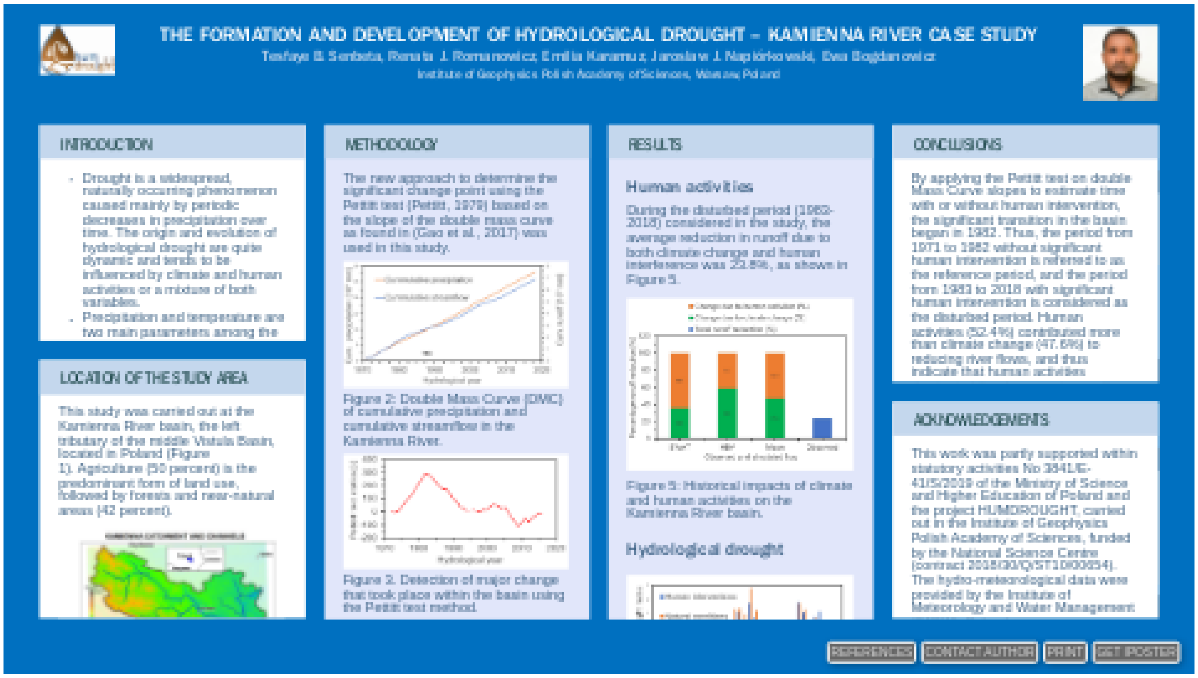
THE FORMATION AND DEVELOPMENT OF HYDROLOGICAL DROUGHT – KAMIENNA RIVER CASE STUDY



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PRESENTED AT:

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

BACKGROUND

- Drought is a widespread, naturally occurring phenomenon that is mainly caused by periodic declines in precipitation over time (Liu et al., 2016).
- Drought can be characterized as meteorological (precipitation and evapotranspiration) drought, hydrological (surface and groundwater) drought (surface and groundwater), agricultural (soil moisture) drought, and socio-economic drought, taking into account hydro-meteorological variables and influencing factors (Gao et al., 2020; Tigkas et al., 2015).
- Hydrological drought formation and development is quite dynamic and tends to be influenced by climate and environmental control or a mixture of both variables (Liu et al., 2016).
- Human activities affecting the hydrological processes in a river basin take many forms, and the influence of these activities on the propagation of drought in a river basin depends on the magnitude of the processes involved.
- The research presented focuses on the influence of reservoir and land use on hydrological drought.

THE STUDY AREA

- The Kamienna River is the tributary of the Vistula River Basin, located in central Poland (Figure 1).
- The Kamienna River has a mountainous character, with several water retention reservoirs and a history of industrial activities in the region.
- Agriculture (50 percent) is the predominant form of land use, followed by forests and near-natural areas (42 percent).
- The hydrometeorological data containing the daily discharge measured at the Czekarzewice gauging station and the daily meteorological data measured at the Sandomierz, Kielce, and Staczow stations, such as temperature, precipitation, relative humidity, and wind speed were used in this analysis.

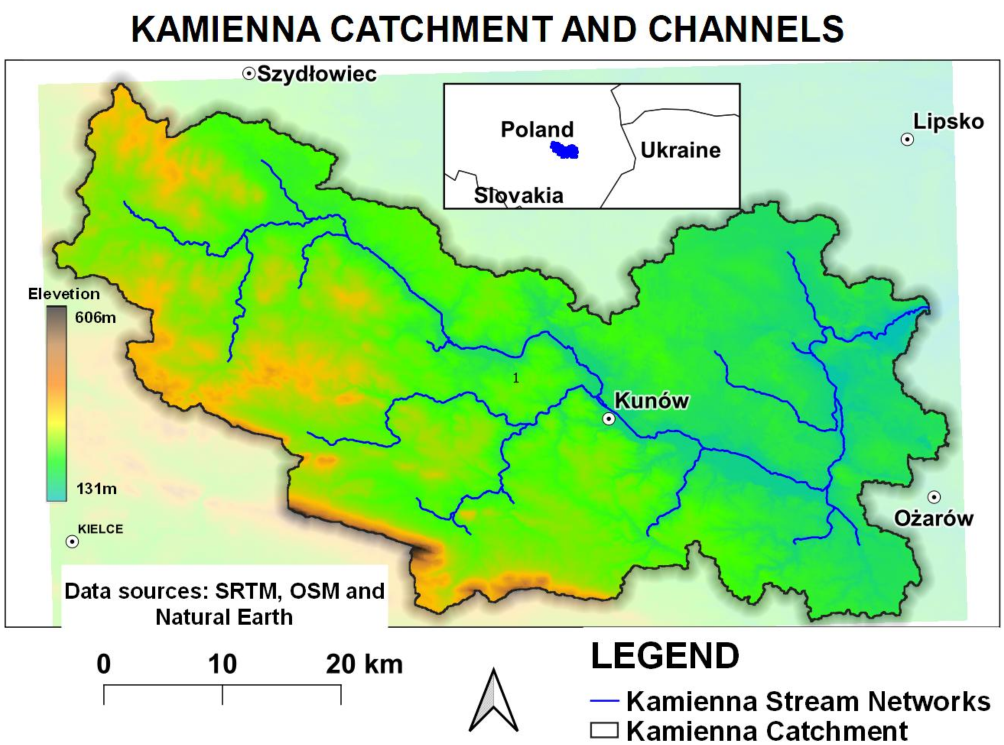

Figure 1: Location of the study area.

METHODOLOGY

Change-point detection: Pettitt' test

- The Thiessen Polygon method was used to generate spatially continuous areal precipitation over the catchment area based on measured point data.
- Annual precipitation and streamflow discharge tested for trend and change-point detection, and double mass curve analysis.
- The Pettitt test (Pettitt, 1979) is a nonparametric statistic widely used in hydrometeorological continuous time series to locate the most important point of shift when the correct time of the shift is uncertain.
- The new approach to determine the change point using the Pettitt test based on the slope of the double mass curve as found in (Gao et al., 2017) was used in this study.
- The period from 1971-1982 and 1983-2018 is taken as a reference and disturbed period respectively, based on the result of the Pettitt test.

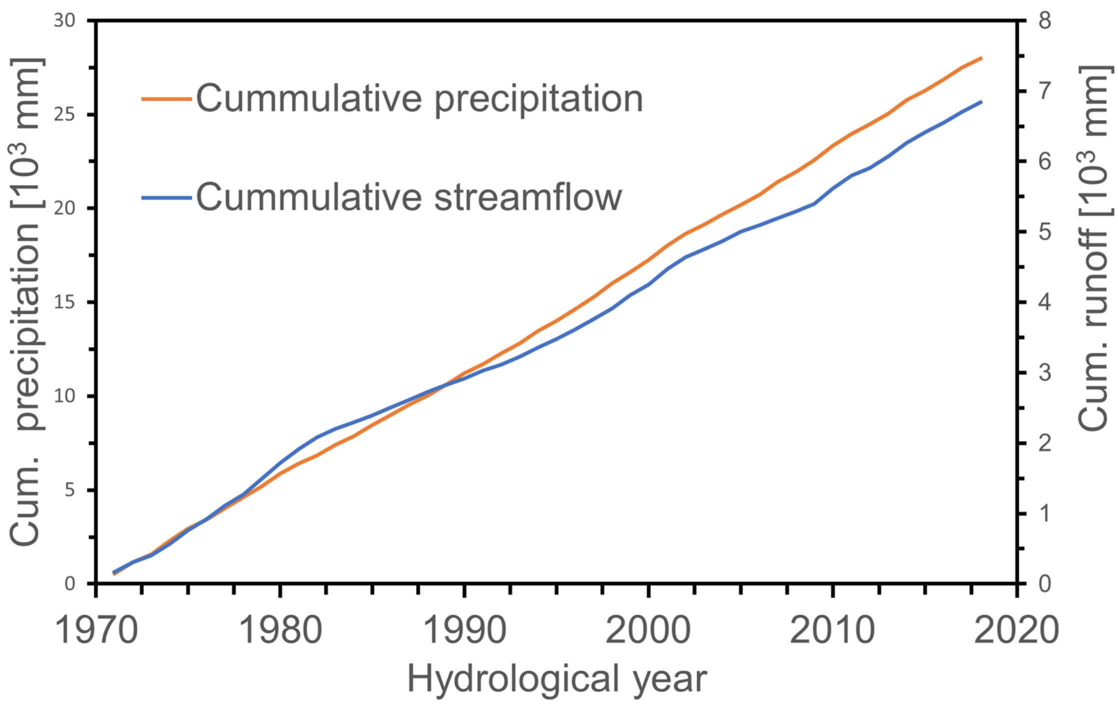

Figure 2: Double Mass Curve (DMC) of cumulative precipitation and cumulative streamflow in the Kamienna River.

Hydrological modeling approaches for separating the impact of climate variability and human activities

- The selected hydrological models (SWAT, HBV, and TOPMODEL) were calibrated and validated in the years 1971-1976 and 1977-1982 respectively.
- The Nash-Sutcliffe efficiency (NSE) and Kling-Gupta efficiency (KGE) were used as objective functions to evaluate model performance.
- Both SWAT and HBV models were calibrated against the observed daily flow. However, the TOPMODEL was calibrated and validated against the baseflow obtained from the observed flow using the Wittenberg approach (Wittenberg, 1999). This model was primarily developed for hourly observations and its unsaturated zone routine does not perform well for the daily data. The models performed well to very well.

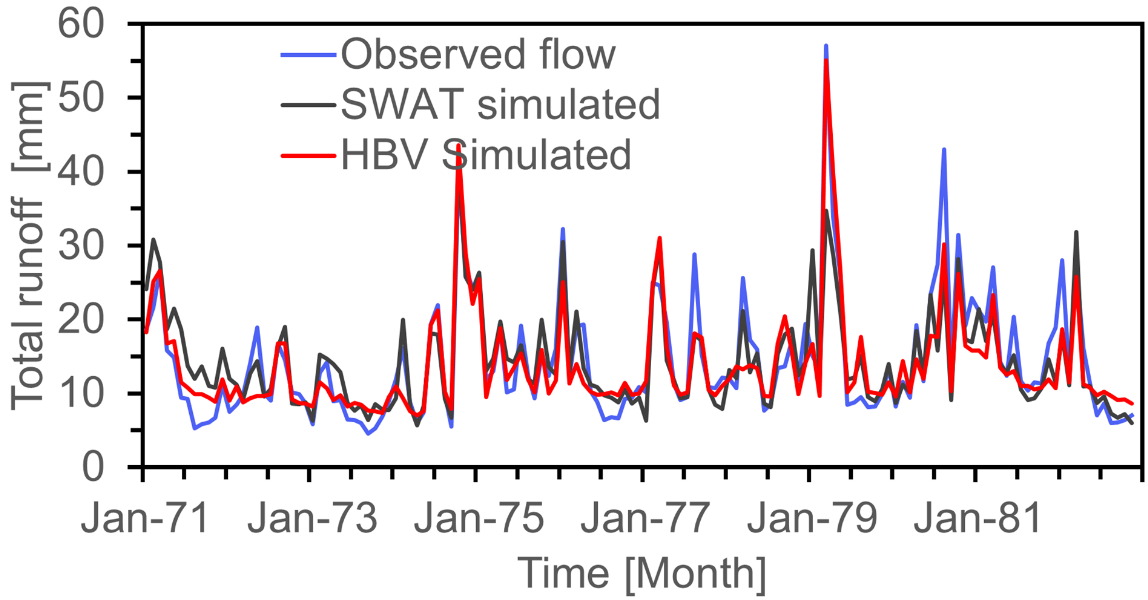

Figure 3: Observed flow, the SWAT and the HBV models simulated the flow during the calibration and validation stages.

RESULTS

Human activities

- During the disturbed period, the average reduction in runoff due to both climate change and human interference was 23.8%, as shown in Figure 4.

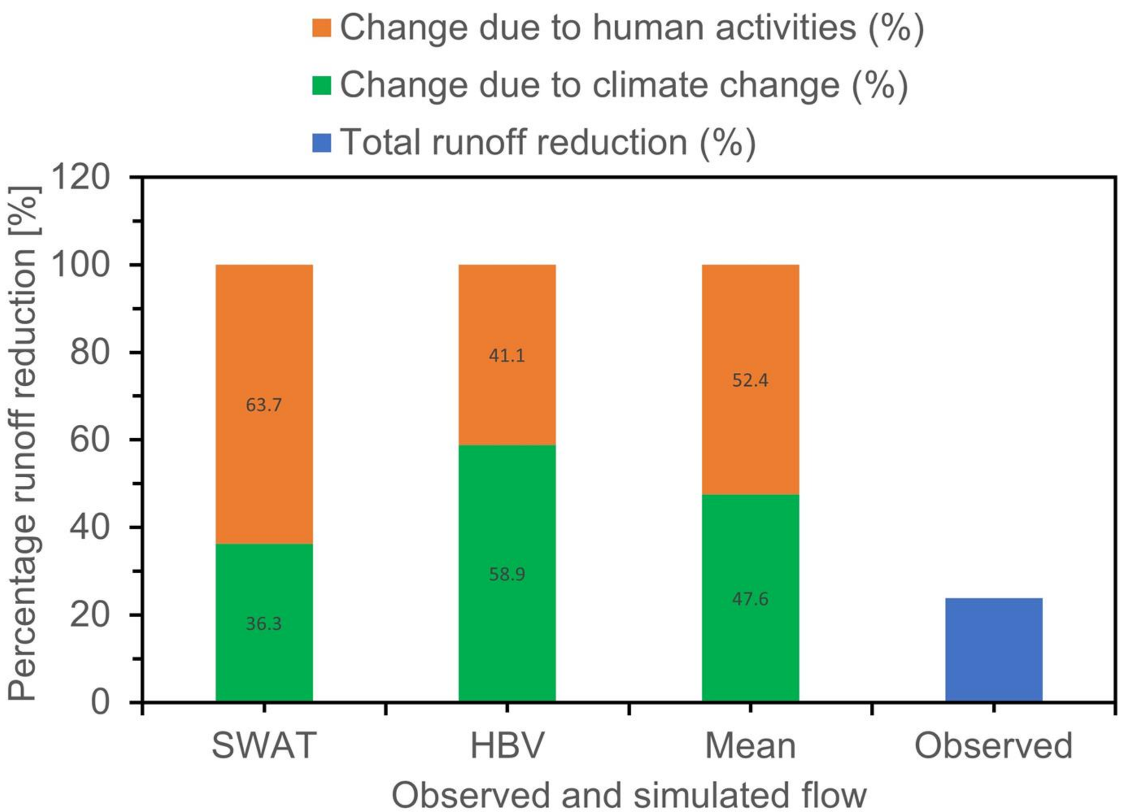

Figure 4: Historical impacts of climate and human activities on the Kamienna River basin.

Hydrological drought

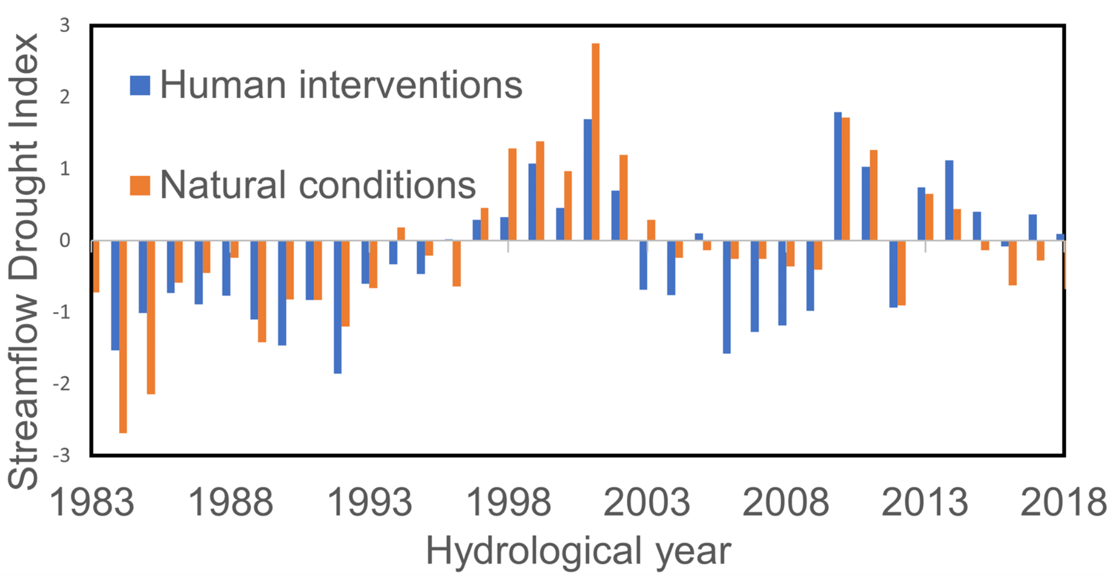

Figure 5: The development of hydrological droughts with significant human intervention (blue) and natural conditions (red) during 1983-2018.

FLOW Regime

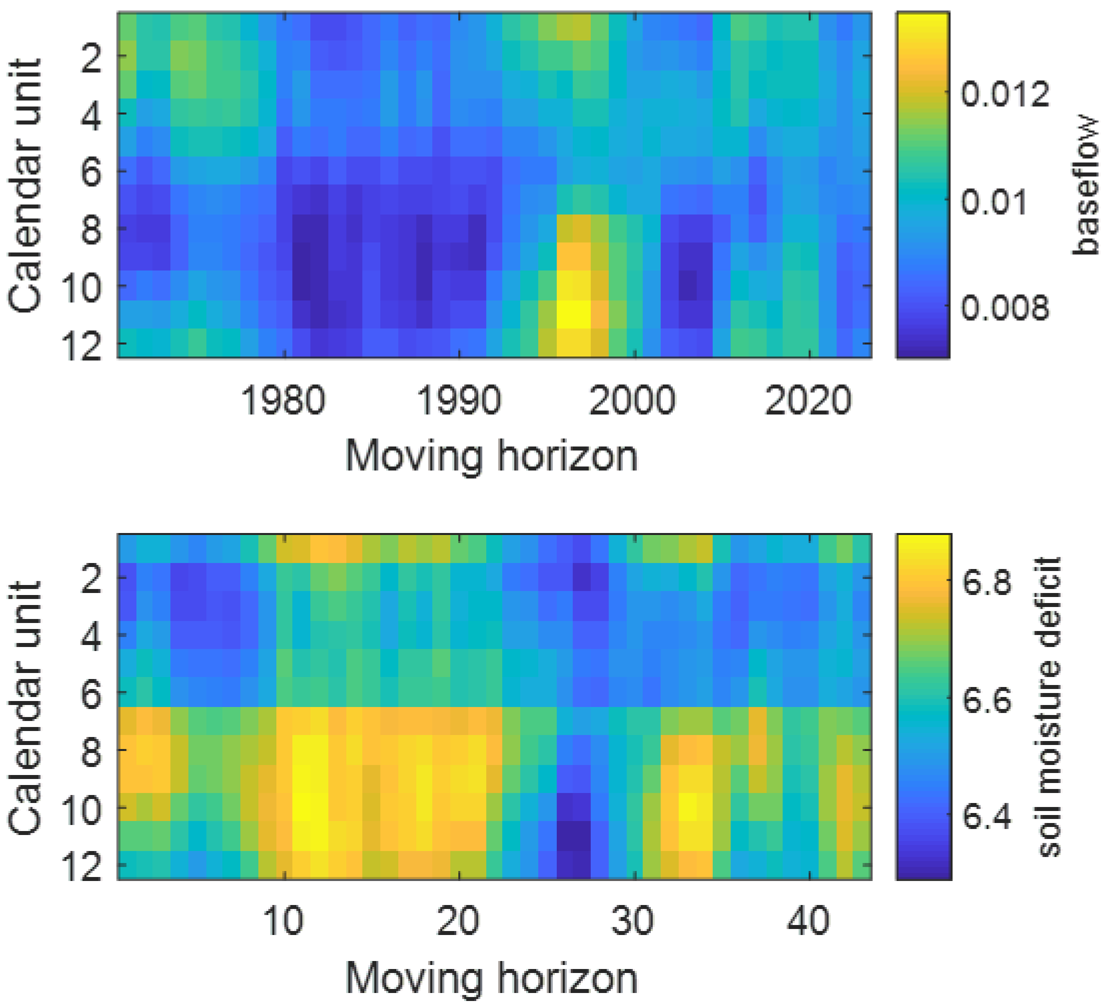

Figure 6: Upper panel: baseflow simulated by the TOPMODEL; lower panel: soil moisture deficit simulated by the TOPMODEL.

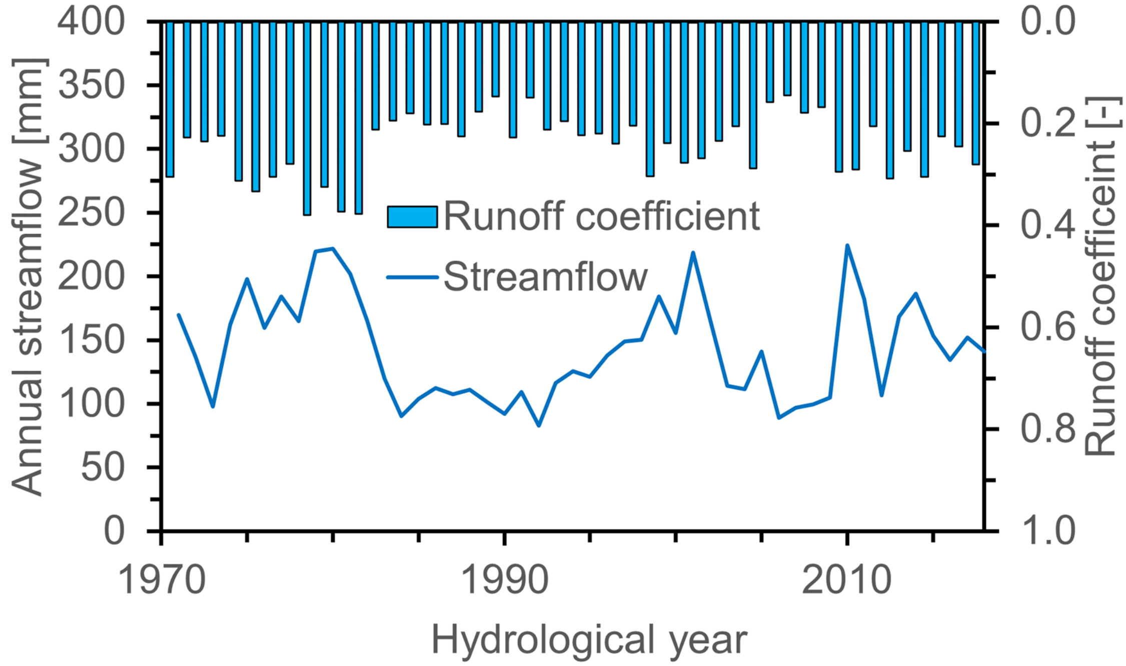

Figure 7: Temporal evolution of streamflow and runoff coefficient over the Kamienna River basin.

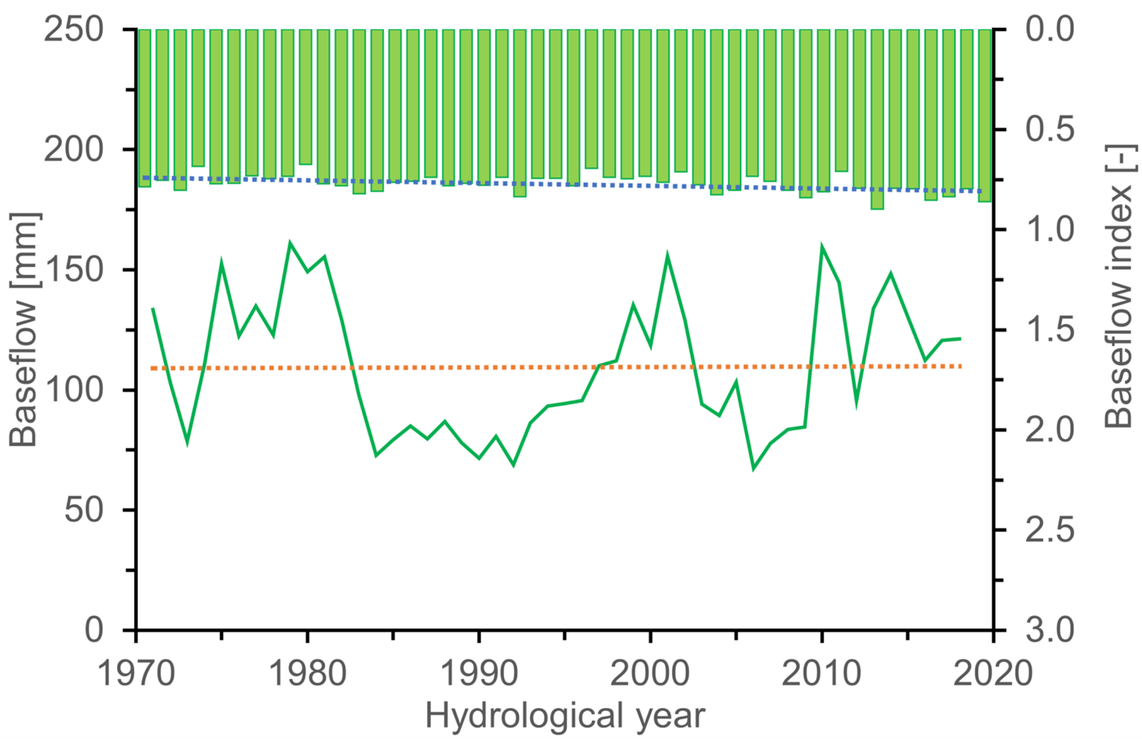

Figure 8: Historical variations of the baseflow and baseflow index over the basin.

CONCLUSIONS

- By applying the Pettitt test on double Mass Curve slopes to estimate time with or without human intervention, the significant transition in the basin began in 1982.
- The period from 1971 to 1982 without significant human intervention is referred to as the reference period, and the period from 1983 to 2018 with significant human intervention is considered as the disturbed period.
- Human activities (52.4%) contributed more than climate change (47.6%) in reducing river flows, and thus indicate that human activities dominated the decrease in runoff over the Kamienna River.
- Of the four decades considered in this study, the first (the 1980s) and the third (2000s) are the two severe decades that suffer successive periods of drought, while in the 1990s there are fewer hydrological droughts.
- Human intervention such as the construction of reservoirs, land-use changes, mining, etc. has led to a more severe hydrological drought than under natural conditions, with a significant difference between the two conditions, particularly in the 2000s (2001-2010).
- The temporal variations in runoff coefficient decline while those of baseflow index increase during the disturbed period.

ACKNOWLEDGEMENTS

This work was partly supported within statutory activities No 3841/E-41/S/2019 of the Ministry of Science and Higher Education of Poland and the project HUMDROUGHT, carried out in the Institute of Geophysics Polish Academy of Sciences, funded by the National Science Centre (contract 2018/30/Q/ST10/00654). The hydro-meteorological data were provided by the Institute of Meteorology and Water Management (IMGW), Poland.

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