

Chapter 10

Hydrological Impacts of Climate Changes in Romania



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Abstract This chapter provides a comprehensive synthesis of researches on hydro-climatic changes in Romania and presents some original results on hydrological responses to climate changes in Valea Cerbului River basin (area of 26 km²) located in the Carpathian Mountains, based on the analysis of historical data and hydrological simulations. Although there are spatial differences, on the whole of Romania, after 1960, a general decreasing trend of the mean annual streamflow was detected. More or less significant changes in the annual flow regime were also noticed: upward trends in winter (related to the increase of the air temperature and liquid precipitations to the detriment of snowfall), downward trends in summer (induced by the general warming and increase of evaporation), and upward trends in the autumn flow. By 2050, the simulations under climate scenarios indicate a general decline of the mean multiannual discharges, significant increases of the discharges during winter and pronounced decreases in late summer and autumn. In Valea Cerbului River basin we investigated the changes in the magnitude and frequency of floods and low flows based on observational data, as well as the expected streamflow changes, as projected by simulations with WaSiM-Eth model (under B1, A2 and A1B climatic scenario, for the period 2001–2065 relative to 1961–2000 period). The simulations indicate a slight decrease in mean annual discharge (of 2% up to 6%) by 2065, an increase of mean monthly discharges from January to April, and a decline during May–December.

Keywords Hydrological impacts · Climate changes · Streamflow · Romania

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10.1 Introduction

In the last decades, significant climatic variations and changes were detected from global to regional and local spatial scales, causing multiple and various impacts on both natural and human systems [1, 2]. One of the most sensitive natural systems to the climate variability is the hydrological one. Thus, the alteration of the climatic parameters has direct and/or indirect effects on the hydrological cycle, causing changes in streamflow regimes and water resources, with negative societal and environmental consequences. Such changes have already been identified in the variability of the observational data and are estimated for the future through model-based simulations under different climate scenarios. Therefore, the water availability and quality could become major issues for societies and the environment under climate change [3]. To address these issues, societies are concerned about the development of appropriate adaptation strategies to the hydrological effects of the climate change [4].

This chapter focuses on Romania, aiming (i) to provide an overview of changes observed and projected for the main climatic and hydrological parameters and (ii) to investigate the hydrological responses to climate changes in a catchment located in the Romanian Carpathians (based on trend detection analysis of recorded data and hydrological simulations). The hydrological changes in Romania are integrated into the context of the changes signaled at global and European levels which are synthesized in the first part of the chapter.

The paper presents a comprehensive synthesis of the main research findings on the hydrological impact of climate changes in Romania and provides new and original information on this topic, derived from our research.

10.2 Synthesis of Studies on Streamflow Change Detection at Global and European Scale

10.2.1 Observed Hydrological Changes

Due to its scientific and practical interest, the analysis of the rivers flow variability and trends, in the context of climate change, based on recorded data, has been a concern for researchers worldwide. Thus, studies with such issue have been conducted in many countries, such as Canada [5–7], China [8–18], Malaysia [19], Russia [20, 21], U.S.A. [22, 23], Turkey [24–26], as well as in countries/regions from the South America [27–29] and from Africa [30]. Some studies investigated the streamflow variation on a global scale [4, 31, 32].

In Europe, a large number of researches on rivers' flow trends have been carried out in the last decades, in many countries or regions: Austria [33], Czech Republic [34], France [35, 36], Germany [37–40], Iceland [41], Poland [42], Slovakia [43, 44], Spain [45–47], Switzerland [48–51], UK [52–57], and the Nordic and Baltic countries [58–62]. Some studies have referred to several countries and rivers within Europe [4, 31, 63].

The results of the studies mentioned above show heterogeneous spatial patterns of the identified streamflow trends, both at regional and national scales. The magnitude and statistical significance of the identified trends are sensitive to the period examined. On a global scale, according to [4], 70% of the total of 195 stations analyzed do not exhibit any statistical trend at the 10% significance level, and the remaining stations had either positive or negative trends in the annual maximum flow (for observation periods of at least 40 years). During 1948–2004, only about one-third of the 200 investigated rivers have registered statistically significant trends, 45 with downward trends and 19 with upward trends [32].

Regionally, some spatial differences can be distinguished. Thus, a streamflow decrease was generally noticed in regions affected by lower rainfall (e.g., vast areas in Africa, eastern and southeastern Asia and eastern Australia) [4, 10, 16, 32 etc.]. In other regions, where rainfall and temperatures increased, higher streamflow was identified, as in some areas of northern Eurasia, Central and Far-East Asia, northern North America, southern South America [4, 21, 22, 27, 28, 31].

In Europe, a regionally coherent picture of mean annual streamflow tendency was identified (during 1962–2004), with negative trends in southern and eastern regions, and generally positive trends elsewhere [63].

Concerning the changes in observed extreme streamflow, the general conclusion is that in recent decades there are no clear trends in flood discharge at a regional or a national scale in Europe [64]. In terms of floods, geographically organized patterns of climate-driven changes in their magnitude and frequency could not be detected, but an increase in the number of large floods in Europe during 1985–2010 has been identified [65]. For some small regions, increases in flood peak discharges were detected, as in some alpine basins [66], in Switzerland [51], northern part of Austria [33], northeast France [35, 36], as well as in some regions in Germany [37–40], and northern and western UK [56]. Decreases in peak discharges were noticed in some areas or at hydrometric stations in the Baltic region [59, 60], in Poland [42], etc.

10.2.2 Future Hydrological Changes

Assessing the potential impacts of climate changes on the hydrological cycle and water resources in the future has become, together with change detections studies based on observational data, one of the most important concerns in contemporary hydrology. This issue has a major interest in developing and implementing appropriate measures to adapt the society to the climate changes related effects. Consequently, worldwide, a large number of researches has focused on the future projections of the hydrological impacts of climate changes. The assessments are made by using model-based simulations, considering different climate scenarios. Depending on the specific climate scenario and model used, the projections may show different results, with more or less severe hydrological impacts. Generally, each climate and hydrological projection is subject to limitations and uncertainties in its ability to model the climate and the water-related system. Most of the hydrological projection are based on cli-

mate change/emission scenarios, without considering other influences such as water uses and political or socio-economic impacts [1]. Therefore, the results projected by the models should be considered with caution, given the associated limitations and uncertainties.

On a global scale, there are many studies on possible future hydrological responses to climate changes [e.g., 67–77]. At continental and regional/national level, numerous studies have been carried out, mainly in Europe [64, 78–88], but also in US [89] and Asia [90–92]. Several papers [93–96] investigated the potential effect of climate change on river flow regimes in some large watersheds on different continents (e.g., Amazon, Rhine, Tagus, Niger, Blue Nil, Mississippi, Mackenzie, Yellow, Yangtze, Lena, Darling).

At the global scale, according to [67], by 2100, the models project a general increase of mean discharges with more than 10%. Some global patterns of change in discharge regimes for 2100 may be distinguished, such as significant decreases in streamflow for southern Europe, southern Australia, south and north of Africa and southwestern South America. Consistent decreases for most African rivers, the Murray and the Danube rivers, as well as slightly increases of discharges for monsoon-influenced rivers are expected. In the sub-Arctic and Arctic regions runoff increases and a phase-shift towards earlier peaks are projected by 2100. An increase in the seasonality of river discharges was identified (both an increase of high flow and a decrease of low flow) for about one-third of the global land surface area for 2071–2100 relative to the reference period 1971–2000 [68]. Most of the 21st climate models used in [69] projected increases in average annual runoff by 2050 in Canada and high latitudes of Eastern Europe and Siberia, and decreases in runoff in central Europe, around the Mediterranean Sea, the Mashriq, central America and Brazil.

A study on impacts of climate change on European hydrology at 1.5, 2 and 3 °C mean global warming above preindustrial level showed that there are clear changes in local impacts on mean, low and high runoff. Important increases in streamflow will affect the Scandinavian countries and northern Poland. Decreases in mean annual runoff were projected only in Portugal at 1.5 °C warming, but at 3 °C warming, the runoff will decrease on the entire Iberian coast, the Balkan Coast and parts of the French coast [86].

Of high interest is the assessment of future changes in the characteristics of the hydrological extreme events (severity and frequency). Therefore, many studies were devoted to these phenomena. Thus, several papers focused on the assessment of future floods and high flow [e.g., 64, 81, 88, 97], while other studies investigated the projections of future low flow and hydrological droughts [70, 71, 73, 74, 83, 87, etc.]. Some authors investigated both hydrological extremes [e.g., 68, 84, 86, 93].

At a global scale, a study on impacts of climate change on river flood risk shows that in 2050 the current 100-year flood would occur at least twice as frequently across 40% of the globe [69]. At 4 °C global warming, countries representing more than 70% of the total population will face increases in flood risk more than 500% [77]. The largest increase in the flood risk will be in Asia, Europe and U.S.A.

In Europe, it was found that, on average, flood peaks with return periods above 100 years are projected to double in frequency within 3 decades [97]. According

to [64], hydrological projections of peak flows illustrate changes in many areas of Europe, both positive and negative, with a general decrease in flood magnitude and earlier spring floods for catchments with snowmelt-dominated peak flows. Similar results were found by Rojas et al. [81], showing that in eastern Germany, Poland, southern Sweden and, to a lesser extent, the Baltic countries, the signal is dominated by the significant reduction in snowmelt induced floods and decrease in 100-year discharge. In other areas, as in western Europe and northern Italy, a strong increase in future flood hazard was projected, mainly due to a pronounced increase in extreme rainfall [81]. The flood magnitudes are expected to increase significantly south of 60° N latitude (mainly in large parts of Romania, Ukraine, Germany, France and north of Spain) and to decrease in most of Finland, northwestern Russia and north of Sweden [84]. In a recent study [88], the climate impact simulations show significant decreasing in high flows for the Mediterranean region, from -11% at $1.5\text{ }^{\circ}\text{C}$ up to -30% at $3\text{ }^{\circ}\text{C}$ global warming, mainly due to reduced precipitation. Small changes ($<\pm 10\%$) are expected for river basins in Central Europe and the British Isles, under different levels of warming. In northern regions, high flows are projected to increase due to rising precipitation, but floods are projected to decrease due to less accumulated snow and thus less snowmelt [88].

The impact of climate change on the low flow and hydrological drought characteristics is projected to be severe and large areas are expected to be affected by water scarcity in the Mediterranean region, Middle East, southeast U.S., Chile, southwest Australia and large parts of Asia [70, 74]. According to [71], the river basins in arid regions will become even drier, while in the cold regions, a shift of the snow melt peak and an increase of low discharges were identified. For most rivers in humid and temperate climates, the results of the projections are considered uncertain.

In Europe, throughout the 21st century, the models indicate that streamflow droughts will become more severe and persistent in many parts of the continent, except for northern and northeastern regions where the drought hazard will decrease. The most affected by the low flows reduction will be the southern regions [83]. The projections showed that the hydrological drought magnitude and duration might increase in Spain, France, Italy, Greece, the Balkans, south of the UK and Ireland [84]. The low flows are expected to increase in the alpine and northern regions [87].

10.3 Overview of Changes in Main Climate Parameters Controlling the River Flow in Romania

Located in the central part of Europe, Romania (area of $238,391\text{ km}^2$) overlaps almost entirely (97% of its territory) the Danube River Basin, occupying approximately one-third of it [98]. The rest of 3% of the national territory is drained by small rivers flowing into lakes located on the Black Sea coast. In the south and south-east of Romania flows the Lower Danube River on a length of 1075 km (i.e., 38% of its entire length of 2780 km) before reaching the Black Sea through the Danube

Delta (Fig. 10.1). The Romanian territory is almost equally distributed between mountainous (Carpathians), hilly and plain territories, with altitudes varying between zero (on the Black Sea coast) and 2544 m amsl.

Due to its location, Romania has a transitional climate between temperate oceanic and continental, with regional differences induced by the orography and external influences. The main climatic influences affecting the Romanian territory are oceanic (in the western part), Mediterranean (in the southwest), Baltic (in the north), excessive continental (in the east), and Pontic (in the southeast, induced by the proximity to the Black Sea). The mean multiannual temperature in Romania varies with latitude (from 8 °C in the North to 11 °C in the South) and altitude (from 11 to 12 °C in the plains to less than 0 °C on the highest mountains). The average multiannual amounts of precipitation increase from less than 300–400 mm (in the southeast) to over 1200 mm on the Carpathians' heights [99].



Fig. 10.1 Physical map of Romania with location of the Valea Cerbului River catchment (the black square) and of the gauging stations mentioned in the text: 1 and 2: Baziaş and Ceatal Izmail/Chilia on Danube River; 3: Vadu Izei on Iza River; 4: Bistra on Vişeu River; 5: Gurahonţ on Crişul Alb River; 6, 7, 8: Luduş, Alba Iulia and Arad on Mureş River; 9: Turda on Arieş River; 10: Mihalţ on Târnava River; 11: Cornet on Olt River; 12, 13, 14: Piteşti Strand, Malu Spart and Budeşti on Argeş River; 15: Lunguleţu on Dâmboviţa River; 16: Bârlad on Bârlad River

10.3.1 Observed Climate Changes

Many previous studies have dealt with climatic variability in Romania based on observational data, at a national or local scale. Several works investigated the variability of thermal parameters [99–106]. Many researches focused on the variability of parameters related to precipitation [e.g., 107–111]. The temporal dynamics of the snow pack was analyzed in [112–114]. Some studies have dealt with changes in reference evapotranspiration [115] and analyzed the dynamic of the aridity, by using different climate specific indices [116, 117]. The spatio-temporal variability of dryness/wetness in the Danube River Basin (from 1901 to 2013) was analyzed in [118] based on the Standardized Precipitation Index (SPI) for an accumulation period of 6 months. Some studies analyzed the climatic variability and changes on the whole Romanian territory by integrating several parameters [119–123] or at the regional scale, such as the Carpathians [124–126].

Regarding the air temperature, an evident warming trend was noticed on the whole country after 1900, more pronounced after 1980 (Fig. 10.2a). Thus, during 1981–2013, the mean air temperature in Romania reached 10.1 °C, by 0.5 °C higher than the mean air temperature of the period 1901–1980 (9.6 °C) and by 0.4 °C higher than the one of the period 1961–1990 (climatic reference period in Romania) [127] (Fig. 10.2a). During the period 1901–2012, the mean annual air temperature increased by 0.8 °C, with regional differences: higher warming in the southern and eastern parts of the country (by up to 0.8 °C in the Bucharest, Constanta and Roman areas) and insignificant thermal variation in Carpathian areas [128, 129].

Studies on recent climatic changes (1961–2013) in Romania [120, 122, 127], based on observational data recorded at more than 150 weather stations (w.s.), showed statistically significant upward seasonal trends in air temperature, especially in spring and summer and partially in winter. The greatest increases of mean monthly air

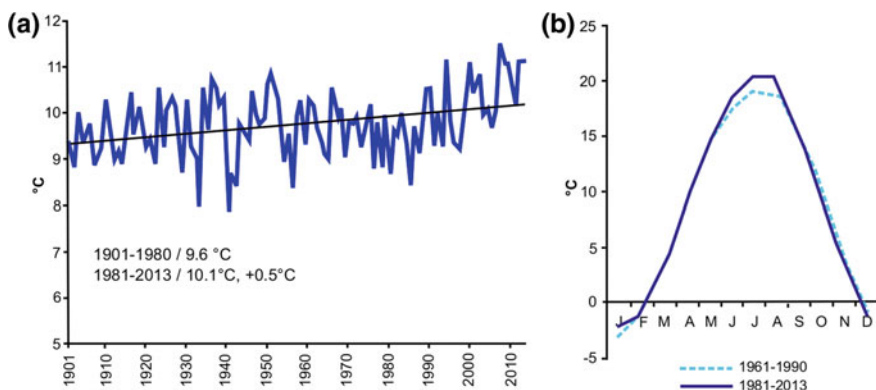


Fig. 10.2 **a** Mean annual air temperature variation in Romania and the linear trend (1901–2013); **b** changes observed in the monthly average air temperature during 1981–2013 relative to the climate reference period 1961–1990 (based on data from 160 weather stations; adapted from [127])

temperature during 1981–2013 when compared to the reference period 1961–1990, were noticed in January–February (1 °C) and in June–August (0.9–1.2 °C), while in autumn months and in December, the modifications were statistically not significant [127] (Fig. 10.2b). The warming tendencies were confirmed by the trends in the annual thermal extremes, in the number of summer days, as well as by other thermal indices, a warming signal being consistent throughout the country. These results are consistent with those found by Busuioc et al. [123] for the period 1961–2010, which detected significant increasing trends for the temperature extremes in all seasons, except for autumn, with the highest increasing rate in summer and the lowest in spring.

In the Carpathian area, general warming was detected, proved by positive trends in warm-related indices and negative trends in cold-related indices. Significant positive trends of air temperature were detected in all seasons, except for autumn which seems to be thermally stable [124–126, 130].

Regarding the precipitation, on the entire Romania, between 1901 and 2013, the annual amount is rather stable (Fig. 10.3a). During 1961–2013, significant upward trends were identified for several stations in autumn (especially in the central and western parts of Romania), while for the other seasons, precipitation did not show significant trends, except for a few isolated stations which recorded negative trends [120, 122]. In the annual regime of precipitation over Romania, for the period 1981–2013, relative to 1961–1990, it was found (based on the analysis of over 150 w.s.), a decline of monthly precipitation especially in spring and summer (by 5–8 mm/month in May and June). A rise was also identified in the first part of autumn, by 8 mm in September and by 5 mm in October [127] (Fig. 10.3b). The annual precipitation extremes indices showed mixed signals, but the majority of the stations had non-significant trends [120]. Upward trends were identified at several weather stations for daily maximum rainfall (mainly in summer and autumn), which increase

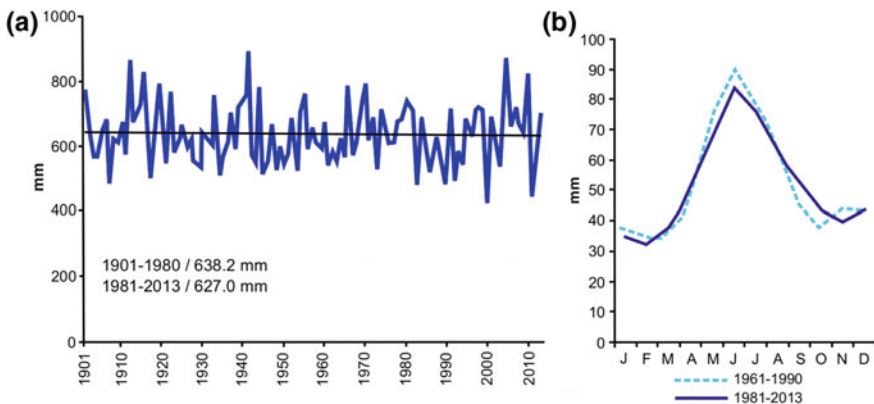


Fig. 10.3 **a** Annual precipitation variation in Romania and the linear trend (1901–2013); **b** changes observed in the monthly precipitation during 1981–2013 relative to the climate reference period 1961–1990 (based on data from 160 weather station; adapted from [127])

the flood risk in these seasons [120, 122]. Regarding precipitation extremes, during 1961–2010, significant increasing trends were detected over large areas in both the frequency of very wet days and maximum daily amount during autumn, and in the maximum duration of dry spells, during summer [123].

The snow-related parameters recorded substantial changes in Romania in the last decades. During the period 1961–2010, general decreasing trends were found in: mean snow depths, number of days with snow cover, number of days with snowfall and continuous snow cover duration. These changes are related mainly to the recent warming and to the slight decrease in winter amounts of precipitation [125]. In the previously mentioned period, the trend analysis of the data recorded at 104 w.s. in Romania showed significant downward trends for the number of days with snow pack at 40% of the stations, and for the mean snow depth, at 20% of the analyzed stations [114]. The most dramatic change concerns the number of snowfall days, which tends to decrease at 82% of the locations. The intra-Carpathian, western and northeastern regions are the most affected by the changes in snow-related parameters.

During 1961–2007, upward trends in the annual reference evapotranspiration were detected in almost 3/4 (72%) of the total of 57 w.s. investigated in Romania, of which 30% is statistically significant. The highest frequency of the positive trends, as well as their absolute maximum magnitude were found during summer in almost the entire country, while in autumn negative trends of the reference evapotranspiration were identified at more than 80% of the locations (but only 20% are significant, mostly in the southern half of the country) [115].

10.3.2 Climate Changes Projections

In order to estimate the future climate in Romania, several studies were made, based on different climate models (both global and regional) and scenarios. Most of the studies were conducted by researchers from the National Meteorological Administration, within European research programs/projects (e.g., ENSEMBLE, SEERISK, ORIENTGATE, etc.).

It is worth noting that all scenarios used for Romania indicate an increase of mean annual air temperature, with different intensities, depending on the time interval and type of scenario considered. The magnitude of the warming varies all over the year, with higher increases projected for summer and winter, and lower increases for autumn [119, 122]. In summer, on the whole country, according to the RCP8.5 scenario, the temperature could rise during 2021–2050 by up to 3 °C (Fig. 10.4a) and by up to 5 °C for 2061–2090 when compared to 1961–1990 (Fig. 10.4b).

Using Global Climate Models—GCMs (available in CMIP 3 and CMIP programs), as well as regional models (available in the EuroCORDEX program) and based on simulations with 6 regional models of EuroCORDEX program (considering RCP 8.5 scenario), it was estimated that, for the 2021–2050 period relative to 1971–2000, the average air temperature will rise by up to 2.5 °C in winter, and by up to 4.6–4.9 °C in summer. In winter, the warming is higher in extra-Carpathians

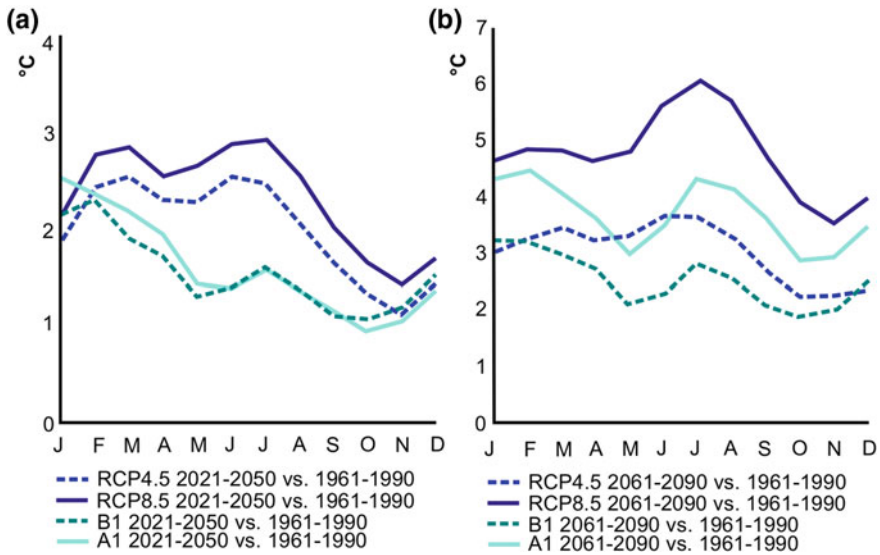


Fig. 10.4 Differences estimated in the multiannual monthly mean air temperatures (averaged for Romania), between the periods 2021–2050 and 1961–1990 (a) and between the periods 2061–2090 and 1961–1990 (b) (adapted from [122])

regions from eastern and southern Romania, as well as in the depression area from the central part of the country, while in summer, the highest heating is projected for the southern part (in Romanian Plain) [122].

Concerning the precipitation, the above-mentioned models and scenario show regional differences in projected changes: decrease of up to -10% of mean summer precipitation amount for the 2021–2050 period relative to 1961–1990, in south and southeast of Romania, and increase of up to 10% in east, west and the Carpathian area. In the annual regime of precipitation, all scenarios indicate a decline over the 21st century, more intense towards the end of the time horizon (2061–2090), when a reduction of -20 to -30% relative to the period 1961–1990 could be registered (Fig. 10.5a, b). In winter and spring months, the trends indicated by various scenarios are incoherent, with both increase and decline phases. A possible explanation is related to the variability of precipitation in winter and partially in spring due to other factors such as the North Atlantic Oscillation [122].

As a direct effect of projected warming, changes in the characteristics of the snowpack are expected, with impact on river flow. The models and scenarios above-mentioned projected the decrease by more than -60% of the snowpack across the country. In some areas of the Carpathian Mountains, the decrease will reach even -80 to -90% [122].

Information on climate projections in Romania can also be found in studies at continental level [131] or regional scale, in southeastern Europe [132, 133].

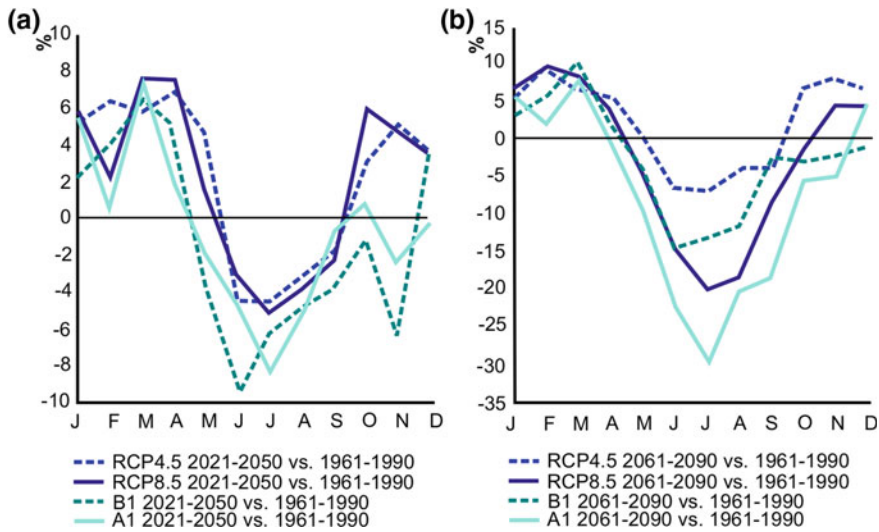


Fig. 10.5 Differences estimated in the multiannual monthly mean precipitation (averaged for Romania), between the periods 2021–2050 and 1961–1990 (a) and between the periods 2061–2090 and 1961–1990 (b) (adapted from [122])

10.4 Review of Studies on Streamflow Trends and Hydrological Impacts of Climate Changes in Romania

The issue of variability and changes in river flow in Romania has been addressed in several studies focused on streamflow trends detection, based both on historical data and under climate scenarios. In this part, a synthesis of such studies is presented, in order to offer an overview of the Romanian researches in this field.

10.4.1 Observed Changes in River Flow at the Country and Regional Scale

The first studies in Romania investigating the changes in streamflow variability, based on the analysis of trends in observational data, have been published in the 1990s. After 2000 the number of studies on this topic has increased significantly [e.g. 134–143, etc.]. They were conducted mostly at regional scale or watershed level, and have analyzed parameters related to the mean, maximum and minimum streamflow.

At the Romanian spatial scale, a first study investigated the rivers’ flow trend during 1976–2005, based on the analysis of mean monthly streamflow from 51 gauging stations (g.s.) corresponding to undisturbed watersheds [140]. The results

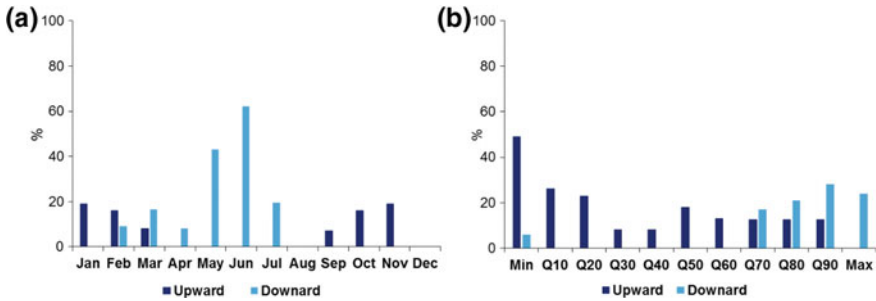


Fig. 10.6 **a** The percentage of gauging stations with monthly trends in mean streamflow at 10% significance level (1976–2005; 51 stations) (adapted from [140]); **b** relative frequency of statistically significant trends in annual streamflow quantiles Q10–Q90, minima (Min) and maxima (Max) (1961–2009; 25 stations) (adapted from [141])

revealed substantial changes in seasonality, more than half of the stations having negative trends in streamflow at the end of spring and in the early summer. The most important changes occurred in June, where over 60% of the stations presented decreasing trends. From April to July the trends were exclusively negative, while during autumn the streamflow increased (Fig. 10.6a). In February and March, the trends were mixed, with a low percentage (under 20%), and no change has been found for August and December. At the annual temporal scale, only the downward trends were statistically significant [140].

A second study on streamflow trends at national spatial scale is based on the mean daily discharges data series from 25 catchments for the 1961–2009 period, and from 44 catchments for 1975–2009 period [141]. It revealed increasing trends in winter streamflow (related to the increase in air temperature and more liquid precipitation than snow) and rising of minimum spring streamflow (because of the climate warming, leading to an earlier snowmelt and a decrease of the snowpack). Upward trends were also found in autumn flow (explained by the increase of precipitation amounts), while in summer were identified negative trends, which can be related to the general warming and, consequently, to the increase of evaporation [141]. During 1961–2009, statistically significant upward trends for small and medium annual discharges (corresponding to the minima and quantiles Q10–Q60) were detected, and downward trends for high discharges (corresponding to the streamflow quantiles Q70–Q90 and maximum discharge) (Fig. 10.6b). Significant increasing trends in winter streamflow (from minimum discharge to quantile Q80), as well as the decreasing trends in spring median quantiles (Q50 and Q60) and summer low flow (Q10–Q40) were identified. The increase in autumn streamflow since 1961 was found significant for all quantiles. For the minimum flow, significant positive trends in winter, spring and autumn were found, while the maximum flow recorded significant negative trends in winter and summer and positive trends in autumn [141].

More recently, in a study conducted also for the entire country, a trend detection analysis of monthly, seasonal and annual mean streamflow was performed, considering 46 g.s., with data recorded during 1935–2010 [144]. The results show increasing

trends (at 95% confidence level) in winter, spring, autumn and at annual time scale over the northwestern part of the country and decreasing trends (at 95% confidence level) in spring over the southern part of the country.

As for the Lower Danube River (on the Romanian territory), it was found by Mikhailova et al. [145] that during 1840–2000, at the entrance to its delta, there were no significant changes in mean annual discharges, but a slightly decreasing trend was identified after 1970. A decreasing trend in mean annual discharges was also noticed after 1975 in [146]. A similar negative trend in the annual mean discharges of the Danube River at the entrance to the delta (at Ceatal Izmail or Ceatal Chilia) was identified during 1948–2004 in [32] and was explained by the global warming, as well as by changes due to human activities (e.g., withdrawal of stream water for different uses, dams and reservoirs).

Between 1931 and 2010, according to [147], the annual average discharge of the Danube River had a slightly decreasing trend at its entry in Romania (at Baziaș g.s.). Meanwhile, at the entrance to the delta, at Ceatal Izmail/Chilia, a slight increasing trend was found, in contradiction to previous studies mentioned above (the divergence could be due to differences in the analyzed periods; additionally, the linear trends with a low slope were visually established without being statistically tested). During the analyzed period (1931–2010), the minimum annual discharges of the Danube River had upward trends at the entry in Romania, as well as at the entrance to the delta, more obvious after 1985. Concerning the maximum annual discharges, at Baziaș, no trend was detected, while at Ceatal Izmail/Chilia, a slight upward trend was found especially after 1990 [147].

During 1930–2008, shifts in seasonal discharge of the Danube River at the entrance to its delta (at Ceatal Izmail/Chilia) were identified. Thereby, after 1991 the present-day spring high flows and floods tend to occur earlier, the summer runoff is diminished and the low flows in autumn are slightly higher (in October–November) compared to those of the early 20th century [85].

The alterations in annual flow and regime of the Danube River on Romanian territory can be attributed to climate variability/changes, water management activities, as well as land use change. Since 1970, the reservoir dam of Iron Gates I, located at the entrance of the river in Romania (Fig. 10.1), had a major influence on the streamflow and sediment load of the Lower Danube River. The dam caused alterations of the natural annual flow regime due to its regularization role. Thus, during low water periods, the discharges increase (in winter and autumn), while during high waters (in spring and early summer) they are reduced in order to mitigate the flood magnitude [148].

At the regional/watershed scale, the identified trends in streamflow are heterogeneous, being influenced by local climate changes (in the lack of major anthropic pressures). In the Carpathian Curvature region, during 1962–2006, no significant trends were found in the annual flood peak variability and the number of floods exceeding the attention stage (corresponding to the yellow warning code) [137]. Similar results were found in the eastern Carpathians, in the Trotuș River catchment [138]. In the Southern Carpathians (more precisely, in the Bucegi Mountains), a significant upward trend in the magnitude of annual floods was identified between 1961

and 2010. After 1990, an increase in the frequency of floods with high magnitude was detected, as well as an increase in the frequency and magnitude of floods occurred in March–June and September–October [142]. In the Lower Buzău River basin (located in plain area, in the eastern part of Romania), between 1960–2009, a general downward trend in average (annual and monthly) flow series was detected, except for the autumn, when upward trends were found, in accordance with increasing precipitation during this season (especially in October) [143].

In watersheds from eastern Romania, during 1950–2006, a rise of the mean monthly discharges of rivers was found, correlated with the precipitation increase, except for winter when declines of the streamflow were identified [149]. In south-western Romania (in Oltenia region), between 1961 and 2009, the runoff decline was noticed, as an effect of the increase in climatic water deficit. Statistically significant negative trends in streamflow were identified especially in spring [150].

10.4.2 Projected Hydrological Changes

Among the first studies in Romania on the hydrological impact of climate changes can be named the ones in the 1990s [151, 152]. The number of such studies increased after 2000, but especially after 2010 [144, 153–166]. This issue has been also addressed in several European research projects, with the participation of Romanian institutions (e.g. National Meteorological Administration, National Institute of Hydrology and Water Management, Institute of Geography of the Romanian Academy etc.). In this regard we mention the project CLAVIER (*Climate Change and Variability: Impact on Central and Eastern Europe*) in which ongoing and future climate changes were investigated (based on observational data and on climate projections) and regional impacts were assessed [167]. The project CECILIA (*Central and Eastern Europe Climate Change Impact and Vulnerability Assessment*) aimed to provide climate change impacts and vulnerability assessment in targeted areas of Central and Eastern Europe (including Romania [168]). We also mention the projects SEERISK (*Changing Risks in Changing Climate*), focused on changes in floods and droughts under future climate in the Danube macro-region, including Romania [169] and the project CLIMHYDEX (*Changes in Climate Extremes and Associated Impact in Hydrological Events in Romania*) [170]. In the Carpathian region (including the whole European Carpathian chain with the adjacent areas of the Carpathian Basin, where Romania is located), researches on the climate changes and impacts on water resources were performed within some projects such as CarpathCC (*Climate Change in the Carpathian Region*) and CARPIVIA (*Climate Change Vulnerability and Ecosystem-based Adaptation Measures in the Carpathian region*) [171].

The studies in Romania on the hydrological impact of climate change have been carried out, generally, at regional or river basin scale, with various areas. The first papers on this topic were focused on estimating the possible alterations in river flow regime as a consequence of changes in air temperature and precipitation—data simulated by the Canadian Climate Center Model (CCCM), supposing that the CO₂ concentration doubles by 2075. The results showed that in the Argeş River basin

(situated in the southern part of the country), at Pitești Ștrand g.s. (Fig. 10.1), when compared to the reference period 1950–1992, the average annual discharge will decrease by almost 22%. Significant decreases (over 40–50%) are expected in spring (mainly in April and May) and autumn (September–October) while in the winter months, the average discharges will be much higher (with up to 86% in January) [152]. In the Târnava River basin (located in the central part of the country, in the Transylvanian Plateau) at Mihaiț g.s. (Fig. 10.1), projections for 2075 with the same climatic model (CCCM) showed a high increase in the average monthly flow in winter (over 70% in January) and decreases of –20 to –30% in the spring months (especially in March and April) and in September, relative to the reference period of 1961–2000 [153].

In the Buzău and Ialomița watersheds (covering External Carpathian Curvature region and the neighboring lowlands—hills and plains), the climate changes impacts on streamflow were estimated in [154, 159], by using three GCMs for three future time horizons (2025, 2050, and 2100), relative to the reference period 1971–2000 (the researches were performed within the European project CECILIA). The hydrological simulation (made with the water balance model WatBal) indicated notable changes in mean annual and monthly streamflow. Thus, the mean annual discharges decrease as the time horizon is larger and could reach 30%. During the winter and early spring periods (from November/December to February/March), an increase in mean monthly flow was detected on long-term, more pronounced for the rivers draining the mountainous area. The simulations also showed the seasonal variability amplification [159].

Also in the Ialomița River basin, it was investigated the potential impact of climate change on maximum flow regime. The discharges for the future period 2011–2050 and the reference period 1951–2010 were simulated with the CONSUL hydrological model, by considering the A1B scenario [157]. The projections show an earlier occurrence of the floods in spring in the future period relative to the reference period. The monthly maximum discharges will be higher in winter and July, and lower in April–June as well as in September–October. While in the reference period the highest number of annual flood peaks was recorded in October, in the future (2011–2050) the most annual floods will occur in March and April [157].

In the Siret River basin (the largest catchment in Romania, draining the eastern part of the country; Fig. 10.1) the climate change impact on maximum flow was investigated based on simulations made for the period 2011–2050, relative to the reference period 1951–2010 [156]. The projections show that in the future, most annual flood peaks will appear earlier in the year, in March–July, compared to the reference period, when they occur during April–August. In the same watershed, according to [172] for the period 2031–2060 (by simulations based on ENSEMBLES data under A1B SRES scenarios) a decline in average runoff from April–September (up to –25%) and tendencies towards an increase in winter (January and February) are expected. The cited reference indicates that during the period 2031–2060, the majority of the climate scenarios applied so far show a clear reduction in summer

runoff for the main tributaries of the Lower Danube Basin (e.g., the Olt River at Cornet g.s.), while in the rest of the year, the scenario trends are partially unclear, mainly for the winter months.

In the Olt River basin, one of the largest watersheds in Romania, draining the Carpathians and the central part of the Romanian plain (Fig. 10.1), the potential impact of climate changes on the maximum streamflow was investigated by hydrological simulations (using the CONSUL model) for two periods: 1951–2010 (as reference period) and 2011–2050 [161]. The results indicated a slight increase in the future (up to 5%) in the annual maximum discharges. Significant increases of maximum monthly discharges are expected in winter, July and August, while during the spring months, in June and autumn, the projections indicate a decrease of the maximum streamflow. In the future period, it is likely that floods will become more frequent in winter and summer compared to the reference period, and rarer in spring and autumn (except October). The high discharges (with return periods of 1000, 100, 50, 20 and 10 years) tend to rise in the upper part of the Olt River basin and to slightly decrease in the lower part [161].

Within the European project CLAVIER (conducted between 2006 and 2009), in which several Romanian institutions were involved, there were estimated the hydrological impacts of climate changes based on the output of regional climate models for several watersheds/rivers in Romania. REMO5.7-ERA40 (1961–2000) and REMO5.7-A1B (1951–2050), data produced by the Max Planck Institute for Meteorology in Hamburg, were used as climate change scenario for the hydrological models (VITUKI-NHFS and VIDRA). The projections were made for some Romanian rivers draining different geographical regions. Thus, Vişeu (at Bistra g.s.) and Iza (at Vadu Izei g.s.) are tributaries of the Upper Tisa, located in the far north of the country. Mureş River (at Arad and Luduş gauging stations) and its tributaries Arieş (at Turda g.s.) and Târnava (at Mihalţ g.s.), drain the central part of Romania. Argeş River (at Malu Spart and Budeşti gauging stations) and its tributary Dâmboviţa (at Lunguleţu g.s.) are located in the south of the country (Fig. 10.1).

For rivers in the northern part of the country (Vişeu and Iza), a slight increase of the mean annual discharges (less than 3%) is expected for the period 2021–2050 relative to the reference period (1961–1990). A significant increase (30–40%) is projected in the winter season. For the spring-autumn period, the hydrological simulations indicate a slight variation, more important in spring, when decreases of –4 to –14% are estimated for mean discharges (Fig. 10.7). For the other analyzed rivers, the hydrological simulations indicated a general decrease of the mean annual discharges up to almost –15% by 2050. This decreasing is caused by the pronounced flow reduction during the spring–autumn period, by up to almost –25% in some catchments (a lower decrease of the average flow is expected in summer). In winter, significant increases are projected, which can reach 30% in the south of the country (e.g., Dâmboviţa River) (Fig. 10.7) [167]. Concerning floods, the simulations made within CLAVIER project do not indicate obvious changes. However, more frequent floods are expected in winter. Torrential flash floods could occur more frequently, while the floods with long duration and large volume may become rarer. The low flows are expected to last longer [167].

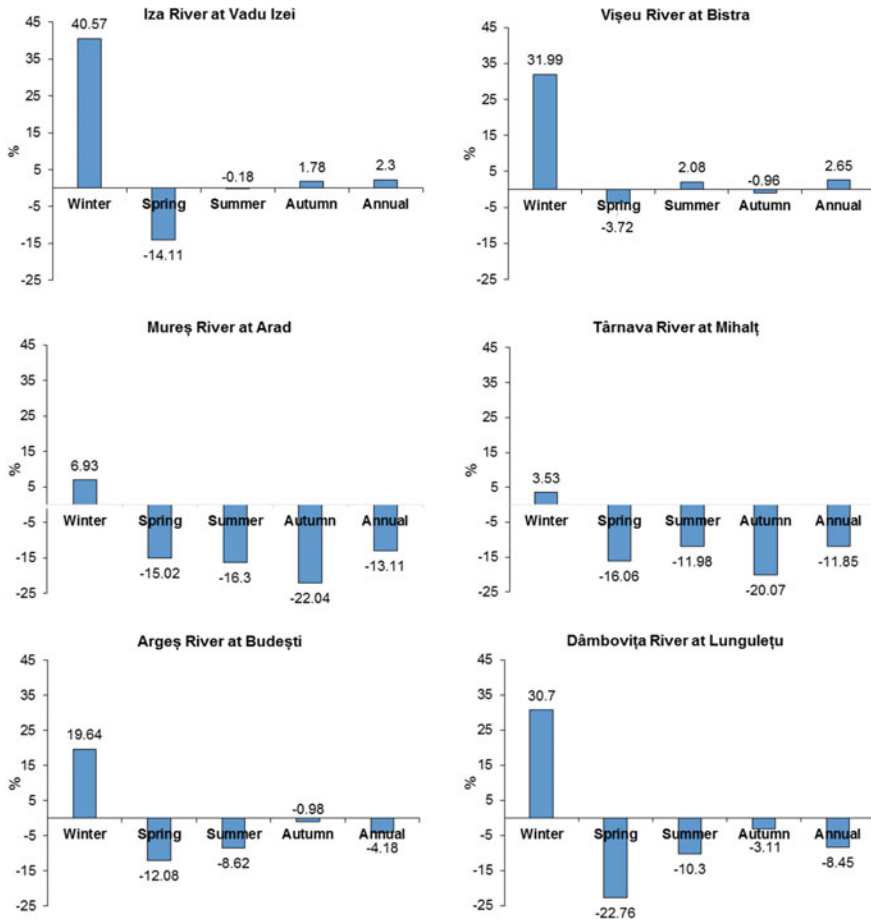


Fig. 10.7 Changes in mean seasonal and annual discharges projected for some rivers in Romania for the period 2021–2050 relative to the period 1961–1990, based on hydrological simulations under the A1B climate change scenario (based on the data from [167])

Within the project CLIMHYDEX, the climate change impacts on extreme flow were estimated in two medium-sized basins in Romania: Crișul Alb (in the western part of Romania) and Bârlad (in the eastern part) (Fig. 10.1). The hydrological simulations were made (using CONSUL and NOAH models) for two future periods 2021–2050 (Scenario S1) and 2071–2100 (Scenario S2). They were compared with the simulations made for the reference period 1976–2005 (Scenario S0), under climate scenarios generated in the CLIMHYDEX Project (8 GCMs have been used, by considering three greenhouse emission scenarios: A1B and E1 for ENSEMBLES GCMs, and RCP4.5 for CMIP5 GCMs) [170].

For the Crișul Alb River basin, the results indicated a general increase of the frequency of flash flood events in the future periods, more pronounced for the second

period 2071–2100 (greater than 20%), and especially the increase (by 30–40%) in the frequency of severe flash flood events. In the case of the Bârlad River basin, a general increase of the flash floods frequency was estimated in the upper part of the catchment, and a decrease in the middle and lower basin, for both future periods relative to the reference period [144].

In Bârlad River basin, the scenarios S1 and S2 indicated an increase of the monthly maximum discharges (multiannual averages) during the winter, spring and summer months (with a significant increase in January and February), and a decrease in the autumn months. Regarding the monthly minimum discharges (multiannual averages), an increase was identified in the late winter, early spring and in the summer months, and a decrease in the rest of the year, more pronounced during October–December (Fig. 10.8a). In the future periods (scenarios S1 and S2) compared to the reference period (S0), the simulations indicated for the annual maximum discharges a positive trend (of maximum 15 and 30% respectively) in the upper and lower part of the watershed, and a negative trend in the middle part (of maximum –5 and –15% respectively). Regarding the annual minimum discharges, the simulations showed a decrease of maximum –5 and –15% respectively, for the whole watershed [144, 165, 166].

In Crişul Alb River basin, the analysis of monthly maximum discharges (multiannual averages) showed, for scenarios S1 and S2 relative to S0 scenario, an increase during the winter, spring and summer months, more pronounced from May to August and a decrease in the autumn months. Concerning the multiannual averages of the monthly minimum discharges, an increase was detected in the late winter, early spring as well as in the summer months, and a decrease in the rest of the year, more significant during October–December (Fig. 10.8b).

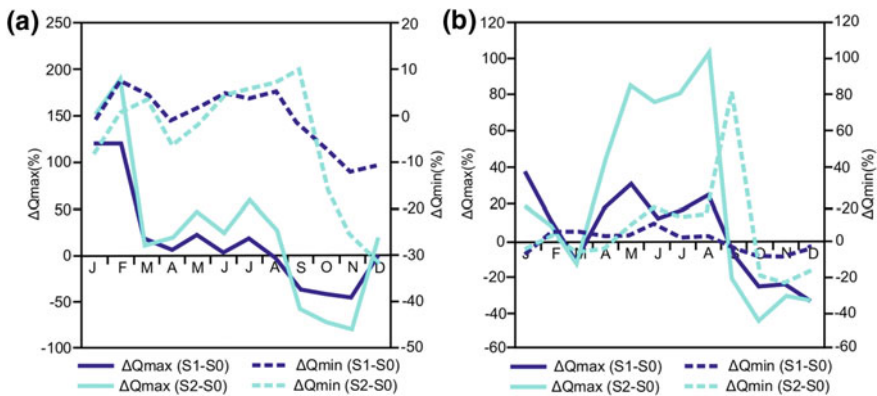


Fig. 10.8 Variation of relative deviation (%) of monthly maximum (Q_{max}) and minimum (Q_{min}) discharges (multiannual averages) under S1 and S2 scenarios relative to S0 scenario, at Bârlad gauging station, on Bârlad River (a) and at Gurahonț gauging station, on Crişul Alb River (b) (adapted from [144])

The simulation of the annual maximum discharges in Crişul Alb River basin, for the scenario S1 compared to S0 scenario, indicated, generally, a slight negative trend in the upper part of the basin (of maximum -3%) and an increasing trend for the lower part (of maximum 7%) while the scenario S2 indicated a significant increase (of maximum 41%) on the entire watershed. Concerning the annual minimum discharges, the simulations indicated for scenario S1 compared to S0 scenario a decrease of up to -8% , and for the scenario S2 an increase of maximum 7% on the entire river basin [144].

A few studies investigated the hydrological alteration induced by climate change in Mureş River basin, the largest catchment in the central part of Romania (Fig. 10.1). Based on scenarios obtained from nine coupled runs of GCM-RCM model driven by A1B socio-economic development scenario and using the SWIM hydrological model, the hydrological response to climate change was simulated in the upper part of the Mureş River basin (upstream Alba Iulia g.s.), for the reference period (1971–2000) and two future periods (2021–2050 and 2071–2100) [173]. The projections indicated a deviation in median monthly discharges, as follows: increase for the winter months for both future periods, and decrease for late spring, summer and early autumn by the year 2100. Over half of the simulations projected a slight increase in median and maximum values for the number of days with high flow, but a more significant increase for the duration of flow events, indicating that it is likely that drought events will become longer by the year [173]. These results are generally consistent with [164], study that investigated the potential hydrological impacts of changes in temperatures and precipitation in the entire Mureş River basin (using the SRES A1B scenario), considering the same future periods (2021–2050 and 2071–2100), compared to the reference period 1961–1990. Based on the results of climate projections (with ALADIN and REMO models), the simulations showed that the annual streamflow will certainly decrease in the long run and early spring snow melt could be more intensive, causing the increase of the river flow. The projections also indicated that the early summer floods might be less significant; summer and autumn low flow extremes may occur more frequent, and severe water scarcity may affect the lower sector of the Mureş River [164].

At national spatial scale, the changes induced by climate change on the mean (monthly and annual) streamflow in 20 large basins (including 275 sections) were investigated for the time horizon 2021–2050, by using the hydrological models WATBAL and CONSUL [174]. The simulations were performed considering two scenarios: Scenario 0, corresponding to the reference period 1971–2000, and Scenario 1, in which the mean monthly discharges for the period 2021–2050 were estimated by using simulations of climate change evolution performed within CLAVIER Project (A1B scenario). The results indicated a general decline of the mean multiannual discharges (of maximum -38% in Vedeia River basin), excepting the Someş River basin where an increase (of maximum 23%) was identified. Regarding the monthly mean multiannual discharges, projections showed in most analyzed catchments significant increases in the winter months (December, January, February) and sometimes in March (i.e., in Mureş, Argeş and Siret watersheds) and pronounced decreases in late summer and autumn (August–November) [174].

Researches on future expected impacts of climate changes on water availability and extreme hydrological events in Romania were also carried out within the International Commission for the Protection of the Danube River (ICPDR). The researches are based mainly on IPCC SRES scenarios A1B and A2 and on RCP scenarios, by considering as future periods 2021–2050 and 2071–2100. According to [175], for the entire Danube River basin, seasonal changes in runoff regime are expected in the 21st century, concretized in the increase of the mean discharge in winter and decrease in summer, with local differences. A decline in solid precipitation and consequently in snow cover, together with an earlier snow melt, will lead to the alteration of the runoff regime, by causing in the high parts of the watersheds draining the Carpathians, a shift in peak runoff from early summer to spring.

In the Lower Danube River basin, the studies based on IPCC SRES scenarios show an increase in flood frequency, but the possible changes in flood frequency and magnitude remain uncertain. Flood events are projected to occur more frequently, particularly in winter and spring. For small catchments, an increase in flash floods due to more extreme weather events (torrential rainfall) is expected. Concerning the drought and low flow events, they are likely to become more intense, longer and more frequent. The frequency could increase especially for moderate and severe events. These extreme events will be more severe in summer, due to less precipitation in this season, whereas they will become less pronounced in winter [175].

The impacts of climate change on the flow regime of the Danube River and its tributaries were investigated in [85] by using an ensemble of climate scenarios and the SWIM hydrological model, for two future periods (2031–2060 and 2070–2100) and the reference period 1971–2000. The simulations showed a possible increase in river runoff for the winter and spring months (especially during January–March), while a general decreasing trend is projected in summer runoff for the whole Danube Basin and, additionally, in autumn runoff for the Middle and Lower Danube Basin. The trends are more evident towards the end of the 21st century. At the entrance of the Danube River to its delta (at Ceatal Izmail/Chilia g.s.), the projections based on ENSEMBLES data under A1B SRES show, for the near future period 2031–2060 relative to the reference period, an increase (of 5–40%) in winter and early spring runoff (from January to March). The flow peak specific for May is projected to decrease slightly (up to –5%) and tends to appear earlier (in April). The projections also indicate, in the Lower Danube River, a decrease (up to –20%) of discharges during the warm season (May–October), aggravating the low flow period in late summer and autumn (August–November). For the far future (2071–2100), the simulations indicate increase in runoff for January–April, with rates similar to those projected for the near future period. In the rest of the year, no clear changes were identified, except for a decreasing trend in late summer [85].

10.5 Hydrological Responses to Climate Changes: The Example of the Valea Cerbului River Catchment

This part is focalized on a case study in which the hydrological responses to climate changes were investigated in Valea Cerbului River catchment, based on recorded data and hydrological simulations.

10.5.1 Study Area, Data and Methods

Valea Cerbului River catchment is located in the eastern extremity of the Southern Carpathians, namely in the Bucegi Mountains, a nationally renowned region for tourism related activities (Fig. 10.1). The main stream has almost 10 km length with a mean slope of about 130 m/km. It has its source in the alpine region at 2125 m amsl and the outlet at 870 m amsl. The catchment extends over an area of only 26 km² and has a mean altitude of 1500 m amsl (the maximum altitude is 2505 m amsl in Vf. Omu peak) (Fig. 10.9). Its upper part overlaps calcareous conglomerates and has steep slopes (between 45° and 80°) favoring rapid runoff and flash floods occurrence [142, 176]. The hydrographic network is dense, but mainly formed by temporary torrential streams.

The altitude imposes important spatial variations of the climatic parameters. Thereby, the mean multiannual air temperature decreases from 5 to 6 °C at lowest altitudes to -2.5 °C at Vârful Omu w.s., located at 2505 m amsl, where the frost lasts, in average, 260 days/year and the snow layer has a mean duration of 140–220 days/year, with a monthly average thickness of up to 70–80 cm in March–April [99]. The snow usually lasts until June on the upper part of the northern valleys, two months longer than in the lower basin [177]. The mean annual precipitation in Valea Cerbului catchment varies between 900 and 1030 mm [99]. The wet period is May–August (over 100 mm/month on average), when heavy, convective rains are specific, while in autumn and winter the amounts of precipitation are low.

The mean multiannual discharge of the Valea Cerbului River (calculated for the period 1961–2012, based on data recorded at Bușteni g.s., which controls approx. 96% of the total area of the catchment), is of 0.502 m³/s, equivalent to a specific discharge of 19.8 l/s/km². The maximum flow recorded is of 62.3 m³/s (on June, 19th 2001) and the minimum discharge is of only 0.030 m³/s (December, 16th 1963). The flow regime is characterized by high waters in summer (38% from the mean multiannual volume), with the maximum percentages in June and July (13% and respectively 15% of the mean multiannual water volume), due to heavy convective rains specific for this season. An important water volume is flowing in spring (30%) when the runoff is influenced by rainfall cumulated with snowmelt. Low flow is specific for both winter and autumn (13% and respectively 19%) [177].

The Lower Valea Cerbului River basin overlaps the northern part of the Bușteni town, a nationally renowned resort for both, winter and summer related tourism activities. The river is crossed by very important international/national terrestrial

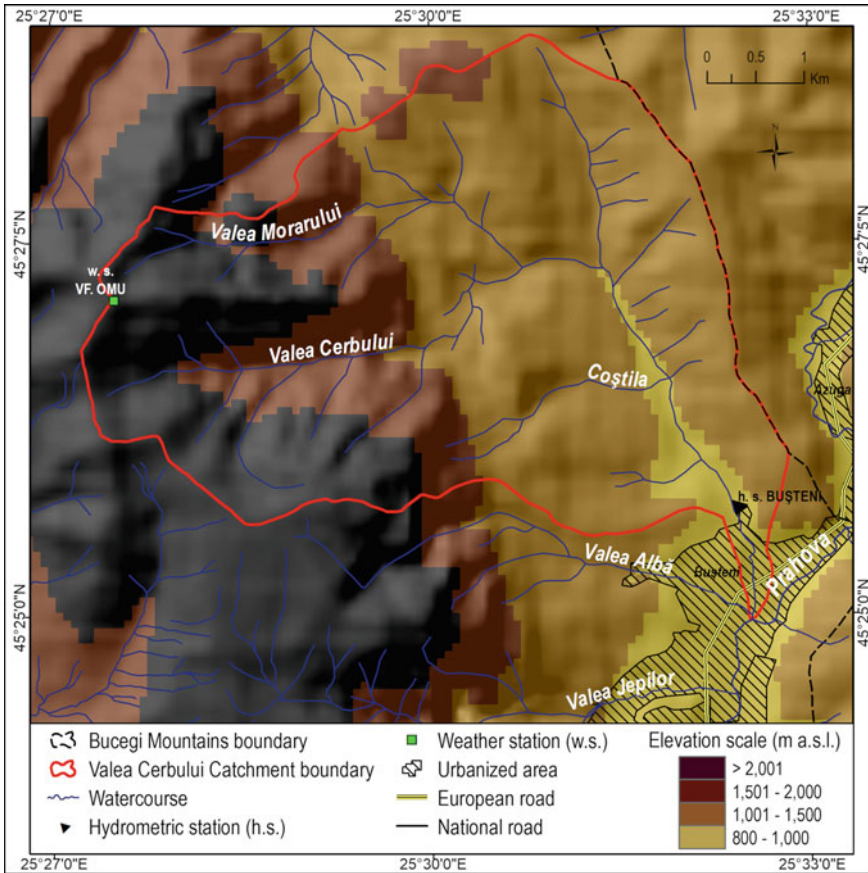


Fig. 10.9 Valea Cerbului River catchment map

routes, namely the European Route E60/National Route 1 (DN1) and the main railway that links Bucharest with major cities from the central and western parts of the country.

The analysis is based on three major types of data: hydrological, climatic, and spatial/cartographic. The hydrological data refers to mean daily discharges measured at Bușteni g.s., used for both the analysis of the observed changes during 1961–2012 and the calibration of the hydrological model. The source of the hydrological data series is the “Romanian Waters” National Administration.

The climatic data refers to recorded and emission scenario data on the main parameters, at daily time step: temperature, precipitation, wind speed, relative air humidity and sunshine duration, respectively solar radiation (substituting the sunshine duration for the scenario data). The recorded data were obtained from the national weather stations network (through National Meteorological Administration and European Climate Assessment and Dataset—ECA&D) and used to simulate the actual hydro-

logical regime of the Valea Cerbului River. The scenario data were obtained within the ESEMBLE project, at Max-Planck Institute (Germany) using the ECHAM5 global climatic model. They were retrieved from the CERA database (Climate and Environmental Retrieval and Archive) and refer to the B1, A2 and A1B scenario families (for the period 2001–2065) and to the reference period C20 (1961–2000) [178]. We considered a medium time horizon which is generally more appropriate to make and implement regional and local policies and adapted management measures. The data on air temperature and precipitation for both the reference (1961–1991) and scenario (2001–2065) periods, were subjected to bias corrections (*delta change* method, as described in [179]).

The spatial data were used as part of the input in the hydrological model and consists of data on altimetry, stream channels, rock and soil types, land cover etc., retrieved from the thematic maps available at different scales (1:25,000, 1:50,000), vectorized, then processed in GIS environment and/or with the specific tools provided by the model's developers.

The changes in the flow data series recorded at Buşteni g.s. were investigated based on frequency and trend analysis for the period 1961–2012. The significance of linear trends was established using the Mann-Kendall test and Sen's slope method, developed on an Excel template [180].

The changes in the hydrological and climatic parameters, as projected by the emissions scenarios, were estimated using WaSiM-ETH (Water Balance Simulation Model), a fully distributed hydrological model that simulates all the components of the water balance. The required input data are climatic data series (e.g., daily data on air temperature, precipitation, sunshine duration, wind velocity, air relative humidity) and gridded spatial data [181]. The model was calibrated and validated using historical data series and with the PEST (Parameter Estimation and Uncertainty Analysis) software [182]. The objective functions used to assess its efficiency were the Nash-Sutcliffe Efficiency Coefficient (NSE = 0.80 in calibration, and 0.60 in validation) and the Pearson Correlation Coefficient ($r = 0.90$ and 0.86 for calibration and validation, respectively).

10.5.2 Observed Changes in Valea Cerbului River Flow

The streamflow changes are mainly caused by climatic and anthropogenic factors. Because the Valea Cerbului Catchment is partially included in the Bucegi Natural Park, the human pressures are quite limited. The intakes for the water supply of Buşteni town are insignificant and do not affect the flow regime [183]. Therefore, the hydrological alteration can mainly be the result of climate changes.

A previous study [177] have shown for the period 1950–2010 a general upward trend in the variability of monthly average discharges. Except for April and May, increasing trends were founded in all the months, statistically significant from August to December (with the level of significance $\alpha = 0.01$ in September and October and $\alpha = 0.05$ in August, November and December). A significant decreasing trend was detected in May (for $\alpha = 0.01$). At the seasonal scale, upward trends were identified

in summer, autumn and winter (statistically significant only in autumn, for $\alpha = 0.01$), while in spring the trend is negative but non-significant. Annually, an increasing trend in average discharges was detected, but non-significant statistically.

In this chapter, we focused the investigation on the changes observed during 1961–2012, in high flows (floods) and the low flows of the Valea Cerbului River.

10.5.2.1 Changes in the Magnitude and Frequency of Floods

The annual flood peaks of the Valea Cerbului River recorded at Bușteni g.s. during the period 1961–2012 occurred most frequently during the summer months, each with more than 20% of the cases, while the lowest frequencies were recorded during winter, with no annual floods in January (Table 10.1).

The magnitude of the annual floods (the largest peak flood of each year) has a statistically significant upward trend (with a level of significance $\alpha = 0.1$). The seasonal trends (analyzed based on the maximum monthly discharges averaged for each season) is consistent with the seasonal trends identified using mean daily and monthly discharges: significant positive trends in autumn and winter (for $\alpha = 0.1$) and non-significant in summer; negative trend in spring, non-significant (Table 10.2).

In order to analyze the temporal variability and frequency of floods (during 1961–2012), we established a threshold discharge, namely three times the mean multiannual discharge [142, 184]. Any mean daily discharge exceeding the threshold was considered a flood, except consecutive days with such values, which were counted as single events. This approach allows to include in the analysis of both exceptional and ordinary floods, for more accurate identification of their temporal frequency. The interannual variability of the number of floods shows a slight upward trend, statistically non-significant. The maximum frequency of floods is identified in 1966, 1998, 2005 and 2010, but there are years without floods (defined as mentioned above): 1976, 1986, 1993, 2002 and 2011 (Fig. 10.10a).

At monthly level, the highest frequency of floods in the analyzed period is met in June (over 20% of the total number of floods), followed by July (approx. 16%) and April (almost 12%), when snowmelt is mixed with spring rainfall. The months with the lowest frequency of floods occurrence are January and February, with less than 2% (Fig. 10.10b).

The decadal analysis of the frequency of floods (as defined above) highlights some changes during the period 1961–2010. The total number of floods was smaller in the second and third decades of the analyzed period (1971–1980 and 1981–1990), namely 34 and 31 floods. The maximum number of floods were recorded between 2001 and 2010. The absolute monthly frequency of floods shows a great decadal variability in March, April and August. The maximum frequency of floods is identified in June for all decades (Fig. 10.11a).

Except for the first decade considered in the study, the floods were recorded most often during summer in each decade. In autumn, the frequency of floods for the

Table 10.1 Monthly number of annual flood peaks recorded between 1961–2012 at Bușteni gauging station on Valea Cerbului River (in some cases the maximum annual discharge is recorded twice, in different months)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No. of annual floods	0	1	2	2	5	11	11	12	4	3	1	1
% of total number of years	0.0	1.9	3.8	3.8	9.4	20.8	20.8	22.6	7.5	5.7	1.9	1.9

Table 10.2 Statistical significance of trends in the seasonal variability of the maximum discharge of the Valea Cerbului River at Buşteni gauging station (1961–2010), according to Mann-Kendall test

Season	Statistical test Z	Level of significance (α)	Sen's slope
Spring (III–V)	-0.49	–	-0.002
Summer (VI–VIII)	0.20	–	0.0011
Autumn (IX–XI)	1.79	0.1	0.0044
Winter (XII–II)	1.81	0.1	0.0027

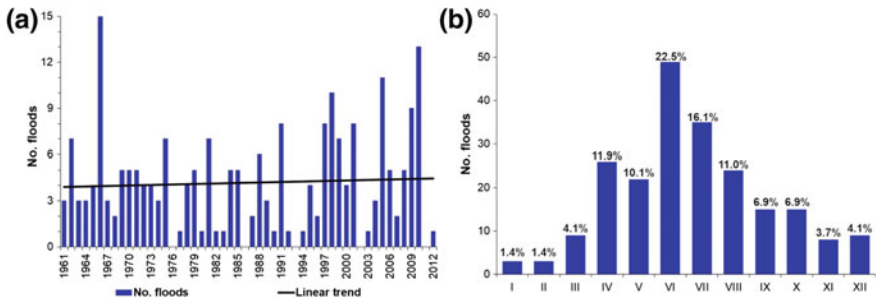


Fig. 10.10 Annual number of floods and the linear trend (a) and total monthly number of floods with the equivalent percentages (b), recorded at Buşteni gauging station between 1961–2012

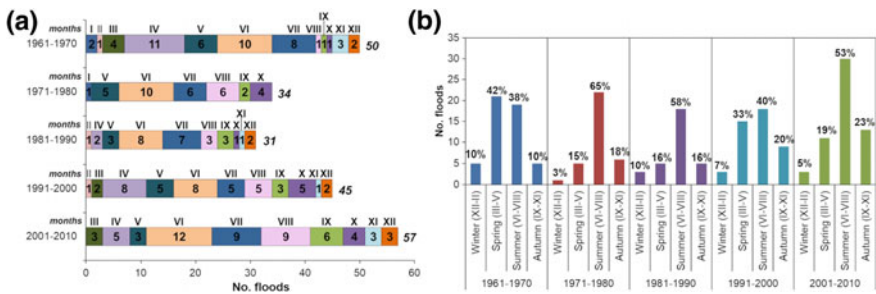


Fig. 10.11 The decadal monthly absolute frequency of floods (a) and decadal seasonal absolute and percentage frequency of floods (b) at Buşteni gauging station on Valea Cerbului River (1961–2010)

last two decades is increasing and consistent with their magnitude, namely with the trends identified for the mean and maximum discharges (Fig. 10.11b).

10.5.2.2 Changes in the Magnitude and Frequency of Low Flows

At interannual level, the magnitude of low annual flows (based on mean daily discharges) is decreasing during the analyzed period (1961–2012). Thus, the data show a positive trend of the annual minimum discharges with a significance level α of 0.05. The low monthly flows have, in general, the same positive trend, statistically significant for January to March and December (for $\alpha = 0.05$ to $\alpha = 0.01$). The exception is given by the low flows in April to July, for which a negative trend was identified (statistically non-significant). Seasonally, the minimum discharges have upward trends in spring (for $\alpha = 0.1$), winter (for $\alpha = 0.01$ in) and autumn (statistically non-significant), and a downward trend in summer (statistically non-significant). The trend identified in the low flows, correlated with the seasonal frequency of floods lead to the conclusion that for the analyzed period, the hydrological regime tends to become more extreme in the summer for both low and high flows and attenuated in the winter.

The frequency and the duration of low flows were determined by considering as a threshold the discharge (Q) with 95% exceedance probability (the 5th percentile), based on recorded mean daily discharges during 1961–2012 ($Q_{95\%} = 0.092 \text{ m}^3/\text{s}$). We considered as low flow period any period of at least 10 consecutive days with discharges below this value. This method helps to identify the driest years for the study area, regarding hydrological drought duration.

The decadal analysis of low flows shows an increase of their magnitude, especially in the last decade (2001–2010) and an important variation of their frequency (expressed as a decadal number of days with discharges below $Q_{95\%}$) (Fig. 10.12a). During the analyzed period, the intervals of dry years are 1963–1968 and 1986–1995 (Fig. 10.12b). The occurrence of low flow periods does not imply that significant

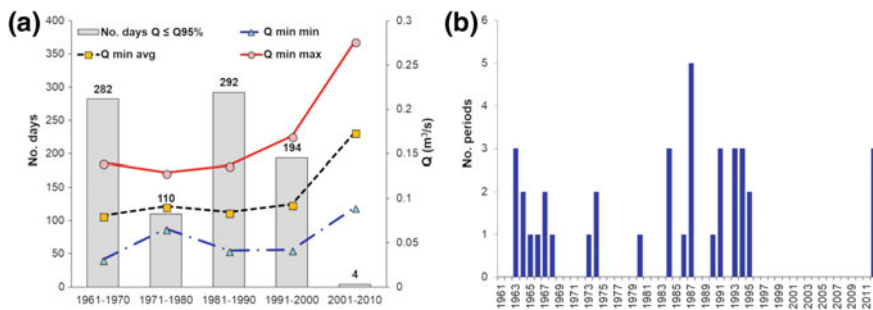


Fig. 10.12 The decadal frequency of discharges below $Q_{95\%}$ and decadal minimum (Q min min), average (Q min avg) and maximum (Q min max) of mean daily discharges (a) and annual number of low flow periods (b) at Bușteni gauging station on Valea Cerbului River (1961–2012)

floods cannot be recorded in the same years, but the interannual distribution of flows can be extremely uneven.

From the total of 38 low flow periods identified during 1961–2012, 63% (24) occurred in winter, 21% (8) in the autumn, 13% (5) in spring and just one case during summer (in July). Monthly, the maximum frequency of the low flow periods is specific in February. On the contrary, in April, May and June, when the snowmelt has an important role in the surface runoff, there were not prolonged intervals with flows below $Q_{95\%}$.

10.5.3 Projected Hydrological Responses to Climate Changes

For Valea Cerbului River catchment the emission scenarios predict a rise in the air temperature of 1.3 °C (the mean value indicated by the emission scenarios used). Compared to the reference period (1961–2000), the scenarios show temperature growths for all seasons, with maximum values in autumn and minimum values in spring. The analysis conducted at the monthly level, reveals upward, significant trends for A2 and A1B scenarios for the future period 2001–2065.

The trends indicated by the simulated precipitation data are not as clear as those of the air temperatures: annually, a slightly descending trend and a higher variability are expected; seasonally, the simulated precipitation shows more important decrease during autumn (from 6.8 to 10.7% depending on the scenario).

The hydrological model used establishes the type of each precipitation event, liquid or solid, by threshold transition temperatures, set in the model optimization stage. Likewise, it can determine the precipitation values and types dissociated for different zones of altitudes, in this case: the zone above 1750 m amsl, the zone between 1250 and 1750 m amsl and the low part, with less than 1250 m amsl. The simulation using the scenarios data as climatic input highlights the diminution of the mean annual snowfall by 5–11% by 2065, relative to the reference period. On the contrary, the projected liquid precipitation slowly increases on the chosen time horizon.

For the winter months, the estimated snowfall is much lower than the simulations for the reference period. Notable differences are estimated for the middle and lower zones of the catchment, namely with approximately 15% less snowfall, but 18–40% more rainfall, as average between the three scenarios (Fig. 10.13a). During spring and summer, projected changes in the precipitation's form have the same tendency: less snow (4% in the spring, 35% in the summer) and more rain (11% in the spring, just 1% in the summer) than during the reference period (as average between the scenarios, for the whole basin). For the autumn, the scenarios show the diminution of precipitation in general, but a strong diminution of snowfall: with 24% in average and over 30% in the middle and lower part of the catchment (Fig. 10.13a). The shift between solid and liquid precipitation during winter and spring entails a significant

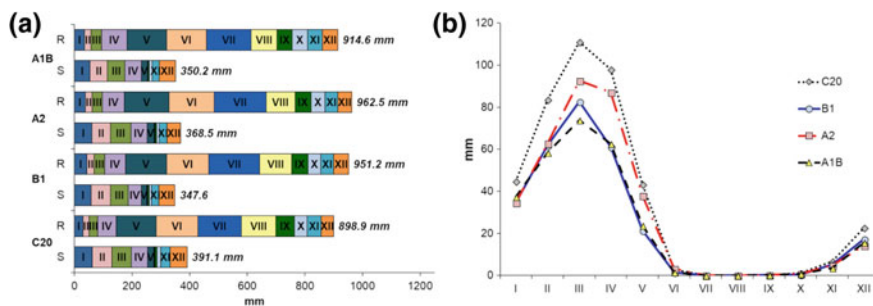


Fig. 10.13 Mean monthly amount of solid (S) and liquid (R) precipitation (a) and mean monthly snow depth (b) in Valea Cerbului River catchment for the climatic scenarios B1, A2, A1B (2001–2065) and the reference period C20 (1961–2000)

decrease of the snow layer depth and duration, directly affecting the streamflow, because in high mountainous regions, the snowmelt is an important component of river flow.

For the interval November–February, the projections show a uniform decrease of snow depth relative to the reference period. From March to May the simulations are still below the monthly values of the reference period, but for the A2 scenario, the decrease is lower (Fig. 10.13b). The changes in the snow depth are of approximately 27% at annual level (scenarios average) and up to 68% at the monthly level.

The simulations of the hydrological regime under the emission scenarios indicate a lower mean annual discharge of -2% up to -6% (depending on the scenario), but with important monthly and seasonal differences. From January to April, all the three scenarios indicate increased mean monthly discharges, of 4–22%, with the maximum difference in January for the B1 scenario (Fig. 10.14). This is the effect of rising air temperatures, fact that triggers liquid precipitation events, a diminished snow depth and earlier snowmelt. For May–December the average of the scenarios estimates lower mean monthly discharges (between -10 and -29%), excepting several months for the A2 scenario (May–July) and B1 scenario (July), for which the simulated mean monthly discharges exceed those simulated for the reference period (with 2–19%) (Fig. 10.14).

The seasonal projected differences are conclusive for the autumn and the winter, when all three scenarios are consistent with each other and with the changes observed in the climatic parameters (temperature and precipitation): significant decrease during autumn (-13 to -19%) and slight increase during winter (1–7%).

To analyze the impact of climate changes on the magnitude and frequency of extreme flows (high and low), we set two thresholds: the discharge with 95% exceedance probability ($Q_{95\%}$) for low flow and the discharge with 5% exceedance probability ($Q_{5\%}$), for high flow.

The results of the simulations show that the $Q_{5\%}$ threshold does not change significantly: the maximum change is predicted by the A2 scenario (8% higher than

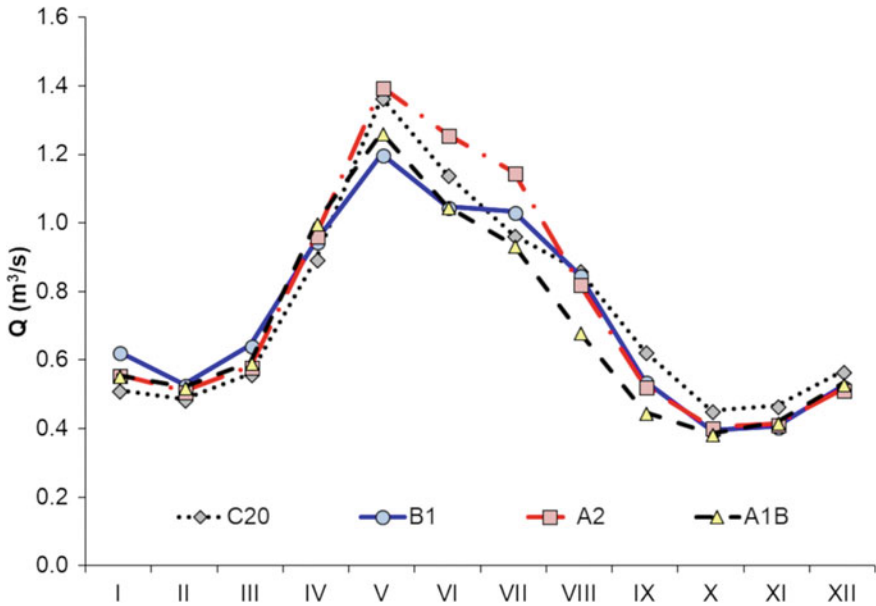


Fig. 10.14 The outcomes of the hydrological model regarding the mean monthly discharge of the Valea Cerbului River at Bușteni gauging station, for the climatic scenarios B1, A2, A1B (2001–2065) and the reference period C20 (1961–2000)

the reference period). The $Q_{95\%}$ decrease up to -12 to -18% relative to the value calculated for the reference period, reflecting the climate’s tendency of becoming hotter and drier. Based on the two thresholds, we analyzed the possible change in the mean annual and monthly frequency of days with discharges below the threshold of $Q_{95\%}$ and above the threshold of $Q_{5\%}$. Even though the projected changes in the $Q_{5\%}$ value are not significant, the mean number of days exceeding it is higher: annually with 2–3.7 days and over 3 days for May–July (Fig. 10.15a). A low decrease (by

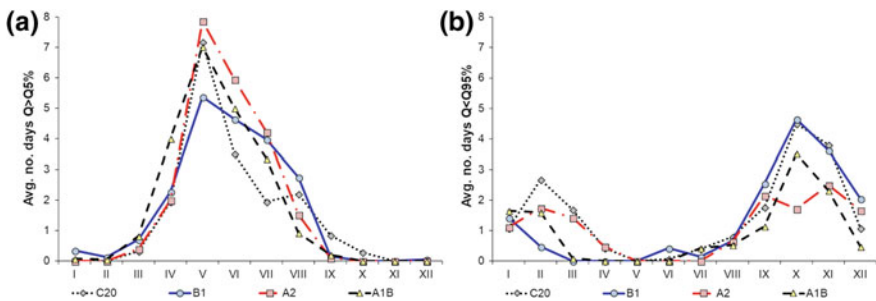


Fig. 10.15 The average monthly number of days with characteristic discharges of the Valea Cerbului River at Bușteni gauging station: greater than $Q_{5\%}$ (a) and lower than $Q_{95\%}$ (b) for the climatic scenarios B1, A2, A1B (2001–2065) and the reference period C20 (1961–2000)

1–2 days) in the number of days with discharges exceeding $Q_{5\%}$ is expected during August–October.

The simulations show that the annual frequency of discharges below $Q_{95\%}$, projected for the future period will be lower compared to the reference period, up to 18 days. Monthly, the same decreasing trend is expected in February, March, August and November. January is the only month for which all the scenarios indicate a possible low increase, by 1–1.4 days (scenarios average). In May there are not discharges below $Q_{95\%}$ for neither the reference and future scenarios periods (Fig. 10.15b).

The results of our simulations emphasize the fact that the alterations of the climatic parameters, as projected by the IPCC emissions scenarios, would impact on the hydrological regime by shifting water volumes from summer and autumn to winter and early spring, and by reducing the frequency of very low flows. However, the magnitude of both high and low flows could increase, amplifying the torrential flow character of the Valea Cerbului River.

10.6 Conclusions and Recommendations

As the hydrological system is highly sensitive to climate, it is expected that the alteration of climate parameters will impact the water cycle, affecting water availability and human uses, as well as the aquatic ecosystems. This chapter presented a review on the main research findings on hydroclimatic changes (observed and projected) in Romania, in the context of the researches at global and European scale, and provided new results on hydrological responses to climate changes issued from investigations in a small mountainous catchment (Valea Cerbului River basin), located in the Romanian Carpathians. The most important climate changes with hydrological impacts detected in the last half-century (after 1960) are a general warming at annual and seasonal scale (excepting autumn) and increase of the precipitation amount in autumn and of the daily maximum rainfall (mainly in summer and autumn). Important changes also affected the snow-related indices (mean snow depth, number of days with snow cover and with snowfall, continuous snow cover duration), which had significant downward trends. According to the climate simulations under different scenarios, it is likely expected that these trends will continue and intensify in the future.

The changes in the climatic parameters could be held responsible for some alterations and trends in the river flow, detected or estimated in studies conducted at national and regional/local scale. At national level, in Romania, a general decreasing trend in the mean annual streamflow was detected after 1960. Some changes in monthly and seasonal runoff variability were also found: upward trends in winter (related to the increase of the air temperature and the shift of the precipitation from solid to liquid form), downward trends in summer runoff (induced by the general warming and increase of evaporation), upward trends in autumn flow. For the future (by 2050), the simulations under climate scenarios indicate a general decline of the

mean multiannual runoff, significant increases of discharges in the winter months and pronounced decreases in late summer and autumn.

In Valea Cerbului River catchment we investigated the streamflow changes based on historical data, as well as the possible hydrological changes, as indicated by simulations using the WaSiM-Eth model, under B1, A2 and A1B climatic scenario, for the time horizon 2001–2065 relative to 1961–2000 period. The simulations indicate a slight decrease in mean annual runoff (of -2% up to -6%) by 2065 and more or less significant changes in the annual flow regime. Thus, from January to April, an increase in mean monthly discharges (of $4\text{--}22\%$) is projected by all considered scenarios, while during May–December the simulations generally show lower mean monthly discharges (between -10 and -29%).

Overall, we highlighted the importance of methodological approaches for estimating climate change and hydrological impacts. Thus, the results of the studies are more or less similar and accurate, depending on the time scale, data used and characteristics of each model. This raises the question of knowing the uncertainties, which is a challenge for interpreting final results. Accordingly, the adaptation policies to climate change and hydrological impacts should take into account this issue of uncertainty, by considering feedback loops, reversible and flexible options, soft strategies for shorter time horizons, or other uncertainty-management methods.

In accordance with the actions taken at international and EU levels, Romania proceeded to the development of strategies and action plans regarding the adaptation to climate changes. The first National Strategy for Climate Change (NSCC) and the related National Action Plan on Climate Change (NAPCC) were designed in 2005 and planned measures and actions for the period 2005–2007. In 2008, the Guide regarding the adaptation to climate change effects was adopted, aiming the identification of necessary measures to limit the negative effects projected by climatic scenarios until 2030 [185]. Later, the NSCC and the related action plan were revised and updated. Currently, in Romania, it is in force the National Strategy on Climate Change and Economic Growth based on Low Carbon Emissions for 2016–2020 and the associated national action plan for its implementation, approved by the Romanian Government in 2016. The strategy addresses two main components: greenhouse gas concentration reduction and adaptation to climate change [186], which has become nowadays a major challenge faced by all, from individuals to local, regional and national authorities. The adaptation is a crucial key to the human existence, enabling the people to survive in changing and critical/extreme conditions, such as those related to climate alteration [187].

According to the NSCC, the process of adaptation to the effects of climate changes must occur at different spatial scales (nationally, regionally, and locally) and in different activity sector, with specific approaches for each location/sector. In the water field, NSCC propose many recommendations and measures to minimize and limit the impacts of the climate changes on water resources and to ensure the adaptation to these changes. A major recommendation concerns the development and updating of scientific knowledge on: water resources availability and requirements for different uses; future impacts of climate changes on rivers flow; water-related risks and their management. The scientific studies must be the basis for the adaptation

measures. To this end, we consider that a better collaboration is needed between the research/academic institutions and stakeholders/authorities responsible for designing and implementing adaptation measures to climate changes (at different spatial scales). We also believe that it is necessary a cooperation between the research/academic institution and those holding hydro-climatic database, based on agreements, which facilitate the use of the database for scientific purposes. In this way it will be possible to use more effectively the hydro-climatic database nationwide, for studying climate change and their effects. It is desirable that the research results on this topic be integrated into a national platform accessible to all those interested.

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