Malmqvist 2004) note that a key influence on life in aquatic environments is the hydro-chemical characteristics of the water. These are strongly influenced by human activities. In cultural landscape, the direct impact of the physical-geographical characteristics of the environment particularly the geology and composition of the watercourse bottom on the chemistry of water is very limited (Hornung et al. 1990). The indirect influence

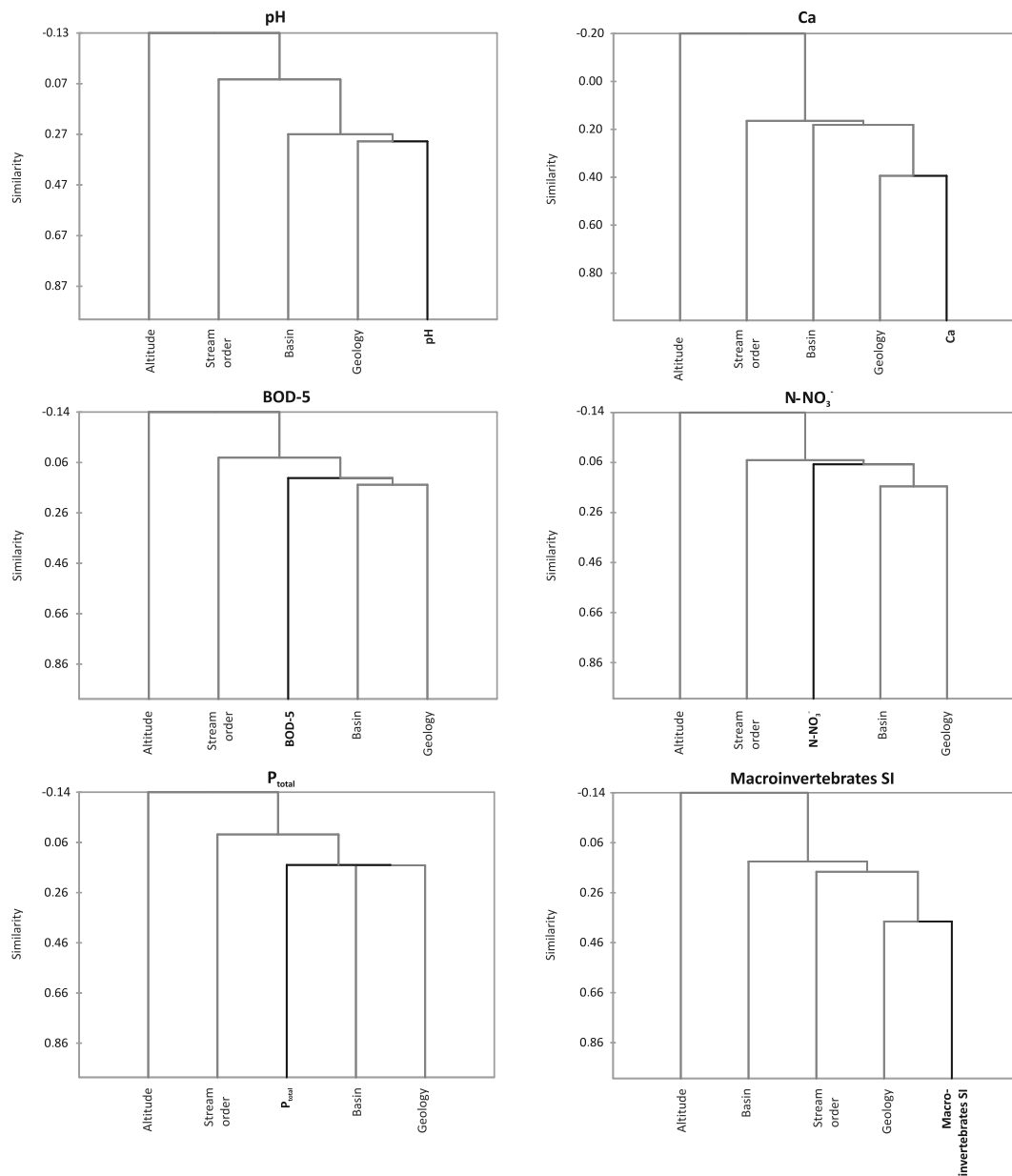


Fig. 8 Cluster analysis of the linkages between selected indicators of water quality and parameters of typology at monitoring stations

of individual parameters in the environment which determine conditions for individual processes in the watercourses however remains significant.

Altitude

Altitude is the parameter with the strongest association with water quality indicators (Fig. 3). This is due to the complex nature of this indicator, which expresses both vertical zoning (and thus many

climatic parameters) and other physical characteristics of the channels (such as stream velocity, grain size of sediments, etc.). The significant effect of altitude on water quality is based primarily on its influence on the oxygen regime and through the self-purification processes inherent in water temperature as the results of analyses confirm the generally valid assumption that higher concentrations of dissolved oxygen and a greater intensity of self-purification processes are found at higher altitudes (Camargo and Garcia De

Table 4 Correlation analysis and principal component analysis of typology parameters

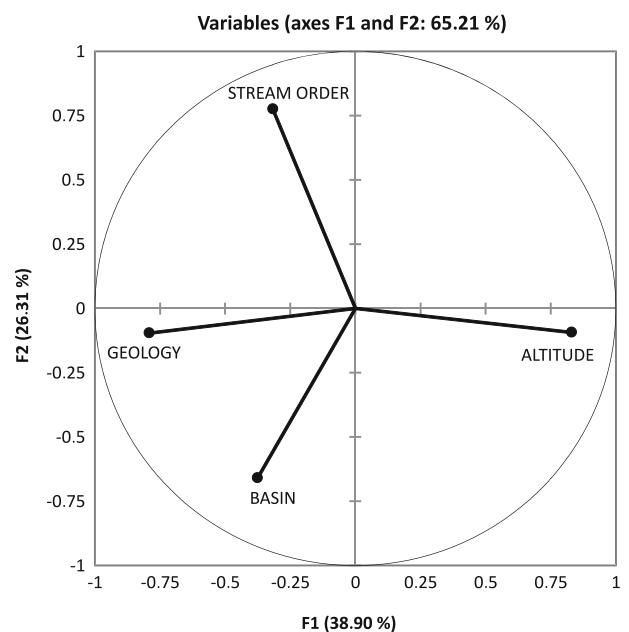
Correlation matrix (Pearson (<i>r</i>)):				
Variables	Basin	Altitude	Geology	Stream order
Basin	1	-0.139	0.136	-0.044
Altitude	-0.139	1	-0.447	-0.180
Geology	0.136	-0.447	1	0.055
Stream order	-0.044	-0.180	0.055	1
Factor loadings:				
	F1	F2	F3	F4
Basin	-0.375	-0.658	0.652	0.032
Altitude	0.831	-0.093	0.145	0.529
Geology	-0.790	-0.096	-0.367	0.481
Stream order	-0.316	0.775	0.526	0.150

Jalon 1995). Allan and Castillo (2007) considered temperature to be one of the three main factors affecting biological community in flowing water, along with velocity and substrate. Temperature affects the biological indicators of photosynthesis and microbial activity and the metabolism of higher organisms, and it is therefore valid that warmer ecosystems found at lower elevation levels show increased productivity. The influence of climatic conditions, within the framework of typology, is considered to be one of the two most important factors when comparing regional similarities and differences (Giller and Malmqvist 2004). A number of studies also demonstrate an overall decline in species with increasing

altitude (Giller and Malmqvist 2004; Ward 1986). In addition, altitude also indirectly determines the nature and intensity of land use and is thus related to the production of pollutants. This factor may explain the strong differentiation in mean values of water quality indicators for individual elevation zones which can be observed from indicators reflecting the load of anthropogenic sources of pollution.

Geology

Geological bedrock and resulting riverbed substrate primarily influence the degree of environmental acidity and alkalinity. In particular, in lightly polluted

Fig. 9 Principal component analysis of typology parameters

watercourses, it is a significant factor in determining the nature of the habitat of the watercourse. As a rule, most waters can be divided into two groups: the silicate type with a small amount of Ca^{2+} and Mg^{2+} and the carbonate type with large numbers of these ions (Cushing et al. 2006). This division corresponds roughly to the newly adapted typological system of watercourses in the Czech Republic (Langhammer et al. 2009). This system distinguishes two types of substrate, one comprising crystalline and igneous rocks and the other comprising sedimentary and Quaternary rocks. The results of our analysis confirm a significant difference in the degree of acidity and alkalinity in these categories of geological bedrock. Watercourses flowing through areas with igneous rock generally have little dissolved salts and higher acidity, while watercourses in areas with sedimentary rock have relatively abundant dissolved salts and are usually either neutral or alkaline. Slightly calcareous substrates (e.g., marls, Mesozoic clay) and highly calcareous substrate (limestone, chalk, dolomitic limestone, heavily fossilized sediments or their metamorphic equivalents) have a strong neutralizing capacity, high conductivity, and manifest more alkalinity (Hornung et al. 1990). In aquatic ecosystems, low calcium levels can cause osmotic problems and affect the shell or cuticular secretions in vertebrates (especially larger ones). Thus, snails (Gastropods) prefer streams with a high calcium content (Smith 2001; Cushing et al. 2006).

Drainage basins

Drainage basin, which in Czech typology has replaced eco-region, is an indicator which manifests an impact on basic regionalization parameters. The influence of the drainage basin on the physiochemical and biological characteristics of water quality is varied. Macro-regional factors, as a rule, are very significant for biological indicators. In fish populations, for example, the influence of factors acting on the regional scale increases the effect of factors acting on the local scale (Tonn et al. 1990). A key role is therefore played by the presence of natural geographic barriers such as drainage divides. In the Czech Republic, the influence of drainage basin is apparent in dissimilarities in the composition of fish stock in the Danube River basin. This area is considered to have been one of the principal refuges of fish fauna in

Europe during the Pleistocene glaciations, and is consequently more species-rich than other basins (Tonn et al. 1990; Banareescu 1989; Wootton 1998). With respect to the specific geography of the Czech Republic, drainage basin fundamentally influences the distribution of invertebrate populations (Zahrádková et al. 2005). The results of biological parameter analyses, e.g., chlorophyll and the saprobity index of macroinvertebrates, show more significant differences than is observed with the physiochemical indicators.

Partial differences in the variability and mean values of physiochemical indicators of water quality in individual drainage basins are, in contrast, a consequence of the influence of indirect factors. The characteristics of acidity and alkalinity (pH, Ca) are mainly influenced by the presence of different rock types within the various drainage basins, in particular, the dominance of crystalline rocks in those catchments draining the North Sea and the dominance of sedimentary and Quaternary rocks those catchments draining to the Black Sea. In the case of anthropogenic load indicators (BOD_5 , N-NO_3^- , P_{total}), where the concentrations are determined by the distribution of pollution emission sources, the impact of the drainage basin on water quality is negligible.

Stream order

The effect of stream order on the distribution of water quality values and their variability is quite evident. Although relative stream order is generally accepted as a useful parameter for organizing information on biota and general changes in the longitudinal stream profile within individual basins, some authors highlight the need for caution when making comparisons between regions (Giller and Malmqvist 2004). The greatest abundance of species is usually found in the watercourses with an intermediate stream order (Rice et al. 2001) because the environments associated with low and high stream orders are less variable. For lowland watercourses with a high stream order, anthropogenic modifications to the river play a significant role. Watercourses with a lower stream order often have an inherently lower number of species due to the nature of the environment. The results of the analysis of long-term monitoring in the Czech Republic primarily demonstrate differences in the variability of values of selected indicators of water quality. In the case of the saprobity index of macro-

invertebrates, there is a slight increase in the index value with increasing stream order, but more notable is a significant decrease in the variability of values in watercourses with high stream orders.

Values of physiochemical parameters in relation to stream order correspond to the predominance of pollution for a given indicator. In the case of nitrate, the highest mean values as well as highest variability are observed in the small streams. This reflects the fact that minor river basins in the Czech Republic are the most exposed to load from general sources of pollution (Langhammer 2010). The increase in the levels of organic pollution (BOD₅) and total phosphorus is observed in watercourses with high stream orders and relates to the greater concentration of large settlements and industrial sources in lowland areas.

Conclusions

In this paper, associations between typological parameters and long-term surface water quality have been assessed. The values of surface water quality were derived from monitoring data recorded between 1970 and 2008. These values were linked to the typological parameters through the application of a GIS. The aim of these analyses was to assess the relationships between typological parameters and indicators of surface water quality. Indicators of surface water quality were considered with regard to both their long-term average values and their variability. Assessment was made on the basis of a box plot and the statistical tools of cluster analysis and canonical correspondence analysis.

The results of these analyses demonstrate that only some of the typological parameters show a direct relationship with long-term surface water quality. Altitude and geology manifest a direct influence on the long-term surface water quality, whereas drainage basin and stream order only show an indirect influence.

Most of the indicators of water quality analyzed here have a strong correlation to the vertical zonality. These results clearly indicate the complex nature of this typological parameter and its both direct and indirect effects on water quality. Altitude is among the typological parameters where a significant relationship is observed between indicators of water quality, reflecting physical parameters and the basic nature of the environment.

Only some indicators of surface water quality show relationships to the given typological parameters. In particular, the basic physiochemical indicators and biological indicators are directly influenced by the character of the natural environment. For those indicators that reflect burden from anthropogenic pollution sources, the link is unclear or unimportant.

Of the indicators of surface water quality where there is a clear association with typological parameters, pH and calcium concentrations are the most important. These indicators reflect the nature of the geology. The nature of the substrate strongly influences the saprobity index of macroinvertebrates. This index is, in turn, linked to the typological parameter of altitude. Of the indicators of surface water quality where there is not a clear association with typological parameters, BOD₅, P_{total}, and N-NO₃⁻ reflect anthropogenic pollution from point and diffuse sources rather than natural environmental characteristics.

These results show a high degree of functional and spatial agreement between typological parameters and the values of a given indicator of surface water quality, if anthropogenic influences are minimal. In contrast, these results show no spatial agreement between typological parameters and the values of a given indicator of surface water quality where the influences of anthropogenic pollution are significant as this dominates natural environmental characteristics. These findings are important for the accurate interpretation of results relating to the assessment of ecological status and for establishing accurate reference conditions.

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