ASSESSING THE CLIMATE CHANGE IMPACT ON RIVER RUNOFF IN SLOVAKIA

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Abstract: The possible impact of climate change on monthly river runoff in selected regions in Slovakia was evaluated using a monthly water balance model. Four basins were selected as representative areas for various types of seasonal runoff distribution in a north-east transect across Slovakia. The monthly water balance model was calibrated with data from a standard period, which is considered to be representative for the distribution of runoff in unchanged conditions. Input data on precipitation and temperature were spatially averaged over the basins using GIS. The coupled GCM – CCCM97 and GISS98 scenarios and two scenarios analogous with the behaviour of hydrometeorological processes during warm periods in the past in Slovakia were used to simulate future runoff conditions. Scenarios of climate change were regionally downscaled for selected basins in Slovakia. Possible modification in mean monthly temperatures and monthly precipitation for future time horizons of 2010, 2030 and 2075 were prepared. Runoff change scenarios show similar trends in monthly runoff changes in all basins. The maximum potential increase of runoff usually occurs in January or February and the highest decline in discharge falls in the summer months.

Key words: monthly water balance model, impact of climate change, seasonal distribution of runoff

ABSCHÄTZUNG VOM EINFLUSS DER KLIMAVERÄNDERUNG AUF DEN ABFLUSS IN DER SLOWAKEI

Abstrakt: Der mögliche Einfluss der Klimaveränderung auf den monatlichen Abfluss in ausgewählten Regionen der Slowakei wurde auswertet mit einem Modell für monatliche Wasserbilanz. Vier Einzugsgebiete, auf einer nord-östlicher Achse durch die Slowakei liegend, wurden gewählt um die verschiedenen Arten der jahreszeitlichen Abflussverteilung darzustellen. Das Modell für die monatliche Wasserbilanz wurde mit Daten aus einer Standarden Zeitdauer kalibriert, von der angenommen ist, dass sie representativ für die Abflussverteilung unter unveränderten Bedingungen ist. Durchschnittswerte von Niederschlag- und Temperatur-Eingangsdaten wurden auf die ganze Fläche mit GIS ermittelt. Um die möglichen zukünftigen Abflussbildungsbedingungen zu simulieren, wurden gekoppelte GCM - CCCM und GISS Szenarien und zwei Szenarien analogisch mit dem Verhalten der hydrometeorologischen Prozessen während wärmerer historischer Perioden in der Slowakei benutzt. Szenarien für die Klimaveränderung wurden regional an die ausgewählte Einzugsgebiete aus dem groseren Massstab angepasst. Mögliche Veränderungen der monatlichen Durchschnittstemperaturen und der Niederschlagsummen für zukünftige Zeitperioden sowohl als Datenserien für die Jahre 2001 – 2090, wurden vorbereitet. Szenarien des Abflussveränderung zeigen ähnliche Trends, was die Veränderungen des monatlichen Abflusses in allen Einzugsgebieten angeht. Der maximale potentielle Anstieg des Abflusses ist in der Regel in Januar oder Februar zu beobachten. Die höchste Verminderung des Abflusses ist in den nördlichen Einzugsgebieten während der Frühlingsmonaten, in den südlichen Einzugsgebieten wird diese Verminderung in die Sommermonaten verschoben.

Schlüsselwörter: Modell für monatliche Wasserbilanz, Einfluss der Klimaveränderung, jahreszeitliche Abflussverteilung

1. Introduction

The importance of water to both society and the environment underscores the necessity to study how the impact of potential climate change may change spatial and temporal distribution of runoff in different regions. Climate change impact studies play a significant role in the literature. For comprehensive contemporary review of climate change impact studies conducted in Slovakia see Szolgay, Hlavčová and Kalaš (2002), where basic adaptation strategies were also discussed and priorities for future research within the Slovak National Climate Programme suggested.

Several climate change impact studies have been conducted in recent years on the territory of Slovakia. Usually, three types of climate change scenarios have been used in previous impact studies: analogue scenarios (making an analogy with warmer periods and periods with a specified variability in the climate in the past), regionally downscaled GCM scenarios (CCCM, GISS, GFDD3) with typical time horizons of 2010, 2030 and 2075, and incremental climate change scenarios.

To estimate changes in hydrological regime, several watersheds or regions of a characteristic location and size were selected. These included existing and/or planned water resources utilisation schemes (reservoirs for drinking water supply, flow augmentation and hydroenergetic use, areas with agricultural water use, etc.) and covered a variety of runoff generating conditions. Observed runoff series from the periods 1931 to 1960 and/or 1931 to 1980 were usually considered as baseline scenarios in the impact studies. Several water balance models were used with annual, monthly and daily time steps to simulate the impact of the climate change scenarios. The model parameter values from the representative periods were considered to be representative of runoff generation conditions in the future. Modified model input time series were usually constructed from the baseline data by adding the differences in mean air temperature and precipitation prescribed by the scenarios for the given time step. Possible changes in the variability of the time series were not considered.

More details can be found in the following studies: Faško et al. (2000), Faško and Štastný (2001), Fendeková (1999), Fendeková and Némethy (2001), Halmová (2000), Hlavčová and Čunderlík (1998), Hlavčová, et al. (1999, 2000), Kostka and Holko (2000, 2001), Lapin, et al. (1995), Lapin, et al. (1997), Lapin and Melo (1999), Majerčáková (2000), Majerčáková and Takáčová (2001), Marečková, et al. (1996), Pekárová et al. (2001), Pekárová and Miklánek (2001), Petrovič (2000), Szolgay, et al. (1997, 2002, 2003), Szolgay and Hlavčová (2000), Takáč (2001).

In this study the potential impact of a changed climate on monthly river runoff in selected regions in Slovakia was evaluated using a monthly water balance model. Four basins representing various types of runoff distribution and water use were selected as representative areas and four climate change scenarios have been applied to test the sensitivity of the basins to climate change.

2. The monthly water balance model

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, ranging from relatively complex conceptual models with 10 to 15 parameters for arid regions to very simple models with 2 to 5 parameters for humid regions in temperate zones. The current state of the art will not be discussed here in detail; a review of approaches is given, e.g., in Xu and Singh (1998), Xu (1999).

In this study, a conceptual spatially-lumped hydrological rainfall-runoff model developed at the Slovak University of Technology was used for modelling river runoff in a monthly time step. The model simplifies a river basin into two nonlinear reservoirs and simulates water accumulation in the basin, 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 several methods for the PET calculation with additional data required: 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 is written as:

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

where S_{max} is the maximum catchment storage capacity [mm], z ($0 \leq z \leq 1$) is the relative value of the water storage in the catchment compared to S_{max}, P is the precipitation [mm.month^{-1}], β is the direct runoff coefficient ($0 \leq \beta \leq 1$), R_s is the surface runoff [mm.month^{-1}], R_{ss} is the subsurface runoff [mm. month^{-1}], E_v is the evapotranspiration [mm.month^{-1}], PET is the potential evapotranspiration [mm.month^{-1}], R_b is the baseflow [mm.month^{-1}] and t is the time [month]. In the study a genetic algorithms (GA) was applied to calibrate the model to at site data. GA are stochastic search methods that simulate the process of the natural selection and the mechanism of population genetics. For the calibration the Nash-Sutcliffe criterion, which is widely used in modelling studies, was used as the objective function.

The hydrological balance model was calibrated for all selected basins with data from the 1951–1980 period. This standard period is usually considered representative of the runoff distribution for stationary climate conditions in the framework of the Slovak National Climate Program (SNCP).

3. Selection of basin and input data

For the evaluation of seasonal runoff changes four river basins were selected: the Váh River in Liptovský Mikuláš, the Topľa River in Hanušovce, the Rimavica River in Lom nad Rimavicou and the Myjava River in Myjava. The catchment areas and mean altitudes of the basins are summarised in Table 1. They are located along two transects from north to south and from west to east across Slovakia. The selected basins are shown in Fig. 1.

The basin of the Topľa River represents the east flysh region of Slovakia, which is an area laying on the outer belt of the West Carpathian mountains range. The basin of the Váh River represents alpine type hydrological regime of the high core mountains region in the West Carpathian belt, which comprise the Západné Tatry and Nízke Tatry. The basin of the Rimavica River represents the hydrological regime of the southern slopes areas of the Slovenské Rudohorie mountains. The Myjava River in western Slovakia is characterising the hydrological regime of the Malé Karpaty mountains, where water use for flow augmentation, irrigation and agricultural water use is prevailing.

For water–balance modelling in the selected basins, climate characteristics from the standard period of 1951-1980 and a suitable number of climate stations were chosen. For computation of the mean areal precipitation and air temperature in the selected basins, the basins were divided into elevation zones containing at least one station in each zone. Based on a digital elevation model (with a resolution of 100 × 100 m), digital raster maps of the mean monthly precipitation and mean monthly air temperature for the individual basins were so obtained. Next, the mean areal monthly precipitation and air temperature was determined from the raster maps as spatially averages over the basins using GIS.

Table 1. The basins selected for the study.

Id	River	Gauge station	Area [km^2]	Observation from	Reference period
5030	Myjava	Šaštín – Stráže	644.89	1969	1969 - 1980
5550	Váh	Liptovský Mikuláš	1107.21	1921	1951 - 1980
7860	Rimavica	Lehota nad Rimavicou	148.95	1931	1951 - 1980

9500	Topľa	Hanušovce	1050.03	1931	1951 - 1980

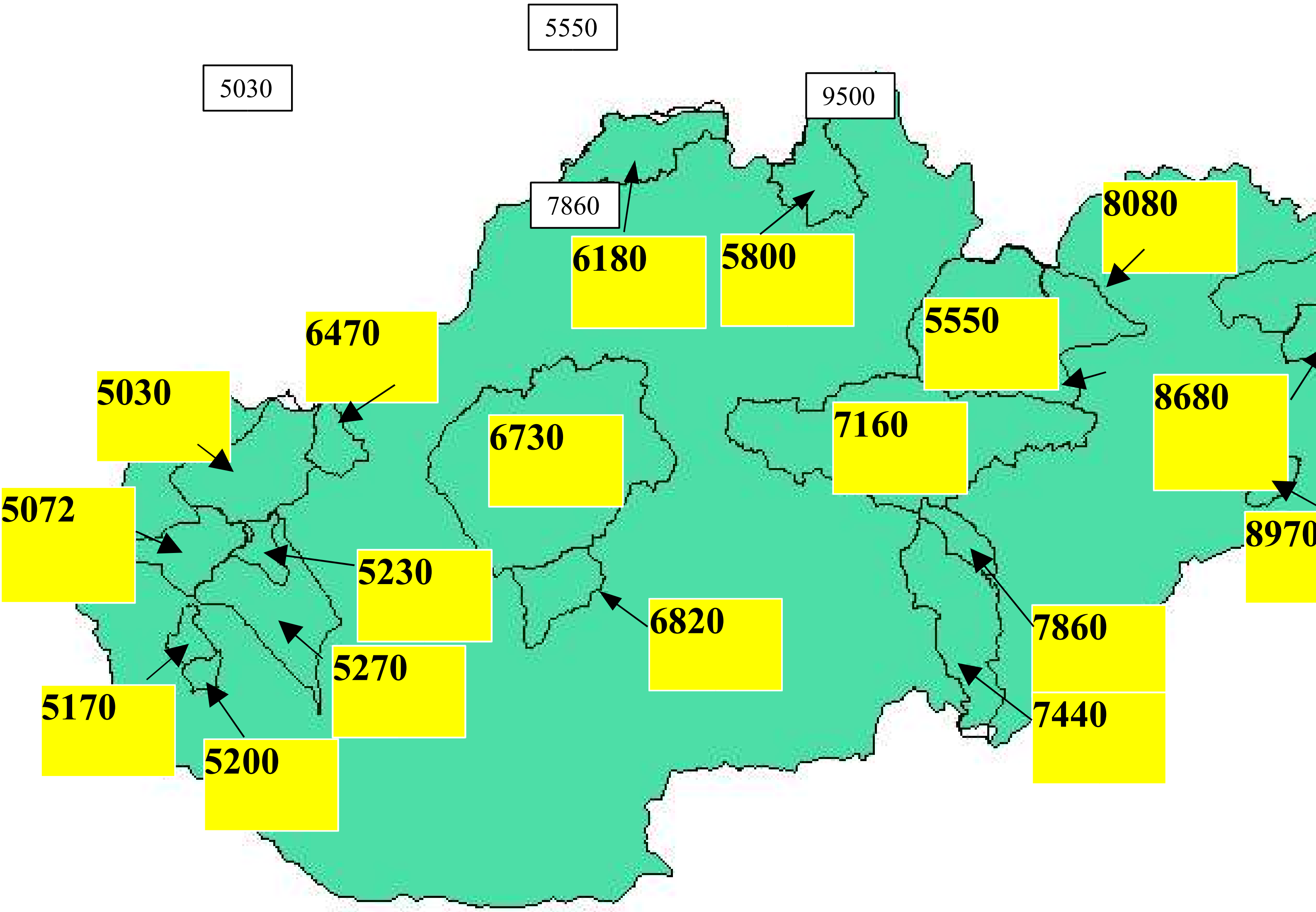

Table 2. *Scenarios of changes in mean monthly and annual air temperatures for Slovakia for the horizons 2010, 2030 and 2075 in °C as compared to the 1951-1980 baseline period.*

CCCM97	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
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	0.72
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	1.14
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	2.74
GISS98													
2010	0.30	0.30	0.50	0.70	0.70	0.60	0.60	0.40	0.30	0.50	0.60	0.50	0.50

2030	1.20	1.00	0.80	0.80	0.90	0.80	0.80	0.70	0.70	0.90	1.20	1.20	0.92
2075	2.70	2.40	2.30	2.20	1.90	1.80	2.10	2.40	2.30	2.30	2.60	2.80	2.32
SD													
2010	1.50	1.40	1.20	0.80	0.80	0.70	0.60	0.60	0.80	0.90	0.90	1.10	0.90
2030	2.50	2.30	2.00	1.40	1.40	1.10	1.10	1.00	1.40	1.40	1.40	1.90	1.60
2075	4.70	4.40	3.80	2.70	2.60	2.10	2.00	2.00	2.60	2.70	2.70	3.60	3.00
WP													
2010	1.30	1.70	1.50	1.30	0.90	0.60	0.90	1.17	0.80	0.40	0.30	0.70	1.00
2030	2.20	2.80	2.50	2.10	1.50	1.00	1.50	1.80	1.30	0.70	0.50	1.10	1.60
2075	4.30	5.30	4.70	4.00	2.80	1.90	2.80	3.40	2.40	1.30	1.00	2.10	3.00

0.1

4. Hydrological scenarios of seasonal runoff distribution

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

a) calibration of the hydrological model in the selected basins,
b) the generation of the reference (baseline) model data using input data from the standard period of 1951-1980,
c) modification of the model input data from the baseline period (precipitation and air temperature) according to the climate change scenarios for the time horizons of 2010, 2030 and 2075,
d) simulation of the monthly runoff series using the hydrological model based on the changed input data and parameters of the model from the calibration,
e) comparison of the differences between the seasonal runoff distribution for the individual scenarios and the time horizons considered.

Detailed results of typical behaviour of the long-term mean monthly runoff under climate change for the CCCM97, GISS98, WP and SD scenarios are given in Table 3 and for the Rimavica basin in Fig. 2. Comparing the expected changes in the seasonal distribution of river flows in the northern part of Slovakia according to the scenarios, it can be concluded that for all the time horizons, a similar redistribution of river runoff within the year can be observed. From October till April (May) an increase in runoff can be expected; on the other hand, during the months of May to September a decrease in discharge may take place. The distribution of runoff changes according to the WP and SD scenarios has a more extreme character.

In southern Slovakia similar changes in the river runoff redistribution within a year can be expected; however, the amplitude of the changes will be greater. From November (December) to February, an increase in river runoff can be assumed. On the other hand, the period from March to October represents a continual period of low flows.

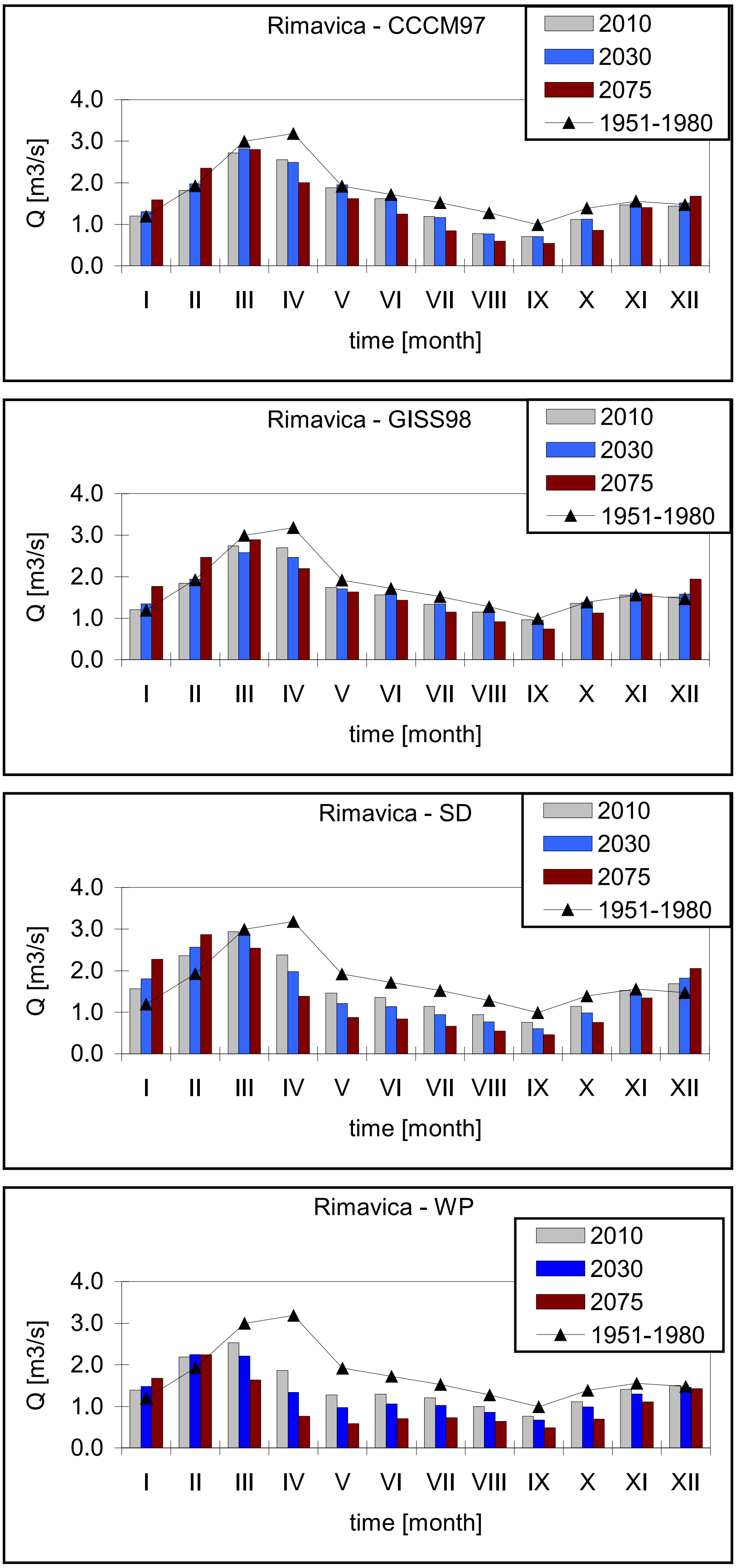

Fig 2. Changes in mean monthly discharges according to all climate change scenarios in the Rimavica basin.

Table 3. Percentage changes in long term mean monthly discharges in selected catchments.

Basin	Scenario	Horizon	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
			[%]											
Myjava Šaštín-Stráže 5030	**CCCM**	2010	33	21	11	4	14	0	0	-2	10	15	24	27
		2030	47	26	11	9	20	3	1	-1	11	17	29	35
		2075	76	26	1	0	6	-15	-18	-20	-9	-6	8	41
	GISS	2010	-37	-39	-27	-4	13	0	15	25	20	-9	-32	-40
		2030	10	-4	-11	-6	-4	-2	-3	-1	3	5	2	5
		2075	38	4	-11	-3	-3	-7	-11	-13	-11	-10	-7	16
	SD	2010	20	1	-12	-12	-13	-14	-16	-15	-14	-13	-8	2
		2030	29	-4	-20	-19	-22	-23	-28	-26	-22	-22	-16	2
		2075	36	-7	-30	-29	-33	-36	-41	-39	-32	-32	-27	-3
	WP	2010	-1	-10	-23	-19	-15	-13	-13	-16	-16	-19	-17	-13
		2030	-2	-19	-34	-29	-24	-21	-22	-25	-23	-26	-26	-21
		2075	-10	-33	-46	-42	-36	-32	-33	-36	-33	-37	-38	-31
Váh 0.1.0.1Liptovský Mikuláš 5550	**CCCM**	2010	6	11	14	-3	-8	-6	-10	-6	-1	5	7	6
		2030	11	23	26	-1	-9	-6	-11	-8	-2	6	10	10
		2075	34	69	57	-7	-22	-19	-22	-17	-12	0	19	24
	GISS	2010	7	9	11	6	-3	2	3	7	11	11	11	10
		2030	17	22	15	2	-6	3	5	8	12	14	17	18
		2075	46	64	51	3	-16	-4	-2	-1	1	9	28	41
	SD	2010	18	29	24	-3	-16	-10	-12	-11	-11	-5	5	11
		2030	35	52	37	-8	-25	-17	-20	-19	-17	-8	7	21
		2075	75	96	46	-27	-39	-28	-32	-30	-27	-15	14	41
	WP	2010	9	26	22	-5	-16	-5	-5	-9	-11	-9	-4	2
		2030	17	44	32	-13	-23	-8	-8	-15	-18	-15	-7	2
		2075	40	80	37	-33	-33	-14	-14	-23	-29	-25	-12	6
Rimavica Lehota nad Rimavicou 7860	**CCCM**	2010	0	-6	-9	-20	-2	-6	-22	-39	-29	-19	-5	-3
		2030	9	2	-6	-22	2	-5	-24	-40	-29	-19	-3	3
		2075	34	22	-7	-37	-16	-28	-45	-54	-45	-38	-10	13
	GISS	2010	1	-4	-8	-15	-9	-9	-12	-10	-2	-2	0	2
		2030	13	1	-14	-23	-11	-8	-12	-10	-4	0	3	7
		2075	48	28	-3	-31	-15	-17	-24	-28	-25	-19	2	32
	SD	2010	31	22	-2	-25	-24	-21	-25	-26	-24	-18	-2	14
		2030	51	33	-5	-38	-37	-34	-38	-40	-38	-29	-7	24
		2075	91	49	-15	-57	-55	-51	-57	-57	-54	-45	-14	39
	WP	2010	17	13	-16	-42	-34	-25	-21	-22	-23	-19	-9	1
		2030	24	17	-26	-58	-49	-38	-33	-33	-32	-29	-16	-1
		2075	40	16	-45	-76	-69	-59	-52	-50	-51	-50	-29	-3
Topľa Hanušovce nad Topľou 9500	**CCCM**	2010	16	19	9	-12	-9	-10	-11	-15	0	5	5	12
		2030	30	33	10	-18	-6	-9	-14	-19	-6	3	6	20
		2075	93	81	6	-36	-20	-25	-28	-29	-22	-15	4	52
	GISS	2010	8	4	1	-4	1	0	-3	1	10	11	6	13
		2030	30	16	-5	-13	0	3	1	5	12	15	13	26
		2075	89	52	1	-26	-4	-4	-9	-12	-11	-1	10	67
	SD	2010	39	28	-9	-33	-25	-17	-20	-18	-20	-16	-3	17
		2030	73	42	-10	-36	-23	-19	-25	-26	-29	-22	-1	38
		2075	142	52	-26	-52	-35	-30	-38	-39	-43	-34	-5	64
	WP	2010	22	24	-8	-24	-5	-1	-8	-17	-24	-25	-14	2
		2030	37	32	-14	-33	-7	-1	-12	-26	-34	-34	-21	1
		2075	74	34	-31	-45	-12	-6	-19	-38	-49	-50	-32	6

5. 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 of 1951 – 1980 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 the most vulnerable to drought.

According to the anticipated changes in the seasonal distribution of the mean monthly runoff, almost the whole territory of Slovakia could become vulnerable to drought in the summer and autumn. In the months with an 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 utilizable 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.

A “no regret” policy based on environmental protection priorities, which is incorporating adaptation measures for the mitigation of the effects of climate changes, is therefore seen here as a solution for the near future. To eliminate the effects of the possible negative trends in the hydrologic cycle and in water resources development in Slovakia, the adaptation strategies addressed on the national level will have to incorporate a number of legislative, organisational and technical actions aimed at protecting the water resources and their source areas.

The results presented here include serious uncertainties. Ongoing research is reported in the literature related to the climate-water resources interface, parameterisation of land surface processes in global and mesoscale atmospheric models, analysis of the sensitivity of water balance components to changes in climatic variables, analysis of the sensitivity of thermal regime of water bodies and of physical, chemical, and biological processes in rivers, lakes, and reservoirs. Also a new generation of climatic scenarios, which will include time series of daily data, is expected to be derived in close future. All these could enable to revisit the results presented here, and also to pay more attention to hydrological extremes.

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