SPATIAL PATTERNS OF PRECIPITATION IN BOSNIA AND HERZEGOVINA

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Abstract: The paper investigates the spatial distribution of the seasonal and annual precipitation in Bosnia and Herzegovina. The mean monthly precipitation data from 40 meteorological stations covering the standard climatological thirty-year period (1961–1990) were used for the analysis. Seven precipitation-based parameters were used to regionalize climate in Bosnia and Herzegovina by using the Principal Component Analysis and clustering techniques. The spatial patterns of precipitation were determined by using the R-mode principal component analysis with varimax rotation. The first two principal components, which describe 97.60% of the total variance, were taken into consideration. The varimax rotated scores were subjected to the Cluster Analysis in order to identify homogeneous precipitation regions over the territory of Bosnia and Herzegovina. The agglomerative hierarchical clustering identified three sub-regions with different precipitation regimes. The complex orography, i.e., the influence of the Pannonian Basin, the Dinaric Alps, and the Adriatic Sea, is one of the most decisive factors that affect spatial patterns of precipitation in Bosnia and Herzegovina.

Keywords: precipitation; spatial patterns; Principal Component Analysis; Cluster Analysis; Bosnia and Herzegovina

Introduction

Spatial and temporal precipitation variability is a fundamental aspect of any regional climate. Understanding the spatial distribution of precipitation patterns is of a great pertinence in many applied studies (e.g., hazard risks management, flood protection, agricultural planning, water resources and biodiversity conservation in a changing climate, etc.).

Significant progress in the field of climatic regionalization has been made since the first attempts to define climate zones in the early 20th century (e.g., Köppen climate classification, Thornthwaite climate classification, Holdridge's life zone classification system, Alisov's climate classification, etc.) up to now as various multivariate techniques and modeling are used for this purpose. In the recent climate regionalization, Principal Component Analysis (PCA) and Cluster Analysis (CA) techniques were often used to define different climate regions. The PCA has been widely used for the analysis of the spatial (or temporal) variability of different physical fields in

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climatology and meteorology since the 1950s (Demšar, Harris, Brunsdon, Fotheringham, & McLoone, 2013; Preisendorfer, 1988). The data for these kinds of studies consist of a time series of one particular meteorological field variable measurements (this can be precipitation, air temperature, sea-level pressure or similar), measured at equidistant time intervals at each sampling location (Demšar et al., 2013). One of the most important applications of this eigenvector analysis in climatology is precisely climate regionalization (White, Richman, & Yarnal, 1991). The PCA has been successfully applied in numerous studies all over the world for the regionalization of climatic variables, in particular to investigate the precipitation spatial regimes over certain areas (Baeriswyl & Rebetez, 1997; Benzi, Deidda, & Marrocu 1997; Comrie & Glenn, 1998; Gocic & Trajkovic, 2014; Martins, Raziei, Paulo, & Pereira, 2012; Matulla, Penlap, Haas, & Formayer, 2003; Norrant & Douguédroit, 2006; Raziei, Bordi, & Pereira, 2008; Rodriguez-Puebla, Encinas, Nieto, & Garmendia, 1998).

The climate of Bosnia and Herzegovina, and particularly the spatial patterns of precipitation, is predominantly determined by the geographical position, large-scale circulation patterns over the Northern Hemisphere, and complex orography (the influence of the Pannonian Basin, the Dinaric Alps, and the Adriatic Sea).

The aim of this study is to determine the spatial distribution of precipitation in Bosnia and Herzegovina. The main goal is to identify regions with similar precipitation regimes. In addition, precipitation variability during the period 1961–2018 will be analyzed.

Data and methods

The study area covers the territory of Bosnia and Herzegovina, which is located in Southeast Europe. It borders with Croatia in the north, northwest and south, Serbia in the east and northeast, and Montenegro in the southeast. The investigated territory lies in the middle part of the northern temperate zone, between latitudes 42°33'00''–45°16'30''N and longitudes 15°44'00''–19°37'41''E.

The spatial regionalization of precipitation in Bosnia and Herzegovina has been carried out using the data on mean monthly precipitation from 40 meteorological stations (Figure 1). The selected stations are located in all parts of Bosnia and Herzegovina and cover all the three physical macroregions of Bosnia and Herzegovina: Peripannonian, Dinaric, and Submediterranean. The largest part of the territory covers the Dinaric Alps that run in the northwest-southeast direction through the central part of the country. The northern part of the territory encompasses the Panonian basin and its Peripannonian rim, whereas in the south it borders with the Adriatic Sea. Given such configuration of the terrain, the selected meteorological stations also cover a wide range of altitudes with relative height difference between highest-located station (Bjelašnica 2,067 m a.s.l.) and lowest-located station (Čapljina 10 m a.s.l.) being 2,057 m.

The data were collected from the Climatic Atlas of Bosnia and Herzegovina (Bajić & Trbić, 2016). The analysis was performed for the standard climatological period 1961–1990. This period was chosen because more than half the stations had had long interruptions in measurements or they had stopped working in the 1990s, which prevented a quality precipitation regionalization from such a sparse network of meteorological stations.

The spatial patterns of precipitation in Bosnia and Herzegovina were investigated using the PCA with the varimax orthogonal rotation. The results of the PCA were then subjected to the CA. The PCA and CA were performed in XLSTAT Version 2014.5.03.

The central idea of the PCA was to reduce the dimensionality of a data set in which there is a large number of interrelated variables, while retaining as much as possible of the variation inherent in the data set (Jolliffe, 2002). It is often used as a preprocessing method either for data orthogonalization and eliminating redundancy caused by variable correlation or for dimensionality reduction, before employing another statistical method (e.g., clustering) (Demšar et al., 2013). The PCA reduces temporal and spatial climatic data to manageable, physically interpretable abstractions by expressing the variance of a sampled data field in a reduced number of variable dimensions (White et al., 1991). This reduction is achieved by transforming into new variables sets (called the principal components—PCs), which are uncorrelated and which are ordered so that the first few PCs retain most of the variation present in all of the original variables (Jolliffe, 2002).

Figure 1. Study area with locations of meteorological stations used in the study.

As the input data for the PCA, seven precipitation-based variables were used: mean annual total precipitation, mean seasonal (winter, spring, summer, and autumn) precipitation, mean growing season (April–September) precipitation and the precipitation concentration index (PCI). The PCI, as a measure of intra-annual precipitation variability (monthly heterogeneity), was defined and calculated as in Oliver (1980). As the selected parameters (variables) were measured in different units, they were standardized prior to a further analysis. Data standardization was performed following the formula $(x_i-x)/\sigma$ where: x_i is the value to normalize, x is the arithmetic mean of the distribution and σ is the standard deviation of the distribution.

Bartlett's test of sphericity was used to test correlations between the variables being statistically significant (at least one). Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was applied to test the principal components quality. The correlation matrix was used for the computation of the eigenvalues and eigenvectors. The PCA of a meteorological field can be made by varying any two of the three existing entities—meteorological field (or parameter), time and a location (or station)—and holding the third fixed (Richman, 1986). In this case, R-mode PCA data matrix with parameters, i. e., precipitation-based variables, in columns and stations in rows, was used (Gocic & Trajkovic, 2014; Martins et al., 2012). The adequate number of the PCs retained for a further analysis was determined following the rule of thumb (North, Bell, Cahalan, & Moeng, 1982). The factor scores after varimax rotation were mapped to show the spatial patterns over the studied area. The results of the first two PCs varimax orthogonal rotation were subjected to a cluster analysis (CA) in order to arrange data into clusters so that the elements within a cluster have a high degree of „natural association" among themselves while are „relatively distinct" from one another (Anderberg, 1973). The goal of clustering was to identify areas with similar precipitation regimes. The hierarchical classification that consists of a series of partitions, which may run from a single cluster containing all the individuals, to *n* clusters each containing a single individual, was applied. Agglomerative hierarchical method runs a series of successive fusions of the *n* individuals into groups, as attempting to find the optimal step (Everitt, Landau, Leese, & Stahl, 2011). In order to achieve the maximum similarity within a group and the minimum similarity between groups, different measures of similarity or distance between pairs of observations/objects can be used. The agglomerative hierarchical clustering (AHC) in this study was performed by using Euclidean distance as a dissimilarity measure and Ward's method as an agglomeration method.

The spatial distribution of mean annual and seasonal precipitation as well as spatial patterns of the first two PCs rotation were mapped using Inverse distance weighted (IDW) interpolation technique in ArcGIS 10.2 with the Spatial Analyst extension. In addition to the horizontal component, the interpolation included a vertical component, i.e., the hypsometric characteristics based on digital elevation model—SRTM DEM 1 Arc-Second (United States Geological Survey, 2014). The results of the cluster analysis (identified sub-regions) were also mapped in ArcGIS using Iso Cluster (iterative self-organizing way of performing clustering) from Spatial Analyst Multivariate toolset.

Annual and seasonal precipitation characteristics of the identified sub-regions were analyzed. The data for annual and seasonal precipitation were obtained as the average of rainfall at meteorological stations in the sub-regions. In addition, the precipitation variability over the sub-regions, i.e., trends in annual and seasonal precipitation, were estimated for the period 1961–2018 using the non-parametric Mann-Kendall test and Sen's non-parametric estimator of slope.

Results and discussion

The mean annual and seasonal precipitation in Bosnia and Herzegovina is shown in Figure 2. In the northern part of the territory, i.e., over the Peripannonian region, the precipitation relatively uniformly declines from about 1,200 mm in the west to 800 mm in the far northeast. This area has a continental precipitation regime with the maximum and the minimum precipitation during summer and winter months, respectively. In general, precipitation increases with the altitude toward central and particularly southern part of the territory. The central part of the territory is typical of the climate of mountain areas with average precipitation about 1,200 mm, which often occurs in the

form of snow. The precipitation maximum occurs in autumn, whereas the patterns of precipitation minimum were not spatially coherent. The modified Adriatic climate is typical for the southern part of the territory (Herzegovina region). It is characterized by mild and rainy winters, and dry and hot summers. The maximum and the minimum precipitation occur in winter and summer months, respectively (Trbić, Ducić, & Rudan, 2009). The highest annual precipitation in Bosnia and Herzegovina is registered over the mountainous area in the far southeastern part of the Herzegovina region (Popov, Gnjato, & Trbić, 2019).
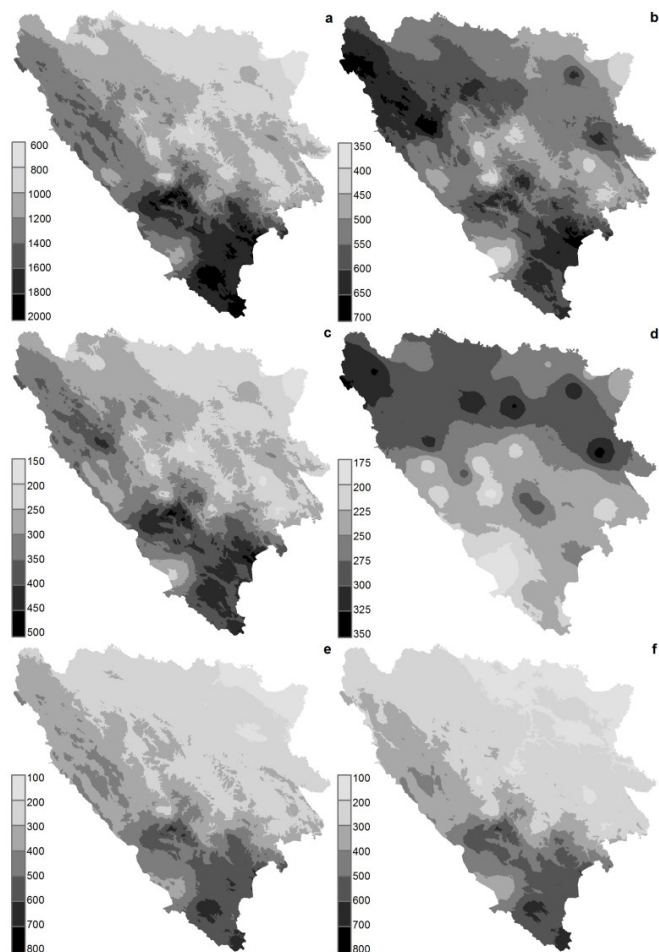

Figure 2. Spatial distribution of annual and seasonal precipitation (mm)—year (a), growing season (b), spring (c), summer (d), autumn (e), and winter (f) in the period 1961–1990.

Bartlett's sphericity test chi-square value of 894.5 with $DF = 21$ and $p < .0001$ and Kaiser–Meyer–Olkin measure of sampling adequacy value higher than 0.500 ($KMO = 0.519$) suggest that the selected precipitation-based variables were adequate for the PCA. Figure 3 shows the scree plot of the variables factor loadings on the components.
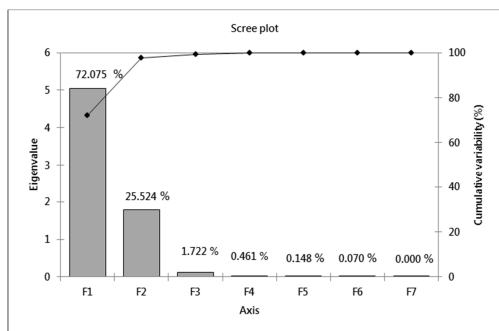
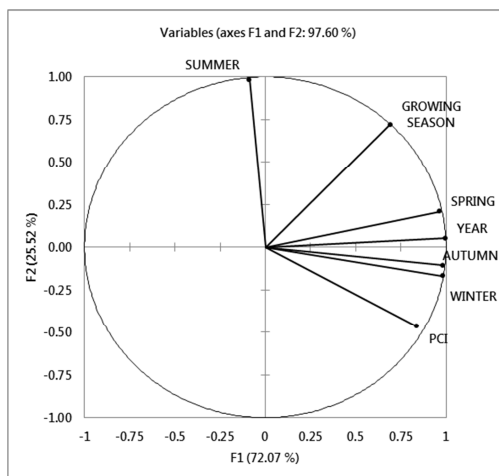*Figure 3.* Scree plot of the eigenvalues (the proportion of the variance).

Figure 4. Plot of correlation of F1 and F2 variables factor loadings.

Table 1
Eigenvectors of the variables for PC1 and PC2

Variables	PC1	PC2
Year	0.444	0.039
Winter	0.437	−0.127
Spring	0.429	0.156
Summer	−0.040	0.735
Autumn	0.438	−0.080
Growing season	0.308	0.539
PCI	0.373	−0.349

Each variable is presented as a point whose coordinates are given by the loadings on the first two PCs. Following the North's rule of thumb and the scree plot of the eigenvalues (Figure 4), the first two PCs were retained for a further analysis. The total variance of these first two PCs are 72.075% and 25.524%, respectively, giving a cumulative variance of 97.60%.

The three variables with large variances, annual total precipitation and autumn and winter precipitation, have a substantial influence on the first PC, whereas summer precipitation influences the second PC the most (Table 1). The results of the first two PCs varimax rotation are displayed in Table 2. After the varimax rotation, the mean winter and autumn precipitation (and then the mean annual total precipitation), have the greatest influence on the first PC, whereas the mean summer precipitation and the mean growing season precipitation influence the second PC the most. Spatial distribution of the component score coefficients—RPC1 and RPC2 is shown in Figure 5.

The comparative analysis of the seasonal and annual precipitation distribution maps on the one side (Figure 2) and the RPC1 and RPC2 on the other (Figure 5), showed that they were largely in agreement. Therefore, it could be inferred that the RPC1 and RPC2 well represent the spatial distribution of precipitation over Bosnia and Herzegovina.

The agglomerative hierarchical clustering (AHC) method, with Euclidean distance as a dissimilarity measure and Ward's method as an agglomeration method, was applied to the results of rotated RPC1 and RPC2 scores to identify different precipitation sub-regions over the study area. Three distinct sub-regions (Figure 6) were identified:

• C1 with 10 stations (Banja Luka, Vrućica Teslić, Kotor Varoš, Mlinište, Drinić, Bosanska Krupa, Bihać, Sanski Most, Ivan Sedlo, and Bjelašnica);

• C2 with 20 stations (Bijeljina, Novi Grad, Prijedor, Doboj, Sokolac, Goražde, Brčko,

Prnjavor, Derventa, Modriča, Sarajevo, Butmir, Tuzla, Jajce, Zenica, Bugojno, Livno, Domanovići, Čapljina, and Prozor);
- C3 with 10 stations (Čemerno, Gacko, Bileća, Trebinje, Kalinovik, Lastva, Berkovići, Mostar, Jablanica, and Rakitno).

Table 2
Results of the principal components varimax rotation

Variables	Factor loadings		Contribution of the variables (%)		Squared cosines	Component score coefficient	
	R-Loading 1	R-Loading 2	D1	D2		RPC1	RPC2
Year	0.985	0.168	19.388	1.541	0.97	0.193	0.052
Winter	0.995	−0.054	19.802	0.162	0.99	0.204	−0.07
Spring	0.932	0.318	17.381	5.538	0.869	0.176	0.138
Summer	−0.202	0.965	0.817	50.87	0.931	−0.08	0.544
Autumn	0.99	0.008	19.605	0.003	0.981	0.201	−0.04
Growing season	0.603	0.795	7.265	34.563	0.633	0.089	0.416
PCI	0.887	−0.366	15.742	7.323	0.787	0.195	−0.24

The obtained variance decomposition for the optimal classification within-class was 24.64%, whereas the between-classes one was 75.36%. Kotor Varoš, Butmir, and Rakitno were determined as the central objects of sub-regions C1, C2, and C3, respectively. C1 sub-region includes the northwestern part of the Bosnia and Herzegovina; the spatially largest C2 sub-region covers the northeastern, eastern and central part of the territory, whereas C3 sub-region includes Herzegovina region in the south.
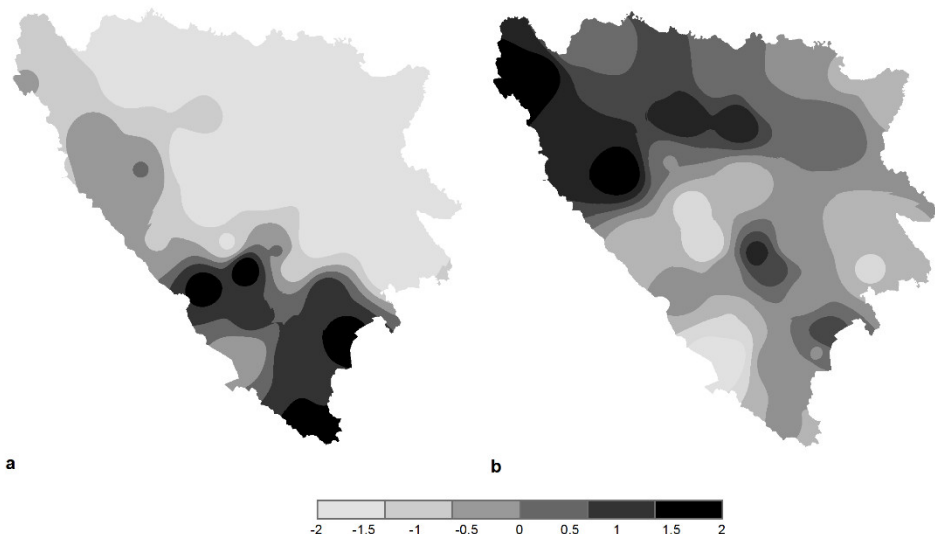

a b

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

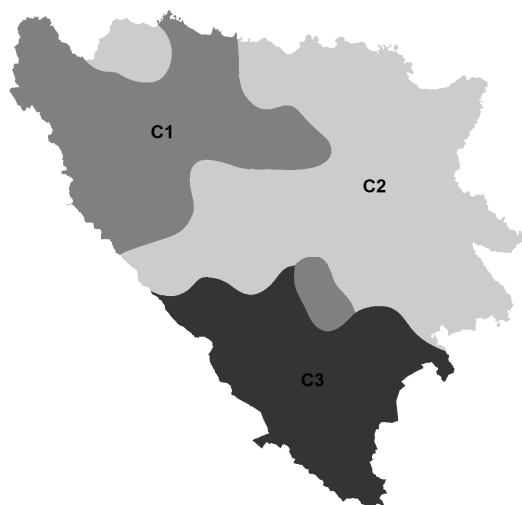*Figure 5.* Spatial distribution of the RPC1 (a) and RPC2 (b).

Figure 6. Precipitation-based spatial regionalization of Bosnia and Herzegovina.

The results of spatial regionalization of Bosnia and Herzegovina obtained in this survey are similar to the results of Mihailović, Drešković, and Mimić (2015) which used the Kolmogorov complexity and three complexity measures to describe the complexity of precipitation spatial distribution. The authors identified the two regions: one strongly influenced by the Adriatic Sea (in the south) and one which is under the influence of the Pannonian Basin (in the north). There is one transitional belt between them covering the central part of the territory.

Annual and seasonal precipitation characteristics of the three identified sub-regions are shown in Table 3. The annual total precipitation values of C1 (in the range of 1,023–1,469 mm) are about Bosnia and Herzegovina average amounts (1,198 mm). C2 with annual total precipitation in the range of 738–1,147 mm is characterized by precipitation below the state average, whereas the highest annual totals occur over the C3 sub-region (1,522–1,826 mm). C1 sub-region is characterized by winter and summer precipitation values below and above state average, respectively (spring and autumn amounts are about average). Seasonal precipitation in C2 sub-region is substantially below the state average throughout the year. In contrast, C3 sub-region seasonal precipitation is far above the average, except in summer season. In this region, PCI values are the highest compared to all the regions. Intra-annual precipitation variability is the greatest in the south, in Herzegovina region, where the greatest rainfall occurs during the colder part of the year—in autumn and winter, whereas much lower precipitation with the frequent occurrence of drought are a typical characteristic of summer season. In addition, over the C1 and the C2 sub-regions, half the annual precipitation occurs during the growing period, whereas in C3 it is only 35%.

Table 3

Seasonal and annual precipitation (mm) and precipitation concentration index (PCI) of the three sub-regions and the state averages in the period 1961–1990

Region	Winter	Spring	Summer	Autumn	Year	Growing season	PCI
C1	273.4	311.3	306.3	318.8	1210.6	613.8	8.55
C2	210.8	219.2	234.2	238.9	903.1	456.3	8.66
C3	539.0	400.1	229.0	535.8	1704.0	591.9	9.50
B&H	315.1	290.3	253.7	338.8	1198.2	529.6	8.86

Decadal trends in annual and seasonal precipitation in the three sub-regions during the period 1961–2018 are shown in Table 4. The estimated trend values in annual and seasonal precipitation were not spatially coherent–trends of different sign were reported by sub-regions in winter, spring

and growing season. However, all the trends are still mainly weak and statistically insignificant. Previous studies found that, over the entire territory of Bosnia and Herzegovina, the most prominent positive changes occurred in autumn season, whereas precipitation decreased the most during summer season (Popov, Gnjato, & Trbić, 2018, Popov et al., 2019). It should be noted that in C3 sub-region (Herzegovina) negative trends prevailed throughout the year (except in autumn season). Similar drying tendency was found in other Mediterranean and Submediterranean regions (Alpert et al., 2002; Philandras et al., 2011).

Table 4

Decadal trends in seasonal and annual precipitation in the three sub-regions in the period 1961-2018 (mm/decade)

Region	Winter	Spring	Summer	Autumn	Year	Growing season
C1 (Sanski Most)	5.8	2.8	−15.9	10.5	6.0	−5.3
C2 (Sarajevo)	−5.3	6.6	−2.2	1.3	2.8	4.6
C3 (Mostar)	−20.8	−8.1	−7.2	0.3	−40.0	0.7

Conclusion

The paper investigates the spatial distribution of precipitation in Bosnia and Herzegovina. Based on the data from 40 meteorological stations covering the standard climatological thirty-year period (1961–1990), precipitation regionalization was performed using the Principal Component Analysis and Cluster analysis. Three sub-regions with different precipitation regimes have been identified over the territory of Bosnia and Herzegovina: C1 in the northwest, C2 that covers the northeast, east and central part, and C3 in the south. The annual total precipitation values of C1 are about Bosnia and Herzegovina average amounts. The values of annual and seasonal precipitation in C2 sub-region are substantially below state average throughout the year, and in C3 sub-region they are far above the average (except in summer season).

The obtained results are similar to the results of other studies focused on spatial distribution of precipitation previously conducted for this area. Studies of this kind can be a useful source of data in a variety of applied research, primarily in the fields of hazard risks management and agricultural planning. Further research should be focused on more detailed analyses of precipitation temporal variability in the identified sub-regions particularly due to recent climate change. Given that results of previous research suggest changes toward more intense and more variable precipitation (i.e., increased frequency of droughts and flooding), particularly pronounced since the beginning of the 21st century), it will be necessary to assess their impact on natural and socio-economic systems.

Acknowledgements

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