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Evaluation of hydrological alterations of the Hron River basin

Zuzana Sabová* and Silvia Kohnová

Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Bratislava, Slovak Republic

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ABSTRACT

This study evaluates future hydrological alterations caused by climatic changes until 2100 using climate change scenarios. The indicators of hydrologic alteration software program assess predicted changes in flow characteristics and the degree of hydrological alteration obtained through a range of variability approach analysis. The study was performed on the Hron River basin in Slovakia, using the daily discharges from the observation period of 1981–2010 and a modelled scenario of daily discharges until 2100. The time period investigated was divided into three periods among which four ranges of variability approach analysis were conducted. The study results presented assume an increased incidence of drought in the summer months. In the winter months, the period of increased flows is expected to intensify.

KEYWORDS

hydrological alteration, climate scenarios, climate change, the hron river basin

1. INTRODUCTION

A warming trend is visible across Europe as a result of climate change, but trends in precipitation are more spatially variable. However, in the conditions of Central Europe, the precipitation conditions have not changed much [1]. Human activities connected with climate change influence the biodiversity and integrity of river ecosystems, which depend on a natural flow regime. One of the leading causes of the degradation of a river ecosystem is a change in the flow regime [2]. River ecology increasingly emphasizes the natural variability of flows, while maintaining biodiversity and the integrity of an ecosystem [3].

Environmental factors, including the temperature, amount of oxygen, channel forms, and sediments, are frequently intertwined with the flow. Natural stream flow regimes change the distribution and availability of a riverine habitat, which adversely affect native biota [4]. The amount of change in natural habitats and the structure of river flows that may occur without causing a significant impact on an ecosystem's health is limited [5]. Maintaining a natural flow regime is a central principle for river biodiversity; however, human activities and climate change factors have a significant influence on the naturalistic flow regimes of rivers across the world. A key stage in the protection and conservation of rivers is determining the degree of change in a flow regime [6]. The development of runoff is a multi-step process involving various factors. As a result, estimating the potential impact of climate change on water resources and suggesting some strategic approaches is critical. Models of rainfall-runoff are frequently used to predict the influence of climate change on runoff [7]. Predicting hydrological features for basins is one of the most important challenges in hydrology and associated disciplines, as well as one of main functions in engineering hydrology [8].

The practicality of the Range of Variability Approach (RVA) analysis has only increased in recent decades when a more significant emphasis has been placed on hydrological regimes and water resources in ecosystem management [9]. More and more scientists are working on

*Corresponding author.
E-mail: zuzana.sabova@stuba.sk

RVA analysis. They focus on the impact of dams on flow regimes [10]; RVA analysis focus on morphological changes of hydrological indicators [11] and the periodicity of hydrological indicators [12]. The Indicators of Hydrologic Alteration (IHA) software has also been used for analysis in Slovakia, i.e., analysis of the changes in low discharges on the Danube River [13], analysis of changes in the daily discharge regimes on Slovak rivers [14], and analysis of the average monthly and minimum discharges in the Myjava River basin and the Upper Hron River basin [15, 16].

RVA analysis is mainly used in assessing changes in a natural river system after the construction of a dam, changes in water abstraction, etc. The present paper deals with the assessment of changes in a hydrological regime due to climate change, using two climate scenarios, i.e., the German climate scenario, developed by the Max Planck Isntitute (MPI) and the Dutch climate scenario, developed by the Koninklijk Netherlands Meteorological Institute (KNMI). The paper aims to detect changes in the characteristics of the hydrological regimes for the MPI and KNMI climatic scenarios investigated until 2100 in the Hron River basin. The time period examined is divided into changes in the hydrological parameters by 2050 and by 2100, while the climate scenarios are compared with the discharges observed by the year 2019.

2. MATERIAL AND METHODS

2.1. Input data and study area

The input data consists of a series of mean daily discharges from real observations (available from 1931 to 2019) and data from the MPI climate scenario (available from 1951 to 2100) and KNMI climate scenario (available from 1950 to 2100). Pre-processing of data from both climate scenarios goes through the Hydrologiska Byråns Vattenbalansavdelning (HBV) rainfall-runoff model with Technical University of Wien (TUW) implementation. The inputs to the HBV rainfall-runoff model were the air temperatures and precipitation according to the climate scenarios in the calibration period (Jan. 1, 2011 – December 31, 2019).

The MPI and KNMI climate scenarios have a more detailed integration of atmospheric and dynamic ocean equations with a resolution of 25×25 km, while boundary conditions are from the outputs of the type of Global Circulation Model (ECHAM5) model and the medium emission of the Special Report on Emission Scenario (SRES A1B) [17]. The scenarios include the daily average maximum and minimum air temperature, daily average of the relative humidity, daily average precipitation, daily average wind speed values, and daily global radiation totals [15].

The IHA program applied in this study used daily hydrological series of discharges from real observations and daily discharges modeled by the HBV rainfall-runoff model, which arose from the data of the MPI and KNMI climate scenarios. Table 1 contains a more accurate distribution of the available data along with the range of time periods.

Table 1. Distribution of the data and their time periods

Data	Time period
Observed data (OBS)	1.11.1981–31.10.2019
Modeled data using the MPI scenario	1.11.2019–31.10.2050
	1.11.2019–31.10.2100
Modeled data using the KNMI scenario	1.11.2019–31.10.2050
	1.11.2019–31.10.2100

The selected gauging station is the Banská Bystrica, with the number of the gauging station, No. 7160, located in the Hron River basin in Slovakia (Fig. 1).

2.2. Methodology

Many streams and rivers in industrialized countries have long-term, daily stream flow data that may be used to assess long-term changes in flow. In this study, the difference in the hydrologic regime featured among two specified time periods at a specific stream gauge is used to analyze hydrological changes. The RVA emphasizes the importance of hydrological variability in the structure and management of a freshwater ecosystem [18].

The goal range for each IHA parameter is determined from the 25th to the 75th percentile of the "pre-impact" parameter value. Change in the IHA parameters is defined as the divergence between the percentage of the "pre-impact" and "post-impact" values. The program calculates the frequency with which the values in the "post-impact" period can fall into one of three categories, i.e., the low category (values up to the 33rd percentile), the middle category (values up to the 67th percentile), and the high category (values above the 67th percentile) [18].

The RVA analysis was employed to estimate the degree of change for each hydrological indicator in IHA; it is referred to as the conventional RVA in this study, based on the IHA approach. The following equation defines the degree of hydrological alteration:

$$HA = \frac{OF - EF}{EF}, \qquad (1)$$

where HA is the hydrological alteration; OF is the observed frequency; and EF is the expected frequency (EF can be

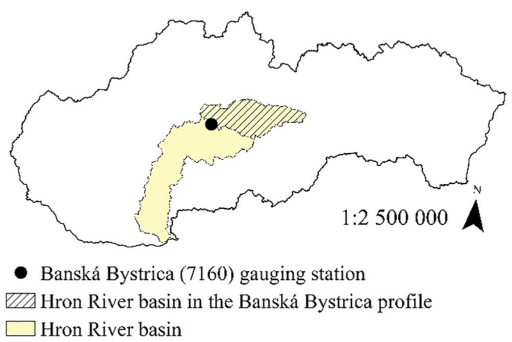

Fig. 1. Location of the Banská Bystrica No. 7160 gauging station in the Hron River basin, Slovakia

calculated as the number of “pre-impact” values multiplied by the ratio of years “post-impact” to years “pre-impact”). The positive *HA* values indicate that the frequency of the parameter in the “post-impact” period has increased in the given category; to the contrary, negative values indicate a decline [18, 19].

In this study, the RVA analysis compares the observed data with the modeled data of the climate scenarios. Analysis was performed using nonparametric statistics, while the water year (from November to October) was considered the selected period of the year.

3. RESULTS AND DISCUSSION

The resulting values of the RVA analysis, which compared the observed data and the modeled data according to the MPI climate scenario (Fig. 2), indicate the largest change in the parameters of the high pulse count and number of reversals, i.e., change is a more frequent occurrence in the low RVA category. The frequency of the high RVA category increases from the 90-day to the 1-day minimum discharges. At the *m*-daily maximum discharges, it sees a change in frequency in the low RVA category and its decrease from the 1-day to the 90-day maximum discharge. For the average monthly discharges, a difference is evident in the high RVA category in February and July according to the simulated data using the MPI climate scenario by 2050, and in December, January, and February by 2100.

By comparing the observed data with the KNMI climate scenario model data (Fig. 3), the greatest hydrological changes are concentrated in the characteristics of the high pulse count, number of reversals and low pulse count. The *m*-daily maximum discharges increases in the low RVA category until 2050; while by 2100, the growth in this category also applies to the m-daily minimum discharges. An expansion of the average monthly discharges is predicted for December, January, February and March in the high RVA category by 2100.

The percentage results of the RVA analysis for both climate scenarios by 2100 are shown in Tables 2–4. The table contains the selected IHA parameters and their changes within each RVA category.

In their study, Blahušiaková and Matoušková [20] pointed out the declining trend in the stream-flow in the upper Hron River basin, which especially showed itself in the years from 1931 to 2010. By 2010, the minimum discharges in the Hron River basin had decreased by an average

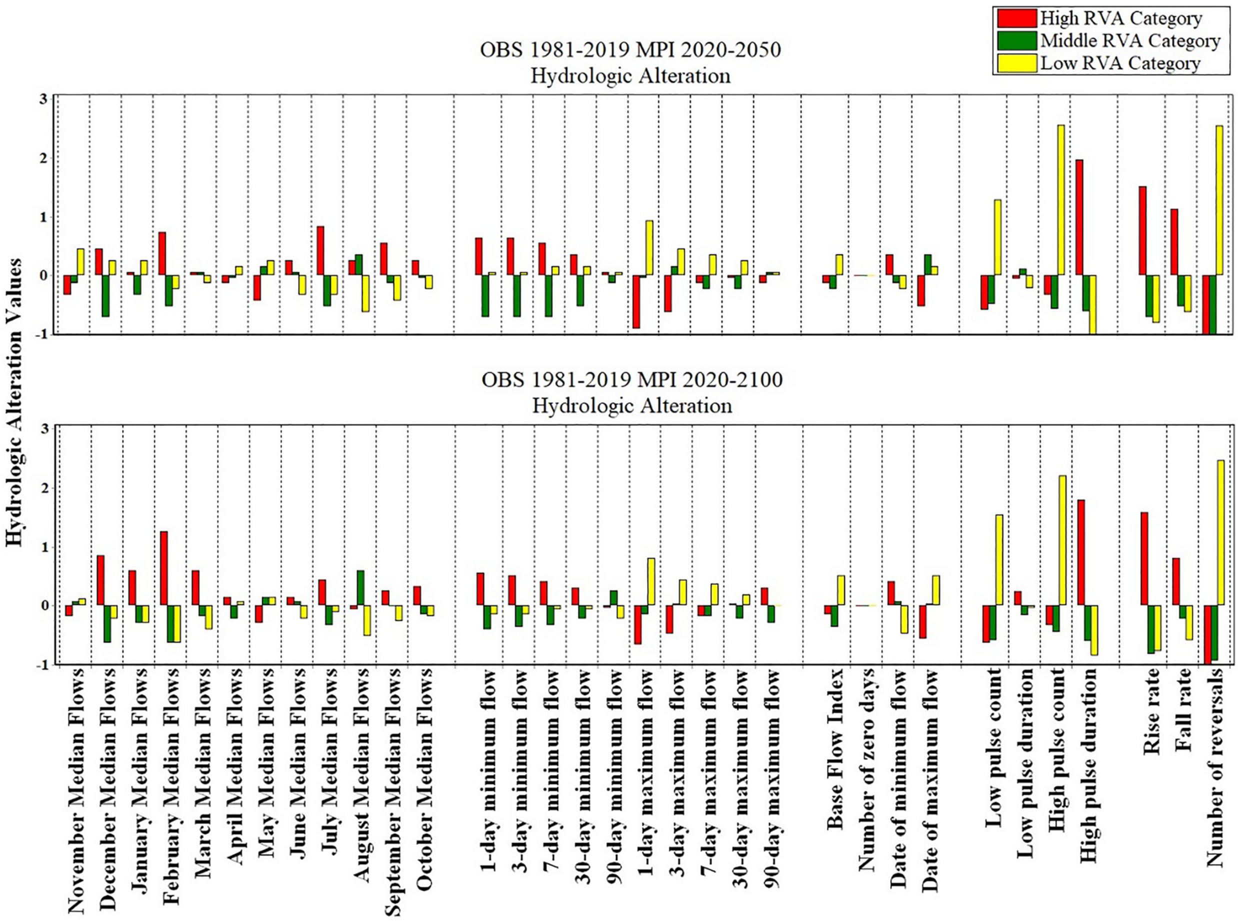

Fig. 2. The results of the RVA analysis of the OBS data in the “pre-impact” period and the simulated data using the MPI scenario in the “post-impact” period of the Hron – Banská Bystrica No. 7160 gauging station

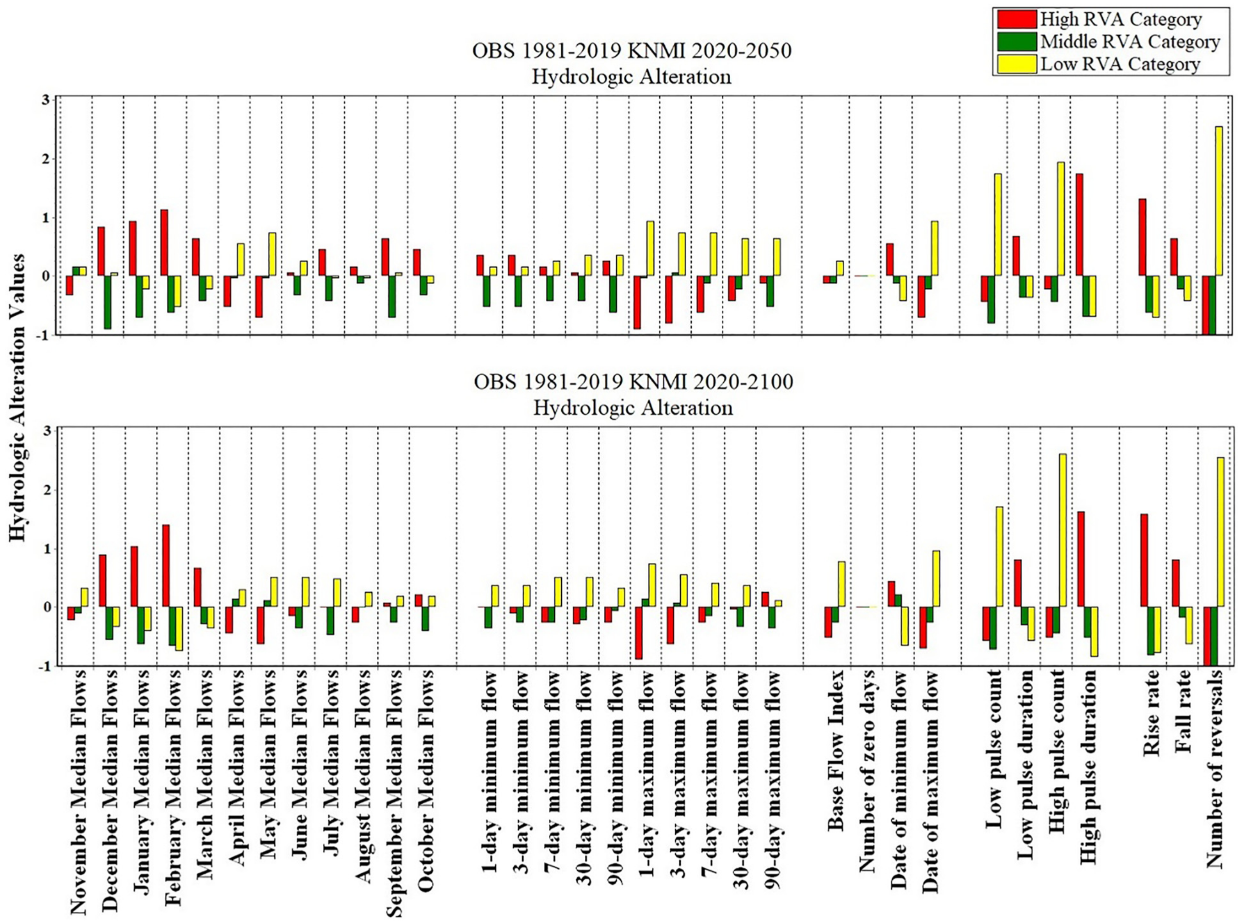

Fig. 3. The results of the RVA analysis of the OBS data in the “pre-impact” period and the simulated data using the KNMI scenario in the “post-impact” period of the Hron – Banská Bystrica No. 7160 gauging station

of 19–24%. For 1, 3 and 7-day maximum discharges, the most significant decrease they recorded in the time period examined was until 2010, and the selected gauging stations were Telgárt and Zlatno [20]. Another study, which dealt with identifying changes in the regime of daily flows of Slovak rivers, also confirmed a significant decrease in the values of flows in the case of the Hron River in the period 1931–2014 [14].

According to the MPI and KNMI climate scenarios, the analysis of the average monthly and minimum discharges in

Table 2. Percentage results of the RVA analysis for average monthly discharges for the Hron – Banská Bystrica No. 7160 gauging station by 2100

	MPI 2100			KNMI 2100		
	Low (%)	Middle (%)	High (%)	Low (%)	Middle (%)	High (%)
November	11	7	−19	33	−11	−22
December	−22	−63	85	−33	−56	89
January	−30	−30	59	−41	−63	104
February	−63	−63	126	−74	−67	141
March	−41	−19	59	−37	−30	67
April	7	−22	15	30	15	−44
May	15	15	−30	52	11	−63
June	−22	7	15	52	−37	−15
July	−11	−33	44	48	−48	0
August	−52	59	−7	26	0	−26
September	−26	0	26	19	−26	7
October	−19	−15	33	19	−41	22

Table 3. Percentage results of the RVA analysis for m-daily maximum/minimum discharges and base flow index for the Hron – Banská Bystrica No. 7160 gauging station by 2100

	MPI 2100			KNMI 2100		
	Low (%)	Middle (%)	High (%)	Low (%)	Middle (%)	High (%)
1-day minimum	−15	−41	56	37	−37	0
3-day minimum	−15	−37	52	37	−26	−11
7-day minimum	−7	−33	41	52	−26	−26
30-day minimum	−7	−22	30	52	−22	−30
90-day minimum	−22	26	−4	33	−7	−26
1-day maximum	81	−15	−67	74	15	−89
3-day maximum	44	4	−48	56	7	−63
7-day maximum	37	−19	−19	41	−15	−26
30-day maximum	19	−22	4	37	−33	−4
90-day maximum	0	−30	30	11	−37	26
Base flow index	52	−37	−15	78	−26	−52

Table 4. Percentage results of the RVA analysis for the rate and frequency of water condition changes for the Hron – Banská Bystrica No. 7160 gauging station by 2100

	MPI 2100			KNMI 2100		
	Low (%)	Middle (%)	High (%)	Low (%)	Middle (%)	High (%)
Rise rate	−78	−81	159	−78	−81	159
Fall rate	−59	−22	81	−63	−19	81
Number of reversals	246	−94	−100	255	−100	−100

the Hron River basin shows that the average monthly discharges are expected to decrease in the summer and increase in the winter months by 2100 [16].

The locality of the Hron River basin is thus far analyzed only within the observed data from historical periods; it is therefore important to focus on predicting changes in the future, which is the subject of the contribution presented.

4. CONCLUSION

The paper deals with the RVA analysis of the hydrological parameters for the Hron – Banská Bystrica No. 7160 gauging station. IHA software was used to perform the analysis. In this work, comparisons of the observed and simulated data according to the MPI and KNMI climate scenarios were presented.

The discharge time series modeled using MPI climate scenario data show changes in the future, especially in the number of reversals especially in the low RVA category. For m-daily minimum discharges, there is a visible increase in frequency in the high RVA category (maximum in the 1-day minimum discharge parameter by 56%) by 2100. To the contrary, for the m-daily maximum discharges, there is an increase in frequency in the low RVA category (a growth of 81% in a 1-day maximum discharge). The highest changes in the mean monthly discharges occur in February and indicate a 126% increase in the high RVA category compared to the observed data until 2019.

The modeled mean daily discharges using the KNMI climate scenario show an increase in the low RVA category in the number of reversals parameter. For the m-daily minimum discharges, the most significant growth is in the low RVA category (max. of 52% at the 7 and 30-day minimum discharge parameter). The m-daily maximum discharges show a decrease of 37% in the 1-day maximum discharge. The largest increase in the high RVA category is in the average monthly discharges in December (89%), January (104%), and February (141%) by 2100.

According to the resulting values presented, it can be predicted that the average monthly discharge values for the Hron – Banská Bystrica No. 7160 gauging station will increase in the winter months, probable due to future increase in air temperatures or change of the solid to liquid form of precipitation in the winter season. In the summer months, the incidence and frequency of droughts period and low flows are expected to be higher in the future.

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