POTENTIAL IMPACT OF CLIMATE CHANGE ON RIVER RUNOFF IN WESTERN SLOVAKIA

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Abstract. In this study the potential impact of a changed climate on river runoff in Western Slovakia was evaluated. A spatially-lumped, simple conceptual hydrological rainfall - runoff model WatBal, which is based on the work of Kaczmarek, was selected to model the impact of climate change on long-term mean monthly discharges. A simple snowmelt model is incorporated into the model. Input is divided into direct surface runoff and infiltration. The soil moisture zone is simulated by one non-linear reservoir. Surface, subsurface and baseflow from the soil moisture reservoir are computed as separate runoff components. Evapotranspiration is computed on the basis of the simulated soil moisture and potential evapotranspiration. Potential evapotranspiration values are estimated by the Priestly-Taylor method or can be supplied by the model users.
The model was calibrated with data from the period 1961-1990 or 1951-1980. The reaction to climate change was analysed with a modified input time series.
A regional modification of the latest results of the General Circulation Model (GCM) outputs – CCCM, was selected as the climate scenario for a study of changes in seasonal runoff. The WP and SD modified scenarios based on comparison of warm periods in the past in Slovakia as alternative scenarios were used. Downscaling into rain-gauge stations in Western Slovakia anticipates an increase in air temperature for the time horizons chosen and an increase or decrease in precipitation for different months.
Runoff generated by the model was considered to represent an estimation of the impact of climate change on river runoff and was compared with a baseline time series.
***Keywords*:** climate change scenarios, hydrological balance model, seasonal runoff distribution

POTENTIELLER EINFLUSS EINES VERÄNDERTEN KLIMAS AUF DEN ABFLUSS IN DER WESTSLOVAKEI

Abstrakt. Der potentielle Einfluss eines veränderten Klimas auf den langjährigen mittleren monatlichen Abfluss in der Westslovakei wurde unter der Anwendung des konzeptuelles Wasserbilanzmodells WatBal untersucht. Das Modell wurde an Daten aus der Baselineperiode 1961 - 1990 in sieben Einzugsgebieten geeicht. Die mögliche Veränderung der Flussgebietreaktion auf das veränderte Klima wurde durch modifizierte Eingangsdaten der Baselineperiode simuliert. Als Klimaveränderungsszenarios wurden eine regionale Modifizierung des GCM Szenarios CCCM und zwei alternative Szenarios des Nationalen Klimaprojektes der Slowakei WP und SD angewendet. Der simulierte veränderte Abfluss wurde mit dem Abfluss der Baselineperiode verglichen.
Keywords: Szenario der Klimawandlung, hydrologische Bilanz, Veränderung des Abflusses, mathematisches Abflussmodell

1. Introduction

Climate change impact studies play a significant role in the literature. No comprehensive review will be therefore attempted here from the vast number of papers published on the subject. For a comprehensive state of the review the reader is referred to the latest reports of the Intergovernmental Panel Council Climate Change, especially to McCarthy et al. (2001).

In climate change impact studies it is often sufficient to use a monthly time step. Several methods and rainfall-runoff models have been developed for this purpose. Physically based models were rarely used, since they require a high resolution of input data, in both space and time. Climatic input data and physiographic catchment characteristics may not be available for such a resolution. The possibilities to use black box models for the given purpose are also limited, since their predictive capabilities are restricted. The parameters of black-box models primarily reflect the relationship between climatic forcing and hydrological response from the calibration period. This may not remain valid in circumstances different from those used for the calibration of the models, and such models are therefore not always suitable for water resources investigations.

Conceptual monthly water balance models can be calibrated with easily obtainable input variables, which can be acquired by the engineers in charge of the water resources projects. The use of monthly conceptual water balance models rather than physically based models or black-box models, is therefore usually favoured for planning purposes. Monthly conceptual water balance models are intended to simulate selected hydrological processes, usually by conceptualising the catchment as an assemblage of interconnected storages through which water passes from input as rainfall to output as streamflow at the catchment outlet; the controlling equations usually satisfy the requirements of the hydrological balance. A wide variety of models and parameter estimation algorithms have been described in the literature, the current state of the art will not be discussed here in detail, a review of approaches is given e.g. in Xu (1999).

Such models have found diverse applications in impact studies. For example Schaake and Liu (1989) developed and used simple monthly water balance models to understand the relationship between climate and water resources. Arnell (1992) used Thornthwaite and Mather's (1955) model together with a number of climate change scenarios to examine the effects of climate change on runoff on 15 catchments in the U.K., which represented a wide range of climatic and geological conditions. Xu (1999b, 2000) applied GCM and incremental scenarios to assess the sensitivity of river basins to climate change and to predict its impact. In Slovakia, a simple, conceptual spatially-lumped hydrological rainfall-runoff model, WatBal, which is based on the works of Yates (1994), was extensively used for modelling river runoff in a monthly time step in water resources studies and climate change impact studies.

2. Climate change scenarios

Several climate change impact studies have been conducted in recent years on the territory of Slovakia. For details, see, e.g. Cunderlik, et al. (1998), Cunderlik, Hlavcova and Szolgay (1998), Fendekova (1995), Hlavcova and Cunderlik (1998), Hlavcova (1999), Lapin, et al. (1995), Lapin et al (1997), Lapin and Melo (1999), Mareckova et al. (1997), Pekarova, et al. (1996), Petrovic (1998), Szolgay, et al. (1997a,b). According to the results of these previous studies a decrease in the mean annual runoff seems to be far more probable than no change in the present conditions or an increase of runoff. The effects of air temperature increase are expected to be decisive for such behaviour, even if the mean annual precipitation would moderately increase. As for the seasonal seasonal distribution of flows it was concluded, that in general discharges should increase in the winter low-flow period and flows could (substantially) decrease in the spring. The flow regime in the summer and autumn could show stable behaviour with a moderate decrease in runoff.

In this study three climate change scenarios have been applied to test the sensitivity of the basins to climate change. The regionally downscaled outputs of the CCCM coupled ocean and atmosphere General Circulation Model (GCM) and as alternative scenarios, the WP and SD scenarios published by the Slovak National Climate Programme, which are based on analogy with warm periods in the past, were selected (Lapin, et al. (1999), Lapin, et al. (2000)). The scenarios represented changes in the long-term mean values of monthly precipitation and temperature for the time horizons 2010, 2030 and 2075. Downscaling was performed into all climatic stations from Western Slovakia selected for the study (Fig. 1).

All scenarios expect an increase in the air temperature for the chosen time horizons; and an increase or decrease in the precipitation. Predicted air temperature changes for Slovakia according to the CCCM scenario for time horizons 2010, 2030 and 2075 are shown in Table 1.

Table 1 Changes in the mean monthly air temperature [°C] in Slovakia according to the CCCM climate scenario

Time Horizon	**Month**											
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
2010	0.49	0.69	0.91	0.68	0.44	0.63	0.92	1.04	1.04	0.88	0.55	0.43
2030	0.86	1.22	1.45	1.10	0.83	1.10	1.41	1.53	1.56	1.24	0.74	0.66
2075	2.21	2.86	2.85	2.33	2.34	2.88	3.36	3.65	3.63	2.96	2.04	1.76

3. Study sites and data

For the evaluation of seasonal runoff changes, several river basins in Western Slovakia were selected: the Myjava in Šaštín–Stráže, the Rudava in Veľké Leváre, the Šurský kanál in Svätý Jur, the Trnávka in Bohdanovce nad Trnavou, the Dolný Dudváh in Čierny Brod, the Žitava in Vieska nad Žitavou and the Nitra in Nitrianska Streda.

Catchment areas and reference periods are summarised in Table 2. Because in most of basins there were discharge data available only from 1961 (or even later), for water–balance modelling in these basins discharges and climate characteristics from the standard period of 1961-1990 and a suitable number of climate stations were chosen. The selected meteorological stations are shown in Fig. 1.

Table 2 Selected river basins in the Western Slovakia region

Id. Number	River	Gauge station	Basin area [km^2]	Data available from	Reference period
5030	Myjava	Šaštín – Stráže	644,89	1969	1969 - 1990
5072	Rudava	Veľké Leváre	300,30	1962	1961 - 1990
5170	Šurský kanál	Svätý Jur	106,10	1968	1969 - 1990
5230	Trnávka	Bohdanovce nad Trnavou	115,02	1961	1961 - 1990
5270	Dolný Dudváh	Čierny Brod	750,50	1968	1969 - 1990
6820	Žitava	Vieska nad Žitavou	295,46	1961	1961 - 1990
6730	Nitra	Nitrianska Streda	2093,71	1931	1951 – 1980

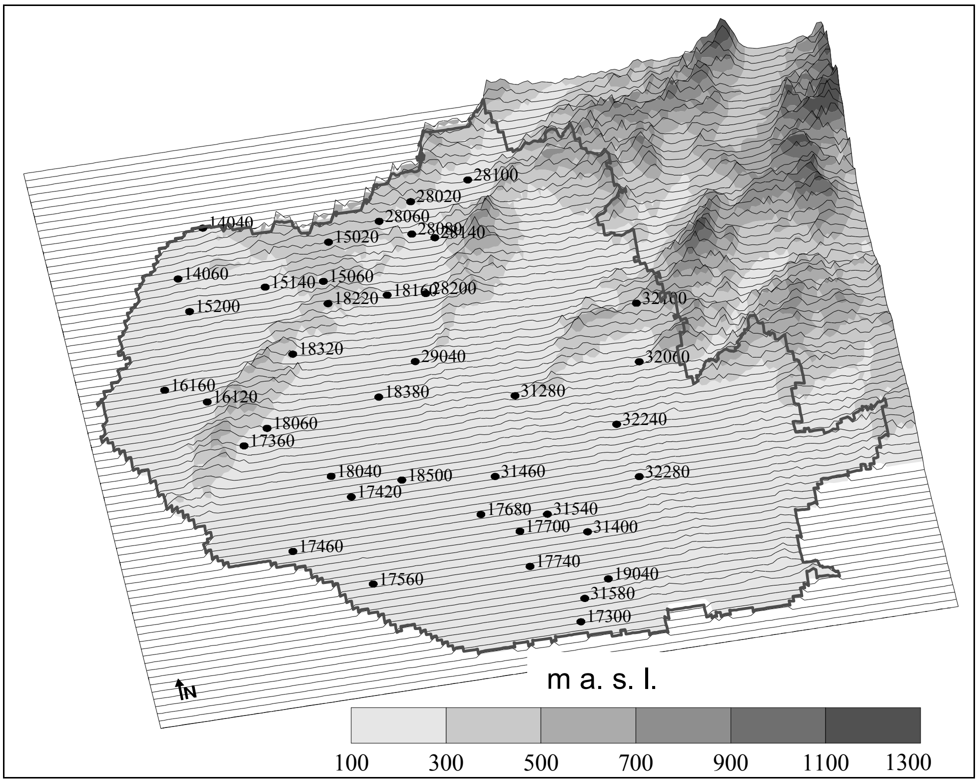

Fig. 1 Selected meteorological stations in the Western Slovakia region

4. The WatBal monthly water balance model

WatBal (Yates, 1994) is a conceptual lumped rainfall-runoff model, which simplifies a river basin into a single nonlinear reservoir. The model simulates water accumulation in the catchment, snowmelt, evapotranspiration, runoff from impermeable areas in the basin, surface and subsurface runoff and baseflow. The inputs required for water balance modelling when using a monthly time step are: the mean monthly precipitation for the basin, the mean monthly river discharges in the closing profile of the basin and the mean monthly potential evapotranspiration (PET). If the PET data is not available, the model uses either the Thornthwaite or the Priestly-Taylor method to compute potential evapotranspiration. The Priestly-Taylor method was used in this study. Its computation requires additional data: the mean long-term monthly hours of sunshine, the mean long-term monthly values of relative air humidity, and the mean monthly air temperature values. The basic mass balance differential equation in the model is written as:

$$S_{max}\frac{dz}{dt} = \left(P(t)(1-\beta)\right) - R_s(z,t) - R_{ss}(z,t) - Ev(PET,z,t) - R_b$$

where S_{max} is the maximum catchment storage capacity [mm], z is the relative water storage ($0 \le z \le 1$) in the catchment, P is the precipitation [mm.month^{-1}], β is the direct runoff coefficient ($0 \le \beta \le 1$), R_s is the surface runoff [mm. month^{-1}], R_{ss} is the subsurface runoff [mm. month^{-1}], Ev is the evapotranspiration [mm.month^{-1}], R_b is the baseflow [mm.month^{-1}] and t is the time [month].

The WatBal model was calibrated by using a genetic algorithm, which minimizes the mean root square error between the observed and predicted monthly runoff values (for details on the calibration see Hlavčová et al. (2000). Only some parameters of the model (e.g. the maximum catchment storage capacity and parameters used in the calculation of surface and subsurface runoff) were calibrated by optimization. Other parameters were supplied a-priory (e.g. the initial relative water storage, the Priestley –Taylor coefficient and the threshold temperatures in the snow routine). These were further optimized by trial and error in the case of necessity. Although this process may not necessarily lead to an overall optimum, its benefit lies in the necessity to get accustomed to the effect of the parameters on the correctness of the mass balance in the catchment and in the use of physically justifiable parameter values.

5. Hydrological scenarios of seasonal runoff distribution

The hydrological scenarios of changes in seasonal runoff distribution were constructed as follows:

a) calibration of the Watbal model using data from the standard period and generation of the referenced model data (baseline) of the mean monthly discharges for this period,
b) generation of the model input data (precipitation and air temperature) according to scenarios of climate change for the time horizons of 2010, 2030 and 2075,
c) simulation of the mean monthly runoff series using the WatBal model based on the changed input data and parameters of the model from the calibration,
d) comparison of the differences between the seasonal runoff distribution for the individual scenarios and the time horizons considered.

As an example the results of changes in long-term mean monthly discharges for the Nitra river basin are shown in Figs. 2, 3, 4 and in the Table 3.

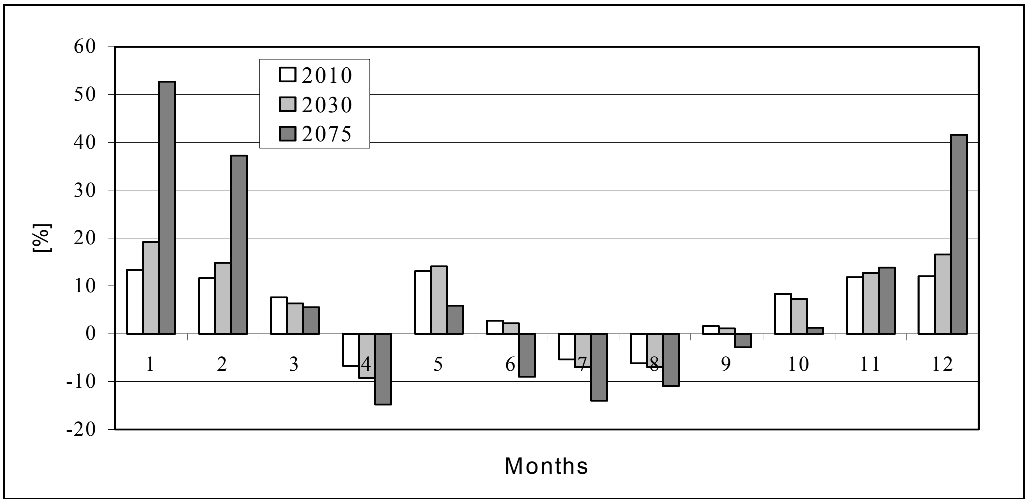

Fig. 2 Changes in long-term mean monthly discharges in the Nitra river basin according to the CCCM scenario

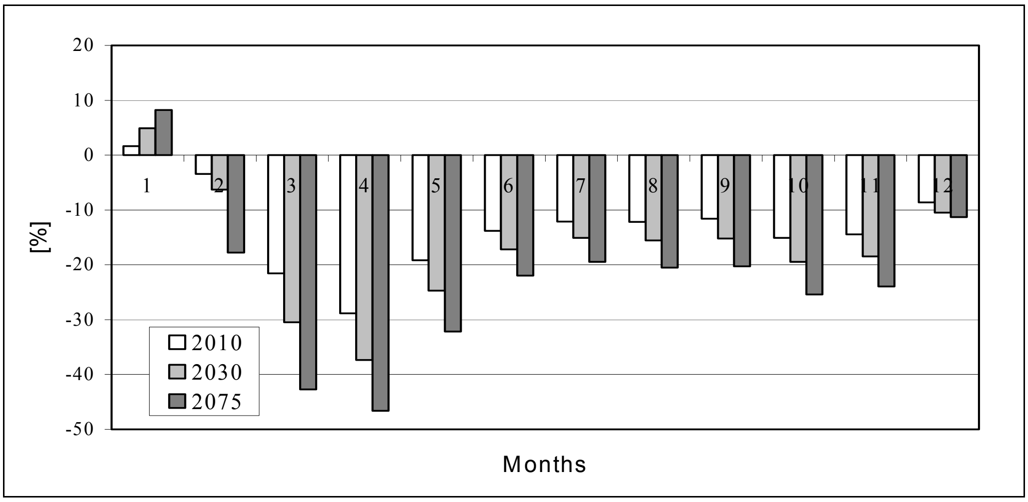

Fig. 3 Changes in long-term mean monthly discharges in the Nitra river basin according to the WP B scenario

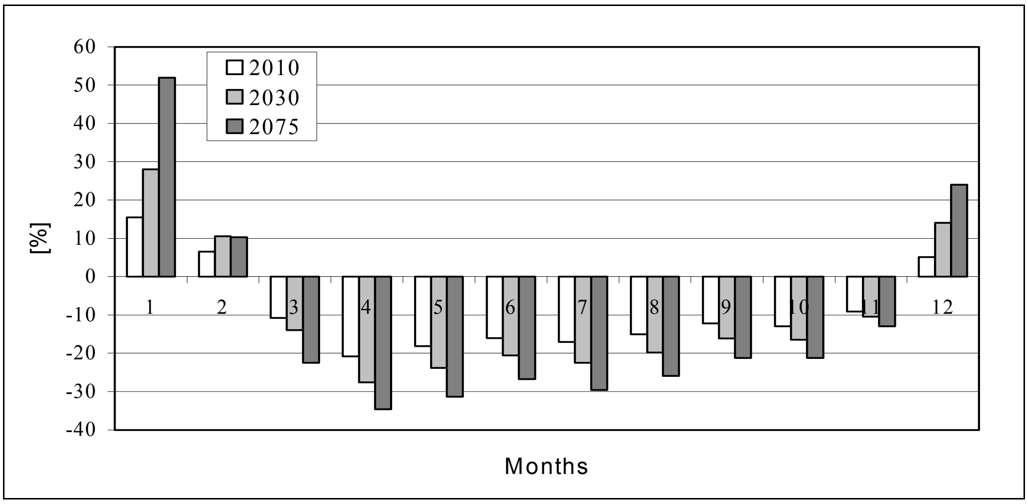

Fig. 4 Changes in long-term mean monthly discharges in the Nitra river basin according to the SD scenario

Tab. 3 Changes in long-term mean monthly discharges in the Nitra river basin for different scenarios and time horizons

Scenario	Horizon	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
CCCM	2010	13	12	8	-7	13	3	-5	-6	2	8	12	12
	2030	19	15	6	-9	14	2	-7	-7	1	7	13	17
	2075	53	37	6	-15	6	-9	-14	-11	-3	1	14	42
WP B	2010	2	-3	-22	-29	-19	-14	-12	-12	-12	-15	-14	-9
	2030	5	-6	-31	-37	-25	-17	-15	-16	-15	-19	-18	-11
	2075	8	-18	-43	-47	-32	-22	-20	-21	-20	-25	-24	-11
SD	2010	15	7	-11	-21	-18	-16	-17	-15	-12	-13	-9	5
	2030	28	11	-14	-28	-24	-21	-22	-20	-16	-16	-10	14
	2075	52	10	-22	-35	-31	-27	-30	-26	-21	-21	-13	24

6. Conclusions

As already indicated by the results of the previous impact studies, a decrease in the long-term mean annual runoff seems to be far more probable for the future than the preservation of the runoff situation from the representative period, or an increase in runoff. The effects of an increase in temperature will be decisive for such changes even in cases when an increase in precipitation is expected. The changes could exhibit a north-south gradient with the north being less affected. The southern lowlands could become vulnerable to drought.

According to the anticipated changes in the seasonal distribution of mean monthly runoff, the whole territory of Slovakia could become vulnerable to drought in the summer and the autumn. In the months with increased water demand for irrigation, domestic and industrial use and tourism, monthly flows could exhibit a decrease under climate change conditions. The intensity of the changes could increase towards the time horizon of 2075. The continuous general decrease in the potential of the surface and subsurface water resources is likely to occur. This will have to be reflected in the planning and management of water resources in the near future.

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