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ABSTRACT BOOK

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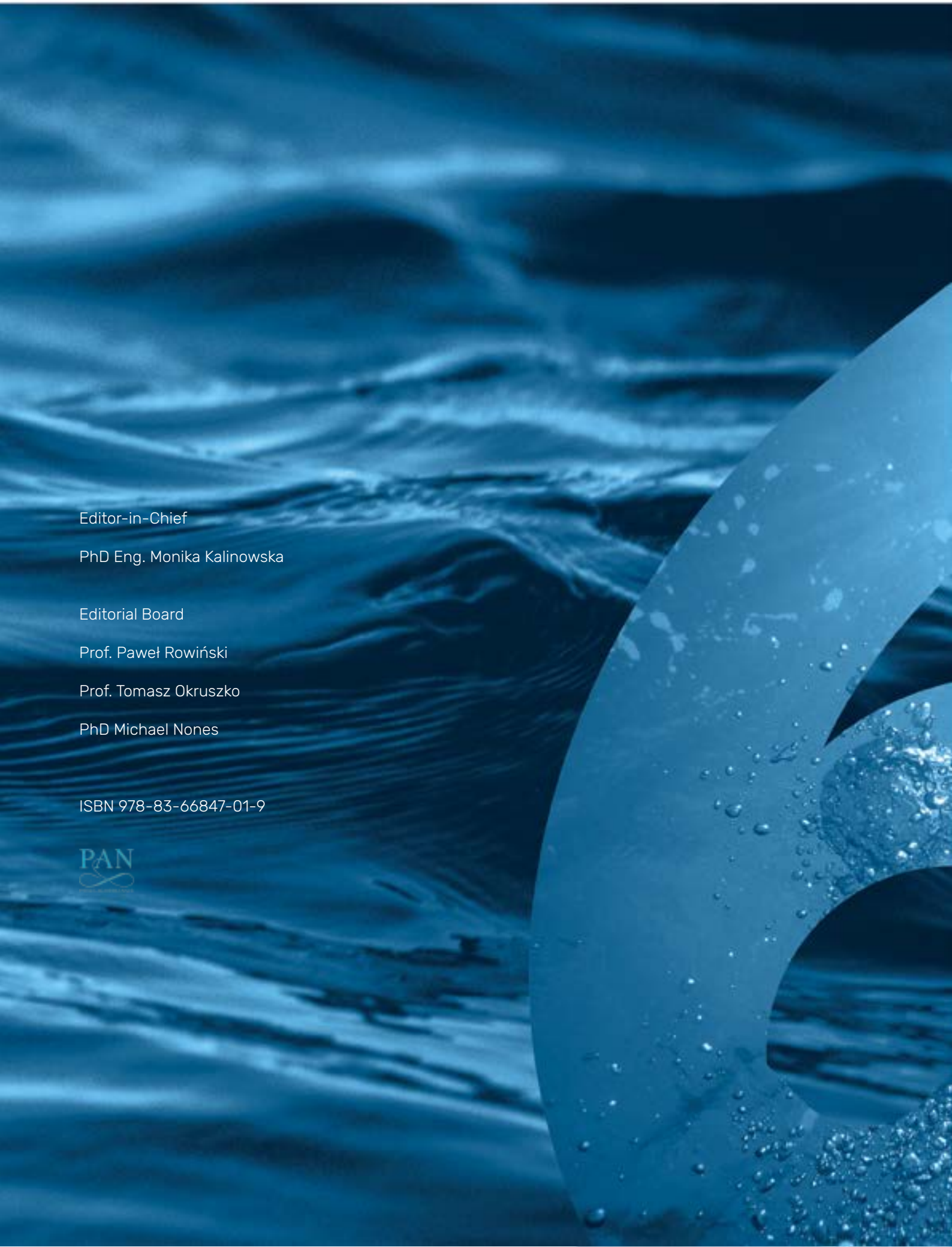

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Long-term hydroclimatic variability and changes in Central Italian Alps

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ABSTRACT

Prolonged and statistically significant decreases in mean riverflows could lead to chronic conditions of freshwater scarcity, seriously compromising the sustainability of the water demand for civil, agricultural and industrial uses. Regional analyses are however still needed to better characterize non-stationarities in different climates, since a clear trend on a global scale does not exist. Herein, long-term and high-quality series of riverflow discharges observed in five rivers in the Central Italian Alps, including two multi-century series, are investigated to statistically characterize individual trends of mean annual riverflows. Non-parametric pooled statistics are also introduced to the assess a regional trend. Climatic and non-climatic factors, namely rainfall trends and land cover transformations, have also been considered as potential change drivers.

1. Introduction

The existence of a global trend in riverflows has recently been questioned by the scientific community. Analyses of the fifth Assessment Report of the International Panel for Climate Change (Hartmann et al., 2013) no longer support the conclusions of earlier studies. Hence, changes in riverflow discharges progressively arise as strongly site-dependent phenomena, which are driven by both climatic and non-climatic factors. There are many reasons for such heterogeneous results: the spatial variability of precipitation trends, the different riverflow time scale considered in the analysis, the changes in the watershed hydrologic response, the different local water management practices and, finally, the length and the reliability of riverflow time series.

Thus, the collection and analysis of high-quality and long-term time series of hydrological data is still needed, not only for improving the understanding of the Earth's climate variability, but also for its practical implications. The literature regarding trends in mean values of hydrologic variables is less abundant than that regarding extreme events. Nevertheless, statistically significant decreases in the mean values of riverflow discharges could have severe consequences on the freshwater demand sustainability, in particular in those regions where their usage is intense and conflicting.

The aim of this study is therefore to add information regarding potential long-term trends in mean annual riverflows in the region of the Central Italian Alps, in northern Italy. Riverflows originating from this mountain area are essential to irrigation, industry and hydropower generation. Trend analyses of individual series were conducted by using non-parametric estimators, which do have some advantages, compared with conventional ones. In addition, a pooled estimator was used to assess the existence of a regional decreasing riverflow trend and to evaluate its intensity and statistical significance.

2. Material and methods

Extended and high-quality time series of five main rivers were collected; the rivers Adige, Mincio, Chiese, Oglio and Adda, originating from the southern side of Alps, from East to West. In particular, the time series of the Adda river (Crespi et al., 2018) and of the Adige river (Ranzi et al., 2017) cover a period that is longer than a century and thus provide a set of data that is highly valuable. Main hydrologic and morphometric characteristics of the analyzed watersheds are listed in Table 1. As can be seen, the total investigated area amounts to 19,395 km^2, which represents most of the Central Italian Alps. The selected case studies also offer a broad set of morphological changes in size, exposure and shape, thus providing an overview of the varying responses. Annual riverflow volumes have been taken into consideration in this study. It is important to underline that this kind of data is not significantly affected by the lake regulations, which are based on annual

and seasonal cycles. The generation of hydropower does not involve any sizeable transfer of water volume from year to year, as well.

Table 1. Studied watersheds and available mean annual riverflow data.

Watershed	Adige	Mincio	Chiese	Oglio	Adda
Rivergauge station	Trento	Monzambano	Gavardo	Sarnico	Lecco
Area [km^2]	9763	2350	934	1840	4508
Maximum elevation [m a.s.l.]	3899	3556	3462	3554	4050
Average elevation [m a.s.l.]	1735	966	1230	1429	1569
Minimum elevation [m a.s.l.]	186	60	198	154	197
Observation period	1862-2011	1950-2011	1934-2018	1933-2011	1845-2016
Sample size	150	62	72	79	172
Mean annual volume [mm]	708	709	1091	979	1151

The non-parametric Theil-Sen estimator for the linear regression slope (Hollander et al., 2014) was used to detect trends in the observed annual flow discharge series. In order to evaluate the trend significance associated with each individual series, the Theil test for the slope of the regression line and the Mann-Kendall test were conducted. In addition, the Sen-Adichie test for trend slope parallelism was conducted to verify the hypothesis of the existence of a common regional trend slope. Such a test involves the estimate of a common pooled slope β_p according to equation (1), where annual river-flow discharges D_i observed in the T_i year and belonging to i-th series with sample size n_i are aligned and pooled together in a unique sample.

$$\beta_p = \sum_{i=1}^{k}\sum_{j=1}^{n_i}\left(T_{ij}-\overline{T}_i\right)D_{ij} \Big/ \sum_{i=1}^{k}\sum_{j=1}^{n_i}\left(T_{ij}-\overline{T}_i\right)^2, \quad where \quad \overline{T}_i = \sum_{j=1}^{n_i}\frac{T_{ij}}{n_i} \quad for \quad i=1,\ldots,k \tag{1}$$

3. Results and discussion

Time series analysis results are reported in Table 2, where the β is the individual series slope, α_{i0} is the significance for the null slope not to be rejected as individual series slope, Z_{MK} is the normalized Mann-Kendall statistics and α_{MK} is the significance obtained by testing the null hypothesis of trend absence according to the Mann-Kendall test. As can be seen, all mean annual riverflows evidence decreasing trends, spanning between -3.33 mm yr^{-1} and 1.16 mm yr^{-1}. Except for the Oglio time series, such trends are statistical significant. When the Shen-Adichie test is conducted, the hypothesis of linear trend parallelism cannot be rejected with 54.5% significance and the regional decreasing trend of -1.45 mm yr^{-1} is estimated. Furthermore, the hypothesis that the pool slope β_p is the slope of the individual time series cannot be rejected with significances α_{ip} larger than 16% (Table 2).

Table 2. Individual series trend analysis (statistically significant trends are highlighted in boldface).

Watershed	Adige	Mincio	Chiese	Oglio	Adda
β [mm yr^{-1}]	**-1.34**	**-3.33**	**-3.12**	-1.16	**-1.29**
α_{i0} [%]	<0.1	0.5	0.8	32.2	<0.1
α_{ip} [%]	66.2	15.8	16.2	71.3	62.2
Z_{MK}	**-5.49**	**-2.78**	**-2.66**	-0.99	**-3.61**
α_{MK} [%]	<0.1	0.6	0.8	32.4	<0.1

Thus, on a regional scale, there is evidence of a statistically significant decreasing trend in the annual riverflows in Central Italian Alps. It is worth to underline that pooling time series according to equation (1) makes it possible to increase the sample size and to improve the understanding of week trends in relatively short time series. Trend analyses on mean annual precipitations revealed that no significant decreases feature the studied area. Land-use transformations can alternatively be taken into consideration as a potential cause. Actually, an expansion of woodlands (+16%) at the expenses of grasslands (-22%) and bushlands (-16%) occurred between 1954 and 2016. This non-climatic factor, coupled with the significant increase in average temperatures, should yield an increase in the hydrologic losses, explaining the decline of riverflows in these watersheds.

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