Chapter 7
The Vulnerability of Water Resources from Eastern Romania to Anthropic Impact and Climate Change

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Abstract The regional and local strategies of the past decade have attempted to introduce the principles of sustainable development, which would allow Romania to both meet economic demands and face increasingly pronounced climate change. With a surface of 20,569 km^2 and a population of 2.2 million, the eastern part of the country, spread between the rivers Siret and Prut and sharing borders with the Ukraine (to the north) and the Republic of Moldova (to the east). All the region is classified as vulnerable from an economic and social point of view, but also as far as the impact of climate change upon water resources is concerned. Anthropic activities and climate change are triggering the modification of the hydrological regime (in both quantity and quality) and an increase in the severity of issues associated with water bodies shared with other countries (such as the river Prut, which acts as the border between Romania and the Republic of Moldova), thus rendering an already overexploited resource even more vulnerable. The conclusions of scientific analyses aimed at assessing the effects of climate change upon water resources allow an evaluation of their degree of vulnerability in the face of irreversible challenges. The trend toward phenomena such as global warming, evaluated for the region at 0.2–0.3 °C for the last 50 years, together with an increase in the frequency of extreme temperature values and precipitation volumes emphasize the degree of vulnerability of water resources to current climate change.

Keywords Anthropic impact · Climate change · Eastern Romania · Vulnerability · Water resources

7.1 Introduction

Water sources may be rendered vulnerable through both natural and anthropic mechanisms, which interfere in the hydrological cycle, modifying the natural regime of the water volumes of aquatic bodies. The anthropic mechanisms which lead to water

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resources becoming vulnerable involve changes in the natural flow regime and evolution of hydrographic networks and groundwater bodies through reservoirs, derivations from one hydrographic basin to another, desiccation, aqueducts or the collection of large volumes of water for economic and social purposes [36]. The changes that such anthropic actions bring to water bodies are both quantitative and qualitative. In areas of water scarcity, large volumes of water are translated across seasons or from neighboring areas, the anthropic impact becoming exponential [16, 43, 48]. Eastern Romania is such an area, its water deficit during the summer months being counteracted with water volumes either translated from one season to another, or from neighboring basins, through various catchments [24]. The role of the latter is, firstly, to ensure a certain volume of water during periods of pluviometric deficit and, secondly, to minimize the effects of extreme hydrologic phenomena (flash floods, floods, drought) [44, 46, 49].

Onto this historical background of water management, current climate change adds itself in an increasingly pronounced manner. Through the cumulation of natural mechanisms, climate change gradually leads to increase of natural extreme phenomena. In this region in the category of the most important extreme phenomena we can include aridization, as a result of an increase in the frequency of extreme temperature values and precipitation volumes [7, 9, 20, 52]. Also the concentration of precipitation within limited time intervals lead to an increase in the frequency of catastrophic floods, in maximum annual flow for the hydrographic network and changes in the groundwater level [3, 4, 6, 8, 60]. Such processes are, as expected, ever more noticeable in areas where resource-related vulnerability is added to economic and social vulnerability.

Through both regional and local strategies, general and coherent sustainable development principles are currently being introduced, so that areas with increased vulnerability of water sources to the impact of anthropic activities and climate change are able to meet economic demands and face increasingly significant climate change [10–12, 61].

The issue of water resources and the anthropic impact upon them is of great scientific interest at international level by assessing the pollution of groundwater [19, 28, 50, 53, 54] or evaluation on water balance in different hdyrological extreme condition [31, 32]. In Romania anthropic impact on water resources was focused on wetlands [33, 34], to capitalize on the hydropower potential [35], or evaluation of surface water pollution in different natural condition [2, 14, 37–41, 47, 59]. For Eastern Romania, given the current issue of drought, the emphasis is laid on the exploitation of groundwater sources, particularly within the Moldavian Plateau [5, 17, 23, 25, 29]. To minimize the effects of drought, large-scale ponds or lakes have been created within the Moldavian Plain and on the most significant streams of the area, namely Siret, Prut, Jijia etc. [42, 45].

As a result, the present paper seeks, primarily, to identify the main issues associated with the anthropic impact and climate change upon the water resources of Eastern Romania, taking into account the social and natural characteristics of the region.

7.2 General Features of the Region

The area under study occupies a surface of 20,569 km^2, is inhabited by approximately 2.2 million, and covers the eastern portion of Romania, between the rivers Siret and Prut, bordering Ukraine (to the north) and the Republic of Moldova (to the east). Economic and social studies classify it as vulnerable to an increase in the severity of issues associated with water bodies that act as borders or are shared with other countries (such as the river Prut, which represents the border between Romania and the Republic of Moldova) or certain groundwater bodies.

Tableland shapes dominate the topography, with altitudes between 5 and 450 m. Geologically speaking, sands prevail in the southern part, where the high infiltration rate of the water from precipitation diminishes the runoff. In the center, there is a mixture of sands and clays, which favor landslides and gully erosion [21, 27]. The presence of clay deposits implies a more rapid reaction of the runoff. The changes in land use of the last two centuries, with continuous deforestation, have increased the runoff in this central area, as well [56, 57]. In the north, clay and marl deposits are dominant, while in the northwest clay and sandstone deposits are more frequent [29].

Regarding the climate of the region, semi-dry continental features are dominant, with maximum temperatures and precipitations in the summer (June or July) and minimum values being recorded during the winter (January or February). The mean annual temperature increases from 7 to 8 °C in the north to 9–10 °C in the south. The annual amounts of precipitation range from 620 to 480 mm and decrease from north to south. In the winter, precipitation is mainly solid, and most of it remains in the form of a snow layer until spring because of frequent negative temperatures, which vary from −4 to −6 °C in the north, and −2 to −3 °C in the south [52]. Seasonal variation indicates that the precipitation amounts recorded in the summer are twice to three times higher than those falling during the winter [15, 55].

In Eastern Romania, the discharge values of small rivers (under 50 km in length) are quite low, less than 1 m^3/s annually, and their regime is characterized by a spring maximum, as well as by late summer and early autumn minimum. The spring maximum runoff is based on precipitation and the melting of snow (see Fig. 7.1).

7.3 Methodologies Implemented in the Assessment of Water Resource Vulnerability

The anthropic impact upon water sources can be evaluated through a series of methodologies. Given, however, the specific natural conditions and the social and demographic evolution of the area under analysis, we consider that the water exploitation index (WEI) is the most suitable in this respect. This index refers to the degree of strain that anthropogenic activities exercise upon natural water sources within a certain space (hydrographic sub-basin, hydrographic basin, national territory or region),

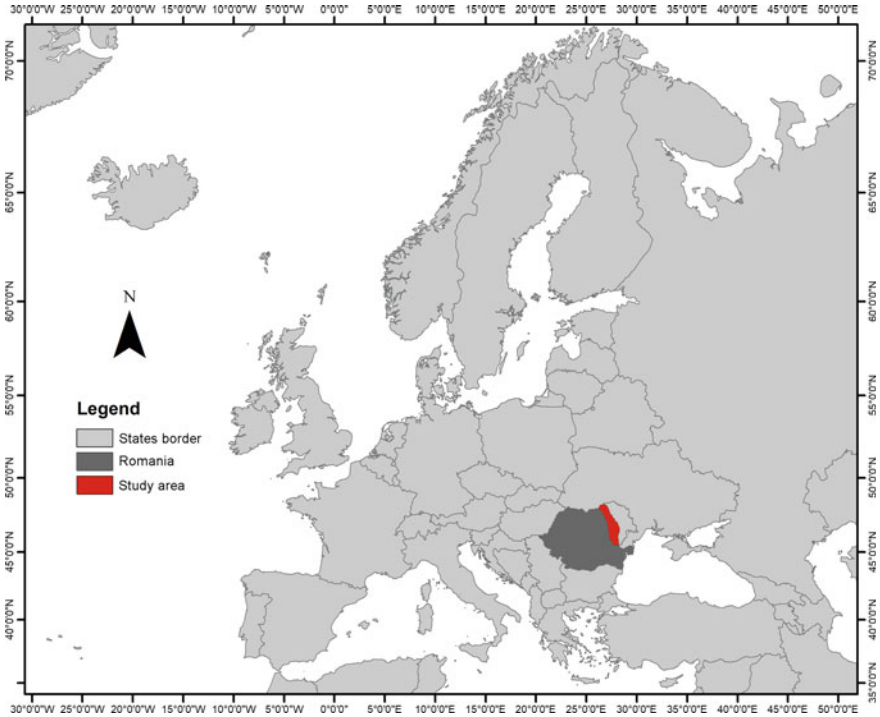

Fig. 7.1 Location of the Siret-Prut hydrographic network in Romania and Europe

and is used to identify areas prone to water deficit. Mathematically speaking, the former is calculated as the ratio between the mean water demand and the long-term water resources of a region. The index is also employed to highlight the anthropic impact upon water sources through their use in various sectors. Developed by the European Environmental Agency, it was then translated from the national level and to that of river basin or sub-basin (WEI+) [13].

If the index is below 10%, then the water sources are not subjected to anthropic strain. If it is between 10 and 20%, then the water sources are exposed to reduced anthropic strain, while values between 20 and 40% suggest increased anthropic strain. Values of the WEI over 40% indicate extreme strain upon water sources, with devastating medium- and long-term effects. The shortest time span taken into account for the calculation of the long-term annual mean of the WEI+ is 20 years. The data sent by Romania to Eurostat between 1990 and 2016 has allowed the calculation of a national water exploitation index and, by applying the WEI+, the indicator was then calculated for the eastern part of the country.

To highlight the impact of climate change upon water sources, 5 series of data were used, namely the seasonal and annual mean values for air temperature, precipitation, river discharge and phreatic level. The climate-related data were acquired at six meteorological stations: Botosani, Iasi, Vaslui, Bârlad, Galati and Roman (for the

1961–2016 interval, under the management of the National Meteorological Administration). The data on river flow were obtained at 17 hydrometric stations located on rivers without hydrotechnical intervention (for the 1961–2016 interval). The values regarding groundwater level were provided by 56 hydrogeological wells (for the 1983–2016 time span, under the management of the Prut-Bârlad Water Basin Administration).

The determination of trends and their slopes was carried out using the nonparametric Mann-Kendal test and the Sen method, developed by researchers from the Finnish Meteorological Institute [51]. The methods in question have been described and widely used to identify the trends of certain climatic and hydrological parameters [7, 58]. In the present study, in order to ensure statistical significance, a value of 0.5 was chosen for the α coefficient.

The correlations between climatic parameters, river flow and variations in the phreatic level were established using the Bravais-Pearson linear correlation coefficient. This index was applied both to the seasonal data series and the annual data series. The pairs of data series were devised based on the minimum distance between meteorological, hydrological and hydrogeological stations, and the same time span (1983–2016) was used for the correlation between precipitation and phreatic level. It was, thus, considered that values of the Bravais-Pearson coefficient of at least 0.5 indicate an acceptable degree of correlation between the data series analyzed, given the spatial variation of natural conditions (topography, geology etc.).

7.4 The Hydrographic Network, Natural and Artificial Lakes and Groundwater Bodies

The total surface of the Siret-Prut hydrographic area represents 8.63% of the territory of Romania. The hydrographic network encompasses 392 streams (according to the official data published by the National Water Administration on www.rowater.ro) [1], with a total length of 7.696 km and a mean density of 0.38 km/km^2. On Romanian territory, the Siret-Prut hydrographic area comprises the middle and lower basin of the river Prut, the hydrographic basin of the river Bârlad, and all the left-side tributaries of the river Siret across the counties of Botoşani, Iași, Vaslui, and Galaţi (see Fig. 7.2).

The Siret-Prut hydrographic area comprises the following categories of surface water bodies: rivers (natural and highly modified by humans)—with a length of 7.696 km (rivers recorded in official documents). Permanent rivers, with a length of 2.269 km, represent 29.48% of the total of streams, and non-permanent rivers, with a length of 5.427 km, represent 70.52% of the total of streams. To all this are added: 7 natural lakes with surfaces greater than 0.5 km^2, and a natural lake that has been significantly altered anthropically, as well as 72 water accumulations with surfaces that exceed 0.5 km^2, and 262 ponds.

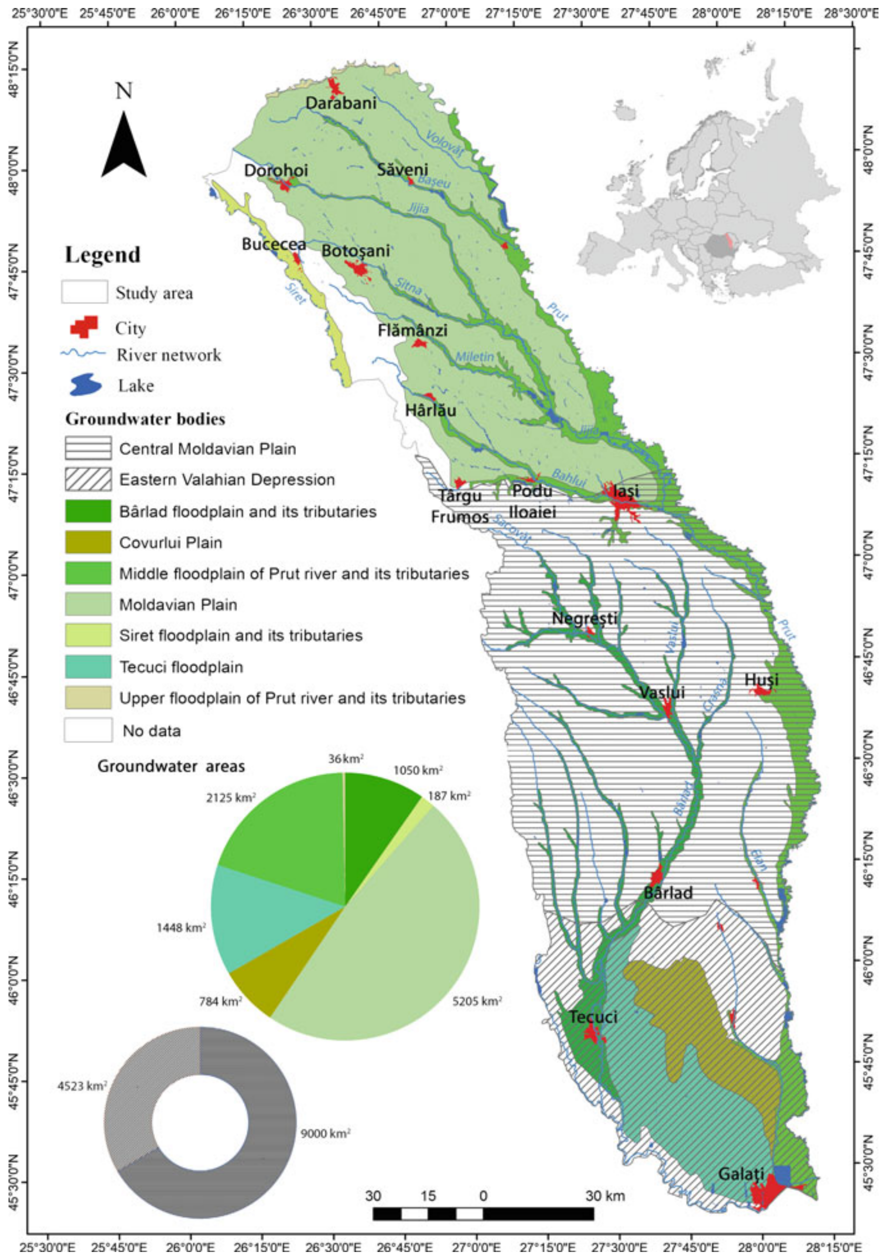

Fig. 7.2 The hydrographic network, natural and artificial lakes and groundwater bodies of the Siret-Prut hydrographic area

The implementation of the principles of the Water Framework Directive EC 2000 has allowed the grouping of surface water bodies (rivers and lakes) based on typology. Thus, 324 surface water bodies have been identified and classified as follows: 230 natural water bodies (223 rivers and 7 natural lakes). Of these, 45 water bodies, corresponding to rivers, have suffered significant anthropic intervention, 1 water body in the form of a lake that has been significantly modified by humans, to which it is added 45 artificial lakes and 3 other artificial water bodies (canals and derivations). The total volume of surface water of the Prut-Bârlad area is around 3.661 M m^3/year, of which roughly 960 M m^3/year is usable. This represents 94% of the total volume and is provided, mainly, by the rivers Prut and Bârlad and their tributaries. The Siret-Prut area also includes 72 significant artificial lakes (with surfaces exceeding 0.5 km^2), of which 49 serve complex purposes and encompass a volume of usable water of 614.85 M m^3.

When calculated in relation to basin population, the specific usable resource is 437.16 m^3/inh./year, while the specific resource, calculated in relation to the volume that is theoretically available (mean and multiannual), is 1.667.12 m^3/inh./year. The water resources of this hydrographic space can, therefore, be considered limited and unevenly distributed across time and space. The mean multiannual discharge values of the main rivers of the area are the following: river Prut 105 m^3/s (3.314 M m^3/year) at its confluence with the Danube, river Jijia 10 m^3/s (316 M m^3/year), river Bârlad 11 m^3/s (347 M m^3/year) at its confluence with the Siret, river Vaslui 1 m^3/s (31.56 m^3/year), river Tutova 1 m^3/s (31.56 M m^3/year). Of the total length of the water bodies of the Siret-Prut basin, the non-permanent streams account for 80% (River Basin Management Plan for the Prut-Barlad hydrographic basin, 2016–2021).

Across the Siret-Prut hydrographic area, 7 groundwater bodies have been identified, delineated and described, of which one is shared with the Republic of Moldova [5]. All 7 belong to the porous type, the water being stored in deposits of Quaternary or Sarmatian-Pontian age. The greatest number of groundwater bodies (6-ROPR01, ROPR02, ROPR03, ROPR04, ROPR06, and ROPR07) has been delineated in the floodplains or on the terraces of the rivers Prut, Bârlad and Siret, being stored in porous and permeable alluvial-fluvial deposits of Quaternary age. Being located close to the surface, they are unconfined, therefore subjected to anthropic strain both quantitatively and qualitatively. The shared groundwater body ROPR05 (Central Moldavian Plateau), stored in Sarmatian-Pontian deposits, is under anthropic pressure, yet has limited economic importance. The groundwater resources are estimated at 251.4 M m^3 (7.97 m^3/s), of which 34.7 M m^3 (1.1 m^3/s) come from phreatic sources, and 216.7 M m^3 (6.87 m^3/s) from sources located at depth.

7.5 Demographic Backgrounds

From an administrative point of view, the Siret-Prut hydrographic area covers almost entirely the counties of Botoşani (90%), Iaşi (83%) and Vaslui (100%), and partially the counties of Neamţ, Bacău, Vrancea, and Galaţi. Its total population is approxi-

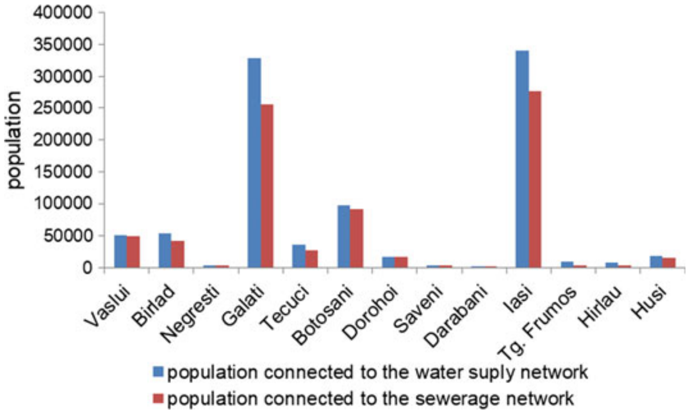

Fig. 7.3 The cities of the Siret-Prut hydrographic area with centralized water distribution and sanitation systems

mately 2.2 million, of which 50.5% live in urban areas. 13 of the 15 cities and towns benefit from a centralized water distribution and sanitation system, and 14 of them also have water treatment stations (see Fig. 7.3). Nevertheless, numerous issues of surface water and groundwater pollution are faced [22].

In the rural areas, only 35% of the communes benefit from a centralized water distribution system, and only 10% have a wastewater treatment plant. The increase in population, coupled with economic activities related to agriculture (pisciculture, livestock farming and the cultivation of arable land occupying approximately 1 million ha) and industry (automotive, industrial equipment, textiles, glass and ceramics, siderurgy), have led to a growing demand for water. As a result, water adductions from neighboring basins have been carried out along with the catchment of significant water volumes from the main hydrographic network (the rivers Siret and Prut) (e.g., the water adduction from the Moldavian basin, located in the vicinity of a mountainous area, to the largest city of the region, Iași, carried out at the beginning of the 20th century, and given new dimensions in the mid-60s),

7.6 The Anthropic Impact upon Water Resources

Such an impact upon the water sources of a densely populated region such as the Siret-Prut hydrographic area manifests itself at various levels (see Fig. 7.4). The first one is related to the changes that occur within the hydrographic network through hydrotechnical constructions, which influence the hydromorphological features of surface water bodies and impact their ecosystems.

Hydrotechnical constructions such as dams, weirs, and bottom sills block the flow of rivers, affecting the hydrological regime, sediment transport and, particularly, the migration of wildlife. Constructions along the banks (levees, regularization and

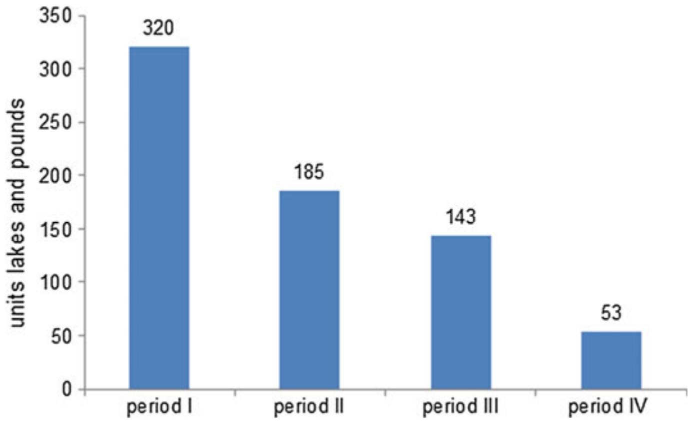

Fig. 7.4 The evolution of accumulations with the Siret-Prut hydrographic area

consolidation works) disrupt the lateral connection between water bodies and their floodplains and reproduction areas, thus altering the natural state of the environment (Figs. 7.5 and 7.6). Consequently, hydro-morphological alterations upon water bodies hinder the migration of fishes, leading to a decline in natural spawning, a reduction in biodiversity and species abundance, as well as changes in the composition of animal populations. There is insufficient knowledge, both at a regional and at a European

Fig. 7.5 Series of lakes on the Bahlueț River

Fig. 7.6 The River Jijia during the floods of the summer of 2010

level, of the relationship between hydro-morphological pressures and their impact, the synergic manner in which the former often act making it difficult to establish a proper connection between the type of pressure and effect.

Another form of anthropic impact is related to the collection and retrieval of water volumes from surface bodies and groundwater bodies, with consequences both on the hydrological regime and the biota of the area.

The volumes of water collected vary according to the socio-economic demands and availability of each year, the amount of water available depending on atmospheric contribution.

The analysis of water collection and retrieval has revealed, in 80% of cases, a drop in the natural discharge values registered at the main hydrometric stations of the region (Fig. 7.7).

The difference between the discharge values measured and those reconstituted for the natural flow regime, calculated taking into account the water lost through collection for various purposes, is 6.8 m^3/s, obviously with higher values for the main rivers. For example to the river Prut, a value of 4.3 m^3/s was calculated as different from the natural flow, which indicates that over 60% of the total discharge is lost within the hydrographic network of the area. At the same time, the water from sewage systems or from other sources leads to an increase in discharge at certain hydrometric stations. The values summed up for the entire region exceed 4.5 m^3/s, substantially modifying the hydrological regime, particularly in the case of rivers that flow through urban agglomerations.

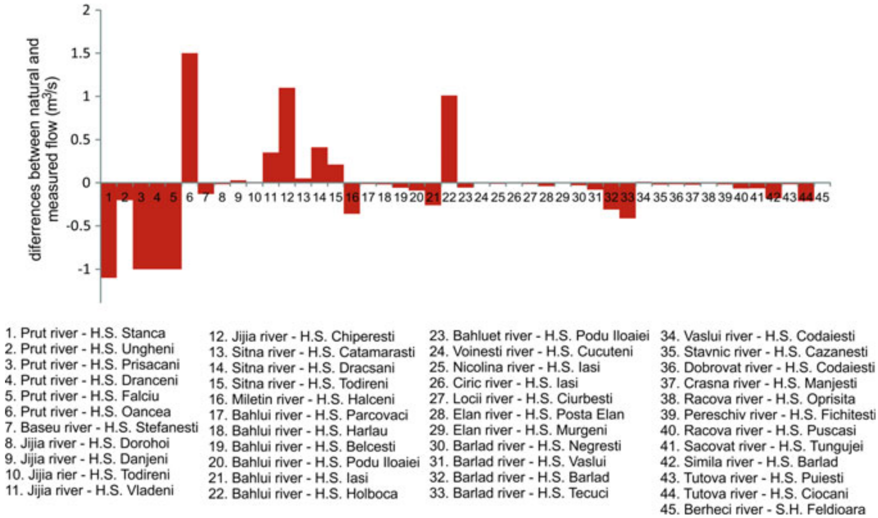

Fig. 7.7 Difference between natural and measured flow in the Siret-Prut area

The collection of water for economic activities is divided into various sectors (Figs. 7.8 and 7.9). The smallest quantities are used in livestock farming, with mean annual values of 2.1 M m^3, and the irrigation of agricultural land, with mean annual values of 90 M m^3. The various forms of industry require the largest amounts of water in the region, with mean annual values of over 140 M m^3. In the Siret-Prut area, the volume of water collected annually for economic purposes reaches a mean of 450 M m^3, with variations based on natural conditions and the dynamics of the activities requiring it.

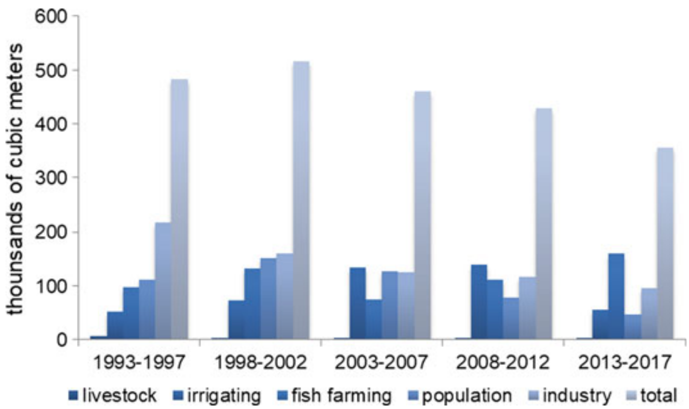

Fig. 7.8 Water collection in the Siret-Prut area, on sectors of economic activity over the period 1993–2017

Fig. 7.9 The Solești accumulation, meant to supply water to the city of Vaslui and to minimize flooding

7.7 The Evaluation of the Anthropic Impact

The official data published by the European Environmental Agency has revealed that Romania suffers from relatively low water stress/deficit, the mean annual value of the WEI+ being around 19.6%, with a minimum of 15.2% recorded in 2013, and a maximum of 41.4% recorded in 1990.

The same type of methodology was applied to Eastern Romania. The region was divided into hydrographic basins corresponding to the typology suggested by the Water Framework Directive EC 2000. The lake units were taken from the vectorial states of Corine Land Cover (Fig. 7.10), while the morphometric data regarding depth and volume were provided by the Prut-Bârlad Water Basin Administration (River Basin Management Plan for the Prut-Bârlad hydrographic basin 2009–2015).

The results obtained are different from the national ones, given the natural conditions and demographic background of the region. The mean annual water resources for the entire region reach values of up to 5185 M m^3. During years with drought, these resources are considerably diminished, down to under 2000 M m^3. As illustrated (in the previous chapter, see Fig. 7.8), the amount of water collected varies between 350 and 525 M m^3. As a result, for the entire region, the values of the WEI+ from 1990 to 2016 are between 5.4 (1994) and 32.5 (2000) (Fig. 7.11). The greatest pressure upon water resources is exercised during the dry years (2000, 2007, 2012), when the values of the WEI+ index exceeded 30. The mean value of the WEI+ is 15.7,

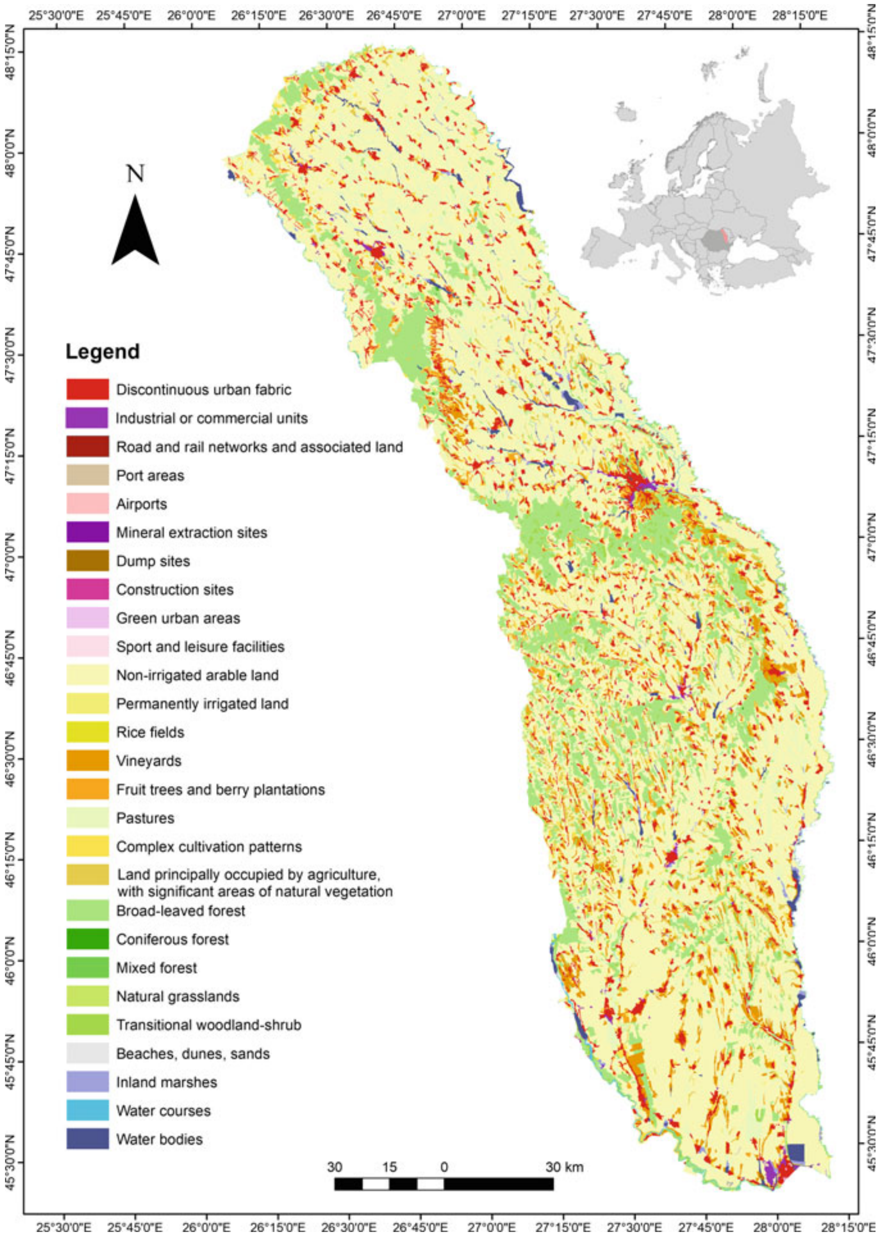

Fig. 7.10 Land use in Eastern Romania (from Corine Land Cover 2012, EEA)

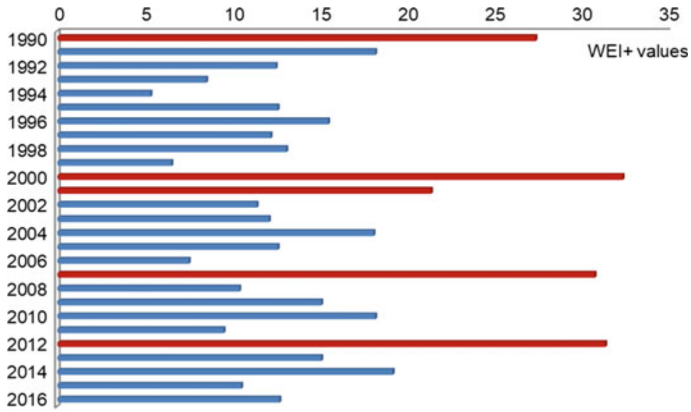

Fig. 7.11 Variation of WEI+ values in Eastern Romania between 1990 and 2016

indicated limited pressure upon water resources, but with the potential of increasing in severity over the following years because of growing demand and the effects of climate change.

7.8 The Impact of Climate Change upon Water Resources

The rapid economic changes caused by increases in the global population and the rate at which resources are being depleted by humanity, by the constant technological advance and socio-political shifts, also imply a series of modifications brought to natural components. The most important one is related to climate change due to the greenhouse effect, which will have a significant impact on the environment and socio-economic activities. Global warming processes have led to an increase in the frequency and amplitude of extreme events that impact the evolution and management of water resources. According to “The annual report on the state of the environment in Romania for the year 2016” [26], climate change will have direct effects upon sectors such as agriculture, forestry, water management. These will lead to an increase in the frequency and intensity of extreme meteorological and hydrological phenomena (storms, floods, drought).

Climate change in Romania follows the global pattern, with certain regional particularities regarding air temperature and precipitation [9]. These modifications have also been highlighted within the *ADER—A system of geo-referential indicators at different spatial and temporal scales for the evaluation of the vulnerability and coping mechanisms of agroecosystems in the face of climate change (2011–2014)* project, devised by the National Weather Administration and financed through the Sectorial Plan for Research and Development in Agriculture and Rural Development 2011–2014 and ADER 2020, coordinated by the Ministry for Agriculture and Rural Development. In this project some climatic scenarios were devised for 2021–2050, compared to 1961–2010, along with the quantifiable effects upon the mean multi-annual temperature and precipitation in Romania. Thus, for 2020–2029, a series of modifications to climatic parameters, similar to those occurring at European level, are expected nation-wide, with increases in mean annual temperature between 0.5 and 1.5 °C. As far as the precipitation regime is concerned, the analyses for the 1901–2010 interval indicate a nation-wide trend, particularly after 1961, towards a decrease in the annual quantity of precipitation, along with a pronounced increase in precipitation deficit for southern and eastern Romania.

Croitoru and Minea [8] and Minea and Croitoru [24, 25] have revealed the effects of climate change upon river flow and phreatic level in the eastern part of the country. The nonparametric Mann-Kendal test, used to determine the trends of the main climatic parameters (temperature and mean seasonal and annual precipitation), hydrological parameters (mean seasonal and annual flow) and hydrogeological ones (mean monthly and annual values of the piezometric level). The following aspects have been identified for the region under study:

– A warming trend is obvious, given the rise recorded in mean annual air temperature values at most of the meteorological stations of the region. The rise rate varies between 0.039 and 0.181 °C/decade. It is noteworthy that the air temperature values recorded during the winter and spring months are statistically significant, in agreement with the observations regarding the rise in air temperature in the Northern Hemisphere made in the 2014 IPCC report.
– There is an increase in the annual values of atmospheric precipitation, yet this increase does not have statistical significance. When analyzing data recorded during different seasons, one can remark that the highest slopes are specific for summer, the season with the highest amounts. Almost half of the slopes recorded during the summer season are also statistically significant, varying from 10.255 to 14.115 mm/decade (Table 7.1). Positive trends are also specific for spring and

Table 7.1 Slopes of temperature (°C/decade) and precipitation (mm/decade) trends in Eastern Romania over the period 1960–2010

Series	Botosani	Iasi	Roman	Vaslui	Barlad	Galati
Annual (°C/decade)	**0.147**[a]	**0.105**	**−0.234**	**0.114**	0.039	**0.181**
Annual (mm/decade)	13.499	14.655	**13.923**	15.225	−3.315	6.750
Winter (°C/decade)	0.238	0.088	**0.653**	0.043	0.048	0.308
Winter (mm/decade)	**−3.562**	**−3.956**	**−4.163**	−3.738	**−6.218**	−4.779
Spring (°C/decade)	**0.282**	**0.306**	**0.477**	**0.258**	0.128	0.230
Spring (mm/decade)	2.408	3.433	2.750	**8.099**	1.460	2.804
Summer (°C/decade)	0.043	0.111	**−0.333**	0.101	0.044	**0.333**
Summer (mm/decade)	**13.513**	6.310	**14.115**	**10.255**	2.381	7.139
Autumn (°C/decade)	0.023	−0.020	−0.103	−0.152	0.059	−0.027
Autumn (mm/decade)	3.891	4.286	3.313	2.265	0.387	4.652

[a]Values in bold are statistically significant

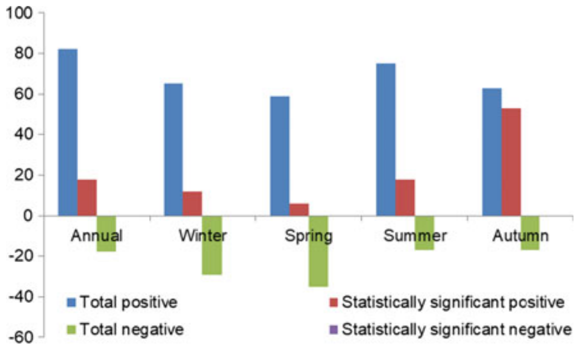

Fig. 7.12 The frequency of positive and negative slopes of river discharge between 1960 and 2015

autumn while decreasing amounts of precipitation characterize winter for all locations considered. The majority have significant slopes, which range from −3.562 to −6.218 mm/decade.

- More than half of the rivers that drain the eastern part of Romania display a trend toward a rise in mean annual and seasonal flow, in agreement with the regional trend also identified in the southern portion of the country [6, 30]. The highest frequency of statistically significant positive trends is recorded in autumn (over 50%), while the statistically significant positive trends of summer and winter are between 10 and 20% (Fig. 7.12). Negative trends, of a decrease in mean seasonal discharge values, with a high percentage during spring (over 30%), have also been identified. They, however, lack statistical significance.
- Given the underground storage conditions, the variations in phreatic level display a delay trend, compared to the water input from precipitation or the hydrographic network. The greater the depth, the less significant is the influence of surface hydric conditions. As a result, starting at depths of 5–6 m, there is no more direct influence from them [24]. The analysis of hydrostatic level values has revealed a slight increasing trend in most of the hydrogeological wells, with a mean value of that 0.3 cm/decade (Fig. 7.13). The explanation lies in the rise in the amounts of precipitation and river discharge values [3], which lead to an increase in the volume of surface water seeping into the underground. The most significant increase occurs at the 200–300 cm depth interval, where the annual increase trend values of the hydrostatic level exceed 20 cm [25]. The trends fade (values under 5 cm) towards the topographic surface and at depths greater than 300 cm, even becoming negative for annual values and those recorded during spring.

The Bravais-Pearson linear correlation coefficient used in the identification of correlations between climatic parameters and river flow indicates a positive connection between the annual data series (in over 50% of cases). The highest values of the coefficient have been established for the central and northern portions of the region (between 0.4 and 0.6). At seasonal level, the best correlations were identified for summer and autumn, when the exclusively liquid precipitation reaches the hydrographic network with ease. The highest values of the coefficient were established for the summer season (0.8), when the rich convective precipitation, which

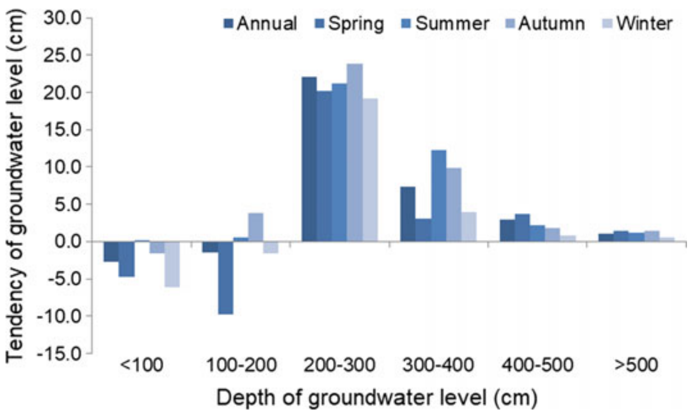

Fig. 7.13 Trends of groundwater level by the depth of drilling in Eastern Romania over the period 1983–2015

sometimes exceeds 100 mm over a few hours, triggers the rapid flow of water downslope, towards river channels. High values of the coefficient were also identified between precipitation and liquid discharge in autumn, explainable through the reduction in vegetative cover, which favors the rapid flow of water towards the hydrographic network. Low values of the correlation coefficient were recorded for winter and spring, when, due to low temperatures, the precipitation is kept in the form of a snow and ice layer, with no influence on river flow.

Given that variations in hydrostatic level are nearly entirely dependent upon the geological features of host rocks and the water input from the surface, the results regarding the correlation between precipitation and groundwater level can vary greatly, even in areas that are hydrogeologically homogeneous. However, by applying the Bravais-Pearson linear correlation coefficient to the seasonal and annual data series, relatively high values (often over 0.3) were obtained for the correlation between precipitation and hydrostatic level for 70% of the datasets analyzed. The geological deposits of the area play an undeniable role, being composed predominantly of sands and silty clays, which favor the infiltration of precipitation, allowing it to reach the water table quickly. As in the case of the correlation between precipitation and river flow, the highest values (with a maximum of 0.6) were obtained for summer and autumn (Fig. 7.14).

The low values calculated for winter and spring (generally under 0.3) are a direct consequence of the reduction in the amount of precipitation fallen throughout the past decades during the two seasons, as well as the water from precipitation being locked in the form of snow and ice. This allows the redistribution of the volume of atmospheric water in the underground across seasons.

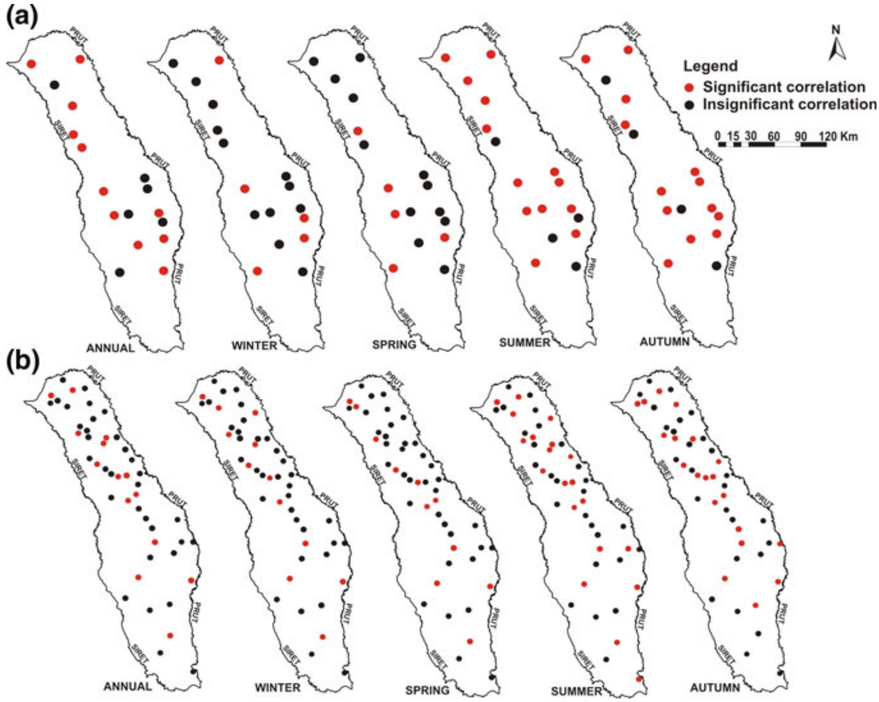

Fig. 7.14 Correlation between precipitation, river flow (**a**) and hydrostatic level (**b**) in Eastern Romania

7.9 Conclusions

Anthropic activities have led to radical changes in the natural conditions under which the water bodies of Eastern Romania have been evolving. Onto them, the regional climatic changes of recent decades have been added, manifesting themselves through modifications in the seasonal thermal and rainfall regime, as well as a secondary trend toward the increase in river discharge and in the underground hydrostatic level. This overlaps with the increasingly negative anthropic impact of the last decades, in the form of significant water collection for the needs of the population, but also for various economic activities (particularly in the industry and the irrigation of agricultural land). These changes require the rethinking of water management systems, both at the surface and in the underground. When devising these systems, one must take into account various climatic scenarios and formulate strategies for the adaptation to climate change both at a regional and at a European level, through the introduction within water management plans of measures regarding the long-term effects of anthropic impact and climate change.

7.10 Recommendations

On the basis of the conclusions of the study on the water resources vulnerability from the eastern part of Romania to anthropic impact and climate change we can make a series of theoretical and practical recommendations. Firstly, it is necessary to include in the local and regional management plans of water resources the scenarios regarding the changes of climatic parameters (both temperature and precipitation) in order to identify the vulnerable areas.

Secondly, in the context of increasing the demand for water for economic and social purposes, it is necessary either to make new large-scale hydro-technical works (such as reservoir lakes) or additions from adjacent water-surplus basins. Last but not least, there is a need for massive investment in expanding water supply systems and waste water collection (especially in rural areas) to reduce river and groundwater pollution.

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