

Observed trends in annual floods and monthly maximum Discharges in the Ialomița river catchment, Romania

Emilia GÎRBEA ^{1*}  and Liliana ZAHARIA ² 

1 Doctoral School "Simion Mehedinți", University of Bucharest, Faculty of Geography, Romania

2 University of Bucharest, Faculty of Geography, Romania

*Correspondence: emilia.avram97@gmail.com

Keywords: annual floods, maximum discharge, trends, Romania, Mann-Kendall, Ialomița watershed

Abstract: This study examines trends in the maximum streamflow within the Ialomița River watershed, which covers 10,350 km² in southeastern Romania and encompasses diverse landforms stretching between the Danube River and the Carpathian Mountains. Trends were assessed using the non-parametric Mann-Kendall test applied to annual and monthly maximum discharge records from 18 gauging stations over a period of up to 60 years (1961–2020), as well as for two climatological subperiods: 1961–1990 and 1991–2020. Over the full study period, the results indicate a balanced pattern: nine gauging stations exhibited positive trends in annual flood magnitudes, whereas the remaining nine showed negative trends. For monthly maximum discharges over the same period, decreasing trends were identified in approximately two-thirds of the total months analyzed. During the first subperiod (1961–1990), predominantly negative trends were detected in both annual and monthly maximum discharges, with notable decreasing trends during the winter months. In contrast, the more recent subperiod (1991–2020) showed predominantly positive trends, particularly in February, March, and October. Overall, the findings indicate a possible intensification of high-flow magnitude during recent decades within the study area. For rivers with a quasi-natural flow regime, observed hydrological alterations are likely linked to changes in climatic parameters. In the case of rivers influenced by dam and reservoir operations, the direct effects of climate variability are often masked or modified by regulation practices. This distinction underscores the importance of differentiating between natural and regulated flow regimes when interpreting long-term hydrological trends. The findings provide a scientific basis for flood risk management and adaptation planning under changing hydroclimatic conditions.

1. Introduction

Numerous flood events have been reported worldwide over the past few decades, causing substantial adverse socioeconomic and environmental impacts. There is growing evidence of changes in flood patterns over recent decades (Bertola et al., 2023). It has been assessed with high confidence that the frequency and magnitude of river floods have changed during the last decades; however, these changes exhibit regional differences, shaped by catchment-specific characteristics as well as anthropogenic influences (Caretta et al., 2022). Analyses of streamflow variability at the global scale have shown both increases and decreases in the frequency of river floods from 1960 to 2010 across Europe and the USA, as well as a general increase in China, Brazil, and Australia. In contrast, declines in flood frequency have been reported in certain Mediterranean catchments and regions of southern Australia (Ishak et al., 2013; Do et al., 2017; Berghuijs et al., 2017; Blöschl et al., 2019; Trambly et al., 2019).

Because of the serious impacts of floods on human and natural systems, their investigation is crucial for both scientific and practical purposes. Understanding the temporal dynamics and spatial variability of high flows is essential for improving hazard assessments and supporting the development of effective flood risk reduction and adaptation strategies under conditions of ongoing climate variability and change. Consequently, flood-related research has expanded substantially worldwide in recent decades. Particular emphasis has been placed on detecting trends in flood occurrence and behavior using both observed records and hydrological projections. Trend analysis serves as a valuable methodological approach for identifying temporal changes in flood characteristics, such as magnitude, frequency, and duration, particularly in the context of climate and anthropogenic changes (Kundzewicz et al., 2014). By identifying spatial and temporal patterns of changes in flood occurrence, trend analysis enhances the understanding of hydrological variability, which is essential for developing effective, evidence-based risk mitigation and water resource management policies adapted to observed trends. Consequently, studies focused on flood trend detection have attracted growing scientific attention in recent decades worldwide, as evidenced by the steadily increasing number of publications dedicated to this topic (Zadeh et al., 2020; Bertola et al., 2020). In Europe, numerous studies over recent decades have addressed changes in flood characteristics using trend analyses conducted at continental, national, regional, or local scales. However, owing to the use of different flood indicators, varying time periods, and diverse methodological approaches, it is difficult to compare their findings to derive a coherent large-scale picture (Mediero et al., 2015). Notable reviews summarizing the results of European studies have been provided by Hall et al. (2014) and Madsen et al. (2014).

At the pan-European scale, more or less clear changes in flood dynamics and characteristics have been identified, although they are spatially heterogeneous, including both increasing and decreasing trends (Madsen et al. 2014; Blöschl et al. 2019). The review conducted by Hall et al. (2014) revealed some large-scale patterns of changes in flood magnitude with similar trends, including a general increase in central and western Europe and a decrease in southern (more specifically in western Mediterranean catchments) and eastern and northern Europe. Madsen et al. (2014) have shown in their review that, at large-scale, regional, or national scales, there is no clear consistent signal of significant trends in extreme streamflow. However, in regions dominated by peak flows induced by snowmelt, several studies have reported decreases in flood magnitude and earlier occurrences of spring floods, likely associated with rising temperatures. Mediero et al. (2015) reported general decreasing trends in flood magnitude in both the Atlantic (western Europe) and continental (central Europe) regions. An unclear pattern of trends was found in the number of floods exceeding defined thresholds across Europe, with the exception of the Alpine region, where a decreasing trend was detected.

Mangini et al. (2018) identified several spatially coherent patterns of significant trends in the magnitude and frequency of flood peaks across five European regions (Alpine, Atlantic, Boreal, Continental, and Mediterranean), based on analyses of the annual maximum flood (AMF) and peak over threshold (POT) series. The results revealed noticeable regional differences, as follows: a general increasing trend in flood magnitude and frequency in the Atlantic region (Northern islands and coasts); a clear tendency towards increasing flood frequency and decreasing magnitude for the POT series, but without an apparent spatial pattern of change in the AMF series, in the Boreal region; a general positive trend in flood magnitude in the northern part of the Alpine region, in contrast with a clear negative trend in its southern part; an increasing trend in flood magnitude but a decreasing trend in flood frequency in the Mediterranean region; and significant positive trends in magnitude in the POT series (considering one flood per year) in the Central (continental) region.

Blöschl et al. (2019) identified clear regional patterns of both increases and decreases in annual maximum floods across Europe between 1960 and 2010, which were attributed to climate change. Their analysis, based on discharge observations from over

3,700 gauging stations, revealed general increasing trends in annual flood peaks in northwestern Europe, in contrast to decreasing trends in southern and eastern Europe. During the same period, Bertola et al. (2020) reported similar findings, highlighting overall upward trends in flood magnitude in northwestern Europe and declining trends in southern and eastern regions. Collectively, these studies reinforce the view that flood trends in Europe exhibit strong spatial heterogeneity, reflecting the combined influence of regional climate variability, catchment characteristics, and human pressures on hydrological processes.

In Romania, several studies have investigated hydrological changes through trend detection analysis. Most of these studies addressed the average streamflow across various river basins and revealed a range of significant alterations in river flow regimes, reflecting responses to both climate change and anthropogenic influences. Relevant studies include those by Neculau and Zaharia (2010), Zaharia and Beltrando (2009), Jipa and Mehedințeanu (2012), Bîrsan et al. (2012, 2014), Mitof and Prăvălie (2014), Perju and Zaharia (2014), Perju et al. (2014), Croitoru and Minea (2015), Mic et al. (2016), Bîrsan (2015, 2017), Prăvălie et al. (2016), Minea et al. (2020), Mocanu-Vargancsik and Tudor (2020), Zaharia et al. (2020), Minea and Chelariu (2021), and Minea et al. (2022). Few studies in Romania have specifically addressed changes in high streamflow and flood characteristics. At the national level, the only studies including references to trends in high streamflow (defined using streamflow quantiles q_{70} – q_{90} and maximum discharges) were conducted by Bîrsan et al. (2014) and Bîrsan (2017) for the periods 1961 – 2009 (25 catchments) and 1975 – 2009 (44 catchments), respectively. At the annual scale, these studies identified a statistically significant general decreasing trend in high flows. Seasonally, similar decreasing trends were observed in spring, summer, and winter for the quantile q_{90} and maximum discharge. In contrast, during autumn, increasing trends were detected for all examined quantiles and for the maximum discharge over the 1961–2009 period at more than one-third of the analyzed gauging stations.

Most studies on changes in floods and maximum runoff in Romania have been conducted at the regional or catchment scale. These studies cover diverse time periods, and their findings are spatially heterogeneous, showing both positive and negative trends in maximum streamflow and flood patterns; however, most of these trends were not statistically non-significant. Zaharia and Beltrando (2009) analyzed catchments located in the Carpathian curvature region over the period 1962–2006 and found no statistically significant trends in either the variability of annual maximum floods or the frequency of flood peaks exceeding a selected threshold. Neculau and Zaharia (2010) reported non-significant trends in both annual maximum floods and the number of yearly floods exceeding a selected threshold over periods ranging from 29 to 57 years in a study focused on the Trotuș River watershed (draining the eastern Carpathians). In a mountainous catchment within the Bucegi Mountains (Southern Carpathians), Perju (2012) and Perju and Zaharia (2014) identified a statistically significant positive trend in the magnitude of annual flood peak after 1961. Similarly, Zaharia et al. (2020) detected statistically significant positive trends in annual maximum discharges in the same region over the period 1961–2012. Their analysis revealed significant positive trends in maximum streamflow during autumn and winter, whereas summer trends were non-significant. Negative trends were observed in spring, but not statistically significant.

In eastern Romania, within catchments located between the Siret and Prut rivers, Minea and Chelariu (2021) and Minea et al. (2022) identified predominantly decreasing trends in the maximum annual streamflow from 1955 to 2010 and 1955 to 2018, respectively. Similar downward trends were also observed for the maximum flows during spring and summer at most of the analyzed stations. In contrast, winter and autumn exhibited spatially heterogeneous trends, with some stations showing positive trends and others displaying negative trends. Collectively, the findings on streamflow variability in Romania highlight the complex temporal and regional variability of high-flow patterns, reflecting the combined influence of climatic variability and local drivers of river flows.

Despite growing awareness of the hydrological impacts of climate change, studies specifically addressing maximum streamflow trends in Romania remain limited. This study addresses this gap by conducting a comprehensive trend analysis of maximum discharges at a regional scale, focusing on the Ialomița River catchment. This catchment is the largest in southeastern Romania, covering over 10,000 km² and encompassing several socio-economically developed regions that are highly vulnerable to flood risk. The primary aim of the study is to investigate the variability of maximum streamflow within the basin to identify potential changes in their temporal dynamics. The specific objectives are to detect trends in monthly, seasonal, and annual maximum discharges, evaluate their spatial distribution across the catchment, and finally, provide up-to-date information on hydrological changes in a region where existing data are scarce and fragmented.

This study is based on trend detection analysis using the non-parametric Mann-Kendall test applied to a time series of maximum monthly and annual discharges recorded at 18 gauging stations along the Ialomița River and its tributaries. The innovative aspect of this study lies in its comprehensive assessment of trends in maximum streamflow across the entire basin, in contrast to previous research that focused on selected sub-basins, a limited number of gauging stations, and shorter time periods. The findings provide an integrated perspective on the spatial and temporal patterns of high flows through the Ialomița River catchment over a period of up to six decades (1961 – 2020), as well as a comparative analysis of trends for two distinct 30-year climatological subperiods, 1961–1990 and 1991–2020. The analyses capture shifts in maximum streamflow at different temporal scales, allowing for a detailed assessment of temporal patterns and their potential drivers. The results offer valuable insights to support the development of adaptive, evidence-based flood risk management strategies that respond to observed hydrological and climatic changes.

Following this introduction, Section 2 provides a detailed description of the study area, data, and methodological approach. Section 3 presents the results, focusing on three key aspects: (i) trends in annual maximum floods, (ii) trends in seasonal maximum discharges, and (iii) trends in monthly maximum discharges. Section 4 offers a detailed discussion of the results, structured into four subsections: (i) summary of findings and the potential role of climatic factors; (ii) comparison of findings with previous studies; (iii) potential non-climatic influences on the variability of maximum streamflow; and (iv) projected future hydrological changes. Finally, Section 5 summarizes the main findings and presents concluding remarks.

2. Materials and Methods

2.1. Study area

The Ialomița River (417 km in length) is the major tributary of the Danube River in southeastern Romania (Figure 1a). Its watershed covers an area of 10,350 km² and encompasses a wide range of landforms, with elevations ranging from approximately 6 m a.s.l. at the river mouth to 2,505 m a.s.l. in the Carpathian Mountains. The upper basin lies within the Carpathians, the middle sector extends across the Subcarpathians, and the lower basin overlaps the Romanian Plain (Figure 1a). The hydrographic network within this basin is dominated by the Ialomița River and its tributaries, the most important of which include the Prahova River and its own tributaries (i.e., Azuga, Valea Cerbului, Doftana, Teleajen, and Cricovul Sărat), Cricovul Dulce, and Sărata rivers (Figure 1b). This complex river system plays a key role in maintaining hydrological connectivity within the basin and contributes to the spatial and temporal variability of high-flow events. The average multiannual discharges range from 0.2 to 39.4 m³/s, while peak flows during flood events can greatly exceed these values (Table 1).

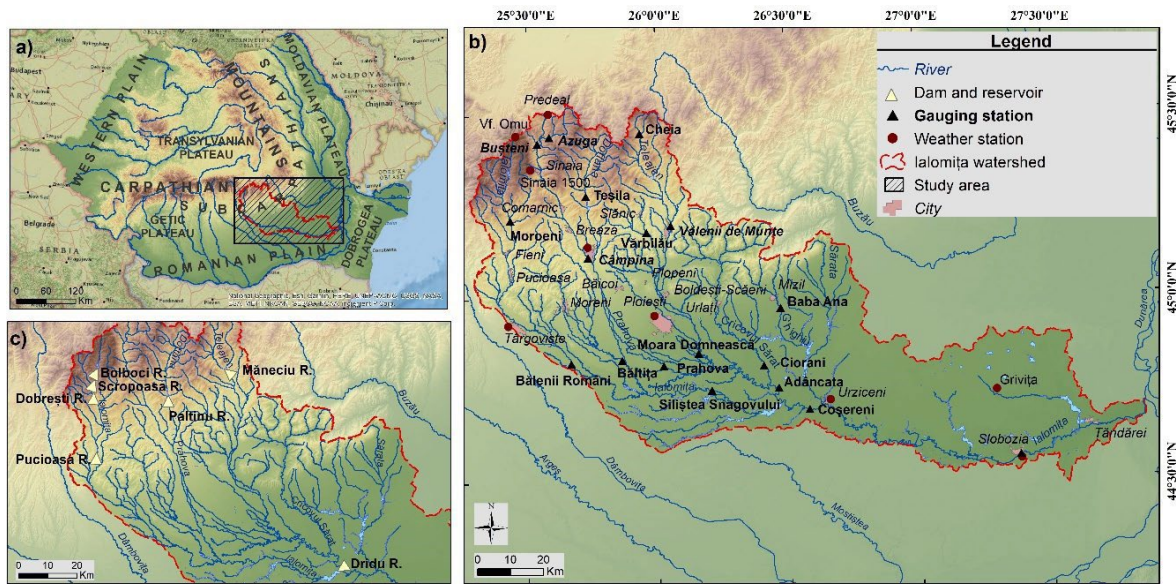


Figure 1. Location of the study area in Romania (a); location of the analyzed gauging stations (b) and location of the dams and reservoirs (c)

The natural flow regime of several rivers within the study area has been altered by the construction of dams and reservoirs, serving multiple purposes, predominantly water supply and hydropower generation. Along the Ialomița River, five major reservoirs have been developed: Bolboci (18 million m³, commissioned in 1985), Scropoasa (0.5 million m³, commissioned in 1930), Dobrești (0.04 million m³, commissioned in 1952), Pucioasa (8 million m³, commissioned in 1976), and Dridu (45 million m³, commissioned in 1985) (according to M.M.A.P. and CONSIB, 2019). In addition, two large reservoirs are located on tributaries: Paltinu on the Doftana River (53.7 million m³, commissioned in 1971) and Măneciu on the Teleajen River (60 million m³, commissioned in 1994) (M.M.A.P. and CONSIB, 2019) (Figure 1c).

The study area is generally well populated and economically developed. The most urbanized sector is the upper Prahova Valley, which includes several towns of notable touristic significance in the mountainous region (e.g., Predeal, Azuga, Bușteni, and Sinaia), as well as other economically important towns in the Subcarpathian area, such as Comarnic and Câmpina. The largest urban centers are in the lowland sector of the Ialomița basin and include Ploiești, Târgoviște, Urziceni, and Slobozia. Numerous other settlements—ranging from small villages to medium-sized towns—are situated along the Ialomița River and its tributaries, making them particularly susceptible to flood hazards.

In the Carpathian region, the land cover is primarily forests and grasslands, whereas in the Subcarpathians, the landscape is further characterized by orchards, vineyards, and cultivated lands. In contrast, the plain sector is primarily covered by non-irrigated arable lands, according to the National Administration "Romanian Waters" (N.A.R.W., 2023). In the mountainous region, tourism, forestry, logging, and livestock farming represent the principal economic activities. In the Subcarpathians, agriculture and industry are more prominent; however, tourism has gained increasing importance in recent decades. In the lowland area, agriculture remains the dominant economic sector, complemented by other activities such as oil extraction. The region is crossed by a relatively dense transport infrastructure, including national and European roads and railways, most of which follow the main river valleys (e.g., Ialomița, Prahova, Teleajen), making them particularly exposed to flood hazards.

Table 1 Data on the analyzed rivers and gauging stations within the Ialomița watershed

No.	River	Gauging station	Drainage area (km ²)	Average altitude (m a.sl.)	Analyzed period	Qav (m ³ /s)	Qmax (m ³ /s)
1	Ialomița	Moroeni	264	1,372	1961-2020	4.25	373
2	Azuga	Azuga	83.7	1,378	1961-2020	1.71	94.0
3	Valea Cerbului	Bușteni	24.9	1,535	1961-2020	0.499	62.3
4	Doftana	Teșila	291	1,174	1961-2020	4.62	311
5	Teleajen	Cheia	39.2	1,275	1962-2020	0.771	83.0
6	Cricovul Dulce	Bălțița	534	394	1961-2020	2.24	434
7	Ialomița	Bălenii Români	916	762	1961-2020	8.36	758
8	Prahova	Câmpina	484	1,115	1961-2020	7.34	399
9	Teleajen	Vălenii de Munte	471	922	1961-2020	4.83	540
10	Slănic	Vărbilău	41.1	517	1966-2020	0.338	175
11	Ghighiu/Istău	Baba Ana	107	291	1967-2020	0.238	183
12	Teleajen	Moara Domneasă	1,400	553	1961-2020 (no data for 1963)	9.88	850
13	Prahova	Prahova	983	1,010	1961-2020	11.8	766
14	Cricovul Sărat	Ciorani	594	291	1966-2020	1.61	273
15	Ialomița	Siliștea Snagovului	1,925	515	1961-2020	10.5	644
16	Prahova	Adâncata	3,688	550	1961-2020	27.1	1220
17	Ialomița	Coșereni	6,320	487	1961-2020	39.4	1440
18	Ialomița	Slobozia	9,063	366	1961-2020	38.7	818

Qav = average discharge (m³/s); Qmax=maximum discharge. The discharges were computed based on the data provided by the National Institute of Hydrology and Water Management (I.N.H.G.A.) for the analyzed periods. Stations located downstream of dams and reservoirs on the Ialomița River and its tributaries are in bold. Data on the drainage area and average altitude were provided by the I.N.H.G.A.

2.2. Data and methods

2.2.1. Data

The study is based primarily on hydrological datasets consisting of monthly and annual instantaneous maximum discharges recorded at 18 gauging stations (g.s.) located on 10 rivers draining the mountainous, hilly, and plain sectors of the Ialomița watershed: five stations are located along the Ialomița River, and 13 are situated on its tributaries (Table 1). These stations were selected to ensure the availability of long-term records, with continuous time series extending up to 60 years. Morphometric and hydrological characteristics of the rivers and basins at the analyzed stations are presented in Table 1. The areas of the catchments range from 25 km² (Valea Cerbului River at Bușteni g.s.) to 9,063 km² (Ialomița River at Slobozia g.s.), while their average

altitudes vary between 291 m a.s.l. (Ghighiu/Istău at Baba Ana g.s. and Cricovul Sărat at Ciorani g.s.) and 1,535 m a.s.l. (Valea Cerbului at Bușteni g.s.) (Table 1).

At several gauging stations, streamflow is influenced by upstream reservoirs (as noted in Section 2.1). This is the case for all stations located on the Ialomița River, as well as for the Vălenii de Munte and Moara Domnească stations on the Teleajen River. Although no major reservoirs are situated directly on the Prahova River, its flow in the lower sector (at the Prahova and Adâncata stations) is indirectly influenced by the Paltinu and Măneciu reservoirs located on its tributaries, Doftana and Teleajen, respectively. In addition to dams and reservoirs, the flow of certain rivers (such as the lower Ialomița and Prahova) may also be influenced by uncontrolled water withdrawals for various uses. Out of the 18 hydrometric stations included in this analysis, only nine (half) can be considered to reflect a quasi-natural flow regime (i.e., streamflow affected by anthropic interventions with negligible effects on natural flow variability, such as small hydropower plants and dams, and minor flood-control structures): Azuga, Bușteni, Teșila, Cheia, Băltița, Câmpina, Vărbilău, Baba Ana, and Ciorani (Table 1).

The hydrological datasets were provided by the National Institute of Hydrology and Water Management (I.N.H.G.A.) in Romania and have undergone quality control. A few gauging stations have slightly shorter records, as they started operating later: Cheia g.s. in 1962, Vărbilău g.s. and Ciorani g.s. in 1966, and Baba Ana g.s. in 1967. Additionally, no data were recorded at Moara Domnească g.s. in 1963. For consistency and simplicity, the analysis period is generalized as 1961–2020 in all figures and discussions.

Hydrological datasets provide a comprehensive basis for assessing the spatial and temporal variability of maximum discharges across the Ialomița watershed. The inclusion of stations across mountainous, hilly, and plain sectors allows for a detailed analysis of hydrological responses to various physiographic and climatic drivers, as well as the influence of anthropogenic factors, such as dam regulation.

In addition to the hydrological data, information derived from the topographic map of Romania (1:25,000) and from the 25m - resolution Digital Elevation Model (DEM) provided by the Topographic Military Directorate (2004), were used to generate maps and to calculate various catchment and river characteristics using GIS tools (ArcMap).

2.2.2. Methodology

Based on the aforementioned data, we investigated variations in maximum discharges (annual, seasonal, and monthly) using trend detection analysis. This approach enables the assessment of temporal non-stationarity in streamflow and is widely applied worldwide to identify changes in hydrological data series, including maximum discharges and flood characteristics. Notable examples include those of Kundzewicz et al. (2005) at the global scale; Mediero et al. (2015), Blöschl et al. (2017, 2019), Mangini et al. (2018), and Bertola et al. (2020) in Europe; Archfield et al. (2016) and Slater and Villarini (2016) in the United States; Zadeh et al. (2020) in Canada, and numerous other studies at regional and national scales.

In this study, trends were examined using the nonparametric Mann–Kendall (MK) test, one of the most common applied methods for detecting monotonic trends in time series without seasonal or cyclic patterns (Salmi et al., 2002). The MK test offers the advantage of not requiring the data to conform to any specific probability distribution, although it assumes independence among observations to ensure the accuracy of significance levels (Kundzewicz et al., 2005). Because the datasets used in our analysis consisted of instantaneous maximum discharges (annual and monthly), this assumption of independence was satisfied. Computations were performed using the freely accessible Excel template application MAKESENS, developed by Salmi et al. (2002) and published by the Finnish Meteorological Institute. A detailed presentation of the MK test is provided by Salmi et al. (2002). The significance levels (α) reported by MAKESENS for the identified trends were 0.001, 0.01, 0.05, and 0.1.

Trend detection analyses were applied to the time series of annual and monthly maximum discharges over a long-term period of up to 60 years, as well as for two 30-year subperiods, 1961–1990 and 1991–2020, corresponding to the climatological standard normal periods, as defined by the World Meteorological Organization (WMO, 2025). For stations exhibiting a quasi-natural flow regime, a comparative analysis of trend results between the two subperiods may allow us to identify changes in the maximum streamflow attributable to climate change during the most recent period relative to the earlier one. For stations monitoring streamflow influenced by anthropogenic interventions (i.e., primarily rivers impacted by dams and reservoirs), comparisons between the two periods are less meaningful for isolating climate-driven effects, as human interventions may mask climatic signals.

Although the data periods are not identical for all stations, they are considered sufficiently long to obtain relevant long-term trend results. However, for the first subperiod, uncertainties may arise at stations that started operating later than 1961, which could potentially affect the robustness of trend detection for those specific locations.

3. Results

The application of the Mann–Kendall test enabled the identification of trends in maximum discharges at annual, seasonal, and monthly temporal scales over the long-term period (1961 – 2020), as well as for the two climatological subperiods separated within it. This approach allowed for the assessment of both long-term changes and shifts in hydrological behavior between the earlier (1961–1990) and more recent (1991–2020) periods.

3.1. Trends in annual maximum floods

Over the **long-term period (1961–2020)**, half of the 18 gauging stations exhibited upward trends in annual maximum discharges; however, these trends were statistically significant at only two stations (Azuga and Teșila). In contrast, statistically significant downward trends were detected at three stations (Câmpina, Baba Ana, and Slobozia) (Figures 2 and 3).

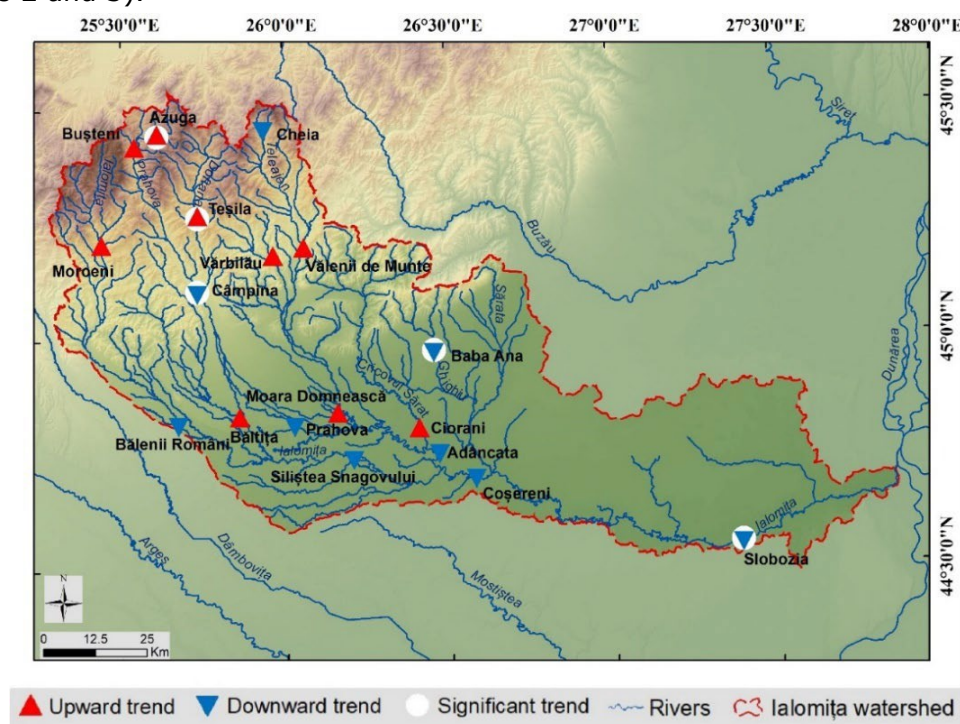


Figure 2. Trends in annual maximum floods series at the analyzed gauging stations over the period 1961–2020

Gauging station (River)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Moroeni (Ialomița)	*	**		*	*						+		
Azuga (Azuga)													+
Busteni (Valea Cerbului)					+								
Teșila (Doftana)										***			*
Cheia (Teleajen)													
Bălțița (Cricovul Dulce)		+								+			
Bălenii Români (Ialomița)	+	+											
Câmpina (Prahova)	*	**	+	+	***	*	**	***			+		***
Vălenii de Munte (Teleajen)			*			*				*			
Vărbilău (Slănic)										***			
Baba Ana (Istau)					*		*	***		+			**
Moara Domnească (Teleajen)					+					**			
Prahova (Prahova)					+					*			
Ciorani (Cricovul Sarat)								**	*				
Siliștea Snagovului (Ialomița)	+	+			*								
Adâncata (Prahova)					*					*			
Coșereni (Ialomița)		+			*					*			
Slobozia (Ialomița)		*			*					*			**

Figure 3. Trends in monthly and annual maximum discharges at the analyzed gauging stations over the period 1961-2020. In yellow: positive trend. In green: negative trend. Significance levels (α): ***, $\alpha = 0.001$; **, $\alpha = 0.01$; *, $\alpha = 0.05$; +, $\alpha = 0.1$; empty cell, $\alpha > 0.1$.

During the period 1961 – 1990, six stations exhibited increasing trends in annual maximum floods, of which only one (Azuga) was statistically significant. Conversely, 12 stations showed decreasing trends, with only one (Baba Ana) reaching statistical significance (Figures 4a and 5).

After 1991, the number of stations with positive trends in the annual maximum flood series increased to 11, but only at two (Moara Domnească and Ciorani) these trends were statistically significant. The remaining seven stations displayed negative trends, of which those at Cheia and Câmpina were statistically significant (Figures 4b and 6).

Opposite trends between the two subperiods were observed at eight stations (Bălțița, Bălenii Români, Vălenii de Munte, Baba Ana, Moara Domnească, Ciorani, Adâncata, and Coșereni), with decreases in the first subperiod followed by increases in the second (Figures 4a and 4b). At three stations (Teșila, Cheia, and Vărbilău), the pattern was reversed, showing negative trends in the second subperiod (Figure 4b). The remaining seven gauging stations maintained their trends observed in the earlier period (whether positive or negative): Moroeni, Azuga, and Bușteni continued with positive trends, while Câmpina, Slobozia, Siliștea Snagovului, and Prahova maintained negative trends (Figure 4b).

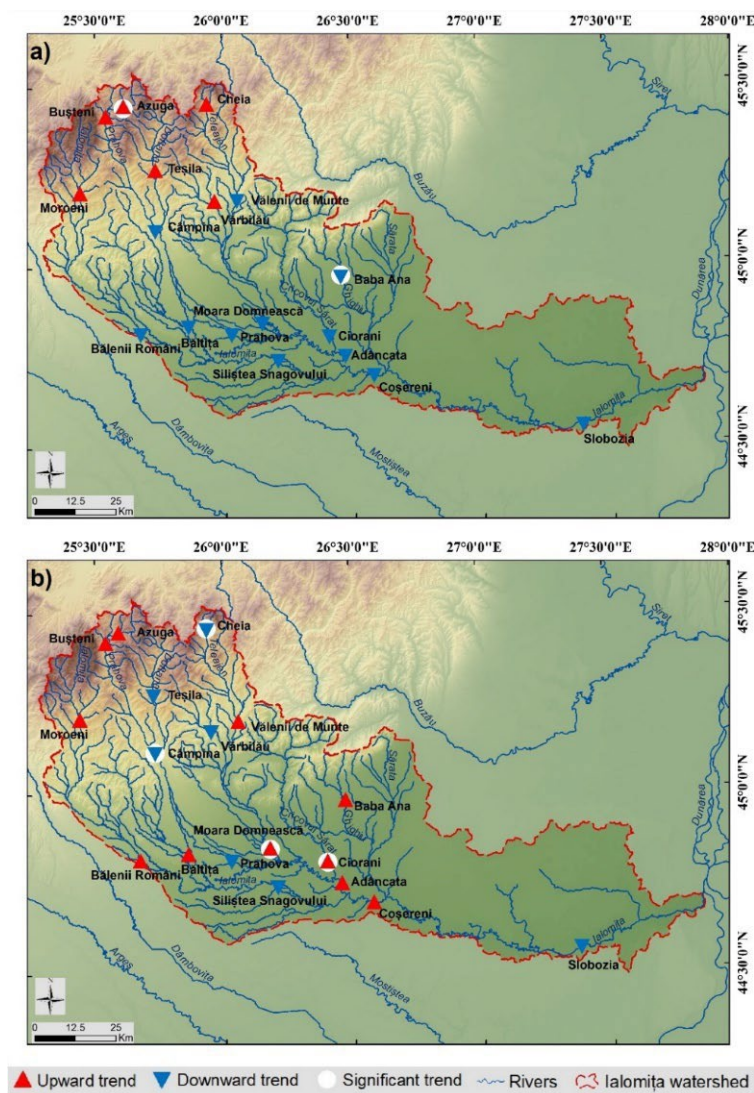


Figure 4. Trends in annual maximum floods series at the analyzed gauging stations over the periods: 1961-1990 (a), and 1991-2020 (b)

Gauging station (River)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Moroeni (Ialomița)		+	*								*		
Azuga (Azuga)	**												*
Busteni (Valea Cerbului)	*			*				+					
Teșila (Doftana)					+								
Cheia (Teleajen)		*				+							
Băltița (Cricovul Dulce)													
Bălenii Români (Ialomița)											+		
Câmpina (Prahova)				+									
Vălenii de Munte (Teleajen)				+									
Vărbilau (Slănic)									*				
Baba Ana (Istau)													**
Moara Domnească (Teleajen)													
Prahova (Prahova)					*								
Ciorani (Cricovul Sarat)	*			+			+	*	**				
Siliștea Snagovului (Ialomița)	*				*						*		
Adâncata (Prahova)	+												
Coșereni (Ialomița)					+								
Slobozia (Ialomița)					*								

Figure 5. Trends in monthly and annual maximum discharges at the analyzed gauging stations over the period 1961 – 1990. In yellow: positive trend. In green: negative trend. Significance levels (α): ***, $\alpha = 0.001$; **, $\alpha = 0.01$; *, $\alpha = 0.05$; +, $\alpha = 0.1$; empty cell, $\alpha > 0.1$.

Gauging station (River)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Moroeni (Ialomița)					+				+				
Azuga (Azuga)	*	*	**					*		*	*		
Busteni (Valea Cerbului)		+											
Teșila (Doftana)													
Cheia (Teleajen)			*			+							+
Bălăta (Cricovul Dulce)	+		+							+			
Băleni Români (Ialomița)	*	*	*			*							
Câmpina (Prahova)				*	**	*		*	***		+		**
Vălenii de Munte (Teleajen)										*			
Vărbilau (Slănic)		+								*			
Baba Ana (Istau)			*								+		
Moara Domnească (Teleajen)		*								*			*
Prahova (Prahova)		+	+										
Ciorani (Cricovul Sarat)			+										**
Siliștea Snagovului (Ialomița)		*	*			+				*			
Adâncata (Prahova)		+	+										
Coșereni (Ialomița)										*			
Slobozia (Ialomița)			+						+				

Figure 6. Trends in monthly and annual maximum discharges at the analyzed gauging stations over the period 1991-2020. In yellow with ↑: positive trend. In green with ↓: negative trend. Significance levels (α): ***, $\alpha = 0.001$; **, $\alpha = 0.01$; *, $\alpha = 0.05$; +, $\alpha = 0.1$; empty cell, $\alpha > 0.1$.

3.2. Trends in seasonal maximum discharges

At the seasonal scale, **over the period 1961-2020**, the Ialomița basin exhibited distinct differences in trends. Autumn stands out with the highest number of positive trends, totaling 34 cases (24 nonsignificant and 10 significant), indicating a consistent increase in maximum discharges during this season. Positive trends were also frequent in summer (15 cases) and winter (16 cases); however, none of these trends reached statistical significance (Figure 7a).

In contrast, negative trends dominated during winter, spring, and particularly summer. The strongest negative signal occurred in summer, with 39 negative trends, including six statistically significant cases. Spring and winter also displayed substantial numbers of cases of decrease (42 and 38, respectively), with 14 significant declines in spring and 12 in winter. Autumn recorded the fewest negative trends (20 cases), reinforcing the predominance of upward trends in this season (Figure 7b).

Overall, these results indicate over the long term a hydrological shift characterized by diminishing high flows from late winter through summer, contrasted by pronounced increases during autumn. This seasonal pattern suggests a redistribution of flood risk within the basin, with potentially greater susceptibility to high-flow events in the autumn months.

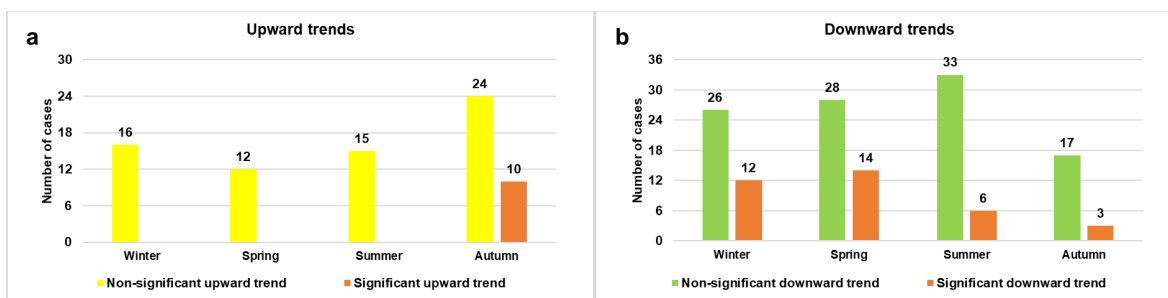


Figure 7. Upward (a) and downward (b) trends in seasonal maximum discharges at the analyzed gauging stations over the period 1961-2020

During the 1961-1990 period, positive trends were markedly less frequent than negative trends. Autumn recorded the highest number of positive trends (20 cases, including one statistically significant), followed by summer (18 cases, two significant), winter (15 cases, one significant), and spring (14 cases, one significant) (Figure 8a).

Conversely, decreasing trends dominated all seasons. The largest number of declines was observed in spring (40 cases, nine significant), closely followed by winter (39 cases, six significant) (Figure 8b). These results indicate a predominantly negative tendency in maximum discharges throughout the year, with only a modest and seasonally restricted positive signal occurring in autumn.

The dominance of downward trends across all seasons from 1961 to 1990 indicates a general reduction in high-flow conditions, with the most statistically significant declines occurring during winter and spring.

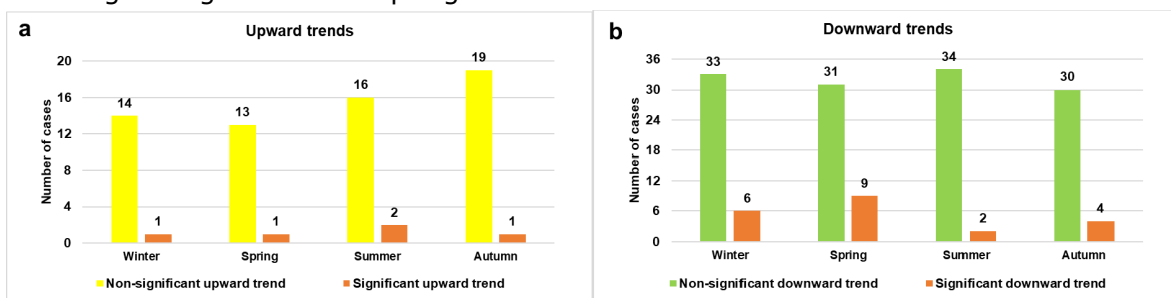


Figure 8. Upward (a) and downward (b) trends in seasonal maximum discharges at the analyzed gauging stations over the period 1961-1990

During the period 1991–2020, the number of stations exhibiting positive trends in seasonal maximum flows increased substantially compared to the previous period (1961–1990). Positive trends dominated all seasons. The highest number of such trends occurred in winter (42 cases, including 12 statistically significant), followed by summer (36 cases, three significant), autumn (36 cases, eight significant), and spring (35 cases, nine significant) (Figure 9a). These results indicate a predominantly positive tendency in maximum discharges throughout the year.

Conversely, downward trends became markedly less frequent than upward trends. Spring recorded the highest number of decreases (19 cases, including three significant), followed by summer (18 cases, three significant), autumn (18 cases, five significant), and winter (12 cases, none statistically significant) (Figure 9b).

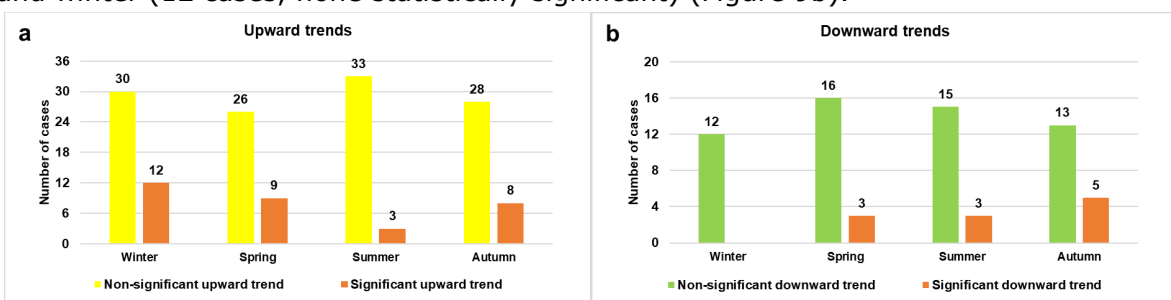


Figure 9. Upward (a) and downward (b) trends in seasonal maximum discharges at the analyzed gauging stations over the period 1991-2020

It can thus be concluded that, across the Ialomița basin, positive trends became the dominant feature in all seasons after 1991, with many of them reaching statistical significance. This contrasts sharply with the 1961–1990 period, during which negative tendencies prevailed throughout the year. The comparison between the two subperiods indicates a pronounced shift in seasonal maximum-flow variability, from predominantly declining patterns before 1990 to widespread increases after 1991. This suggests changes in seasonal hydrological behavior, potentially driven by climate variability or anthropogenic influences, or a combination of both.

3.3. Trends in monthly maximum discharges

Over the **long period (1961–2020)**, across the entire basin, 77 cases (36% of the total number of months) exhibited increasing trends, of which only 10 (5%) were statistically significant. The monthly distribution of stations exhibiting increasing or decreasing trends in maximum discharges is presented in Figure 10, highlighting the variations in the occurrence of positive and negative trends across the Ialomița catchment.

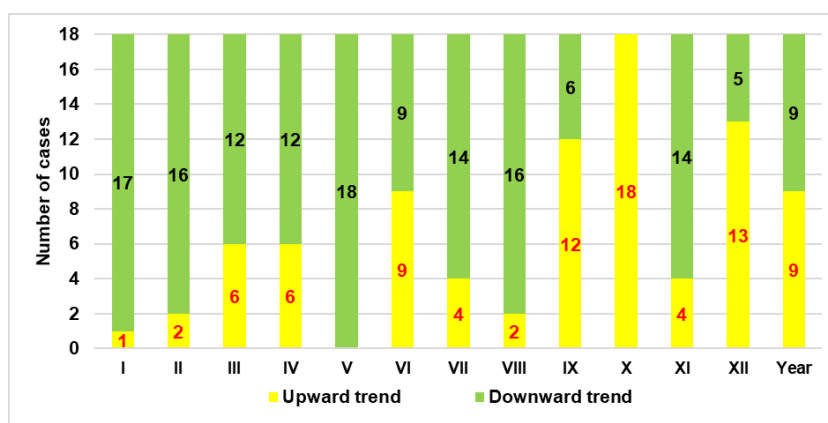


Figure 10. Trends in monthly and annual maximum discharges series at the analyzed gauging stations over the period 1961–2020

Notably, increasing trends were observed at all stations in October, with statistical significance recorded at 10 stations. Frequent, although non-significant, increases were also found in September (12 cases) and December (13 cases) (Figures 3 and 11a). The high frequency of positive trends during the autumn months can be attributed to increasing precipitation trends identified across Romania and the Carpathian region during this season (Cheval et al., 2014; Micu et al., 2015), as discussed in Section 4.1.

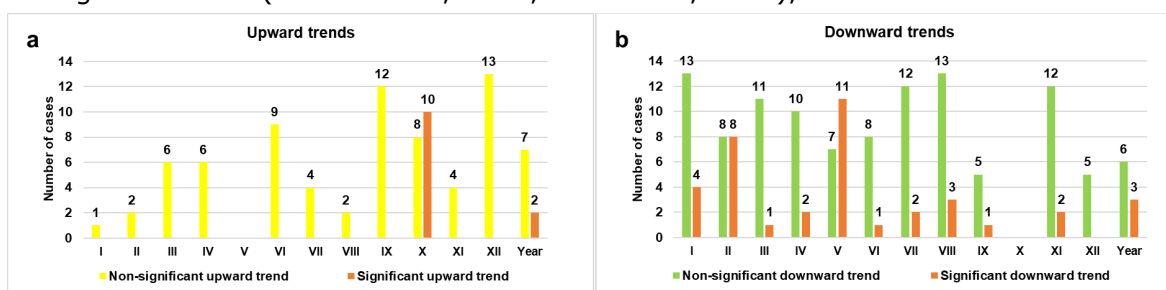


Figure 11. Upward (a) and downward (b) trends in monthly and annual maximum discharges at the analyzed gauging stations over the period 1961–2020

During the 6-decade period, 35 cases (25%) of significant **decreasing trends** were recorded, occurring most frequently in May (11 cases), February (eight cases), and January (four cases). Negative trends (both significant and nonsignificant) were identified at all stations in May (Figures 3 and 11b).

For the **subperiod 1961–1990**, the monthly distribution of stations exhibiting increasing or decreasing trends in maximum discharges is presented in Figure 12. Across the entire catchment, when considering both significant and nonsignificant trends, fewer cases (months) of increasing trends (62) were identified compared with decreasing trends (128). Of these, only five positive trends were statistically significant (in February, March, June, August, and November), while 21 negative trends reached statistical significance, occurring most frequently in January (six cases), April (five cases) and May (four cases) (Figures 5 and 13).

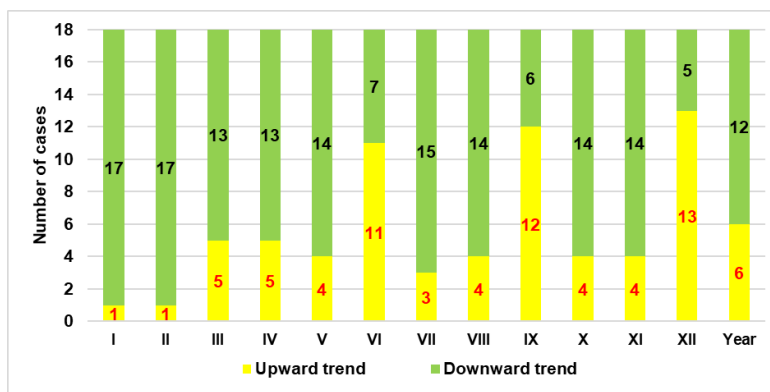


Figure 12. Trends in monthly and annual maximum discharges series at the analyzed gauging stations over the period 1961-1990

Positive trends were most often recorded in December (13 stations), September (12 stations), and June (11 stations, of which one was statistically significant – Cheia g.s.) (Figures 5 and 13a). **Negative trends** occurred most frequently in January and February at nearly all stations (17) (Figure 12 and 13b). Moroeni was the only station that did not exhibit negative trends during these two months (Figure 5).

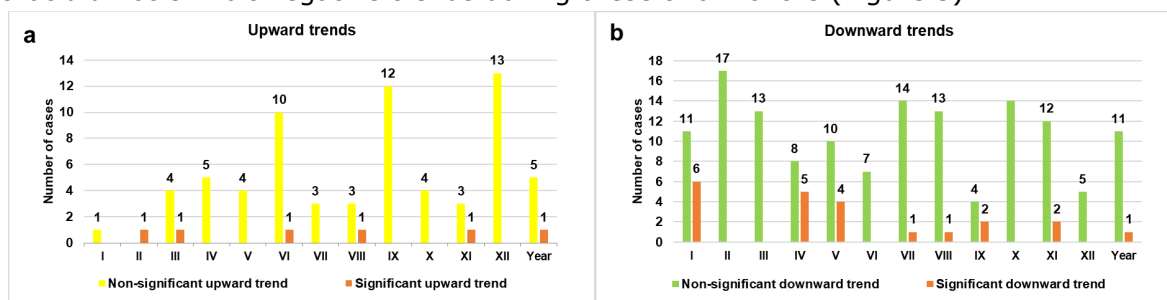


Figure 13. Upward (a) and downward (b) trends in monthly and annual maximum discharges at the analyzed gauging stations over the period 1961-1990

In the **second subperiod (1991 – 2020)**, the total number of **positive monthly trends** (both significant and nonsignificant) increased substantially to 149, representing an increase of 87 cases compared with the previous subperiod. Notably, 32 of these trends were statistically significant, compared to five in the earlier subperiod. The months with the highest number of stations exhibiting positive trends were March (17 stations), followed closely by February and October (16 stations each). In January and July, 14 out of the 18 stations recorded positive trends (Figure 14).

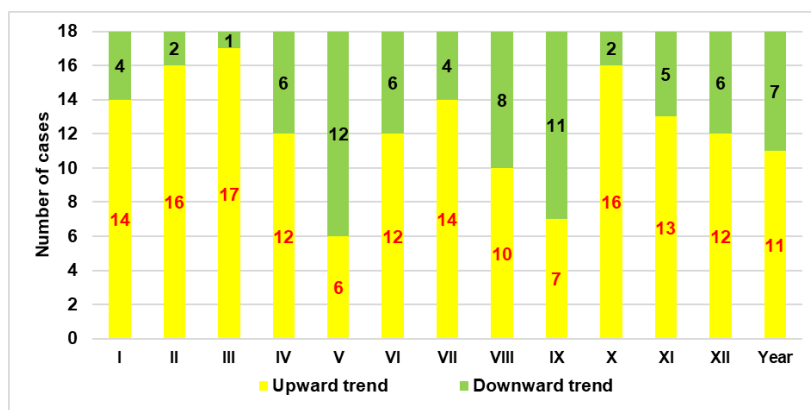


Figure 14. Trends in monthly and annual maximum discharges series at the analyzed gauging stations over the period 1991-2020

Over the study region, during the period 1991 – 2020, positive trends were most frequently observed between January and March, and in October, many of which were statistically significant (Figures 6 and 15a). This contrasts with the previous subperiod, during which trends were predominantly negative, highlighting a notable shift in the variability of maximum monthly flows between the two intervals.

Positive trends were observed at both Bălțița and Bălenii Români stations throughout all months. However, these trends were statistically significant for three months at Bălțița (January, March, and October) and for four months at Bălenii Români (January to March and June) (Figure 6).

After 1991, **negative trends** were identified in 67 cases (61 fewer than in the previous subperiod), of which 11 were statistically significant: three cases in September, two cases each in May, June, and November, and one case each in April and August. The most frequent negative trends were observed in May (12 stations), September (11 stations), and August (eight stations) (Figures 6 and 15b). At Câmpina g.s., negative trends were recorded in all months, of which six were statistically significant, a pattern closely resembling that of the first subperiod. Across the study region, negative trends exceeded positive trends in only two months: May and September.

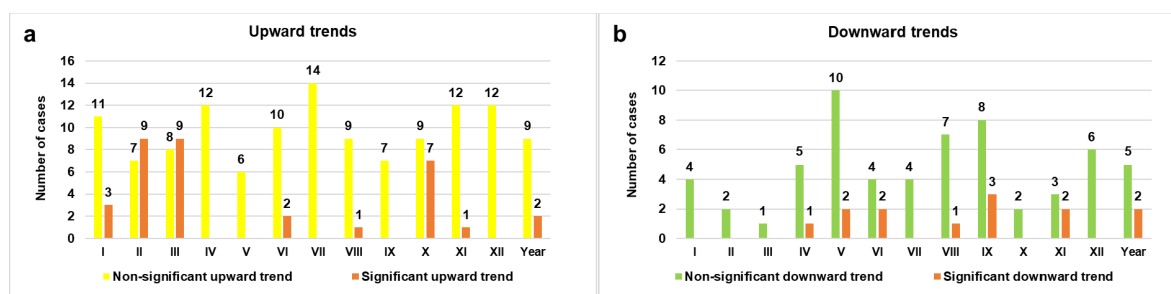


Figure 15. Upward (a) and downward (b) trends in monthly and annual maximum discharges at the analyzed gauging stations over the period 1991-2020

4. Discussion

4.1. Summary of findings and the potential role of climatic factors

The trend analysis of annual, seasonal and monthly maximum discharges conducted using the nonparametric Mann–Kendall test over the long period 1961–2020 and the two 30-year subperiods (1961–1990 and 1991–2020) revealed several changes in maximum streamflow across the study region. Predominantly upward trends in annual maximum discharges were detected after 1991 at 11 out of 18 gauging stations, compared with only six stations during 1961–1990. Generally, these increasing trends were not statistically significant, with five exceptions: two during 1961–2020, two during 1991–2020, and one during 1961–1990. Additionally, several stations exhibited statistically significant negative trends (a total of six cases), three over the full 60-year period, one prior to 1990, and two after 1991.

At the monthly level, the comparison between the two subperiods revealed a 38% increase in the total number of months with positive trends (both significant and nonsignificant) during the second subperiod, rising from 67 to 149 cases. Positive trends during the second period accounted for 69% of the total number of months, thereby reversing the earlier dominance of months exhibiting negative trends. Notably, 32 of these positive trends were statistically significant, compared with only five significant positive trends identified in the earlier subperiod.

During the period 1991 – 2020, positive trends were most frequently observed in January – March, with many reaching statistical significance. This pattern contrasts with both the earlier subperiod (1961–1990) and the entire 6-decade interval, during which trends in these months were predominantly negative. The higher frequency of positive

trends in January – March during the more recent period may be associated with an increased contribution of snowmelt to streamflow, resulting from significant positive trends in temperature-related indices observed since 1961, which have favored earlier and more intense snowmelt (Bîrsan et al., 2014; Cheval et al., 2014; Micu et al., 2021), particularly during episodes of rapid warming in winter and early spring. Additionally, the increasing proportion of winter precipitation falling as rain rather than snow may explain the upward trends observed in maximum streamflow during this season (Bîrsan and Dumitrescu, 2013; Bîrsan et al., 2014).

In October, a notable increase in the number of stations showing positive trends, from four in the first subperiod to 16 in the second, was also observed. This change may be attributed to the wetter conditions characterizing this month, as evidenced by the upward precipitation trends identified in the analyzed area (primarily in the Carpathians) during autumn (Cheval et al., 2014; Micu et al., 2015).

It is worth noting that for the first subperiod (1961–1990), results from the few stations that became operational after 1961 may be subject to some uncertainties. Nevertheless, these uncertainties are likely minimal, as no major floods were recorded in the Ialomița catchment during 1961 – 1966. Moreover, the shorter record length for some stations in the earlier period is unlikely to have substantially affected the overall trend analysis, given the consistency of observed patterns across the majority of long-term stations. Therefore, while caution is warranted when interpreting these results, the trends detected for this subperiod can be considered pertinent.

Finally, we can conclude that trend detection analysis across the Ialomița River catchment revealed a clear shift in maximum flow patterns over the past six decades. While the period 1961–1990 was characterized predominantly by decreasing trends, particularly in winter and spring, the period after 1991 was marked mainly by increasing trends, especially in winter, early spring (January–March), and autumn. Many of these increases are statistically significant, indicating emerging changes in hydrological behavior. The observed trends appear to be driven primarily by climate-related processes. As noted above, positive trends in high flows in winter and early spring may be attributable to earlier and more intense snowmelt, associated with rising winter temperatures and shifts in precipitation phase from snow to rain. In autumn, increasing high flows reflect enhanced rainfall during this season, as confirmed by regional precipitation trends. Nevertheless, other natural and anthropogenic factors that may influence runoff should not be overlooked, as discussed in a later section (4.3).

4.2. Comparison of findings with previous studies

Our findings are generally consistent with those of previous studies cited in the Introduction. Bîrsan et al. (2014) reported predominantly significant decreasing trends in the maximum flow, expressed by the high quantiles of the average daily streamflow series ($q_{0.7}$ – $q_{0.9}$ and q_{max}), over the periods 1961–2009 and 1975–2009 on an annual time scale, as well as during winter, spring, and summer. Our results for the long period (1961–2020) closely align with these findings. However, a comparative analysis between the two subperiods revealed predominantly positive trends during winter to early spring (January – March). In autumn, our results similarly indicate upward trends, in agreement with the findings of Bîrsan et al. (2014).

Our findings are also similar to those of Perju (2012) and Perju and Zaharia (2014) for the small watershed of Valea Cerbului in the Bucegi Mountains (located in the upper Ialomița watershed), showing a significant increasing trend in the magnitude of maximum annual floods after 1961, as well as during autumn, winter, and summer (although the trend in summer was not statistically significant). In spring, they detected a negative trend (not non-significant), which differed from our findings. Zaharia et al. (2020) observed, for the same catchment, after 1990, an increase in the frequency of high-magnitude floods, as well as an increase in the frequency and magnitude of floods occurring in March–June and September–October, which closely aligns with our results.

Since Romania lies at the intersection of several regions considered in European-scale studies (e.g., Central, Eastern, and Southern Europe), its classification within a specific pattern of changes in maximum flow, as identified by some authors cited in the Introduction, remains debatable. Thus, if Romania is considered part of Central Europe, our findings are consistent with those reported by Hall et al. (2014) and Mangini et al. (2018), which indicated an increase in flood magnitude. Conversely, if Romania's geographical position is considered within Eastern Europe, our results diverge from those of Blöschl et al. (2019) and Bertola et al. (2020), who reported decreasing trends in annual maximum floods for this region.

4.3. Potential non-climatic influences on the variability of maximum streamflow

Streamflow reflects the combined influence of climate and catchment-specific characteristics, both natural and socio-economic. For stations with a quasi-natural flow regime, observed changes in climatic parameters are the most plausible drivers of the alterations identified in high-flow variability. However, for rivers impacted by dams and reservoirs, the direct influence of climate may be less evident because of reservoir operations, particularly at stations located close to dams. Downstream, the effects of reservoir operations may be attenuated, allowing climatic signals to exert a stronger influence on hydrological responses.

The possible impact of reservoirs on trends in maximum streamflow does not exhibit a homogenous pattern across the Ialomița catchment. At some stations located downstream of reservoirs (e.g. Bălenii Români and Coșereni on the Ialomița River, and Vălenii de Munte on the Teleajen River), mostly upward trends in monthly and annual maximum discharges were observed in the second subperiod compared to the first; in contrast, at Moroeni g.s. (on the upper Ialomița River), the opposite pattern was detected. These differences suggest the potential influence of additional factors on maximum streamflow dynamics downstream of dams, including distance from the dam, catchment size and geomorphology, contributions from intermediate tributaries, reservoir operational practices, and water use patterns. For stations located downstream of reservoirs commissioned before 1961, it is likely that their effects are not readily discernible when comparing the two subperiods analyzed in this study.

In addition to dams and reservoirs, maximum streamflow may also be influenced by other engineered structures and direct human interventions, such as water abstraction for various uses, the volumes of which are generally unknown. Indirectly, land use changes within the catchments may also play a role in shaping long-term streamflow dynamics, potentially affecting the maximum discharges.

Although it is evident that human activities can affect river flow, the observed alterations in streamflow in the study area are most likely attributable to climate change. Thus, Chelu et al. (2022) estimated that, over the period 1966–2010, approximately 79% of the observed streamflow changes within the Ialomița catchment were attributable to climatic factors, whereas only 21% were linked to anthropogenic influences. This finding underscores the dominant role of climate variability in shaping long-term trends in maximum discharges within the Ialomița basin.

A key role in the spatial differences of flood characteristics and dynamics is played by the geospatial morphometric parameters of basins and river networks (i.e., drainage area size and elevation, catchment and channel slope, catchment shape, drainage density etc.) (Arash et al., 2025). Small basins with steep slopes, drained by rivers with pronounced gradients and high density, typical of the mountainous sector (e.g., Ialomița at Moroeni, Valea Cerbului, Azuga, Doftana, Teleajen at Cheia g.s.) (Table 2), exhibit a rapid hydrological response to conditions conducive to high flows and flash floods. In contrast, larger basins characterized by gentler slopes drained by rivers with lower channel gradients (e.g., Ialomița at Slobozia Slobozia, Prahova at Adâncata, Teleajen at Moara Domneasă) tend to display a more attenuated response, with slower runoff generation and reduced flood peak amplification. The shape of the catchments,

expressed through specific coefficients (i.e., circularity ratio/coefficient, form factor, and elongation ratio) may exert a notable influence on runoff dynamics within the catchment and flood magnitude. Circular basins (characterized by high values of the form coefficients) tend to exhibit rapid and synchronized runoff responses, leading to short lag times and high flood peaks. In contrast, elongated basins (with lower form coefficients) generate more spatially and temporally distributed runoff, resulting in attenuated peak flows (Prabhakar et al., 2019). In the Ialomița catchment, most subbasins have elongated shapes, with circularity coefficients below 0.5 (Table 2). However, several small mountain basins (such as Valea Cerbului, Azuga, Teleajen at Cheia, and Doftana) display higher form coefficients, which favor the occurrence of flashy high flows.

Table 2 Morphometric characteristics of rivers and catchments at gauging stations within the Ialomița watershed

No.	River	Gauging station	Catchment slope (%)	Channel slope (%)	Circularity coefficient (Cr)*
1	Ialomița	Moroeni	32.1	6.29	0.45
2	Azuga	Azuga	36.5	2.88	0.55
3	Valea Cerbului	Bușteni	47.1	23.3	0.68
4	Doftana	Teșila	30.2	2.84	0.52
5	Teleajen	Cheia	33.5	6.69	0.64
6	Cricovul Dulce	Bălțița	13.6	0.89	0.38
7	Ialomița	Bălenii Români	20.0	2.27	0.25
8	Prahova	Câmpina	30.8	1.15	0.25
9	Teleajen	Vălenii de Munte	25.7	2.56	0.50
10	Slănic	Vărbilău	17.9	3.25	0.48
11	Ghighiu/Istău	Baba Ana	12.5	1.31	0.41
12	Teleajen	Moara Domneasca	15.7	1.44	0.33
13	Prahova	Prahova	27.2	0.84	0.19
14	Cricovul Sărat	Ciorani	13.9	0.65	0.23
15	Ialomița	Siliștea Snagovului	14.0	1.31	0.28
16	Prahova	Adâncata	15.8	0.52	0.32
17	Ialomița	Coșereni	13.7	1.04	0.40
18	Ialomița	Slobozia	10.3	0.67	0.29

The catchment slope was derived in ArcMap from the DEM using the Slope tool. The channel slope was calculated in ArcMap as the ratio between the difference in elevation of the river's extreme points and its length, based on the topographic map of Romania (1:25 000) and the Digital Elevation Model (DEM). The circularity coefficient was computed using the formula $Cr = 4IF/P^2$, where F= drainage area and P= catchment perimeter (according to Joy et al.,2023), GIS-based determined.

4.4. Projected future hydrological changes

Trend detection analysis test provides evidence of potential ongoing hydrological changes, which are validated and complemented by streamflow projections. Historical observed trends in the maximum streamflow serve as a precursor signal, indicating that the projected hydrological impacts of climate change are plausible and grounded in observed hydrological behavior.

According to the *Preliminary Flood Risk Assessment* for the Buzău–Ialomița River Basin Water Administration (N.A.R.W., 2022) assessments of the potential future impacts of climate change on the maximum flow regime of the Buzău and Ialomița rivers were conducted using long-term simulations based on the deterministic CONSUL model. Two 30-year simulation periods were considered and compared: a reference period (1971–2000) and a future period (2021–2050), corresponding to the A1B greenhouse gas emission scenario, with boundary conditions provided by the coupled ocean–atmosphere global climate model ECHAM5. The simulation results indicated the main potential changes in high flows between 2021 and 2050 relative to the reference period as follows (N.A.R.W., 2022):

- monthly maximum discharges are projected to increase during winter months and in July–August, while decreasing during the remaining months of the year;
- annual maximum flood peaks are expected to exhibit an overall declining trend, with an average of approximately -7.2%, although spatial variations range from -20.9% to +14.4%;
- the seasonal distribution of annual flood peaks is projected to shift: whereas during the reference period (1971–2000), annual flood peaks occurred most frequently in spring and early autumn; for 2021–2050, they are anticipated to occur mainly in early spring, late summer, and early autumn.
- compared with the reference period, the number of flood events is expected to increase in February–March, August, November, and December, with the most pronounced increase in March; in contrast, flood events are projected to become less frequent in April–June and October, with the largest decrease occurring in October. Corbus et al. (2013) assessed the potential impact of climate change on the maximum streamflow within the Ialomița catchment for the period 2011–2050, compared with the reference period 1951–2010, using simulations with the CONSUL hydrological model under the A1B scenario. Their findings indicated a general increase in monthly maximum discharges of the Ialomița River during the winter months, early spring (March), and July, with the highest increase (exceeding 40%) projected for February. In contrast, decreases in monthly maximum discharges were expected during April – June and September–October, with the most pronounced declines (40–50%) occurring in June and October. During the reference period, the highest frequency of annual flood peaks was recorded in October; by 2050, these peaks are projected to occur in March – April (Corbus et al. 2013).

The findings of the trend detection analysis conducted in our study are generally consistent with future projections of high flows within the Ialomița River catchment:

- seasonal and monthly shifts identified by the Mann-Kendall test support projections of lower summer flows and higher winter flows, as indicated by the hydrological simulations up to 2050;
- increasing high flow trends in early spring and winter observed after 1991 suggest that future snowmelt-driven floods are likely to occur earlier and with greater magnitude.

However, it should be noted that although climate-driven processes appear to be the primary drivers of hydrological changes, other factors may modulate the influence of climate on maximum flows, as discussed in the previous section (4.3). Therefore, a comprehensive understanding of maximum streamflow dynamics requires an integrated approach that considers both climatic and non-climatic drivers to support effective water resources management and flood risk mitigation in the Ialomița River catchment.

5. Conclusions

This study examined the variability of the maximum streamflow within the Ialomița watershed, which extend over more than 10,000 km² in southeastern Romania, with the aim of detecting potential changes in annual flood peaks and seasonal and monthly maximum discharges. Trend detection analysis was applied to datasets from 18 gauging stations spanning up to six decades (1961 – 2020). To identify potential changes attributable to climate variability, two subperiods of 30 years each (1961–1990 and 1991–2020) were considered and compared. These subperiods correspond to the climatological standard normal periods defined by the World Meteorological Organization (WMO), with the first (1961–1990) serving as the standard reference period for long-term climate change assessments (WMO, 2025).

The main findings of the study are summarized as follows:

1. During the long period 1961–2020, a balanced distribution between positive and negative trends in annual flood peaks was observed: nine stations recorded increasing trends (two of which were statistically significant), while the other nine exhibited decreasing trends (three statistically significant). This period shows clear seasonal contrasts, with declining maximum flows from late winter through summer and consistent increases in autumn, highlighting a mixed hydrological response across the basin. Regarding monthly maximum discharges, over the 60-year period, most of the detected trends (64%) were negative. Statistically significant decreasing trends were found in 10 out of the 12 months (the only exceptions being October and December), amounting to a total of 35 cases (25%). In contrast, only 10 positive trends (13%) were statistically significant.

2. During the subperiod 1961–1990, negative trends in maximum streamflow were predominant, both annually and across most months and seasons, with the exception of autumn, when increasing trends were detected. Notable declines were most frequently observed in winter and spring. This pattern reflects a general weakening of winter and spring peak flows, which may be associated with lower precipitation, reduced snow accumulation, or delayed snowmelt during this period.

3. In the most recent 30-year period (1991–2020), a marked increase in the number of positive trends in high flow was observed for annual, seasonal, and monthly maximum discharges. The most pronounced increases occurred in February, March, and October, indicating a shift in the timing and magnitude of high flows compared with the earlier subperiod. This pattern suggests that winter and early spring flows, likely influenced by earlier and more intense snowmelt, are becoming more significant, whereas autumn flows also show enhanced maxima, consistent with increased seasonal rainfall.

Although general patterns in the trends of the maximum streamflow were identified, the results were not uniform across the study region. Spatial differences can be attributed to local factors, such as basin size and topography (i.e., altitude and slope), land use, degree of river regulation, and anthropogenic influences (e.g., dams, reservoirs, and water abstractions). These factors can modulate the effects of climatic drivers, leading to spatial variability in both the magnitude and direction of the detected trends. Consequently, while overarching climatic influences are evident, the local context may play a critical role in shaping the hydrological response of individual subcatchments.

The results of our analyses provide a comprehensive overview of the changes observed in the temporal variation of the maximum streamflow in the Ialomița catchment. Although many of the detected trends are not statistically significant, they nonetheless suggest a potential intensification of high flows in recent decades, likely linked to climate change. For rivers impacted by hydraulic structures (e.g., dams and reservoirs), the observed trends may also reflect the effects of their operation, which can modulate or obscure the direct influence of climatic drivers. Consequently, caution is warranted when interpreting these results, as the combined effects of human

interventions and natural variability may lead to complex and locally specific responses in maximum streamflow dynamics.

The trend detection analysis of the maximum annual, seasonal, and monthly discharges over the period 1961–2020 provides a robust statistical basis for understanding how rivers within the Ialomița catchment are responding to key hydrological drivers, primarily climatic and anthropogenic. Recognizing trends in the maximum streamflow is crucial for the effective and adaptive management of high-flow-related risks according to hydrological changes identified based on both historical observations and future projections.

The findings of this study offer a scientifically based, practical tool for long-term policy and sustainable flood-risk management in the Ialomița catchment at both regional and local scales. By highlighting monthly, seasonal, and annual shifts in the maximum streamflow, the findings provide policymakers and risk managers with evidence-based guidance to identify periods and areas prone to flood events, thereby enabling the prioritization of measures for flood risk mitigation, such as upgrading hydraulic infrastructure, protecting floodplains, implementing nature-based solutions, and investing in climate-resilient systems. Furthermore, the detailed trend analyses support improved preparedness for future flood events through enhanced early-warning systems, refined hydrological models, updated flood-risk maps, and targeted local emergency planning. Overall, this study not only informs adaptive and proactive flood management strategies but may also contribute to strengthening the capacity of authorities and communities to anticipate, prevent, and respond effectively to flood events under changing hydro-climatic conditions.

Acknowledgments: This work was carried out within the PhD research program of Emilia Gîrbea at the “Simion Mehedinți” Doctoral School of the University of Bucharest. The authors thank the Romanian National Institute of Hydrology and Water Management (I.N.H.G.A.) for providing the hydrological data used in this study.

Author contributions: Emilia Gîrbea and Liliana Zaharia contributed equally to this study. They conceived the study, designed the research methodology and figures, performed the analyses, and wrote the manuscript. Both authors reviewed and approved the final version of the manuscript.

References

1. Arash, A. M.; Fryirs, K.; Ralph, T. J. (2025) Using a Hydro-Morphic Classification of Catchments to Characterise and Explain High Flow and Overbank Flood Behaviour. *Geosci.*, 15, 141. <https://doi.org/10.3390/geosciences15040141>
2. Archfield, S. A.; Hirsch, R. M.; Viglione, A.; Blöschl G. (2016) Fragmented patterns of flood change across the United States. *Geophys. Res. Lett.*, 43, 10232–10239. <https://doi.org/10.1002/2016GL070590>
3. Berghuijs, W. R.; Aalbers, E. E.; Larsen, J. R.; Trancoso, R.; Woods, R.A. (2017) Recent changes in extreme floods across multiple continents. *Environ. Res. Lett.*, 12, 114035. doi: 10.1088/1748-9326/aa8847
4. Bertola, M.; Viglione, A.; Lun, D.; Hall, J.; Blöschl, G. (2020) Flood trends in Europe: are changes in small and big floods different? *Hydrol. Earth Syst. Sci.*, 24, 1805–1822. <https://doi.org/10.5194/hess-24-1805-2020>
5. Bertola, M.; Viglione, A.; Lun, D.; Blöschl, G. (2023) Flood changes in Europe: from detection to attribution. Proceedings paper in EGU General Assembly, Vienna, Austria, 24–28 Apr 2023, EGU23-5595. <https://doi.org/10.5194/egusphere-egu23-5595>
6. Bîrsan, M.V. (2015) Trends in Monthly Natural Streamflow in Romania and Linkages to Atmospheric Circulation in the North Atlantic. *Water. Resour. Manage.* 29, 3305–3313 <https://doi.org/10.1007/s11269-015-0999-6>

7. Bîrsan, M.V. (2017) *Variability of the natural river flow regime in Romania [Variabilitatea regimului natural al scurgerii râurilor din România]*. Ars Docedi Publisher: Bucharest, Romania, 2017.
8. Bîrsan, M.V.; Dumitrescu, A. (2013) Snow variability in Romania in connection to large-scale atmospheric circulation. *Int. J. Climatol.*, 34, 134–144. <https://doi.org/10.1002/joc.3671>
9. Bîrsan, M.V.; Zaharia, L.; Chendeş, V.; Brănescu, E. (2012) Recent trends in streamflow in Romania (1976–2005). *Rom. Rep. Phys.*, 64, 275–280.
10. Bîrsan, M.V.; Zaharia, L.; Chendeş, V.; Brănescu, E. (2014) Seasonal trends in Romanian streamflow. *Hydrol. Process.*, 28, 4496–4505. <https://doi.org/10.1002/hyp.9961>
11. Blöschl, G.; Hall, J.; Parajka, J.; Perdigão, R.A.P.; Merz, B.; Arheimer, B.; ... Živković, N. (2017) Changing climate shifts timing of European floods. *Science*, 357, 588–590. doi:10.1126/science.aan2506
12. Blöschl, G.; Hall, J.; Viglione, A.; Perdigão, R.A.; Parajka, J.; Merz, B.; ... Živković, N. (2019) Changing climate both increases and decreases European river floods. *Nature*, 573, 108–111. <https://doi.org/10.1038/s41586-019-1495-6>
13. Caretta, M.A.; Mukherji, A.; Arfanuzzaman, M.; Betts, R.A.; Gelfan, A.; Hirabayashi, Y.; Lissner, T.K.; Liu, J.; Lopez Gunn, E.; Morgan, R.; Mwanga, S.; Supratid, S. (2022) Water. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., Rama, B., Eds.; Cambridge University Press: Cambridge, UK and New York, NY, USA, 2022; pp. 551–712. <https://doi.org/10.1017/9781009325844.006>
14. Chelu, A.; Zaharia, L.; Dubreuil, V. (2022) Estimation of climatic and anthropogenic contributions to streamflow change in southern Romania. *Hydrol. Sci. J.*, 67, 1598–1608. <https://doi.org/10.1080/02626667.2022.2098025>
15. Cheval, S.; Bîrsan, M.V.; Dumitrescu, A. (2014) Climate variability in the Carpathian Mountains region over 1961–2010. *Glob. Planet. Change.*, 118, 85–96. <https://doi.org/10.1016/j.gloplacha.2014.04.005>
16. Corbuş, C.; Mic, R.P.; Mătreău, M. (2013) Potential climate change impact upon maximum flow in Ialomita river basin. In *National Institute of Hydrology and Water Management - Scientific Conference, Water Resources Management under Climate and Anthropogenic Changes*, Bucharest, România, 23–26 September 2013, pp 237–242.
17. Croitoru, A.E.; Minea, I. (2015) The impact of climate changes on rivers discharge in Eastern Romania. *Theor. Appl. Climatol.*, 120, 563–573. <https://doi.org/10.1007/s00704-014-1194-z>
18. Do, H. X.; Westra, S.; Leonard, M. (2017) A global-scale investigation of trends in annual maximum streamflow. *J. Hydrol.*, 552, 28–43. <https://doi.org/10.1016/j.jhydrol.2017.06.015>
19. Hall, J.; Arheimer, B.; Borga, M.; Brázdil, R.; Claps, P.; Kiss, A.; Kjeldsen, T. R.; ... Blöschl, G. (2014) Understanding flood regime changes in Europe: A state-of-the-art assessment. *Hydrol. Earth Syst. Sci.*, 18, 2735–2772. <https://doi.org/10.5194/hess-18-2735-2014>
20. Ishak, E. H.; Rahman, A.; Westra, S.; Sharma, A.; Kuczera, G. (2013) Evaluating the non-stationarity of Australian annual maximum flood. *J. Hydrol.*, 494, 134–145. <https://doi.org/10.1016/j.jhydrol.2013.04.021>
21. Jipa, N.; Mehedinţeanu, L. (2012). Trends in variability of water flow of Teleajen river. *Proceedings paper in Air and Water–Components of the Environment*, Cluj Napoca, România, 23–24 Martie 2012, pp 535–542.

22. Joy, M. A. R.; Upaul, S.; Fatema, K.; Amin, F. R. (2023). Application of GIS and remote sensing in morphometric analysis of river basin at the south-western part of great Ganges delta, Bangladesh. *Hydrol. Res.*, 54, 739-755. <https://doi.org/10.2166/nh.2023.087>.
23. Kundzewicz, Z. W.; Graczyk, D. ; Maurer, T.; Pińskwar, I.; Radziejewski, M.; Svensson, C.; Szwed, M. (2005) Trend detection in river flow series: 1. Annual maximum flow/ / Détection de tendance dans des séries de débit fluvial: 1. Débit maximum annuel. *Hydrol. Sci. J.*, 50, 797-810. <https://doi.org/10.1623/hysj.2005.50.5.797>
24. Kundzewicz, Z.W.; Kanae, S. ; Seneviratne, S. I.; Handmer, J.; Nicholls, N.; Peduzzi, P.; ... Sherstyukov, B. (2014) Flood risk and climate change: global and regional perspectives. *Hydrol. Sci. J.*, 59, 1-28. <https://doi.org/10.1080/02626667.2013.857411>
25. Madsen, H.; Lawrence, D.; Lang, D.; Martinkova, M.; Kjeldsen, T.R. (2014) Review of trend analysis and climate change projections of extreme precipitation and floods in Europe. *J. Hydrol.*, 519, 3634-3650. <https://doi.org/10.1016/j.jhydrol.2014.11.003>
26. Mangini, W.; Viglione, A.; Hall, J.; Hundecha, Y.; Ceola, S.; Montanari, A.; ... Parajka, J. (2018) Detection of trends in magnitude and frequency of flood peaks across Europe. *Hydrol. Sci. J.*, 63, 493-512. <https://doi.org/10.1080/02626667.2018.1444766>
27. Mediero, L.; Kjeldsen, T. R.; Macdonald, N.; Kohnova, S.; Merz, B.; Vorogushyn, S.; Wilson, D.; Albuquerque, T.; Blöschl, G.; Bogdanowicz, E.; Castellarin, A.; Hall, J.; ... Þórarinnsson, Ó. (2015) Identification of coherent flood regions across Europe by using the longest streamflow records. *J. Hydrol.*, 528, 341-360. <https://doi.org/10.1016/j.jhydrol.2015.06.016>
28. Mic, R.P; Mareş, C.; Corbuş, C.; Mătreacă, M.; Chendeş, V.; Radu, E.; Stănescu, G.; Chelcea, S.; Teodor, S.; Mătreacă, S.; Adler, M.J.; Mareş, I.; Achim, D.; Preda, A.; Borcan, M.; Retegan, M.; Apostu, A.D.; Brănescu, E. (2016) Climate change impact on hydrology, CLIMHYDEX – Changes in climate extremes and associated impact in hydrological events in Romania. Final Report, Bucharest.
29. Micu, D. M.; Dumitrescu, A.; Cheval, S.; Bîrsan, M.-V. (2015) Observed variability and trends from instrumental records. In *Climate of the Romanian Carpathians*; Micu, D.M., Dumitrescu, A., Cheval, S., Bîrsan, M.-V., Eds.; Springer Atmospheric Sciences: Springer International Publishing, Switzerland, 2015; pp. 149-186.
30. Micu, D.M.; Amihaesei, V. A.; Milian, N.; Cheval, S. (2021) Recent changes in temperature and precipitation indices in the Southern Carpathians, Romania (1961-2018). *Theor. Appl. Climatol.*, 144, 691-710. <https://doi.org/10.1007/s00704-021-03560-w>
31. Minea, I.; Boicu, D.; Iosub, M.; Chelariu, O.-E.; Solomon, B. (2020) Long-term trends in rivers flow from north-eastern part of Romania. *Proceedings paper in 20th International Multidisciplinary Scientific GeoConference SGEM 2020*, 225-231. <https://doi.org/10.5593/sgem2020/3.1/s12.030>
32. Minea, I.; Chelariu, O. E. (2021) Anomalies and trends of high river flow under temperate climatic conditions in north-eastern Romania. *J. Water Clim. Change*, 12, 552-565. <https://doi.org/10.2166/wcc.2020.124>
33. Minea, I.; Iosub, M.; Enea, A.; Boicu, D.; Chelariu, O.E. (2022) Hydrological Extremes Anomalies and Trends in Lower Danube Basin: Case Study—Romanian Drainage Area Between Siret and Prut Rivers. In *The Lower Danube River. Earth and Environmental Sciences Library; Negm, A., Zaharia, L., Ioana-Toroimac, G., Eds.* Springer: Springer Nature Switzerland, 2020; pp. 381-401. https://doi.org/10.1007/978-3-031-03865-5_13
34. Ministry of Environment, Water and Forests (M.M.A.P), National Commission for the Safety of Dams and other Hydrotechnical Works (CONSIB) (2019) National Register of Dams in Romania (REBAR) [Registrul Național al Barajelor din România]. Available online: <https://www.mmediu.ro/articol/registrului-national-al-barajelor-din-romania-rebar/6229> (accessed 15 March 2025)

35. Mitof, I.; Prăvălie, R. (2014) Temporal trends of hydroclimatic variability in the lower Buzău catchment. *Geographia Technica*, 9, 87–100.
36. Mocanu-Vargancsik, C.; Tudor, G. (2020) On the linear trends of a water discharge data under temporal variation. Case study: the upper sector of the Buzău river (Romania). *Forum geografic*, XIX, 37–44. doi:10.5775/fg.2020.041.i
37. National Administration "Romanian Waters" (N.A.R.W.) (2022) Preliminary Flood Risk Assessment for Buzău–Ialomița Basin Water Administration [Evaluarea preliminară a riscului la inundații, Administrația Bazinală de Apă Buzău–Ialomița] - Available online: https://inundatii.ro/wp-content/uploads/2022/07/PFRA_Report_RO5_Buzau-Ialomita.pdf (accessed 20 March 2025)
38. National Administration "Romanian Waters" (N.A.R.W.) (2023) Flood Risk Management Plan for Buzău – Ialomița Basin Water Administration, Implementation of the Floods Directive Cycle 2 [Plan de management al riscului la inundații, Administrația Bazinală de Apă Buzău – Ialomița, Ciclul II de implementare a Directivei privind inundațiile]. Available online: https://inundatii.ro/wp-content/uploads/2023/09/PMRI_Ciclul-II_ABA-Buzau-Ialomita.pdf (accessed 20 March 2025)
39. Neculau, G.; Zaharia, L. (2010) Maximum flow variability and flood potential in Trotuș Catchment Area. *Studia Universitatis Babeș Bolyai – Geographia*, 1, 87–98
40. Perju, R. (2012) Characteristics of floods in Valea Cerbului Catchment. In: Gâstescu, P., Lewis, W. Jr, Brețcan, P., Eds. *Water resources and wetlands*, 14–16 September 2012, Tulcea – Romania. Transversal Publishing house: Târgoviște, Romania, 2012; pp. 248–253.
41. Perju, R.; Zaharia, L. (2014) Changes in the frequency and magnitude of floods in the Bucegi Mountains (Romanian Carpathians). In: Gâstescu, P., Wlodzimierz, M., Brețcan, P., Eds. *Water resources and wetlands*, 11–13 September 2014 Tulcea (Romania). Transversal Publishing house: Târgoviște, Romania, 2014; pp. 321–328.
42. Perju, E.R.; Zaharia, L.; Balin, D.; Lane, S. (2014) Changements climatiques dans les Carpates Roumaines et impacts hydrologiques. Étude de cas: les Monts de Bucegi. *Actes du XXVIIe Colloque de l'Association Internationale de Climatologie*, pp. 73–79.
43. Prabhakar, A.K.; Singh, K.K.; Lohani, A.K.; Chandniha, S. K. (2019) Study of Champua watershed for management of resources by using morphometric analysis and satellite imagery. *Appl. Water Sci.* 9, 127. <https://doi.org/10.1007/s13201-019-1003-z>
44. Prăvălie, R.; Zaharia, L.; Bandoc, G.; Petrișor, A.I.; Ionuș, O; Mitof, I. (2016) Hydroclimatic dynamics in southwestern Romania drylands over the past 50 years. *J. Earth Syst. Sci.*, 125, 1255–1271. <https://doi.org/10.1007/s12040-016-0730-x>
45. Salmi, T.; Määttä A.; Anttila, P.; Ruoho-Airola, T.; Amnell, T. (2002) *Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates – the Excel template application MAKESENS*. Publications on Air Quality No. 31: Finnish Meteorological Institute, Helsinki, pp.35.
46. Slater, L. J.; Villarini, G. (2016). Recent trends in U.S. flood risk. *Geophys. Res. Lett.*, 43, 12428–12436. <https://doi.org/10.1002/2016GL071199>
47. Topographic Military Directorate (2004) Digital Elevation Modeling with a resolution of 25 m, first edition, Stereographic projection 1970 [Modelul Numeric al Terenului cu rezoluția de 25m ediția I, Proiecție Stereografică 1970]. Topographic Military Directorate: Bucharest, Romania
48. Tramblay, Y.; Mimeau, L.; Neppel, L.; Vinet, F.; Sauquet, E. (2019) Detection and attribution of flood trends in Mediterranean basins. *Hydrol. Earth Syst. Sci.*, 23, 4419–4431. <https://doi.org/10.5194/hess-23-4419-2019>
49. World Meteorological Organization (W.M.O.) (2024). Available online: <https://community.W.M.O.int/en/W.M.O.-climatological-normals> (accessed 2 March 2025).

50. Zadeh, S.M.; Burn, D.H.; O'Brien, N. (2020) Detection of trends in flood magnitude and frequency in Canada. *J. Hydrol. Reg. Stud.*, 28, 100673. <https://doi.org/10.1016/j.ejrh.2>
51. Zaharia, L.; Beltrando, G. (2009) Variabilité et tendances de la pluviométrie et des débits de crue dans la région de la Courbure de l'Arc carpatique (Roumanie). *Geogr. Tech.*, Numéro Spécial, 471–476.
52. Zaharia, L.; Ioana-Toroimac, G.; Perju, R. (2020) Hydrological Impacts of Climate Changes in Romania. In *Water Resources Management in Romania*; Negm A., Romanescu, Gh., Zeleňáková, M. Eds.; Springer Water: Springer Nature Switzerland, 2020; pp. 309-351. Doi:10.1007/978-3-030-22320-5



© 2021 by the authors. Licensee UAIC, Iasi, Romania. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY-NC-ND) license (<https://creativecommons.org/licenses/by-nc-nd/4.0>).