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Understanding the Temporal and Spatial Dimensions of Socio-hydrological Vulnerability to Drought in the Context of Climate Change, Vistula River

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Abstract

In the Anthropocene, droughts cannot be considered as natural phenomena/ hazards. Therefore, it became crucial to assume human impacts and their interactions with the water system in drought vulnerability assessment through the concept of the socio-hydrology. We applied the socio-hydrological approach for identifying drought-vulnerable areas in the Vistula River basin. The Soil and Water Assessment Tool (SWAT) model was used to derive missing hydro-climatic variables, such as soil moisture at sub-basins and hydrological response unit level. The vulnerability indicator was selected based on the statistical significance of the factors affecting the water resources and socio-economics of the drought-prone. The preliminary results showed that the middle part of the Vistula catchment is more exposed to drought than the upper and lower parts of the main river course.

Keywords: drought vulnerability, socio-hydrology, SWAT model, Vistula River basin, vulnerability indicators.

1. INTRODUCTION

One of the droughts definitions often considers it as a climatic phenomenon triggered by a precipitation deficits alone. However, in the Anthropocene when human activities strongly influence the Earth’s system, anthropogenic activities also play an important role in influencing drought dynamics. Therefore, the new concept of socio-hydrological approach has been proposed in hydrology to consider the impact of humans and their interactions with the water system (Boori and Voženílek 2014). This new approach is used to assess the dynamics of drought vulnerability over time and space based on an integrated approach that considers multiple factors, including physiographic, social, and hydroclimatic factors. The factors are selected according to their impact, data availability, and reliability out of the three basic dimensions of socio-hydrological vulnerability: (i) Exposure, (ii) Sensitivity, and (iii) Adaptive Capacity. Previous studies on drought vulnerability focused on physiographic and hydro-climatic factors (e.g., Jain et al. 2015; Pandey et al. 2010; Singh et al. 2019) and to our knowledge only few studies considered socio-economic factors, especially people's coping capacity, in assessing drought vulnerability. The aim of this study is, therefore, to assess and identify social and physical vulnerability to drought through the socio-hydrological approach. The novelty of this study is the integration of several hydro-climatic drought indicators as a single index in socio-hydrological vulnerability mapping using marginal likelihood function. This will help with the identification of the areas vulnerable to drought risks and support a drought prevention and climate change adaptation.

2. DATA AND METHODS

2.1 Study area

The study area consists of six sub-basins in the Vistula River basin (Fig. 1). These sub-basins were selected to reflect hydrological conditions caused by significant change in runoff due to human impacts. The predominant land use in the Vistula River basin is agriculture, followed by forest and semi-natural areas. The most severe and longest-lasting drought in the catchment occurred in 1982–1993 (Karamuz et al. 2021). The long-term average hydroclimatic variables varies spatially across the basin, with the highest values occurring near the headwaters and the lowest in the middle part (Senbeta et al. 2022).

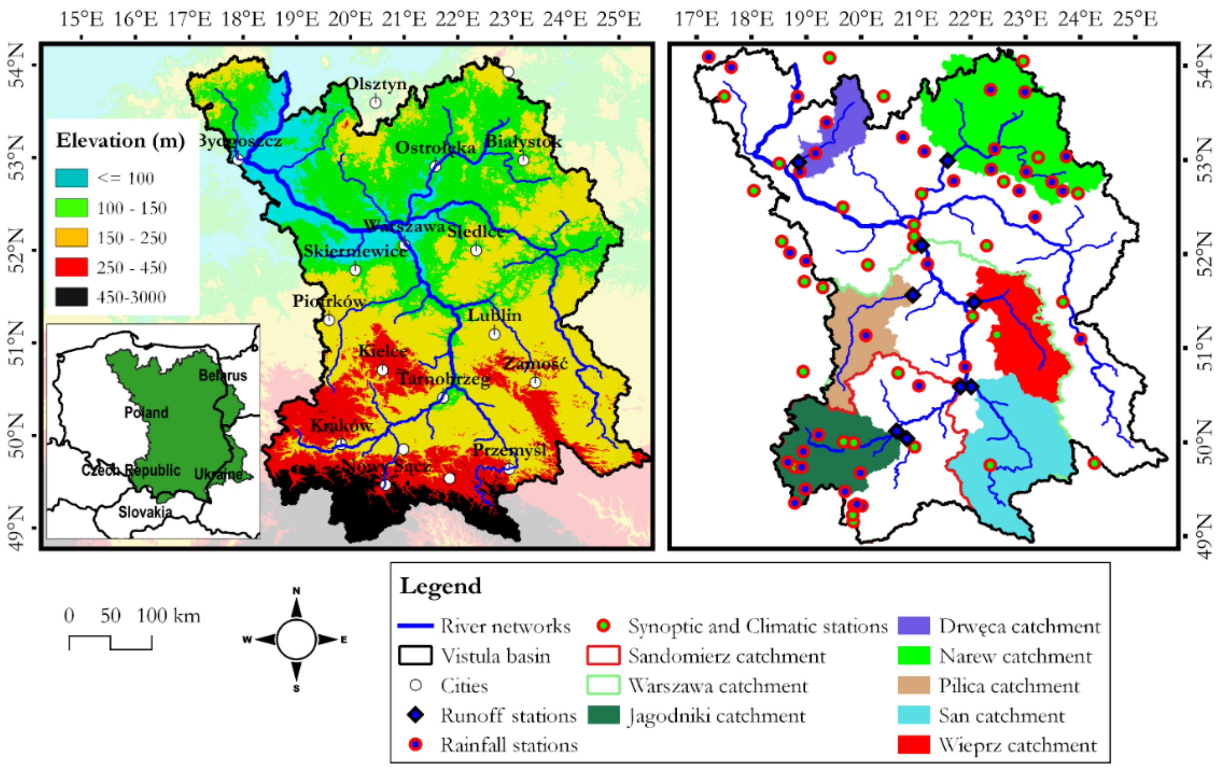

Fig. 1. The location of the Vistula River basin with topographical features (left panel), six selected sub-basins and their hydroclimatic variables (right panel) (Senbeta et al. 2022).

2.2 Methodology

The Drought Vulnerability Index (DVI) was proposed based on vulnerability factors selected considering the three vulnerability dimensions (exposure, sensitivity, and coping capacity) in an integrated perspective. The geophysical, hydroclimatic, and socio-economic data for the study area were collected from the relevant authorities in Poland and worldwide database, while others were prepared by means of Geographical Information System (GIS) using remote-sensing data. The vulnerability indicators were considered in drought vulnerability assessment if the proposed indicator significantly affect the social and hydrological conditions of areas (Boori and Voženílek 2014). Each indicator was firstly standardised and used to determine the DVI using balanced weighting scheme. The Soil and Water Assessment Tool (SWAT) was applied to derive the hydroclimatic variables for sub-basins where measurements were not available.

3. PRELIMINARY RESULTS

In the last 7 decades, the Vistula River basin has experienced several droughts. For example, majority of the basin was affected by the drought events of the 1980s which varied in terms of the severity, spatial extent, and duration of occurrence. The sub-basins in the middle of the Vistula River basin (Rivers Pilica and Wieprz) were affected stronger in terms of exposure than the sub-basins in the upper and lower basin (Fig. 2). However, vulnerability to drought varies within the basin when considering the three dimensions (E, S, and AC). Shallow aquifer in the sub-basins near the outflow feeds the runoff during drought, which could help to reduce the vulnerability of the areas (Fig. 3). The potential evapotranspiration had been declining until the early 1980s and then steadily increasing, similar to temperature, as a result of climate change. This could increase the impact of droughts on water availability and vulnerability, unless policy-makers introduce sustainable water resource management that takes climate change into account in the future.

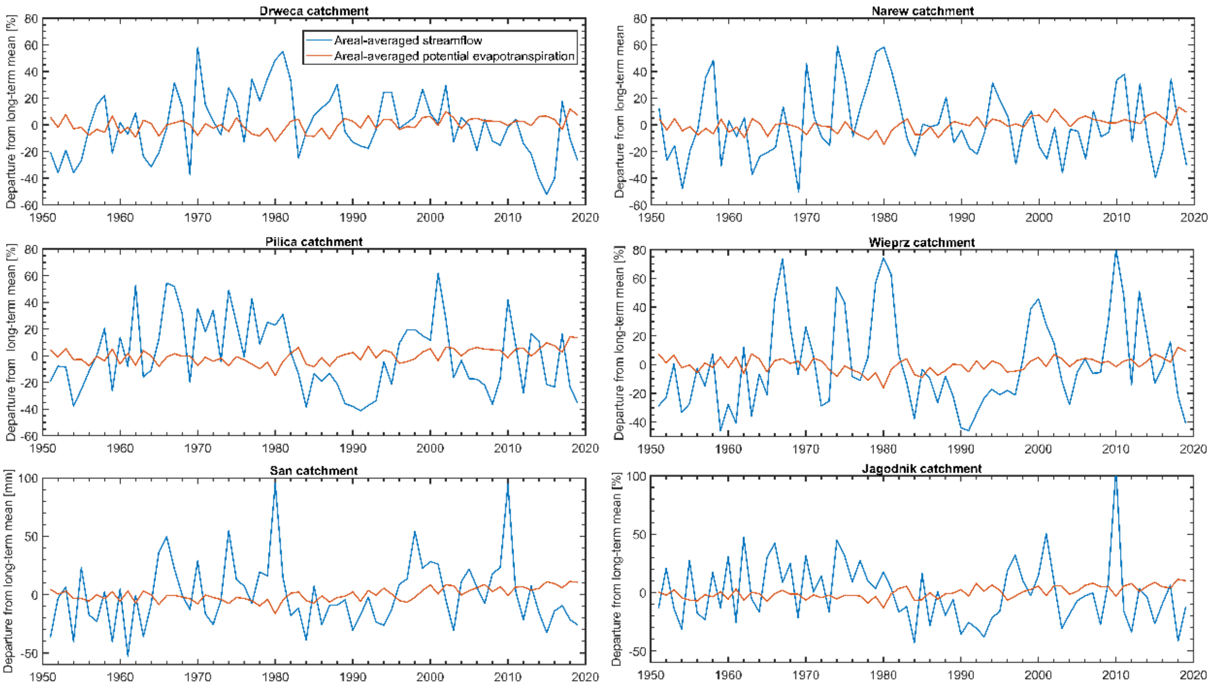

Fig. 2. Annual departure in streamflow and potential evapotranspiration from the long-term mean in the study area.

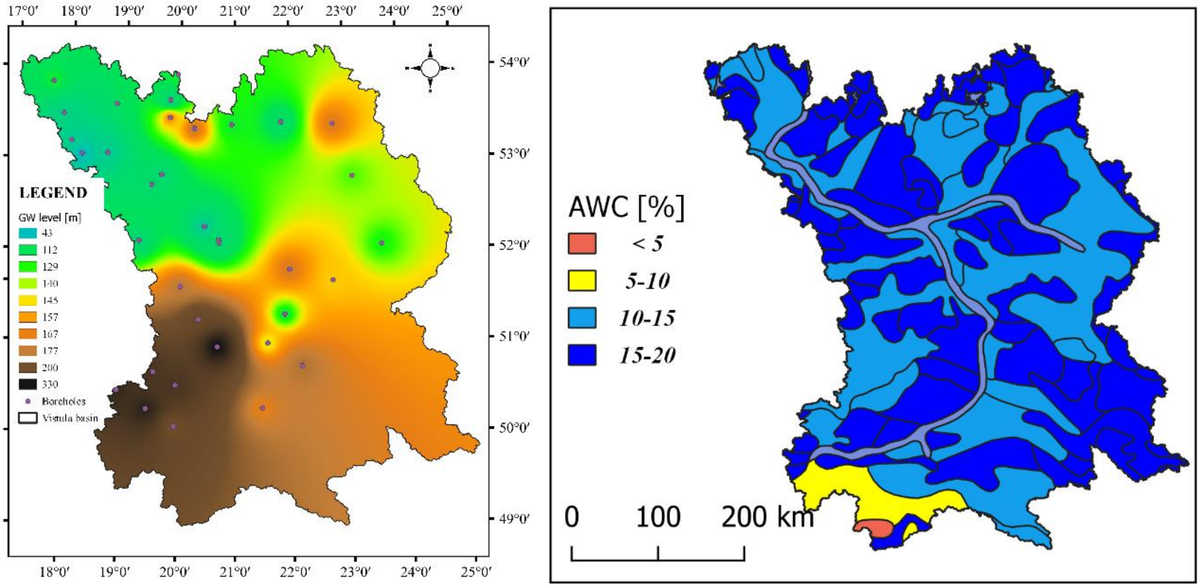

Fig. 3. Long-term average groundwater level (GW) below ground surface and soil available water capacity (AWC) in the Vistula River basin.

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