Impact of the Climate Change on Water and Snow Balance in the "Jizerské" Mountains in the Czech Republic

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Einfluss der Klimaänderung auf die Wasser- und Schneebilanz im Jizerské-Gebirge in der Tschechischen Republik

1 Preface

The study deals with data from experimental basins in the Jizerské Mts. and their foothills (Fig. 1). Spatial and temporal distribution analyses of meteorological and hydrological series from various geographical sites were performed. The meteorological data analyses deal mostly with precipitation, temperature and snow cover and snow fall parameters. Discharge series in the winter half year were studied in the hydrological part. The main aim of the study was to find, describe and assess potential changes, trends and relations in the series in the catchments with different geographical conditions.

All experimental data come from the northern part of the Czech Republic, from the Jizerské Mts. And their northern and southern foothills (Fig. 2). Seven small experimental basins (1,8 to 10,6 km^2) are situated on the mountainous plateau in elevations between 756 and 1,122 m a.s.l. This region is one of the rainiest in the country and annual sum amounts up to 1,500 mm. The northern part of the mountains is drained by the river Smědá (belonging to the Nisa > Odra > Baltic Sea basin). Southern streams fall to the Jizera river > Labe (Elbe) > Northern Sea basin. The Mohelka river situated at the southern foothills also belongs to the Labe basin.

2 Data background and processing

2.1 Smědá and Mohelka river basin

The first issue was to compare two different catchments situated on opposed sides of the Jizerské Mts. The Smědá river basin (in the north) has its upper part situated in those mountains. They are built by compact granitic pluton and covered with shallow Quaternary weathered layer. The lower part of the Smědá catchment is built by Paleozoic shales and Pleistocene (glacial) sediments. The Mohelka

Zusammenfassung

Der Beitrag befasst sich mit den klimatischen und hydrologischen Bedingungen im tschechischen Isergebirge (Jizerské-Gebirge) und dessen Ausläufern. Es wurden klimatische (Temperatur, Niederschlag, Schnee) und hydrologische (Abfluss-)Datenreihen und ihre Wechselbeziehung mit anderen Parametern untersucht. Die Trends der letzten 50 Jahre und ihre Vorhersage für das aktuelle Jahrhundert durch Wasserbilanzmodellierung wurde für Gebirgsstandorte, Übergangsbereiche und Niederungen berechnet.

Schlagworte: Hydrologie, Klimatologie, Klimaänderung, Wasserbilanz, Schneehydrologie.

Summary

The paper deals with climatic and hydrologic conditions in the "Jizerské" Mountains and their foothills in the Czech Republic. Climatic (temperature, precipitation, snow features) and hydrological (outflow) data series and their relations among various parameters were studied. Trends in the last 50 years and their prediction with water balance modelling in the current century were processed for mountainous, foothill and lowland regions.

Key words: Hydrology, climatology, climate change, water balance, snow hydrology.

Figure 1: General map of the Czech Republic with studied basins
Abbildung 1: Allgemeine Karte der Tschechischen Republik mit den Untersuchungsgebieten

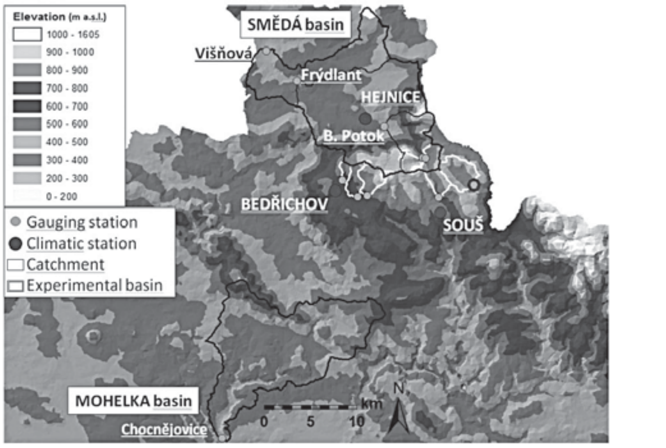

Figure 2: Detailed map of studied catchments of Mohelka and Smědá rivers, seven experimental basins in the Jizerské Mountains and analysed climatic stations (Bedřichov, Souš, Hejnice)
Abbildung 2: Detailkarte der Untersuchungsgebiete der Flüsse Mohelka und Smědá, der sieben Testgebiete im Isergebirge und der verwendeten Klimastationen (Bedřichov, Souš, Hejnice)

basin (in the south) is situated on Paleozoic metamorphic rocks, Mesozoic (Cretaceous) sandstones and clay stones, and Quaternary sediments (loams, sands, gravels) and is surrounded by highlands up to 1,000 m a.s.l. The lower parts of the basins consist of Cretaceous resp. Quaternary sediments. These parts show typically stronger influence of infiltration and groundwater flow on water balance regime.

Hydrologic characteristics of the catchments (area, mean annual discharge, mean maximal and minimal discharge, precipitation, runoff coefficient, specific discharge) were compared. The higher the ratio of sediment rocks in the catchment, the lower the runoff coefficient, specific discharge, interannual and month-on-month variability appear. Daily discharge data series from the period 1957–2007 were analysed. A slight increase in annual mean discharge was observed. During the winter half year an increase on the Smědá, but decrease on the Mohelka can be observed. This is probably caused by different snow cover influence during winter. Maximal discharges prevail on the Smědá in summer and in winter on the Mohelka. Minimum discharges in February are the same for both. Despite that, all trends appearing in the series were assessed as non-significant.

2.2 Mountainous snow hydrometeorology

Meteorological data series and discharges in experimental basins situated in the Jizerské Mountains were analysed in the second step. Three climatic stations holding 50 year-long series (1961–2010) were used: two mountainous stations Bedřichov (777 m a.s.l.), Souš (772 m a.s.l.) and Hejnice (396 m a.s.l.) situated at foothills (Fig. 2).

The following data were calculated only for the winter half of the year (November–April): number of days with snow cover [1]; maximum snow depth [cm]; date of maximum snow depth [dd.mm.rrrr]; number of days with new snow [1]; sum of new snowfall [cm]; number of days with precipitation [1]; precipitation sum [mm]; maximum snow water equivalent during winter [mm]; snow depth in term of maximum snow water equivalent [cm]; average temperature [°C]. Daily values, sums and mean values of daily data of winter half year were used for calculation. This means that each parameter is represented only by one number per half year, i.e. 50 year-long series consists of 50 unique values. The series were assessed by linear regression, 3rd degree polynomic regression, 3, 5, and 10-year moving average.

The Bedřichov and Souš stations are located at a distance of about 15 km from each other. The data series are quite similar and well representative for the mountains. Hejnice station –situated at altitude approx. 400 m lower – shows a mean temperature about 3,5 °C higher. All stations show a positive linear trend in their temperature series, which is 1,6 °C, 1,3 °C, resp. 1,4 °C in the 50-year-long series (Fig. 3). This trend is crucial for snow cover processes (snowfall, accumulation, transformation, melting and runoff) in the mountains. If the trend continues, mean temperature will exceed 0 °C, which will strongly affect snow conditions in decreasing snow accumulation, increasing snow melt, and respective changes in outflow character. For the Hejnice station this trend is not charged as so relevant because snow cover does not play such an important role. Snow cover occurs here on approximately 70 days a year. This is about half the number of days with snow cover at the mountainous stations.

Generally a slight increase of sum precipitation and snow water equivalent is observed. Other snow cover features are slightly decreasing (number of days with snow cover, maximal snow depth, number of days with snowfall) in all three climatic stations during winter half year.

Subsequently discharge data series (winter half year mean discharge) from closing profiles of seven experimental basins were calculated, standardized (by long-term mean discharge) and studied. These small catchments are situated in the highest parts of the Jizerské Mts. There were tight correlations among discharge series, but only very slight increasing trends (line direction a = 0,073) that were not significant during the observed period (1981–2010). This fact corresponds with previous analysis of climatic stations and also with the following study and correlations in other observed catchments: snow cover and snow melt do not play very important role in semi-annual mean value of discharge in the last 30 resp. 50 years. The experimental catchments are usually covered in thick snow pack during the whole winter. Strong or weak winters affect runoff conditions only a few days during spring thaw, and the reaction strongly depends on actual meteorological conditions (precipitation, sunshine, temperature, daily temperature oscillation, wind, air humidity).

2.3 Hydrometeorological interactions

The summary combines results of the previous tasks and deals with the analysis of climatic and hydrologic data. Climatic data were used from the stations described above. Hydrologic series were used from Mohelka and Smědá river for the period 1957–2010. The highest gauging station Bílý Potok is situated at foothills of the Jizerské Mts. at 400 m a.s.l. and closes the mountainous part of the catchment. The Frýdlant station is 14 km downstream and represents equal combination of mountainous and highland terrain. Višňová and Mohelka basins are situated farther downstream to compare changes in outflow with different influence of snow (Fig. 2). Data were calculated in the same way as climatic data, i.e. mean winter half year discharge is an average of daily discharge from November to April. Trends of the series were also assessed by linear regression, 3rd degree polynomic regression, 3, 5, and 10-year moving average.

All three series show slight increase in winter discharges (Fig. 4). The more downstream, the gentler the rise occurs. This can happen due to bigger influence of snow and snow melt in mountainous parts of the catchments. This fact corresponds with the analysis of climatic data that show increasing trend in winter precipitation and maximal snow water equivalent. Interannual fluctuation seems to be more

Table 1: Hydrologic specification of studied catchments in the Smědá and Mohelka basin
Tabelle 1: Hydrologische Charakterisierung der Untersuchungsgebiete im Smědá- und Mohelka-Einzugsgebiet

	Bílý Potok	Frýdlant	Višňová	Chocnějovice
Basin/river	Smědá	Smědá	Smědá	Mohelka
Area (km^2)	26.1	132.1	187.5	155.2
Average elevation (m a.s.l.)	742	513	348	356
Gauge elevation (m a.s.l.)	400	329	250	232
Maximal elevation (m a.s.l.)	1124	1124	1124	950
Station location (km)	38.6	24.5	16,4	3.2
Mean discharge ($m^3.s^{-1}$)	1.0	3.2	4.0	2.22
Maximal discharge ($m^3.s^{-1}$)	1.7	5.3	6.7	3.5
Minimal discharge ($m^3.s^{-1}$)	0.4	1.4	2.5	1.3
Standard deviation	0.28	0.80	0.87	0.45
Variational coefficient	0.29	0.25	0.22	0.20

stable related to an increasing catchment area, lower mean elevation a.s.l. and higher storativity in the catchments situated in well permeable fluvial and glacial quaternary sediments (Frýdlant, Višňová) rather than Bílý Potok basin situated on compact granitic rock with shallow weathered layer.

Correlation and graphs of the Frýdlant and Višňová gauging stations show a similar hydrologic behaviour. Bílý Potok, featuring a steeper mountainous relief, has different course and its climate is better represented by the Souš climatic station. There is clear tight correlation between winter discharge and precipitation (r = 0,59) resp. temperature (r = 0,46). An interesting correlation was found between discharge and all features describing snow conditions (r < 0,10) (Tab. 2). This allows concluding that snow conditions have almost no influence on the winter mean discharge. However, some of them (snow depth, resp. snow water equivalent) play an important role during a relatively short period of spring thawing. But similar importance is accorded to the actual meteorological situation as mentioned above (2.2).

Table 2: Correlation coefficients of discharge data series (station Bílý Potok) with climatic series in Hejnice and Souš calculated for average winter half-year values (November–April) in years 1960–2009

Tabelle 2: Korrelationskoeffizient zwischen Abflüssen (Station Bílý Potok) und Klimadaten in Hejnice und Souš anhand gemittelter Winterhalbjahreswerte (November–April) der Jahre 1960–2009

Average discharge in winter: Q_{whhy} correlated with:	**Hejnice** (foothills)	**Souš** (mountainous)
Number of days with snow cover	–0,25	0,09
Maximum snow depth	–0,04	0,06
Number of days with new snow	–0,10	0,09
Sum of new snow fall	–0,04	0,25
Number of days with precipitation	0,35	0,13
Precipitation sum	**0,51**	**0,59**
Maximal snow water equivalent during winter	–0,09	0,09
Average temperature	**0,35**	**0,46**

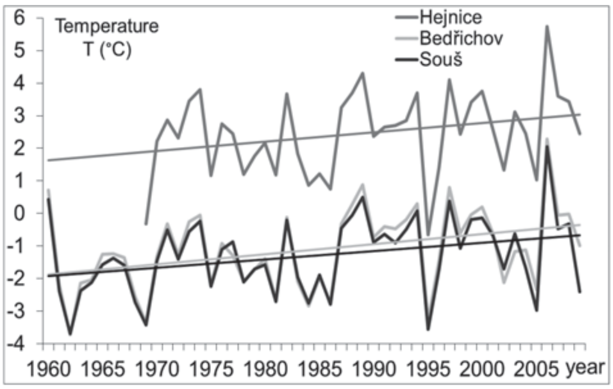

Figure 3: Average winter temperature observed at the climatic stations in the Jizerské Mts.

Abbildung 3: Mittlere Wintertemperatur an der Klimastation im Isergebirge

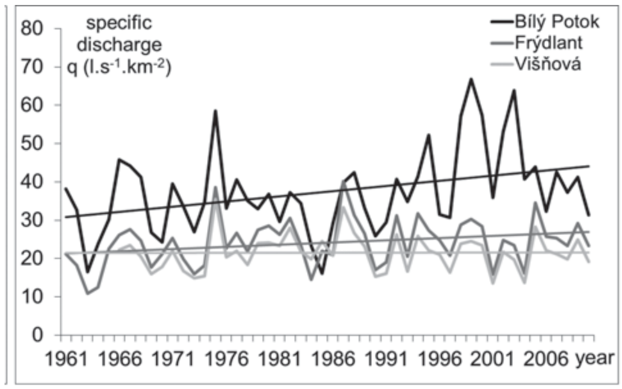

Figure 4: Average winter specific discharge observed at the gauging stations in the Smědá basin.

Abbildung 4: Mittlerer spezifischer Winterabfluss am Beobachtungspegel Smědá.

2.4 Runoff modelling in conditions of climate change

The non-parametric Mann-Kendall test with the correction of the first order autocorrelation was used for trend detection (Kendall, 1975), (Libiseller & Grimvall, 2002).

The runoff process was simulated in the two experimental basins and in the downstream basin up to the gauge Frýdlant. The BILAN model was used for simulation. The model solves rainfall-runoff relations in monthly time step. Input data include time series of rainfall amount, air temperature and relative humidity. The observed discharge is employed for calibration of model parameters. The system of linear reservoirs produces surface, hypodermic and groundwater flow. A detailed description of the BILAN model is provided in Tallaksen & Lannen (2004).

The periods used for model calibration were determined depending on input data availability. Therefore, the experimental basins were calibrated in the period 1986–2008, Frýdlant in 1961–2008. Meteorological input data were used from stations located in experimental basins where observation is conducted, otherwise like air humidity were derived from neighbouring stations using kriging interpolation. The logarithmic Nash-Sutcliffe efficiency achieved 0.6 in experimental basins and 0.66 in Frýdlant (Fig. 5) (HIRSCH & SLACK, 1984).

To encompass the climate change development into the runoff models, the original meteorological input series were modified with respect to probable future climatic changes to time horizons 2025, 2055 and 2085. For purpose of this study, the mean change of precipitation and temperature for each month from the ensemble of 20 regional climatic models (RCM) of the project ENSEMBLES driven by emission scenario A1B was employed. Since humidity projections are highly uncertain they remained at current values through the simulations.

According to the simulation results the mean annual temperature rise of 1.2 °C, 2.2 °C and 3.1 °C can be expected to the time horizons 2025, 2055 and 2085, respectively (Fig. 6). Increase of temperature varies through the year, the highest temperatures can be observed in mountainous basins in winter and summer season while in Frýdlant basin rather in spring and autumn.

The RCM simulations suggest general increase of annual precipitation amount about 5 % in all time horizons, even though lower precipitation can be observed during summer. General trend tends to emphasize seasonal changes in more distant horizons. The most significant changes in precipitation make up to 15 %.

The BILAN model denotes nearly no change of mean annual discharge in mountainous basins. In the Frýdlant gauge the discharge is projected to become slightly decreased to 92 % of current amount in horizon 2055 and 2085. The experimental basins exhibit significant seasonal variability in discharge that is assessed to rise up to 150 % in late winter months for horizon 2025 and up to 200 % in more distant future. In contrary, the model results suggest discharge diminishing to 90 % in the middle of spring for horizon 2025 and nearly 50 % for 2085. Minimum discharge that usually occurs in June and during autumn could go down to 70–80 % and even less. In Frýdlant basin, a tendency to increasing discharge up to 110 % in winter and decreasing to 95 % in late spring and 90 % during autumn can be observed in horizon 2025. Also in Frýdlant the future changes were projected to grow stronger, up to 115 % of current discharge in winter, while 90 % and 60 % in spring and autumn, respectively, when minimum discharge usually occurs.

The above described climate change impact was studied also using the meteorological variables simulated by the ALADIN/CZ model, which was developed in the frame of the CECILIA project regarding to the Central European conditions with 25 × 25 km of spatial resolution. Despite of its more significant changes in precipitation and temperature variability, and thus effect to discharge, only the results using the mean of 20 RCM are presented here, because of their more general plausibility.

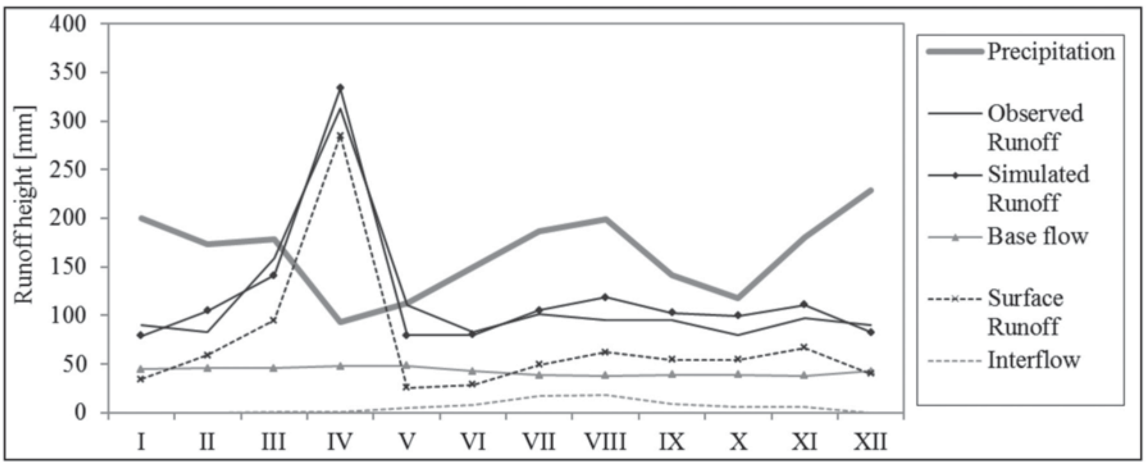

Figure 5: Seasonal development of runoff components in one of the experimental basins in comparison with observed discharge in the period 1986–2008

Abbildung 5: Saisonale Entwicklung der Abflusskomponenten in einem der Testgebiete im Vergleich zu den Beobachtungswerten der Periode 1986–2008

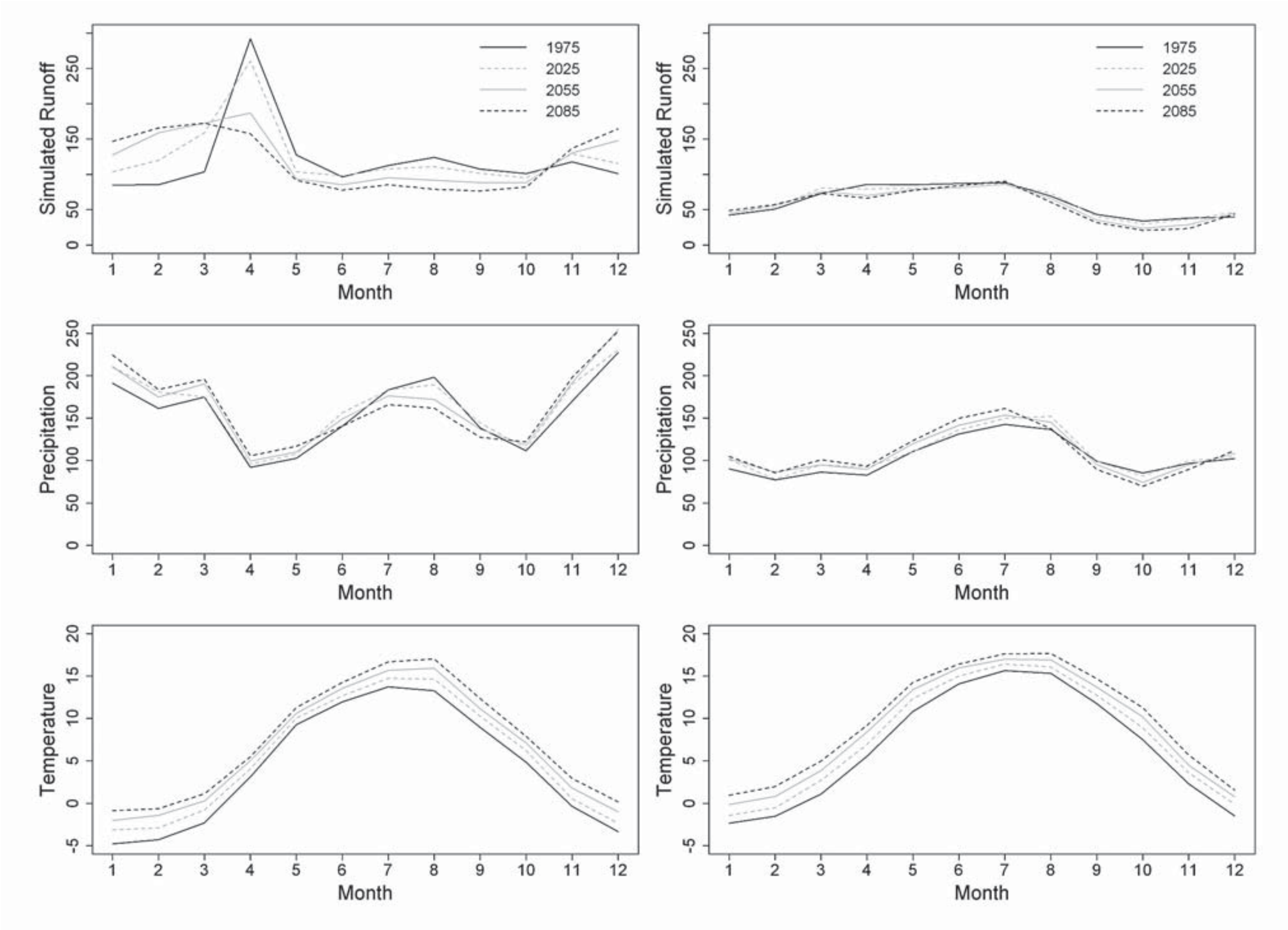

Figure 6: Seasonal development of simulated runoff, precipitation and temperature in one of the experimental basins (left) and the gauge Frýdlant (right) for current conditions (1975) and the time horizons 2025, 2055 and 2085. Emission scenario was A1B. Climatic variables were calculated as a mean of the ensemble of 20 RCM, runoff was simulated by BILAN

Abbildung 6: Saisonale Entwicklung des berechneten Abflusses, des Niederschlags und der Temperatur in einem der Testgebiete (links) und der Beobachtungsstation Frýdlant (rechts) unter den aktuellen Bedingungen (1975) und den Zeithorizonten 2025, 2055 und 2085 bei Emmissionszenario A1B. Die Klimavariable wurden als Mittelwert einer Ensembleschätzung aus 20 RCMs berechnet, der Abfluss wurde mittels BILAN modelliert

3 Conclusion

In general, all data series show very slow changes that might be caused by climate change. Relations among rising temperature, resp. evapotranspiration, changing precipitation scheme during the year, decrease of humidity, snow cover parameters and discharges (in summer) appear. Time series are relatively short for their extrapolation or climate change assessment. All trends and simulations expect general temperature rise, slight increase of precipitation and runoff in winter and spring months and decreasing trends in those parameters during summer.

4 Discussion

Compactness and reliability could be a problem of all data series. This has been caused by changing of measuring equipment, observers, consumption curves, observation methods and terms or influence of meteorological conditions (for example freezing of gages during strong frosts or low snow cover) or incompleteness of series. From that point of view, it is crucial to judge all data, trends and predictions very critically. On the other hand, assessed parameters show some rate of shift that corresponds to other analyses taken in respect to climate change in the Czech Republic, resp. in Central Europe. The shift of precipitation towards the winter months, more frequent summer droughts and flash floods, weaker winters and temperature rise are expected and accepted changes in the region for the following decades (Benčoková, 2010, Daňhelka, 2012; Kašpárek, 2006; Kliment, 2010; Lenartowicz, 2010; Metelka, 2010).

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