WATER BALANCE ESTIMATION UNDER A CHANGING CLIMATE IN THE TURIEC RIVER BASIN

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The article deals with the estimation of water balance components under a changing climate in selected catchments in Slovakia. Climate change has a significant impact on the hydrological cycle and water resources. In this research, the GIS-based, spatially distributed WetSpa rainfall-runoff model was used to simulate mean daily discharges in the outlet of the basin as well as the individual components of the water balance. The WetSpa model simulations are often used to evaluate the impact of changes on the generation of runoff and water balance. The parameters of the model were estimated using climate data and three digital map layers: a land-use map, soil map and digital elevation model. In this research, the KNMI and MPI regional models with SRES A1B (moderate) emission scenario were used. Outputs from the KNMI and MPI climate scenarios (as input data) were used to estimated future behavior of characteristics of water balance as an actual evapotranspiration and soil moisture. The results showed an increase of actual evapotranspiration and decrease of soil moisture in future horizons in comparison with the reference period of 1981–2010.

KEY WORDS: water balance, climate change scenarios, rainfall-runoff modelling

Introduction

Climate change is a phenomenon that deals with countless numbers of scientific researches. Problematic changes in runoff conditions due to climate change are currently one of the main sources of uncertainty in the long-term planning of water resources and flood protection. The problematics of climate change have also been dealt with by several authors from Slovakia (Rončák et al., 2016). Changing the environment (including changing land use and climate change) and its impact on water resources has been a relatively hot topic in recent years. The direct or indirect consequences on the hydrological regime due to changes in land use and climate have undoubtedly contributed to problems such as water scarcity, proliferation of lightning floods, or damage caused by massive deforestation. Rainfall-runoff models are often used as a tool for assessing the impacts of climate and land use change on the hydrological cycle. While modeling of climate change can be used especially for conceptual rainfall-runoff models, simulating the influence of land use change on the runoff processes in the river basin requires models with spatially distributed parameters. The climate change is caused by increasing concentrations of greenhouse gases in the atmosphere may affect the hydrological cycle and human availability of water and therefore affect agriculture, forestry and other industries (Rind et al., 1992). Changes in the hydrological cycle may cause more incidence of floods in some areas.

Actual evapotranspiration and soil moisture are important in many hydrological conditions. Actual evapotranspiration, reflects complex interactions between climate, vegetation, soil and catchment hydrological processes (Donohue et al., 2006), and is one of the most important variables to diagnose the changes of water regime in the basin scale (Liu and Yang, 2010). Soil moisture has an important effect on the partitioning of precipitation in surface runoff, infiltration and groundwater recharge, and is also a key factor for plant growth, land degradation, flood generation and drought mitigation (Tavakoli and De Smedt, 2013). Decreasing of soil moisture may causes generation of floods as a principal soil threat and soil erosion as an additional soil threat mainly on arable lands of hillslope areas (Hlavčová et al., 2019).

Particularly interesting, as important indicators of global warming, are the projected trends of climate variables such as temperature and rainfall on the Central Europe area. Not only in this region, annual mean temperatures will rise and the warming is likely to be largest in summer (Christensen et al., 2013). Moreover, the majority of the general circulation models (GCMs) foresee an increase, in frequency, of extreme daily precipitation, despite a decrease in total values. Thus, this tendency can lead to longer dry periods, increasing the risks of droughts, interrupted by extreme intense precipitation, enhancing the flood risk (Ayanshola et al., 2018; Wani et
Average runoff in Slovakian rivers is projected to decrease with increasing temperatures and decreasing precipitation. In particular, some river basins may see decreases below today's levels in the future.

Distributed hydrological models (spatially distributed models) take into account the spatial variability of atmospheric processes and the physical-geographic characteristics of river basins that control rainfall-runoff processes. In this paper, we are focusing on a physically based model with spatially distributed parameters. These models are based on a physical description of rainfall-runoff processes and seek to respect the laws of conservation of matter, momentum and energy. The physically based distributed hydrological models are directly capable using geospatial information. The intense development of computer programs promotes the ability to exploit the rich content of information describing land use or soil moisture. Physically-based distributed models are a constantly evolving tool in the hydrology, particularly in the flood protection, or the estimation of the impact of climate and land use change on the runoff processes. Conceptual models are also used to estimate the impact of climate change on components of water balance (Slezia et al., 2016).

In this paper we evaluated the possible impacts of climate change on the components of water balance in the selected river basins, where the simulation of future changes in rainfall-runoff processes were based on the outputs of the KNMI and MPI regional climate models (RCMs).

Data and methodology

In this research the WetSpa model was used for estimating the impact of global climate change on the components of water balance in the selected river basins in Slovakia. This work contains scenarios of global climate change. Outputs from the KNMI and MPI climate scenarios were used to simulation components of water balance. Both types of scenarios of changes were prepared, and the components of water balance under the new conditions was simulated. Then, the calculation of actual evapotranspiration and soil moisture were made. After that, we compared the components of water balance between the reference period 1981–2010 and the climate change scenarios.

Rainfall-runoff model

For simulations of water balance components under changed conditions, the distributed rainfall-runoff WetSpa model was used (Rončák et al., 2016). This research was made for 5 selected basins in Slovakia. For this paper the Turiec River catchment was chosen as example (Fig. 1).

The model uses geospatially referenced data as the input for deriving the model parameters, which includes most data types supported by ArcGIS, such as coverage, shape files, grids and ASCII files. An image can be used for reference within a view, but is not used directly by the model. Digital maps of the topography, land use and

![Fig. 1. The location of the selected catchments within Slovakia.](image)
soil types are the 3 base maps used in the model, while other digital data are optional, depending upon the data available, the purpose, and the accuracy requirements of the project (Wang et al., 1996). The following hydro-meteorological data were used in the model: daily precipitation totals from spot measurements at 17 stations, and the average daily values for the air temperature at 5 climatological stations. The flow data consisted of the average daily flows at the Turiec-Martin profile. The calibration period was from 1981–1995. Twelve parameters for which a range of admissible values set were optimized.

The climate change scenarios

Climate scenarios Dutch KNMI (with A1B emission scenario) and German MPI (with A1B emission scenario) were used for this research. These regional circulation models take over boundary conditions for the solution of equations from the outputs of ECHAM5 global model. Both models are coupled, i.e., atmosphere-ocean circulation models with greenhouse gasses and aerosols influence on change in radiative forcing. The latest climate change scenarios for the territory of Slovakia were processed on the basis of outputs from climatic atmospheric models at the Department of Astronomy, Earth Physics and Meteorology at the Faculty of Mathematics, Physics and Informatics of Comenius University (Lapin et al., 2012). Table 1 illustrates the long-term mean monthly values of the air temperatures and precipitation for the reference period 1981–2010 in the Turiec River basin and their differences for the three future time horizons according to the KNMI and MPI regional climate change scenarios. According to the individual climatic models, as seen in Table 1, a decrease in mean monthly precipitation in the summer period can be expected. On the other hand, the winter period should be more humid in comparison with the current conditions. The mean monthly air temperature will rise, without exception, in the catchment at about the same rate. The mean monthly air temperatures will increase with the increasing time horizons.

Actual evapotranspiration (average actual evapotranspiration losses [mm])

Evapotranspiration from the soil and vegetation is calculated based on the relationship developed by (Thorntwaite and Mather, 1955):

$$ES_i(t) = \left\{ \begin{array}{ll}
\frac{\theta_i(t) - \theta_i(w)}{\theta_i(f) - \theta_i(w)} & \text{for } \theta_i(t) < \theta_i(f) \\
\frac{\theta_i(f) - \theta_i(w)}{\theta_i(f)} & \text{for } \theta_i(t) \geq \theta_i(f)
\end{array} \right.$$

where $ES_i(t)$—actual soil evapotranspiration for the time increment [mm],
$c_i$—vegetation coefficient determined by land use classes varying throughout the year,
$\theta_i(t)$—cell average soil moisture content at time $t$ [m³ m⁻³],
$\theta_i(f)$—soil moisture content at field capacity [m³ m⁻³],
$\theta_i(w)$—soil moisture content at plant permanent wilting point [m³ m⁻³].

Table 1. Long-term mean monthly values of air temperatures and precipitation of reference period and their differences for the future time horizons in the Turiec River basin

| Air Temperature [°C] | I   | II  | III | IV  | V   | VI  | VII | VIII | IX  | X   | XI  | XII |
|----------------------|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|
| 1981–2010            | -3.7| -2.6| 1.1 | 6.5 | 11.7| 14.4| 16.4| 15.9 | 11.3| 6.8 | 1.7 | -2.6|
| KNMI                 | 2025| 0.3 | 1.4 | 1.5 | 0.9 | 1.4 | 1.3 | 1.4  | 1.5 | 1.4 | 1.9 | 0.9 |
|                      | 2055| 1.8 | 3.1 | 1.8 | 1.5 | 2   | 2.4 | 2.3  | 2.4 | 2   | 2.3 | 1.8 |
|                      | 2085| 3.2 | 3.4 | 2.7 | 2.1 | 3.1 | 3.9 | 4.2  | 3.8 | 2.9 | 3.4 | 3.8 |
| MPI                  | 2025| 0.4 | 1.3 | 0.8 | 0.7 | 1   | 1.1 | 1.2  | 1.5 | 1.4 | 1.9 | 1.2 |
|                      | 2055| 2.4 | 3.4 | 1.8 | 1.2 | 1.6 | 1.6 | 2    | 2.7 | 2.2 | 2.2 | 2.2 |
|                      | 2085| 3.7 | 4   | 2.4 | 1.8 | 2.5 | 3.4 | 3.3  | 4   | 3.6 | 3.7 | 3.9 |

| Precipitation [mm]   | I   | II  | III | IV  | V   | VI  | VII | VIII | IX  | X   | XI  | XII |
|----------------------|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|
| 1981–2010            | 60.3| 51.3| 60.2| 57.7| 92.3| 95.5| 100.2| 87.4 | 76.2| 62.5| 69.5| 67.4|
| KNMI                 | 2025| -3.1| 0.2 | -4.5| -8.5| -13.4| -4.4 | -23.4| -3.9 | 30.1| -6.3| -1  | 21.9|
|                      | 2055| 2.1 | 3.7 | 9.1 | 12.9| -14.1| -13.4| -21.4| 0.4  | 14  | 6.2 | -0.5| 24.8|
|                      | 2085| 16.5| 14.4| 23.7| 7.8 | -20.1| -33.2| -32.9| -5.5 | 30.1| 9.5 | 5.8 | 28.6|
| MPI                  | 2025| -0.5| 7.1 | -0.9| -5.6| -14.9| 16.3 | -0.2 | -10.4| 22.1| -7.4| 1.6 | 11.1|
|                      | 2055| 2.5 | 3.7 | 13.4| 19.1| -13.3| 9.3  | -12  | -10.9| 13.1| 4.3 | -7.1| 19  |
|                      | 2085| 12.7| 11.8| 22.5| 14.1| -17  | 0.8  | -19.5| -10.8| 22.6| 12.7| 4.8 | 11.6|
Soil moisture (average soil moisture in the root zone [mm])

For each grid cell, the root zone water balance is modelled by equating inputs and outputs (Liu and De Smedt, 2004):

\[
D \frac{d\theta}{dt} = P - I - S - E - R - F
\]

(2)

where
- \(D\) – root depth [L],
- \(\theta\) – soil moisture content of the root zone [L^3 L^{-3}],
- \(t\) – time [T],
- \(P\) – precipitation intensity [L T^{-1}],
- \(I\) – initial loss due to interception and depression storage [L T^{-1}],
- \(S\) – surface runoff [L T^{-1}],
- \(E\) – evapotranspiration [L T^{-1}],
- \(R\) – percolation to groundwater [L T^{-1}],
- \(F\) – interflow [L T^{-1}].

Results and discussion

In simulating, the expected parameters of the model were obtained from model calibration in period 1981–1995. For the reference period has been selected 1981–2010. The simulated long-term mean monthly actual evapotranspiration and soil moisture were compared with long-term mean monthly values of the reference period. Then, the comparison between the reference period and the climate change scenarios was made.

Figs. 2 and 3 show the calculated values of the components of water balance and their comparison between the reference period and future time horizons.

Looking at Fig. 2 and Table 2, there is an increase in long-term average monthly actual evapotranspiration in selected river basin in each future time horizons. The increase in actual evapotranspiration depends mainly on the increasing air temperature, which directly affects the evapotranspiration value, and whose increase will be characteristic of future time horizons. The increase in long-term average monthly actual evapotranspiration is

![Fig. 2. Comparison of the long-term mean monthly values of actual evapotranspiration in the reference period and in the future time horizons.](image)

| period/scenario | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Øyear |
|-----------------|---|----|-----|----|---|----|-----|------|----|---|----|-----|-------|
| 1981–2010 [mm]  | 0.30 | 1.80 | 12.80 | 39.61 | 70.26 | 83.18 | 86.70 | 69.98 | 42.95 | 16.50 | 3.17 | 0.18 | 427 |
| Turiec KNMI [%]  | 2025 | 47 | 100 | 29 | 6 | 4 | 0 | -2 | -3 | 7 | 22 | 24 | 44 | 4 |
| 2055            | 203 | 163 | 37 | 13 | 10 | 4 | -1 | 2 | 5 | 24 | 55 | 272 | 8 |
| 2085            | 377 | 178 | 61 | 18 | 11 | 2 | -4 | -6 | 7 | 40 | 109 | 844 | 8 |
| Turiec MPI [%]  | 2025 | -30 | 53 | 14 | 5 | 5 | 4 | 3 | 4 | 8 | 18 | 23 | 22 | 6 |
| 2055            | 147 | 169 | 34 | 11 | 9 | 6 | 7 | 6 | 10 | 26 | 80 | 178 | 10 |
| 2085            | 290 | 206 | 51 | 16 | 10 | 8 | 4 | 5 | 11 | 41 | 116 | 383 | 13 |

![Table 2. Simulated long-term mean monthly actual evapotranspiration using the parameters from the 1981–1995 calibration period in the Turiec River basin and its changes for the 3 future time horizons [%]](image)
practically every month. The largest increase (in relative values) is visible in winter period.

Based on Fig. 3 and Table 3, there is a modest decrease in long-term mean monthly values of soil moisture in Turiec River basin in each future time horizon. The reduction in long-term average monthly soil moisture is mainly related to the summer period. On the contrary, there is a slight increase in winter months.

In future time horizons, it is likely that there will be a reduction in the sum of precipitation totals in the summer months and an increase in precipitation in the winter period. Consequently, while in the winter months the soil moisture will grow slightly, it will decline in the summer period.

**Conclusion**

This paper describes the possible impact of climate change on the components of water balance. Actual evapotranspiration and soil moisture are important in many hydrological processes. Therefore, it is important to know their behaviour in the future, especially how the climate change affect them.

The KNMI and MPI climate change scenarios represent less extreme changes (the A1B emission scenario). Based on a scenarios of long-term average components of water balance of future horizons and their comparison with a reference period 1981–2010 it shows that in the future we can expect some change (but not significant) of the long-term mean monthly actual evapotranspiration and soil moisture in the simulated catchments. These changes are predominantly due to the increase of air temperature and decline in precipitation total. This change may reflect differently, depending on several climate change scenarios. Of the considered scenario it suggests that practically all simulated basins could be at risk from the summer or the autumn drought. Based on the simulated watershed in this work it is likely that this effect will apply to the whole territory of Slovakia. On the other hand, it is possible that it runoff will increase in the winter and the loss precipitation of natural snow accumulated.

For an interpretation of these findings, however, one should not forget the limits of rainfall-runoff modeling. Computer simulation models are inherently uncertain, and even more so when considering future projections.

**Fig. 3.** Comparison of the long-term mean monthly values of soil moisture in the reference period and in the future time horizons.

**Table 3.** Simulated long-term mean monthly soil moisture using the parameters from the 1981–1995 calibration period in the Turiec River basin and its changes for the 3 future time horizons [%]

| period/scenario | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Øyear |
|-----------------|---|----|-----|----|---|----|-----|------|----|---|----|-----|-------|
| 1981–2010 [mm]  | 392 | 395 | 399 | 384 | 359 | 351 | 343 | 337 | 344 | 355 | 372 | 385 | 368   |
| KNMI [%]        |    |    |     |     |    |     |     |      |    |    |     |      |       |
| 2025            | 4  | 3  | -1  | -4  | -3 | -3  | -4  | -5   | -1 | -2 | 1   | -1   |       |
| 2055            | 2  | 0  | -2  | -3  | -1 | -4  | -7  | -5   | -4 | -1 | -2  | 1     | -2    |
| 2085            | 1  | 1  | -2  | -3  | -5 | -9  | -11 | -5   | -1 | -1 | 1   | -1   | -4    |
| MPI [%]         |    |    |     |     |    |     |     |      |    |    |     |      |       |
| 2025            | 0  | 1  | -1  | -1  | -1 | -1  | 1   | -2   | 0  | -1 | -2  | 0    | -1    |
| 2055            | 1  | 0  | -2  | -1  | -1 | -1  | -2  | -4   | -2 | 0  | -2  | 0    | -1    |
| 2085            | -1 | -1 | -3  | -2  | -3 | -4  | -5  | -7   | -5 | 0  | -2  | -1   | -3    |
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