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# Spatiotemporal dynamics of spring and stream water chemistry in a high-mountain area

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*Spatiotemporal dynamics of spring and stream water chemistry in unique high-mountain area was evaluated by the self-organizing map technique.*

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ABSTRACT

The present study deals with the application of the self-organizing map (SOM) technique in the exploration of spatiotemporal dynamics of spring and stream water samples collected in the Chochołowski Stream Basin located in the Tatra Mountains (Poland). The SOM-based classification helped to uncover relationships between physical and chemical parameters of water samples and factors determining the quality of water in the studied high-mountain area. In the upper part of the Chochołowski Stream Basin, located on the top of the crystalline core of the Tatras, concentrations of the majority of ionic substances were the lowest due to limited leaching. Significantly higher concentration of ionic substances was detected in spring and stream samples draining sedimentary rocks. The influence of karst-type springs on the quality of stream water was also demonstrated.


## 1. Introduction

Waters draining high mountain basins can serve as models of natural basin functioning. The chemical composition of water in high mountain springs and streams and changes therein are determined primarily by natural factors such as tectonics, geologic structure, land cover, and land use (Allan and Flecker, 1993). The monitoring of chemical, physical, and biological properties of water resources plays an important role in understanding biogeochemical cycles. This matter is of great importance, especially in the case of water bodies (springs, streams, lakes) located in mountain ecosystems, as they provide considerable amounts of surface water of high purity. Until now, there have been only a few studies specified addressing water bodies in the Tatra Mountain ecosystem. Advanced water research in the Tatra Mountains usually dealt differences in water chemistry in springs, surface waters, and lakes. In the 1950s, one study was carried out on about 800 spring, surface, and lake water samples (Oleksynowa and Komornicki, 1960; Oleksynowa, 1970). A hydrochemical map was then produced and published in the Tatra National Park Atlas (scale: 1:50,000) (Trafas, 1985). Kopáček et al. (2004) correlated chemical and biochemical characteristics of alpine soils in the Tatra Mountains with lake water quality. Stuchlík et al. (2006) explored the chemical composition of Tatra Mountain lakes based on their response to acidification, while Křeček et al. (2006) analyzed hydrological processes in small catchments. However, none of these studies dealt with a complex analysis of the quality of water via the use of chemometric expertise. The quality of water depends on many factors and this is why a number of researchers have attempted to study it in various ecosystems using principal component analysis (Stanimirova et al., 2007), linear discriminant analysis (Astel et al., 2009), and classification tools (Astel et al., 2006). Although self-organizing maps (SOMs) are well known in environmetric studies (Tsakovski et al., 2009; Skwarzec et al., 2009; Simeonov et al., 2007) and have already been used for surface water quality analyses (Astel et al., 2007; Boszke and Astel, 2009), it is surprising that the technique has not been applied in the interpretation of spatiotemporal dynamics data for spring and stream water chemistry in a high-mountain area. Self-organizing maps of Kohonen, being resistant to departures from the rules concerning data distributions as well as to gaps in a data set, deliver extraordinary visualization ability coupled with classification tools (Astel et al., 2007; Zhang et al., 2008). Therefore, the purpose of the

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research was to explore natural spatiotemporal dynamics of spring and stream water chemical composition in the high mountain drainage basin of Chochołowski Stream. Additional aim was to characterize the usefulness of the SOM technique in the exploration and interpretation of hydrochemical data.

## 2. Materials and methods

### 2.1. Sampling site

The Tatras are the highest range in the Carpathian mountain belt and are located along the national border between Poland and Slovakia. The highest peak in the Carpathians, Mount Gerlach (2655 m a.s.l.), is located on the Slovak side. In Poland, the highest peak in the Tatras is Mount Rysy (2499 m a.s.l.). The drainage basin of Chochołowski Stream is located in the Western Tatras and receives water from the largest valley on the Polish side of the Tatra Mountains. The basin is also part of Tatrzański National Park (TNP), a biosphere reserve and a "Nature 2000" area. The Chochołowski Stream Basin has an area of 35 $km^2$ and is 11.1 km long. The mean rate of discharge in Chochołowski Stream is 1.27 $m^3 s^{-1}$ and specific discharge between 1983 and 1987 has been 36.4 $dm^3 s^{-1} km^{-2}$ (Krzemień, 1991). Fig. 1 shows the location of the Chochołowski Stream Basin.

The basin features a number of climate and vegetation zones. The mean annual air temperature ranges from 6 °C at lower elevations to nearly 4 °C at the highest elevations. At the higher elevations eight times more dynamic increase of an average annual temperature is observed. The calculated increase of average annual temperature at Kasprowy Wierch (1991 m a.s.l.) in the period between 1976 and 2000 is equal to 0.33 °C per 25 years while in Zakopane (857 m a.s.l) 0.04 °C per 25 years (Trepińska, 2004). In Hala Gąsienicowa the total annual precipitation in the period between 1927 and 2002 ranged from minimum 1.038 mm (1946) to 2.626 mm (2001), with an average value 1.689 mm and coefficient of variation equal to 17% (Niedźwiedź, 2003).

In the Western Matra Mts. (47% of the entire surface of the Tatra Mts.) a high percentage of grass-covered areas (44.1%) is to be noted, as well as lower than in the entire Tatras amount of rocky terrains (11.9%) (Guzik and Skawiński, 2009). The woodland vegetation zone begins at an elevation of 650 m a.s.l. and includes three kinds of forest. Lower forest extends between 650 and 1.250 m a.s.l., upper forest ranges from 1.250 to 1.550 m a.s.l. and dwarf mountain pine zone covers an area between 1.550 and 1.850 m a.s.l. (Guzik and Skawiński, 2009). The lower woodland belt consists of beech forest and in same ranges by beech-fir, fir – spruce or mainly artificial spruce stands. Beech stands (*Dentario glandulosae-Fagetum* – *Fagetum Carpaticum*) dominate across the earthen base course, abundant with calcium carbonate and a thin belt of spruce stands exists on poor moraines. Spruce forest stands (*Polysticho-Piceetum* and *Plagiothecio–Piceetum)* exist on limestone and granite rocks covering the upper woodland belt. Dwarf mountain pine covers nearly 37% of the area. The alpine (1.800–2.300 m a.s.l.) and subnival (2.300–2.499 m a.s.l.) belts occupy the highest elevations in the Tatra National Park (Guzik and Skawiński, 2009; Grodzińska et al., 2002).

The Chochołowski Stream Basin is very complex in terms of geology and tectonics. The southern part of the basin, a part of the main Tatra crystalline core, is formed of granitoid formations, gneiss, alaskite, mylonite, and crystalline shale. The basin consists of the High-Tatra zone and the sub-Tatra zone north of the crystalline core. The two zones are composed of sedimentary rocks – primarily limestone, dolomite, shale, marl with cherts, and sandstone (Bac-Moszaszwili et al., 1979; Krajewski, 2003). The waters of the Chochołowski Stream Basin and its component basins drain different types of rocks. Fig. 2 shows the geology of the Chochołowski Stream Basin, while Tables 1 and 2 show morphometric features of the sub-basins and percentages of various bedrock types in the Chochołowski Stream Basin, respectively.

The complex geologic and tectonic structure of the basin results in variability in water chemistry.

### 2.2. Spring and stream samples

The research was performed in the Chochołowski Stream Basin in the Western Tatra Mountains. A total of 31 unique sub-basins were identified along with 12 sampling sites found with increasing basin area along the main stream. Thirteen springs were also identified. Characteristics of the sub-basins and the location of the springs are shown in Table 3.

### 2.3. Analytical techniques

Measurements were performed once per month, starting in November of 2008 and ending in October of 2009. Physical and chemical data (pH, electrolytic conductivity (EC) [$\mu S\, cm^{-1}$]) were collected in the field using a WTW Multi350i meter with a POLYPLAST PRO-Hamilton (WTW, Germany) glass electrode and a WTW LR-325/01 conductometric sensor (WTW, Germany) with a built-in thermometer and a conductometric sensor constant of $k = 0.1$. The pH and EC of the water samples were double-checked once the samples had been delivered to the laboratory. In the winter, the samples were not analyzed until they had reached room temperature (about 20 °C). A 0.45 μm syringe filter was used to filter the water samples. The chemical composition of the water samples was determined using an ion chromatography system – DIONEX ICS 2000 (DIONEX, USA). A chromatographic system composed of two chromatographs – an anion module and a cation module – allows for the simultaneous separation and determination of 14 ions present in water: $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$, $HCO_3^-$, $SO_4^{2-}$, $Cl^-$, $NH_4^+$, $NO_3^-$, $NO_2^-$, $PO_4^{3-}$, $Li^+$, $Br^-$ and $F^-$. The aforesaid system was connected to an AS-40 autosampler and run using Chromeleon 6.70 software. The accuracy of the output was estimated based on certified

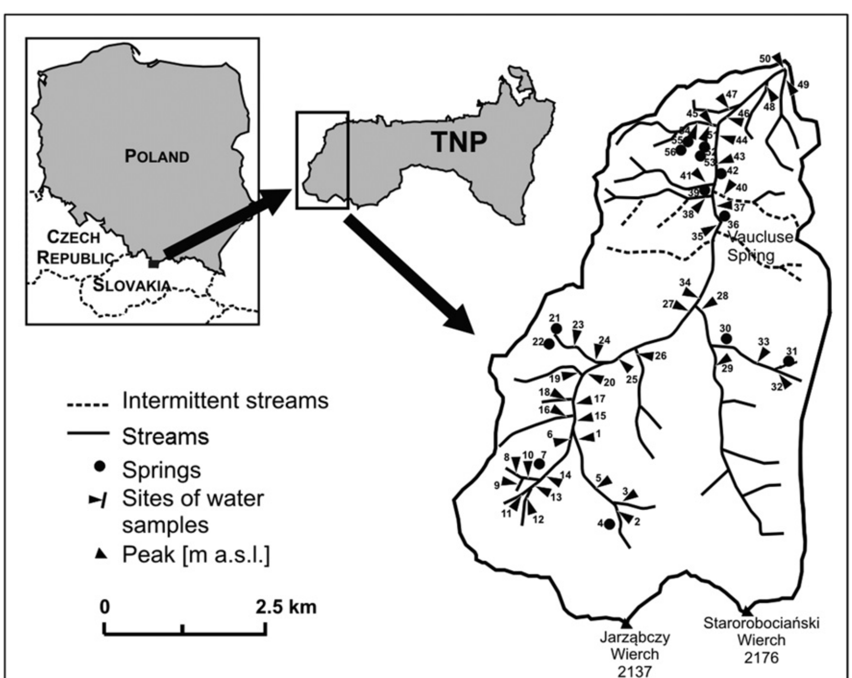


**Fig. 1.** Location of study area.